Technical Study of New York State Heat Pump Performance

Final Report

Prepared for:

New York State Department of Public Service
Albany, NY

Laurie Kokkinides
Project Manager, New York State Department of Public Service

Prepared by:

DNV

Corporate Headquarters: Katy, TX

Patrick Hewlett, Principal, DNV

Maura Nippert, Principal, DNV

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Glossary of key terms

Air-Conditioning Contractors of America (ACCA) - A nationwide, non-profit association for professionals that install and maintain heating, ventilation, air-conditioning, refrigeration, indoor environment and building performance systems. ACCA writes standards for the design, maintenance, installation, testing, and performance of indoor environment systems. In the context of this study, ACCA is referenced for building heating and cooling load estimation and HVAC equipment sizing.

Air-Conditioning, Heating, and Refrigeration Institute (AHRI) - A trade association representing manufacturers of heating, ventilation, air-conditioning, refrigeration, and water heating equipment. AHRI establishes certifications and standards related to HVAC and refrigeration equipment. In the context of this study, AHRI is referenced as a source of equipment performance ratings at design testing conditions.

Air source heat pump (ASHP) - An HVAC system that provides space heating using electricity through vapor-compression refrigeration cycle. An ASHP extracts heat from outdoor air and transfers the extracted heat into the conditioned spaces via various means. ASHPs are also used to provide space cooling by reversing the cycle to extract heat from a building and transfer the heat to the outside air.

Base temperature - The outside air temperature at which a building's HVAC system is switched from heating mode to cooling mode. Base temperature is synonymous with "switch-point." Heating base temperature is the highest outside air temperature at which the facility requires heating.

Building cooling load (BCL) - Cooling load is the rate at which sensible and latent heat must be removed from the space to maintain a constant space dry-bulb air temperature and humidity.

Building heating load (BHL) - Heating load is the amount of heat energy that needs to be added to a space to maintain a desired temperature setpoint.

British thermal unit (Btu) - A unit of energy equivalent to the energy required to raise one pound of water by one degree Fahrenheit.

Building equivalent full-load hours (BEFLH) - The ratio of an HVAC system's annual heating or cooling energy output (in Btu) to the building's heating or cooling load (in Btu per hour), respectively, as calculated by the HVAC contractor (see definition for Manual J).

Coefficient of performance (COP) - COP is the ratio of work or useful energy output of a system versus the work or energy input, measured in the same units. A higher system COP typically corresponds to more efficient operation.

Coincidence factor (CF) - The Coincidence Factor (CF) is expressed as a ratio with the numerator being the simultaneous demand of a similar group of electrical appliances (measures) within a specified period, to the sum of their individual maximum demands within the same period.

Cold-climate air source heat pump (ccASHP) - A heat pump system that extracts heat from (or rejects heat to) the ambient outside air to heat (or cool) a building. ccASHPs are a subset of ASHPs that identify air source heat pumps best suited to heat efficiently in cold climates (IECC Climate Zone 4 and higher).

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, 80/10 confidence/precision implies 80% confidence that the result falls within ±10% of the true value.

Consumption data analysis - In this study, this technique refers to the analysis of premise-level utility consumption records as available from monthly billing data from the electric utilities.

Cooling degree day (CDD) - A measurement that quantifies a building's cooling energy requirement due to weather conditions. Cooling degree days represent the number of degrees that a daily average temperature is above the facility's base temperature (see definition for base temperature).

Core metering - Denotes the standard measurement and verification rigor applied in this study. All sites sampled for M&V received at least core metering rigor, with a subset of eight sites receiving intensive rigor as defined later in this glossary.

Dedicated domestic hot water water-to-water heat pump (DHW WWHP) - A water-to-water heat pump (WWHP) dedicated to providing domestic hot water in conjunction with a GSHP ground loop. DHW WWHPs operate in response to the DHW loads, independent of GSHP unit operation to meet space loads. Full-load DHW WWHPS may be installed as a priority zone on a GSHP HAVC system, or as a stand-alone system and are designed to provide a building's DHW needs.

Desuperheater - An optional feature of a GSHP system that takes advantage of waste heat generated by the compressor and transfers the waste heat to a domestic hot water system.

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) - A type of cold climate ASHP or ccASHP that can circulate refrigerant between an outdoor unit containing a variable capacity compressor and one or more indoor air handlers. DMSHPs are often referred to as "ductless mini-splits" because they are typically ductless. These units can also be installed with short duct runs that enable single air handlers to serve more than one room at a time.

Energy efficiency ratio (EER) - A cooling efficiency rating for heat pumps that compares heating output (in Btu) with electric input (in Watt-hour) at full-load operation.

Equivalent full-load hours (EFLHs) - The ratio of an HVAC system's annual heating or cooling energy output (in Btu) to the system's rated heating or cooling capacity (in Btu per hour).

Engineering desk review - For less prominent technologies incented by the programs over the study period, including desuperheater and dedicated DHW WWHP systems, the study team conducted lower-rigor assessments of compliance with the TRM algorithms and assumptions.

Full-load heat pump (FLHP) - A ccASHP system for which the "total heat pump system heating capacity satisfies at least 90% of the [building heating load]" per NYS Clean Heat Program rules.[1] During the study period, the NYS Clean Heat Program differentiated between full-load and part-load heat pumps (see definition below) in reported energy savings and incentives values.

Ground source heat pump (GSHP) - A heat pump system that extracts heat from (or rejects heat to) the ground to heat (or cool) a building. GSHPs typically achieve higher efficiencies than other HVAC alternatives due to the relative stability of ground temperatures throughout the year.

Heat pump water heater (HPWH) - A storage tank water heating appliance that uses a refrigeration cycle to extract energy from ambient air to heat domestic hot water (DHW). During periods of high DHW demand or low ambient temperature, HPWHs typically utilize integrated supplemental electric resistance heat to meet the load.

[1] NYS Clean Heat Statewide Heat Pump Program Manual, Version 7, page 35.

Heating degree day (HDD) - A measurement that quantifies a facility's heating energy requirement due to weather conditions. Heating degree days represent the number of degrees that a daily average temperature is below the facility's base temperature (see definition above).

Heating season performance factor (HSPF) - A seasonal heating efficiency rating for heat pumps that compares heating output (in Btu) with electric input (in Watt-hour).

Effective HSPF - To compare actual seasonal performance with rated seasonal heating efficiency, the study team occasionally converted COP to effective HSPF in this report. Effective HSPF is equivalent to the product of heating COP and a 3.412 Btu/Watt-hour conversion factor.

Heating signature - The observed correlation of heat pump energy use with outside air temperature during the heating season.

Intensive metering - In the context of this study, intensive metering refers to the subset of eight sites that received enhanced measurement and verification rigor to inform additional operating parameters such as SEER and HSPF. Intensive metering sites are distinguished from core metering sites as defined previously in this glossary.

Load factors - The TRM ccASHP energy savings algorithms include factors that adjust for the portion of the building's heating and cooling loads satisfied by the heat pump. The TRM load factor estimates take into account system type, rated capacity, controls, and location.

Manual J - The ACCA Manual J® Residential Load Calculation (8th Edition) is used to estimate the heating and cooling loads of a building. Manual J-based heating and cooling load estimates are inputs to the TRM algorithms for ccASHP and GSHP systems. Manual J is often used in association with ACCA Manual S® Residential Equipment Selection (3rd Edition, Version 1.01) which involves right-sizing of HVAC equipment to satisfy the estimated heating and cooling loads.

Measurement & 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. In this report, M&V is synonymous with "on-site metering."

MMBtu at site - A consolidated savings value (one million Btu) that combines electric energy impacts at the customer site (i.e., excluding generation, transmission, and distribution losses) with fossil fuel energy savings. MMBtu at site is synonymous with "site MMBtu" in this report.

NYS Clean Heat Program - The New York State Clean Heat Statewide Heat Pump Program launched on April 1, 2020, and provides incentives for building electrification solutions to residential and commercial customers throughout New York. The Joint Efficiency Providers administer the NYS Clean Heat Program, which currently incentivizes high-efficiency electric heating options such as cold-climate air source heat pumps (ccASHPs), ground source heat pumps (GSHPs), and heat pump water heaters (HPWHs).

Part-load heat pump (PLHP) - A ccASHP system for which the total heat pump system heating capacity satisfies less than 90% of the building heating load.

Heat pump performance curves - The variation in heat pump performance as a function of outside air temperature (for air source systems) or ground temperature (for ground source systems). Heat pump manufacturers generally provide performance curves for different models as determined through laboratory testing. The study team calculated performance curves for the subset of sites receiving intensive metering.

Predecessor programs - Prior to the NYS Clean Heat Program, the electric utilities, including PSEG-LI and NYSERDA administered several programs offering heat pump incentives. This study's sample design included participation records from predecessor programs after January 1, 2019.

Premise - In the context of utility services, a premise refers to the physical location receiving electric or natural gas distribution. In the context of this study's consumption data analysis (defined above), premise is used to define the physical space(s) associated with an electric or natural gas account. An individual site (defined later in this glossary) may contain more than one premise.

Prior study - In 2022, the study team completed an evaluation of energy impacts resulting from heat pump installation projects completed through NYSERDA programs between 2017-2018. Data from this 2022 NYSERDA Heat Pump Impact Evaluation[2] supplemented the on-site metering data from the current study.

Program or programs - In this study, programs refer to the NYS Clean Heat Program and any predecessor programs offering heat pump incentives in New York over the study period.

[2] The prior study report can be accessed via https://www.nyserda.ny.gov/-/media/Project/Nyserda/Files/Publications/PPSER/Program-Evaluation/Heat-Pump-Impact-Evaluation-Report-August-2022.pdf.

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 realization rate.

Reported savings - Energy and demand savings estimated by the Program Administrator as a result of an incentivized energy conservation measure.

Seasonal energy efficiency ratio (SEER) - A cooling efficiency rating for heat pumps that compares heating output (in Btu) with electric input (in Watt-hour) over the full cooling season. SEER is equivalent to the product of rated cooling COP and 3.412 Btu/Watt-hour.

Effective SEER - To compare actual performance with rated cooling efficiency, the study team occasionally converted COP to effective SEER in this report. Effective SEER is equivalent to the product of cooling COP and a 3.412 Btu/Watt-hour conversion factor.

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

Study period - The period of program activity assessed by this study. This study assessed heat pump projects incented through the NYS Clean Heat Program or predecessor programs in New York between January 1, 2019, and October 31, 2020.

Supplemental heat - Supplemental heat refers to heating sources that are installed separate from the heat pump, such as legacy fossil fuel-fired systems, but work in tandem with the heat pump to meet the building's heating load. The term *integrated supplemental heat* refers to integrated heating components that augment the heat pump's heating output; some ducted heat pumps are installed with integrated heating sources, such as electric resistance or gas-fired heaters.

Technical Resource Manual (TRM) - A collection of energy savings algorithms and assumptions used across a portfolio of energy efficiency measures. The Commission-approved TRM is designed to provide a standardized, fair, and transparent approach for measuring energy efficiency program energy savings. In this report, the abbreviation "TRM" is used in place of the full title, *New York Standard Approach for Estimating Energy Savings from Energy Efficiency Programs – Single and Multi-Family Residential, and Commercial/Industrial Measures*.

Typical meteorological year (TMY)[3] **-** A set of meteorological data with data values for every hour in a year for a given geographical location. The data are selected from hourly data in a longer time period (normally 10 years or more). For each month in the year the data have been selected from the year that was considered most "typical" for that month.

[3] Definition transcribed from https://e3p.jrc.ec.europa.eu/articles/typical-meteorological-year-tmy.

Uniform energy factor (UEF) - Similar to COP, the UEF is a unitless ratio between output water heater energy and input energy from electricity or fossil fuels. The higher the UEF, the more efficient the water heater. UEFs of HPWHs typically exceed 3, as compared with traditional storage water heaters with UEFs below 1.

Water-to-water heat pump (WWHP) - A heat pump system that uses a refrigeration cycle to transfer heat between two water flows.

Executive summary

The New York State (NYS) Public Service Commission (the Commission)'s January 20, 2020, *Order Authorizing Utility Energy Efficiency and Building Electrification Portfolios Through 2025* ("January 2020 Energy Efficiency Order" or "Order") initiated a common statewide heat pump framework for NYS designed to guide the efforts of the NYS electric utilities[4] and NYSERDA (referred to as the Joint Efficiency Providers). Pursuant to the Order, the Commission directed the NYS Department of Public Service (DPS) to refine savings estimation approaches for heat pump performance through a statewide evaluation, measurement, and verification (EM&V) study. This report provides the objectives, methods, results, and findings of the Technical Study of New York State Heat Pump Performance ("current study" or "study") conducted by DNV with partner Frontier Energy and directed by DPS.

Study objective

The purpose of this study is to refine statewide savings estimates based on NYS-specific performance data by assessing the operational performance of cold-climate Air Source Heat Pump (ccASHP), Ground Source Heat Pump (GSHP), and Heat Pump Water Heater (HPWH) system projects. The study also aims to assess heat pump system customers' usage patterns and understanding of the heat pump technology and the impact these have on system performance and overall customer satisfaction with the heat pump system.

Approach

The technical approach to this study emphasizes developing and refining the *New York Standard Approach for Estimating Energy Savings from Energy Efficiency Programs – Residential, Multi-Family, and Commercial/Industrial*, known as the Technical Resource Manual (TRM).[5] These specifications provide the basis for estimating energy impacts of future heat pump installation projects through the NYS Clean Heat Program, a common statewide heat pump program implemented by the Joint Efficiency Providers since April 1, 2020.

[4] Central Hudson Gas & Electric Corporation (Central Hudson), Consolidated Edison Company of New York, Inc. (Con Edison), Niagara Mohawk Power Corporation d/b/a National Grid (National Grid), New York State Electric & Gas Corporation (NYSEG), Orange and Rockland Utilities, Inc. (Orange & Rockland), and Rochester Gas and Electric Corporation (RG&E) (collectively, electric utilities).

[5] New York Standard Approach for Estimating Energy Savings from Energy Efficiency Programs – Residential, Multi-Family, and Commercial/Industrial Measures, Version 11 – Filed October 6, 2023 (effective January 1, 2024), https://dps.ny.gov/technical-resource-manual-trm. A consolidated TRM is filed annually that incorporates changes from the previous twelve month's record of revision filings.

The population of ccASHP installations includes NYS Clean Heat Program and predecessor program projects with project end dates from January 1, 2019, through October 31, 2020. The GSHP study population also includes projects with project end dates from January 1, 2019, through October 31, 2020, but includes earlier predecessor program tracking data, with the earliest project installed in October 2017.

To fulfill the study objectives, the project team collected between nine and 12 months of metered data from 72 heat pump installations across NYS. The team collected project tracking data from NYSERDA and the electric utilities, administered surveys to heat pump program participants, and analyzed building consumption data from 384 survey respondents who provided permission.

Findings and recommendations

The primary findings of this study yield recommendations to improve TRM savings algorithms and assumptions. The sections below highlight primary findings and recommendations derived from the review of NYS-specific performance data for each of the heat pump technologies (ccASHP, GSHP, and HPWH).

cold-climate Air Source Heat Pump (ccASHP)

The operational performance of ccASHP projects revealed opportunities to improve TRM savings assumptions related to weather data, efficiency deration, baseline fuel options, and peak coincidence factors. Additionally, the study team identified opportunities to clarify application of the TRM methodologies. These recommendations are further detailed in Table ES-1.

ES-1. Opportunities to improve TRM savings assumptions for ccASHP

Category	Finding	Recommendation
Weather Data	Other jurisdictions such as Massachusetts have explored the adoption of more recent weather datasets, such as TMYx, which is a data set derived from more recent weather than TMY3 and may reflect some of the widespread impacts of climate change recently experienced.[6]	Investigate TMYx or similar, more recent weather datasets to define typical meteorological year-based assumptions in future iterations of the TRM.

[6] Massachusetts Program Administrators and Energy Efficiency Advisory Council Consultants, "Massachusetts Typical Weather – Research and Dataset Development." August 2023. https://ma-eeac.org/wp-content/uploads/MA22C04-B-TMY-Final_Report.pdf.

Category	Finding	Recommendation
Efficiency and Deration	The TRM (Version 10)[7] algorithm includes a term to account for "when the system is sized such that [integrated] supplemental electric resistance heat (ER) is included within the heat pump to help meet the design heating load".[8] However, installation contractors did not appear to use the algorithm properly for ducted ASHPs that regularly required integrated supplemental ER to meet the heating load. Eight of 16 metered ducted ASHPs required substantive ER throughout the year, accounting for 24% of annual heating kWh.	As an alternative method of estimating the ducted ASHPs reliance on integrated supplemental heat, the study team suggests adding an efficiency deration factor of 0.84 for any ducted ASHPs installed with integrated supplemental ER heat. If this alternative approach is pursued, the algorithm should be modified to remove the term discussed in the Efficiency and Deration finding.
	The incentivized ccASHPs performed to near rated efficiencies, with average effective HSPFs and SEERs within 2% and 4% of average AHRI ratings, respectively. The study team does not recommend further adjustment to the current ccASHP algorithm to derate efficiencies as a function of installation scenario and location.	N/A
Baseline	This study and the 2022 NYSERDA Heat Pump Impact Evaluation showed that wood occasionally constitutes the baseline heating system. For ccASHPs, wood accounted for 13% of achieved MMBtu impacts in this cycle.	Expand baseline fuel options in the tracking database for proper accounting of carbon offset from heating electrification measures.
Coincident Peak Impacts	Study results showed that ccASHPs, including ducted ASHPs and ductless mini-split heat pumps (DMSHPs), exhibited a summer peak coincidence factor of 0.30 as compared to the current TRM-recommended summer coincidence factor of 0.69. Part-load DMSHPs are particularly less likely to exhibit strictly weather-dependent operation, as customers may operate them in on/off modes or occupancy-based patterns.	Modify the summer peak coincidence factor to 0.30 for DMSHPs. Since ducted ASHPs are more likely to exhibit operation similar to central air conditioners, the study team does not recommend adjustment to the 0.69 summer coincidence factor for ducted ASHPs as presently recommended in the TRM.
	As more heating electrification measures are adopted, winter peak demand impacts will be increasingly important. Sampled ccASHPs and GSHPs exhibited winter peak coincidence factors of 17% and 48%, respectively, per a winter version of the TRM system peak definition.	Consider winter peak demand impact estimation in future iterations of the TRM. Assume winter peak coincidence factors of 0.17 and 0.48 for ccASHPs and GSHPs, respectively, as an initial assumption to be refined with future research.
Algorithm Accuracy	The TRM algorithm is more accurate at predicting site MMBtu impacts from ccASHPs than an alternative simplified algorithm would have been. The study team does not recommend the redesign or overhaul of the existing ccASHP savings algorithm.	N/A
Load Factors	At the time of this writing, the NYS Clean Heat Program has discontinued offering incentives for PLHP systems. The study team acknowledges that the findings and recommendations in this sub-section may not be pertinent to the NYS Clean Heat Program moving forward. Nonetheless, the	

[7] New York Standard Approach for Estimating Energy Savings from Energy Efficiency Programs – Residential, Multi-Family, and Commercial/Industrial Measures, Version 10 – Filed December 30,2022 (effective January 1, 2023), https://dps.ny.gov/technical-resource-manual-trm. At the time of this writing, Version 10 of the TRM was in effect. Version 11 went into effect on January 1, 2024. The study team compared the two versions to confirm that all findings and recommendations in this report are applicable to Version 11.

[8] TRM Version 10, page 234.

Category	Finding	Recommendation
	study team has included them below for completeness and transparency should PLHP systems be reintroduced in future iterations of the NYS Clean Heat Program or other programs.	
	Single-zone DMSHPs exhibited a heating load factor well below the minimum range currently available in the TRM (0.30). In fact, the results examined in Section 3.2.4 show that each of the load ranges corresponding to single-zone mini-splits (0.30 and 0.50) exhibited similar heating load values (0.15 and 0.13, respectively).	For single-zone DMSHPs not installed with integrated controls, modify the heating load factor to 0.15. Results from this study and from the prior NYSERDA study show that single-zone DMSHPs provide significantly less heat output than that corresponding to the minimum 30% load factor option available in the TRM.
	Multi-zone DMSHPs exhibited significantly lower heating load factors than the 70% minimum range option available in the current TRM. Section 3.2.4 results show actual load factors of 0.45, 0.42, and 0.49 corresponding to the program-predicted load factors of 0.70, 0.90, and 1.00, respectively.	Diversify the available sizing ratios for multi-zone DMSHPs. Such systems can hypothetically be installed in scenarios that do not exceed 50% of the total building heating load, especially if the legacy heating system is not decommissioned.

Beyond the TRM algorithm and assumptions, the study team identified opportunities to improve the NYS Clean Heat Program administration. Notable opportunities include more extensive tracking of relevant project information, such as equipment capacity, and more accurate classification of ccASHP load designation in accordance with NYS Clean Heat Program rules.

On the other hand, the study team identified several "program successes" that demonstrated accuracy of reported energy savings or adherence to industry best practices. Commendable successes include the quality of tracking data and statistically significantly higher heating hours from ccASHPs classified as full-load as compared with part-load systems.

Ground Source Heat Pump (GSHP)

The operational performance of GSHP systems revealed opportunities to improve TRM savings assumptions related to weather data, efficiency deration, peak coincidence factors, and load factors. Additionally, the study team identified opportunities to clarify application of the TRM methodologies. These recommendations are further detailed in Table ES-2.

ES-2. Opportunities to improve TRM savings assumptions for GSHP

Category	Finding	Recommendation
Weather Data	Other jurisdictions such as Massachusetts have explored the adoption of more recent weather datasets, such as TMYx, which is a data set derived from more recent weather than TMY3 and may reflect some of the	Investigate TMYx or similar, more recent weather datasets to define typical meteorological year-based assumptions in future iterations of the TRM.

Category	Finding	Recommendation
	widespread impacts of climate change recently experienced.[9]	
Efficiency Deration	One of the metered GSHPs required integrated supplemental heat on over 100 days of the yearlong metering period. However, the TRM does not include an algorithm component (as with ccASHPs) or an efficiency degradation factor for possible reliance on integrated supplemental heat. Due to limited data, the study team does not recommend revision to the TRM algorithm or assumptions related to integrated supplemental heat on GSHP systems.	Program Administrators should require that contractors document when GSHP systems are installed with integrated supplemental ER heat. If such installations become more prominent, additional research may be warranted on efficiency degradation effects.
	The 12 GSHP systems sampled for M&V exhibited lower effective cooling and heating EERs and COPs, respectively, than average full- and part-load ratings. However, due to limited sample size, the study team does not recommend adjustment to the TRM GSHP efficiency deration algorithms or assumptions.	N/A
Coincident Peak Impacts	As more heating electrification measures are adopted, winter peak demand impact will be increasingly important. Sampled ccASHPs and GSHPs exhibited winter peak coincidence factors of 17% and 48%, respectively, per a winter version of the NY TRMs system peak definition.	Consider winter peak impact estimation in future iterations of the TRM. Assume winter peak coincidence factors of 0.17 and 0.48 for ccASHPs and GSHPs, respectively, as an initial assumption to be refined with future research.
Loads and Load Factors	The evaluation sample of 10 GSHP projects included three with multi-system installations for which the associated heating and cooling load estimates (based on ACCA Manual J) did not necessarily match the zones conditioned by the respective GSHPs. The TRM does not provide guidance on how to distribute the whole-building heating and cooling load estimates in such situations. The Program Administrators appeared to split loads equally among differently sized systems.	The TRM should more explicitly instruct contractors and Program Administrators on how to estimate heating and cooling loads for multi-system installations.
Algorithm Accuracy	The TRM algorithm is more accurate at predicting site MMBtu impacts from GSHPs than an alternative simplified algorithm would have been. The study team does not recommend any modifications to the existing GSHP savings algorithm.	N/A

Beyond the TRM algorithm and assumptions, the study team identified opportunities to improve the NYS Clean Heat Program administration. Notable opportunities include more extensive tracking of relevant project information, such as Manual J heating and cooling loads, and more granular impact calculation for GSHPs installed with desuperheater systems.

On the other hand, the study team identified several "program successes" that demonstrated accuracy of reported energy savings and adherence to industry best practices. Commendable

[9] Massachusetts Program Administrators and Energy Efficiency Advisory Council Consultants, "Massachusetts Typical Weather – Research and Dataset Development." August 2023. https://ma-eeac.org/wp-content/uploads/MA22C04-B-TMY-Final_Report.pdf.

successes include the quality of tracking data and the accuracy of savings predictions as compared with study findings.

