Field Monitoring Ground Source Heat Pumps on Long Island

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NEW YORK STATE | NYSERDA

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Field Monitoring Ground Source Heat Pumps on Long Island

Final Report

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Abstract

This field test study evaluated the performance of 33 ground source heat pump systems installed in 27 Long Island homes. Measured data for the Water Furnace dual stage and variable speed heat pumps were collected for a year or more using the on-board Symphony™ monitoring system. A survey was also conducted to capture homeowner perceptions and experiences with the systems. This study follows a similar test of 49 Water Furnace heat pumps in Upstate New York (NYSERDA Report 18.03). The results showed that the seasonal average heating COP was 3.8 (with pumps, fans, and resistance elements), compared to 3.6 for the upstate systems. Ground loop temperatures were correspondingly higher in the milder heating climate. Homeowners reported that these systems maintained good comfort in the winter, which was corroborated by the minimal resistance heat use. Greenhouse gas savings were also documented, and annual cost savings were as high as $295 per installed ton compared to fuel oil at current, post-pandemic prices.

Keywords

Ground source heat pumps, field testing, Measurement and verification, Customer comfort

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Acronyms and Abbreviations

AC	air conditioning
AEG	Applied Energy Group
ASHP	air source heat pump (interchangeable with ccASHP)
ccASHP	cold-climate air source heat pump
Clg	cooling
COP	coefficient of performance
DHW	domestic hot water
eGrid	Source of electricity emissions factors by region from the Environmental Protection Agency
EPA	US Environmental Protection Agency
EWT	entering water temperature (to the heat pump)
FE	Frontier Energy (formerly CDH Energy)
ft	feet
GHG	greenhouse gas
GSHP	ground source heat pump
Htg	heating
HVAC	heating, ventilating and air conditioning
kW	kilowatt
kWh	kilowatt hours
MW	megawatt
NY	New York
NYISO	New York Independent System Operator
NYS	New York State
NYSERDA	New York State Energy Research and Development Authority
PON	Project Opportunity Notice
PSE&G-LI	Public Service Electric and Gas of Long Island
PV	photovoltaic
RHT	resistance (electric) heating
SEER	seasonal energy efficiency ratio
sq	square
TRM	technical resource manual
W	watts

Executive Summary

The project was initiated under New York State Energy Research and Development Authority's (NYSERDA) Emerging Technology and Accelerated Commercialization (ETAC) program, or Program Opportunity Notice 3127. The Applied Energy Group (AEG) team ultimately identified and recruited 27 homes on Long Island and installed a total of 33 ground source heat pump (GSHP) units to replace fossil fuel and electric resistance heating systems. All GSHP systems were installed by ZBF Geothermal and used Water Furnace heat pumps. NYSERDA hired Frontier Energy to conduct the measurement and verification (M&V) at these sites (as well as for other similar ETAC projects). The Water Furnace heat pumps all included the Symphony™ monitoring system that allowed for the collection of measured data.

The GSHP systems all used one or more vertical bore, closed-loop ground heat exchanger(s). The systems were installed from late 2017 through mid-2020. Six homes had two GSHP units installed. The heat pump installed capacity at each site ranged from 2 to 8 tons. The average installed cost was $10,570 per installed ton, including the heat pump equipment, ground loop heat exchanger, and ducting modifications to accommodate the new system. After applying incentives and tax credits available at installation time, the net cost to the homeowner dropped to $5,987 per installed ton.

The M&V approach relied on measured data collected by the Symphony™ monitoring system incorporated into each Water Furnace dual-stage or variable speed heat pump. Measured data were collected at 15-minute intervals, including electric consumption, thermal loop loads, and various temperatures and status points to understand system operation. Data collection was successfully completed for 28 of the 33 GSHP units (5 units had internet connectivity issues that hindered data collection). Corrections were made to the measured thermal data using the manufacturer's published performance tables. Measured loads and energy use in the post-retrofit period were used to predict the fuel consumption of the previously installed pre-retrofit equipment (i.e., pre-retrofit performance was not directly measured).

Analysis of the measured data showed the average corrected annual heating Coefficient of Performance (COP) was 3.8 for the GSHP systems (including the heat pump, loop pump and electric resistance heat). This COP was slightly higher than the average COP of 3.6 in a previous study of similar GSHP systems in Upstate New York (NYSERDA Report 18-03). The average entering water temperature (EWT) was 42.7°F for the heating season, about 2°F higher than EWTs measured for upstate GSHPs in the previous study. The better heating performance was consistent with the milder heating climate on Long Island.

The peak heating demand for days near 10°F was 0.75 kilowatts (kW) per installed cooling ton. This diversified average demand was about 20% lower than the demand measured for cold climate air source heat pumps (ccASHPs) in the same climate (NYSERDA Report 22-04). In the summer, the normalized peak demand for the GSHP units was about the same as for the ccASHPs, after accounting for sizing and other differences between the studies.

The cost savings for GSHP systems were highest when the displaced heating fuel was fuel oil and lowest for the natural gas sites. The average annual cost savings for the fuel oil homes was \$173 per installed ton, or 34¢ per square foot of floor area. For the natural gas sites, the average annual cost savings were \$76 per installed ton, or 7¢ per square feet of floor area. The costs analysis used regional 2020 rates of \$0.2019/kWh, \$1.385/therm, and \$3.23/gallon. A sensitivity analysis showed that assuming 40% higher fuel costs–reflecting current post-pandemic conditions–increases the annual savings from \$173 per ton to \$295 per ton for fuel oil and from \$76 per ton to \$145 per ton for natural gas. The simple payback for the GSHP systems based on the net installation costs to the homeowner were 41 years for natural gas and 20 years for fuel oil, using these post-pandemic utility costs.

The greenhouse gas (GHG) savings attributable to the GSHP systems were determined to be 877 pounds of carbon dioxide (CO_2) equivalent per year per installed ton, compared to using a natural gas furnace. The GHG savings were 1,333 pounds of CO_2-equivalent per year per installed ton compared to a fuel oil system.

The homeowner surveys indicated that most homeowners were satisfied with the heat pump system but did think the installation process was more onerous than a simple replacement of their original heating and cooling systems. The main homeowner motivations for installing the heat pumps were to lower operating costs and take advantage of financial incentives. Having a system that could both heat and cool was less important than was observed in the other NYSERDA-sponsored studies of ccASHPs, since most Long Island homes in the study already had central air conditioning. Environmental considerations, such as reduced greenhouse gas emissions, were less of a factor in homeowner's decisions to install the heat pumps.

1 Project Introduction and Overview

1.1 NYSERDA's Original Goals for Project Opportunity Notice 3127

New York State's residential buildings account for more than 35% of total electricity consumption in the State, nearly 28% of net energy consumption in the State, and emit 18% of the State's greenhouse gases (GHG). Therefore, Project Opportunity Notice (PON) 3127, the "Emerging Technologies Demonstration Projects–Residential HVAC" initiative was created to identify ways to accelerate the market uptake of commercially available, but underused building technologies and strategies in the residential sector. The PON solicited projects that would deliver significant and measurable energy savings and GHG reductions for existing homes and residential buildings. PON 3127 sought proposals for multi-site demonstration or pilot projects that addressed the barriers to wider commercialization of various eligible heating, ventilation, and air conditioning (HVAC) systems in the existing residential building market (excluding new construction).

1.2 Pilot Program Goals

Geothermal or ground source heat pumps (GSHPs) offer lower energy costs and reduced GHG emissions compared to other heating and cooling options. In the winter, GSHPs extract heat from the ground, eliminating the consumption of fossil fuels for heating. In the summer, GSHPs have the potential to reduce the peak load on Long Island's electric grid compared to conventional cooling systems. Therefore, GSHPs offer significant benefits to the electric utility: increasing annual electric sales while reducing peak summer electric demand. Like all heat pumps, GSHPs are also compatible with an electric grid that is increasingly served by renewable energy sources.

GSHP systems use water-to-air heat pump equipment that is connected to loop: to form either an open loop or a closed loop system. Closed loop systems are the much more common arrangement, with a freeze-protected fluid circulating in closed plastic piping loop that is buried in the ground. Closed loop systems can have horizontal ground loops with pipe buried in trenches a few feet deep or can have vertical ground loops with piping inserted down a bore that can be hundreds of feet deep. Vertical ground loops are usually the only option in suburban residential applications where limited yard space is available around the home. This NYSERDA website provides further background on GSHP technology (https://cleanheat.ny.gov/geothermal-heat-pumps/)

A goal of this field test pilot is to measure and document the technical and economic benefits of GSHP systems–including the reduction of greenhouse gas emissions relative to base case fossil fuel systems. The pilot project also sought to gather homeowner feedback on their perceptions and experiences with GSHP systems.

GSHPs are currently experiencing slow growth in New York State, mostly due to the higher installed costs than other technologies. A goal of the Technology Transfer activities is to show that the market barrier of high costs—which limits widespread adoption—is due to a lack of standardization. Therefore, the pilot aims to develop a standardized geothermal system package and design documentation that can be broadly applied to as many installations as possible. This standardization can lower costs by streamlining building department plan review and facilitating bundling of many installations to attract investment capital for installations at much larger scale.

1.3 Program Approach

This project focused on variable-speed and dual stage ground source heat pump (GSHP) systems manufactured by Water Furnace and installed in Long Island single family homes. These GSHP systems included the on-board Symphony™ real time energy and monitoring system that was able to collect performance data–similar to an analysis of data from nearly 50 similar units in Upstate New York (NYSERDA Report 18-03). AEG worked with an installation contractor, ZBF Geothermal (ZBF), to identify, recruit and install GSHP systems at 27 locations. The original plan called for 36 heat pump installations. The team also planned to install Onicon BTU meters at a subset of homes to directly measure the accuracy of the Symphony™ sensors. However, since some of the recruited sites were signed up after installation and COVID limited our access to homes in many cases, returning to install the Onicon BTU meters was deemed to be impractical and not attempted.

AEG worked with NYSERDA's third-party measurement and verification (M&V) consultant, Frontier Energy (formerly CDH Energy) to develop the "Performance Validation Plan" and to collect and analyze the data. Owahgena Consulting helped to complete the data analysis and prepare the final report. Fronter Energy also conducted a survey of the homeowners to gauge their perception of the GSHP systems and satisfaction with the installation. Surveys were sent to participants around the time of system installation. Follow up phone surveys with some homeowners provided additional feedback.

All the GHSP systems used a "closed loop" ground heat exchanger made up of one or more vertical bores. All systems are expected to provide both heating and cooling to the homes.

1.4 Customer Outreach and Recruitment

ZBF recruited customers by using their natural flow of GSHP installations. The recruitment process screened sites find homes and systems that met the criteria. Also, ZBF worked with Public Service Electric and Gas of Long Island (PSE&G-LI) to reach out to customers via an email campaign targeting 998 customers who previously completed energy audits and had forced air heating in their house. Two customers signed up as a result of the email campaign.

At the start of selection process, ZBF focused on finding existing single-family sites that were heated/cooled by a single ducted fuel oil furnace. As the recruitment progressed over multiple years, the criteria were expanded to include a wider array of homes, including customers with natural gas, houses with two heat pump units, and houses that needed ductwork retrofits. The recruitment process was also eventually broadened to include new homes.

1.5 Overall Project Timeline

The project was initiated in early 2017 and Performance Validation (PV) plan was finalized in September 2017. The first ten systems were identified and recruited in 2018. Measured data was periodically provided by WaterFurnace (in some cases with data back to 2017) and the surveys were completed through 2018 and 2019. A presentation on initial results was given in April 2019 at the NY-GEO conference. In early 2020, efforts for on-site M&V verification were planned and then abandoned as COVID curtailed home access for many months. In the latter half of 2021, recruitment efforts were restarted and more sites completed the survey and measured data was collected. By the beginning 2022 all 27 homeowners had been identified and recruited. The last batch of measured data was collected in March 2022. The detailed data analysis and reporting was completed in 2022.

2 Home Characteristics and Equipment Details

Twenty-seven homes participated in this study and the houses included a total of 33 heat pump units or systems (the system IDs run from S01 to S40 since some systems were considered but not ultimately included). All of the sites were single-family homes located on Long Island. First, this section describes the homes and provides the characteristics of the original heating and cooling systems. Then it describes the details of the heat pump units that were installed. Finally, installation costs are summarized.

2.1 House Characteristics

Table 1 summarizes the size and age of each home along with the original heating fuel used before GSHP installation. Figure 1 shows four examples of the suburban single-family homes included in the study. Five of the homes were new construction (built in 2018 or 2019). Six of the homes originally used (or would have used) natural gas while nineteen of the sites used fuel oil for heating. Two homes had used electric resistance heating. The design heating and cooling loads are given along with the relative sizing of the installed GSHP units. The heating design condition was typically 15 to 17°F, consistent with the 1% design conditions for Long Island. Design loads are also normalized based on floor area. In six homes, two Water Furnace heat pump units were installed to serve the home. The ratio of the design cooling and heating loads – a metric of interest to the NYS Clean Heat program–are also calculated.

Figure 1. Examples of Homes with GSHP Systems Installed

Table 1. Home Characteristics and Original Heating and Cooling Information

ID	Town	GSHP Unit Model	GSHP Unit Size (tons)	Floor Area (sq. ft.)	Year Built	Fuel	Design Heating (MBtu/h)	Design Cooling (MBtu/h)	Htg Sizing (%)	Clg Sizing (%)	Design Htg Load (Btu/h-sq. ft.)	Design Clg Load (Btu/h-sq. ft.)	Design Clg-Htg Ratio
s01	Farmingdale	NDV026	2	950	1951	Oil	25.0	18.0	78%	147%	26.3	18.9	72%
s02	Lynbrook	NDV026	2	1200	1947	Gas	30.0	18.0	65%	147%	25.0	15.0	60%
s03	Islip	NVV060	5	2000	1952	Oil	50.0	40.0	103%	140%	25.0	20.0	80%
s04	East Islip	NVV060	5	1800	1970	Oil	40.0	28.0	129%	200%	22.2	15.6	70%
s05	Setauket	NVV048	4	3500	1963	Oil	65.0	42.0	97%	170%	18.6	12.0	65%
s06		NDZ026	2										
s07	Smithtown	NDZ049	4	2631	1961	Oil	60.0	48.0	150%	223%	22.8	18.2	80%
s08		NVV060	5										
s09	Copiague	NDZ064	5	1900	1970	Oil	62.0	41.0	76%	160%	32.6	21.6	66%
s10	Remsenburg	NVV060	5	2723	1991	Oil	55.0	42.0	94%	133%	20.2	15.4	76%
s11	Coram	NSV018	1.5	2500	1995	Gas	50.0	38.5	124%	218%	20.0	15.4	77%
s16		NDZ064	5										
s12	Northport	NVV060	5	3100	1955	Oil	52.0	41.0	99%	137%	16.8	13.2	79%
s13	Syosset	NVV036	3	3100	1950	Oil	78.0	65.0	108%	141%	25.2	21.0	83%
s14		NVV060	5										
s15	Manorville	NDZ038	3	2500	1950	Oil	55.0	41.0	52%	93%	22.0	16.4	75%
s17	Hewlett	NDZ064	5	2100	2018	Gas	50.0	35.0	95%	187%	23.8	16.7	70%

Table 1 continued

ID	Town	GSHP Unit Model	GSHP Unit Size (tons)	Floor Area (sq. ft.)	Year Built	Fuel	Design Heating (MBtu/h)	Design Cooling (MBtu/h)	Htg Sizing (%)	Clg Sizing (%)	Design Htg Load (Btu/h-sq. ft.)	Design Clg Load (Btu/h-sq. ft.)	Design Clg-Htg Ratio
s18	East Hampton	NVV060	5	1850	1994	Oil	51.3	39.9	101%	141%	27.7	21.5	78%
s19	Port Jefferson	NVV048	4	4000	1987	Oil	75.0	60.0	116%	75%	18.8	15.0	80%
s20		NVV048	4										
s21	Seaford	NVV036	3	2200	1950	Gas	39.0	29.0	84%	123%	17.7	13.2	74%
s22	Bellmore	NDZ064	5	2500	2018	Gas	69.4	44.3	68%	148%	27.8	17.7	64%
s23	Manhasset	NVV048	3	3100	2019	Gas	73.9	61.5	97%	135%	23.8	19.8	83%
s24		NDZ038	4										
s25	East Northport1	NVV060	5	2100	2019	Oil	55.0	38.0	94%	147%	26.2	18.1	69%
s26	East Northport2	NDZ064	5	2200	1950	Oil	45.5	39.8	104%	165%	20.7	18.1	87%
s28	Levittown	NDZ064	5	2392	1950	Oil	56.3	52.0	84%	126%	23.6	21.7	92%
s29	Patchogue	NDZ064	5	2500	1890	Oil	58.1	49.5	81%	132%	23.2	19.8	85%
s30	Remsensburg	NDZ064	5	2500	1950	Oil	58.4	48.9	81%	134%	23.3	19.6	84%
s31	Port Jefferson	NVV060	5	3200	1960	Oil	61.7	42.4	84%	132%	19.3	13.3	69%
s37	Syosset	NVV060	5	3500	2013	Oil	51.9	40.0	100%	140%	14.8	11.4	77%
s39	Bellport	NVH060	5	2100	1960	Electric	61.0	50.2	85%	112%	29.1	23.9	82%
s40	Medford	NVV036	3	1924	2018	Electric	21.1	19.1	156%	188%	11.0	9.9	90%

2.2 Installed Ground Source Heat Pump Systems and Costs

Table 2 summarizes the heat pumps installed for each system as well as the ground heat exchanger details. All the ground loops were closed loop with one or more vertical bores. The length of the vertical bore per installed ton is also given. All the ground loops used at least 20% propylene glycol. Thermally enhanced grout (with a conductivity of 1.2) was also used for all the installations. All of the vertical bores were under 330 feet deep, since most residential well drillers in the area do not typically go deeper due to local soil and geological conditions (e.g., risk of hole collapse, etc.). The high-density polyethylene piping in the bore was 1-1/4 inch diameter in all cases.

Table 3 lists the installed costs for each heat pump system. Costs are also summarized per installed nominal cooling ton and per floor area. The system cost (before incentives) ranged from $25,000 to $114,500, with an average cost of $51,572. The cost per installed ton ranged from $5,000 to $19,821, with an average cost per ton of $10,570. The cost per sq. ft. of floor area ranged from $11 to $41, with an average cost per sq. ft. of $22.

Net costs to the homeowner would be reduced by utility incentive of $2,000 per rated cooling ton offered by the local electric utility (PSE&G-Long Island) as well as a 30% federal tax credit that was available when these units were installed (2017 to 2020). Table 4 shows the impact of applying these available incentives and credits to these sites. These incentives and credits would have lowered the average net homeowner cost to $5,987 per installed cooling ton. In 2022, a new tax credit became available in NYS in addition to the federal credit and the PSEG-LI incentive. Applying the new 25% tax New York State credit (capped at $5,000) would hypothetically lower the average net customer cost to $5,206 per installed cooling ton.

Table 2. GSHP Installation Details for Each System

System ID	Town	GSHP Unit Model	GSHP Unit Size (tons)	Rated Clg Capacity @ 77F (MBtu/h)	Rated Htg Capacity @ 32F (MBtu/h)	Install Date	Bore Depth (ft)	Total Bore Length (ft)	Number of Bores	Bore Length per ton (ft/ton)
s01	Farmingdale	NDV026	2	26.4	19.5	1/25/2018	225	450	2	205
s02	Lynbrook	NDV026	2	26.4	19.5	1/1/2018	250	500	2	227
s03	Islip	NVV060	5	56	51.7	7/1/2018	260	540	2	116
s04	East Islip	NVV060	5	56	51.7	5/1/2019	260	540	2	116
s05	Setauket	NVV048	4	45	43.5	10/1/2017	300	900	3	151
s06		NDZ026	2	26.4	19.5	10/1/2017				
s07	Smithtown	NDZ049	4	50.8	38.2	7/1/2018	275	1100	4	124
s08		NVV060	5	56	51.7	7/1/2018				
s09	Copiague	NDZ064	5	65.5	47.3	5/1/2019	267	800	3	147
s10	Remsenburg	NVV060	5	56	51.7	11/1/2018	267	800	3	171
s11	Coram	NSV018	1.5	18.5	14.5	11/1/2018	250	1000	4	143
s16		NDZ064	5	65.5	47.3	12/1/2018				
s12	Northport	NVV060	5	56	51.7	6/1/2019	267	800	3	171
s13	Syosset	NVV036	3	35.8	32.9	6/1/2019	250	1200	5	157
s14		NVV060	5	56	51.7	7/1/2019				
s15	Manorville	NDZ038	3	38.2	28.5	12/1/2018	250	500	2	157
s17	Hewlett	NDZ064	5	65.5	47.3	8/1/2018	270	800	3	147

Table 2 continued

System ID	Town	GSHP Unit Model	GSHP Unit Size (tons)	Rated Clg Capacity @ 77F (MBtu/h)	Rated Htg Capacity @ 32F (MBtu/h)	Install Date	Bore Depth (ft)	Total Bore Length (ft)	Number of Bores	Bore Length per ton (ft/ton)
s18	East Hampton	NVV060	5	56	51.7	9/1/2019	250	750	3	161
s19	Port Jefferson	NVV048	4	45	43.5	5/1/2019	330	1320	4	176
s20		NVV048	4	45	43.5	5/1/2019				
s21	Seaford	NVV036	3	35.8	32.9	7/25/2019	320	640	2	215
s22	Bellmore	NDZ064	5	65.5	47.3	8/15/2018	265	800	3	147
s23	Manhasset	NVV048	3	45	43.5	6/17/2018	265	801	3	116
s24		NDZ038	4	38.2	28.5	6/18/2018				
s25	East Northport1	NVV060	5	56	51.7	11/1/2019	265	800	3	171
s26	East Northport2	NDZ064	5	65.5	47.3	8/8/2020	235	700	3	128
s28	Levittown	NDZ064	5	65.5	47.3	7/1/2019	250	750	3	137
s29	Patchogue	NDZ064	5	65.5	47.3	8/5/2019	175	700	4	128
s30	Remsensburg	NDZ064	5	65.5	47.3	5/8/2019	250	750	3	137
s31	Port Jefferson	NVV060	5	56	51.7	6/4/2020	250	750	3	161
s37	Syosset	NVV060	5	56	51.7	12/1/2019	250	750	3	161
s39	Bellport	NVH060	5	56	51.7	8/1/2019	325	650	2	139
s40	Medford	NVV036	3	35.8	32.9	3/1/2021	260	540	2	181

Table 3. GSHP Installation Costs Each Site

ID	Town	GSHP Unit Model	GSHP Unit Size (tons)	Floor Area (sq. ft.)	Installed Cost	Installed Cost per ton	Installed Cost per sq. ft.	Notes
s01	Farmingdale	NDV026	2	950	$39,641	$19,821	$42	
s02	Lynbrook	NDV026	2	1200	$25,000	$12,500	$21	
s03	Islip	NVV060	5	2000	$25,000	$5,000	$13	
s04	East Islip	NVV060	5	1800	$47,533	$9,507	$26	
s05	Setauket	NVV048	4	3500	$63,850	$10,642	$18	
s06		NDZ026	2					
s07	Smithtown	NDZ049	4	2631	$73,250	$8,139	$28	
s08		NVV060	5					
s09	Copiague	NDZ064	5	1900	$52,000	$10,400	$27	
s10	Remsenburg	NVV060	5	2723	$36,250	$7,250	$13	
s11	Coram	NSV018	1.5	2500	$40,250	$6,192	$16	
s16		NDZ064	5					
s12	Northport	NVV060	5	3100	$33,000	$6,600	$11	
s13	Syosset	NVV036	3	3100	$80,000	$10,000	$26	
s14		NVV060	5					
s15	Manorville	NDZ038	3	2500	$40,000	$13,333	$16	
s17	Hewlett	NDZ064	5	2100				

Table 3 continued

ID	Town	GSHP Unit Model	GSHP Unit Size (tons)	Floor Area (sq. ft.)	Installed Cost	Installed Cost per ton	Installed Cost per sq. ft.	Notes
s18	East Hampton	NVV060	5	1850	$36,725	$7,345	$20	
s19	Port Jefferson	NVV048	4	4000	$66,000	$8,250	$17	
s20		NVV048	4					
s21	Seaford	NVV036	3	2200	$42,000	$14,000	$19	
s22	Bellmore	NDZ064	5	2500	$55,000	$11,000	$22	
s23	Manhasset	NVV048	3	3100	$114,500	$16,357	$37	System cost included new ductwork, dehumidification, and humidification on the system
s24		NDZ038	4					
s25	East Northport1	NVV060	5	2100	$58,736	$11,747	$28	
s26	East Northport2	NDZ064	5	2200	$58,786	$11,757	$27	Zoning system, 4 zones in house
s28	Levittown	NDZ064	5	2392	$52,920	$10,584	$22	
s29	Patchogue	NDZ064	5	2500	$51,600	$10,320	$21	
s30	Remsensburg	NDZ064	5	2500	$51,200	$10,240	$20	
s31	Port Jefferson	NVV060	5	3200	$66,869	$13,374	$21	
s37	Syosset	NVV060	5	3500				
s39	Bellport	NVH060	5	2100	$48,900	$9,780	$23	Tie-into existing ductwork. Line voltage electrical by others
s40	Medford	NVV036	3	1924	$30,300	$10,100	$16	Nonprofit–tax exempt. Did not include ductwork, electrical, or DHW plumbing costs.

Table 4. GSHP Net Installation Costs for Each Homeowner

ID	Town	GSHP Unit Model	GSHP Unit Size (tons)	Installed Cost	Installed Cost per ton	PSE&G LI Incentive	Federal Tax Credit	Net Installed Costs	Net Installed Costs per ton
s01	Farmingdale	NDV026	2	$39,641	$19,821	$4,400	$10,572	$24,669	$12,334
s02	Lynbrook	NDV026	2	$25,000	$12,500	$4,400	$6,180	$14,420	$7,210
s03	Islip	NVV060	5	$25,000	$5,000	$9,333	$4,700	$10,967	$2,193
s04	East Islip	NVV060	5	$47,533	$9,507	$9,333	$11,460	$26,740	$5,348
s05	Setauket	NVV048	4	$63,850	$10,642	$11,900	$15,585	$36,365	$6,061
s06		NDZ026	2						
s07	Smithtown	NDZ049	4	$73,250	$8,139	$17,800	$16,635	$38,815	$4,313
s08		NVV060	5						
s09	Copiague	NDZ064	5	$52,000	$10,400	$10,917	$12,325	$28,758	$5,752
s10	Remsenburg	NVV060	5	$36,250	$7,250	$9,333	$8,075	$18,842	$3,768
s11	Coram	NSV018	1.5	$40,250	$6,192	$14,000	$7,875	$18,375	$2,827
s16		NDZ064	5						
s12	Northport	NVV060	5	$33,000	$6,600	$9,333	$7,100	$16,567	$3,313
s13	Syosset	NVV036	3	$80,000	$10,000	$15,300	$19,410	$45,290	$5,661
s14		NVV060	5						
s15	Manorville	NDZ038	3	$40,000	$13,333	$6,367	$10,090	$23,543	$7,848
s17	Hewlett	NDZ064	5						

Notes: PSE&G LI incentive is $2,000 per rated cooling ton (at 77°F). Tax credit applied to balance after incentive.

Table 4 continued

ID	Town	GSHP Unit Model	GSHP Unit Size (tons)	Installed Cost	Installed Cost per ton	PSE&G LI Incentive	Federal Tax Credit	Net Installed Costs	Net Installed Costs per ton
s18	East Hampton	NVV060	5	$36,725	$7,345	$9,333	$8,218	$19,174	$3,835
s19	Port Jefferson	NVV048	4	$66,000	$8,250	$15,000	$15,300	$35,700	$4,463
s20		NVV048	4						
s21	Seaford	NVV036	3	$42,000	$14,000	$5,967	$10,810	$25,223	$8,408
s22	Bellmore	NDZ064	5	$55,000	$11,000	$10,917	$13,225	$30,858	$6,172
s23	Manhasset	NVV048	3	$114,500	$16,357	$13,867	$30,190	$70,443	$10,063
s24		NDZ038	4						
s25	East Northport1	NVV060	5	$58,736	$11,747	$9,333	$14,821	$34,582	$6,916
s26	East Northport2	NDZ064	5	$58,786	$11,757	$10,917	$14,361	$33,509	$6,702
s28	Levittown	NDZ064	5	$52,920	$10,584	$10,917	$12,601	$29,402	$5,880
s29	Patchogue	NDZ064	5	$51,600	$10,320	$10,917	$12,205	$28,478	$5,696
s30	Remsensburg	NDZ064	5	$51,200	$10,240	$10,917	$12,085	$28,198	$5,640
s31	Port Jefferson	NVV060	5	$66,869	$13,374	$9,333	$17,261	$40,275	$8,055
s37	Syosset	NVV060	5						
s39	Bellport	NVH060	5	$48,900	$9,780	$9,333	$11,870	$27,697	$5,539
s40	Medford	NVV036	3	$30,300	$10,100	$5,967	$7,300	$17,033	$5,678

Notes: PSE&G LI incentive is $2,000 per rated cooling ton (at 77°F). Tax credit applied to balance after incentive.

3 Results: Energy Impacts and Cost Savings

This section describes the data collected for the monitoring and verification (M&V) effort and uses the collected data to analyze the performance of the GSHP systems.

3.1 Monitoring Approach

A “Performance Validation” Plan was written at the beginning of the project to arrive at a common understanding of what measured data would be collected from each site and how it would be used to quantify the savings and performance of each GSHP site (see appendix A).

The overall monitoring approach in this study was to use the measured data points collected by the Water Furnace Symphony™ system in the post-retrofit period. The detailed post retrofit measurements also provided the means to determine the heating and cooling loads so that fuel use can be estimated with the original (pre-retrofit) heating fuel. The team also intended to collect pre- and post-retrofit fuel bills to provide an additional confirmation of pre-retrofit fuel use, but this data was difficult to collect.

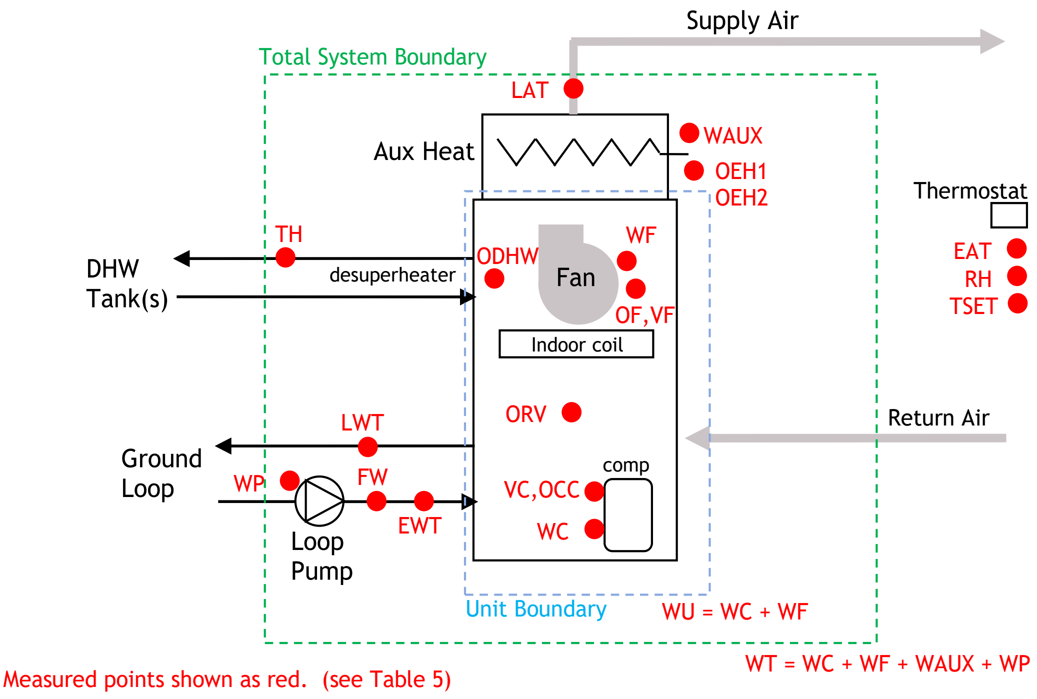
The Symphony™ monitoring points are schematically shown in Figure 2 and listed in Table 5. The data point names on schematic are identified as the “CDH Variable” name in the table. All GSHP systems had the full set of Symphony™ monitoring points collected, including the energy, refrigeration, and performance data point identified by the color-coding in Table 5. These sensor locations were confirmed during the on-site verification efforts in the original study of 49 upstate systems (NYSERDA Report 18-03).

Most of these points are direct measurements by temperature sensors, flow meters and refrigerant pressures. Refrigeration saturation temperatures, superheat temperatures, and subcooling temperatures are determined using the measured readings combined with refrigerant property calculations. Temperature sensors are 10k thermistors. Water flow is measured with a Grundfos vortex-shedding flow meter. Component statuses are used to determine the runtime of components and control settings. The power readings are inferred or determined by various means:

- Compressor current is directly measured and used to infer power (dual stage).
- The compressor inverter reports the power determined by its internal calculations (variable speed).

- Fan current is measured and used with user-entered site voltage to infer power. For variable speed fans, a correlation is used to relate current to power (to account for the changing power factor).
- Pump power is read directly from the pump's variable speed drive, or for constant speed pumps, it is inferred from the user-entered pump information and the pump activation command.
- The heat rejection/extraction is calculated from the flow and temperatures along with user-entered fluid characteristics (which are supposed to be entered by the installer at setup).

Figure 2. Schematic of Heat Pump System with Measured Data Points Shown as Circles



The Symphony™ monitoring system transmits instantaneous, 10-second data back to the server in near real time. It does not have a large on-board storage buffer, so if the internet connection resets or is lost for more than 6 minutes, some data records are lost. Water Furnace used the 10-second data collected by their server for each site to develop averaged or summed data at 15-minute intervals; they provided files of 15-minute data to our team. The team used the 15-minute interval data to analyze system performance. Most of the plots and tables in this section use either the 15-minute or daily data to understand performance.

The calculations below were used to calculate higher level quantities such as capacity and efficiency (also see Figure 2). The heating (QH) and cooling (QC) output for any period of interest can also be determined by:

Equation 1 $$\boldsymbol{QH = QWE + (WUH + WAUX) \cdot 3.412}$$

Equation 2 $$\boldsymbol{QC = QWR - WUC \cdot 3.412}$$

These variables are defined in Figure 2 and in Table 5.

Table 5. Data Points in the Symphony™ Monitoring System (also shown in Figure 2)

Symphony Name	Symphony Description	CDH Variable
id		
logtime	date time	
logtimeepoch		
activeinputsatlockout		
activeoutputsatlockout		
actualcompressorspeed	Act Comp Speed	VC
aircoiltemp	FP2	TCOIL
airflowcurrentspeed	Fan Speed	VF
airflowpwmdutycycle		
aocalarm		
aocambienttemp	AOC Ambient Temp	TAO1
aocderatingstatus		
aocdrivestatus		
aocenteringwatertemp	AOC EWT	EWT1
aocsafemodestatus		
aurorainputdh	DH	SDH
aurorainputes		
aurorainputg	G	SG
aurorainputh	H	SH
aurorainputhps		
aurorainputlps		
aurorainputls		
aurorainputo	O	SO
aurorainputw	W	SW
aurorainputy1	Y1	SY1
aurorainputy2	Y2	SY2
auroraoutputacc		
auroraoutputalm		
auroraoutputcc	CC	OCC
auroraoutputcc2	CC2	OCC2
auroraoutputeh1	EH1	OEH1
auroraoutputeh2	EH2	OEH2
auroraoutputf	Fan Relay	OF
auroraoutputl		
auroraoutputrv	RV	ORV
auxcurrent	Aux Current	
auxpower	Aux Power	WAUX
coaxtemp	Clg LL	TLQC
compressor1current	Comp1 Current	
compressor2current	Comp2 Current	
compressorpower	Comp Power	WC
condensertemp	Sat Cond	TSATC
currentecmspeed		
desiredcompressorspeed	Des Comp Speed	VC_SET
dhwsetpoint	HW Setpoint	TH_SET
digitaloutputk1		
digitaloutputk2		
digitaloutputk3		
digitaloutputk5		
digitaloutputk6	DHW Relay	ODHW
dischargepressure	Disch Press	PDIS
dischargetemp	Disch Temp	TDIS
eev1openingpct	EEV1 Open %	VEEV1
eev2openingpct	EEV2 Open %	VEEV2
enteringwatertemp	EWT	EWT
estimatedlinevoltage	Line Voltage	
evaporatortemp	Sat Evap	TSATE
fancurrent	Blower Current	
fanpower	Fan Power	WF
fp1inputreading	FP1	
fp2inputreading	FP2	
heatingliquidlinetemp	Htg LL	TLQH
heatofextrej	HE / HR (KBtuh)	QL
hotwatertemp	HW Temp	TH
htgclgsubcooling	Htg/Clg SC	T_SC
internalinputs		
lastfault		
leavingairtemp	LAT	LAT
leavingwatertemp	LWT	LWT
lockedout		
lockoutstatuscode		
lockoutstatuslast		
looppumppower	Pump Power	WP
looppumppressure	Loop Press	DPL
modeofoperation		
suctionlinetemp	Suct Temp	TSUC
suctionpressure	Suct Press	PSUC
superheat	SH	T_SH
totalamps		
totalunitpower	Total Power	WT
tstatactiveoutputs		
tstatactivesetpoint	Active Setpoint	TSET
tstatcoolingsetpoint		
tstatdehumidsetpoint	Dehumid Setpoint	DSET
tstatheatingsetpoint		
tstathumidsetpoint	Humid Setpoint	HSET
tstatmode		
tstatoutdoorairtemp	OAT	TAO
tstatrelativehumidity	Dehumid %	RH
tstatroomtemp	EAT	EAT
universalinput1		
variablespeedpumppwm	Loop Pump PWM	
vspumppwmoutput		
vspumpspeedpct	Loop Pump Speed	VP
waterflowrate	FLOW	FW

QH includes space heating as well as any heat provided to the hot water load by the desuperheater. The calculation for cooling output (QC) includes a slight error when the desuperheater operates, since approximately two thousand British Thermal Units per hour (2 MBtu/h) less heat is rejected to the loop. The impact of this was disregarded for the analysis in this report.

Unit efficiency is defined by the heating coefficient of performance (COP) and cooling energy efficiency ratio (EER) of the heat pump "unit" can be determined for the period of interest by:

Equation 3 $$\boldsymbol{COP_{htg}} = \frac{\boldsymbol{QH}}{\boldsymbol{WUH}}$$

Equation 4 $$\boldsymbol{EER_{clg}} = \frac{\boldsymbol{QC}}{\boldsymbol{WUC}}$$

The unit COP—which can be compared to manufacturers published specifications—would only be meaningful for periods when auxiliary heat is off. These equations result from first law of thermodynamics analysis, i.e. heat balance, on the heat pump unit. The COP is dimensionless, and EER has units of Btu/Wh. The calculations ignore the small amount of heat dissipated from the compressor shell as well as any control power (these items are generally small).

The heating COP can be determined for the total system by replacing WUH in the denominator with WTH. Similarly, for the total system cooling EER, WUC is replaced with WTC in the denominator. Note that in both cases, the values of QH and QC in the numerator are not changed, since the pump does not affect the unit heat balance. These variables are defined in Table 5.

3.2 Data Collection and Local Utility Costs

Table 6 summarizes the amount of data ultimately collected for each GSHP system. At four sites no data was ever collected since the Symphony™ system was never able to connect to the internet and send data to the Water Furnace server (shaded in the table). For other systems, some data was collected but not enough to have full 12-month period (shaded in the table). This data shortfall mostly happened due to a loss of internet conductivity and in one case because data collection started late in the monitoring period that ended in February 2022. At some of the early sites several years of data were collected. Ultimately, only 28 systems had sufficient data to use in the analysis.

Table 6. Amount of Data Collected for Each System

System ID	City	GSHP Unit Model	Data Collection Period
s01	Farmingdale	NDV026	Nov 2017 to Feb 2022
s02	Lynbrook	NDV026	Jan 2017 to Feb 2022
s03	Islip	NVV060	Aug 2018 to Feb 2022
s04	East Islip	NVV060	Aug 2018 to May 2019
s05	Setauket	NVV048	Oct 2017 to Feb 2022
s06		NDZ026	Oct 2017 to Feb 2022
s07	Smithtown	NDZ049	Sep 2017 to Jul 2019, Apr 2021 to Feb 2022
s08		NVV060	Jul 2018 to Feb 2022
s09	Copiague	NDZ064	Dec 2018 to Feb 2022
s10	Remsenburg	NVV060	Jan 2019 to Feb 2022 (w/ some missing months)
s11	Coram	NSV018	Feb 2019 to Sep 2019
s16		NDZ064	no data
s12	Northport	NVV060	Jan 2019 to Feb 2022
s13	Syosset	NVV036	Sep 2019 to Dec 2021
s14		NVV060	Sep 2019 to Feb 2022
s15	Manorville	NDZ038	Sep 2019 to Feb 2022
s17	Hewlett	NDZ064	Apr 2020 to Jan 2022
s18	East Hampton	NVV060	no data
s19	Port Jefferson	NVV048	Jan 2020 to Feb 2022
s20		NVV048	Jul 2020 to Feb 2022
s21	Seaford	NVV036	no data
s22	Bellmore	NDZ064	no data
s23	Manhasset	NVV048	Sep 2020 to Feb 2022
s24		NDZ038	Jan 2020 to Feb 2022 (no power data)
s25	East Northport1	NVV060	June 2021 to Feb 2022
s26	East Northport2	NDZ064	Sep 2020 to Feb 2022
s28	Levittown	NDZ064	Jan 2020 to Feb 2022
s29	Patchogue	NDZ064	Jan 2020 to Mar 2021, Oct 2021 to Feb 2022
s30	Remsensburg	NDZ064	Jan 2020 to Dec 2021
s31	Port Jefferson	NVV060	Oct 2020 to Feb 2022
s37	Syosset	NVV060	Jan 2020 to Feb 2022
s39	Bellport	NVH060	Jan 2020 to Apr 2020, Jul/Aug 2020, and Apr 2021 to Sep 2021
s40	Medford	NVV036	Mar 2021 thru Feb 2022

Local utility costs are shown in Table 7. These costs are from NYSERDA's Energy Analysis group and were used for the cold climate air source heat pump (ccASHP) Proforma Tool (circa 2020) that is used to calculate cost savings. These costs were also used for the studies of ccASHPs in Brooklyn Queens (NYSERDA Report 22-04) and the Hudson Valley (NYSERDA Report 22-08). These costs were consistent with the anecdotal cost information the team received from some of the customers in each region. A sensitivity analysis of higher (and lower) costs is also completed to reflect more recent changes in fuel and electric costs.

Table 7. Utility Fuel Costs

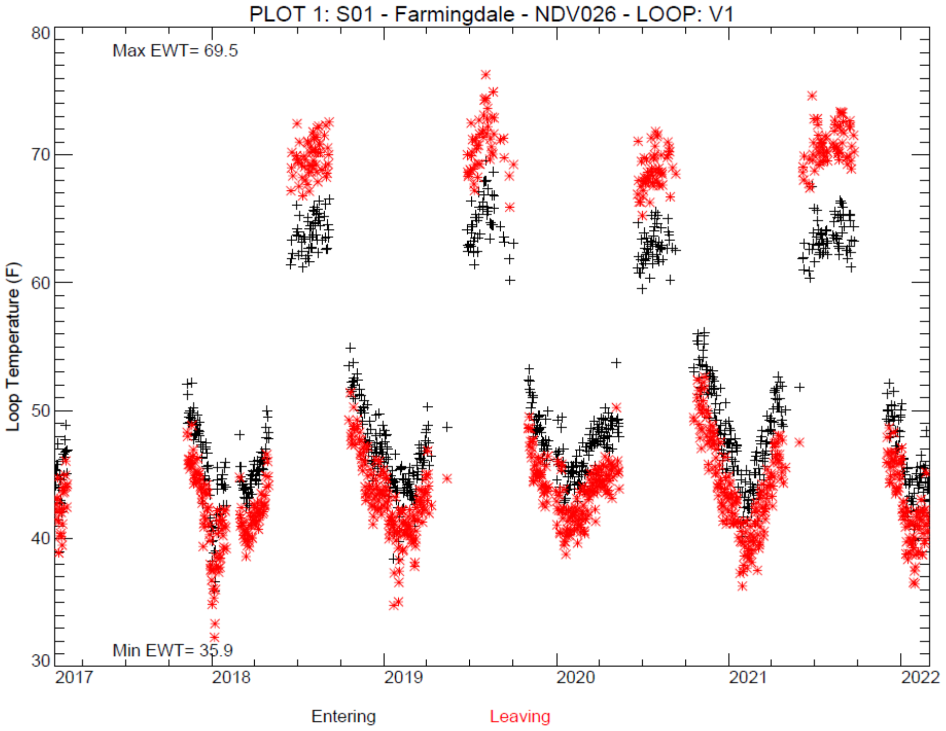
Utility Region	Electric Cost ($.kWh)	Natural Gas Cost ($/therm)	Fuel Oil Cost ($/gal)
Long Island/National Grid/PSE&G	0.2019	1.385	3.2300

3.3 Ground Loop Temperatures

The key factor driving efficiency of a geothermal heat pump is the entering water temperature (EWT) to the unit and from the ground loop. The heat pump pulls water from the ground loop heat exchanger and sends back colder water in the winter (heating mode) and returns warmer water in the summer (cooling mode). The two factors that affect EWT are loop size and ground temperature. The two plots in Figure 3 show the temperature profile across several years for systems S1 and S5 (plots like this are available in appendix C for other systems). In each plot the daily average, weighted EWT is shown as a black plus sign ('+') and the daily average leaving temperature is shown as an asterisk ('*'). The minimum and maximum EWTs (based on daily data) are also listed on each plot. System S1 had loop temperatures typical of all the systems—the average entering temperature for the heating season was 45.1°F and the cooling seasonal average was 64.2°F. The plot shows that the temperatures at S1 remained stable over multiple years. System S5 had colder entering temperatures in the winter (average 35.5°F) and warmer temperatures in the summer (average 68.2°F). The temperature difference between entering and leaving temperatures were typically about 10°F in the summer and approximately -5°F in the winter.

Table 8 lists the loop temperatures observed for each system. For each system, the minimum temperature is the average of the four lowest values in the 15-minute data set. The maximum temperature is the average of the four highest readings in the 15-minute data set. The average temperatures corresponding to heating and cooling are the weighted average using the compressor power.

Figure 3. Daily Loop Temperatures for S01 and S05



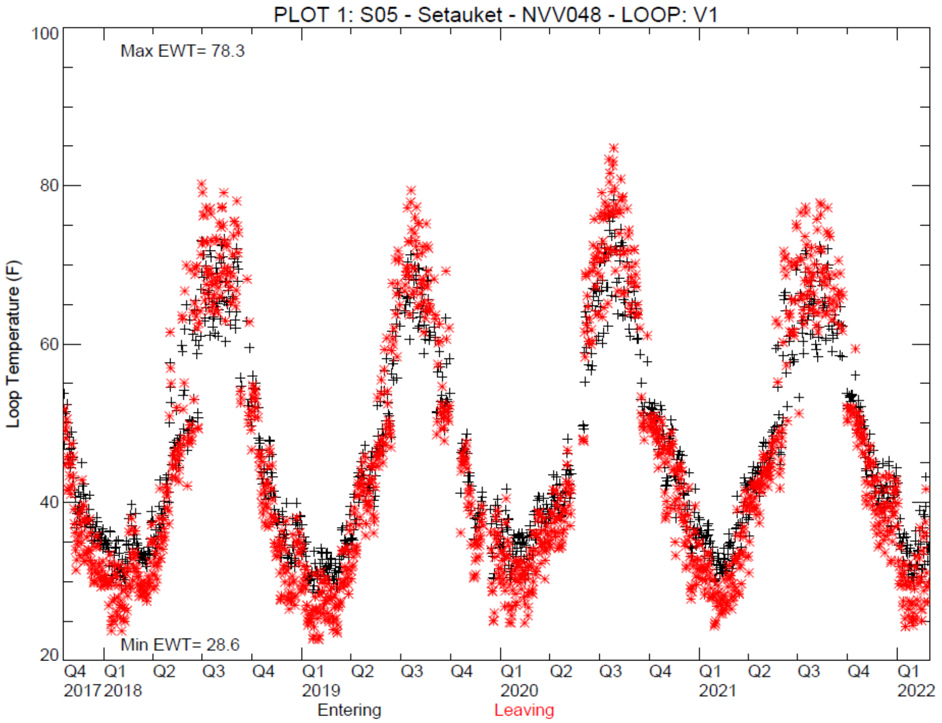


Table 8. Loop Entering Water Temperatures (°F) for Each System

System ID	Town	Minimum EWT	Average EWT Heating	Average EWT Cooling	Maximum EWT
s01	Farmingdale	34.9	45.1	64.2	73.7
s02	Lynbrook	35.6	43.5	75.8	86.8
s03	Islip	32.6	42	70.3	118*
s04	East Islip	37.9	44.8	63.9	71.7
s05	Setauket	28.2	35.5	68.2	83.3
s06	Setauket	28.2	36.1	65.3	83.3
s07	Smithtown	33.2	40.3	58.5	68.2
s08	Smithtown	32.7	41.2	59.2	75.3
s09	Copiague	34.2	46.1	73.5	96.6
s10	Remsenburg	29.4	37.3	69.6	80.4
s11	Coram	35.5	42.4	62.2	73.9
s16	Coram				
s12	Northport	35.3	43.5	60.8	70.3
s13	Syosset	31.6	41.5	68.9	82.8
s14	Syosset	32.1	41	69.6	83
s15	Manorville	27.4	36.9	69.4	80.7
s17	Hewlett	38.9	47.5	69.7	83.1
s18	East Hampton				
s19	Port Jefferson	37.9	44.2	62.6	72.6
s20	Port Jefferson	37.6	43.9	61.8	79.3
s21	Seaford				
s22	Bellmore				
s23	Manhasset	42.4	50	72.2	87.7
s24	Manhasset				
s25	East Northport1	45.1	54.6	69	76
s26	East Northport2	34.6	43.8	71.9	89.9
s28	Levittown	39.1	48.7	73.4	85.6
s29	Patchogue	29.9	38.6	66.5	79.6
s30	Remsensburg	31.0	41	69.8	85.9
s31	Port Jefferson	28.4	35.5	67.3	78.8
s37	Syosset	41.0	46.6	63.7	71.3
s39	Bellport	34.2	41.6	79.1	94.5
s40	Medford	36.6	43.1	63.4	74
	AVERAGE	34.5	42.7	67.5	81.7
	MEDIAN	34.4	42.8	68.6	80.6
	MINIMUM	27.4	35.5	58.5	68.2
	MAXIMUM	45.1	54.6	79.1	96.6

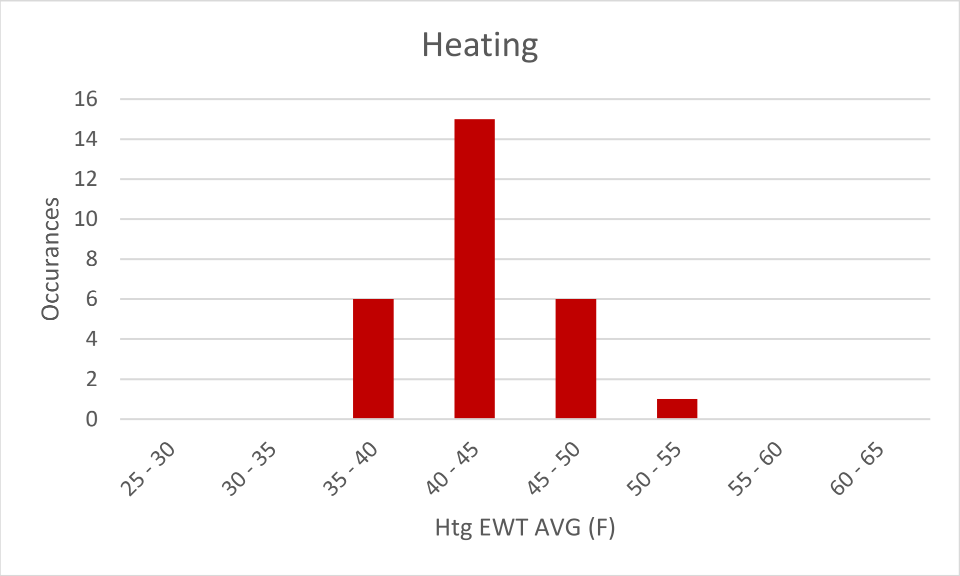
At six homes, two heat pumps were installed on the same ground loop, yet the average EWTs for each unit shown in Table 8 were different. S05 and S06 are an example where the average temperatures were different by 3°F in cooling because the two units ran at different times and had different loading patterns (e.g., because one unit serves an upstairs zone that required more cooling than the downstairs unit).