Heat Pump Water Heater (HPWH)

The operational performance of HPWH systems revealed opportunities to improve TRM savings assumptions related to efficiency deration, hot water consumption, and the preheating of inlet water. These recommendations are further detailed in Table ES-3.

ES-3. Opportunities to improve TRM savings assumptions for HPWH

Category	Finding	Recommendation
Efficiency Deration	The study team determined that 17 of 20 metered HPWHs required integrated supplemental resistance heat to meet the DHW load over the course of a year. Integrated supplemental resistance heat accounted for 11% of total metered kWh overall and reduced the overall UEF by 9%.	An additional UEF deration factor of 0.91 should be added to the HPWH savings algorithms in future TRM updates to account for the likelihood of integrated supplemental ER heating.
Hot Water Consumption	The study team determined more than double the DHW consumption predicted by the TRM among the sample of 20 metered HPWHs. TRM savings estimates are based on an average of 17.2 gallons per day (GPD) of DHW consumption per occupant; the study team determined 35.5 GPD per occupant on average. This study's sample size of 20 HPWHs is not sufficient to override the current assumption in the TRM, which is based on over 1,000 studied homes across the country. The study team therefore does not recommend adjustment to the TRM.	N/A
Inlet Water Preheating	The study team determined that six of 20 metered HPWHs received inlet water that was preheated by the hydronic space heating system. While an energy-efficient design, this preheating reduced HPWH savings.	Program Administrators should require that contractors identify and track when such preheating occurs. In these situations, the inlet water temperature should be increased by 24% to account for the HPWH's reduced savings potential.

Beyond the TRM algorithm and assumptions, the study team identified opportunities to improve NYS Clean Heat Program administration. For example, Program Administrators and contractors should more closely adhere to the TRM methodology for assigning baselines in normal replacement situations and more broadly consider the review of key terms used in the TRM.[10]

The study team also identified several "program successes" that demonstrated accuracy of reported energy savings and adherence to industry best practices. Commendable successes

[10] The TRM does not currently distinguish between supplemental and integrated supplemental heating.

include the comprehensiveness of tracking data and the accuracy of the efficiency deration factor to account for HPWHs installed in unconditioned spaces.

1 Introduction

This report provides the objectives, methods, results, and findings of the Technical Study of New York State Heat Pump Performance ("current study" or "study") conducted by DNV with partner Frontier Energy and directed by the NYS Department of Public Service (DPS).

The purpose of the study is to refine statewide energy savings estimates based on performance data specific to NYS by assessing the operational performance of cold-climate Air Source Heat Pump (ccASHP), Ground Source Heat Pump (GSHP), and Heat Pump Water Heater (HPWH) system projects. The study also aims to assess heat pump system customers' usage patterns and understanding of the heat pump technology, the impact these have on system performance, and overall customer satisfaction with the heat pump system.

1.1 Study objectives

The technical approach to this study emphasizes developing and refining the *New York Standard Approach for Estimating Energy Savings from Energy Efficiency Programs – Residential, Multi-Family, and Commercial/Industrial*, known as the Technical Resource Manual (TRM),[11] specifications for heat pumps. These specifications provide the basis for estimating the energy savings and demand impacts of future heat pump installation projects through the NYS Clean Heat Program, a common statewide heat pump program implemented by NYS electric utilities[12] and NYSERDA since April 1, 2020.

The population of heat pump installations for ccASHP includes the NYS Clean Heat Program and predecessor program projects with project end dates from January 1, 2019, through October 31, 2020. The GSHP and HPWH study populations include earlier predecessor program tracking data, the earliest project installed in October 2017.

Table 1-1 lists the study objectives, associated research questions, analytical methods, and data sources. To fulfill the study objectives, the project team collected between nine and 12 months of metered data from 72 heat pump installations across NYS. The team collected project tracking

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[11] New York Standard Approach for Estimating Energy Savings from Energy Efficiency Programs – Residential, Multi-Family, and Commercial/Industrial Measures, Version 11 – Filed October 6, 2023 (effective January 1, 2024), https://dps.ny.gov/technical-resource-manual-trm. A consolidated TRM is filed annually that incorporates changes from the previous twelve month's record of revision filings.

[12] Central Hudson Gas & Electric Corporation (Central Hudson), Consolidated Edison Company of New York, Inc. (Con Edison), Niagara Mohawk Power Corporation d/b/a National Grid (National Grid), New York State Electric & Gas Corporation (NYSEG), Orange and Rockland Utilities, Inc. (Orange & Rockland), and Rochester Gas and Electric Corporation (RG&E) (collectively, electric utilities).

data from NYSERDA and the electric utilities, surveys of heat pump program participants, and building consumption data for 384 participants who both responded to the survey and provided permission to access the data.

Table 1-1. Study objectives, research questions, and methods

Objective	Research questions	Analytic methods & data sources[13]
1. Evaluate the annual gross energy impacts of ccASHPs, GSHPs, and HPWHs.	• What are the annual gross fuel savings (MMBtu and gallons of delivered fuel) and electricity savings (kWh) from equipment operation? • What is the additional annual gross energy consumption (kWh) from the operation of heat pumps? • What are the winter and summer peak demand impacts (kW) from the operation of heat pumps?	Electric utility consumption data analysis of a representative sample of projects by heat pump technology category,[14] equipment size and market sector; normalized weather data; on-site metering and data collection analysis; peak load data from the New York Independent System Operator and electric utilities.
2. Analyze factors associated with observed performance of the technology.	What effect do the following factors have on energy savings? • Building type • Building vintage • Building envelope • Building condition • DHW heat pump location within the building • Existence of a secondary heating source(s) in use • Presence or absence of integrated controls and choice of setpoints	Engineering desk review, electric utility consumption data analysis, on-site metering and data collection analysis, modeling.
3. Characterize seasonal usage of ccASHPs and GSHPs and degree of use as displacement versus replacement of existing heating and cooling systems.	• To what extent are specific ccASHPs and/or GSHPs used for cooling and/or heating in a seasonal application? • What effect does occupancy/seasonal usage have on energy savings? • To what extent are heat pumps used to fully displace existing fossil fuel systems?	Participant surveys, engineering desk review, electric utility consumption data analysis, on-site metering and data collection analysis, modeling.

[13] Primary data sources include those available from NYSERDA and the electric utilities and those the study team collected.

[14] Heat pump technology categories are defined in the NYS Clean Heat Program Manual. Predecessor program heat pump projects included in the sample frame for this study are segmented into similar categories. Their characteristics are confirmed as appropriate to the assigned category through survey responses.

Objective	Research questions	Analytic methods & data sources[13]
4. Develop information for updating the TRMs prescriptive energy savings estimation methods and custom energy savings analysis approaches.	• What revisions or additions are necessary to the heat pump measures in the TRM to improve accuracy of savings estimations including, but not limited to: o EFLH variables used to calculate consumption (heating hours derived from bin analysis, cooling hours from prototype modeling) in the TRM (GSHP and ccASHP) o Adjustments to seasonal COP and EER used in the TRM (GSHP and ccASHP) o Pumping power and fan power adjustments used in the TRM (GSHP) o DHW loads served by GSHP systems and assumed displacement of fossil fuel DHW production. o Part-load mini-split assumptions developed for the TRM (ccASHP) o Types of control systems installed with heat pump systems (mainly ccASHP) o Factors not currently accounted for in the TRM. • Assessment and recommendations for improvement to custom analysis approaches.	Engineering desk review, electric utility consumption data analysis, on-site metering and data collection analysis, modeling.
5. Assess participant use, understanding, and satisfaction with heat pump systems.	• How do customers operate their heat pumps and perceive the available benefits (reduced energy costs, comfort)? • What role do contractors play in educating the customer on the proper operation of heat pump systems to maximize energy savings potential? • How satisfied are customers with the technology?	Participant surveys

1.2 NYS heat pump programs

To support the State's ambitious clean energy policies, and in particular its efforts to advance the development of energy efficiency and building electrification, the NYS Public Service Commission (the Commission) initiated a common statewide heat pump framework for NYS designed to guide the efforts of the Joint Efficiency Providers. The Commission's January 16, 2020, *Order Authorizing Utility Energy Efficiency and Building Electrification Portfolios*

Through 2025 (January 2020 Energy Efficiency Order or Order)[15] established energy efficiency targets and budgets for the utilities that met the intended principle of an "all cost-effective measures" policy to dramatically scale energy efficiency while retaining budget boundaries to ensure cost containment. The Order additionally outlines a long-term, far-reaching heat pump strategy for NYS with a focus on heating applications and an agenda to expand rapidly beyond single family building typologies. This strategy is manifested in the development and deployment of the NYS Clean Heat Program. The January 2020 Energy Efficiency Order further describes how the targets established therein were based on savings estimation approaches, subsequently documented in the TRM, for installing heat pumps for detached single family and one- to four-unit multi-family residential applications. The Order acknowledges that the TRM calculations are estimations and that several variables and assumptions affect the ultimate savings realized.

Recognizing that heat pumps incented through the NYS Clean Heat Program are not limited to the residential market and that custom savings estimation approaches are to be used for commercial and multi-family applications, the Commission directed DPS Staff to refine savings estimate approaches through a statewide evaluation, measurement, and verification (EM&V) study.

1.2.1 Heat pump program descriptions

The Technical Study of New York State Heat Pump Performance draws from heat pump installations through energy efficiency program activity of NYSERDA and the electric utilities. The universe of projects considered in this study is comprised of heat pump installations incentivized by the NYS Clean Heat Program in 2020 and by applicable predecessor programs in prior years. The study team included predecessor program activity in the study scope to build a robust sample frame for installed technologies, prioritizing the projects installed in 2019. Section 2.1 describes the approach and design of the sample frame. The NYS Clean Heat Program and predecessor programs are described here in brief.

[15] Case 18-M-0084, *In the Matter of a Comprehensive Energy Efficiency Initiative*, Order Authorizing Utility Energy Efficiency and Building Electrification Portfolios Through 2025 (January 2020 Energy Efficiency Order) (issued January 16, 2020).

1.2.1.1 ***NYS Clean Heat Program***

The NYS Clean Heat Program launched on April 1, 2020,[16] with a goal of supporting the installation of heat pump technologies that are best suited to cold climates. The framework is designed to provide contractors and other heat pump solution-providers with a consistent experience and business environment throughout NYS, promoting contractors and other heat pump solution-providers with training and consumer education. This includes operation and maintenance guidance from participating contractors to customers who have heat pumps installed. The NYS Clean Heat Program also requires participating contractors to follow best practices and comply with applicable state and local code related to building load calculations, equipment sizing, and selection for the installation of cold-climate heat pump technologies. As part of NYS Clean Heat Program delivery, the Joint Efficiency Providers monitor the extent to which the NYS Clean Heat Program-incentivized heat pump systems displace or replace electric resistance and fossil fuel systems.[17] At the time the current study was initiated, the NYS Clean Heat Program provided incentives under nine categories reflecting applicable technology type, system size, and incentive structure. The heat pump technologies defined in the NYS Clean Heat Program Manual[18] are listed below.

- *Category 1: ccASHP: Partial Load Heating*[19]
- *Category 2: ccASHP: Full Load Heating*
- *Category 2a: ccASHP: Full Load Heating with Integrated Controls*
- *Category 2b: ccASHP: Full Load Heating with Decommissioning*
- *Category 3: GSHP: Full Load Heating*
- *Category 4: Custom Space Heating Applications*
- *Category 4a: Heat Pump + Envelope*
- *Category 5: HPWH (up to 120 gallons of tank capacity)*
- *Category 6: Custom Hot Water Heating Applications*
- *Category 7: GSHP Desuperheater*
- *Category 8: Dedicated Domestic Hot Water (DHW) Water-to-Water Heat Pump (WWHP)*
- *Category 9: Simultaneous Installation of Space Heating & Water Heating*

[16] Beyond anticipated transition impacts between NYS Clean Heat Program and predecessor programs, effects of the COVID-19 pandemic may have significantly impacted the 2020 program experience.
[17] The NYS Clean Heat Program includes incentives offered by the participating electric utilities and a portfolio of market development initiatives administered by NYSERDA.
[18] New York State Clean Heat Statewide Heat Pump Program Manual, Version 7, pages 32-33.
[19] Incentives for *Category 1: ccASHP: Partial Load Heating* have been discontinued statewide as of January 1, 2024.

The NYS Clean Heat Program Manual also specifies the technologies eligible for incentives within each category:

(1) Air Source Heat Pumps for space heating applications, including:

a. Cold Climate Air-to-Air Mini-Split Heat Pumps
b. Cold Climate Air-to-Air Single Packaged Heat Pumps
c. Air-to-Air Large Commercial Unitary heat pumps (single packaged or split system)
d. Air Source Variable Refrigerant Flow heat pumps
e. Packaged Terminal Heat Pumps
f. Single Package Vertical Heat Pumps

(2) Ground Source Heat Pumps for space and water heating applications

(3) Heat Pump Water Heaters for domestic and service water heating applications, including:

a. Air-to-Water HPWHs
b. Ground Source Heat Pump Desuperheaters
c. Dedicated Water-to-Water Heat Pump added to Ground Loop

(4) Non-Code Required Energy Recovery Ventilators (ERVs) and Heat Recovery Ventilators (HRVs) paired with eligible heat pumps

(5) Building Envelope Upgrades paired with eligible heat pumps

1.2.1.2 *Predecessor NYSERDA and NYS electric utility heat pump programs*

Prior to the launch of the Clean Heat Program, NYSERDA incentivized ASHP and GSHP projects through various initiatives from 2017 through 2019. Similarly, several of the electric utilities offered incentives for ASHP and GSHP systems within their programs. The first utility-administered program was offered as early as 2012. A variety of incentives were offered throughout the utility territories, including for ductless and ducted ASHP and GSHP in residential, small and medium business, and commercial and industrial (C&I) customer applications, and often included partnerships with contractors. In some instances, customers were also eligible to leverage ASHP and GSHP incentives through NYSERDA initiatives. Generally, the goals of these initiatives varied and included increasing the installation of heat pumps for full-load and part-load air conditioning and to a lesser extent more recently reducing carbon emissions associated with space heating.

1.2.2 NYS Clean Heat Program changes since study inception

The NYS Clean Heat Program has evolved in response to differences in utility service territory-specific market activity, to include adjustments and changes to incentive categories and incentive structure, among others. As such, the description of the NYS Clean Heat Program and associated characteristics largely reflect the current offering. Where applicable, NYS Clean Heat Program changes as of the time of writing are indicated throughout the report. Current information can be found on the NYS Clean Heat Program website.[20,21] The current version of the TRM and information on the revision process is available on the DPS website.[22]

As previously described, NYS's heat pump activities underwent a transition in 2020 with the launch of the NYS Clean Heat Program on April 1, 2020, including revised energy savings estimation methods for air source and ground source heat pump measures. Projects incented during the first quarter of 2020 represent the savings estimation approaches that had historically been in place under the predecessor programs. An additional program change occurred in early 2023 when Con Edison instituted revised incentive eligibility categories based on sector.[23] An alternative programmatic approach to calculate residential ccASHP deemed heating savings was also instituted and is described in Appendix R of the TRM (Version 11). Further, as of January 1, 2023, Con Edison discontinued incentives for *Category 1: ccASHP: Partial Load Heating,* a segment of this study population.

[20] https://cleanheat.ny.gov/.
[21] https://cleanheat.ny.gov/resources-for-applications.
[22] https://dps.ny.gov/technical-resource-manual-trm.
[23] The NYS Clean Heat Program for Con Edison provides incentives under the following 10 categories: *Category 2a: ccASHP: Residential Full Load Heating with Integrated Controls, Category 2b: ccASHP: Residential Full Load Heating with Decommissioning, Category 2c: ASHP MF Full Load Heating with Decommissioning, Category 2d: ASHP SMB Full Load Heating with Decommissioning, Category 3: GSHP: Residential Full Load Heating, Category 4: Custom Full Load Space Heating Applications, Category 4a: Custom Full Load Space Heating Applications + Envelope, Category 5: HPWH (up to 120 gallons of tank capacity), Category 6: Custom Hot Water Heating Applications, Category 10: Custom Partial Load Space Heating Applications.*

2 Methods

This section outlines the methods employed by the study team to identify the sample frame and design the sampling approach, gather primary data, and conduct analysis to fulfill the objectives of the study.

2.1 Sample frame

The sample frame for the study was designed to leverage the program tracking data that was available for heat pump projects installed prior to October 31, 2020. The study team established this study period to enable analysis of at least a full year of pre- and post-installation electric consumption data. Since the NYS Clean Heat Program launched on April 1, 2020, NYS Clean Heat Program project eligibility was limited to the first nine months of the NYS Clean Heat Program. All heat pump technology categories from predecessor program projects were included in the sample frame. The resulting ccASHP study population includes NYS Clean Heat Program and predecessor program projects with project end dates from January 1, 2019, through October 31, 2020. The GSHP and HPWH study populations include earlier predecessor program tracking data; the earliest project having been installed in October 2017. The additional predecessor program data increases the project population counts to meet survey and meter data precision targets for statistically significant results for each heat pump technology category.

2.2 Sample design

Table 2-1 outlines the strategy for constructing a representative sample of NYS Clean Heat Program and predecessor program heat pump projects. Table 2-1 illustrates the study's nested sample strategy, such that each data collection mode was completed for a narrower subset of the population of projects, building on the prior data collection completed. This sample design was used to achieve response rates that meet precision targets[24] and ensure the most comprehensive information available for on-site metering, the final data collection mode.

[24] Precision targets are described in Appendix B.

Table 2-1. Sampling approach per data collection mode[25]

Data collection mode	Sampling approach	Source	Key data collected	Uses
Project tracking data	Population	NYSERDA and the electric utility requests	Installed equipment characteristic, participant contacts	Basis of sample frame
Participant surveys	Sample	Web/phone survey of participants	HP use cases, baseline fuels, baseline equipment characteristics, presence of other electric heating, major changes	Segmentation, consumption data analysis, interpretation
Consumption data	Requested for all survey recipients	Electric utility requests	Electric and natural gas meter reading quantities and dates per premise	Summer and winter HP EFLH, bill for key use cases, baseline parameter calibration
On-site metering	Attempted recruitment of all with successful surveys, adequate consumption data, and agreement to meter	On-site observation, meter installation, and interview	Hourly or finer HP kW usage and temperature, facility and use characteristics	Summer and winter HP $EFLH_{meter}$, peak usage factor
On-site intensive metering	Subsample of on-sites	Supplemental metering, spot measurement	Output heating and cooling	SEER, EER, COP

Project tracking data was requested from the NYSERDA and the electric utilities for heat pump projects completed prior to October 31, 2020, providing the basis of the sample frame. Next, electric consumption data for the survey sample was requested from the utilities. As detailed in Section 2.4.1, the study team reviewed and analyzed the provided consumption data for all survey respondents with eligible heat pump applications and use profiles.[26] The study team designed an

[25] The population available for the C&I sector is limited, such that sampling of the full population and with repeated follow-ups the study team achieved only 18 survey completes and two meter installations (of 12 targeted). The limited C&I sample frame (population) indicates low installation activity for these technologies in the sector, and those recruited sites are not well representative of heat pump performance in the sector. Accordingly, further C&I metering recruitment was suspended on May 31, 2022.

[26] Eligibility for metering was screened through criteria for survey responses matching the frame assignments. These criteria included: 1) appropriate heat pump technology category assignment in the sample segmentation based on definitions in the NYS Clean Heat Program Manual, 2) cold-climate application, 3) customer-reported usage patterns that met full load/partial load criteria between *Category 1: ccASHP: Partial Load Heating* and *Category 2: ccASHP: Full Load Heating*, and 4) building type category (single family, multi-family, and commercial) per TRM building type definitions.

on-site metering sample among surveyed customers with complete consumption data. Finally, a subsample of metered projects was selected for more intensive on-site metering.

Table 2-2 provides the completed counts of participant surveys as well as targeted and completed counts of on-site metering deployments by technology category. The targeted and completed sample counts by technology differ due to variations in participant survey response rates and willingness of site contacts to participate in on-site metering. Across all the targeted technology categories, the study team installed 72 meters.

The completed sample counts include shifts of heat pump project data between *Category 1: ccASHP: Partial Load Heating* and *Category 2: ccASHP: Full Load Heating*. These shifts were based on the study team's corrections to the category classifications in utility project tracking data. The study team reclassified a portion of sampled ccASHP projects based on usage patterns reported by survey respondents and/or preliminary reviews of the collected utility consumption data.

Table 2-2. Sample targets and completed data collection[27]

Heat Pump Technology Category	Project tracking data	Completed participant surveys	Prior study on-site meter data	On-site metering target		Completed on-site metering	
				Current study	Current + prior study	Current study	Current + prior study
Category 1: ccASHP: Partial Load Heating	5,472	70	31	33	64	14	45
Category 2: ccASHP: Full Load Heating	4,982	152	55	38	93	28	83
Category 3: GSHP: Full Load Heating[28]	381	73	36	8	44	10	46
Category 5: HPWH (up to 120 gallons of tank capacity)	1,053	89	0	26	26	20	20
Category 7: GSHP Desuperheater	14	14	0	0	0	0	0
Category 8: Dedicated DHW WWHP	7	7	0	0	0	0	0
Total	**11,909**	**384**	**122**	**105**	**227**	**72**	**194**

[27] *Category 4: Custom Space Heating Applications* and *Category 6: Custom Hot Water Heating Applications* were excluded from the sample due to the absence of projects in the project tracking data. *Category 9: Simultaneous Installation of Space Heating & Water Heating* was also excluded because only two sites were installed within the sample frame. Independent site reviews were necessary to these unique projects. The study team requested all project files for projects within *Category 7: GSHP Desuperheater* and *Category 8: Dedicated DHW WWHP*. These categories were not targeted for on-site metering due to their limited potential to contribute to the updates of the TRM variables.

[28] For *Category 3: GSHP: Full Load Heating* projects, prior study on-site meter data (36 projects) includes five commercial sites. The current study includes two commercial sites within the *Category 3: GSHP: Full Load Heating* on-site metering sample. All other GSHP sites in the completed on-site metering sample are single family residential.

In 2022, the study team completed an evaluation of energy impacts from heat pump installation projects completed through NYSERDA programs between 2017-2018. Data from this 2022 NYSERDA Heat Pump Impact Evaluation ("prior study") supplemented the on-site metering data from the current study. Use of data from the prior study was advantageous because it included the same types of heat pump equipment (mini-split, multi-split,[29] whole house air,[30] and GSHP systems) within the same sectors (residential and commercial). The utilization of the prior study's metered data reduced the on-site metering sample counts required in the current study to achieve parameter-level findings. HPWHs were not included as part of the prior study.

The current study's web survey was emailed to the full population of commercial and multi-family project participants to recruit as many customers as possible for on-site metering. However, due to low population counts and low response rates in those sectors, the recruitment efforts resulted in on-site metering for only one multi-family site (classified as *Category 2: ccASHP: Full Load Heating*) and two commercial sites (each classified as *Category 3: GSHP: Full Load Heating*). All other sites in the completed on-site metering sample are single family residential. The prior study included five commercial sites, each of which was most appropriately classified as *Category 3: GSHP: Full Load Heating*.

2.3 Data collection

The data collection modes for each heat pump technology category are summarized in Table 2-3. Primary data collection included a web-based participant survey,[31] the gathering of participant consumption data, and on-site data collection, including the deployment of heat pump–specific meters for a sample of sites. A subset of the on-site sample received intensive metering to quantify heat pump performance during heating and cooling seasons.[32]

The study team conducted consumption data analysis and on-site metering for the most prominent technology categories incentivized by the programs over the study period: *Category 1: ccASHP: Partial Load Heating*, *Category 2: ccASHP: Full Load Heating*, *Category 3: GSHP: Full Load*

[29] To accurately leverage data from the prior study, the study team reviewed the heating season results of the sampled air source heat pump equipment to classify operation between partial load heating versus full load heating, because these definitions were not distinguished in the prior study.

[30] Each of the whole-house air source heat pumps and ductless mini-split heat pumps sampled for M&V in the prior study were designated as suitable for cold-climate conditions.

[31] Web outreach was supplemented with phone calls and mailers to prior participants who installed equipment in the prioritized technology categories.

[32] Intensive metering involved enhanced M&V rigor to measure additional operation and performance metrics of the installed heat pumps. In this study, intensive metering sites are distinguished from core metering sites, which received standard M&V rigor as described in Section 2.3.2.

Heating, *Category 5: HPWH (up to 120 gallons of tank capacity)*, and *Category 9: Simultaneous Installation of Space Heating & Water Heating*.[33] For the remaining categories, the study team conducted engineering desk reviews that involved a comprehensive assessment of program tracking data and project documents to assess the compliance of reported energy savings with TRM specifications.

Table 2-3. Data collection summary

Heat Pump Technology Category		Participant surveys	Consumption data analysis	On-site metering	Intensive metering	Engineering desk reviews
1	*ccASHP: Partial Load Heating*	✓	✓	✓	✓	
2	*ccASHP: Full Load Heating*	✓	✓	✓	✓	
3	*GSHP: Full Load Heating*	✓	✓	✓	✓	
4	*Custom[34] Space Heating Applications*					✓
4a	*Heat Pump + Envelope*					✓
5	*HPWH (up to 120 gallons of tank capacity)*	✓	✓	✓		
6	*Custom Hot Water Heating Applications (above 120 gallons of tank capacity)*					✓
7	*GSHP Desuperheater*	✓				✓
8	*Dedicated Domestic Hot Water (DHW) Water-to-Water Heat Pump (WWHP)*	✓				✓
9	*Simultaneous Installation of Space Heating & Water Heating*	✓	✓	✓		

2.3.1 Participant surveys

This section summarizes the objectives and methods of the participant survey. The study employed a web-based survey administered through Qualtrics[35] to collect permission from survey respondents to request utility consumption data, gather heat pump usage characteristics, and inquire about interest in participating in on-site metering. The study team emailed requests to eligible NYS Clean Heat Program and predecessor program participants with links to the web-based survey. To meet precision targets for on-site metering across the technology categories,

[33] The study period did not include any installations of the remaining heat pump technology categories: *Category 4: Custom Space Heating Applications*, *Category 4a: Heat Pump + Envelope*, and *Category 6: Custom Hot Water Heating Applications*.

[34] Custom projects include projects that do not utilize the prescriptive savings estimation approach identified in the TRM.

[35] Qualtrics is web-based software that allows users to securely generate and administer surveys and analyze results.

email outreach was supplemented with additional phone calls and mailers to prior participants who installed equipment in prioritized technology categories.

Participant responses to the survey were used to support the consumption data analysis as well as the analysis of on-site metering data. Survey responses allowed the study team to characterize the seasonal usage of the heat pump equipment and the displacement of existing heating and cooling systems by the heat pump equipment. The survey also investigated key characteristics of the participant's home or business, such as the presence of solar photovoltaic systems or significant changes to the building's systems or occupancy during the study period.

Survey respondents also reported on perceived benefits from the heat pump installation, including comfort level and changes in energy costs. The survey explored the level of education the equipment installation contractors provided on the proper operation of the heat pump equipment. Finally, survey respondents described their motives for participation in the heat pump program and overall satisfaction with the heat pump technology.

Appendix A further describes the data collected in the participant survey.

2.3.2 On-site data collection and metering

This section details the methods employed through the on-site data collection and equipment-level metering for the selected sample of installations. Each site visit involved physical confirmation of installed heat pump equipment specifications and building characteristics. Field engineers conducted on-site interviews with the participating customers to confirm survey responses and collect additional information to support the analysis detailed in Section 2.4.

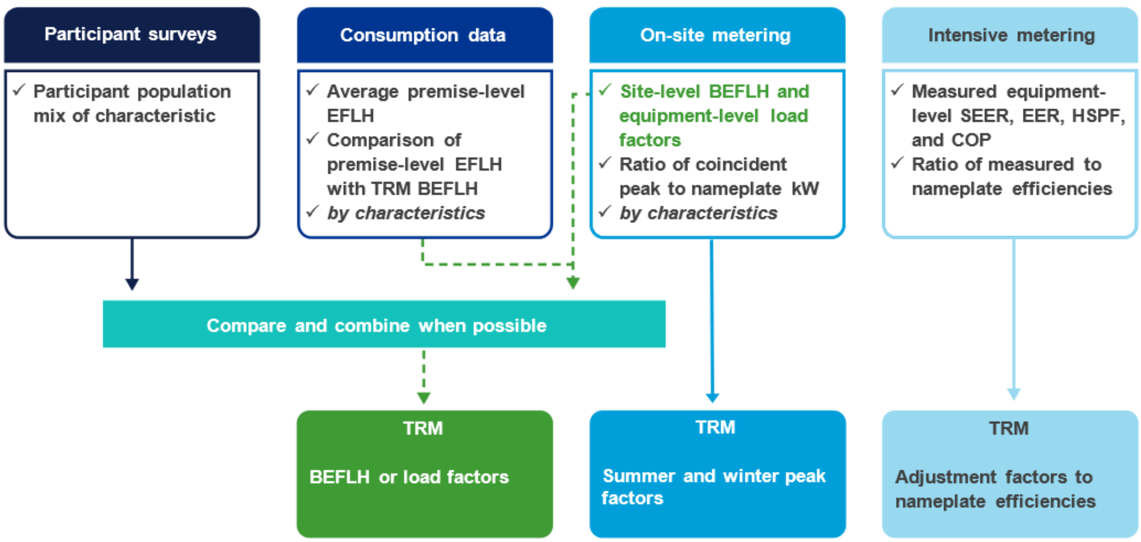
On-site metering informed the calculation of operational and performance variables used to calculate energy use and energy savings of installed heat pump equipment. Section 2.4.2 outlines the metering techniques used by the study team for DMSHP, ducted ASHP, GSHP, and HPWH equipment types. For all sampled sites, on-site metering informed the operating hours and power consumption of installed heat pump equipment. For a subset of sampled ccASHP and GSHP projects, field staff used an intensive M&V approach that measured heat pump energy output. As detailed in Section 2.4.3, energy output data, in conjunction with electrical power input data, allowed the study team to quantify performance variables SEER, EER, HSPF, and COP used in the TRM algorithms.

The on-site meters installed at the project sites were remote communicating meters. Each meter was installed for a minimum of nine months to capture equipment performance during the winter, summer, and at least one full shoulder season. Once the meters were installed, field engineers verified the connectivity of the communication device and the successful wireless transfer of data from the meter to a secure, cloud-based data collection platform.

2.4 Data analysis

This section details the analysis of data collected from surveys, utility consumption data, and on-site metering. Figure 2-1 illustrates the interplay of the various data sources to calculate adjustments to TRM variables.

Figure 2-1. Analysis methods and TRM variable results by data source[36, 37]



The study team completed the following steps to perform the aggregate analysis. The following steps are further detailed in the remainder of Section 2.4.

1. Conduct premise-level analysis of utility-supplied energy consumption data before and after heat pump installation to determine preliminary EFLH estimates during heating and cooling seasons. Examine EFLHs by survey data characteristics as available.
2. Determine equipment-level EFLHs, site-level BEFLHs, heating load factors, and peak coincidence factors using heat pump-specific data from on-site metering.

[36] Quantification of BEFLH and EFLH is contingent upon the quality of tracked building heating load (i.e., Manual J) and installed system capacity, respectively, which serve as the denominators to the BEFLH and EFLH calculations.
[37] Consumption data analysis may be untenable for facilities that added or removed non-program energy-consuming equipment during the pre/post period.

3. For intensive metering sites, quantify achieved performance by analyzing the heat pumps' energy output with electrical power input. Apply performance results to other sampled sites by equipment type.
4. Compare EFLHs determined through consumption data analysis and on-site metering data analysis. If feasible, synthesize the two sets of results to enhance statistical precision. Otherwise, use the on-site metering results to define EFLHs and BEFLHs.
5. Develop aggregate or average results reflecting the mix of equipment types and climate zones in the sample and population of projects over the study period.
6. Recommend revisions to the TRM methods and associated variables using aggregate results.
7. Estimate overall annual and seasonal energy impacts by fuel and peak demand impacts using the revised methods, factors, and variables.

Simultaneously, the study team conducted engineering desk reviews of the heat pump technology categories incented least frequently during the study period, including *Category 7: GSHP Desuperheater* and *Category 8: Dedicated Domestic Hot Water (DHW) Water-to-Water Heat Pump (WWHP)*. The study team also conducted secondary research to compare other jurisdictions' savings estimation algorithms and assumptions with the TRM method for the GSHP desuperheater and DHW WWHP technology categories.

2.4.1 Consumption data analysis

For this study, the consumption data analysis compares a year of pre-installation energy usage from electric billing data to a year of post-installation electric usage for a premise.[38] This analysis allowed preliminary estimation of the seasonal operation of the incentivized heat pumps, with a particular focus on heating season operation.

Heat pumps can fully or partially displace a building's heating load, cooling load, or both, once installed. A building owner may utilize supplemental heating after the heat pump is installed. This supplemental heating can come from many different fuel sources and, in some cases, from multiple sources at a single site. Similarly, the pre-installation system configuration may have been modified, used a different fuel source, or not have provided either heating or cooling. Such diversity in site and system characteristics complicates the use of consumption data analyses to determine seasonal operation. To understand site and system characteristics for each participant,

[38] Ideally, the analysis would also compare pre- and post-installation fossil fuel consumption data for the same premises. However, sufficient natural gas consumption data was only available for a small subset of premises, as the programs generally did not collect the applicants' natural gas account numbers. The collection of delivered fuels data (e.g., propane, oil) was not in the scope of this study.

the study team incorporated response data from the participant survey in the consumption data analysis.

Since heat pump operation varies with weather conditions, consumption data analysis required the processing of historical and typical weather data. The study team collected hourly historical weather for New York's 24 weather stations administered by the National Oceanic and Atmospheric Administration (NOAA). Hourly typical weather was derived from typical meteorological year (TMY) datasets for the same weather stations. For each premise analyzed, the study team used the historical and typical weather data to develop historical and typical cooling degree days (CDDs) and heating degree days (HDDs) for the nearest weather station.

The study team used statistical analysis software to analyze the premise-level consumption data. The analysis included the following steps for each premise:

1. Correlating pre- and post-heat pump installation consumption data with historical CDD and HDD data to quantify the effects of weather on electric consumption during cooling and heating seasons, respectively.
2. Applying the cooling and heating correlations to typical weather data to calculate weather-normalized pre- and post-installation electric consumption.
3. Incorporating program tracking data on the rated capacities and efficiencies of heat pump(s) installed at the site to quantify $EFLH_{cooling}$ and $EFLH_{heating}$ using the following formulas.

$$EFLH_{cooling} = \frac{\Delta kWh_{cooling} \times SEER_{rated}}{Capacity_{cooling} \times 1{,}000}$$

$$EFLH_{heating} = \frac{\Delta kWh_{heating} \times HSPF_{rated}}{Capacity_{heating} \times 1{,}000}$$

EFLHs derived from consumption data analysis were eventually compared with EFLHs and BEFLHs calculated from M&V data as described in the next section.

2.4.2 On-site metering data analysis

Table 2-4 outlines the M&V data analysis approaches for the four primary equipment types addressed in the study. The rightmost column summarizes how the on-site metering data was analyzed to refine the BEFLH values assumed in the TRMs heat pump measure algorithms. The study team conducted these core analysis techniques for all sites in the on-site metering sample.[39]

[39] Core M&V sites are distinguished from intensive M&V sites as described in Section 2.4.3.

Table 2-4. Core M&V approach to quantify BEFLH

Installed equipment	M&V deployment	M&V analysis approach
Ductless Mini-Split Heat Pump (DMSHP)	• Current transformer (CT) in each DMSHP's compressor (outdoor unit) • Temperature/relative humidity (RH) logger in each indoor head's supply air stream	• Correlate DMSHP electric usage with NOAA weather conditions, time-of-day • Confirm heating or cooling modes via airstream temperatures • Extrapolate usage patterns over a full year using TMY weather, estimate BEFLH using tracked Manual J building load data • Confirm pre-existing conditions and load sharing as preliminarily assessed in participant survey
Whole-home ccASHP	• CT on compressor, air handler, and integrated supplemental electric resistance (ER) (if available) • Temperature / RH logger(s) in supply air ducts	• Correlate ccASHP usage with NOAA weather conditions, time-of-day • Confirm heating or cooling modes via airstream temperatures • Extrapolate usage patterns over a full year using TMY weather, quantify BEFLH using tracked Manual J building load data • Isolate integrated supplemental ER heating and extrapolate over a full year • Confirm pre-existing conditions and load sharing as preliminarily assessed in participant survey
Whole-home GSHP	• CT on compressor, air handler(s), integrated supplemental ER, and pump • Surface temperature loggers on groundwater in, groundwater out, DHW out (if applicable)	• Correlate GSHP performance with groundwater trends, NOAA weather conditions, and time-of-day • Extrapolate usage patterns over a full year using TMY weather, quantify BEFLH using tracked Manual J building load data • Isolate integrated supplemental ER heating and extrapolate over a full year • Quantify auxiliary equipment loads (e.g., pump) from metered trends extrapolate over a full year • Quantify recovered DHW as function of GSHP operation
Heat Pump Water Heater (HPWH)	• CTs on HPWH compressor and integrated supplemental ER heat circuit • Ambient temperature / RH loggers near HPWH unit • Surface temperature loggers on DHW recovery inlet and outlet piping	• Extrapolate heat pump consumption over full year using metered correlations with NOAA weather • Quantify energy output of HPWH by comparing surface temperatures on inlet and outlet piping • Extrapolate HPWH operation with typical weather conditions and other seasonal factors

The study team used M&V analysis tools developed from prior templates used in heat pump impact evaluations in New York and Maine. The tools are designed to handle all relevant heat pump configurations and baseline scenarios resulting from installations incentivized through the NYS Clean Heat Program and predecessor programs.

2.4.3 Intensive M&V data analysis

Intensive M&V data analysis involved additional measurement to quantify seasonal performance values of the installed heat pump equipment. The sample included eight intensive M&V on-site metering sites that supplemented the core analysis activities with:

- Deployment of real power loggers on heat pump outdoor units,
- Spot measurement of supply airflow at varying fan speeds, if applicable,
- Correlation of airflow with fan amps to develop fan speed curves,
- Additional temperature / RH logger deployments and analysis to measure the supply air temperature change caused by the heat pump,
- Comparison of the heat pump's electrical energy input to measured energy output to determine coefficients of performance as a function of outside air temperature.

The study team determined performance curves for all intensive sites. These curves were applied to core M&V sites by equipment type to estimate performance as a function of outside air temperature. To bolster the representativeness of this data, the study team leveraged similar data collected from intensive sites in the 2022 NYSERDA Heat Pump Impact Evaluation.

2.4.4 Engineering desk reviews

Engineering desk reviews involved detailed assessments of tracking data and associated project documents that are typically maintained by the Program Administrator, such as copies of invoices, manufacturer specification sheets, project inspection reports and photographs, to determine the compliance of reported energy savings with TRM methods. Section 2 has thus far pertained to prominent measure categories over the study period: DMSHP, ducted ASHP, GSHP, and HPWH. The study period also included 21 installations of less prominent equipment included within two NYS Clean Heat Program measure categories: *Category 7: GSHP Desuperheater* and *Category 8: Dedicated Domestic Hot Water (DHW) Water-to-Water Heat Pump (WWHP)*. Predecessor programs did not provide incentives for installations of equipment in these two categories. The study team conducted the following engineering desk review activities for all 21 installations:

- Review of the applicant savings methods to determine if the approach is appropriate for the given measure and operating conditions.
- Review of the installation documentation to confirm that the installed measure matches the description in the application.
- Assessment of the measure's expected performance based on the provided specifications and any available third-party performance data.
- Comparison of the heat pump measure characteristics and performance with the requirements and assumptions identified in the TRM.
- Quantification of TRM-compliant savings based on tracked and documented information per installation.
- Comparison of TRM-compliant savings with program-estimated energy savings to identify discrepancies.
- Development of recommendations to clarify application of TRM methodologies.

3 Air source heat pump results

The NYS Clean Heat Program offers incentives for the installation of air source heat pumps (ASHPs) designated as suitable for cold-climate conditions by the Northeast Energy Efficiency Partnerships (NEEP).[40] Eligible ccASHPs include ducted systems and ductless mini-split systems.[41] The NYS Clean Heat Program Manual distinguishes among the different installation types through a load designation of part-load (PLHP) or full-load (FLHP) ccASHPs, which correspond to Categories 1 and 2 of the NYS Clean Heat Program eligible technologies list.[42, 43]

As shown in Table 3-1, during the study period years of 2019 and 2020, the programs[44] incented 10,454 ccASHPs among 6,546 unique customers. The majority of ccASHP installations occurred in the residential sector.[45]

Table 3-1. ccASHP installation activity during 2019-20 study period

Heat Pump Technology Category[46]	1. Single family	2. Multi-family	3. C&I	4. Unknown	Grand total
1A Partial Load HP 1-3 Units	3,779	1,215	18	62	5,074
1B Partial Load HP >3 Units	192	177	19	10	398
2A Full Load HP 1-3 Units	2,257	944	41	56	3,298
2B Full Load HP >3 Units	1,044	531	43	66	1,684
Total population	**7,272**	**2,867**	**121**	**194**	**10,454**

[40] The NEEP cold-climate product list can be found here: https://ashp.neep.org/#!/product_list/.

[41] Eligible ductless mini-split systems include both single- and multi-zone systems. Eligible ducted systems include central ducted systems as well as compact ducted units associated with outdoor units serving other indoor sections. Additionally, the following technologies are currently eligible for NYS Clean Heat Program incentives but were not installed over the study period: air-to-water heat pumps (AWHPs), commercial unitary ASHPs, air source variable refrigerant flow (ASVRF) systems, packaged terminal heat pumps (ccPTHPs), and single package vertical heat pumps (ccSPVHPs).

[42] NYS Clean Heat: Statewide Heat Pump Program Manual, Version 7, page 32.

[43] Effective January 1, 2024, PLHP installations are no longer eligible to receive incentives through the NYS Clean Heat Program.

[44] The NYS Clean Heat Program was responsible for the majority of 2019-20 ccASHP installations in New York State. A limited number of ccASHP installations from the predecessor programs carried over into early 2019; however, none of the predecessor projects were sampled for M&V as part of this study.

[45] Approximately 1% of ccASHP installations occurred in the commercial sector. Such installations were classified as "C&I" within the tracking data and are labeled as such within Table 3-1. The vast majority of C&I participants were commercial customers.

[46] To achieve sampling targets by residential building type, the study team differentiated by number of residential dwellings, although this is not an official designation by the NYS Clean Heat Program.

3.1 TRM algorithm

The TRM (Version 10)[47] estimates ccASHP energy savings using the algorithms illustrated in Figure 3-1.

Figure 3-1. ccASHP savings algorithms in TRM Version 10

Annual Electric Energy Savings

$$\Delta kWh = \Bigg(\bigg(BCL \times \frac{1}{1{,}000} \times \left(\frac{1}{SEER_{baseline}} - \frac{1}{EER_{season,ee}}\right) \times BEFLH_{cooling} \times F_{load,cooling}\bigg) + \bigg(BHL \times \frac{1}{1{,}000} \times \left(\frac{F_{ElecHeat}}{COP_{season,baseline}} - \frac{1}{COP_{season,ee}}\right) \times \frac{1}{3.412} \times BEFLH_{heating} \times F_{load,heating,ElecHeat}\bigg) - \bigg(BHL \times \frac{1}{1{,}000} \times F_{ElecHeat,new} \times \frac{1}{3.412} \times BEFLH_{heating} \times \left(1 - F_{load,heating}\right)\bigg)\Bigg)$$

Summer Peak Coincident Demand Savings

$$\Delta kW = BCL \times \frac{1}{1{,}000} \times \left(\frac{1}{EER_{baseline}} - \frac{1}{EER_{ee}}\right) \times F_{load,cooling} \times CF$$

Annual Fossil Fuel Energy Savings

$$\Delta MMBtu = BHL \times \frac{1}{1{,}000{,}000} \times \frac{F_{FuelHeat}}{AFUE_{baseline}} \times BEFLH_{heating} \times F_{load,heating,FuelHeat}$$

The various ccASHP technologies—ducted, single-zone ductless, multi-zone ductless, and compact ducted systems—share the same savings algorithm in the TRM. This is possible using load factors that derate the building's heating load (BHL) and cooling load (BCL) as a function of equipment type, equipment rated capacity, controls strategy, and weather reference city. Table 3-2 provides a summary of the different variables included in the above algorithms.

Table 3-2. Summary of ccASHP savings variables and sources

Variable category	Variables	Description and current sources
Building heating and cooling loads	BHL, BCL	Manual J-based calculations of building heating and cooling loads at design conditions
Baseline efficiencies	$SEER_{baseline}$, $COP_{baseline}$, $AFUE_{baseline}$	Efficiencies of various baseline systems as defined by the Code of Federal Regulations
ccASHP efficiencies	EER_{ee}, COP_{ee}	Application-specific AHRI ratings of the installed ccASHP
Annual full-load operating hours	$BEFLH_{cooling}$, $BEFLH_{heating}$	Building-equivalent full-load hours as a function of facility type, vintage, and location
Fuel factors	$F_{ElecHeat}$, $F_{FuelHeat}$, $F_{ElecHeat,new}$	Binary flags indicating the presence of electric or fossil fuel heating

[47] Version 10 of the TRM was effective when the study team analyzed the results presented in this report. Version 11 of the TRM became effective January 1, 2024. The study team compared the two versions to confirm findings and recommendations in this report are applicable to Version 11.

Variable category	Variables	Description and current sources
Load factors	$F_{load,cooling}$, $F_{load,heating}$, $F_{load,heating,FuelHeat}$, $F_{load,heating,ElecHeat}$	Load factors to derate the building's full heating and cooling loads to reflect the anticipated loads met by the ccASHP

Through M&V and premise-level analysis of utility consumption data, the study team investigated several of the algorithm's variables: operating hours, load factors, efficiencies, and fuel-by-fuel baselines. These results are explored in Sections 3.2 through 3.7.

3.2 Heating loads and operating hours

As described in Section 2.4, the study team deployed measurement devices across 63 ccASHP systems at 42 participant homes. The devices collected between nine and 12 months of data on ccASHP operation and performance, allowing for comprehensive analysis of system operation during heating and cooling seasons. Additionally, the study team collected pre- and post-ccASHP installation utility consumption data to estimate ccASHP operating hours based on the change in weather-dependent consumption at the customer meter. The following subsections explore results by season and by method.

3.2.1 Heating loads and operating hours from M&V

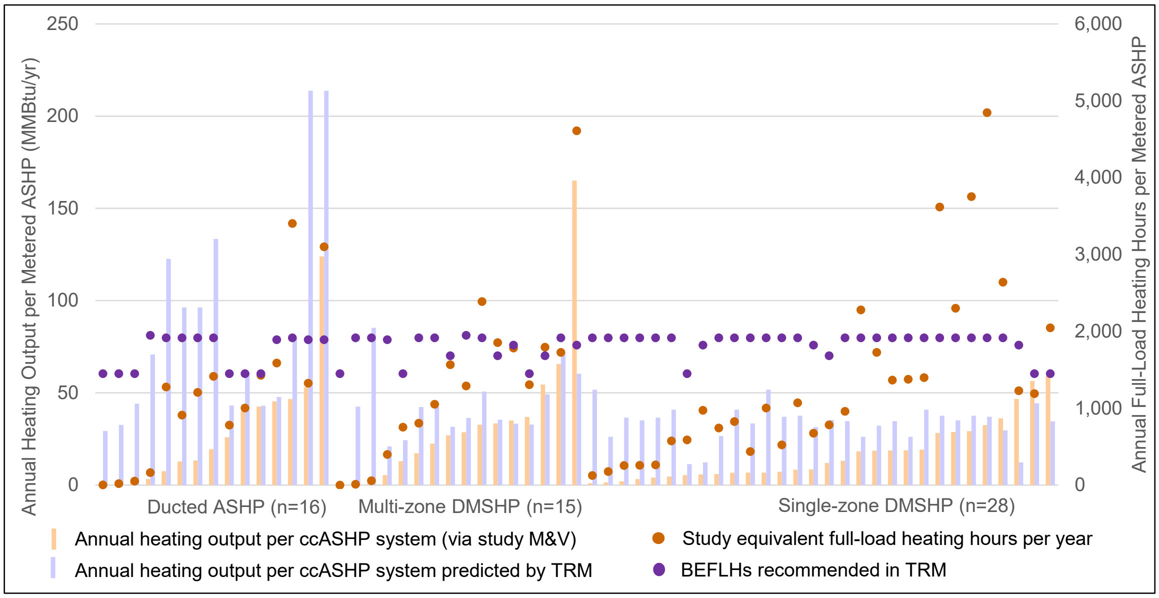
In simplest terms, the ccASHP savings algorithm combines three variables—load (in Btu/hour), hours, and efficiency (in Btu/Watt-hour)—to estimate annual energy impacts. The load calculation relies on a Manual J-compliant calculation of building heating load adjusted to reflect the installed ccASHP type, capacity, and weather reference city. BEFLHs similarly correspond to weather reference city. The product of heating load and BEFLH provides the TRMs estimate of the annual heating output of the installed ccASHP.