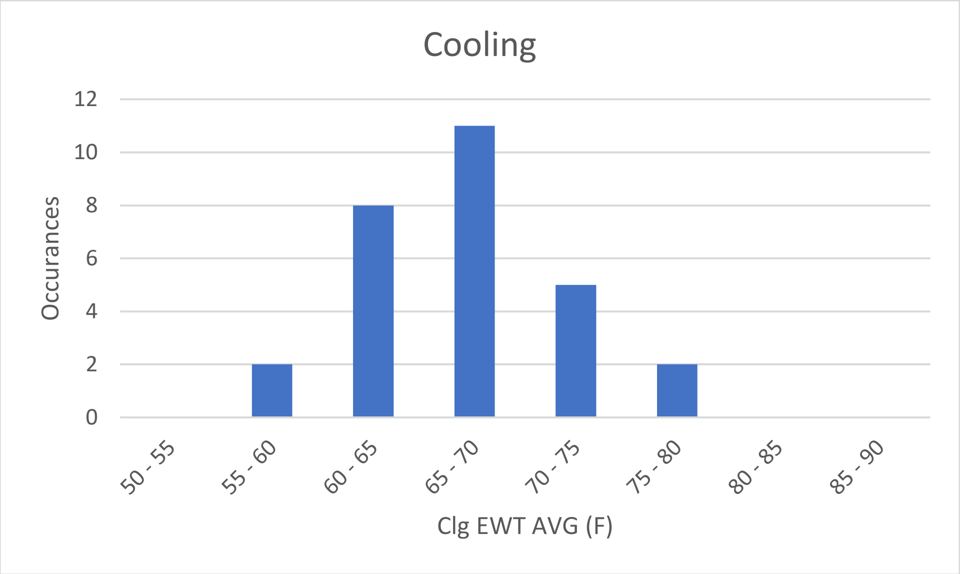
The bottom of the table shows the overall seasonal average EWTs across all the systems. The average of all heating seasonal average temperatures was 42.7°F, compared to 40.2°F for the previous study of upstate sites (NYSERDA Report 18-03). The minimum EWTs for the systems ranged from 27.4°F to 45.1°F with an average of 34.5°F. The measured minimums EWTs are consistent with the design condition of 30°F used by the installer to size the ground loops.

The average of the seasonal average entering temperature in the cooling mode was 67.5°F, just a bit warmer than the average of 65.8°F for the 49 upstate sites. The maximum EWTs across the systems ranged from 68.2°F to 96.6°F with an average for all systems of 81.7°F. Note that the 118°F maximum at S3 was caused by a temporary heat pump/loop pump malfunction in September 2019. Therefore, the next highest maximum of 96.6°F at S9 is used at the bottom of the table). The observed maximums were less than the 90°F design condition used by the installer for sizing the loops at all but two of the sites (S09 and S39). This confirms that the ground loops were sized primarily to meet the heating requirements.

Figure 4 shows the overall distribution of seasonal average entering water temperatures from all the systems in the heating mode (top plot) and the cooling mode (bottom plot). The distributions are centered around the overall average for the 28 systems where loop temperature data was available.

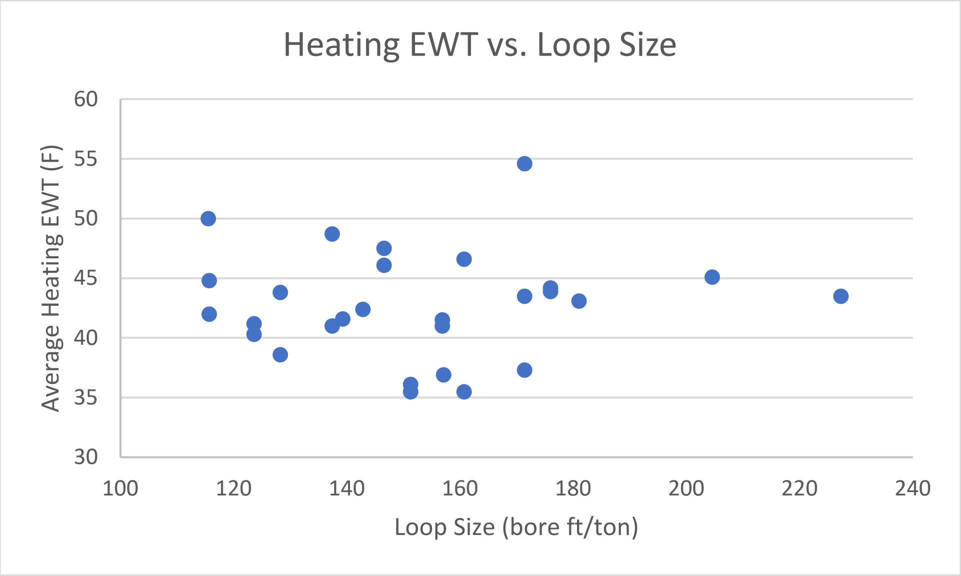
Figure 4. Distribution of Seasonal Average EWT from All Sites for both Heating (top plot) and Cooling (bottom plot)

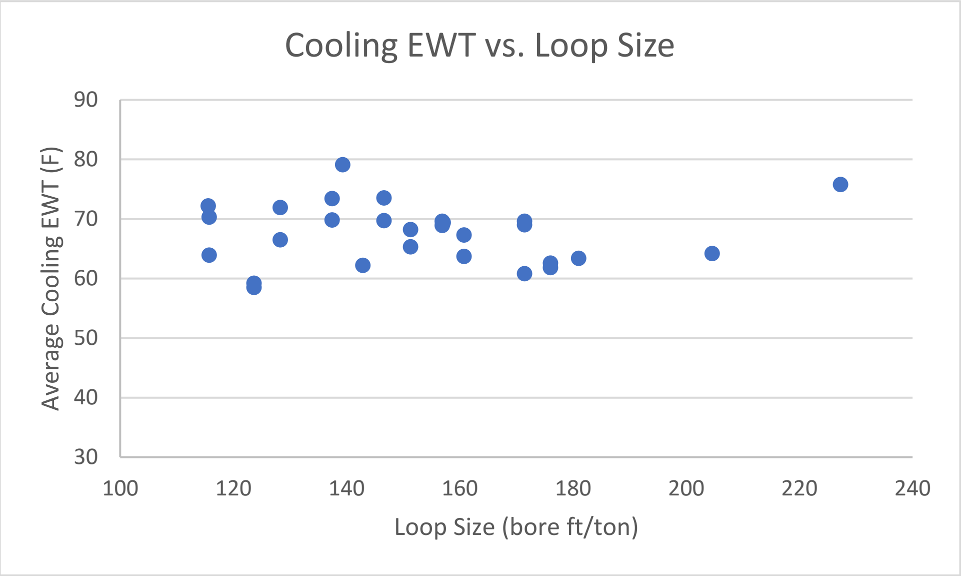




The plots in Figure 5 compare the average seasonal loop temperatures to the normalized loop size (linear feet of bore per ton of cooling capacity). The normalized loop sizing comes from Table 2. The result shows the seasonal average entering water temperatures at each site do not systematically vary with normalized loop sizing. This implies that the designer (properly) took into account the expected heating and cooling loads at each site and increased (and decreased) the normalized loop sizing to meet the needs at each home. For the home with the largest normalized loop length, the seasonal average heating EWT is near the average, but the seasonal average cooling EWT is higher than the other sites; this probably due to unexpected variations in the occupant's use of the heat pump in their homes (different cooling set points, occupancy patterns, etc.).

Figure 5. Relationship Between Average Seasonal Entering Water Temperatures and Loop Sizing for Heating (top) and Cooling (bottom)





3.4 Energy Use and Component Runtimes

The annual energy use in kilowatt-hours (kWh) of the GSHP system and its components are summarized for each system in Table 9. Each system used a different 12-month period for the annual values. Four of the systems did not have data for a complete 12-month period and are therefore labeled as “Partial” in the table.

The compressor uses most of the energy, but the fan and pump also have a significant impact. The power reading for the compressor is determined from current and voltage measurements, while fan power is determined from current readings and user-entered voltage. Pump power is determined from a lookup for constant speed pumps based on contractor-entered information. In many cases the pump power reported in the table was zero, probably indicating that pumping information was not entered properly. A section below corrects for the missing pump energy in the determination of seasonal efficiency.

Some of the sites used a small amount of auxiliary heat with the onboard resistance heating (RHT) elements. Only one system (S31) used a significant amount of resistance heating (over 1000 kWh for 150 hours). Even in this case the resistance heat was less than 10% of the total annual energy use. This auxiliary heater use seems mostly linked to how the homeowners controlled the heat pump (e.g., behaviors such as using excessive thermostat setbacks). However, this system also happened to have colder ground loop temperatures, as shown in Table 8. The portion of total annual electricity use attributable to heating is also given in Table 9.

Table 10 shows the corresponding operating hours for each system component. Note that the dual stage units (ND series) show a compressor runtime for the first and second state separately, while the variable speed units (NV series) only have compressor runtime in the Stage 1 column. The variable speed units typically had much longer runtimes. The RHT heating runtime increases from stage 1 to stage 2 as the resistance elements stay on for a longer period.

Table 9. Energy Use Breakdown of System Energy Use on an Annual Basis

System ID	City	Annual Period	Valid Data	Comp (kWh)	Fan (kWh)	Pump (kWh)	RHT (kWh)	Total (kWh)	Heating Portion (%)
s01	Farmingdale	2020	100%	880	57	254	104	1,292	93%
s02	Lynbrook	2018	98%	2,200	458	677	30	3,363	72%
s03	Islip	2020	94%	3,832	541	-	4	4,362	54%
s04	East Islip	Partial	95%	2,911	289	284	-	3,450	86%
s05	Setauket	2020	93%	5,263	434	972	21	6,684	90%
s06	Setauket	2020	99%	2,245	448	695	3	3,390	75%
s07	Smithtown	Partial	96%	2,516	241	90	-	2,790	85%
s08	Smithtown	2020	98%	3,092	312	-	3	3,407	87%
s09	Copiague	2020	100%	2,656	544	446	0	3,635	29%
s10	Remsenburg	2020	96%	5,461	815	1,107	1	7,384	84%
s11	Coram	Partial	83%	1,764	464	-	2	2,227	60%
s16	Coram								
s12	Northport	2020	99%	1,774	450	111	17	2,343	77%
s13	Syosset	2020	94%	4,059	739	-	182	4,974	82%
s14	Syosset	2020	99%	5,355	693	-	62	6,111	81%
s15	Manorville	2020	98%	2,221	276	-	8	2,509	80%
s17	Hewlett	2020	91%	2,392	556	-	6	2,954	87%
s18	East Hampton								
s19	Port Jefferson	2021	94%	2,790	1,120	-	-	3,910	84%
s20	Port Jefferson	2021	94%	2,813	613	-	-	3,426	79%
s21	Seaford								
s22	Bellmore								
s23	Manhasset	2020	100%	2,162	319	-	-	2,481	59%
s24	Manhasset								
s25	East Northport1	Partial	75%	1,319	606	-	-	1,925	7%
s26	East Northport2	2021	95%	6,565	890	215	1	7,671	56%
s28	Levittown	2020	99%	4,186	796	913	6	5,901	63%
s29	Patchogue	2020	99%	6,465	990	424	58	7,938	88%
s30	Remsensburg	2021	95%	2,985	858	190	101	4,134	76%
s31	Port Jefferson	2021	94%	7,809	2,003	-	1,039	10,851	89%
s37	Syosset	2020	99%	3,516	196	1,962	-	5,674	79%
s39	Bellport	2020	43%	3,141	122	1,464	-	4,726	65%
s40	Medford	2021	94%	3,323	331	122	33	3,809	84%

Table 10. Operating Hours Breakdown for System Components on an Annual Basis

System ID	City	GSHP Unit Model	Comp Stage 1 (hrs)	Comp Stage 2 (hrs)	Fan (hrs)	DHW Pump (hrs)	RHT Stg 1 (hrs)	RHT Stg 2 (hrs)
s01	Farmingdale	NDV026	1,072.8	156.8	1,138.3	1,050.3	21.9	15.7
s02	Lynbrook	NDV026	2,868.2	656.5	2,898.5	-	20.5	18.7
s03	Islip	NVV060	3,787.6	-	3,843.8	3,645.1	0.7	0.3
s04	East Islip	NVV060	3,939.8	-	4,043.7	3,468.5	-	-
s05	Setauket	NVV048	5,019.9	-	5,063.1	4,862.5	2.9	2.2
s06	Setauket	NDZ026	2,965.6	156.6	3,010.9	2,965.1	0.7	0.4
s07	Smithtown	NDZ049	1,417.2	4.9	2,469.9	160.4	35.7	33.9
s08	Smithtown	NVV060	3,690.7	-	3,838.0	3,697.0	0.4	0.3
s09	Copiague	NDZ064	1,251.0	28.2	1,269.5	1,082.9	0.0	-
s10	Remsenburg	NVV060	4,680.5	-	6,844.6	4,282.7	0.3	0.1
s11	Coram	NSV018	1,040.5	191.4	1,061.3	1,019.6	0.5	0.3
s16	Coram	NDZ064						
s12	Northport	NVV060	2,257.0	-	2,296.5	2,140.2	2.7	1.6
s13	Syosset	NVV036	4,010.4	-	4,361.2	-	23.3	22.9
s14	Syosset	NVV060	3,993.7	-	4,044.4	3,990.1	8.1	6.4
s15	Manorville	NDZ038	2,323.6	355.8	2,455.5	2,299.5	1.6	1.0
s17	Hewlett	NDZ064	1,394.4	116.6	1,434.1	866.9	1.5	0.4
s18	East Hampton	NVV060						
s19	Port Jefferson	NVV048	2,629.4	-	6,041.7	2,577.5	40.2	33.3
s20	Port Jefferson	NVV048	3,306.2	-	5,679.3	3,291.8	13.7	11.4
s21	Seaford	NVV036						
s22	Bellmore	NDZ064						
s23	Manhasset	NVV048	2,573.9	-	2,987.7	2,462.0	3.8	1.2
s24	Manhasset	NDZ038	1,188.7	59.3	1,359.6	-	4.7	1.7
s25	East Northport1	NVV060	686.0	-	938.8	690.3	-	-
s26	East Northport2	NDZ064	2,880.5	271.5	3,006.3	2,853.9	0.1	-
s28	Levittown	NDZ064	1,919.8	366.0	1,979.5	1,919.9	0.8	0.6
s29	Patchogue	NDZ064	2,893.7	368.3	3,006.3	-	12.8	2.4
s30	Remsensburg	NDZ064	1,281.7	139.2	1,598.4	-	12.0	10.4
s31	Port Jefferson	NVV060	4,476.5	-	5,218.9	3,656.8	150.2	99.2
s37	Syosset	NVV060	4,884.8	-	4,925.5	3,863.5	0.6	0.4
s39	Bellport	NVH060	3,093.7	-	3,116.6	3,093.9	-	-
s40	Medford	NVV036	4,701.8	-	6,542.6	3,227.1	4.9	4.1

Note: Variable speed units (NV series) show all compressor runtime in the Stage 1 column.

3.5 Heating and Cooling Efficiencies

This subsection seeks to correct the heating and cooling efficiencies related to two issues with the measured data:

- Some systems had missing or erroneous pumping power.
- Differences between the measured steady-state efficiency and the manufacturer's published performance data.

Each of these issues is addressed below.

3.5.1 Correcting for Missing Pumping Power

Several of the systems in Table 9 showed no pumping energy use, most likely due to the fact that the required pumping information was not properly entered into the Symphony™ system when the system was installed. Other systems showed pumping energy that exceeded 30% of the total energy—well beyond what is conceivable. From the previous study (NYSERDA Report 18-03) we expect the pumping power to be different between dual stage units (models beginning with "ND") and variable speed units (models beginning with "NV"). Therefore, we used the measured ratios of pump-to-total energy use over the year from the valid sites (nine systems for dual stage and five systems for variable speed). For the valid systems, we excluded systems with no pumping power as well as systems where the pumping energy exceeded 30% of the total annual energy. The resulting pump-to-total ratios Table 11 are 11.6% for dual stage and 9.1% for variable speed, which were consistent with previous study. The analysis used these factors to correct the pumping energy for the systems with invalid or missing pumping power.

Table 11. Average Pump-to-Total Energy Ratios for Dual Stage and Variable Speed

	Range of Pump-to-total ratios	Average of Pump-to-total ratios
Dual Stage "ND" (9 systems)	0.03 to 0.20	0.1156
Variable Speed "NV" (5 systems)	0.03 to 0.15	0.0914

Table 12 shows the process of correcting the pumping energy use for the systems where it was originally invalid or missing. The first columns in the table show the measured data for the total unit and pumping from Table 9. The average pump-to-total ratios (pr) from Table 11 are applied to the dual stage and variable speed units in the next columns. The NEW columns (shaded as gray) are calculated using the ratio (pr) [i.e., NEW pumping = Total x pr / (1-pr)]. Then the NEW total using the change in the NEW pumping power. The heating portion of the energy use from Table 9 is finally used to determine the NEW pumping energy use in the heating season.

Table 12. Determining the Corrected Pumping Power

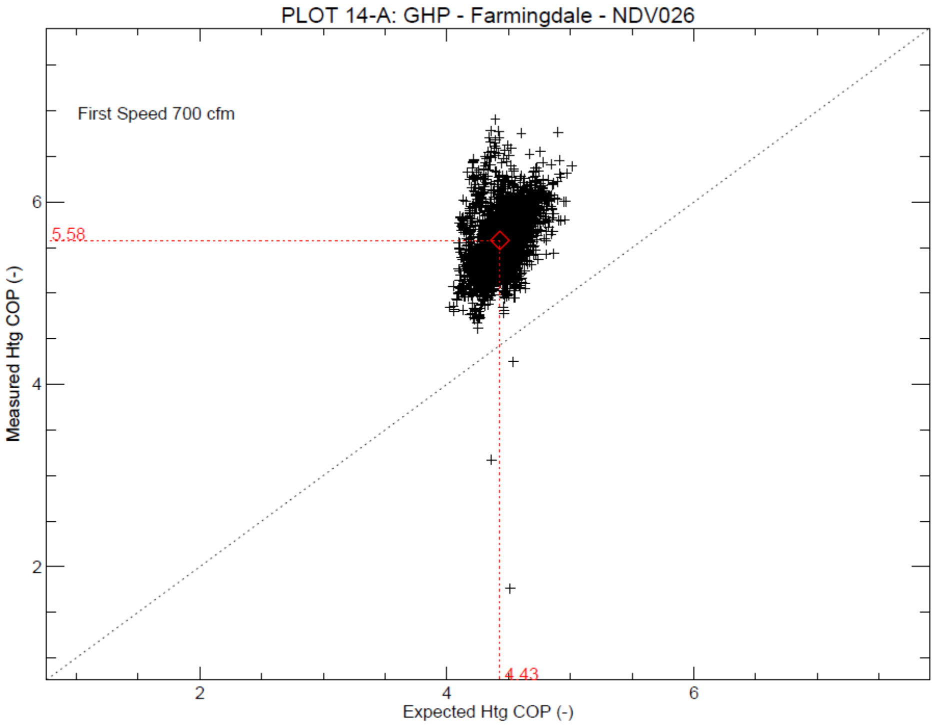
ID	City	GSHP Unit Model	Total (kWh)	Pump (kWh)	NEW Pump-to-total Ratio	NEW Total (kWh)	NEW Pump (kWh)	NEW Htg Pump (kWh)
s01	Farmingdale	NDV026	1,291.9	254.4	0	1,291.9	254.4	237.2
s02	Lynbrook	NDV026	3,363.1	677.0	0	3,363.1	677.0	487.6
s03	Islip	NVV060	4,362.4	-	0.0914	4,801.0	438.6	236.2
s04	East Islip	NVV060	3,450.0	284.1	0	3,450.0	284.1	243.5
s05	Setauket	NVV048	6,684.3	972.2	0	6,684.3	972.2	878.5
s06	Setauket	NDZ026	3,390.5	694.8	0	3,390.5	694.8	522.7
s07	Smithtown	NDZ049	2,790.2	90.4	0	2,790.2	90.4	76.6
s08	Smithtown	NVV060	3,406.5	-	0.0914	3,749.0	342.5	298.8
s09	Copiague	NDZ064	3,635.2	446.0	0	3,635.2	446.0	131.2
s10	Remsenburg	NVV060	7,383.9	1,106.6	0	7,383.9	1,106.6	932.2
s11	Coram	NSV018	2,227.4	-	0.1156	2,518.5	291.1	174.8
s16	Coram	NDZ064	-	-	0	-	-	-
s12	Northport	NVV060	2,342.9	110.5	0	2,342.9	110.5	85.2
s13	Syosset	NVV036	4,973.6	-	0.0914	5,473.7	500.0	412.0
s14	Syosset	NVV060	6,110.5	-	0.0914	6,724.9	614.3	496.7
s15	Manorville	NDZ038	2,509.2	-	0.1156	2,837.2	328.0	261.5
s17	Hewlett	NDZ064	2,954.3	-	0.1156	3,340.5	386.2	335.9
s18	East Hampton	NVV060	-	-	0	-	-	-
s19	Port Jefferson	NVV048	3,909.5	-	0.0914	4,302.6	393.1	330.0
s20	Port Jefferson	NVV048	3,426.3	-	0.0914	3,770.7	344.5	270.8
s21	Seaford	NVV036	-	-	0	-	-	-
s22	Bellmore	NDZ064	-	-	0	-	-	-
s23	Manhasset	NVV048	2,480.8	-	0.0914	2,730.3	249.4	148.1
s24	Manhasset	NDZ038	-	-	0.1156	-	-	-
s25	East Northport1	NVV060	1,925.0	-	0.0914	2,118.5	193.5	13.7
s26	East Northport2	NDZ064	7,671.1	214.8	0	7,671.1	214.8	120.4
s28	Levittown	NDZ064	5,901.0	913.0	0	5,901.0	913.0	576.9
s29	Patchogue	NDZ064	7,937.7	424.3	0	7,937.7	424.3	373.1
s30	Remsensburg	NDZ064	4,134.1	190.1	0	4,134.1	190.1	145.2
s31	Port Jefferson	NVV060	10,850.7	-	0.0914	11,941.6	1,090.9	967.6
s37	Syosset	NVV060	5,673.6	1,961.8	0.0914	4,282.2	570.4	448.7
s39	Bellport	NVH060	4,726.3	1,463.5	0.0914	3,738.0	475.2	308.8
s40	Medford	NVV036	3,809.1	121.7	0	3,809.1	121.7	102.7

3.5.2 Correcting for Differences Between Measured and Expected Efficiencies

One means to assess the inaccuracies and systematic biases in the measured data from Symphony™ is to compare the measured unit COP and EER to the expected performance from the Water Furnace performance data tables (see appendix D). Using the measured EWT with the manufacturer's data tables, the process determined the expected COP for each 15-minute interval and compared that to the measured COP. The expected COP and EER for the unit in these tables both assume a minimal amount of fan power (slightly greater than the fan power required to provide zero static as per standard AHRI/ISO 13256-1). However, the actual measured fan power is most likely larger than the value assumed in the Water Furnace data tables, so the measured COP should be somewhat lower than the expected value.

Figure 6 compares the measured and expected unit heating COPs at low- and high-speed operation for this dual stage unit. The data are shown for each 15-minute interval when the compressor has operated at that stage for the entire interval, or at approximately steady state conditions. For Unit S1 at the first stage, the average measured COP is 5.58 while the expected COP (determined using the EWT in each interval) was 4.43. The ratio of measured-to-expected COP is 1.26 in this case. Similarly, at high stage operation, the average measured COP is 5.22 and the averaged expected COP is 4.37, resulting in a measured-to-expected ratio of 1.19. Plots like this are provided for each GSHP system in appendix C.

Figure 6. Comparing Measured Heating Unit COP to Expected COP for S1 for Low Stage (top) and High Stage (bottom)



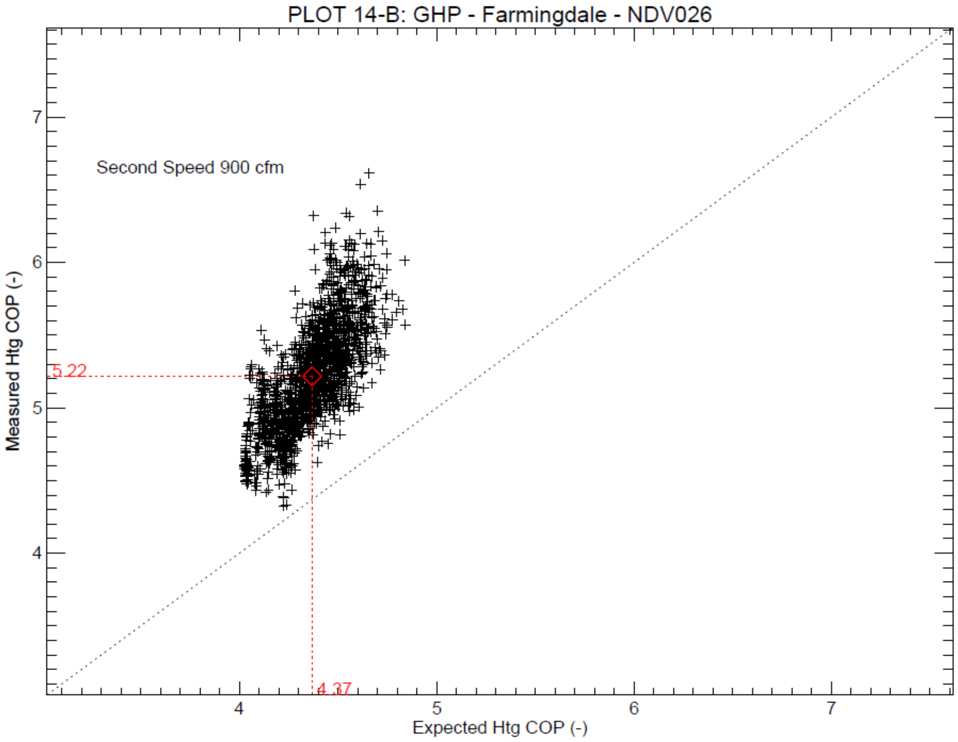


Figure 7 compares the measured-to-expected (M-to-E) ratios for heating COP at steady state conditions for all the sites. The values are also listed in Table 13. For dual stage systems, the plot shows the M-to-E ratio for low-speed operation. For variable speed units, the M-to-E ratio is at 50% compressor speed. The ratios vary widely from 0.5 to 2, indicating that measured heating COP can be 50% lower than the expected values, or as high as 2 times the expected values. The error is somewhat proportional to the COP value itself, which makes sense: the unrealistically high measured COPs of 8 strongly implies that the measured data are incorrect. Similarly, the more realistic COPs around 3.5 to 4 have a measured-to-expected ratio near unity. The average M-to-E ratios for heating are near 1.2.