Figure 3-2 illustrates the distribution of actual annual heating outputs (orange bars corresponding to the left-hand y-axis, in MMBtu per year) and equivalent full-load heating hours (orange dots, corresponding to the right-hand y-axis) by ccASHP type. Additionally, the figure's purple dots and bars respectively illustrate each installation's TRM-recommended $BEFLH_{heating}$[48] and

[48] Capacity-based EFLH and building-equivalent full-load hours (BEFLH) are not equivalent. ccASHP systems may have been sized by the contractor to exceed the portion of the Manual J-based heating loads to be met by the ccASHP, thereby decreasing EFLH as compared to its corresponding BEFLH. The study team did not calculate Manual J-based BEFLHs; rather, the team quantified heating load factors using the TRM-recommended BEFLHs as shown later in this section.

predicted heating output using the TRM and project information tracked by the Program Administrator.

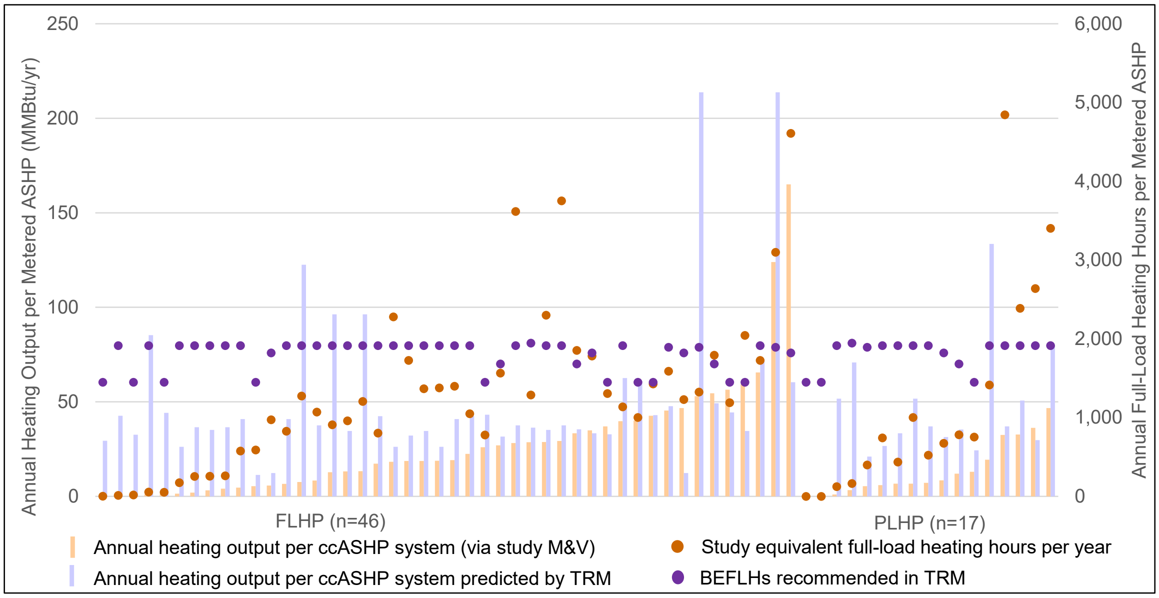
Figure 3-2. Comparison of heating output and full-load hours between study results and TRM predictions by ccASHP type



The figure shows that the majority of rebated ccASHPs provided less heating than predicted by the TRM. Interestingly, three ducted ASHPs and three multi-zone DMSHPs provided very little heating over the course of a year. As expected, ducted ASHPs and multi-zone DMSHPs provided more heating than single-zone DMSHPs. **On average, study results showed 1,535 and 597 equivalent full-load heating hours per year for ducted ASHPs and DMSHPs, respectively.**

Figure 3-3 illustrates a similar comparison for ccASHPs as distinguished by their claimed heating load displacement category: FLHP and PLHP.

Figure 3-3. Comparison of heating output and full-load hours between study results and TRM predictions by ccASHP load displacement category

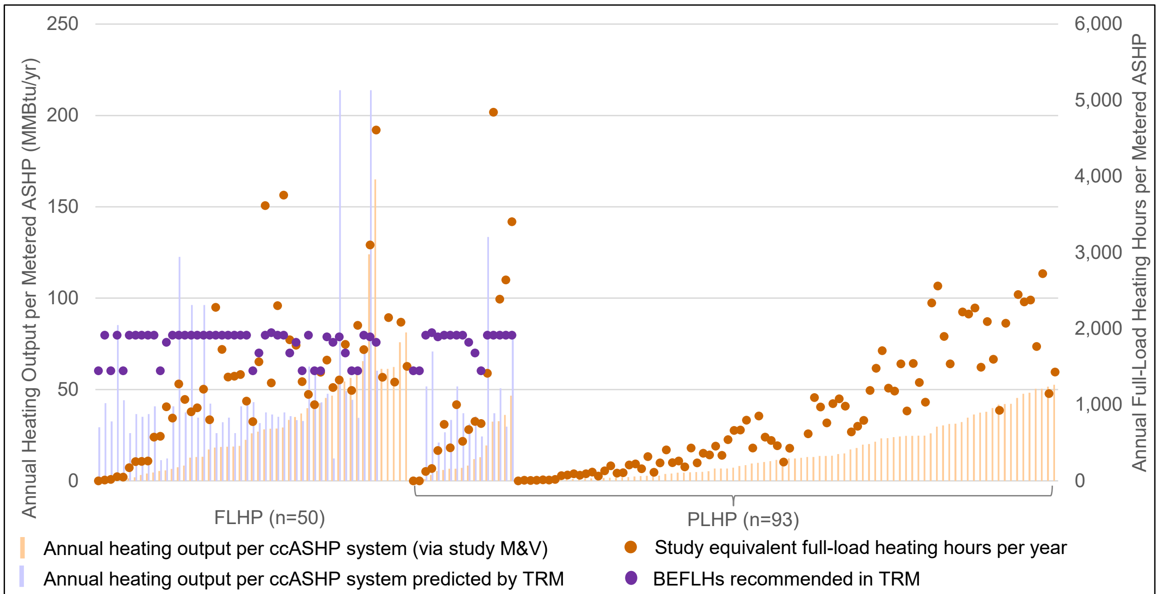


Full-load ccASHPs clearly provided more heating than part-load systems; however, several of the FLHP systems did not exhibit operation typical of a full-load system. **On average, study results showed 1,146 and 473 equivalent full-load heating hours per year for FLHP and PLHP classifications, respectively. Overall, the 63 metered ccASHPs operated 741 equivalent full-load heating hours per year.**

3.2.2 Heating loads and operating hours pooled with prior M&V results

The study team previously evaluated the predecessor NYSERDA heat pump programs through the 2022 NYSERDA Heat Pump Impact Evaluation, conducting similar M&V among a sample of 88 ASHP systems installed between 2017 and 2018. The NYSERDA-incented ASHPs were similarly designated as cold-climate systems. To bolster the sample size of ccASHP M&V results across New York, the study team pooled the heating operation results as illustrated in Figure 3-4.

Figure 3-4. Comparison of heating output and full-load hours between study results and TRM predictions by ccASHP load displacement category including 2022 NYSERDA Heat Pump Impact Evaluation results



The 2022 NYSERDA Heat Pump Impact Evaluation results do not include corresponding purple bars or dots, as the predecessor programs did not require Manual J heating load calculation on which heating outputs and BEFLHs are based. Additionally, the NYSERDA-rebated installations did not distinguish between FLHP and PLHP. Nonetheless, the study team retrospectively classified the NYSERDA results into FLHP and PLHP categories based on system output and building square footage. Seventy-six of the 80 sets of usable NYSERDA results were designated as PLHP due to the prevalence of DMSHPs incented by the predecessor programs.

The pooled results show that this study's sampled PLHPs provided more heating than the predecessor NYSERDA-administered PLHPs. This difference may be attributable to a more intentional heating displacement focus by the NYS Clean Heat Program as compared with predecessor programs. Overall, **the pooled results led to annual $\mathbf{EFLH_{heating}}$ averages of 1,128 and 513 for FLHP and PLHP, respectively**. These averages were statistically significantly different at the 90% confidence interval.

A strong predictor of heating output is the presence of supplemental heating sources. As part of the initial participant survey and metering on-sites, the study team investigated whether the ccASHPs shared the residence's heating load with other heating sources such as the pre-existing, predominantly fossil fuel-fired systems. **ccASHPs that do not share the heating load with other supplemental systems produce twice as much annual heating output on average as**

ccASHPs that do share the heating load.[49] The 2022 NYSERDA Heat Pump Evaluation results corroborate this finding, as ccASHPs that did not share the heating load achieved annual site MMBtu savings over twice as much as ccASHPs that did share the heating load.

3.2.3 Heating operating hours from premise-level analysis

As described in Section 2.3.1, the study team quantified EFLH using an alternative method involving analysis of utility consumption data. The objective of this additional analysis was to explore if premise-level data, when paired with M&V results, could strengthen the statistical stability of EFLH estimates for heating and cooling. The team worked with the electric utilities to obtain consumption data for all available ccASHP participants over the study period.[50] Table 3-3 summarizes the quality control checks and associated attrition from vetting the electric consumption data prior to EFLH analysis.[51]

Table 3-3. Premise-level ccASHP heating analysis attrition

Heating analysis quality control step	Remaining premises	Dropped premises	% of premises remaining
Received electric data	2,181		100%
Remove premises with insufficient baseline data (<= 1 bill)	1,985	196	91%
Remove premises with solar	1,824	161	84%
Remove premises with < 5 months of data during heating season (Oct - Mar) - during pre or post period	1,756	68	81%
Remove premises with < 500kWh annual usage in pre or post based on thresholds selected via CBECS and RECS	1,729	27	79%
Remove premises with no tracked heating capacity	1,466	263	67%
Remove premises with no tracked HSPF	1,396	70	64%
Remove premises that had < 42kWh during a monthly reading in either pre or post periods	1,143	253	52%
Remove premises that exhibited < 0 EFLH Heating	1,134	9	52%
Remove premises that exhibited > 8,760 EFLH Heating	1,133	1	52%
Final remaining	**1,133**	**1,084**	**52%**

[49] This finding does not account for the presence of integrated supplemental heating sources. As noted in the definition of supplemental heat, *integrated supplemental heat* refers to heating sources integrated within the heat pump unit, such as a backup electric resistance heating circuit. As discussed in Section 3.8.4, field engineers observed the presence of integrated supplemental heat on ten of 16 ducted ASHPs in the metering sample. None of the DMSHPs in the metering sample included integrated supplemental heat.

[50] GSHP participants were ultimately excluded from this analysis due to limited availability of utility consumption data.

[51] The study team attempted to collect premise-level natural gas consumption data from utilities to assess the ccASHPs' impact on gas heating displacement. However, the NYS Clean Heat Program tracking data did not include natural gas account numbers for participating customers. The study team attempted to collect natural gas account numbers from the 222 ccASHP participants that responded to the on-line participant survey. Ultimately, the team collected 274 sets of natural gas consumption data, but only a small portion of these accounts were viable for pre/post analysis using steps similar to those identified in Table 3-3.

Next, the study team examined the 1,133 sets of premise-level consumption data to apply the most appropriate method for estimating heating EFLH. Depending on the heating signatures of the pre- and post-installation electric consumption data, the team applied one of two methods to quantify the EFLH of the ccASHP(s) installed at the premise: 1) analysis of **post-only** electric consumption data's dependence on observed heating degree days, or 2) analysis of the difference between **post- and pre-installation** electric consumption and its dependence on observed heating degree days. Table 3-4 provides three scenarios of how the appropriate method was selected.

Table 3-4. ccASHP premise-level analysis method selection

Scenario	Method	Reasoning
• Pre-installation electric data showed no heating signature. • Post-installation data showed strong heating signature. • Customer tracked as having fossil fuel baseline.	Post-only	The customer presumably displaced fossil fuel heating with the ccASHP, which is the lone heating-dependent electric end-use in the post case.
• Pre-installation electric data showed moderate heating signature. • Post-installation electric data showed stronger heating signature. • Customer tracked has having electric baseline.	Post vs. pre	The customer has presumably added ccASHP(s) to existing electric heat. In order to not overestimate the ccASHP run hours, the team analyzed the change in heating-dependent electric use.
• Pre-installation electric data showed moderate heating signature. • Post-installation electric data showed stronger heating signature. • Customer tracked as having fossil fuel baseline.	Post-only	The customer likely used an electric system (e.g., space heater) as a secondary heating source to complement the primary fossil fuel system. The post-only data is most appropriate for assessing ccASHP run hours.

Ultimately, the study team employed the post-only method across 80% of the 1,133 viable premises, with post vs. pre making up the remaining 20%.

The study team sought to compare premise-level results with M&V results for customers that overlapped between the two pools of collected data. Unfortunately, only 14 of the 42 ccASHP premises sampled for M&V yielded viable electric consumption data for heating EFLH analysis. For these customers, the weighted average heating EFLH from the premise-level analysis was 13% higher than the weighted average heating EFLH derived from M&V. However, due to high variability within the 14 overlapping premises, the result exhibited significant error (±60% precision at 90% confidence).

Table 3-5 compares the heating EFLH averages between the premise-level consumption analysis and M&V analysis approaches for all available participants. It should be noted that the premise-level results reflect single family residential dwellings only for appropriate comparison with

M&V results. The M&V-based EFLH is 70% higher, on average, than the consumption analysis-based EFLH.

Table 3-5. Comparison of heating EFLH between premise-level and M&V analysis methods

Method	Sample n	Average heating EFLH	Error bound at 90% confidence
Premise-level electric consumption analysis	575	441	±54
M&V analysis	61	750	±183

3.2.4 Heating load factors

As described in Section 3.2, predicted heating output is the product of three variables in the TRM: $BEFLH_{heating}$, Manual J-based building heating load (BHL), and heating load factor ($F_{load,heating}$). The TRMs heating load factor selection considers the ccASHP system type, rated heating capacity, controls strategy, BHL, and building location among seven weather reference cities. For all ccASHP installations, the heating load factor assumed by NYS Clean Heat Program Administrators was not available in tracking data; however, the study team recreated the most appropriate load factor based on those variables.[52]

Table 3-6 illustrates a comparison of presumed predicted $F_{load,heating}$ (binned to the nearest tenth decimal place) with actual $F_{load,heating}$ based on M&V data across the various displacement ratios.[53]

Table 3-6. Comparison of TRM-predicted and M&V-based ccASHP heating load factors

Presumed TRM-predicted $F_{load,heating}$	Sample n	$F_{load,heating}$ from M&V	% difference
0.30	9	0.15	49%
0.40[a]	8	0.13	68%
0.50	8	0.13	74%
0.70	25	0.45	36%
0.90	8	0.42	54%
1.00	4	0.49	51%
0.69	**62**	**0.40**	**42%**

[a] 0.4 is not a TRM-recommended load threshold; rather, this weighted average value reflects projects that included more than one DMSHP with different load factors.

The M&V-based $F_{load,heating}$ was at least 36% lower than the presumed TRM-predicted value across all load thresholds. Interestingly, the three $F_{load,heating}$ thresholds that correspond to single-

[52] This analysis presumed that the TRM-recommended $BEFLH_{heating}$ values were correct. Since only one of the TRM algorithm's three variables required for heating output estimation was known (BHL), the study team "fixed" the $BEFLH_{heating}$ variable to examine how the M&V-based load factors compared with TRM predictions.

[53] TRM Version 10, page 243.

zone DMSHPs (0.3 through 0.5) showed similar $F_{load,heating}$ from M&V. This observation is apparent in the comparison of $F_{load,heating}$ by system type, as shown in Table 3-7.

Table 3-7. M&V-based ccASHP heating load factors by system type

System type	Sample n	$F_{load,heating}$ from M&V
Ducted ASHP	16	0.71
DMSHP	42	0.34

Table 3-7 shows statistically significantly different load results for ducted ASHP and DMSHP systems. Table 3-8 compares load factors between FLHP and PLHP load classifications made by Program Administrators and contractors.

Table 3-8. M&V-based ccASHP heating load factors by load classification

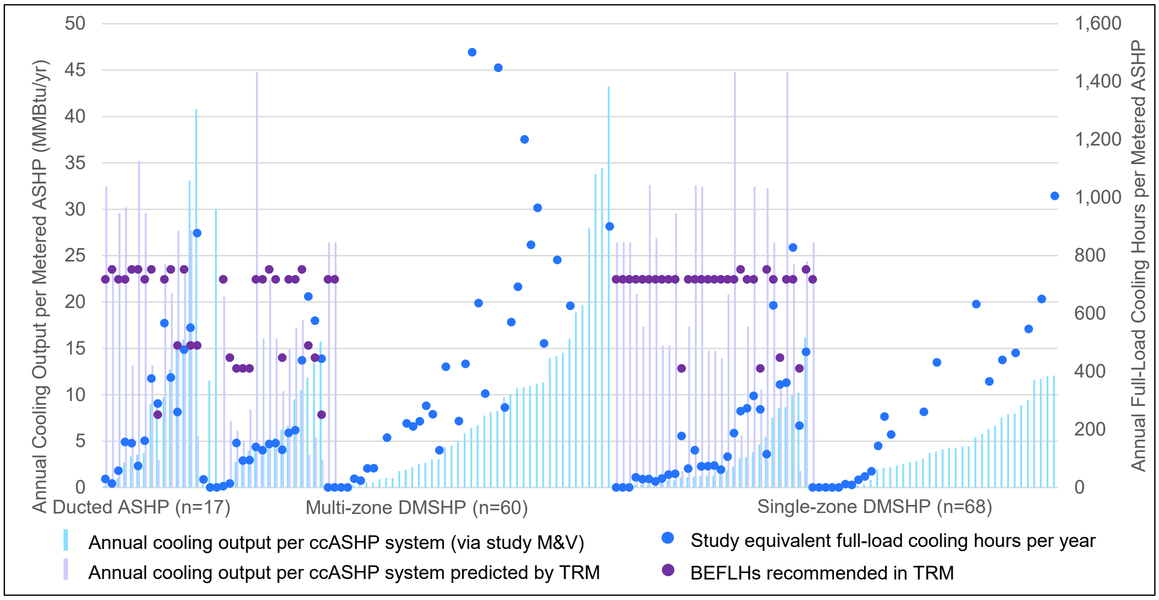
Load classification	Sample n	$F_{load,heating}$ from M&V
FLHP	46	0.49
PLHP	16	0.31

Table 3-8 shows the load factors were closer (and not statistically significantly different) between FLHP and PLHP system classifications. This observation corroborates Figure 3-3, which shows several systems classified as FLHP that did not exhibit full-load operation during the heating season.

3.3 Cooling loads and operating hours

The study team performed similar analysis of ccASHP operation during the cooling season. Figure 3-5 illustrates the annual cooling outputs (left-hand y-axis) and equivalent full-load cooling hours (right-hand y-axis) among all ccASHPs metered in this study (n=63) and the 2022 NYSERDA Heat Pump Impact Evaluation (n=82) distinguished by system type. The NYSERDA study results do not include corresponding purple bars or dots, as the predecessor programs did not require Manual J cooling load calculation on which cooling outputs and $BEFLH_{cooling}$ are based.

Figure 3-5. Comparison of cooling output and full-load hours between study results and TRM predictions by ccASHP type



The figure shows that the NYS Clean Heat Program-incented ccASHPs generally fell short of the cooling output predicted using the TRM algorithm and tracked Manual J data. As expected, multi-zone DMSHPs provided more cooling than single-zone DMSHPs.

NYS Clean Heat Program-incented systems provided less cooling on average (324 $EFLH_{cooling}$ per year) than NYSERDA-incented systems (434 $EFLH_{cooling}$ per year). The study team believes this difference may be attributable to a more intentional heating displacement focus of the NYS Clean Heat Program as compared to predecessor programs. Overall, **the pooled results led to 330 $EFLH_{cooling}$ on average**. Ducted ASHPs (260 $EFLH_{cooling}$ per year) exhibited slightly less cooling than DMSHPs (352 $EFLH_{cooling}$ per year).

3.3.1 Cooling operating hours from premise-level analysis

The study team applied similar methods as described in Sections 2.4.1 and 3.2.2 to estimate ccASHP cooling hours from utility consumption data. Table 3-9 provides a comparison of cooling EFLH results between M&V and premise-level analysis methods.

Table 3-9. Comparison of cooling EFLH between premise-level and M&V analysis methods

Method	Sample n	Average cooling EFLH	Error bound at 90% confidence
Premise-level electric consumption analysis	259	1,494	±297
M&V analysis	61	331	±36

The table shows significantly higher cooling EFLH from premise-level analysis than from M&V. The study team believes the premise-level method overestimates the cooling EFLH, as the tracking data only provides information on the ccASHPs incented by the NYS Clean Heat Program, not on any other cooling systems that were present at the building before or after the heat pump was installed. As a result, the cooling capacity (the denominator of the cooling EFLH calculation) likely underestimates the actual cooling capacity present at the home, subsequently overestimating the calculated cooling EFLH.

3.4 Performance efficiencies

The study team examined the ccASHPs' energy output as compared with power input to quantify performance efficiencies as compared with rated efficiencies. The TRM applies deration factors to manufacturer ratings for ccASHPs based on load scenario and location.[54] These deration factors span 19 scenarios and 7 weather reference cities leading to 133 unique deration permutations. As a result, a simplified comparison of study results and TRM deration factors is not feasible.

Table 3-10 compares the weighted average actual efficiencies quantified through M&V data—which the study team termed "effective" efficiencies—and the rated ccASHP efficiencies established by the American Heating and Refrigeration Institute (AHRI). The table distinguishes between heating and cooling efficiencies using the terms heating season performance factor (HSPF), energy efficiency ratio (EER), and seasonal energy efficiency ratio (SEER), respectively. All three variables correspond to units of Btu per Watt-hour. The table also distinguishes between this study's results and the 2022 NYSERDA Heat Pump Impact Evaluation results.

[54] TRM Version 10, page 244.

Table 3-10. Comparison of average rated and effective ccASHP efficiencies including NYSERDA study results

Study	Variable	Sample n	Weighted average rated value	Weighted average effective value	Ratio between effective and rated values
Technical Study of New York State Heat Pump Performance (2019-2020)	SEER	63	21.23	20.66	0.97
	EER	63	12.42	N/A[a]	N/A[a]
	HSPF	63	10.79	11.23	1.04
2022 NYSERDA Heat Pump Impact Evaluation (2017-2018)	SEER	85	22.97[b]	21.62[b]	0.94
	EER	0	N.D[c]	N.D[c]	N/A
	HSPF	82	11.65	11.34	0.97
Combined	**SEER**	**148**	**21.76**[b]	**20.79**[b]	**0.96**
	EER	**63**	**12.36**	**N/A** [a]	**N/A** [a]
	HSPF	**145**	**11.39**	**11.65**	**1.02**

[a] The study team did not quantify effective EERs, as rated EER reflects performance at a specific design condition that could not be replicated with actual data.
[b] Indicates statistically significant difference at the 90% confidence interval.
[c] The 2022 NYSERDA Heat Pump Impact Evaluation did not include peak demand impact assessment and therefore did not investigate EER.

The efficiency results show only slight differences between effective and rated ccASHP seasonal efficiencies during both heating and cooling seasons. The effective HSPF exceeded the rated HSPF by 2% overall. The study team believes this increased efficiency is a result of the incented ccASHPs operating at milder temperatures than those reflected in the AHRI's seasonal rating test conditions. On the other hand, the effective SEER fell short of the rated SEER by 4% due to more operation at warmer-than-design temperatures.

3.5 TRM algorithm assessment

The study scope included an assessment of the TRM algorithm's efficacy at predicting energy impacts from incented ccASHPs. To conduct this assessment, the study team compared the achieved MMBtu impacts with ex-ante (predicted) MMBtu impacts calculated four different ways:

1. **Estimated savings** – the Program Administrator reported savings estimates evident in tracking data.
2. **Recreated savings** – the study team's attempt to recreate the program-estimated savings using the information available in tracking data (e.g., loads, capacities, baseline) with no consideration of its accuracy.
3. **TRM-compliant savings** – the savings value that the Program Administrator should have estimated if they followed the TRM appropriately using the best available information. This calculation involved the study team's independent assessment of the most appropriate inputs

for each sampled ccASHP measure, such as BEFLHs and load factors, depending on information available from utility-provided tracking data.