Therefore, as a correction to the measured unit COPs for each site, we use the measured-to-expected ratio determined from steady state conditions to correct all the data over the season for that site. The resulting correction is:

$$\text{Corrected Unit COP} = \frac{\text{Measured Unit COP}}{\text{measured-to-expected heating ratio}}$$

Figure 7. The Measured-to-Expected (M-to-E) Ratio for Each System Compared to Total Heating COP

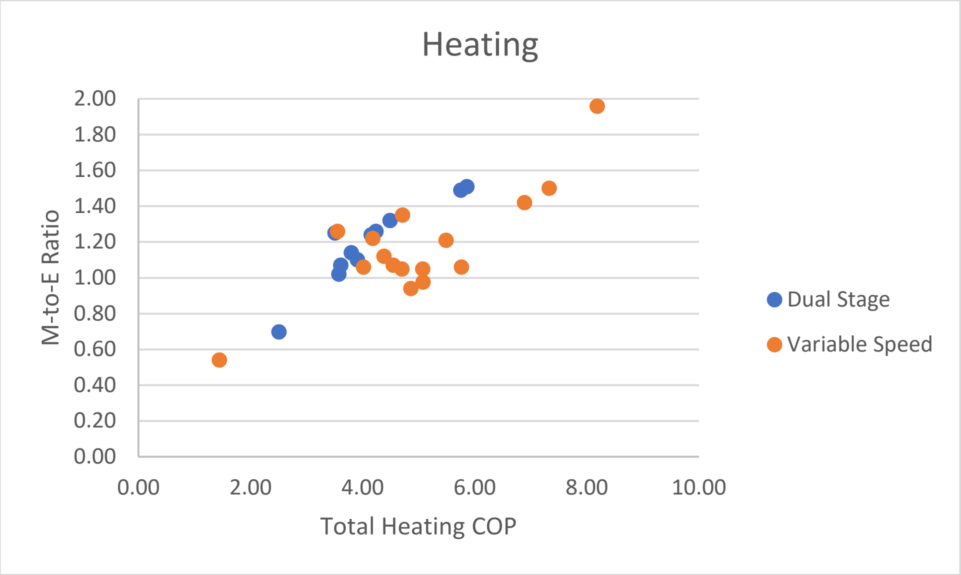


Table 13 uses these M-to-E ratios to correct the heating COPs. First the pumping adjustments from the previous section are applied to the heating COPs. Then the M-to-E ratios are used to correct the pump-adjusted COPs.

Table 13. Determining Corrected Values for Heating COPs

			Original Data			Pump-Adj			Corrected	
ID	**City**	**GSHP Model**	**Heating Load (MBtu)**	**RHT (kWh)**	**Total COP**	**Total COP**	**Unit COP**	**M-to-E ratio**	**Unit COP**	**Total COP**
s01	Farmingdale	NDV026	17,411	103.7	4.24	4.24	5.79	1.26	4.60	3.38
s02	Lynbrook	NDV026	37,075	30.1	4.49	4.49	5.69	1.32	4.31	3.40
s03	Islip	NVV060	55,225	4.1	6.89	6.26	6.90	1.42	4.86	4.41
s04	East Islip	NVV060	73,902	0.0	7.32	7.32	7.98	1.50	5.32	4.88
s05	Setauket	NVV048	82,675	21.0	4.01	4.01	4.71	1.06	4.44	3.78
s06	Setauket	NDZ026	21,790	3.1	2.50	2.50	3.15	0.70	4.52	3.59
s07	Smithtown	NDZ049	28,839	0.0	3.58	3.58	3.70	1.02	3.62	3.51
s08	Smithtown	NVV060	55,659	2.6	5.49	4.99	5.49	1.21	4.54	4.12
s09	Copiague	NDZ064	12,794	0.1	3.51	3.51	4.00	1.25	3.20	2.81
s10	Remsenburg	NVV060	100,039	1.2	4.71	4.71	5.55	1.35	4.11	3.49
s11	Coram	NSV018	20,858	2.3	4.57	4.04	4.58	0.00		
s16	Coram	NDZ064	-							
s12	Northport	NVV060	28,970	16.7	4.70	4.70	4.97	1.05	4.74	4.48
s13	Syosset	NVV036	61,234	181.6	4.38	3.98	4.54	1.12	4.05	3.56
s14	Syosset	NVV060	76,664	61.8	4.55	4.13	4.59	1.07	4.29	3.86
s15	Manorville	NDZ038	39,975	8.4	5.86	5.18	5.88	1.51	3.89	3.43
s17	Hewlett	NDZ064	50,404	5.9	5.75	5.08	5.76	1.49	3.87	3.41
s18	East Hampton	NVV060	-							
s19	Port Jefferson	NVV048	56,802	0.0	5.07	4.61	5.07	1.05	4.83	4.39
s20	Port Jefferson	NVV048	44,680	0.0	4.86	4.42	4.86	0.94	5.17	4.70
s21	Seaford	NVV036	-							
s22	Bellmore	NDZ064	-							
s23	Manhasset	NVV048	25,515	0.0	5.08	4.61	5.08	0.98	5.20	4.73
s24	Manhasset	NDZ038	6,505							
s25	East Northport1	NVV060	2,678	0.0	5.76	5.24	5.76	1.06	5.44	4.94
s26	East Northport2	NDZ064	57,268	0.7	3.90	3.90	4.02	1.10	3.65	3.55
s28	Levittown	NDZ064	48,289	5.7	3.80	3.80	4.50	1.14	3.94	3.33
s29	Patchogue	NDZ064	98,908	58.0	4.15	4.15	4.42	1.24	3.56	3.35
s30	Remsensburg	NDZ064	38,887	100.8	3.61	3.61	3.88	1.07	3.63	3.38
s31	Port Jefferson	NVV060	137,341	1039.1	4.18	3.80	4.57	1.22	3.74	3.13
s37	Syosset	NVV060	21,950	0.0	1.44	1.91	2.20	0.54	4.07	3.53
s39	Bellport	NVH060	37,200	0.0	3.55	4.49	5.14	1.26	4.08	3.56
s40	Medford	NVV036	89,805	33.4	8.18	8.18	8.53	1.96	4.35	4.18
	AVG				4.65	4.48	5.05	1.18	4.30	3.81
	MEDIAN				4.52	4.33	4.92	1.14	4.29	3.56

The process includes first determining the unit heating COPs and then applying the M-to-E factors. The conversion between unit and total COPs (in both directions) uses both the pumping and the resistance heating (RHT) energy use. The total heating COP is determined by assuming the heating load is adjusted and total power remains the same (in other words, we assume the total kWh is correct and the heat load changes).

The average total heating COP for all the systems was 4.65 before any corrections. The pumping corrections from section 3.5.1 reduced the average to 4.48. Further adding in the correction for the M-to-E ratio from section 3.5.2 reduces the fleet-average total heating COP to 3.81. Overall, these corrections are consistent with what we observed in the previous study in Upstate New York (NYSERDA report 18-03).

We repeated this process for cooling and the resulting M-to-E ratios are shown in Figure 8. In this case the average M-to-E ratio was 0.9 for all systems. The average was 0.81 for variable speed systems at 50% and the average was 1.03 for dual stage units at low speed. As for heating, the ratios are lower for the unexpectedly low EERs and higher for higher EERs. The measured-to-expected cooling ratio is most likely less than one because the measured performance corresponds to the actual entering air wet bulb conditions. Actual wet bulb values are consistently lower than the nominal wet bulb value of 67°F, which is the basis for the manufacturer's published data. The lower entering wet bulb for the systems at least in part contributes to the lower measured cooling efficiencies. The other factor that may have lowered the measured cooling EERs for variable speed systems is unit operation in the dehumidification mode. High-speed compressor operation with low-speed fan operation during high humidity periods lowers the actual cooling efficiency compared to published performance. Some of the systems with lower cooling EERs (such as S19) apparently chose to operate in the dehumidification mode more often.

Figure 8. The Measured-to-Expected (M-to-E) Ratio for Each System Compared to Total Cooling EER

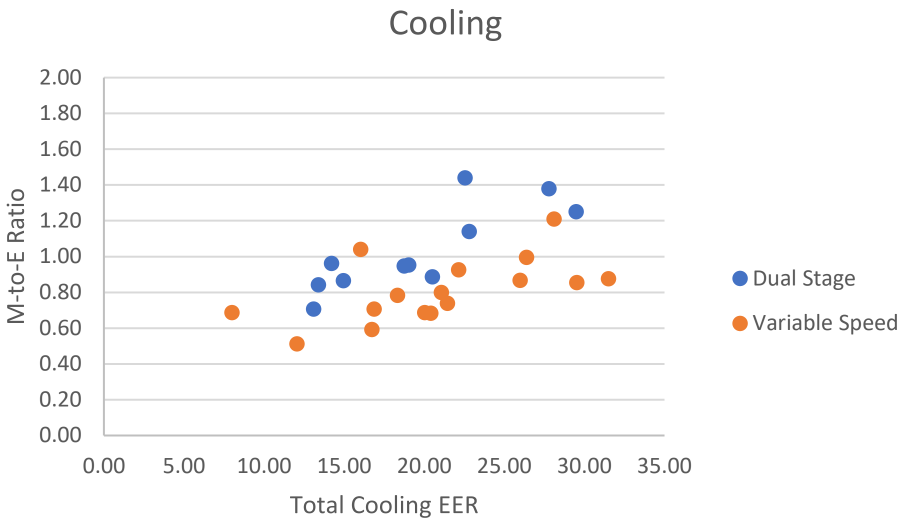


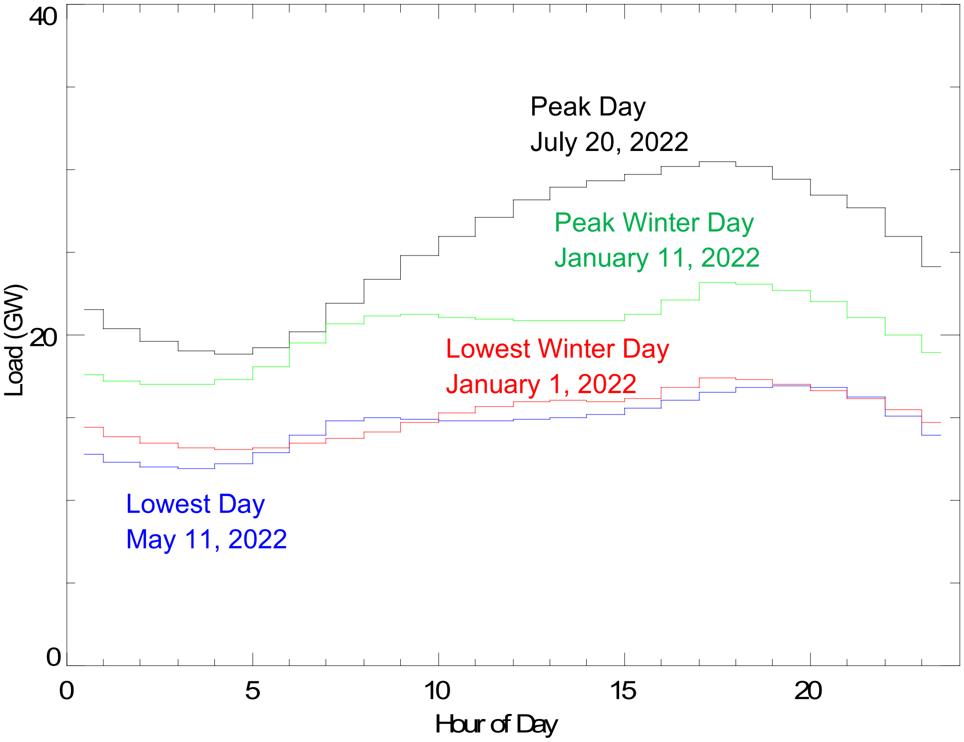
Table 14. Determining Corrected Values for Cooling EERs

			Original Data		Pump Adj			Corrected	
ID	City	GSHP Unit Model	Cooling Load (MBtu)	Total EER	Total EER	Unit EER	M-to-E ratio	Unit EER	Total EER
s01	Farmingdale	NDV026	2,583	29.48	29.48	36.72	1.25	29.37	23.59
s02	Lynbrook	NDV026	17,904	19.03	19.03	23.83	0.95	25.03	19.99
s03	Islip	NVV060	33,955	16.87	15.33	16.87	0.71	23.86	21.68
s04	East Islip	NVV060	8,246	16.73	16.73	18.23	0.59	30.79	28.26
s05	Setauket	NVV048	14,264	22.14	22.14	25.91	0.93	27.98	23.91
s06	Setauket	NDZ026	18,924	22.54	22.54	28.35	1.44	19.69	15.65
s07	Smithtown	NDZ049	8,751	20.50	20.50	21.19	0.89	23.91	23.14
s08	Smithtown	NVV060	13,692	31.51	28.63	31.51	0.88	35.97	32.69
s09	Copiague	NDZ064	38,352	14.95	14.95	17.04	0.87	19.67	17.26
s10	Remsenburg	NVV060	21,313	18.32	18.32	21.55	0.78	27.52	23.39
s11	Coram	NSV018	19,610	22.04	19.49	22.04	0.00		
s16	Coram	NDZ064	-						
s12	Northport	NVV060	15,863	29.53	29.53	30.99	0.85	36.29	34.58
s13	Syosset	NVV036	22,748	25.99	23.62	25.99	0.87	29.94	27.21
s14	Syosset	NVV060	24,646	21.07	19.14	21.07	0.80	26.37	23.96
s15	Manorville	NDZ038	14,136	27.78	24.56	27.78	1.38	20.13	17.80
s17	Hewlett	NDZ064	8,765	22.80	20.17	22.80	1.14	20.00	17.69
s18	East Hampton	NVV060	-						
s19	Port Jefferson	NVV048	5,008	7.98	7.25	7.98	0.69	11.62	10.56
s20	Port Jefferson	NVV048	15,700	21.44	19.48	21.44	0.74	29.01	26.36
s21	Seaford	NVV036	-						
s22	Bellmore	NDZ064	-						
s23	Manhasset	NVV048	20,572	20.41	18.55	20.41	0.68	29.84	27.12
s24	Manhasset	NDZ038	24,925						
s25	East Northport1	NVV060	21,549	12.05	10.95	12.05	0.51	23.53	21.38
s26	East Northport2	NDZ064	44,131	13.08	13.08	13.46	0.71	19.07	18.53
s28	Levittown	NDZ064	29,062	13.38	13.38	15.83	0.84	18.80	15.89
s29	Patchogue	NDZ064	17,944	18.74	18.74	19.80	0.95	20.88	19.77
s30	Remsensburg	NDZ064	13,882	14.22	14.22	14.90	0.96	15.51	14.79
s31	Port Jefferson	NVV060	24,558	20.03	18.20	20.03	0.69	29.16	26.49
s37	Syosset	NVV060	34,015	28.10	37.23	42.96	1.21	35.50	30.77
s39	Bellport	NVH060	26,546	16.04	20.28	23.23	1.04	22.34	19.50
s40	Medford	NVV036	15,628	26.38	26.38	27.25	1.00	27.36	26.49
	AVG			20.47	20.07	22.54		25.15	22.53
	MEDIAN			20.46	19.31	21.49		25.03	23.14

3.6 Electric Demand Impacts

Adding geothermal heat pumps into building stock will potentially impact the electric demand on the utility grid in various ways. The total electric demand for New York State is shown in Figure 9 for the peak day of the year in 2022. The NYISO load exceeded 30,000 MW at 6 pm on July 20. This peak is primarily driven by air conditioning load on this hot day. In contrast, the load on May 11 was the low for the year and ranged from 12,000 to 17,000 MW. During the month of January, the peak day was just over 23,000 MW at 6:00 p.m. The lowest day in January was just slightly above the low for the year in May.

Figure 9. New York State Electric Load Profiles for Various Days in 2022



Geothermal heat pumps will result in a similar load shape as air conditioners for the summer, though with a potentially 40%-50% lower electric demand per ton because of their higher cooling efficiency as shown by the data Table 14. The winter load shape for geothermal heat pumps has the potential to "fill in" the early morning valley in the State's current electric load profile.

The plots in Figure 10 show the average electric load profiles for sites S2 and S5, respectively. Each line on the plot as average profile for a group of days at each site when the daily average outdoor temperature was within a narrow range. For instance, the green line in the top plot for S2 is the average profile for days when the average outdoor temperature was near 10°F (i.e., between 7.5 and 12.5°F). In this case, there were only six days in the range, as indicated by the number in parentheses. The average profile for days with different daily average outdoor temperatures are shown with different colors.

Similarly, the average electric load profiles for summer days are shown in Figure 11 for sites S2 and S5. The light blue line in the plot shows the average profile for days when the average daily temperature was near 85°F (i.e., between 82.5 and 87.5°F). In this case the average profile is made using data for nine days for S2 and for 8 days for S5. Note that each site also shows a pink profile line corresponding to 90°F. However, since there was only one day at this temperature, the profile is less meaningful as it is not an average, diversified profile based on many days.

Figure 10. Winter Demand Profiles at Various Temperatures for S2 (top plot) and S5 (bottom plot)

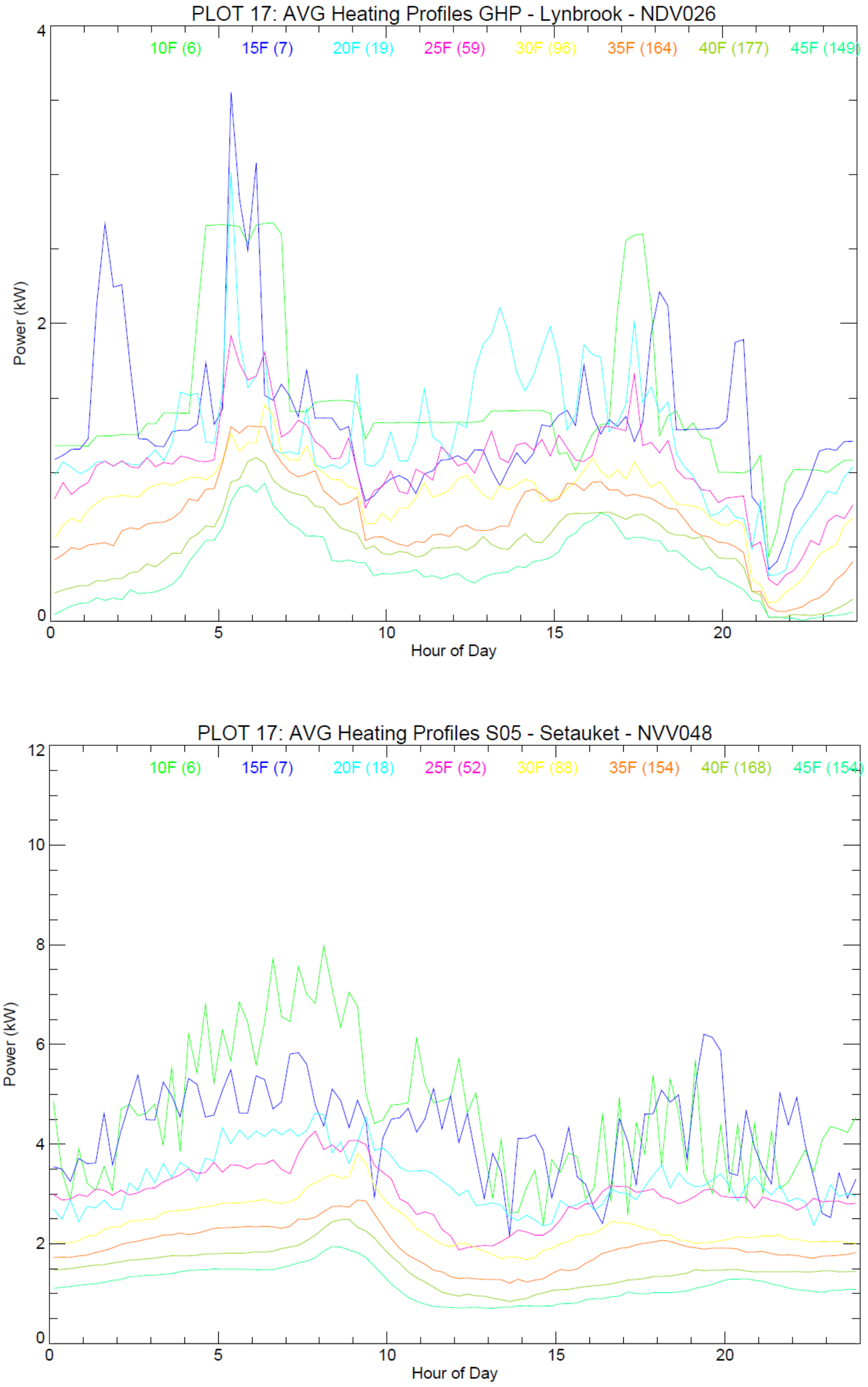
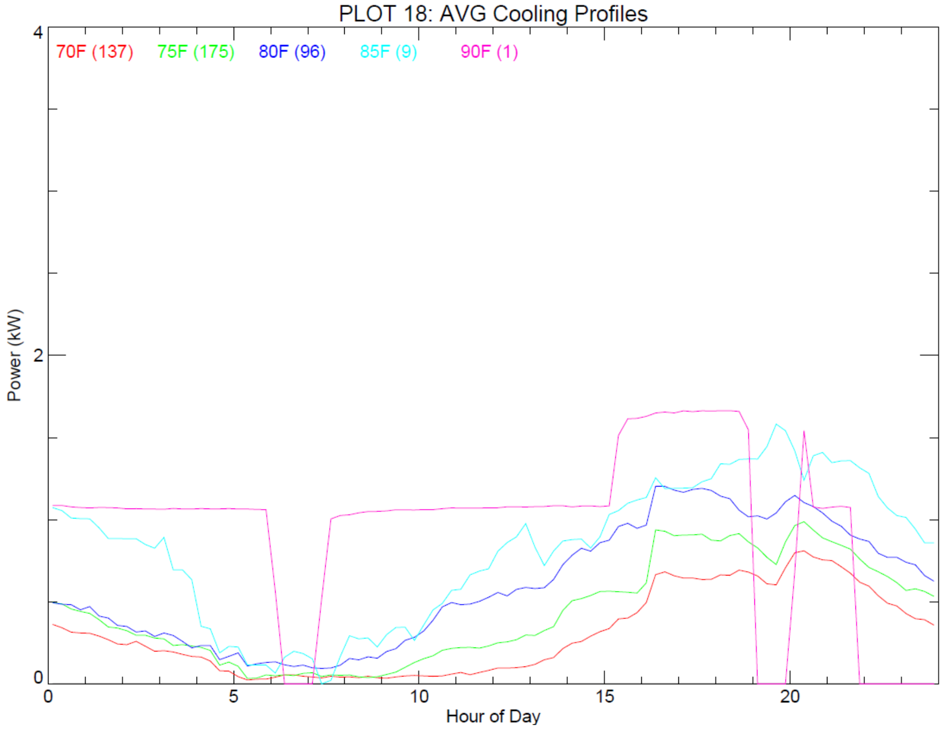
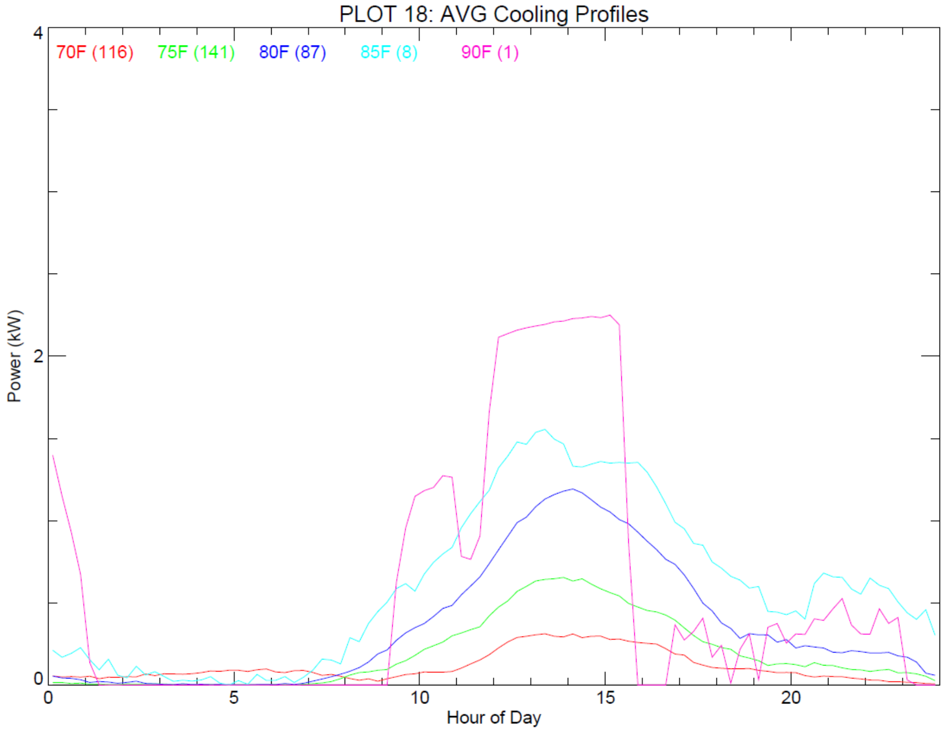


Figure 11. Summer Demand Profiles at Various Temperatures for S2 (top plot) and S5 (bottom plot)





The demand profile at each site depends on the size of the heat pump and the load of the house. One way to normalize the electric load profile and compare several sites is to divide the electric demand by the nominal size of each heat pump (i.e., the rated cooling capacity in tons). Figure 12 shows the average profiles in the heating season based on averaged data from several sites, in units of kilowatt (kW) per installed ton (hourly values are given in Table 15). The black line shows the average profile when ambient temperatures are near 10°F. The average profile includes 38 days from 11 different sites. Similarly, the red line shows the average of 63 days (from 19 sites) when the ambient temperature was near 15°F. The plot shows that the profile at 10°F has the highest peak and that the profile subsides as the temperature increases later in the day.

The average profiles for the summer period are shown in Figure 13 (hourly values are given in Table 16). The black line represents the average of 9 days (from 9 different sites) when the daily average temperature was around 90°F. Similarly, the red line represents the average from more than 121 days from 28 sites when the temperature was near 85°F. The summer profiles subside at lower temperatures as expected.