4. **Simplified savings alternative** – an estimate of how a more simplified TRM algorithm would have estimated savings.

Table 3-11 compares the ratio of achieved MMBtu impacts (numerator) to these four ex-ante savings estimates (denominators) across various segments of interest. The higher the number, the more accurate the ex-ante estimate was at predicting achieved MMBtu savings. The table is conditionally formatted to illustrate the highest ratios in green and the lowest ratios in red.

Table 3-11. Comparison of achieved MMBtu savings vs. different ex-ante estimates for ccASHPs

Ex-ante savings definition	Achieved savings ÷ ex-ante savings				
	Overall	Load classification		System type	
		FLHP	PLHP	Ducted ASHP	Ductless ASHP
n	63	46	17	16	43
1. Estimated	0.46[a]	0.47	0.42	0.60	0.39
2. Recreated	0.46[a]	0.47	0.43	0.63	0.38
3. TRM-Compliant	0.57[b, c]	0.59	0.54	0.81	0.48
4. Simplified	0.54[c]	0.70[d]	0.37	0.95[d]	0.41

The study team observed the following four conclusions corresponding to the superscript in the table:

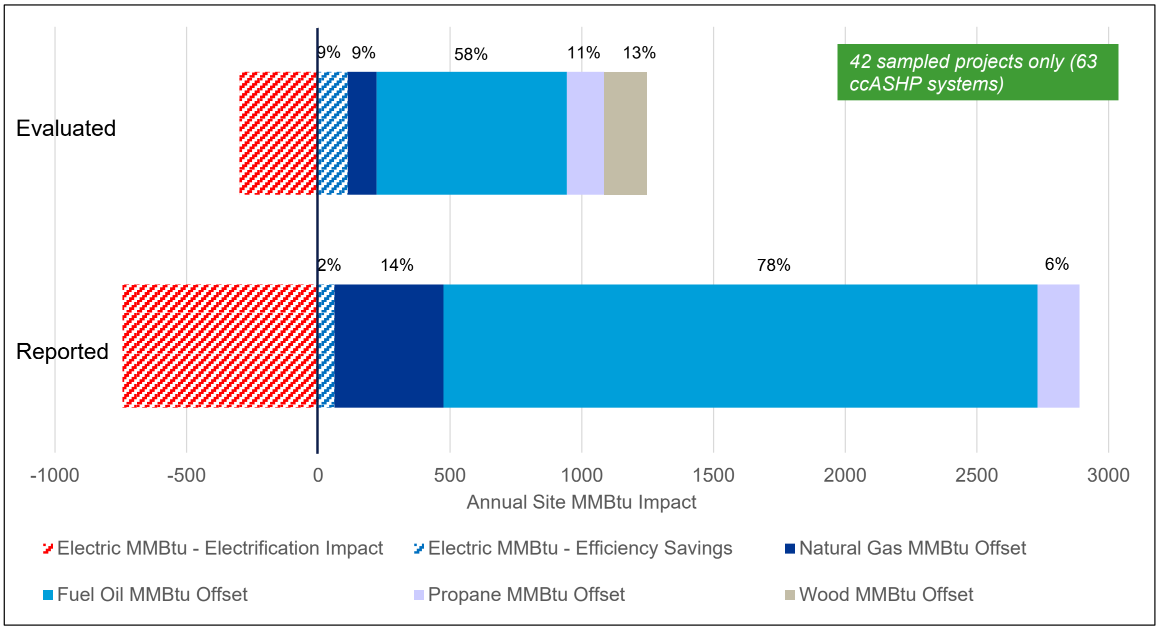
a. Overall, the estimated and recreated MMBtu savings aligned; however, the study team observed significant site-by-site variation between estimated and recreated MMBtu savings impacts.
b. The study team estimated a 20% difference (0.57 vs. 0.46) in MMBtu savings between contractor estimates and *what they should have estimated* if using the TRM appropriately. In other words, contractor estimates exceeded the correct savings prediction by 20%.
c. The TRM algorithm is 5% more accurate (0.57 vs. 0.54) at predicting MMBtu impacts than a simplified alternative algorithm.
d. A simplified algorithm may be more effective than the TRM algorithm for more predictable systems and loads—i.e., full-load or ducted ccASHPs. However, the TRM's use of ACCA load calculations may have been instrumental in right sizing the system capacities considered in such a simplified algorithm.

3.6 Energy impact results

An additional objective of the study was examining the energy impacts of the incented ccASHPs by fuel, as illustrated in Figure 3-6. The energy impacts have been consolidated into site MMBtu values, which comprise all fossil fuels as well as electric consumption at site.[55] The figure compares evaluated and reported site MMBtu impacts by fuel, with beneficial electrification (added electric use due to heating electrification) illustrated as the leftmost striped bar. MMBtu savings due to efficiency gains—either from increased cooling efficiency or offset of less efficient electric heating— are illustrated by the blue-striped bar. The solid bars depict the various offsets of fossil fuels.

As the baseline assumptions applied by the Program Administrators often differed from study findings, the study team did not expand the ccASHP impact results from the sample to the population. Figure 3-6 therefore presents impacts among only the 63 ccASHP systems sampled for M&V.

Figure 3-6. Evaluated vs. reported site MMBtu impacts by fuel across sampled ccASHPs



The figure illustrates that evaluated site MMBtu savings generally fell short of the estimated savings reported by the programs for ccASHPs. The primary driver for this reduction in savings was the lower-than-anticipated heating output—and associated fossil fuel displacement—as explored in Section 3.2.

The figure also illustrates differences in MMBtu savings by fuel between study findings and estimated savings. The study team determined fewer natural gas and oil impacts and more propane impacts than estimated by the programs. Additionally, the study team found that

[55] Site MMBtu savings do not account for losses due to generation, distribution, or transmission.

ccASHPs offset a notable amount of wood heat, which was not reflected as the baseline assumption for any programs' estimates in the 2019-20 population.

3.7 Additional air source heat pump results

The study team determined the following additional results of interest:

- Yearlong M&V data informed how ccASHPs operate during peak periods. Using the TRM definition of summer peak,[56] the study team determined a coincidence factor of 0.30. Comparatively, the TRM recommends a summer coincidence factor of 0.69 for ccASHPs.
- While the TRM does not currently address winter peak coincidence, the study team nonetheless estimated that ccASHPs exhibit a winter peak coincidence factor of 0.17 using a winter version of the TRM peak definition.[57]
- Integrated controls are an increasingly common strategy to maximize ccASHP use in partial displacement scenarios. Among the 63 ccASHPs sampled for M&V, 41 shared the heating load with other systems and would therefore be viable candidates for integrated controls. However, the study team found only seven instances of integrated controls among such systems.
- Snow buildup can prohibit proper heat absorption by the ccASHPs outdoor unit; to prevent such inefficiency, ccASHP outdoor units should be mounted off the ground when possible. The study team determined across the study sample that ccASHP outdoor units were installed 10.1 inches above ground on average; however, 10 of 46 inspected outdoor units were not installed above the local snow line. Eight ccASHP outdoor units had a "snow cap" overhang to prevent snow buildup.

3.8 Findings and recommendations

The study results led to the following findings and recommendations for ccASHP installations administered by NYS Clean Heat Program and predecessor programs.

3.8.1 Program successes

- Across 10,454 systems incented by the NYS Clean Heat Program and predecessor programs in 2019 and 2020, ccASHPs offset 93,638 MMBtu of fossil fuel consumption per year. Factoring in the fuel-by-fuel distribution shown in Figure 3-6, fossil fuel savings led to 7,968 tons of CO_2 emissions reduction.

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[56] TRM Version 10, page 4, stipulates that "system peaks generally occur during the hour ending at 5 pm on the hottest non-holiday weekday. The peak day can occur in June, July, or August, depending on the weather."

[57] The study team quantified winter peak impacts by examining operation at the hour ending 6 pm on the coldest non-holiday weekday between December and January. This is not an officially adopted winter electric peak definition. The hourly data collected in this study can be used to quantify the winter peak coincidence factor once the official winter electric peak definition is established.

- All Program Administrators maintain comprehensive and clean tracking data. This data generally included accurate customer contact information and ccASHP characteristics such as make/model.
- FLHPs achieved over twice as much site MMBtu savings per installation than PLHPs. Additionally, FLHPs exhibited statistically significantly higher heating hours than PLHPs. These findings indicate that the NYS Clean Heat Program distinctions between full- and part-load ccASHPs have been meaningful predictors of system operation.
- The TRM algorithm is 5% more accurate at predicting site MMBtu impacts from ccASHPs than an alternative simplified algorithm would have been.
- The incented ccASHPs performed near rated efficiencies, with average effective HSPFs and SEERs within 2% and 4% of average AHRI ratings, respectively. The study team does not recommend further adjustment to the current ccASHP algorithm to derate efficiencies as a function of installation scenario and location.

3.8.2 Opportunities to improve program administration

- The success of NY's ccASHP algorithm is predicated on accurate calculations of the building's heating and cooling loads. However, the study team found that the applicable NYS Clean Heat Program tracking data did not contain one or both of the Manual J heating and cooling load calculation values for 29% of ccASHP installations in 2020.

  - **Recommendation**: Contractors should calculate and document all input values required by the TRM algorithms, including the building heating and cooling loads on which savings estimates are based.

- When assessing contractor compliance with the TRM algorithms and assumptions, the study team determined instances of deviation from the TRM, leading to a 20% overestimate of MMBtu savings as compared with TRM-compliant values. Examples include:

  - For projects with more than one ccASHP installation, contractors occasionally divided the whole-home building load among the different systems. However, the TRM instructs contractors to use the home's total Manual J value with associated load factor per system.
  - In some cases, the home's Manual J heating or cooling load value was equal to the system's installed heating or cooling capacity, bringing into question whether the contractor calculated Manual J values at all.

  - **Recommendation**: Contractors should perform accurate Manual J heating and cooling load calculations and more closely adhere to NYS Clean Heat Program definitions of installation scenarios and the TRM associated load factors. Additional contractor screening, training, and/or oversight may be required to increase compliance with NYS Clean Heat Program rules and TRM guidance.

- Several FLHP projects exhibited operation of a partial-load system and did not meet the requirements for full-load designation set forth by the NYS Clean Heat Program: "a full load heat pump system is defined as a system installed as a building's primary heating source, with a total system heating capacity that satisfies at least 90% of the BHL at design conditions."[58]

  Additionally, the study team recreated the program estimated savings using the best available information from the tracking data. Occasionally, the estimated savings for part-load ccASHPs apparently reflected that of an integrated controls scenario when no such controls were present.

  - **Recommendation:** Contractors should follow NYS Clean Heat Program rules more closely when designating FLHP vs. PLHP and when choosing the most appropriate heating and cooling load factors. The distinction of FLHP is expected to become even more important as NYS Clean Heat Program recently discontinued incentives for PLHP installations.[59] Additional contractor screening, training, and/or oversight may be required to increase compliance with NYS Clean Heat Program rules and TRM guidance.

- ccASHPs that do not share the residence's heating load with other heating sources, such as the pre-existing, predominantly fossil fuel-fired boiler or furnace, produced twice as much annual heating output as ccASHPs that do share the heating load with other systems.

  - **Recommendation**: Program Administrators should continue to offer increased incentives to participants that decommission their legacy heating systems as part of full-load ccASHP installation.[60]

- As illustrated in Figure 3-6, the study team determined significant differences in actual baseline fuel as compared with the tracked claims. In isolated cases, the tracked baseline fuel did not correspond to the reported baseline (e.g., tracking data indicated electric baseline but the estimated savings showed natural gas).

  - **Recommendation**: Program Administrators and contractors should more carefully select the baseline fuel in accordance with the TRM, the NYS Clean Heat Program guidelines, and the customer's pre-existing system. In cases of normal replacement, the baseline fuel should reflect the customer's preferred alternative for space heating absent the influence of the NYS Clean Heat Program.[61]

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[58] NYS Clean Heat Statewide Heat Pump Program Manual, Version 7, pages 34-35.

[59] On January 1, 2024, all of the electric utilities discontinued incentives for PLHPs.

[60] NYS Clean Heat Statewide Heat Pump Program Manual, Version 7, *Category 2b: ccASHP: Full Load Heating with Decommissioning*.

[61] TRM Version 10, pages 237-238.

- As discussed in Section 3.2.3, the study team excluded 333 premises (15% of all available premises) from the billed consumption analysis due to insufficient tracking data on heating capacity or efficiency.

    - **Recommendation**: For transparency and contractor accountability, Program Administrators should enhance the NYS Clean Heat Program tracking data by adding or improving upon the following fields:

        - Equipment classification (e.g., ducted ASHP, single- or multi-zone DMSHP, compact ducted)
        - DMSHP number of indoor heads
        - Heat pump controls classification (e.g., programmable, integrated)
        - Heating and cooling capacities and efficiencies
        - Load factor assumption and/or scenario

3.8.3 Opportunities to improve TRM savings estimation: All ccASHPs

- Section 3.5 showed that the TRM ccASHP algorithm slightly outperformed a simplified alternative from other jurisdictions, leading to 5% more accuracy at predicting achieved MMBtu savings. However, the study results revealed opportunities to improve or diversify the TRM ccASHP savings algorithm and assumptions:

    - **Recommendation**: Expand baseline fuel options in the tracking database. This study and the 2022 NYSERDA Heat Pump Impact Evaluation showed that wood occasionally constitutes the baseline heating system. Wood accounted for 13% of achieved MMBtu impacts across all ccASHPs in this study. For proper accounting of carbon offset from heating electrification measures, the baseline heating options should be expanded to cover the full range of fuels offset by programs participants.

    - **Recommendation**: Explore incorporating more recent typical meteorological data. Other jurisdictions have explored the adoption of more recent weather datasets, such as TMYx,[62] which is a data set derived from more recent weather than TMY3 and may reflect some of the widespread impacts of climate change recently experienced.[63]

    - **Recommendation**: Modify the summer peak coincidence factor for ductless mini-split heat pumps (DMSHPs). Study results showed that ccASHPs exhibited an overall summer peak coincidence factor of 0.30 as compared to the TRM-recommended summer coincidence factor of 0.69. Part-load DMSHPs are particularly less likely to exhibit strictly weather-dependent operation, as customers may operate them in on/off

[62] TMYx weather files are typical meteorological data derived from hourly National Oceanic and Atmospheric Administration (NOAA) weather data through 2021. For more information, see https://climate.onebuilding.org/.

[63] The Massachusetts study compared annual Boston CDDs and HDDs between TMY3 and TMYx. The comparison showed that TMYx led to 24-27% higher annual CDDs and 6-7% lower HDDs. https://ma-eeac.org/wp-content/uploads/MA22C04-B-TMY-Final_Report.pdf.

modes or occupancy-based patterns. Since ducted ASHPs are more likely to exhibit operation similar to central air conditioners, the study team does not recommend adjustment to the 0.69 summer coincidence factor for ducted ASHPs as currently recommended in the TRM.

- **Recommendation**: Consider winter peak impacts. As more heating electrification measures are adopted, winter peak impacts will be increasingly important. The study team determined that ccASHPs exhibit a winter peak coincidence factor of 17%.[64]

3.8.4 Opportunities to improve TRM savings estimation: Ducted ASHPs

- The TRM algorithm includes a component to account for "when the system is sized such that [integrated] supplemental electric resistance (ER) heat is included within the heat pump to help meet the design heating load".[65] However, contractors did not appear to use the algorithm properly for ducted ASHPs that regularly required integrated supplemental ER to meet the heating load. Ten of 16 metered ducted ASHPs featured integrated supplemental ER heating circuits. Two had an inaccessible ER circuit, but five of the remaining eight required substantive electric resistance throughout the year, accounting for 24% of annual heating kWh.

    - **Recommendation**: As an alternative method of estimating the ducted ASHPs reliance on integrated supplemental heat, the study team suggests adding an efficiency deration factor of 0.84 for any ducted ASHPs installed with integrated supplemental ER heat. If this alternative approach is pursued, the algorithm should be modified to remove the ER component discussed in the prior paragraph.

3.8.5 Opportunities to improve TRM savings estimation: Ductless mini-split ASHPs

At the time of this writing, the NYS Clean Heat Program has discontinued offering incentives for PLHP systems. The study team acknowledges that the findings and recommendations in this sub-section may not pertain to the NYS Clean Heat Program moving forward. Nonetheless, the study team has included them below for completeness and transparency.

- Single-zone DMSHPs exhibited a heating load factor well below the minimum range currently available in the TRM (0.30). In fact, the results examined in Section 3.2.4 show that

[64] The study team quantified winter peak impacts by examining operation at the hour ending 6 p.m. on the coldest non-holiday weekday between December and January. This is not an officially adopted winter electric peak definition. The hourly data collected in this study can be used to quantify the winter peak coincidence factor once the official winter electric peak definition is established.

[65] TRM Version 10, page 234.

each of the load ranges corresponding to single-zone mini-splits (0.30 and 0.50) exhibited similar heating load factors (0.15 and 0.13, respectively).

  - **Recommendation**: For single-zone mini-splits not installed with integrated controls, modify the heating load factor to 0.15. Results from this study and from the prior study show that single-zone DMSHPs operate significantly less than the minimum 30% load factor category available in the TRM.

- Multi-zone DMSHPs exhibited significantly lower heating load factors than the 70% minimum range option available in the TRM. Section 3.2.4 results show load factors of 0.45, 0.42, and 0.49 among the load factor predictions of 0.70, 0.90, and 1.00, respectively.

  - **Recommendation**: Diversify the available sizing ratios for multi-zone DMSHPs. Such systems can hypothetically be installed in scenarios that do not exceed 50% of the total building heating load, especially if the legacy heating system is not decommissioned.

3.8.6 Lessons learned from premise-level analysis

- Quantifying heat pump operating hours from utility consumption data is challenging for the following reasons:

  - Significant attrition, as examined in Section 3.2.3, due to lack of seasonal coverage, anomalous values, or estimated meter reads.
  - Uncertainty in matching accounts with participants, particularly for multi-family and commercial premises.
  - Insufficient tracking data to quantify EFLHs, such as capacity and efficiency.
  - Unknown pre-existing conditions (e.g., electric space heaters) that affect baseline.
  - For cooling, likelihood of pre-existing A/Cs that are still in operation alongside the heat pump and therefore exaggerate the cooling EFLH attributed to ccASHPs, as discussed in Section 3.3.1
  - High variation in results.

  As a result, DNV recommends using the M&V-based results to define BEFLH values for future consideration in the TRM.

- Premise-level analysis may be viable in the future with a more extensive participant survey and more comprehensive tracking data to mitigate several of the uncertainties listed above. Additionally, as the NYS Clean Heat Program shifts to more of a full-displacement focus, the impact of ccASHPs on pre/post utility consumption data should become more apparent, making premise-level analysis a more viable option.

4 Ground source heat pump results

The NYS Clean Heat Program offers incentives for ground source heat pumps (GSHPs) that meet or exceed ENERGY STAR geothermal heat pump specifications.[66] Eligible GSHPs must satisfy at least 90% of the building's heating load; all GSHPs are therefore categorized by the NYS Clean Heat Program as "full load."[67]

As shown in Table 4-1, during the studied program years of 2019 and 2020, 620 GSHPs were incented among 381 unique customers. The majority of GSHP installations occurred in the residential sector.[68]

Table 4-1. GSHP installation activity during 2019-20 study period

Heat Pump Technology Category	1. Single family	2. Multi-family	3. C&I	4. Unknown	Grand total
3. *GSHP: Full Load Heating*	519	12	58	31	620

4.1 TRM algorithm

The TRM (Version 10)[69] estimates GSHP energy savings using the algorithms illustrated in Figure 4-1.

[66] ENERGY STAR, "Geothermal Heat Pumps." https://www.energystar.gov/products/geothermal_heat_pumps.
[67] NYS Clean Heat: Statewide Heat Pump Program Manual, Version 7, page 44.
[68] The NYS Clean Heat Program was responsible for the majority of 2019-20 GSHP installations in New York. A limited number of GSHP installations from predecessor programs carried over into early 2019; however, none of the predecessor projects were sampled for M&V in this study.
[69] Version 10 of the TRM was effective when the study team analyzed the results presented in this report. Version 11 of the TRM became effective January 1, 2024. The study team compared the two versions to confirm findings and recommendations in this report are applicable to Version 11.

Figure 4-1. GSHP savings algorithms in TRM Version 10

Annual Electric Energy Savings

$$\Delta kWh = \left[\frac{BCL}{1{,}000} \times \left(\frac{1}{EER_{season,baseline}} - \frac{1}{EER_{season,ee}}\right) \times BEFLH_{cooling}\right] + \left[\frac{BHL}{3{,}412} \times \left(\frac{F_{ElecHeat}}{COP_{season,baseline}} - \frac{1}{COP_{season,ee}}\right) \times BEFLH_{heating}\right]$$

Summer Peak Coincident Demand Savings

$$\Delta kW = \frac{BCL}{1{,}000} \times \left(\frac{1}{EER_{peak,baseline}} - \frac{1}{EER_{GSHP,full,ee}}\right) \times CF$$

Annual Fossil Fuel Energy Savings

$$\Delta MMBtu = \frac{BHL}{1{,}000{,}000} \times \frac{F_{FuelHeat}}{AFUE_{baseline}} \times BEFLH_{heating}$$

GSHPs are distinguished in the TRM as closed-loop or open-loop systems. Savings are calculated for each using the above algorithms; the $EER_{season,ee}$ and $COP_{season,ee}$ terms are adjusted depending on loop classification, pumping power and control strategy, and baseline scenario. The TRM also includes additional algorithms and assumptions for domestic hot water savings from integrated desuperheaters or dedicated water-to-water heat pumps; these add-on systems are addressed in Section 6.2 of this report. Table 4-2 provides a summary of the variables included in the above algorithms.

Table 4-2. Summary of GSHP savings variables and sources

Variable category	Variables	Description and current sources
Building cooling and heating loads	BCL, BHL	Manual J-based estimates of building cooling and heating loads at design conditions
Baseline efficiencies	$EER_{season,baseline}$, $COP_{season,baseline}$, $EER_{peak,baseline}$, $AFUE_{baseline}$	Efficiencies of various baseline systems as defined by the Code of Federal Regulations
GSHP efficiencies	$EER_{season,ee}$, $COP_{season,ee}$, $EER_{GSHP,full,ee}$	Application-specific AHRI ratings of the installed GSHP
Annual full-load operating hours	$BEFLH_{cooling}$, $BEFLH_{heating}$	Building-equivalent full load hours as a function of facility type, vintage, and location
Fuel factors	$F_{ElecHeat}$, $F_{FuelHeat}$	Binary flags indicating the presence of electric or fossil fuel heating
Performance correction factors	F_{full}, F_{part}, $F_{pump,full}$, $F_{pump,part}$, $F_{dist,c}$, $F_{dist,h}$	Factors related to GSHP full- and part-load efficiencies, pumping power and controls, and baseline fan scenario

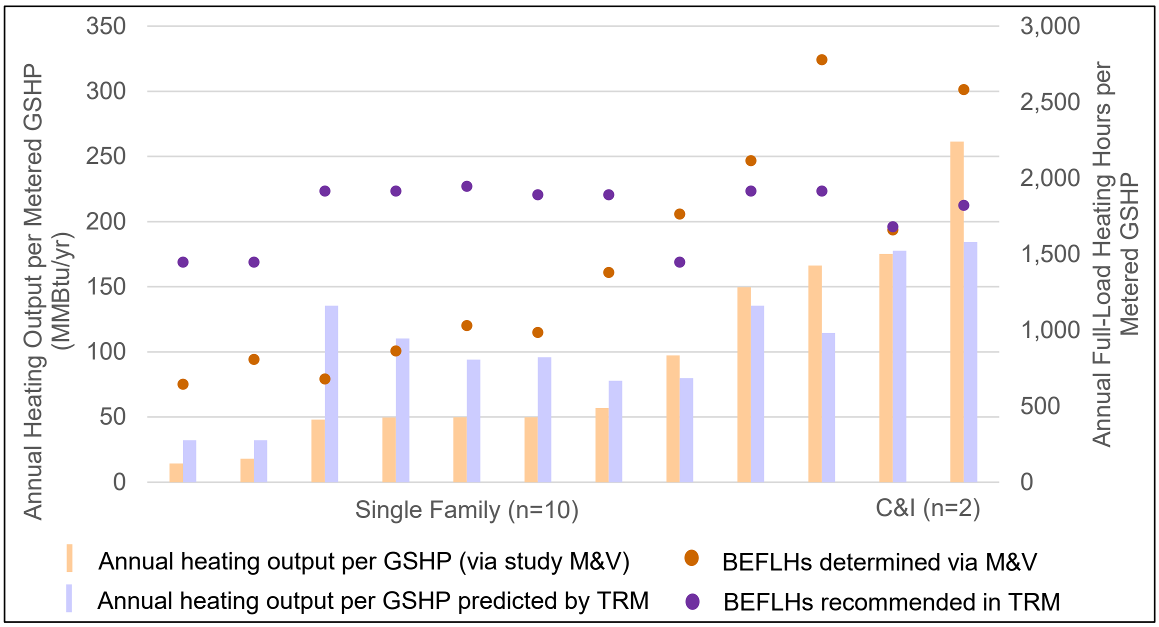
Through analysis of yearlong M&V data, the study team investigated several of the algorithm's variables: operating hours, efficiencies, and fuel-by-fuel baselines. These results are explored in the following sections.