Figure 12. Average Winter Electric Demand Profiles at Various Outdoor Temperatures

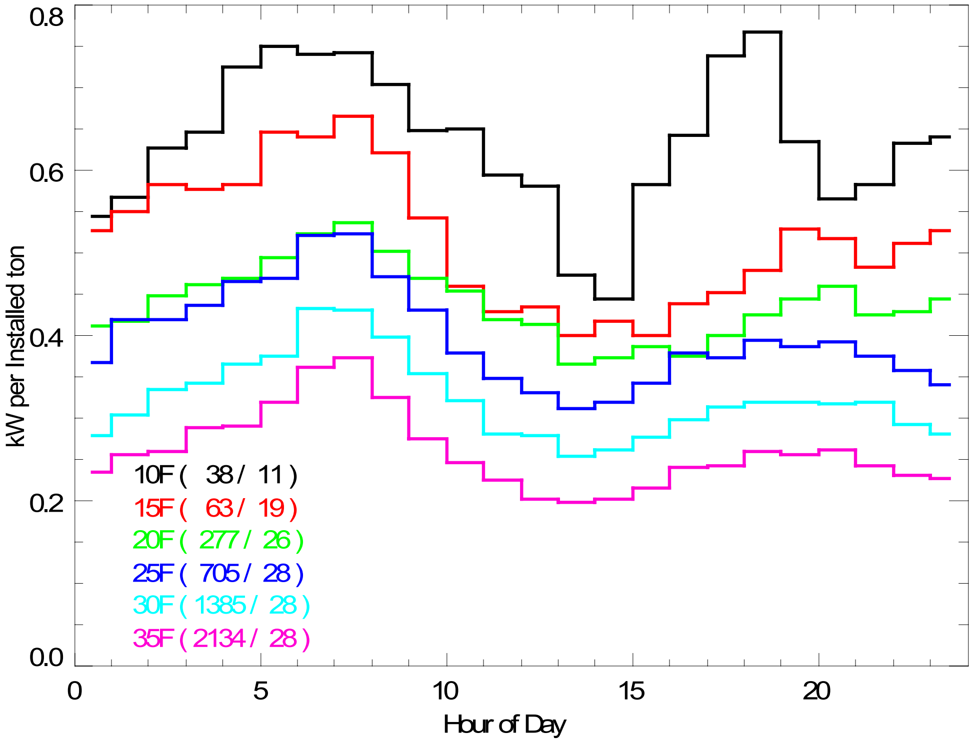


Table 15. Average Kilowatt per Installed Ton for Winter Profiles (data in Figure 12)

Temp (F)	Average Normalized Demand for Each Hour: 1 to 24 (kW per nominal ton)
10	0.54 0.57 0.63 0.65 0.73 **0.75** 0.74 0.74 0.71 0.65 0.65 0.59 0.58 0.47 0.45 0.58 0.64 0.74 0.77 0.64 0.57 0.58 0.63 0.64
15	0.53 0.55 0.58 0.58 0.58 0.65 0.64 0.67 0.62 0.54 0.46 0.43 0.44 0.40 0.42 0.40 0.44 0.45 0.48 0.53 0.52 0.48 0.51 0.53
20	0.41 0.42 0.45 0.46 0.47 0.50 0.52 0.54 0.50 0.47 0.45 0.42 0.42 0.37 0.37 0.39 0.38 0.40 0.43 0.45 0.46 0.43 0.43 0.44
25	0.37 0.42 0.42 0.44 0.47 0.47 0.52 0.52 0.47 0.43 0.38 0.35 0.33 0.31 0.32 0.34 0.38 0.37 0.39 0.39 0.39 0.38 0.36 0.34
30	0.28 0.31 0.34 0.34 0.37 0.38 0.43 0.43 0.40 0.36 0.32 0.28 0.28 0.25 0.26 0.28 0.30 0.31 0.32 0.32 0.32 0.32 0.29 0.28
35	0.24 0.26 0.26 0.29 0.29 0.32 0.36 0.37 0.33 0.28 0.25 0.23 0.20 0.20 0.20 0.22 0.24 0.24 0.26 0.26 0.26 0.24 0.23 0.23

Figure 13. Average Summer Electric Demand Profiles at Various Outdoor Temperatures

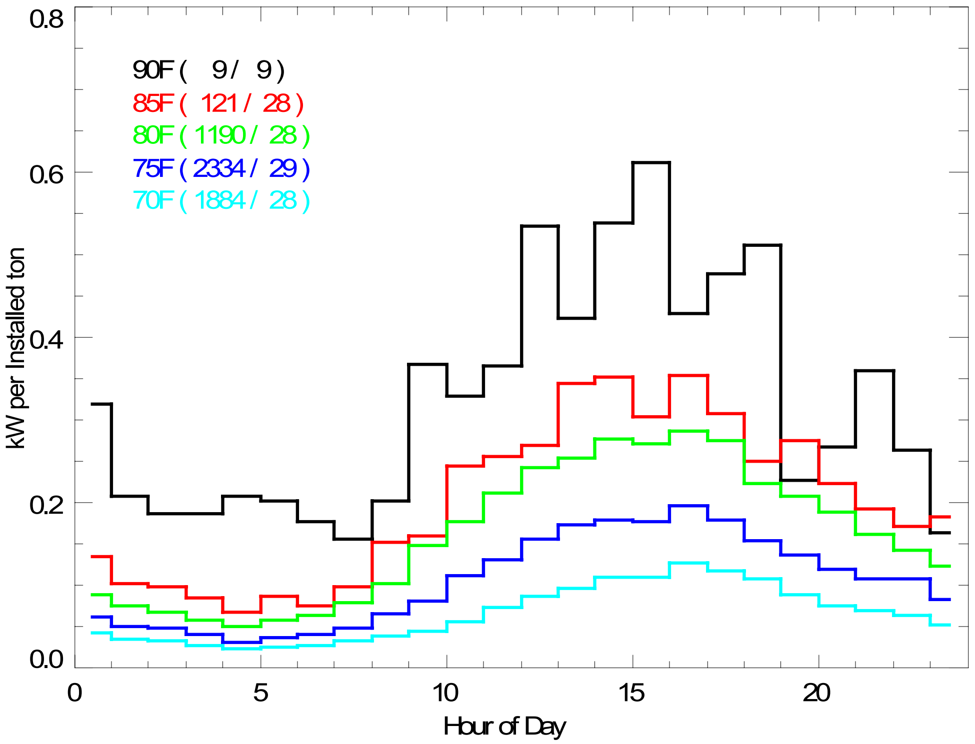


Table 16. Average Kilowatt per Installed Ton for Summer Profiles (data in Figure 13)

Temp (F)	Average Normalized Demand for Each Hour: 1 to 24 (kW per nominal ton)
65	0.04 0.04 0.03 0.03 0.02 0.03 0.03 0.03 0.04 0.05 0.06 0.07 0.09 0.10 0.11 0.11 0.13 0.12 0.11 0.09 0.08 0.07 0.06 0.05
70	0.04 0.04 0.03 0.03 0.02 0.03 0.03 0.03 0.04 0.05 0.06 0.07 0.09 0.10 0.11 0.11 0.13 0.12 0.11 0.09 0.08 0.07 0.06 0.05
75	0.06 0.05 0.05 0.04 0.03 0.04 0.04 0.05 0.07 0.08 0.11 0.13 0.16 0.17 0.18 0.18 0.20 0.18 0.15 0.14 0.12 0.11 0.11 0.08
80	0.09 0.08 0.07 0.06 0.05 0.06 0.06 0.08 0.10 0.15 0.18 0.21 0.24 0.25 0.28 0.27 0.29 0.28 0.22 0.21 0.19 0.16 0.14 0.12
85	0.14 0.10 0.10 0.09 0.07 0.09 0.08 0.10 0.15 0.16 0.24 0.26 0.27 0.34 0.35 0.31 0.36 0.31 0.25 0.28 0.22 0.19 0.17 0.18
90	0.32 0.21 0.19 0.19 0.21 0.20 0.18 0.16 0.20 0.37 0.33 0.37 0.54 0.42 0.54 **0.61** 0.43 0.48 0.51 0.23 0.27 0.36 0.26 0.16

The analysis above is for all the GSHP units, including both variable speed (VS) and dual stage (DS) systems. The analysis was also completed considering the VS and DS systems separately, and the results are shown in Table 17. The values in the first column correspond to the peak values from the plots and tables above, and the other columns show the results for VS and DS units separately. The VS units have a slightly higher demand than the DS units at peak heating conditions. This occurs because all the heat pumps are providing their full output at the coldest conditions, but the inverter losses on the VS units lower the peak efficiency and therefore increase the peak demand. Similar trends are shown for the normalized peak demand at 10°F and 20°F. For peak cooling the opposite occurs: the VS units have considerably lower peak demand than the DS units: since the peak cooling loads are smaller than the heating loads, the VS units operate at an intermediate speed for cooling where efficiency is higher than for the DS units. As a result, the VS units have a lower demand at peak cooling conditions. The peaks from the profiles at 80°F and 90°F are shown.

Table 17. The Impact of GSHP Unit Type on Normalized Peak Demand for Highest Hour

	All Units (Peak kW per ton)	Variable Speed (VS) (Peak kW per ton)	Dual Stage (DS) (Peak kW per ton)
Peak Heating at 10°F	0.75	0.78	0.72
Peak Heating at 20F	0.54	0.60	0.45
Peak Cooling at 90°F	0.61	0.41	0.74
Peak Cooling at 80°F	0.29	0.24	0.36

Notes: The units are evenly split between VS and DS units at most temperatures.

Table 18 compares the normalized peak demand for this study to other study findings for both ccASHP and GSHP systems. First, we focus on ccASHPs from the Brooklyn Queens (BQ) field test. The peak demand for ccASHPs at 10°F is 0.95 kW per installed cooling ton, compared to 0.75 kW per installed ton for the GSHP units. So as expected, the heating peak demand of ccASHPs is higher than for GHSPs in the same climate. This occurs because, while the cASHP units are directly exposed to ambient temperature on the coldest day, the GSHPs benefit from the moderating influence of the ground temperature. GSHPs have nearly 20% lower peak demand.

Table 18. Comparing Normalized Peak Demand Impacts for GSHPs and ccASHPs

	LI GSHPs (peak kW per ton)	BQ ccASHPs (peak kW per ton)	Upstate GSHPs (peak kW per ton)
Peak Heating at 10°F	0.75 0.78 VS only	0.95	0.68
Peak Cooling at 90°F	0.61 0.41 VS only	0.34	No Days
Peak Cooling at 80°F	0.29 0.24 VS only	0.21	0.22

Notes: The Brooklyn-Queens ccASHP results are from (NYSERDA Report 22-04. The upstate GSHP results are from NYSERDA Report 18-03.

Surprisingly the BQ ccASHPs at 90°F have a peak demand of 0.34 kW per installed ton, compared to 0.61 kW per installed ton at the same temperature for this GSHP study. However, the VS GSHP units alone have a peak demand at 0.41 kW per installed ton at 90°F, which is more in line with the ccASHP units—which of course are all VS units.

The modest cooling demand differences that remain between the variable speed ccASHP and GSHP units in the two studies are probably due to the differences in heat pump sizing between the two projects. Sizing affects the demand values that are normalized per installed ton (i.e., more tons per actual load). The GSHP systems were sized on average so that the heating capacity at 32°F EWT was 97% of the design heating load. For the ccASHP's, the maximum heating capacity at 17°F was sized on average to be 129% of the design heating load. Another approximate metric corroborating the sizing differences between the two projects is that the GSHP systems were sized at 500 square feet of floor area per cooling ton for the AEG project, but the BQ ccASHPs were sized 450 square feet per cooling ton for essentially the same climate. The larger sizing of the ccASHP units at least in part explains the smaller normalized demand values for cooling. The sizing difference also implies that the heating demand differences between ccASHPs and GSHPs might be even larger than 20%, if all the heat pumps had been similarly sized.

Table 18 also includes the normalized demand values from the upstate GSHP study (NYSEDA report 18-03). Both studies include about same mix of VS and DS units. The corresponding peak demand at 10°F was slightly lower at 0.68 kW per installed ton for the upstate study, compared to 0.75 kW per installed ton in this study. The lower normalized demand for upstate is probably because the units are sized for peak heating loads that happen at 10-15°F lower temperatures than for the Long Island climate, If we look at the corresponding peak demand at 10-15°F lower temperatures for the upstate GSHPs, the normalized peak demand increases to 0.85 kW per installed ton at 0°F and 0.95 kW per installed ton at -5°F.

The corresponding cooling peak demand at 80°F from the upstate GSHP study was 0.22 kW per installed ton, which compares well with the value of 0.24 kW per installed ton in this study.

3.7 Energy Cost Savings

The energy cost savings for each GSHP system are given in Table 19. The energy costs from Table 7 were used for fuel and electricity. The table lists the corrected heating and cooling loads as well as the electric consumption of the GSHP in each season. The base case energy use and costs per determined using the heating efficiencies listed in the table (79% for gas, 84% for fuel oil, 100% for resistance electric). The base cooling seasonal efficiency was assumed to be 11.5 Btu/Wh (corresponding to a code minimum AC with a seasonal energy efficiency ratio (SEER) of 13) with added fan power to reflect actual conditions based on Rudd et al (2013). Savings are shown separately for heating and cooling and normalized per installed ton.

Table 19. Annual Energy Cost Savings for Each System

			Annual Load (MMBtu)		Annual GSHP Electric (kWh)		Base Htg	Annual Cost Savings			
ID	City	Fuel	Htg	Clg	Htg	Clg	Eff	Htg	Clg	Total	per ton
s01	Farmingdale	Oil	13.9	2.1	1,204	88	84%	$147	$19	$165	$83
s02	Lynbrook	Gas	28.1	18.8	2,422	941	79%	$4	$140	$144	$72
s03	Islip	Oil	38.9	48.0	2,585	2,216	84%	$570	$396	$966	$193
s04	East Islip	Oil	49.3	13.9	2,957	493	84%	$786	$145	$931	$186
s05	Setauket	Oil	78.0	15.4	6,040	644	84%	$970	$140	$1,110	$278
s06			31.2	13.1	2,551	840	84%	$361	$61	$422	$211
s07	Smithtown	Oil	28.3	9.9	2,363	427	84%	$316	$87	$404	$101
s08			46.0	15.6	3,271	478	84%	$631	$178	$809	$162
s09	Copiague	Oil	10.2	44.3	1,069	2,566	84%	$71	$259	$331	$66
s10	Remsenburg	Oil	74.1	27.2	6,220	1,164	84%	$824	$243	$1,067	$213
s11	Coram	Gas		-			79%				
s16				-			79%				
s12	Northport	Oil	27.6	18.6	1,806	537	84%	$410	$218	$628	$126
s13	Syosset	Oil	54.7	26.2	4,510	963	84%	$626	$266	$891	$297
s14			71.7	30.8	5,437	1,287	84%	$914	$282	$1,195	$239
s15	Manorville	Oil	26.5	10.2	2,262	575	84%	$287	$64	$350	$117
s17	Hewlett	Gas	33.8	7.7	2,906	435	79%	$6	$47	$54	$11
s18	East Hampton	Oil		-			84%				
s19	Port Jefferson	Oil	54.1	7.3	3,612	691	84%	$789	-$11	$778	$194
s20			47.5	21.2	2,965	806	84%	$736	$210	$946	$236
s21	Seaford	Gas		-			79%				
s22	Bellmore	Gas		-			79%				
s23	Manhasset	Gas	26.1	30.1	1,621	1,109	79%	$131	$304	$435	$145
s24				-			79%				
s25	East Northport1	Oil	2.5	42.1	150	1,969	84%	$41	$341	$382	$76
s26	East Northport2	Oil	52.1	62.5	4,298	3,373	84%	$593	$416	$1,010	$202
s28	Levittown	Oil	42.4	34.5	3,729	2,172	84%	$436	$167	$604	$121
s29	Patchogue	Oil	79.8	18.9	6,980	958	84%	$831	$139	$970	$194
s30	Remsensburg	Oil	36.4	14.4	3,158	976	84%	$383	$56	$440	$88
s31	Port Jefferson	Oil	113.2	35.7	10,592	1,349	84%	$1,039	$355	$1,394	$279
s37	Syosset	**Oil**	40.6	28.1	3,369	914	84%	$459	$309	$768	$154
s39	Bellport	Elect	29.5	25.5	2,429	1,309	100%	$1,257	$184	$1,440	$288
s40	Medford	Elect	45.9	15.7	3,217	592	100%	$2,065	$156	$2,221	$740

Note: Clg = Cooling, Htg = Heating. S37 is assumed to have oil heat (the previous fuel was unknown).

The cost savings depend on the displaced fuel in each case. Table 20 shows the average cost savings for all the sites broken down by the fuel type. The savings per square foot of floor area are also given by combining up the per system results in the homes that have multiple GSHP units.

Table 20. Annual Energy Cost Savings by Fuel Type

Fuel	Number of Units/Homes	Average of Total Cost Savings per GSHP	Average of Total Cost Savings per Installed Ton	Average of Total Cost Savings per Square Feet
Gas	3 / 2	$211	$76	7¢
Oil	22 / 18	$753	$173	34¢
Electric	1 / 1	$1,441	$288	69¢

Note: System S40 was excluded since the savings (and load) per ton was extraordinarily high.

Table 21 shows the impact of assuming higher and lower costs for fuel and electric. For natural gas, the savings would nearly double from $76 to $145 per ton if the fuel cost was 40% higher. The savings for fuel oil would also nearly double from $173 to $295 per ton if fuel was 40% more expensive. In early 2022, fuel prices were 40% or more above the 2020 baseline (e.g., 1.90 per therm and $4.50 per gallon). Annual savings for the GSHP system versus electric resistance only depends on electric costs, so a 40% increase in electric costs results in a proportional increase in savings.

Table 21. Sensitivity of Annual Cost Savings to Fuel and Electric Costs ($ per installed ton)

		Electric Cost			
		-20%	**0**	**+20%**	**+40%**
Gas Cost	**-20%**	61	41	22	2
	0	95	**76**	57	37
	+20%	130	110	91	72
	+40%	164	145	126	106

		Electric Cost			
		-20%	**0**	**+20%**	**+40%**
Oil Cost	**-20%**	139	113	86	60
	0	200	**173**	147	121
	+20%	260	234	208	182
	+40%	321	295	269	243

Electric Cost			
-20%	**0**	**+20%**	**+40%**
230	**288**	346	403

Table 3 showed that the average installation costs for GSHP systems was \$10,570 per installed ton. After applying PSE&G rebates (\$2000 per installed ton) and the Federal tax credit (30%), the net installed cost to the homeowner was \$5,987 per installed ton. Using the savings from Table 20, the simple payback for systems replacing natural gas was 79 years, the payback compared to fuel oil was 35 years, and the payback compared to electric resistance heat was 21 years. Assuming 40% higher fuel rates (from Table 21), the payback for natural gas drops to 41 years and the payback for fuel oil drops to 20 years.

3.8 Greenhouse Gas Savings

The measured energy savings were used to predict the reduction in GHG emissions for the ccASHP systems. The eGrid 2018 data Long Island was used to determine the GHG emission factor for electric generation in the region https://www.epa.gov/sites/production/files/2020-01/documents/egrid2018_summary_tables.pdf. EPA's eGrid publishes the overall average emission factor for the region as well as the non-baseload emissions factor. For Long Island, the overall average factor is 1.193 pounds (lbs) of CO2 equivalent for each kWh. The non-baseload factor is 1.3223 pounds of CO_2 equivalent per kWh. GHG CO_2 equivalent factors for the fossil fuels are 11.7 pounds/therm for natural gas and 22.4 pounds/gal for fuel oil. The analysis below uses both the overall and non-baseload values.

Table 22. Annual Greenhouse Gas Savings for Each System (using Overall Avg GHG Factors)

			Annual Load (MMBtu)		Annual GSHP Electric (kWh)		Base Htg	Annual GHG Savings (lbs/year)			
ID	City	Fuel	Htg	Clg	Htg	Clg	Eff	Htg	Clg	Total	Per ton
s01	Farmingdale	Oil	13.9	2.1	1,204	88	84%	1,267	110	1,377	689
s02	Lynbrook	Gas	28.1	18.8	2,422	941	79%	1,274	829	2,102	1,051
s03	Islip	Oil	38.9	48.0	2,585	2,216	84%	4,486	2,339	6,826	1,365
s04	East Islip	Oil	49.3	13.9	2,957	493	84%	6,062	857	6,919	1,384
s05	Setauket	Oil	78.0	15.4	6,040	644	84%	7,977	829	8,806	2,202
s06			31.2	13.1	2,551	840	84%	3,032	362	3,394	1,697
s07	Smithtown	Oil	28.3	9.9	2,363	427	84%	2,684	515	3,199	800
s08			46.0	15.6	3,271	478	84%	5,052	1,051	6,103	1,221
s09	Copiague	Oil	10.2	44.3	1,069	2,566	84%	717	1,533	2,250	450
s10	Remsenburg	Oil	74.1	27.2	6,220	1,164	84%	7,003	1,436	8,439	1,688
s11	Coram	Gas		-			79%				
s16				-			79%				
s12	Northport	Oil	27.6	18.6	1,806	537	84%	3,217	1,286	4,503	901
s13	Syosset	Oil	54.7	26.2	4,510	963	84%	5,274	1,570	6,844	2,281
s14			71.7	30.8	5,437	1,287	84%	7,462	1,664	9,126	1,825
s15	Manorville	Oil	26.5	10.2	2,262	575	84%	2,457	376	2,833	944
s17	Hewlett	Gas	33.8	7.7	2,906	435	79%	1,544	279	1,823	365
s18	East Hampton	Oil		-			84%				
s19	Port Jefferson	Oil	54.1	7.3	3,612	691	84%	6,221	(68)	6,153	1,538
s20			47.5	21.2	2,965	806	84%	5,715	1,242	6,957	1,739
s21	Seaford	Gas		-			79%				
s22	Bellmore	Gas		-			79%				
s23	Manhasset	Gas	26.1	30.1	1,621	1,109	79%	1,938	1,797	3,735	1,245
s24				-			79%				
s25	East Northport1	Oil	2.5	42.1	150	1,969	84%	313	2,018	2,331	466
s26	East Northport2	Oil	52.1	62.5	4,298	3,373	84%	5,006	2,461	7,467	1,493
s28	Levittown	Oil	42.4	34.5	3,729	2,172	84%	3,797	989	4,786	957
s29	Patchogue	Oil	79.8	18.9	6,980	958	84%	7,206	821	8,027	1,605
s30	Remsensburg	Oil	36.4	14.4	3,158	976	84%	3,311	334	3,645	729
s31	Port Jefferson	Oil	113.2	35.7	10,592	1,349	84%	9,400	2,099	11,499	2,300
s37	Syosset	Oil	40.6	28.1	3,369	914	84%	3,879	1,826	5,705	1,141
s39	Bellport	Elect	29.5	25.5	2,429	1,309	100%	7,426	1,086	8,512	1,702
s40	Medford	Elect	45.9	15.7	3,217	592	100%	12,202	921	13,123	4,374

Note: Clg = Cooling, Htg = Heating. S37 is assumed to have oil heat (the previous fuel was unknown).

The GHG savings depend on the displaced fuel in each case. Table 23 shows the average GHG savings for all the sites broken down by the fuel type. The savings per square foot of floor area are also given by combining up the per system results in the homes that have multiple GSHP units.

Table 23. Annual GHG Savings by Fuel Type (Pounds of CO_2-equialent per year using overall emission factor for electricity)

Fuel	Number of Units / Homes	Average of GHG Savings per GSHP (pounds/year)	Average of GHG Savings per Installed ton (pounds/year-ton)	Average of GHG Savings per sq. ft. (pounds/year-sq. ft.)
Gas	3 / 2	2,553	887	1.3
Oil	22 / 18	5,781	1,337	2.6
Electric	1 / 1	8,512	1,702	4.0

Note: System S40 was excluded since the savings (and load) per ton was extraordinarily high.

Table 24 shows the results using the non-baseload emissions factor of 1.3223 pounds per kWh from eGrid instead of the overall average value used in the tables above. The impact of the different factors are small for Long Island given mix of electric generation for the region.

Table 24. Annual GHG Savings by Fuel Type (Pounds of CO_2-equialent per year using non-baseload emission factor for electricity)

Fuel	Number of Units / Homes	Average of GHG Savings per GSHP (lbs/year)	Average of GHG Savings per Installed ton (lbs/year-ton)	Average of GHG Savings per sq. ft. (lbs/year-sq. ft.)
Gas	3 / 2	2,359	825	1.1
Oil	22 / 18	5,431	1,253	2.3
Electric	1 / 1	9,343	1,887	4.4

Note: System S40 was excluded since the savings (and load) per ton was extraordinarily high

3.9 Determining Heating and Cooling BEFLH Values

Many sections of the New York State Technical Refence Manual (TRM 2021) use the concept of building equivalent full-load hours (BEFLH), which is the annual building load divided by the design load determined by Air Conditioning Contractors of America (ACCA) Manual J or other similar load calculation methods. BEFLH values for heating were theoretically determined by a white paper related to the development of the GSHP measure section in the TRM (Henderson 2020 and TRM 2021).

For all these sites, both the Manual J design heating and cooling loads used for sizing the heat pumps were available. The team also have predictions for the annual heating and cooling load for the building, so it was possible to calculate the measure BEFLH values.

Table 25 uses these values to calculate the BEFLH for heating at each home. Loads were summed appropriately for homes with multiple units. Figure 15 shows the distribution of these measured values and compares them to the BEFLH values from the TRM for heating in New York City (the nearest weather city). The TRM values of 1329, 1485 and 1636 correspond to new, average, and older construction vintages. The average of the 19 measured values was 1070, which is 72% of the TRM value for average vintage.

Similarly, Table 26 uses the design cooling loads and the annual cooling load to find the cooling BEFLH for each home. Loads were summed appropriately for homes with multiple units. Figure 14 shows the distribution of these measured values and compares them to the BEFLH values from the TRM for cooling in New York City. The TRM values of 788, 811 and 838 correspond to new, average and older construction vintages. The average of the 20 measured values was 622, which is 77% of the TRM value for average vintage.

Table 25. Using Design Load and Annual Load to Determine Heating BEFLH

ID	City	GSHP Unit	Size (tons)	Floor Area (ft^2)	Year Built	Design Heating (MBtu/h)	Annual Heating Load (MMBtu)	Htg BEFLH	Annual Htg Load (MBtu/ sq. ft.)
s01	Farmingdale	NDV026	2	950	1951	25	13.9	556	14.6
s02	Lynbrook	NDV026	2	1200	1947	30	28.1	937	23.4
s03	Islip	NVV060	5	2000	1952	50	38.9	778	19.4
s04	EastIslip	NVV060	5	1800	1970	40	49.3	1,232	27.4
s05	Setauket	NVV048	4	3500	1963	65			
s06		NDZ026	2						
s07	Smithtown	NDZ049	4	2631	1961	60	28.3	1,238	28.2
s08		NVV060	5				46.0		
s09	Copiague	NDZ064	5	1900	1970	62	10.2		
s10	Remsenburg	NVV060	5	2723	1991	42	74.1	1,764	27.2
s11	Coram	NSV018	1.5	2500	1995	50			
s16		NDZ064	5						
s12	Northport	NVV060	5	3100	1955	52	27.6	531	8.9
s13	Syosset	NVV036	3	3100	1950	78	54.7	1,621	40.8
s14		NVV060	5				71.7		
s15	Manorville	NDZ038	3	2500	1950	55	26.5	482	10.6
s17	Hewlett	NDZ064	5	2100	2018	50	33.8	677	16.1
s18	East Hampton	NVV060	5	1850	1994	51.3			
s19	Port Jefferson	NVV048	4	4000	1987	75	54.1	1,355	25.4
s20		NVV048	4				47.5		
s21	Seaford	NVV036	3	2200	1950	39			
s22	Bellmore	NDZ064	5	2500	2018	69.4			
s23	Manhasset	NVV048	3	3100	2019	73.9	26.1		
s24		NDZ038	4						
s25	East Northport1	NVV060	5	2100	2019	55	2.5		
s26	East Northport2	NDZ064	5	2200	1950	45.5	52.1	1,144	23.7
s28	Levittown	NDZ064	5	2392	1950	56.3	42.4	752	17.7
s29	Patchogue	NDZ064	5	2500	1890	58.1	79.8	1,374	31.9
s30	Remsensburg	NDZ064	5	2500	1950	58.4	36.4	623	14.5
s31	Port Jefferson	NVV060	5	3200	1960	61.7	113.2	1,835	35.4
s37	Syosset	NVV060	5	3500	2013	51.9	40.6	782	11.6
s39	Bellport	NVH060	5	2100	1960	61	29.5	484	14.1
s40	Medford	NVV036	3	1924	2018	21.1	45.9	2,174	23.8
							AVG	1,070	21.8
							MEDIAN	937	23.4

Table 26. Using Design Load and Annual Load to Determine Cooling BEFLH

ID	City	GSHP Unit	Size (tons)	Floor Area (ft^2)	Year Built	Design Cooling (MBtu/h)	Annual Cooling Load (MMBtu)	Clg BEFLH	Annual Clg Load (MBtu/ sq. ft.)
s01	Farmingdale	NDV026	2	950	1951	18.0	2.1	115	2.2
s02	Lynbrook	NDV026	2	1200	1947	18.0	18.8	1,045	15.7
s03	Islip	NVV060	5	2000	1952	40.0	48.0	1,201	24.0
s04	EastIslip	NVV060	5	1800	1970	28.0	13.9	497	7.7
s05	Setauket	NVV048	4	3500	1963	42.0	15.4		
s06		NDZ026	2				13.1		
s07	Smithtown	NDZ049	4	2631	1961	48.0	9.9	531	9.7
s08		NVV060	5				15.6		
s09	Copiague	NDZ064	5	1900	1970	41.0	44.3		
s10	Remsenburg	NVV060	5	2723	1991	55.0	27.2	495	10.0
s11	Coram	NSV018	1.5	2500	1995	38.5	-		
s16		NDZ064	5				-		
s12	Northport	NVV060	5	3100	1955	41.0	18.6	453	6.0
s13	Syosset	NVV036	3	3100	1950	65.0	26.2	878	18.4
s14		NVV060	5				30.8		
s15	Manorville	NDZ038	3	2500	1950	41.0	10.2	250	4.1
s17	Hewlett	NDZ064	5	2100	2018	35.0	7.7	220	3.7
s18	East Hampton	NVV060	5	1850	1994	39.9	-		
s19	Port Jefferson	NVV048	4	4000	1987	60.0	7.3	476	7.1
s20		NVV048	4				21.2		
s21	Seaford	NVV036	3	2200	1950	29.0	-		
s22	Bellmore	NDZ064	5	2500	2018	44.3	-		
s23	Manhasset	NVV048	3	3100	2019	61.5	30.1	489	9.7
s24		NDZ038	4				-		
s25	East Northport1	NVV060	5	2100	2019	38.0	42.1		
s26	East Northport2	NDZ064	5	2200	1950	39.8	62.5	1,572	28.4
s28	Levittown	NDZ064	5	2392	1950	52.0	34.5	664	14.4
s29	Patchogue	NDZ064	5	2500	1890	49.5	18.9	382	7.6
s30	Remsensburg	NDZ064	5	2500	1950	48.9	14.4	295	5.8
s31	Port Jefferson	NVV060	5	3200	1960	42.4	35.7	842	11.2
s37	Syosset	NVV060	5	3500	2013	40.0	28.1	703	8.0
s39	Bellport	NVH060	5	2100	1960	50.2	25.5	509	12.2
s40	Medford	NVV036	3	1924	2018	19.1	15.7	823	8.2
							AVG	622	10.7
							MEDIAN	503	8.9

Figure 14. Measured Cooling BEFLH Values Compared to TRM Values for NYC

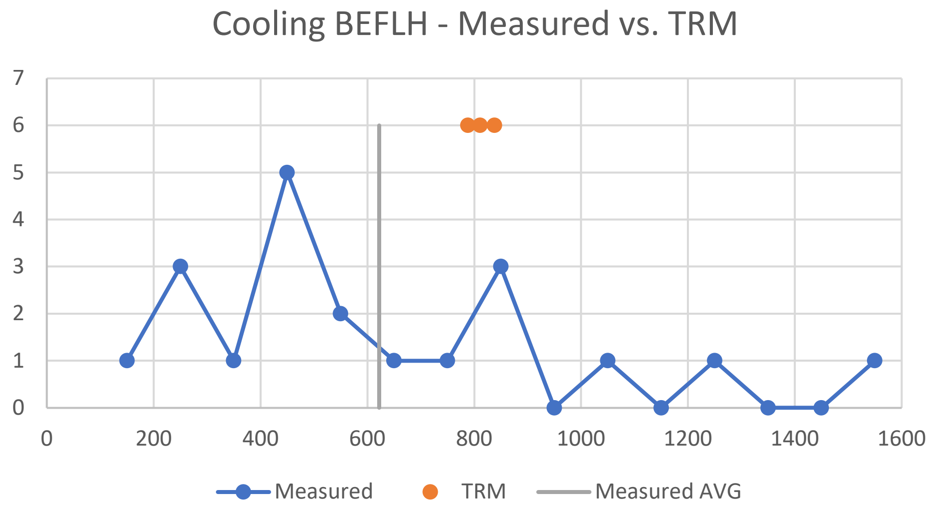
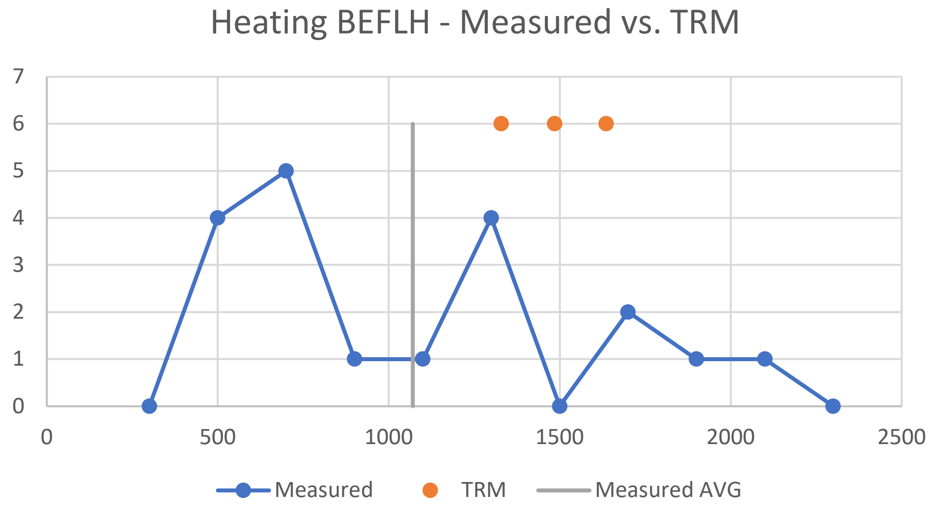


Figure 15. Measured Heating BEFLH Values Compared to TRM Values for New York City



Each of the tables above also normalizes the heating and cooling loads by the floor area. The normalized annual space heating load ranges from 9 to 41 MBtu per square feet, with an average of 22 MBtu per square feet per year. The Brooklyn Queens ccASHP study (NYSERDA Report 22-04) had average loads that were much higher at 40 MBtu per square feet per year in a similar climate. The measured loads in the Hudson Valley ccASHP study (NYSERDA Report 22-08) saw heating loads that averaged 30 MBtu per square feet per year.

The average heating loads at these Long Island sites were less than the loads in Hudson Valley homes as would expected based on the climate differences. The houses in this study and the Hudson Valley study were traditional single family suburban houses of similar vintage. The higher loads for the older (perhaps less insulated) homes in Brooklyn and Queens appear to be the outlier.

The average measured cooling loads for these Long Island homes were 11 MBtu per square feet per year.

4 Results: Customer Surveys

This section presents the results from the customer surveys completed by Frontier Energy (FE).

4.1 Survey Approach and Goals

As initially planned, FE administered a survey of participating residents using SurveyMonkey®. A web survey was first conducted around the time of installation of the GSHPs. Eighteen respondents completed at least part of the survey between March 2019 and May 2022, out of the 23 we were ultimately able to contact. We completed follow-up phone surveys with six of those homeowners.

The survey results are presented below. FE received seventeen full responses on the web survey (one answered only the first stage questions). The success rate with phone surveys was much lower since it was especially difficult to get these participants to agree to a phone survey during COVID. The survey questions are listed in appendix A.

Table 27. Responses to Survey Questions

Survey Instrument	Responses	Out of	Completion
Web Surveys	18	23	78%
Phone Surveys	6	23	26%

The remainder of this section provides a summary of the findings that FE obtained through the web surveys and phone surveys. In all graphs, the number of responses is shown on the bars in each chart. Not all participants answered every question.

The survey questions were developed to focus on seven key areas:

- Customer's decision process to install a ground source heat pump (and consideration/decision to install solar).
- Customer's satisfaction with the contractor and installation process.
- Customer's experience with heating/cooling equipment maintenance.
- Customer's perceived comfort with heating/cooling equipment.
- Customer's experience operating the heat pump(s).
- Customer's satisfaction with the heating/cooling equipment.
- Other feedback.

Each of these are addressed separately in the following sections.

4.2 Decision to Install

Participants were asked how important ("very," "somewhat," "not at all") a variety of factors were in their decision-making process to install a ground-source heat pump system. The fifteen factors that respondents had to choose from can be broadly grouped as follows: two related to climate change, five related to financial savings, six related to health/comfort, one related to feeling comfortable making the investment "recommended by someone I trust" and one related to status image, or "modern, trendy technology."

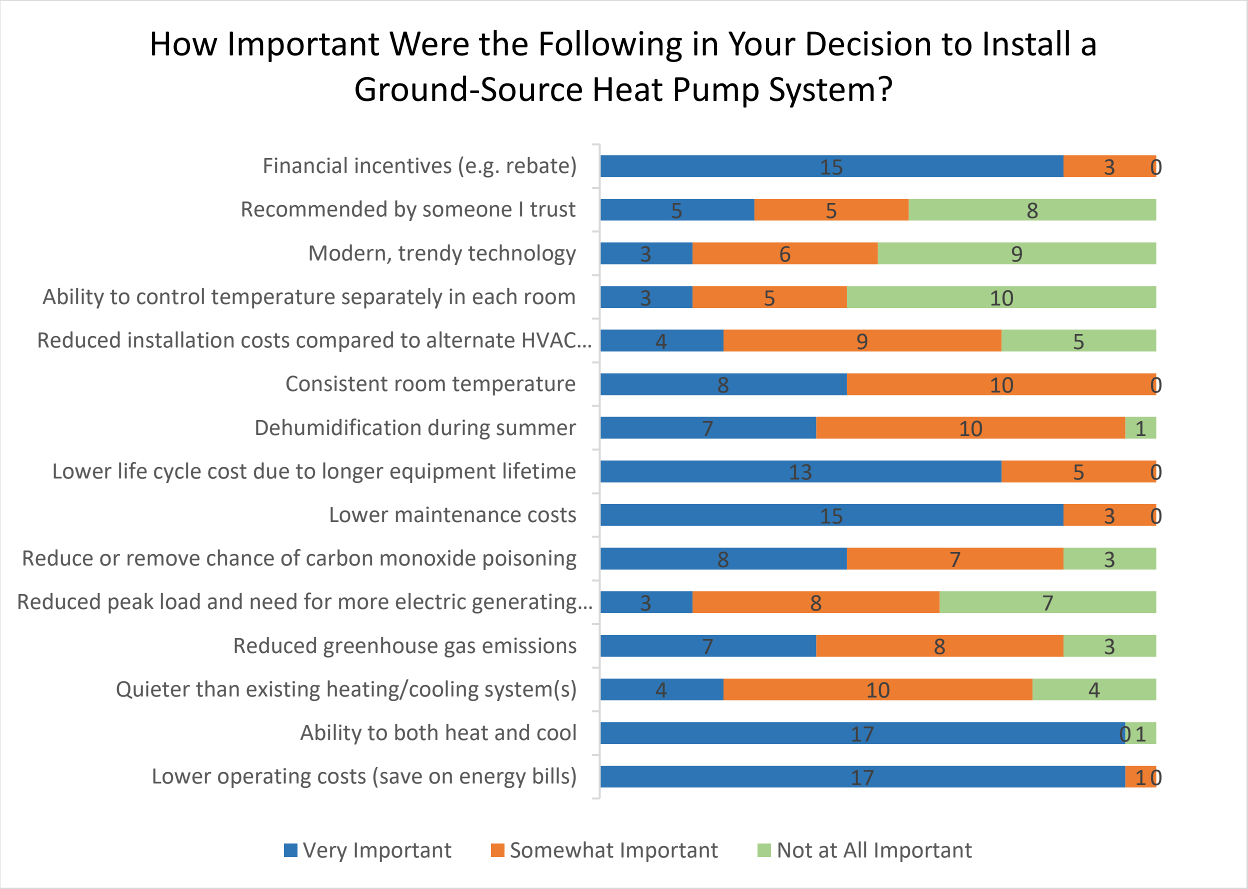
As shown in Figure 16, "ability to both heat and cool" and "lower operating costs" received 94% of the most "very important" responses (17 out of 18). The next most important factors were the ability to receive a "financial incentive" and "lower maintenance costs," both with 15 out of 18 responding very important. Not surprisingly, lower energy and operating costs was a major driver for most homeowners and, at least for this group, recommendations by "someone I trust" was not a major driver.

"Reduced peak load and need for more electric generating plants" only received 17% (three total) of respondents selecting these factors as "very important," though eight additional respondents viewed it as somewhat important. This difference may be due to many homeowners' lack of awareness concerning the role of peak demand on greenhouse gas emissions. "Reduced greenhouse gas emissions" responses were approximately the same, with seven (39%) viewing it as very important and an additional eight viewing it as somewhat important. Overall, environmental and utility infrastructure concerns were not major driver in the installation decision for these homeowners.

Comfort was not very important with approximately 17% (3 total) of respondents indicating "ability to control temperature separately in each room" and 39% (7 total) of respondents indicating "dehumidification during summer" being very important. Having a system that is a "modern, trendy technology" was not at all important to nine respondents (50%), somewhat important to only six (33%) and very important to three respondents (17%). Overall, the consumers felt their original systems provided reasonable comfort, so the perception that the new system might provide better comfort was not a major driver.

Figure 16. Importance of Factors in Decision to Install a GSHP System

Numbers represent the number of respondents who selected each option.



4.3 Installation Experience

Customers were asked how satisfied they were with the work carried out by the heat pump contractor, and how they felt about the installation process compared to an equipment replacement (e.g. replacing an old furnace with a new furnace). As shown in Figure 17, the majority of homeowners were very satisfied with the work carried out by the contractor, with only three homeowners indicating they were somewhat or very dissatisfied. Assessing how invasive the installation process was in comparison to replacing the existing heating system varied, however, almost two-thirds of the respondents agreed it was more invasive (Figure 18).

Figure 17. Customer Satisfaction with Work Carried Out by Heat a Pump Contractor

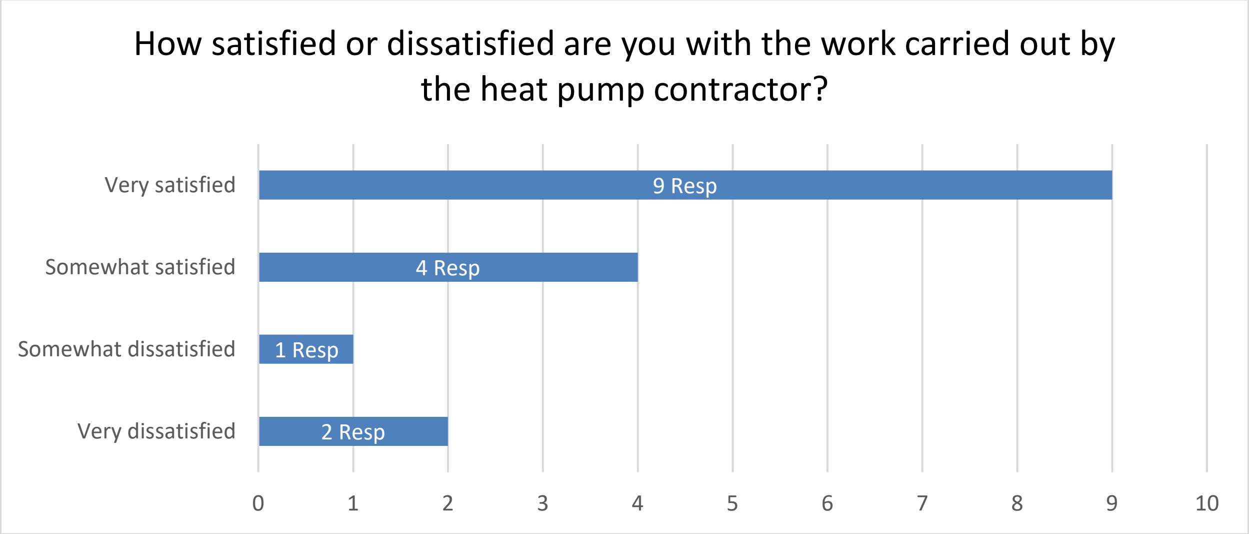
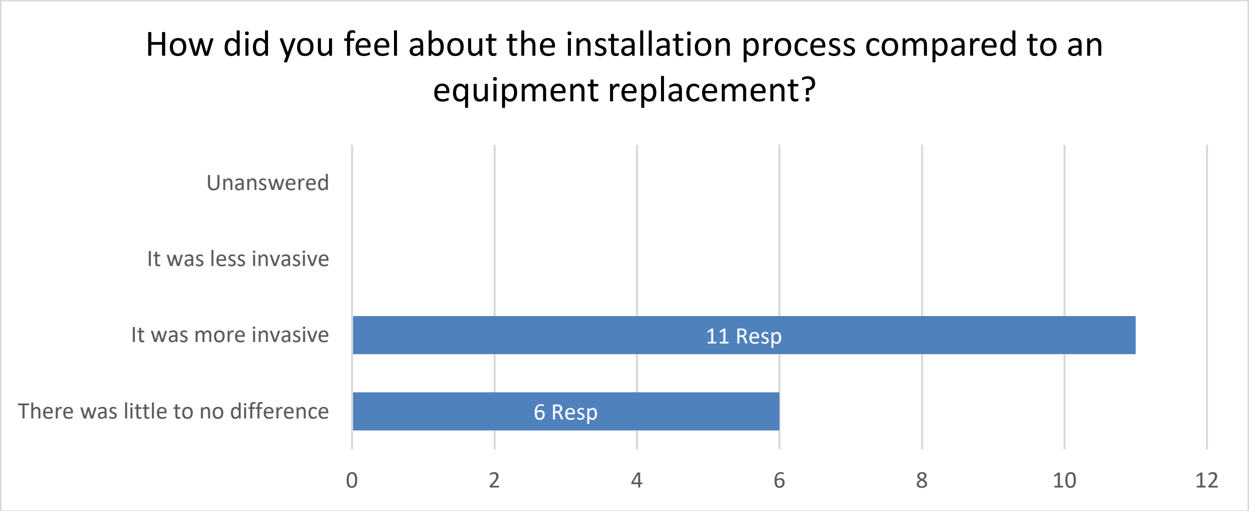


Figure 18. Customer Experience with the Installation Process

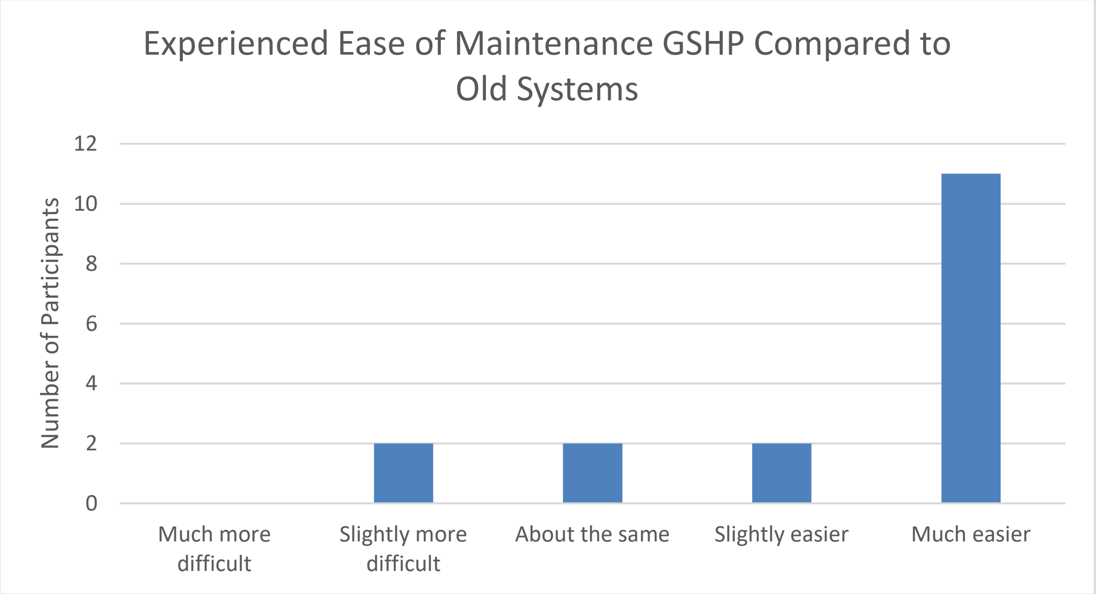


4.4 Maintenance Experience

Customers were asked about maintenance from three perspectives. First, the expected level of effort to maintain the heat pumps in comparison to their original heating and cooling systems. Second, how much effort it took them to maintain their original heating and cooling systems prior to the heat pump installation. Third, after they had at least a year of experience with the heat pumps, how much effort it took them to maintain the new heat pumps.

As shown in Figure 19, participants experienced an improvement in the ease of maintenance with their GSHP system when compared to their prior heating and cooling systems. After a year or more of experience with the GSHP pump system, 77% stated it was slightly to much easier, with two stating it was "about the same." Two respondents stated that it was slightly more difficult than their original systems.

Figure 19. Experienced Level of Effort to Maintain GSHP in Comparison with Prior Heating and Cooling System

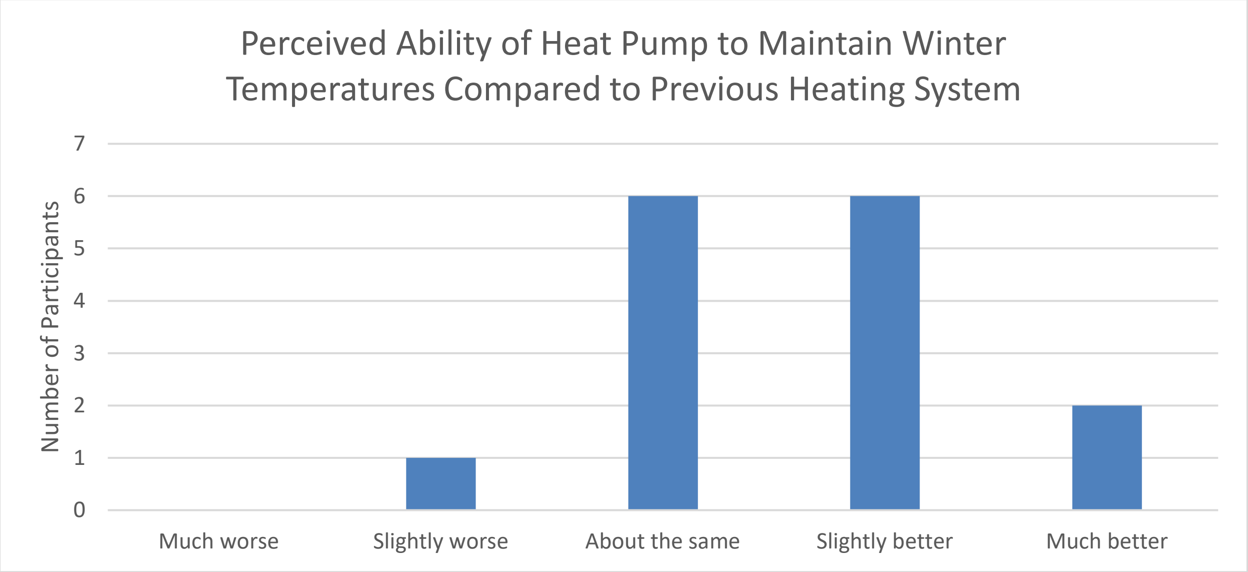


These results show the participants felt that generally, maintenance was either easier or comparable to their conventional systems.

4.5 Perceived Comfort

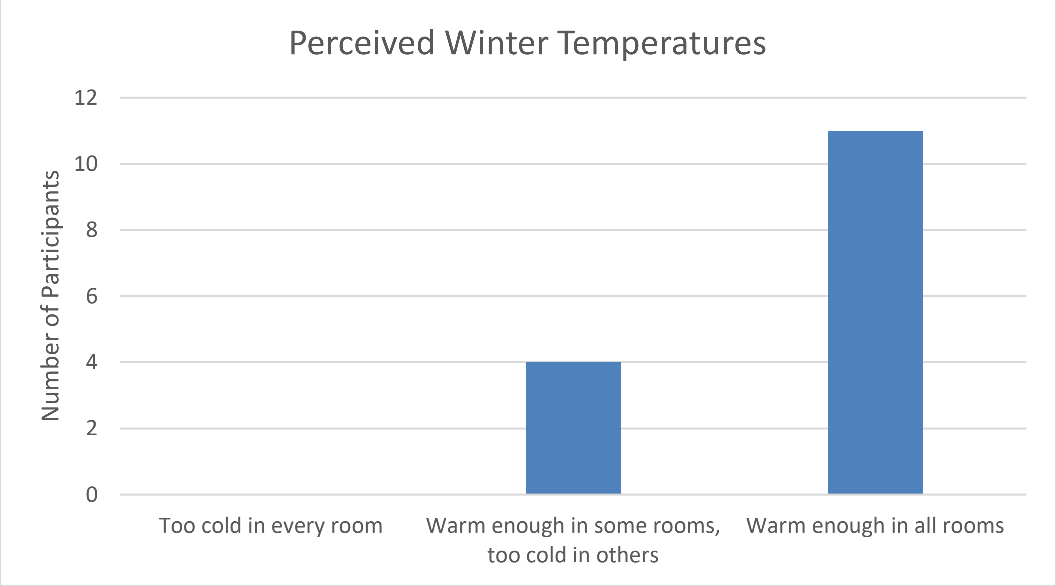
Customers were asked a series of questions related to comfort, such as how well space temperatures were maintained in the winter. Two participants did not answer the perceived comfort questions. Overall, most participants found that their heat pumps maintained temperatures during winter relatively well, though some did feel that it was about the same as their previous heating system and one participant said the heat pump was slightly worse in maintaining temperature. As Figure 20 shows, 53% of the participants felt the heat pumps maintain their desired heating temperature slightly or much better than their original heating system, with six respondents (40%) felt it was about the same.