4.2 Heating loads and operating hours

As described in Section 2.4, the study team deployed measurement devices across 12 GSHP systems at 10 participant buildings (eight residences, two businesses). The devices collected data on GSHP operation and performance over 12 to 16 months, allowing for comprehensive analysis of system operation during heating and cooling seasons.

Figure 4-2 illustrates the distribution of actual annual heating outputs (orange bars corresponding to the left-hand y-axis, in MMBtu per year) and building-equivalent full-load heating hours (orange dots, corresponding to the right-hand y-axis) by GSHP distinguished between residential and commercial installations. Additionally, the figure's purple dots and bars respectively illustrate each installation's TRM-recommended $BEFLH_{heating}$ and predicted heating output using the TRM and project information tracked by the Program Administrator.

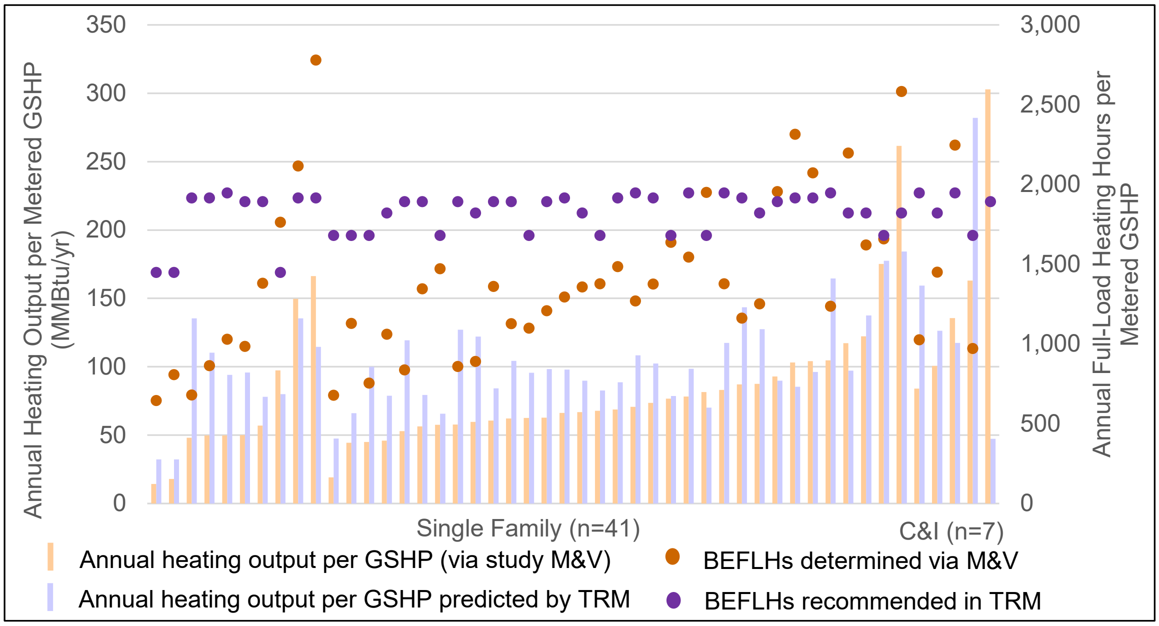
Figure 4-2. Comparison of GSHP heating output and $BEFLH_{heating}$ between study results and TRM predictions



The figure shows that the majority of incented GSHPs provided less heating than predicted by the TRM. Installations in the C&I sector generally met or exceeded TRM predictions on heating output and $BEFLH_{heating}$, though low sample size is a consideration. **On average, study results showed that sampled GSHPs operated for 1,463 $BEFLH_{heating}$ per year.** GSHPs in single family residences corresponded to 1,389 $BEFLH_{heating}$ per year on average, while GSHPs in commercial buildings operated for 2,062 $BEFLH_{heating}$ per year on average. For comparison, TRM-recommended $BEFLH_{heating}$ range from 1,448 to 1,915 $BEFLH_{heating}$ depending on weather region.

Next the study team pooled GSHP M&V results between this study's 12 sampled systems and 36 GSHPs sampled in NYSERDA's prior study, as illustrated in Figure 4-3.

Figure 4-3. Comparison of GSHP heating output and $BEFLH_{heating}$ between study results and TRM predictions including the NYSERDA prior study results



In general, the GSHPs incented by predecessor NYSERDA programs in 2017-2018 operated for more heating hours per year than the GSHPs incented by the NYS Clean Heat Program.[70] **On average, the pooled results showed that GSHPs incented between 2017 and 2020 operated for 1,548 $BEFLH_{heating}$ per year on average**. On average, residential GSHPs operated for 1,538 $BEFLH_{heating}$ per year, while commercial GSHPs operated for 1,647 $BEFLH_{heating}$ per year. These values fall between the ranges of $BEFLH_{heating}$ recommended in the TRM.

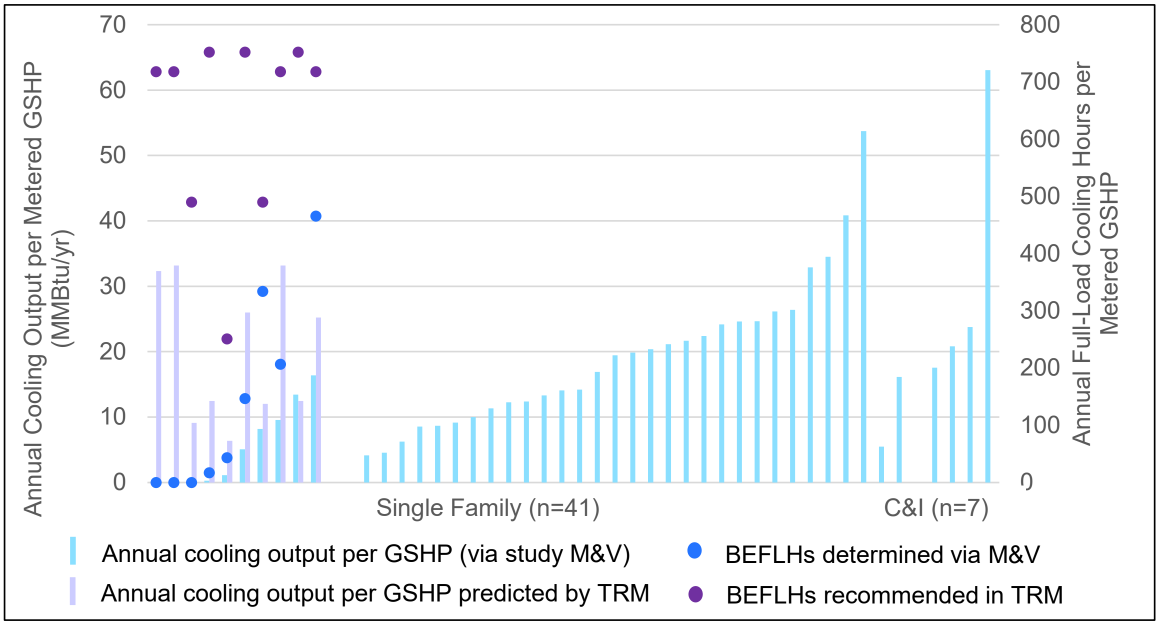
4.3 Cooling loads and operating hours

The study team performed similar analysis of GSHP operation during the cooling season. Figure 4-4 illustrates the annual cooling outputs (left-hand y-axis) and equivalent full-load cooling hours

[70] This difference was not statistically significant. Due to the relatively low sample size of GSHPs in this study, the study team is unable to pinpoint specific characteristics of participants or systems that caused this difference in heating operation.

(right-hand y-axis) among all GSHPs metered in this study (n=12) and NYSERDA's prior study (n=35) distinguished by system type. The NYSERDA study results do not include dots or purple bars, as the predecessor programs did not require Manual J cooling load calculation on which cooling outputs and $BEFLH_{cooling}$ are based.

Figure 4-4. Comparison of GSHP cooling output and full-load hours between study results and TRM predictions by sector



The figure shows that GSHPs operated for fewer cooling hours, and produced less cooling output, than anticipated by the TRM algorithm and assumptions. **NYS Clean Heat Program-incented GSHPs operated for 319 $BEFLH_{cooling}$ per year on average**. In comparison, NYSERDA-incented GSHPs operated for 434 $EFLH_{cooling}$ per year on average.[71] Notably, four GSHPs sampled in this study produced no cooling (three residential and one commercial system).

4.4 Performance efficiencies

For all twelve GSHP systems sampled in this study, the study team deployed monitoring devices to estimate the amount of energy delivered to satisfy the building's heating and cooling loads. By comparing this output energy with input electrical energy, the study team quantified effective energy efficiency ratios (EERs) and coefficients of performance (COPs). Table 4-3 compares the

[71] $EFLH_{cooling}$ and $BEFLH_{cooling}$ are not equivalent variables. $EFLH_{cooling}$ corresponds to a denominator of rated cooling capacity, while $BEFLH_{cooling}$ corresponds to a denominator of Manual J cooling load. Since Manual J cooling load information was unavailable for GSHPs incentivized by the predecessor NYSERDA program, the study team calculated $EFLH_{cooling}$ as a proxy for comparison.

average effective EERs (cooling) and COPs (heating) with AHRI ratings at full- and part-load design conditions.

The three variables in the table are not fully comparable. AHRI full-load EER and COP ratings are determined at specific design conditions—groundwater temperatures of 77°F and 32°F for cooling and heating, respectively—that necessitate the GSHPs full cooling and heating capacities. Similarly, AHRI part-load ratings are determined at groundwater temperatures of 68°F and 41°F for cooling and heating, respectively. The effective EERs and COPs determined in this study reflect the ratio of the total annual cooling or heating energy, respectively, delivered to the conditioned space divided by the input electrical energy required over a full season. Nonetheless, Table 4-3 illustrates that GSHPs operated less efficiently on average, over a full cooling or heating season, than manufacturer ratings at full- or part-load design temperatures.

Table 4-3. Comparison of weighted average rated and effective GSHP efficiencies

Variable	Unit	Sample n	Full-load rating	Part-load rating	Effective value
EER (Cooling)	Btu/Watt-hour	8[a]	18.38[b]	28.58[b]	11.88[b]
COP (Heating)	Btu/Btu	12	3.59	4.31	3.68

[a] The four GSHPs that did not operate during the cooling season were excluded from this analysis.
[b] Indicates statistically significant differences at the 90% confidence interval.

The table shows that GSHPs exhibited an effective EER statistically significantly lower than rated EERs. The study team attributes the reduced cooling efficiency to suboptimal actual conditions as compared to laboratory testing: e.g., reduced heat exchange effectiveness between loop-side and customer-side components, differences in groundwater temperature, additional losses due to distribution inefficiencies.

Table 4-3 shows results for the 12 GSHP systems sampled in this study. The GSHPs examined as part of the 2022 NYSERDA Heat Pump Evaluation did not correspond to the same level of metering rigor and therefore cannot be pooled with this study's results.

4.5 TRM algorithm assessment

As in Section 3.5 for ccASHPs, the study team assessed the TRM algorithm's efficacy at predicting energy impacts from incented GSHPs. Table 4-4 compares the ratio of achieved MMBtu impacts (numerator) to these four ex-ante estimates[72] (denominators) across various

[72] See Section 3.5 of this report for more information on the four ex-ante savings definitions.

segments of interest. The higher the number, the more accurate the ex-ante estimate was at predicting achieved MMBtu savings.

Table 4-4. Comparison of achieved MMBtu savings vs. different ex-ante estimates for GSHPs

Ex-Ante Savings Definition	Ratio: Achieved MMBtu ÷ Ex-Ante Savings
Estimated	0.90
Recreated	0.98
TRM-Compliant	0.98
Simplified	5.33

The study team concluded the following from the table:

- Overall, estimated and recreated MMBtu savings aligned within 2%; however, the study team observed significant site-by-site variation between estimated and recreated MMBtu savings impacts.
- By comparing reported energy savings with what the programs should have estimated (i.e., TRM-compliant savings), results show that the programs slightly underestimated the MMBtu reported energy savings.
- A simplified alternative algorithm is not appropriate for complex systems like GSHPs and would have significantly underestimated savings.

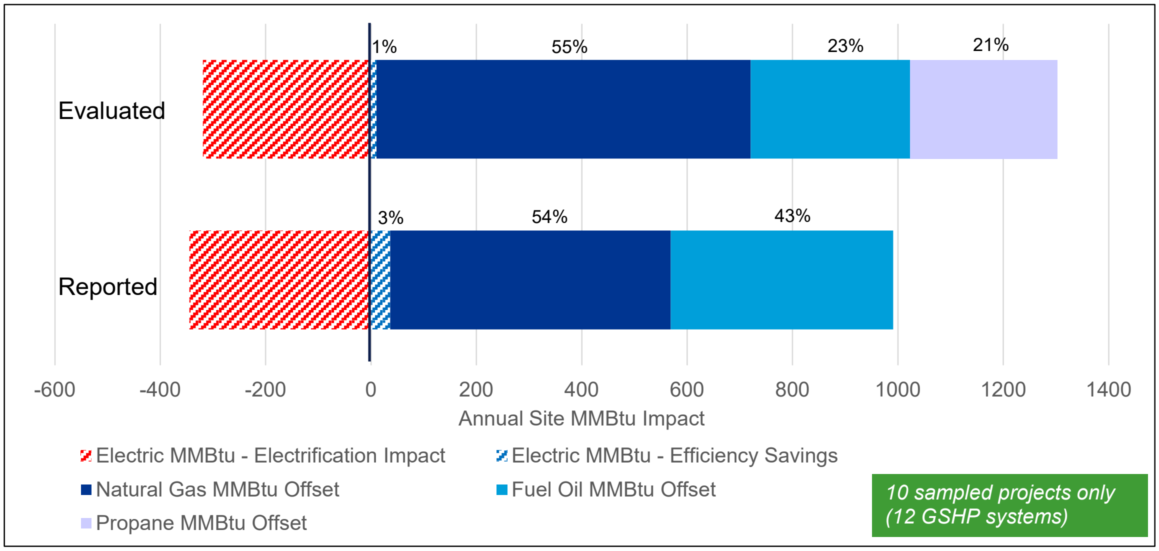
4.6 Energy impact results

An additional objective of the study was examining the energy impacts of the incented GSHPs by fuel, as illustrated in Figure 4-5. The energy impacts have been consolidated into site MMBtu values, which comprise all fossil fuels as well as electric consumption at site.[73] The figure compares evaluated and reported site MMBtu impacts by fuel, with beneficial electrification (added electric use due to heating electrification) illustrated as the leftmost striped bar. MMBtu savings due to efficiency gains—either from increased cooling efficiency or offset of less efficient electric heating— are illustrated by the blue-striped bar. The solid bars depict the various offsets of fossil fuels.

As program baseline assumptions occasionally differed from study findings, the study team did not expand the GSHP impact results from the sample to the population. Figure 4-5 therefore presents impacts among only the 12 GSHP systems sampled for M&V.

[73] Site MMBtu savings do not account for losses due to generation, distribution, or transmission.

Figure 4-5. Evaluated vs. reported site MMBtu impacts by fuel across sampled GSHPs



The figure illustrates differences in MMBtu savings by fuel between study findings and the estimated savings reported by the programs. The study team determined more natural gas and fewer oil impacts than estimated by the program. Additionally, the study team found that GSHPs offset a notable amount of propane, which was not claimed as the baseline fuel for any of the sampled installations.

4.7 Additional results

Table 4-5 provides additional results from GSHP metering as compared with equivalent variables recommended in the TRM.

Table 4-5. Additional GSHP study findings vs. TRM assumptions

Parameter	Study average (n=12)	Current TRM assumption
Average entering groundwater temp (cooling) (°F)	64.6	77.0
Average entering groundwater temp (heating) (°F)	45.9	40.0
Summer peak coincidence factor	0.54	0.69
Winter peak coincidence factor	0.48	N/A

4.8 Findings and recommendations

The study results led to the following findings and recommendations for GSHP installations administered by the NYS Clean Heat Program and predecessor programs.

4.8.1 Program successes

- Across 620 systems incented by the NYS Clean Heat Program and predecessor programs in 2019 and 2020, GSHPs offset 46,882 MMBtu of fossil fuel consumption per year. Factoring in the fuel-by-fuel distribution shown in Figure 4-5, fossil fuel savings led to 3,103 tons of CO_2 emissions reduction.
- The NYS Clean Heat Program and predecessor programs accurately predicted electric, fossil fuel, and overall energy impacts from GSHP installations. The study team determined for GSHPs that the achieved site MMBtu impacts exceeded the programs predictions by 3% on average.
- Similarly, the TRM algorithm and assumptions were effective at forecasting GSHP impacts. The TRM algorithm (Version 10) was significantly more accurate than a simplified alternative would have been. As illustrated in Figure 4-2, the study team determined similar building-equivalent full-load heating hours ($BEFLH_{heating}$) as those recommended in the TRM.
- Participating contractors generally interpreted the TRM GSHP algorithm and assumptions correctly. After recreating reported energy savings with the best available tracked information, the study team determined TRM-compliant MMBtu savings that aligned with program-reported estimates within 3%.
- All Program Administrators maintain comprehensive and clean tracking data. This data generally included accurate customer contact information and GSHP characteristics such as make/model and loop type.

4.8.2 Opportunities to improve program administration

- The success of the TRM GSHP algorithm is predicated on accurate estimates of the building's heating and cooling loads. However, the study team found that the NYS Clean Heat Program tracking data did not contain one or both of the Manual J heating and cooling load values for 45% of GSHP installations in 2019-20.

  - **Recommendation**: Contractors should quantify and document all input values required by the TRM algorithms, including the building heating and cooling loads on which savings estimates are based.

- Six of the 10 GSHP projects sampled for M&V included a desuperheater to preheat domestic hot water. It was unclear in the tracking data whether savings from these desuperheaters were reported by the program. As examined in Section 6.2, desuperheaters account for approximately 9% additional savings as compared with the host GSHP system itself.

  - **Recommendation**: When desuperheaters are installed with a GSHP, Program Administrators and contractors should report those additional impacts as a separate line item.

- One of the 10 sampled projects involved two GSHPs serving the same load (i.e., a redundant system) at a commercial facility. Such redundant systems are typically ineligible for program incentives. Additionally, the two systems did not have AHRI-rated part-load COPs and therefore would not align with the TRM algorithm.

- **Recommendation**: Program Administrators should enhance the eligibility screening process to scrutinize multi-system installations in the commercial and industrial sectors to confirm no redundant or backup systems receive program incentives. Additionally, all eligible GSHPs should include AHRI ratings that align with the full- and part-load COP and EER requirements in the TRM algorithms.

4.8.3 Opportunities to improve TRM savings estimation

- The evaluation sample of ten GSHP projects included three with multi-system installations for which the associated heating and cooling load estimates (based on Manual J) did not necessarily correspond to the zones conditioned by the respective GSHPs. The TRM does not provide guidance on how to distribute the whole-building heating and cooling load estimates in such situations. The Program Administrators appeared to split loads equally among differently sized systems.

  - **Recommendation**: The Program Administrators should ensure contractors are properly calculating the appropriate heating and cooling loads for multi-system installations based on Manual J.

- One of the metered GSHPs required integrated supplementary heat on over 100 days of the yearlong metering period.[74] However, the TRM does not include an algorithm component (as with ccASHPs) or an efficiency degradation factor for possible reliance on integrated supplemental heat. Since only one of 13 sampled GSHP systems required significant integrated supplemental heat, the study team does not recommend revision to the TRM's algorithm or assumptions related to integrated supplemental heat on GSHP systems. However, these instances can severely affect achieved savings and may warrant further research.

  - **Recommendation**: Program Administrators should require that contractors document when GSHP systems are installed with integrated supplemental electric resistance heat. If such installations become more prominent, additional research may be warranted on efficiency degradation effects.

- Other jurisdictions, such as Massachusetts, have explored the adoption of more recent weather datasets, such as TMYx,[75] which is a data set derived from more recent weather than

[74] In this case, the GSHP required more integrated supplemental electric resistance heat than typical due to a clogged filter, which was identified and rectified during the M&V period.

[75] TMYx weather files are typical meteorological data derived from hourly National Oceanic and Atmospheric Administration (NOAA) weather data through 2021. For more information, see https://climate.onebuilding.org/.

TMY3 and may reflect some of the widespread impacts of climate change recently experienced.

- **Recommendation**: Investigate TMYx or similar, more recent weather datasets to define typical meteorological year-based assumptions (e.g., HVAC full-load hours) in future iterations of the TRM.[76]

- As more heating electrification measures are adopted, winter peak demand impacts will be increasingly important. Sampled GSHPs exhibited a winter peak coincidence factor of 48% per a winter version of the TRM system peak definition.

  - **Recommendation**: Consider winter peak impact estimation in future iterations of the TRM. Assume a winter peak coincidence factor of 0.48 as an initial assumption to be refined with future research.[77]

- The 12 GSHP systems sampled for M&V exhibited lower effective cooling and heating EERs and COPs, respectively, than average full- and part-load ratings. However, due to limited sample size, the study team does not recommend adjustment to the TRM GSHP efficiency deration algorithms or assumptions. Further primary or secondary research may be warranted to refine EER and COP deration to reflect actual conditions.

[76] The Massachusetts study compared annual Boston CDDs and HDDs between TMY3 and TMYx. The comparison showed that TMYx led to 24-27% higher annual CDDs and 6-7% lower HDDs. https://ma-eeac.org/wp-content/uploads/MA22C04-B-TMY-Final_Report.pdf.

[77] The study team quantified winter peak impacts by examining operation at the hour ending 6 pm on the coldest non-holiday weekday between December and January. This is not an officially adopted winter electric peak definition. The hourly data collected in this study can be used to quantify the winter peak coincidence factor once the official winter electric peak definition is established.

5 Heat pump water heater results

The NYS Clean Heat Program offers incentives for ENERGY STAR-qualified heat pump water heater (HPWH) units with no greater than 120 gallons of domestic hot water (DHW) storage capacity. During the studied program years of 2019 and 2020, the NYS Clean Heat Program distinguished between two HPWH installation scenarios: contractor-install and self-install.[78] The program incented 1,053 HPWH installations over the evaluated period; as shown in Table 5-1, the majority of HPWH installations were designated as self-install in the residential sector.

Table 5-1. HPWH installation activity during 2019-20 study period

HPWH Installation Scenario	1. Single family	2. Multi-family	3. C&I	4. Unknown	Grand total
HPWH <120 gallons - contractor install	277	0	0	9	286
HPWH <120 gallons - self-install	722	42	3	0	767
Total population	**999**	**42**	**3**	**9**	**1,053**

5.1 TRM algorithm

The TRM (Version 10)[79] estimates HPWH energy savings using the algorithms illustrated in Figure 5-1.

[78] The NYS Clean Heat Program has since modified the HPWH measure to be incented through retail or distributor channels (midstream) and no longer distinguishes between contractor- and self-install categories.

[79] Version 10 of the TRM was effective when the study team analyzed the results presented in this report. Version 11 of the TRM became effective January 1, 2024. The study team compared the two versions to confirm findings and recommendations in this report are applicable to Version 11.

Figure 5-1. HPWH savings algorithms in TRM Version 10

Annual Electric Energy Savings

$$\Delta kWh = units \times \frac{GPD \times 365 \times 8.33 \times \Delta T_{main}}{3{,}412} \times \left(\frac{F_{eDHW}}{UEF_{baseline}} - \frac{1}{UEF_{ee} \times F_{derate}}\right) + \Delta kWh_{cooling} - \Delta kWh_{heating}$$

$$\Delta kWh_{cooling} = units \times \frac{GPD \times 365 \times 8.33 \times \Delta T_{main}}{3{,}412} \times \frac{1}{UEF_{ee}} \times F_{Loc} \times \frac{F_{Cool}}{SEER/3.412}$$

$$\Delta kWh_{heating} = units \times \frac{GPD \times 365 \times 8.33 \times \Delta T_{main}}{3{,}412} \times \frac{1}{UEF_{ee}} \times F_{Loc} \times F_{ElecHeat} \times \frac{F_{Heat}}{HSPF/3.412}$$

Peak Coincident Demand Savings

$$\Delta kW = units \times (\Delta kW/unit)$$

Annual Fossil Fuel Energy Savings

$$\Delta MMBtu = units \times \frac{GPD \times 365 \times 8.33 \times \Delta T_{main}}{1{,}000{,}000} \times \left[\frac{F_{FFDHW}}{UEF_{baseline}} + \frac{F_{BoilerDHW}}{AFUE} - \left(\frac{1}{UEF_{ee}} \times F_{loc} \times F_{FuelHeat} \times \frac{F_{Heat}}{AFUE}\right)\right]$$

The algorithms' inputs can be classified into six categories as shown in Table 5-2.

Table 5-2. Summary of HPWH savings variables and sources

Parameter category	Parameter(s)	Description and current sources
DHW usage	Gallons per day (GPD)	Gallons per day of hot water usage based on number of occupants[a]
Temperature difference	T_{inlet}, $T_{setpoint}$	Difference between DHW setpoint[b] and assumed inlet temperature based on region
Baseline performance	F_{DHW}, $UEF_{baseline}$, AFUE	Factors and efficiencies related to baseline DHW performance[c]
Efficient performance	UEF_{ee} , F_{derate}	Deration factor based on HPWH location and region[d] and efficiency related to HPWH performance
Location factor	F_{loc}	Binary factor indicating if HPWH is located in a conditioned or unconditioned space
Interactive HVAC effects	$\Delta kWh_{heating}$, $\Delta kWh_{cooling}$	Interactive impacts if HPWH is located in a heated and/or cooled space

[a] Water Research Foundation: Residential End Uses of Water, Version 2, April 2016, pg. 5; 17.2 GPD equated from the report findings indicating an average 2.65 people per household and 45.5 GPD per household.

[b] 10 CFR 430 Appendix E to Subpart B of Part 430 Uniform Test Method for Measuring the Energy Consumption of Water Heaters, Section 2. Test Conditions, 2.5 Set Point Temperature.

[c] Per federal standards 10 CFR 430.32(d).

[d] Derived from Residential Heat Pump Water Heater Evaluation: Lab Testing & Energy Use Estimates, Bonneville Power Administration, November 2011.

The following sections explore the study results related to different parameter groups.

5.2 Domestic hot water usage

The study team used M&V data among the parameters described in [methods section] to estimate the daily hot water consumption (in gallons) among the 20 participant sites sampled for M&V. Table 5-3 compares the average TRM-recommended GPD with the average study result.

Table 5-3. DHW usage result vs. TRM-recommended average

Parameter	TRM-compliant average	Average study result (n=20)
Gallons Per Day	49.75	102.45

The TRM GPD assumption is based on the number of occupants in the residence receiving the HPWH. The 20 sampled sites showed an average of 2.89 occupants. The TRM recommends 17.2 GPD per occupant, whereas the M&V results showed 35.5 GPD per occupant.

5.3 Temperature difference

Table 5-4 compares the TRM-compliant and evaluated values across the inlet and heated temperatures.

Table 5-4. DHW temperature findings vs. TRM recommendations

Parameter	TRM-compliant values	Study results (n=20)
A. Average Inlet Water Temperature (°F)	58.2	64.4
Average Inlet Water Temperature when Preheated (n=6) (°F)	N/A	70.4
B. Average DHW Setpoint (°F)	125.0	122.0
C. Average Temperature Delta (°F) (B minus A)	66.8	57.6

Overall, the study team determined an average temperature delta 9.2°F lower than TRM Version 10 recommends. Contributors to the lower temperature difference were:

- Yearlong M&V data among 20 sampled sites showed an average inlet temperature value 6.2°F higher than the TRM regional recommendations.
- Six of the 20 sites sampled for M&V featured hydronic space heating systems integrated with the HPWH that preheated the inlet water, contributing to the higher average inlet temperature described in the above bullet.
- During M&V site visits, field staff noted a DHW setpoint 3°F lower than the TRM recommendation of 125°F.

5.4 Efficiency and deration

The study team next compared the rated uniform energy factor (UEF), associated derating factors, and effective UEF for the 20 sampled HPWHs with TRM assumptions, as shown in Table 5-5.

Table 5-5. HPWH efficiency and deration findings vs. TRM recommendations

Parameter	TRM-compliant values	Study results (n=20)
A. Average UEF_{rated}	Application-specific	3.59
B. Average Deration Factor due to Ambient Conditions	0.95	0.97
Count of Unconditioned Spaces	5	5
Average Deration Factor when Unconditioned	0.82	0.84
C. Average Integrated Supplemental Heat Share of kWh (%)	0%	11%
D. Average Deration Factor due to Integrated Supplemental Heat	1.00	0.91
E. Average $UEF_{effective}$ (A × B × D)	Application-specific	3.17

HPWH efficiency varies as a function of ambient temperature; therefore, HPWH installation location (conditioned versus unconditioned space) is an input to the TRM algorithm. The study team found that Program Administrators correctly identified that five of the sampled 20 HPWH installations were installed in unconditioned spaces. Study results show that these five systems performed at an efficiency 16% lower than the 15 systems installed in conditioned spaces.

HPWH UEF also varies as function of how much integrated supplemental electric resistance heat was required to meet the home's DHW loads. The TRM does not include a parameter to address this deration. The study results showed that 17 of the 20 sampled systems required integrated supplemental electric resistance heat at some point during the yearlong M&V period. Overall, integrated supplemental electric resistance heat accounted for 11% of annual kWh across the M&V sample, reducing the UEF by 9% overall across the sample of studied HPWHs.

5.5 Baseline

HPWH reported energy savings are affected by the baseline system type and fuel assumed by the Program Administrator. As illustrated in Table 5-6 for eight of the 20 sites sampled for M&V, the study team determined a different baseline than was assumed by the Program Administrator, resulting in two more instances of electric baseline and two fewer instances of natural gas baseline.

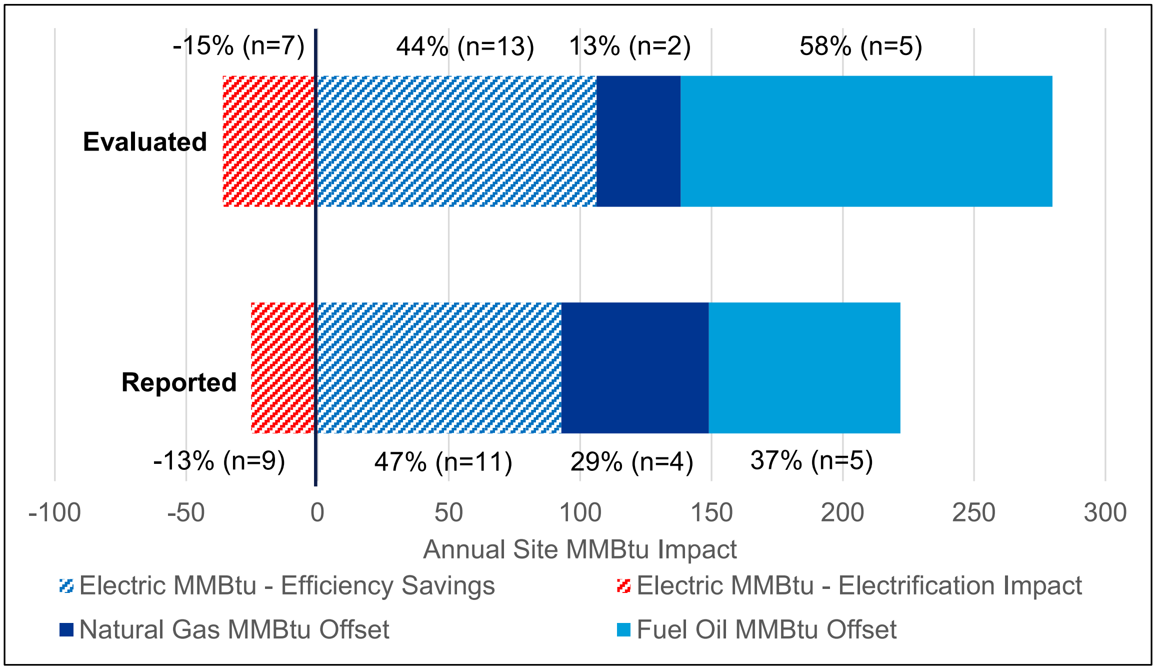
Table 5-6. Claimed vs. verified baseline fuel type among HPWH M&V sample

Site ID	Tracked baseline fuel	Evaluated baseline fuel
DNV-00003412	Electric	Electric
DNV-00003706	Electric	Electric
DNV-00004183	Electric	Electric
DNV-00005251	Electric	Electric
DNV-00005624	Electric	Natural Gas
DNV-00005909	Electric	Oil
DNV-00006429	Electric	Electric
DNV-00006643	Electric	Electric
DNV-00007341	Electric	Electric
DNV-00007399	Electric	Oil
DNV-00007422	Electric	Electric
DNV-00001509	Natural Gas	Electric
DNV-00004882	Natural Gas	Electric
DNV-00005467	Natural Gas	Natural Gas
DNV-00005655	Natural Gas	Electric
DNV-00002080	Oil	Oil
DNV-00002886	Oil	Oil
DNV-00005338	Oil	Oil
DNV-00006356	Oil	Electric
DNV-00007262	Oil	Electric

5.6 Energy impact results

The study team quantified the energy impacts by fuel resulting from the HPWH installations sampled for M&V. Figure 5-2 illustrates the fuel-by-fuel breakdown of reported versus evaluated MMBtu, including electric impacts at site. The striped bars reflect electric energy consumption converted to MMBtu at site (no generation, transmission, or distribution losses accounted for). The red striped bars indicate “beneficial electrification” resulting from the offset of fossil fuels. The blue striped bars indicate electric-to-electric MMBtu savings resulting from the higher efficiency of the HPWH. The solid bars reflect fossil fuel savings—natural gas (dark blue) and oil (lighter blue)—in MMBtu.

Figure 5-2. Evaluated vs. reported energy impacts from HPWH installations by fuel



The study results led to 71% higher achieved MMBtu savings as compared to the estimated savings reported by the programs. The study team found higher impacts for electric-to-electric (blue striped bar) and oil-to-electric (light blue solid bar) installations.

Table 5-7 investigates the contributors to the higher achieved HPWH savings determined by the study team. The table diagnoses the categorical differences between evaluated and reported savings among categories of interest for HPWHs: baseline determination, unknown differences between TRM-compliant and reported savings, differences in DHW setpoint, differences in inlet temperature, differences in gallons per day, and differences in efficiency deration. The table shows both the frequency and MMBtu magnitude of negative and positive discrepancies by category.

Table 5-7. Categorical differences between reported and achieved MMBtu savings for HPWHs

	Negative		Positive	
Difference Category	**Instances**	**MMBtu %**	**MMBtu %**	**Instances**
TRM-Compliant vs. Tracking Difference due to **Baseline Fuel**	5	-76%	56%	2
Unknown Remaining Differences between TRM-Compliant and Tracking Claims	11	-79%	60%	9
Evaluated vs. TRM-Compliant Difference due to **DHW Setpoint**	12	-12%	6%	5
Evaluated vs. TRM-Compliant Difference due to **Inlet Temperature**	17	-28%	0%	3
Evaluated vs. TRM-Compliant Difference due to **Gallons per Day**	4	-6%	167%	16
Evaluated vs. TRM-Compliant Difference due to **Efficiency Deration**	11	-20%	2%	9
Total Difference between Evaluated and Tracking Values	**60**	**-221%**	**292%**	**44**

The study team examined three notable differences further:

- Differences in GPD – 16 of 20 instances of higher GPD resulted in 161% higher MMBtu savings overall.
- Differences in inlet temperature – as discussed, the study team found a higher inlet temperature overall, which reduced MMBtu savings by 28%.
- Differences in efficiency deration – integrated supplemental electric resistance heat required by 17 of 20 metered HPWHs led to an overall 18% decrease in achieved MMBtu savings.

5.7 Findings and recommendations

The study results led to the following findings and recommendations for HPWH installations administered by the NYS Clean Heat Program.

5.7.1 Program successes

- The electric utilities maintain comprehensive and clean tracking data for HPWHs, including accurate customer contact information and HPWH characteristics such as capacity and make/model.
- Participating contractors correctly identified and tracked whether the installed HPWHs were located in conditioned or unconditioned spaces.
- The savings algorithm in the current TRM is generally reasonable at predicting HPWH impacts due to the following:
  - Starting with Version 8, the TRM algorithm is designed to properly handle a variety of fuel-switching scenarios and baselines.
  - For HPWHs in unconditioned spaces, the TRM recommends a UEF deration factor within 2% of study findings.
  - The algorithm appropriately quantifies interactive HVAC effects when HPWHs are installed in conditioned spaces.

5.7.2 Opportunities to improve TRM savings predictions

- The study team determined that 17 of 20 metered HPWHs required integrated supplemental electric resistance heat to meet the DHW load over the course of a year. Integrated supplemental electric resistance heat accounted for 11% of total metered kWh overall. Integrated supplemental electric heat is approximately 70% less efficient than the HPWH's compressor and thereby reduced the overall UEF by 9%.
  - **Recommendation**: An additional UEF deration factor of 0.91 should be added to the HPWH savings algorithms in future TRM updates to account for the likelihood of integrated supplemental electric resistance heating.
- The study team determined that six of 20 metered HPWHs received inlet water that was preheated by the hydronic space heating system. While an energy-efficient design, this

preheating reduced the work required by (and potential savings from) the HPWH to produce DHW at the desired setpoint.

  - **Recommendation**: Program Administrators should require that contractors identify and track when such preheating occurs. In these situations, the inlet water temperature should be increased by 24% to account for the HPWH's reduced savings potential.

- The study team determined more than double the DHW consumption predicted by the TRM among the sample of 20 metered HPWHs. TRM savings estimates are based on an average of 17.2 gallons per day (GPD) of DHW consumption per occupant; the study team determined 35.5 GPD per occupant on average. This study's sample size is not sufficient to modify the TRM assumption, which is based on over 1,000 studied homes across the country. However, further research may be warranted if New York HPWH recipients exhibit different water usage patterns than the average resident nationwide.

5.7.3 Opportunities to improve program administration

- The study team determined a baseline fuel different from the tracked baseline fuel for eight of 20 studied HPWHs. In isolated cases, the tracked baseline fuel did not correspond to the reported energy savings (e.g., tracking data indicated electric baseline but reported energy savings showed natural gas).

  - **Recommendation**: Program Administrators and contractors should more carefully select the baseline fuel in accordance with the TRM, the NYS Clean Heat Program guidelines, and the customer's pre-existing system. In cases of normal replacement, the baseline fuel should reflect the customer's preferred alternative for DHW heating absent the influence of the program.[80]

- The study team attempted to recreate the HPWH savings estimates reported by the Program Administrator among the 20 studied systems using the best available tracking data on system capacity, UEF, baseline fuel, and location. However, the study team was unable to recreate the savings for any of the 20 systems.

  - **Recommendation**: Program Administrators and contractors should more closely adhere to the TRM algorithms and guidance on baseline selection, DHW use, UEF deration, and interactive HVAC impacts. Additional contractor training may be required to ensure the tracked information aligns most closely with participant characteristics.

- The TRM applicable during the 2019-20 studied program years (Versions 6.1 and 7) did not accommodate for fuel switching for HPWHs as TRM Version 8 through the current version

[80] TRM Version 10, page 128: "The baseline for a fuel switching installation at the end of the appliance effective useful life is the minimally compliant, state or municipal energy code or federal standard, that is applicable to the measure or system, similar to the existing measure or system, that the consumer would have had installed without the influence of the energy efficiency program."

do.[81] Several of the studied HPWHs were installed in a normal replacement scenario—i.e., the prior DHW system had failed or reached end of useful life— but the reported energy savings did not appear to consider the customer's preferred alternative DHW system type and fuel.

- **Recommendation**: To align with current TRM guidance, Program Administrators should collect and consider what the "consumer would have had installed without the influence of the energy efficiency program" when determining baselines in normal replacement scenarios.

[81] Version 10 of the TRM was effective when the study team analyzed the results presented in this report. Version 11 of the TRM became effective January 1, 2024. The study team compared the two versions to confirm findings and recommendations in this report are applicable to Version 11.

6 Additional results

This section describes additional notable results from the participant survey data collection and engineering desk reviews of DHW waste heat recovery measures.

6.1 Participant survey results

Table 6-1 shows the count of participant survey responses by sector and technology. The survey collected responses from 385 participants across residential, commercial, and multi-family sectors. Participant response rates were higher for those heat pump technology categories with higher populations in the tracking data (ccASHP, GSHP, and HPWH). A single WWHP project participant responded. Response counts by category are also influenced by higher levels of study team outreach to achieve the target sample for FLHP.

Table 6-1. Participant survey response counts by sector and technology

Sector	ccASHP FLHP	PLHP	GSHP	HPWH	WWHP	Total	% total
Residential	126	59	50	82	1	318	**83%**
Commercial	1	3	20	-	-	24	**6%**
Multi-family	25	8	3	7	-	43	**11%**
Total	152	70	73	89	1	385	
% Total	39%	18%	19%	23%	0%		**100%**
Population	**2,287**	**4,164**	**365**	**904**	**7**	**7,727**	

The primary purpose of the survey is to characterize participants' use of heat pump equipment to displace fossil fuel systems during both cooling and heating seasons. Almost all respondents claimed to use their heat pump for heating and cooling rather than only cooling or only heating. The effect of occupancy and seasonal usage on energy efficiency is indicated by nearly all respondent reporting occupancy year-round. Of 290 respondents to this question, 96% claimed they occupy the building year-round. Three percent of those who do not use the residence year-round use it as a vacation home.

Heat pumps are not used to fully displace existing fossil fuel systems as intended. Pre-existing equipment is disproportionately remaining in use after heat pump installation—only 25% of 203 respondents claim to have removed pre-existing equipment, 11% of which still own the equipment and it is in working order (just not installed). Sixty-seven percent of pre-existing equipment is still installed and being used. Another 12% of 114 respondents installed systems with integrated controls that manage the heat pump operation with a secondary heating system.

Changes to heat pump conditioned space before and after project implementation can make energy consumption of heat pump loads difficult to distinguish from the pre-installation building consumption during analysis. A large proportion (83%) of 327 respondents' heat pumps continued to serve the pre-existing space. However, 17% of 208 respondents modified their heated square footage, and 45% of the same respondents modified cooling space.

The survey also asked participants to report on their satisfaction with the heat pump equipment among several topics, including comfort level, ease of use, and reliability. Overall, ninety percent or more respondents were satisfied or neutral for all but two categories: maintenance and comfort level on extremely cold days. Customers were most satisfied with their comfort level on extremely hot days but least satisfied with reliability and comfort on extremely cold days. Nonetheless, nearly 80% of respondents were extremely or somewhat satisfied with reliability or comfort on cold days.

Twenty-five percent of respondents experienced challenges with their heat pumps, and 13% of respondents needed heat pump repairs. Thirty-five percent of 115 respondents said that the equipment thermostat/control panel is too complex, or that the equipment is difficult to learn to operate. Another 17% did not feel comfortable with the heating or cooling of the space, did not think the system is adequate to heat or cool the space, or complained of uneven heating or cooling. One participant stated: *"We did not realize how cold rooms without a mini split in them would become (e.g., our bathrooms, basement and breezeway)."* An additional 7% disliked the amount of maintenance required. A total of 44 respondents reported "other" issues. Some of these participants requested that contractors better communicate proper maintenance and cleaning protocols of the equipment. Other participants complained about noise, smells, bacteria, or mildew.

6.2 Engineering desk review results

The NYS Clean Heat Program incentivized the installation of GSHP DHW waste heat recovery measures during the 2019-20 study period. GSHP DHW waste heat recovery installations involve two main components: the GSHP system and a heat exchanger that recovers the GSHP compressor's waste heat to preheat water for DHW use. Energy savings are generated from each component: the GSHP itself (when compared to less-efficient alternative HVAC sources) and the

DHW waste heat recovery device (by reducing the amount of energy required to achieve the DHW setpoint).

Two different GSHP DHW waste heat recovery measures appeared in the population of projects over the study period: *Category 7: GSHP Desuperheater*[82] (14 projects) and *Category 8: Dedicated Domestic Hot Water (DHW) Water-to-Water Heat Pump (WWHP)* (seven projects). Due to their relatively low counts compared to other, more prominent technologies such as ccASHPs, GSHPs, and HPWHs, these DHW waste heat recovery measures were not included in the sample frame of projects selected for premise-level analysis or for M&V. Instead, the study team performed engineering desk reviews of all 21 projects to assess adherence to TRM Version 11 and recommend best practices for estimating and tracking savings. The study team determined the following conclusions from the engineering desk reviews:

- DHW waste heat recovery measures increase the reported energy savings for GSHPs by 8% on average. However, the study team believes that savings from such add-on measures were largely unreported by the Program Administrators over the 2019-20 period. Site visits at 10 GSHP projects, included in the study's M&V sample but not addressed in this engineering desk review analysis, revealed five instances of DHW waste heat recovery components that were not incented or reflected in the savings estimates. The study team noticed a similar trend of unreported waste heat recovery measures in the 2022 NYSERDA Heat Pump Impact Evaluation.

- Program-reported savings for GSHP waste heat recovery measures were reasonably compliant with the TRM. Program Administrators incentivized 21 installations of *Category 7: GSHP Desuperheater* and *Category 8: Dedicated Domestic Hot Water (DHW) Water-to-Water Heat Pump (WWHP)* measures over the study period. The study team determined that TRM-compliant site MMBtu savings (across all fossil fuels) were 12% lower than program-reported estimates.

- One of the 21 reviewed projects involved the installation of two GSHPs with DHW heat recovery devices. The Program Administrator assumed the whole-home building load in the savings calculation of each GSHP and DHW heat recovery component. The study team

[82] NYS Clean Heat Statewide Heat Pump Program Manual, Version 7, page 92, defines a desuperheater as "an optional feature of a GSHP system that takes advantage of waste heat generated by the compressor and transfers the waste heat to a domestic hot water system." TRM Version 10, page 265, further explains the desuperheater technology: "The waste heat from the compressor of the GSHP system is transferred through a heat exchanger to heat or preheat water that is delivered to a storage tank-type water heater. The benefit of the desuperheater varies throughout the year and depends on whether the system is operating in heating mode or cooling mode, and the duration of compressor operation. A desuperheater only heats DHW when the GSHP unit runs to meet the space heating or cooling load." Desuperheater measures correspond to heat pump technology *Category 7*.

believes that the whole-home building load should have been distributed between the two installations, which would reduce the savings for that project by approximately half.

Appendix A: Survey data collection

The study team administered a web-based participant survey primarily to gather heat pump usage characteristics, request permission for collection of utility consumption data, and inquire about interest in participating in the on-site metering phase of study. Participant responses to the survey were used to support the consumption data analysis as well as the analysis of on-site metering data. This Appendix details the information collected through the participant survey.

- **Energy usage and savings analysis information.** The programs' heat pump incentive applications required the customer to identify the existing fuel source and heating and cooling equipment type. Survey responses were used to confirm and update the information in the program tracking data for each piece of equipment. In multi-zone systems, the information was collected for each indoor air-handler because distinct indoor air-handlers can have unique pre-existing equipment characteristics. The specific types of data collected to inform energy usage and savings analysis included:

  - A determination of whether the heat pump-conditioned space had pre-existing air conditioning and/or heating, and if so, the type of pre-existing equipment and the area of conditioned space served by each piece of equipment, and fuel source(s).
  - The presence and use of secondary heating equipment and fuel source(s) prior to the heat pump equipment installation and after.
  - The type of equipment that would have likely been installed in the space(s) if the heat pump equipment was not installed.
  - The thermostat heating and cooling setpoints and the perceived comfort of occupants of the space(s) before and after heat pump installation.
  - The identification of any major changes to the building in the year prior to and after the heat pump equipment was installed.
  - The presence of on-site generation (e.g., solar photovoltaic systems or generators), large electricity using equipment installations (e.g., electric vehicle charging equipment), or other large efficient equipment replacements that might significantly change the building energy consumption data.