Figure 20. Perceived Ability of Heat Pump to Maintain Desired Winter Temperatures Compared to Previous Heating System



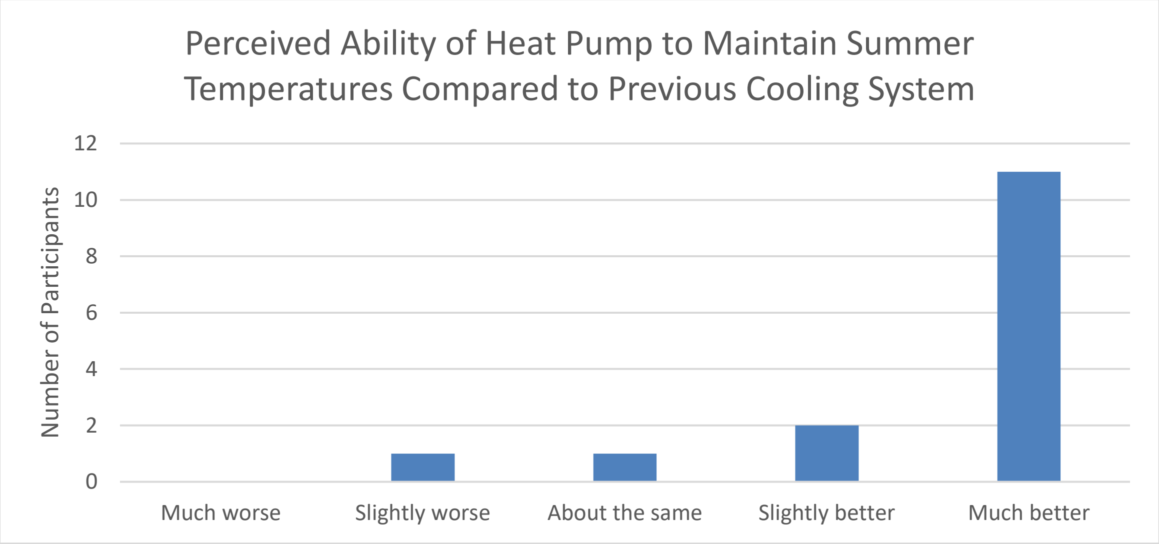
Participants reported an improvement in the distribution of temperatures throughout the home, as seen in Figure 21. After the GSHP system was installed eleven (73%) participants indicated all rooms were warm enough with only four participants (27%) reporting that some rooms were too cold in winter.

Figure 21. Perceived Distribution of Comfort Throughout Home During Winter for Previous Heating System and GSHP



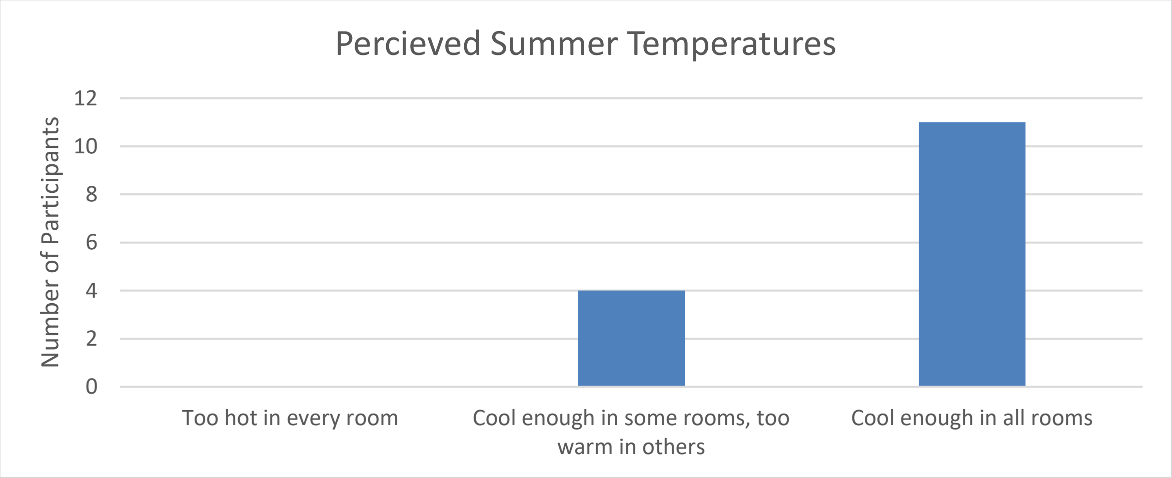
Participant responses for summer temperatures also indicate an improvement in the ability for the heat pump to maintain cool enough temperatures for comfort. For cooling, 73% indicated their heat pumps maintain their desired cooling temperature much better than their original system. Two respondents indicated that it is slightly better. One person felt that it performed worse than their previous system in the summer.

Figure 22. Perceived Ability of Heat Pump to Maintain Desired Summer Temperatures Compared to Previous Cooling System



Eleven out of 15 participants reported that all rooms were able to achieve their desired temperature with the GSHP with four participants feeling that with the GSHP some rooms were still too hot. The general trend is toward higher comfort with the GSHP installation.

Figure 23. Perceived Distribution of Comfort Throughout Home During Summer for GSHP



With regards to the final question pertaining to comfort, four of the respondents noticed a change in basement temperature.

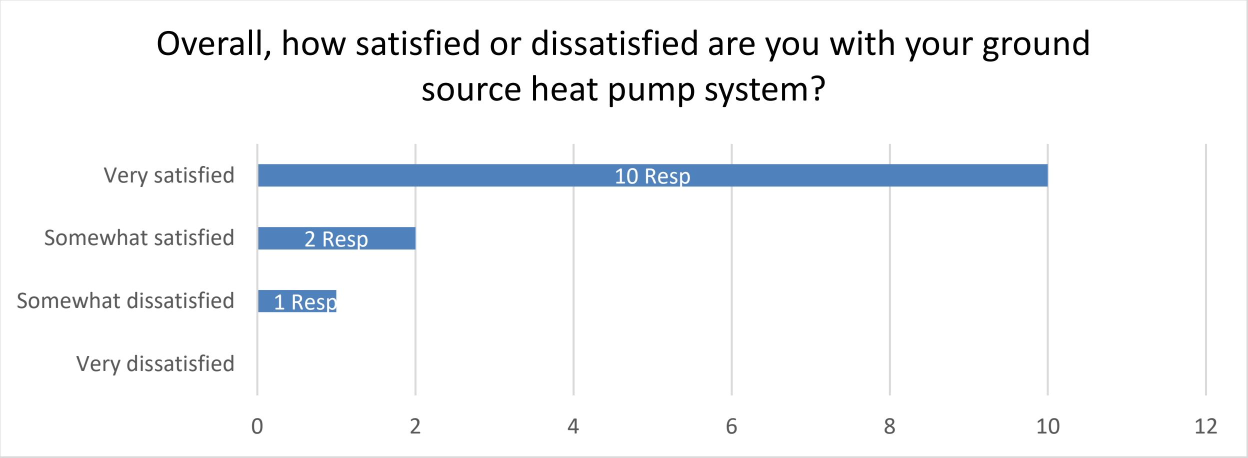
4.6 Operation

Of the 15 respondents to this survey question, 12 reported that it was “very easy” to operate their heat pump, two reported that it was “easy,” and one said it was “difficult.” Two did not answer the question.

4.7 Satisfaction

The survey asked those who had experienced their heat pumps for a year, about their satisfaction level with their heat pumps in both the heating and cooling seasons. As shown in Figure 24, 12 out of 16 responses to the final survey have reported that they are “very satisfied” or “somewhat satisfied” with their GSHP system, the level of effort they put into the project was worth the achieved benefits. No respondents are very dissatisfied with their ground source heat pump system: however, one answered they were “somewhat dissatisfied.”

Figure 24. Participant Satisfaction with GSHP Systems



4.8 Other Feedback

Between the various surveys (web and phone, pre- and post-retrofit), homeowners provided a number of other comments that did not necessarily fit within a specific survey question. Below are some additional comments given by the participants:

After 1-year of GSHP Operation—Positives/Benefits

- “With the cost of fuel continuing to increase the savings from not having to get oil delivered every month is good.”
- “No banging radiators. Quiet operation.”
- “Air humidity better, air is cleaner, quieter, basement smells better. Folks like it. Like not having to buy fuel oil.”
- “It's quieter than I expected.”
- “Total cost of energy is lower. The variable speed heat pump/fan modulates the temperature more gradually, smoother, and it thus much quieter. Fewer noxious oil by-product smells. Humidity is better (35–40% in the winter) and we don't need the humidifier as we did with the oil burner and old A/Cs.”

After 1-year of GSHP Operation—Negatives/Issues

- “It’s very loud and it is housed in a room under my bedroom so I always hear the pump.”
- “Doors slam shut. Temperature on especially cold days does drop below setting.”
- “Forced air is not ideal for slab houses.”
- “We had lots of freeze outs in the first winter—didn't install antifreeze, delayed installing it, lost web access and data for a few months due to installer delay responding to outage. I believe it is under warranty but still don't know what maintenance is recommended. I think the entering water temp is too low in the winter, not sure if the well was done to optimally.”

- “The system struggles in the wintertime when the temperatures are extremely low. Single digit and sub-zero temperatures are challenging for the system to warm my home.”
- “It's happened once where it didn't heat at all. I ended up resetting the circuit breakers and it was fine.”
- “I'm more conscience of drafts. My next plan is to get better insulation and seal up the house better.”
- “The inability to get my master bedroom to be a temp I desire.”

4.9 Summary of Customer Survey Findings

Based on participants responses it is apparent that homeowners were driven to install heat pumps as a way to lower conditioning costs and increase comfort throughout the year. Concerning the installation, most homeowners were very satisfied with their contractor even though more than half thought the installation process was more invasive than installing a traditional system. Almost all thought the heat pumps were very easy to maintain and operate, more so than their original systems, though some felt there should be a service available to conduct regular maintenance such as a service contract. One participant said the ground source heat pump was more difficult to maintain than their previous system.

Participants had a range of satisfaction levels with their original heating and (if applicable) cooling equipment, but most expected the heat pumps to maintain temperatures better (especially in cooling) when compared to their previous system. This was achieved in cooling for all but two out of seventeen respondents. In heating, expectations were not met by all participants with just under half indicating the ground source heat pump maintained the temperature in the rooms about the same (6 participants) or slightly worse (1 participant). No respondents indicated they were too cold or too hot in every room with the heat pumps installed. In the end, overall satisfaction with the heat pumps system was achieved with only one out of seventeen respondents expressing dissatisfaction (somewhat), and no one indicated they were very dissatisfied.

5 Technology Transfer

A Technology Transfer plan will be developed to address market barriers preventing more widespread adoption of geothermal technology.

The primary focus of this Technology Transfer plan will be on deliverables that speak to New York State homeowners looking for unbiased, third-party data to help inform purchasing decisions. Second, the plan will provide information to HVAC installation contractors to enhance their knowledge of geothermal systems and the benefits to becoming an installer through the use of case studies or other pertinent data gathered from the demonstration.

Materials that showcase important findings and lessons learned will be generated. Table 28 summarizes the type of activities and information that could be developed.

Table 28. Tech Transfer Materials That Will Be Developed

Segment	Activities	Information
Homeowners	Fact sheets Case studies Photography	Average bill savings, available incentives & GJGNY financing, average payback, advantages, lessons learned, testimonials, societal benefits.

6 Findings and Recommendations

This section summarizes the key lessons and findings that resulted from this project.

6.1 Findings from Measured Performance Data

This follow-on study using the Water Furnace Symphony™ system to collect data from residential GSHPs installed on Long Island proved to be a successful extension of a similar study of GSHPs in Upstate New York (NYSERDA Report 18-03). Though the challenges of using the Symphony™ embedded heat pump controls for monitoring were apparent here, in that 5 of 33 sites could not maintain internet connectivity for sufficient data collection. While the Symphony™ approach is cheaper than using dedicated data loggers, allowing for some data loss as well as accounting for sensor accuracy issues must be factored into project planning for this approach.

As expected, the ground loops for the Long Island homes were still sized to meet the peak heating loads— even though the peak heating loads were lower in the milder downstate climate. The average entering water temperatures for heating were 2.5°F higher than for the upstate homes (42.7°F compared to 40.2°F). In cooling, the average EWTs were just under 2°F higher than for the upstate GSHP systems (67.5°F compared to 65.8°F). Cooling operation in the Long Island homes accounted for a larger fraction of total system energy use than for the upstate homes. Correspondingly, the average corrected total heating COP were higher on Long Island, with fleet average of 3.81 compared to 3.62 for the upstate sites.

The peak heating demand for days near 10°F was 0.75 kW per installed cooling ton. This diversified average demand was about 20% lower than the demand measured for ccASHPs in the Brooklyn-Queens study (NYSERDA Report 22-04). In the summer the normalized peak demand for the GSHP units was about the same as for the ccASHPs in Brooklyn Queens, after adjusting for sizing and other issues. This finding confirms the demand reduction benefits of GSHPs compared to other heat pump technologies—especially in the winter. The often-anticipated summer demand reductions of GSHPs were not realized from the measured results in these studies.

The cost savings for GSHP systems were highest when the displaced heating fuel was fuel oil or electricity and lowest for the natural gas sites. The average annual cost savings for the 18 fuel oil homes was $173 per installed ton, or 34¢ per square feet of floor area. For the two natural gas sites, the average annual cost savings were $76 per installed ton, or 7¢ per square feet of floor area. The one site that originally had electric resistance heating had annual cost savings of $288 per installed ton, or 69¢ per square feet of floor area. The costs analysis used regional 2020 rates of $0.2019/kWh, $1.385/therm, and $3.23/gallon. A sensitivity analysis showed that assuming 40% higher fuel costs—reflecting current post-pandemic conditions—increases the annual savings from $76 to $145 per ton for natural gas and from $173 to $295 per ton for fuel oil.

The average installed cost of the GSHP systems was $5,987 per installed ton, after factoring in PSE&G-LI incentives as well as federal tax credits. The average simple payback for the GSHP systems was 41 years compared to natural gas and 20 years compared to fuel oil using the 40% higher fuel costs.

Applying the EPA eGrid overall average factors for the Long Island electric grid allowed us to determine the greenhouse gas (GHG) savings for various fossil fuel scenarios. For the homes that originally use natural gas, the GSHP systems reduce GHG emissions by 877 pounds of CO_2-equivalent per year per installed ton, or 1.3 pounds per year per square feet of floor area. For homes that used fuel oil, the reduction due to GSHP installation was 1,337 pounds of CO_2-equivalent per year per installed ton, or 2.6 pounts per year per square feet of floor area.

6.2 Homeowner Perceptions and Motivations

The survey results confirmed the importance of homeowner economics—that is, energy costs, maintenance costs, and financial incentives—in their decision to install a geothermal heat pump. Environmental and utility infrastructure concerns were less important than important then homeowner economics. Most homeowners were happy with the comfort (i.e., thermal distribution and indoor temperature control) provided by the new GSHP installation. Compared to the studies with cold climate ccASHPs (NYSERDA Reports 22-04 and 22-08), homeowners with GSHPs appeared to be more satisfied with the comfort provided with these systems. Corroborating this point, the measured data showed that the majority of GSHP systems used little or no backup resistance heating.

6.3 GSHPs Compared to ccASHPs

This study confirmed the expected benefits of dual stage and variable speed GSHPs in terms of fossil fuel reductions and electric utility impacts. The total seasonal heating COP was over 3.8 for the GSHPs and the heat pumps replaced 100% of fossil fuel use. In contrast, the ccASHPs in the companion study

(NYSERDA Report 22-04) had a seasonal heating COP of 2.4 and the heat pumps displaced 80% of fossil fuel use. The GSHP units had 20% lower diversified peak electric demand in winter compared to the ccASHPs in the companion study, even though the ccASHPs had mostly fossil fuel backup. Obviously, ccASHPs with electric resistance backup would have an even higher winter peak demand.

From the homeowner's perspective, GSHPs provide better comfort and GSHP economics are slightly better than for ccASHPs. The total installed cost per ton for the GSHPs is more than twice as much as for ccASHP systems before incentives and tax credits ($10,570 per ton vs. $4,483 per ton). However, the best-case GSHP cost savings per ton compared to fuel oil were approximately three times better than for the ccASHPs ($295 per ton vs. $99 per ton with current fuel costs). With incentives and the newest 2022 tax credits applied, the installed cost of GSHPs drops to near $5,200 per ton, giving a best-case simple payback near 18 years. This payback for GSHPs is better than can be achieved for the ccASHPs in the companion study, even after incentives and the newest tax credits are applied to these systems. Further, the benefit-to-cost ratio is greater than one for GSHPs since the simple payback is shorter than the expected life of 25 years.

6.4 Recommendations for Future Studies

One issue that should be addressed by future field tests is the reliability and accuracy of the on-board monitoring systems like the Water Furnace Symphony™ system. This project had planned to do further on-site verification of the Symphony™ sensors by a comparison to other independent measurements. The plan was to install Onicon flow meters (with HOBO dataloggers) was ultimately abandoned because of limited access to each home during COVID. Future field test studies with the Symphony™ system or other similar on-board monitoring systems should plan to complete this independent evaluation of the on-board flow meter.

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Appendix A. Performance Validation Plan and Survey Instrument

Performance Validation Plan

for

Applied Energy Group:

Demonstrating WaterFurnace Geothermal Heat Pumps in Long Island Homes

under

NYSERDA PON 3127
Emerging Technologies Demonstration Projects – Residential HVAC

Revised

August 14, 2017

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Contents

Introduction

Background

The Applied Energy Group (AEG) has been awarded a project under NYSERDA PON 3127 (Residential HVAC) to install 40 residential geothermal heat pump (GHP) systems on Long Island using a standardized approach. NYSERDA's Residential HVAC initiative seeks to accelerate the market uptake of commercially available, but underused building strategies in the residential sector. This initiative aims to demonstrate technologies that offer measurable energy savings and greenhouse gas (GHG) reductions. It seeks to address barriers to wider commercialization in the residential market via a series of multi-site demonstration projects in existing homes and residential buildings.

Geothermal heat pumps (GHPs) offer lower energy costs and reduced GHG emissions compared other heating and cooling options. In the winter, GHPs extract heat from the ground, eliminating the consumption of fossil fuels for heating. In the summer, GHPs have the potential to reduce the peak load on Long Island's electric grid compared to conventional cooling systems. Therefore, GHPs offer significant benefits to the electric utility: increasing annual electric sales while reducing peak summer electric demand. GHPs are also compatible with an electric grid that is increasingly served by renewable energy sources.

Despite this, GHPs are currently experiencing slow growth in New York State, mostly due to the higher installed costs than other technologies. AEG asserts that the market barrier of high costs—which limits widespread adoption—is due to a lack of standardization. Therefore, they are developing a standardized geothermal system package and design documentation that can be broadly applied to as many installations as possible. This standardization can lower costs by streamlining building department plan review and facilitating bundling of many installations to attract investment capital for large scale installations.

The AEG project will develop formal customer selection and acquisition procedures to address a number of additional barriers to increase GHP market uptake. These include consumer and installer awareness and demand, technical challenges relating to design and specification, and a lack of high-quality field performance data in New York.

AEG will install 40 residential GHP systems on Long Island using the standardized approach. They will identify a set of homes on Long Island that are good candidates for geothermal installations. All installations will be closed loop systems, which removes site groundwater variability and allows for a more replicable and standardized design and installation. They will target homes that have both heating and cooling loads.

AEG will aim to install GHP systems in homes that are part of PSEG LI's Home Performance Program. Some sites will have envelope improvements made at the same time as the geothermal installation. All systems will use WaterFurnace heat pump units that come with the Symphony™ monitoring system. This monitoring system will facilitate the collection of measured performance data at regular intervals. The measured data will allow for an independent evaluation and analysis of GHP performance, to confirm cost savings are achieved and to build market confidence.

Performance Validation Approach

Overview

The AEG team will identify sites and install WaterFurnace GHPs at 40 homes on Long Island. The units will either be Series 5 (dual capacity) or Series 7 (variable speed) units. All heat pump units will have the Symphony™ monitoring system with the "Performance" option to ensure that the loop-side flows and temperatures, air-side temperatures, operating statuses, refrigeration data, and power readings are all collected. This monitoring system will provide high-resolution performance measurements at a large sample of sites.

In addition to the heat pump installation, some sites will also have envelope improvements implemented at the same time in accordance with the Home Performance with Energy Star (HPwES) program requirements. Some houses that have previously been through the HPwES program may have the GHP installed without further envelope improvements.

The 40 sites are expected to be existing homes that are now heated by either natural gas, fuel oil, propane, or an air-source heat pump. Some homes may also use electric resistance heat. The existing heating systems at the targeted sites are expected to be a mix of furnaces and boilers. Most homes are expected to have some form of existing cooling installed, likely central air conditioning or room/window air conditioning units. In many cases the GHP system may also provide supplemental water heating using a desuperheater feature.

Pilot Design

The overall goal of this performance validation effort is to gather the necessary field data from this sample of pilot sites to address market barriers and other concerns of various stakeholders:

- Consumers/homeowners want confidence and confirmation that the expected benefits will be achieved, namely reduced fuel bills and net energy cost savings while maintaining adequate comfort.
- Policy makers similarly want to confirm that expected energy impacts and GHG reductions are realized.
- Designers and installers need feedback on the impact that ground loop design decisions and heat pump equipment sizing have on realized performance and efficiency.
- Installers want to understand what issues motivate consumers/homeowners to purchase a GHP system, so that marketing strategies can be tuned to focus on key issues.
- Installers and the finance community want to understand the range of variation of installation costs and cost savings across a portfolio of installations, understanding the variability of cost savings at a known level of confidence.
- Utilities want to understand the impact that GHPs will have on electric load growth, residential load shape, and peak demand.

The selection criteria for test sites included in sample for this study must be focused on the goals listed above. Further, measurements at each site must be designed to gather the required information. Each of these issues are addressed below.

Site Selection Criteria (Sample Design)

All forty sites will be retrofits of closed-loop GHP systems at single-family residential homes on Long Island. The heat pumps will be WaterFurnace Series 5 (dual capacity) or Series 7 (variable speed) units. As many as 10 sites may also have an additional single-stage, “split-system” Water Furnace heat pump installed (with the AHU located in the attic). The GHP system will replace an existing heating system with either fuel oil, propane, natural gas, electric resistance, or conventional air-source heat pumps. All homes will have some kind of existing cooling (central or window air conditioning). Some homes may use the desuperheater feature of the WaterFurnace unit to provide supplemental water heating (i.e., free water heating in the cooling mode).

Many of the homes will have building envelope improvements implemented as part of the GHP system installation under the PSEG Long Island Home Performance Program. This is in keeping with the EPA Home Performance with Energy Star (HPwES) performance criteria. At some homes the envelope improvements may have been completed previously, so the retrofit may only include the GHP system improvement.

Homeowners will voluntarily choose to participate in this study and ultimately make the final purchase decision for what is installed and retrofitted into their home. The AEG team will propose various options for each homeowner based on upfront estimates of cost effectiveness as well as homeowner interests and preferences.

For all homes in the study, CDH will document the key characteristics and details so that these factors can be compared to performance variations we observe in the sample.

Data Collected at Each Site

The measured performance data will be collected for each GHP system using the WaterFurnace Symphony™ monitoring system. Pre-retrofit utility bills and customer survey results will round out the data collection at each site. The collected data will answer the following questions:

- What are the heating and cooling energy and cost savings achieved with the retrofit? What portion of the savings can be attributed to the GHP system and to the building envelope improvements?
- What are the seasonal average heating COP and seasonal average cooling efficiency?
- What are the average ground loop temperatures (entering the heat pump) during each season? How do loop temperatures change across the year?
- How does unit capacity and efficiency vary over a range of operating conditions (different loop temperatures, different loading)? Does measured performance match the manufacturer’s published data?
- How does the GHP system impact the electric load shape or demand profile for the home that is imposed on the electric utility? What are the peak demands during key seasons?
- How are comfort conditions (measured and perceived) impacted by the GHP retrofit?
- Is the Symphony™ monitoring system sufficiently accurate to be used for tracking system performance? Is the instrumentation sufficient for thermal metering or billing purposes?

Data Collection Details

CDH will verify the performance of the GHPs using Symphony™ data to measure post-retrofit energy use, efficiency, and comfort conditions. Pre-retrofit energy use will be quantified with monthly utility bills or fuel delivery logs from before the GHP installation. A survey will be administered to assess the comfort conditions and occupant satisfaction.

GHP Monitoring at Each Site (Post-Retrofit)

The Symphony™ system, will be used to measure the performance of the GHP systems after the retrofit. The WaterFurnace units will include full Symphony™ monitoring with all of energy, refrigeration, and performance data points (control option “D” for Series 5 / ND units, and control option “K” for Series 7 / NV units).

The data points collected by the various Symphony™ system listed in Table 1 below. The points are schematically shown in Figure 1 (these locations will be confirmed during the on-site verification).