- **Participant demographics or firmographics, experience, and satisfaction.** The survey gathered information on the building characteristics, operation of the heat pump equipment, and the participant's satisfaction with the installed heat pump equipment. The specific data collected to inform the participant's firmographics, experience, and satisfaction included:

  - The building age and a description of the building shell.
  - The presence and use heat pump system controls.
  - The type of heat pump refrigerant.
  - Experience with the installed heat pump, including problems with operation or repairs needed.
  - Perceived comfort in the conditioned space due to cooling and heating functions.

  - The participant's motivation for participation in the program.
- **Consumption data waiver and on-site metering interest.** The survey was also used to request participant permission to obtain electric consumption data and to solicit interest in participating in on-site metering data collection.

Appendix B: Sample design assumptions

A primary objective of this work is to refine TRM algorithms to more accurately predict heat pump energy savings, wherein the on-site metering analysis produced variables for use in the TRM equations. The target on-site metering sample size for each heat pump technology category was calculated based on an assumed population variability for each of these variables. For example, the TRM parameter with the highest variability for heating applications, and therefore the largest (worst) expected precision, is the ratio of design equivalent full load hours based on on-site meter data ($EFLH_{meter}$) to design equivalent full load hours based on consumption data analysis ($EFLH_{bill}$). For water heating, the highest variability and largest (worst) expected precision is the ratio of on-site meter data to consumption data analysis for the equipment increase in electric consumption. The targeted sample of participant surveys reflected an assumed response rate that would ultimately provide sufficient completed surveys for the successful recruitment of enough on-site metering participants to achieve the study's precision targets based on the assumed variability. Both meter and survey target sample sizes are constrained by the participant population that can be recruited.

A subsample of recruited on-site metering participants were subsampled for intensive metering to provide key inputs for adjustment factors to TRM algorithm variables such as SEER, EER, and COP. The study team's experience is that the metered result for these quantities have a tight relationship to the nameplate values. Therefore, it was estimated that a sample size of three to four per category would be sufficient to provide 90/20 precision at the category level, and 90/10 across all categories.

The study team did not anticipate on-site meter data collection for *Category 7: GSHP Desuperheater* and *Category 8: Dedicated DHW Water-to-Water Heat Pump;* therefore, the survey sample sizes are based on an assumed coefficient of variation (CV) of 0.5 for a proportion, and a target category confidence/precision of 90/20 for each category in the residential sample. These targets were subject to the achievable response rates and quality of collected data.

The exceptions to 90/20 target sample confidence/precision were:

- *Category 2: ccASHP: Full Load Heating* with a target of 90/15, is the largest contributor to savings across the projects in the project tracking data provided for the study.
- The commercial sample does not achieve reasonable precision for this study because of the small population available to recruit for this sector. The three commercial heat pump water heaters in the sample frame were insufficient to allow for precision estimation.

Table B-1 provides the initial and final assumptions made in designing the initial and final samples and estimating the associated precision.[83] These assumptions are used to predict the final precisions achievable through analysis of the collected data.

Table B-1. Initial and final sample design assumptions

Assumption	Initial assumption	Final assumption	Basis for initial assumption	Basis for final assumption
Survey Response Rate	10%	15%	Surveys in the prior study used a similar data collection approach and yielded response rates of 11%[84]	Achieved response rate across final sample as of May 31, 2022
Proportion of projects that are commercial (%)	10%	1%	RFP information	Proportions available in program tracking data
Proportion of projects with adequate data for consumption analysis (%)	66%	60%	2022 NYSERDA Heat Pump Impact Evaluation	2022 NYSERDA Heat Pump Impact Evaluation
Proportion of respondents agreeing to metering (%)	50%	56%	2022 NYSERDA Heat Pump Impact Evaluation	Achieved through final sample as of May 31, 2022

Table B-1 refers to the proportion of customers who agreed to on-site metering that are eligible for metering. Eligibility for metering was screened through the following criteria based on survey responses matching the frame assignments. These criteria included:

- Equipment meeting heat pump technology category definitions.
- Cold-climate application.
- Customer-reported usage patterns that met full load/partial load criteria between *Category 1: ccASHP: Partial Load Heating* and *Category 2: ccASHP: Full Load Heating* as described in Section 2.1.3.1.
- Building type category (single family, multi-family, and commercial) per TRM building type definitions,

[83] The target sample design was updated May 31, 2022.

[84] During the pandemic, residential response rates have been much higher, and commercial response rates have been more of a challenge. To ensure adequate sample pulls to meet targets, a conservative response rate assumption was used.

Projected precision depends on the assumed coefficient of variation (CV) for estimating a mean or simple proportion, or the error ratio for estimating a ratio. Sample sizes are set to produce the target precision given these assumptions. The error ratios and CV driving sample sizes are provided in Table B-2.

Table B-2. Key parameter uncertainty that drives the sample design

Sample	Heat Pump Technology Category	Target parameter with highest variability	Initially assumed error ratio or CV	Updated (5/31/22)[85] assumed error ratio or CV
Meter	*Category 1: ccASHP: Partial Load Heating*	Ratio of metered to billing-analysis EFLH	0.65	0.50
Meter	*Category 2: ccASHP: Full Load Heating*	Ratio of metered to billing-analysis EFLH	0.50	0.50
Meter	HPWH	Ratio of metered HP usage to normalized change in kWh	0.60	0.60[86]
Survey	Any	Proportion close to 50%	0.50	0.50

Because the goal of the study is to develop TRM variables for ongoing use, the Finite Population Correction factor did not apply in determining sample sizes and precision, nor in estimating the final precisions during the analysis of results.

[85] Updated error ratio/CV estimates based on more current information from the 2022 NYSERDA Heat Pump Impact Evaluation.

[86] HPWHs were not included in the 2022 NYSERDA Heat Pump Impact Evaluation, therefore this estimate remains unchanged.

Appendix C: Survey results

The study team administered a web-based survey among program participants over the study period to achieve the following objectives:

- Characterize seasonal usage of ccASHPs and GSHPs and degree of use as displacement versus replacement of existing heating and cooling systems.
- Assess participant use, understanding, and satisfaction with heat pump systems.
- Collect variables of interest to inform the analysis results described in Sections 3, 4, and 5 of this report.

The following four sections summarize survey results by participant characteristics, customer decision-making, customer satisfaction, and equipment characteristics.

C.1 Participant characteristics

Table C-1 summarizes the sectors and primary equipment types associated with the web survey's 385 respondents. The majority of survey respondents (33%) represent residential ccASHP FLHP installations, followed by residential HPWH (21%). The percentages in all tables of this appendix represent the relative shares of unique survey respondents. In Table C-1, the population of projects by equipment type over the study period is provided in the last row for reference.

Table C-1. Participant survey respondents by sector and equipment type (n=385)

Sector	ccASHP FLHP	ccASHP PLHP	GSHP	HPWH	WWHP	Total	% of Survey Respondents
Residential	126	59	50	82	1	318	**83%**
Commercial	1	3	20	-	-	24	**6%**
Multi-Family	25	8	3	7	-	43	**11%**
Total	152	70	73	89	1	385	
% of Survey Respondents	39%	18%	19%	23%	<1%		**100%**
Study Population	2,287	4,164	365	904	7	7,727	

Table C-2 illustrates that the majority of participants (82%) installed the heat pumps in an existing space as opposed to a newly constructed or rehabilitated space. Notably, 17% of the respondents did not answer this question.

Table C-2. HP installations by space classification (n=332)

Space Type Classification	ccASHP FLHP	ccASHP PLHP	GSHP	HPWH	WWHP	Total	% of Survey Respondents
Existing space	113	47	38	72	1	271	**82%**
A newly constructed building	1	1	14	1	-	17	**5%**
Combination of new and existing spaces	1	1	4	4	-	10	**3%**
Addition or remodel	4	3	2	2	-	11	**3%**
Gut renovation	7	1	3	-	-	11	**3%**
Other	2	3	3	-	-	8	**2%**
Don't know/Blank	25	14	9	10	-	58	**17%**
Total	153	70	73	89	1	332	
% of Survey Respondents	46%	21%	22%	27%	<1%		**100%**

Table C-3 shows that the vast majority of heat pump recipients (96%) occupy their home or business year-round.

Table C-3. HP installations by customer's reported occupancy classification (n=290)

Occupancy Classification	ccASHP FLHP	ccASHP PLHP	GSHP	HPWH	WWHP	Total	% of Survey Respondents
Full-year occupancy	104	58	69	46	1	278	**96%**
Occupied most of the year except for winter months	2	-	-	1	-	3	**1%**
Occupied only during summer months	1	-	-	-	-	1	**0%**
Used primarily as a weekend home	3	2	3	-	-	8	**3%**
Total	110	60	72	47	1	290	
% of Survey Respondents	38%	21%	25%	16%	<1%		**100%**

C.2 Customer motivations and satisfaction

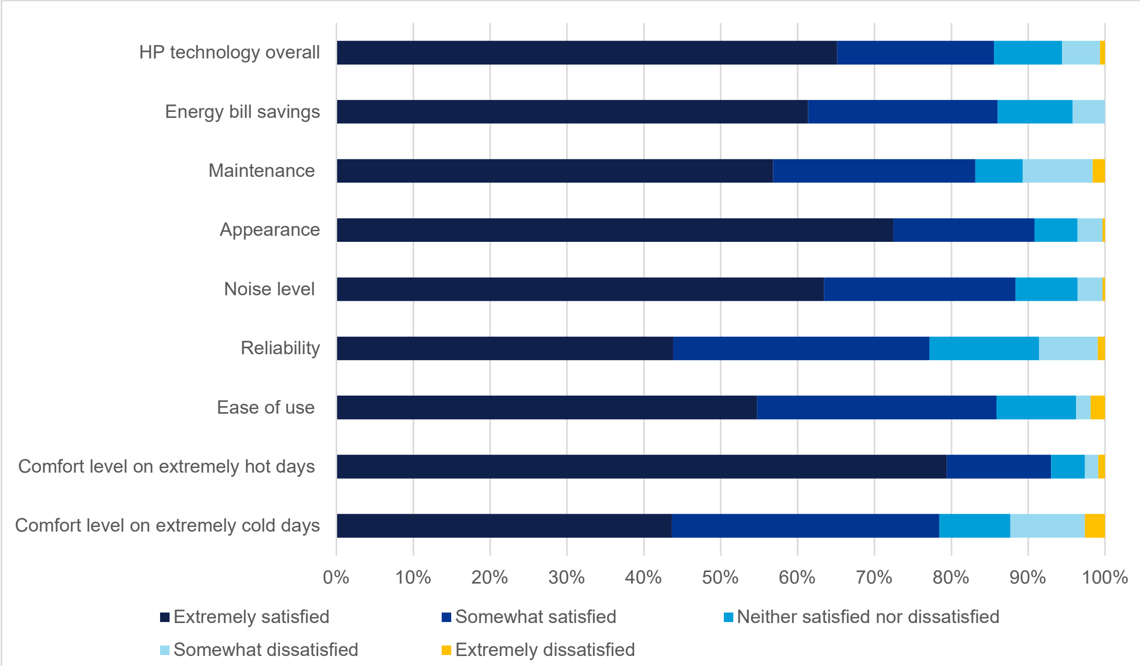
Table C-4 illustrates the different motivations that caused the customer to install the program-eligible space conditioning heat pump. This question allowed multiple responses; therefore, the rightmost column represents the share of total responses, not the share of respondents. Energy efficiency, reduced operating costs, program incentives, and cooling capability were the primary motivators among respondents.

Table C-4. Motivators for heat pump installation by equipment type (n=200)

Customer Motivations for Installing HP (Multiple Responses Allowed)	ccASHP FLHP	ccASHP PLHP	GSHP	Total	% of Survey Responses
More energy efficient	79	29	48	156	**15%**
Reduce or minimize heating costs	69	23	46	138	**13%**
Reduce or minimize cooling costs	54	26	39	119	**11%**
Availability of incentives	67	20	29	116	**11%**
Reduce environmental impacts	61	13	40	114	**11%**
Add cooling where none existed previously	63	28	15	106	**10%**
Replace a system using natural gas, propane, heating oil or wood	43	7	33	83	**8%**
Replace broken or aging equipment	33	5	22	60	**6%**
Supplement heating/cooling from the main system	28	25	3	56	**5%**
Improve air quality (air-filtration, dehumidify, etc.)	30	10	14	54	**5%**
Contractor recommendation	18	2	2	22	**2%**
Add heating where none existed previously	9	3	6	18	**2%**

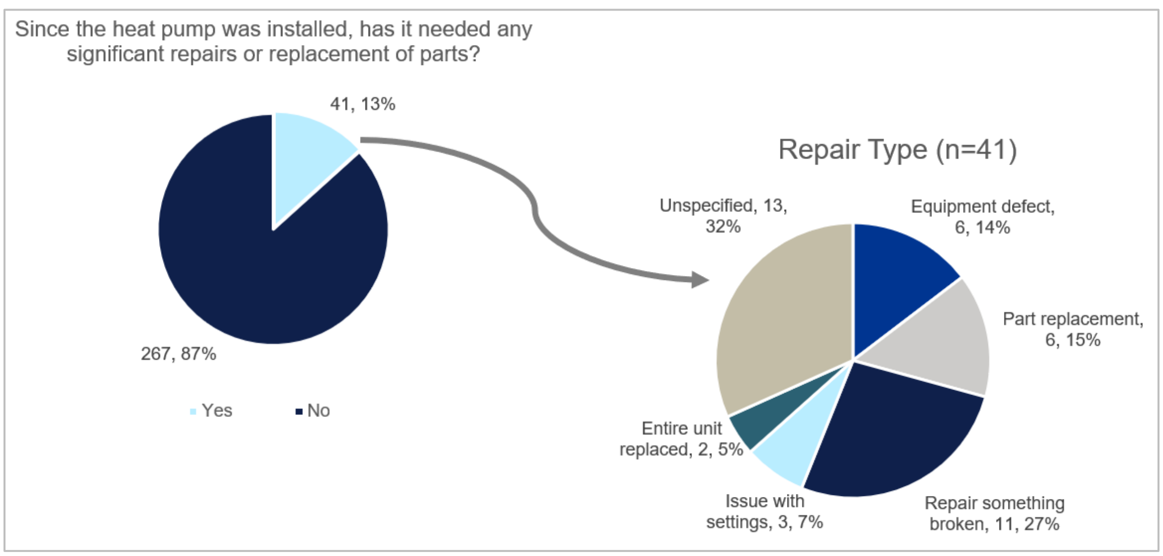
Figure C-1 illustrates customer satisfaction among a number of topics related to the heat pump installation, including comfort level, ease of use, reliability, and observed energy savings. Ninety percent or more respondents were satisfied or neutral for all but two categories: maintenance and comfort level on extremely cold days. Customers were most satisfied with their comfort level on extremely hot days but least satisfied with reliability and comfort on extremely cold days. Nonetheless, nearly 80% of respondents were extremely or somewhat satisfied with reliability or comfort on cold days. Maintenance, ease of use, and comfort level on extremely cold days garnered the most “extremely dissatisfied” responses.

Figure C-1. Respondent satisfaction on various topics related to the installed heat pump (n=298)



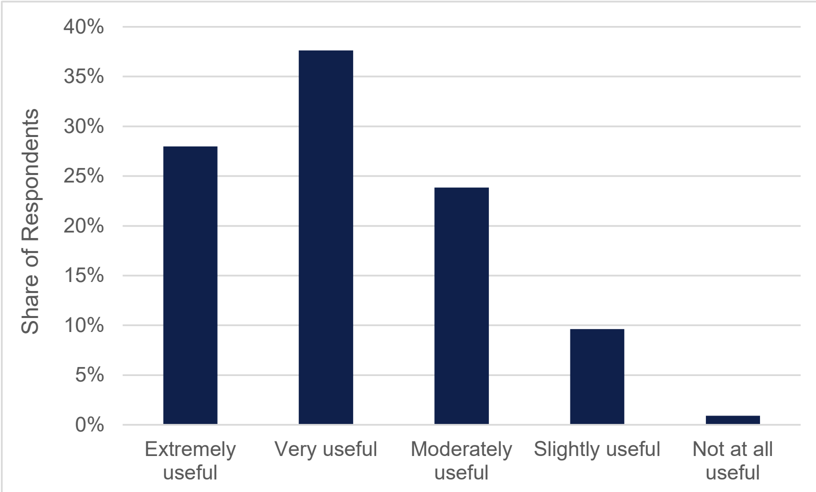
Regarding equipment repairs, 13% of respondents indicated that their heat pump required repair or replacement beyond typical maintenance practices, as illustrated in Figure C-2. That subset of 41 respondents described the repairs as primarily equipment defects or replacements of inoperable parts. Notably, two of the 308 respondents reported having to replace the entire heat pump unit.

Figure C-2. Frequency and classification of heat pump repairs (n=308)



76% of respondents received instruction from the installation contractor on how to operate and maintain the newly installed heat pump. As Figure C-3 shows, nearly two-thirds of those respondents found the contractor guidance extremely or very useful.

Figure C-3. Usefulness of contractor guidance after heat pump installation (n=218)



Respondents generally found the installed heat pump straightforward to operate, with only 9% of respondents characterizing the heat pump operation as moderately or very challenging. The most challenging aspects of heat pump operation included the complexity of equipment controls and the frequency of required maintenance such as cleaning.

C.3 Equipment characteristics

The following sections explore the characteristics of the heat pump and the displaced heating and cooling equipment.

C.3.1 Heating

Table C-5 illustrates that, overall, pre-existing heating systems were more likely to remain in place even after the heat pumps were installed. Only 14% of respondents reported replacing failed or near-failed equipment.

Table C-5. Status of pre-existing heating system (n=203)

Status of Pre-existing Heating System	ccASHP FLHP	ccASHP PLHP	GSHP	Total	% of Survey Respondents
Working and still in use	77	38	20	135	**67%**
Working and installed but disconnected or not in use	9	4	2	15	**7%**

Removed, was still working but with significant performance or maintenance problems	9	5	8	22	**11%**
Removed but was still in good working condition at the time	14	1	7	22	**11%**
Removed, was no longer working	2	2	3	7	**3%**
Don't know	2	0	0	2	**1%**
Total	113	50	40	203	
% of Survey Respondents	56%	25%	20%		**100%**

Given the prevalence of preexisting heating systems remaining in place, Table C-6 illustrates that the majority of installed heat pumps share the heating load with at least one other system. Unsurprisingly, this load-sharing is most prevalent with PLHPs.

Table C-6. Prevalence of heating load sharing between HP and other heating sources (n=185)

HP Load-Sharing with Other Heating Systems	ccASHP FLHP	ccASHP PLHP	GSHP	Total	% of Survey Respondents
Yes, the heat pump(s) are used along with other heating sources	62	36	8	106	**57%**
No, all heating comes from the heat pump(s)	41	7	31	79	**43%**
Total	103	43	39	185	
% of Survey Respondents	56%	23%	21%		**100%**

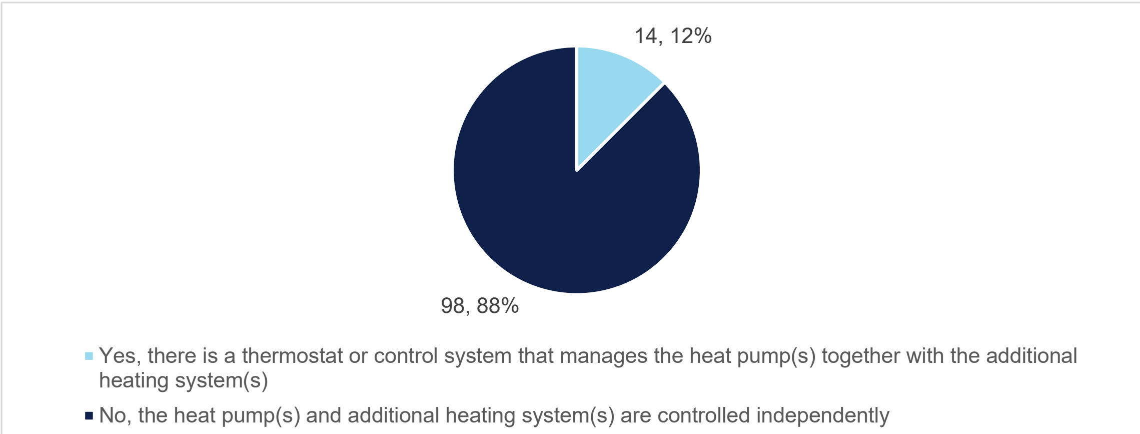
Table C-7 illustrates the customers' strategies on when to use the heat pump instead of other available heating sources. While most respondents indicated that they use the heat pump first, opportunities remain to prioritize heat pumps over other heating alternatives.

Table C-7. Heating load sharing strategies with HPs and other systems (n=116)

HP Load-Sharing with Other Heating Systems	Total	% of Survey Respondents
Use heat pump(s) first and activate other heating systems as needed	53	**46%**
Use pre-existing/additional heat system first and activate heat pump(s) as needed	33	**28%**
Set temperature and allow thermostat or controls system determine which heating equipment is used	16	**14%**
The new heat pump(s) is the only heating equipment serving this space	5	**4%**
Other	9	**8%**
Total	116	**100%**

Integrated controls offer an automated method of load sharing between HPs and other heating systems. Survey responses showed that the majority of load-sharing HPs were not installed with integrated controls, as shown in Figure C-4. Should PLHP systems be reintroduced in future iterations of the NYS Clean Heat Program or other programs integrated controls should be required or encouraged to maximize heat pump use.

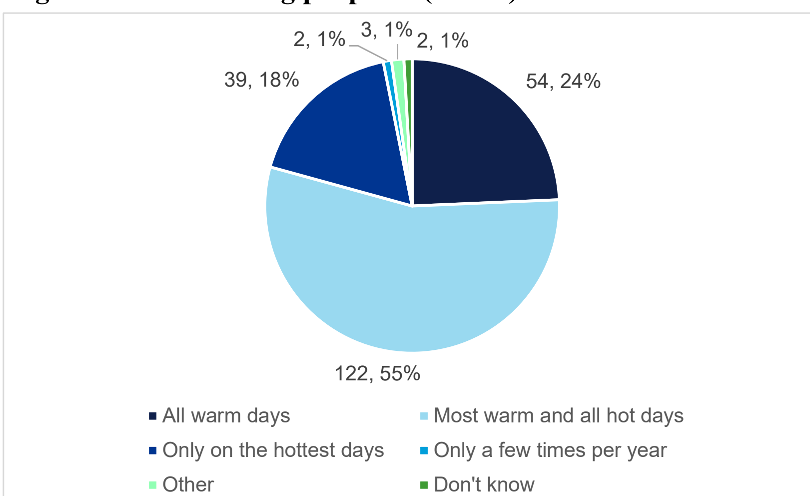
Figure C-4. Prevalence of integrated controls among heating load-sharing HPs (n=112)



C.3.2 Cooling

Figure C-5 illustrates that the majority of incented HPs are used for cooling on most or all warm days.

Figure C-5. Usage of HPs for cooling purposes (n=222)



Overall, HPs displaced or replaced preexisting cooling systems that were generally working, as illustrated by Table C-8.

Table C-8. Status of pre-existing cooling systems before HP installation (n=156)

Pre-Existing Cooling System Status	ccASHP FLHP	ccASHP PLHP	GSHP	Total	% of Survey Respondents
Working and still in use	21	11	3	35	**22%**
Working and installed but disconnected or not in use	6	6	2	14	**9%**
Removed, was still working but with significant performance or maintenance problems	10	6	8	24	**15%**
Removed but was still in good working condition at the time	43	12	11	66	**42%**
Removed, was no longer working	11	2	4	17	**11%**
Don't know	2	3	0	5	**3%**
Total	93	40	28	156	**100%**

Of the pre-existing cooling systems that are working and still in use, the majority are still used on most or all warm days even after the HP installation, as illustrated in Table C-9.

Table C-9. Use of pre-existing cooling systems after HP installation (n=40)

Use of Pre-Existing Cooling System after HP Installation	ccASHP FLHP	ccASHP PLHP	GSHP	Total	% of Survey Respondents
Only the hottest days	3	2	0	5	**13%**
Only a few times per year	2	2	0	4	**10%**
Most warm and all hot days	6	6	1	13	**33%**
All warm days	6	2	1	9	**23%**
Never	8	0	1	9	**23%**
Total	25	12	3	40	**100%**