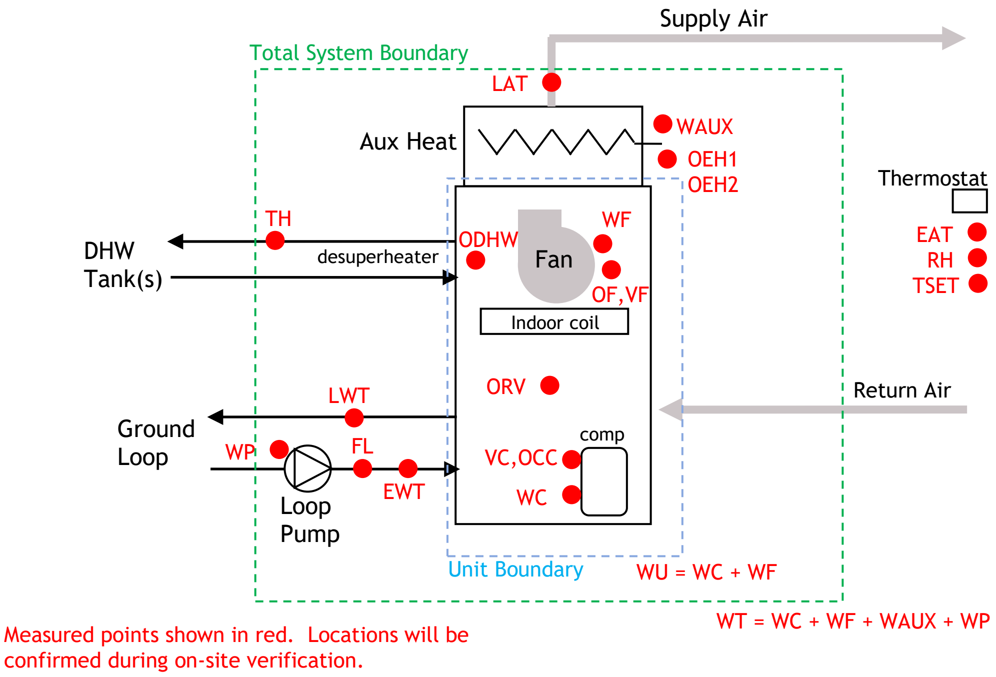

Figure 1. Schematic of Heat Pump System Showing Measured Data Points

Table 1. Data Points in the Symphony™ Monitoring System

Symphony Name	Symphony Description	CDH Variable
id		
logtime	date time	
logtimeepoch		
activeinputsatlockout		
activeoutputsatlockout		
actualcompressorspeed	Act Comp Speed	VC
aircoiltemp	FP2	TCOIL
airflowcurrentspeed	Fan Speed	VF
airflowpwmdutycycle		
aocalarm		
aocambienttemp	AOC Ambient Temp	TAO1
aocderatingstatus		
aocdrivestatus		
aocenteringwatertemp	AOC EWT	EWT1
aocsafemodestatus		
aurorainputdh	DH	SDH
aurorainputes		
aurorainputg	G	SG
aurorainputh	H	SH
aurorainputhps		
aurorainputlps		
aurorainputls		
aurorainputo	O	SO
aurorainputw	W	SW
aurorainputy1	Y1	SY1
aurorainputy2	Y2	SY2
auroraoutputacc		
auroraoutputalm		
auroraoutputcc	CC	OCC
auroraoutputcc2	CC2	OCC2
auroraoutputeh1	EH1	OEH1
auroraoutputeh2	EH2	OEH2
auroraoutputf	Fan Relay	OF
auroraoutputl		
auroraoutputrv	RV	ORV
auxcurrent	Aux Current	
auxpower	Aux Power	WAUX
coaxtemp	Clg LL	TLQC
compressor1current	Comp1 Current	
compressor2current	Comp2 Current	
compressorpower	Comp Power	WC
condensertemp	Sat Cond	TSATC
currentecmspeed		
desiredcompressorspeed	Des Comp Speed	VC_SET
dhwsetpoint	HW Setpoint	TH_SET
digitaloutputk1		
digitaloutputk2		
digitaloutputk3		
digitaloutputk5		
digitaloutputk6	DHW Relay	ODHW
dischargepressure	Disch Press	PDIS
dischargetemp	Disch Temp	TDIS
eev1openingpct	EEV1 Open %	VEEV1
eev2openingpct	EEV2 Open %	VEEV2
enteringwatertemp	EWT	EWT
estimatedlinevoltage	Line Voltage	
evaporatortemp	Sat Evap	TSATE
fancurrent	Blower Current	
fanpower	Fan Power	WF
fp1inputreading	FP1	
fp2inputreading	FP2	
heatingliquidlinetemp	Htg LL	TLQH
heatofextrej	HE / HR (KBtuh)	QL
hotwatertemp	HW Temp	TH
htgclgsubcooling	Htg/Clg SC	T_SC
internalinputs		
lastfault		
leavingairtemp	LAT	LAT
leavingwatertemp	LWT	LWT
lockedout		
lockoutstatuscode		
lockoutstatuslast		
looppumppower	Pump Power	WP
looppumppressure	Loop Press	DPL
modeofoperation		
suctionlinetemp	Suct Temp	TSUC
suctionpressure	Suct Press	PSUC
superheat	SH	T_SH
totalamps		
totalunitpower	Total Power	WT
tstatactiveoutputs		
tstatactivesetpoint	Active Setpoint	TSET
tstatcoolingsetpoint		
tstatdehumidsetpoint	Dehumid Setpoint	DSET
tstatheatingsetpoint		
tstathumidsetpoint	Humid Setpoint	HSET
tstatmode		
tstatoutdoorairtemp	OAT	TAO
tstatrelativehumidity	Dehumid %	RH
tstatroomtemp	EAT	EAT
universalinput1		
variablespeedpumppwm	Loop Pump PWM	
vspumppwmoutput		
vspumpspeedpct	Loop Pump Speed	VP
waterflowrate	FLOW	FL

Key: Yellow – Energy; Green – Refrigeration; Blue – Performance; Purple/Orange – Control; Rose – Misc.

Most of these points are direct measurements by temperature sensors, flow meters and refrigerant pressures. Refrigeration saturation temperatures, superheat temperatures, and subcooling temperatures are determined using the measured readings combined with refrigerant property calculations. Component statuses are used to determine the runtime of components and control settings. The power readings are inferred or determined by various means (this will be documented in the on-site verification report, see below). The heat rejection/extraction is calculated from the flow and temperatures along with user-entered fluid characteristics (entered by the installer at setup).

The Symphony™ monitoring system transmits 10 second data back to the server in close to real time. It does not have a large on-board storage buffer, so if the internet connection resets or is lost for more than 6 minutes, some data records are lost.

On Site Measurement Verification

CDH shall visit four GHP sites and use our independent instruments to check the data readings from the Symphony™ system (preferably, CDH can schedule the four visits in 2 consecutive days). The hand-held measurements we expect to make are listed in Table 3.

Table 2. On-Site Verification Measurements

Measurements	CDH Instrument	Accuracy
Power use (kW) of each component (unit, pump, compressor, fan)	Fluke 39 Power Meter (true power)	±1% of reading for Watts
Pipe temperatures (water and refrigerant)	Fluke 51 II Temp Sensor (surface)	~ ±1.4°F (approx. half for ΔT)
Water flow rates	Fuji Portiflow FSCS Transit Time Ultrasonic Dynasonics DUFX1-D1 Ultrasonic Doppler	~ ±0.25 gpm @ 1 inch ~ ±1.5 gpm @ 1 inch
Air temperatures and humidity	TSI VelociCalc T9545	±0.5°F and ±3% RH
Airflow rate	TSI VelociCalc T9545 (equal area traverse)	±3% of reading

We will take various measurements with these handheld meters that can directly compared to the Symphony™ readings at the same moment to confirm the validity of the Symphony™ measurements. For each measurement, we will collect several pairs of Symphony™ and handheld readings so that the average difference can be determined.

- The Fluke power meter will be used to take power readings for the compressor, fan, pump and auxiliary resistance heater that will be directly compared to the Symphony™ power readings (WC, WF, WP, WAUX).
- The surface temperatures on the entering and leaving loop temperatures will be measured with the handheld meter and compared to Symphony™ readings. We will compare both absolute temperature readings and temperature differences.

- The loop water flow rate will be measured with the Fuji Ultrasonic flow meter and compared to the Symphony™ readings. If the Fuji (transit time) meter is unable to get a reading, then we will use the less accurate Dynasonic (Doppler) meter.
- The Fluke or TSI handheld meters will be used to confirm air temperatures on the Symphony™ system. We will confirm relative humidity readings with the TSI probe.
- We will make an independent measurement of the unit air flow rate by completing a velocity traverse on the GHP unit. We will take 10-16 velocity readings by the equal area method to determine airflow (with homeowners permission, we will drill 4 to 5 ¼-inch holes in the ducts to measure airflow; when we are finished, the holes will be sealed with standard red plastic plugs). We will also record the fan power and fan speed corresponding to each airflow reading.

We will summarize and compare the handheld readings and Symphony™ readings in an on-site verification report to evaluate the accuracy of the instrumentation included with the Symphony™ package. The on-site verification report will document details of the individual Symphony™ sensors (sensor type/model, locations, installation details, etc.), and will also include any details we receive from the manufacturer on how the various readings from the Symphony™ system are measured, collected, or determined.

Uncertainty Analysis

Once we have completed the on-site inspection and verification process, we will develop estimates of uncertainty that can be applied to each Symphony™ measurement (Δx_1, Δx_2, … Δx_n). Then the measurement uncertainties can be propagated for each calculated quantity Y that is determined from independent measurements X_1, X_2, to X_n using:

$$\text{Probable error of Y} \quad = \quad \Delta Y \quad = \quad \sqrt{+\left(\Delta x_1 \cdot \frac{dY}{dx_1}\right)^2 + \left(\Delta x_2 \cdot \frac{dY}{dx_2}\right)^2 \ldots. + \left(\Delta x_n \cdot \frac{dY}{dx_n}\right)^2}$$

This process will be applied to calculated quantities such as heating and cooling output, ground loop heat rejection, coefficient of performance (COP), energy efficiency ratio (EER), etc.

Heat Measurement Verification

As an additional verification step, AEG will fit the four sites used for on-site measurement verification with a BTU meter that meets industry standards for accuracy,[1] such as the Onicon System 40. CDH will install a HOBO UX90 data logger on each BTU meter to collect the flow and energy data at 15-minute intervals. AEG will acquire and install the BTU meter with assistance from CDH. CDH will supply and install the data logger on the BTU meter. AEG will retrieve the data logger from the site and ship it to CDH at the end of the measurement period. After BTU meters are installed at these four sites, AEG will install additional BTU meters at six more sites. These six sites will be nominated by AEG as part of the site selection/approval process (and should be at homes that that only include Symphony-equipped heat pump units). CDH will also supply AEG with six additional data loggers to install at those sites.

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[1] Existing standards for heat meters globally include OIML R-75 (International Organization of Legal Metrology), EN1434 (European Committee for Standardization), C900-1 (CSA Group, Canada). The draft standard for the U.S., ASTM, is under development and is based largely on EN1434.

CDH will compare flow and heat data from the BTU meter with the data collected by the Symphony™ system. This comparison will serve as an additional step to validate the accuracy of the Symphony™ system, aiming to answer the question of whether the Symphony™ heat measurement instrumentation is adequate for thermal metering and billing purposes.

Data will be compared using plots of Symphony™ data versus the BTU meter data for each time interval, conducting regression analysis to identify any slope, offset, regression coefficient, and associated p value (confidence interval). Plots will also be created showing the difference between the data points versus temperature and flow to identify any variations in measurement error that may exist across the range of operation.

Pre-Retrofit Utility Bills/Fuel Logs

Because detailed pre-retrofit performance data will not we available, the energy use and heating load data will be determined by evaluating monthly fuel oil and propane delivery logs, and gas and electric utility bills. AEG will provide CDH with at least 12 months of logs and bills (with exact delivery dates or meter read dates) to quantify pre-retrofit performance. CDH will correlate this data with outdoor temperature data from the nearest airport weather station for each monthly period (from Weather Underground, www.wunderground.com). CDH will use the linear trend of energy use with temperature to discern the portion of the bill attributable to space heating. The same process will be repeated for electric utility bill data to discern the space cooling energy use trend with ambient temperature.

Site Characteristics Data Collection

We will also collect information on the GHP installation and other details about the existing facility at each site (Table 3). Some GHP system information is available in the Symphony™ database, as is noted in the table below. The AEG team will help provide the other information to CDH.

Table 3. Site and System Characteristics

Parameter	Description
City or Town	From Symphony
Heat Pump Model and Size	From Symphony
Number of Units at Site	From Symphony
Desuperheater Option Available?	From part number
Desuperheater piping installed?	Has it been connected
Desuperheater/DHW Arrangement	Plumbed into existing tank or new pre-heat tank
Building Size	Gross sq ft
Manual J Load Calcs	Load calculation details, Heat & cool
Ground Loop Type	V1, V2, H2, H4, H6, HS, open, pond

Parameter	Description
Closed Loop Type	# circuits – circuit length – pipe diam – depth
Loop fluid	Water, methanol, ethanol, prop glycol
Freeze protection	Min. fluid temperature rating
Description of any envelope improvements	Envelope measure details
Description of any distribution system improvements	Ductwork or distribution modifications
Existing heating system	Model, type, size, fuel source
Existing cooling system	Model, type, size

Note: Data in shaded rows is available from the Symphony™ System

Customer Feedback Survey

In addition to the measurements described above, CDH will administer web-based surveys to each homeowner. The goal of the surveys is to solicit feedback from customers to assess their perceptions and satisfaction of the geothermal heat pump system. In many cases, we will ask for their perceptions of metrics that we will also directly measure.

Two surveys will be administered to each of the 40 homeowners who participate in the geothermal heat pump upgrade under this program: The first will be around the time of the GHP system installation, and the second will be after 9 to 12 months of operation. Table 4 lists the research questions that the web survey intends to address and the specific subtopics through which responses will be elicited. Draft survey questions are given in Appendix A.

CDH Energy will prepare the survey with the assistance of AEG and/or NYSERDA. CDH will design the survey using the online service SurveyMonkey. AEG’s mechanical contractor (ZBFGeothermal) will send out an email letting their customers know the survey will be forthcoming. AEG/ZBF will also provide a list of the customer email addresses for entry into SurveyMonkey. The official survey email and link will be sent to the customers via the SurveyMonkey system.

After each round of surveys, we expect to follow up by phone with at least 10 homeowners with a series of follow-on questions that are based on responses to the web-based survey.

Table 4. Research Questions to be Addressed via Web Survey

Research Question	Topic(s)	Subtopic(s)
How does customer satisfaction change between the original system and the new system?	Overall rating	Satisfaction with original heating and cooling systems Satisfaction with new GHP system
How does customer perception of comfort levels change from before to after the GHP and building envelope retrofit?	Comfort levels	Perceived temperature and temperature distribution during winter and summer at time of retrofit Expected temperature and temperature distribution during winter and summer after retrofit (asked at time of retrofit) Perceived temperature and temperature distribution during winter and summer after retrofit
How do customers perceive energy costs, maintenance, and performance of the new system compared to the original system?	Perception and expectation of systems	<u>At time of retrofit:</u> Perceived energy costs of original heating and cooling systems Expected change in energy costs during winter and summer Perceived level of effort to maintain original heating and cooling systems Expected level of effort to maintain new GHP system <u>After retrofit:</u> Perceived energy costs of new GHP system Perceived energy costs compared to expectations Perceived level of effort to maintain new GHP system Perceived change in basement temperature
What motivated the customer to install a GHP system?	Motivations	Why customer decided to purchase and install the system
Do the customers experience any unexpected benefits or problems, and if so, what are they?	Unexpected effects	Unexpected benefits Unexpected problems
Has household occupancy changed? Is thermostat setback/setup used? Other control changes?	Occupancy or Control Changes	Track these issues pre and post as well as across the post period
How did customers perceive the installation process?	Installation	Level of “invasiveness” of installation compared to boiler replacement.

The responses from each survey will be paired with the site so that site and system characteristics can be part of the analysis where required. Survey data will be presented as an aggregate or in subsets. Individual surveys received will not be published without the express permission of the homeowner. The survey results will be collected in a Survey Findings document, which will appear as an Appendix in the Validation Report.

In addition to the summary of results for each question, the survey analysis will compare expectations and perceived changes to actual changes for each point where possible. We will also investigate potential reasons for any variations in changes for subsets of the group, for example the level of satisfaction with the original system, the type of equipment replaced, and the site and system characteristics.

Data Analysis

Pre-Retrofit Data Analysis

CDH will correlate the pre-retrofit utility bill or fuel log data with outdoor temperature data from the nearest airport weather station for each monthly billing period. We will use the exact dates of the billing period to find the average temperature corresponding to that period as well. CDH will use the linear trend of energy use with temperature to discern the portion of the bill attributable to space heating and space cooling. The result is expected to be similar to the data shown in Figure 2 for a multi-family building. In this example from a real site, the average fuel use for each billing period (in therms per day) is well-correlated to the average temperature in the period.

Gas use reaches a minimum value in the summer, which may correspond to gas use for domestic water heating (DHW). For GHP systems with a desuperheater installed, we will also use monthly fuel logs or energy bills to estimate the fuel/energy use associated with DHW during the pre-retrofit period.

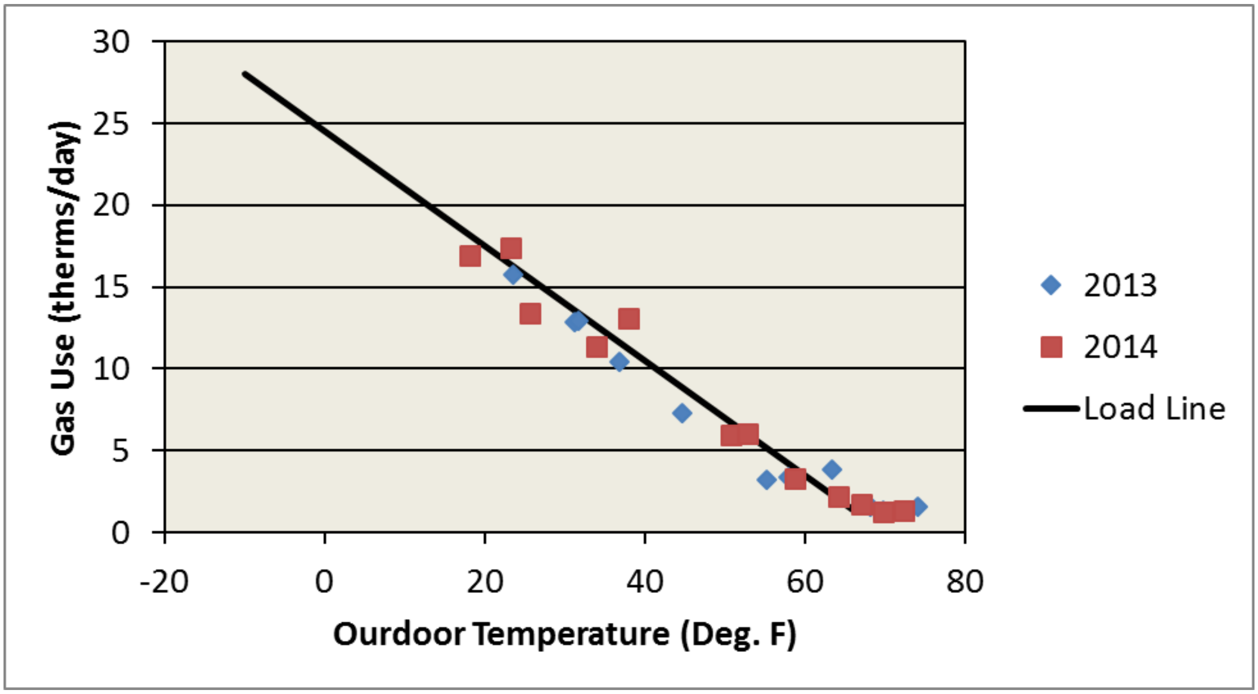

Figure 2. Example of Building Gas Use Correlated to Average Ambient Temperature in Monthly Billing Periods

The pre-retrofit space heating and cooling loads will be determined by the energy and fuel use trends using appropriate heating efficiencies and air conditioner performance curves (extracted from mainstream simulation models such as EnergyPlus).[2] From this analysis, we will be able to measure or infer:

- Heating and cooling energy use trends with outdoor temperature (measured)
- DHW fuel or energy use
- Space heating and cooling loads with outdoor temperature (inferred)

Post-Retrofit Data Analysis

The Symphony™ monitoring system will provide detailed performance data for the post-retrofit conditions. The system collects 10-second data that will be aggregated into 15-minute data to quantify seasonal performance. The calculation procedures to determine these quantities or interest are described below.

Calculated Quantities

The heat rejection or extraction to and from the ground loop will be integrated using:

$$QW = \sum_{j=1}^{N} qw_j \cdot \Delta t = \sum_{j=1}^{N} k \cdot FW_j \cdot (EWT_j - LWT_j) \cdot \Delta t$$

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[2] At sites with no envelope improvements, the heating and cooling loads inferred from the pre-retrofit period can be directly compared to the post-retrofit measured heating and cooling loads to gauge the effectiveness of this analysis method.

Where:

QW - Total heat extraction or rejection (Btu). Extraction is positive.
qw - Heat extraction or rejection rate (Btu/h)
EWT - Entering water temperature (°F)
LWT - Leaving water temperature (°F)
FW - Water flow rate (gpm)
k - Product of specific heat and density for fluid in loop (~500 Btu/h-gpm-°F for water at 60°F). This can be a function of fluid temperatures.
Δt - Time increment (1/360 hrs for 10 second data)

The jth value corresponds to each 10 second interval. N is number of intervals over the period of interest (i.e., hour, day, month, or season). If the flow, FW, does not go to zero when the pump is off, we may also include pump status in the calculation to ensure the measurement errors when the heat pump is off do not skew the measurements.[3]

We also may separately sum (or integrate) positive and negative values of qw_j to find the total heat extraction (QWE) and heat rejection (QWR) for each period of interest.

The total electric use for the heat pump unit can be determined by summing the power in each interval:

$$WU = \sum_{j=1}^{N} wu_j \cdot \Delta t$$

Where:

WU - Total power use for heat pump unit (kWh), including compressor, fans)
wu - Power for the heat pump unit (kW)
Δt - Time increment (0.25 hrs for 15-minute data)

The jth value corresponds to each 15-minute interval. N is number of intervals over the period of interest (i.e., hour, day, month, or season). The energy associated with heating (WUH) and cooling (WUC) can also be determined by summing values when the heat pump is each particular mode.

Similarly, the total system energy use (WT) can be determined by adding in the auxiliary heating element power and pumping power to the unit power (WU). As for the unit power, it can be segregated into the energy associated with cooling (WTC) and the energy associated with heating (WTH).

The heating COP and cooling EER of the heat pump <u>unit</u> can be determined for the period of interest as:

$$COP_{htg} = \frac{QWE/3413 + WUH}{WUH} \qquad EER_{clg} = \frac{QWR/1000 - WUC \cdot 3.413}{WUC}$$

These equations result from first law analysis, or heat balance, on the heat pump unit. The COP is dimensionless, and EER has units of Btu/Wh.

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[3] We have determined that heat transfer values calculated by the Symphony™ system do ignore erroneous small flow values and match the values we calculate, so we will use the Symphony™ values directly.

Similarly, the heating COP can be determined for the total system by replacing WUH in the denominator with WTH. Similarly, for the total system cooling EER, WUC is replaced with WTC in the denominator. Note that in both cases, the values of WUC and WUH in the numerator are not changed, since the pump and auxiliary heater are external to the unit heat balance (see the boundaries in Figure 1).

The heating and cooling output for any period of interest can also be determined by:

$$QH = QWE + WUH \cdot 3413 \qquad QC = QWR - WUC \cdot 3.413$$

Time-weighted and load-weighted average temperature can also be determined for each site for any period of interest. Load-weighted average temperatures for the ground loop will put more weight on temperatures that occur when loads are higher while time-weighted temperatures equally average or weight all temperatures when the unit is on. The calculations are of the following form:

$$T_{load-wt} = \frac{\sum_{j=1}^{N} q_j \cdot T_j}{\sum_{j=1}^{N} q_j}$$

Where j is every 15-minute interval and q_j is the appropriate load.

For a time-weighted average, the average is taken whenever the criteria are met:

$$T_{time-wt} = \sum_{k=1}^{N_k} T_k / N_k$$

Here, k is every 15-minute interval that meets the criteria (i.e., unit is ON in the cooling mode), and N_k is the total number of intervals that meet the criteria.

Separating Desuperheater Performance

In many cases, the heat pump's desuperheating heat exchanger and pump will be attached to a tank. The tank pre-heats domestic hot water when the compressor operates and certain criteria are met. This water heating is part of the heating output of the unit in the heating mode and is already included in the COP above. In the cooling mode, the desuperheating energy is free (i.e., would have otherwise been rejected to the ground loop). The Symphony™ data point list in Table 2 includes two points related to desuperheater operation:

- desuperheater pump runtime (ODHW)
- hot water temperature from the desuperheater (TH)

The Symphony™ system has insufficient data to calculate the heating output based on these values. Therefore, we propose to use the published performance tables for the heat pump unit to predict the expected desuperheater heating output, and use the expected output along with the measured desuperheater pump runtime to estimate the DHW heating provided in both the heating and cooling modes.

From the measured data and the calculation procedures described above, we will be able to directly determine:

- Electricity use for each month and for the heating and cooling seasons (total system, HP unit, and for each component: compressor, fan, pump, auxiliary heater)
- The seasonal variation in ground loop temperatures as well as the (weighted) seasonal average in heating and cooling modes
- Seasonal average heating COPs and cooling EERs (for the total system and for the heat pump unit, see boundaries in Figure 1)
- Coincident peak demand profiles of the total system for both summer and winter seasons
- Space heating and cooling loads (seasonally; and as a function of outdoor temperature) for the post-retrofit building
- Space/thermostat temperatures and supply air temperatures to understand and quantify the post-retrofit comfort conditions
- Unit capacity, energy, and efficiency over a range of operating conditions.

Separating Heat Pump and Envelope Improvements

At some sites, it is likely that some envelope improvements will be included with GHP installation as part of each retrofit. In these cases, it would be desirable to separate the energy impacts of the GHP and envelope measures. We will use the measured space heating and cooling loads from the post-retrofit conditions (i.e., the Symphony™ data) to predict fuel and energy use for the original heating and cooling systems running to meet the post-retrofit loads. We will use appropriate heating efficiencies and air conditioner performance curves, as described in the pre-retrofit section above. We will contrast modeled performance with and without building envelope improvements.

Determining Energy Impacts and Cost Savings

The energy savings for the GHP and envelope improvements combined will be determined by directly comparing pre-retrofit energy use and post-retrofit energy use. Both electricity and fuel use will be determined. The pre- and post-retrofit data can also be correlated to outdoor temperature and combined with hourly typical year weather data (or bin data) to determine normalized energy use impacts for a normal or typical year.

To determine the impact of the GHP alone (i.e., separate from envelope improvements), we will use the predicted energy use for the original system meeting the post-retrofit heating and cooling loads (described above) compared to the measured post-retrofit energy use data.

Determining Energy Cost Savings

Utility costs for each home (or average costs for a sample of homes) will be used to determine energy costs and savings. The energy impacts described above will be used to determine energy costs in pre- and post-retrofit conditions. Electric tariff details (classification changes, kWh blocks, demand charges, etc.) will be applied as appropriate in the pre- and post-retrofit periods.

Validation Results and Reporting

Cross Site Analysis and Comparisons

Based on the analysis at each site, we can compare high level performance metrics at the sites, factoring in the different characteristics and customer perceptions for each site. The goal is to look for performance trends in the 40 site sample that can be correlated or explained by the characteristics of the site that are listed in Table 3. We will also compare customer perceptions of cost savings and comfort with actual measured results. We will use regression analysis or statistical methods to assess trends and understand the uncertainty associated with them. Some of the performance metrics we plan to compile for each site are listed in Table 5.

Table 5. High Level Performance Metrics (Values) for Each Site

Seasonal Heating COP (total system)
Seasonal Cooling EER (total system)
Average EWT in Heating (avg or load-weighted)
Average EWT in Cooling (avg or load-weighted)
Max and Min EWT
Total kWh (or kWh per sq ft) for heating season
Total kWh (or kWh per sq ft) for cooling season
% of total power use for each component (compressor, fan, pump, aux htr
Total runtime for each component (comp1, comp2, fan, pump, aux1, aux2)
DHW pump (desuperheater) runtime
Ratio of measured and expected heating COP (and cooling EER)
Average on-peak demand in each season (noon to 9 pm)
Heating Costs Savings (using local fuel and electric costs)

The characteristics collected from all the sites, as well as the high level metrics (annual energy use and cost savings, seasonal COPs, etc.), will be summarized and compared. It is likely that 40 sites will provide statistically representative sample of homes that provide a P95 prediction for the performance metrics of interest (e.g., the heating COP is 2.5 ± 0.4 at the 95% confidence interval). It is also likely that several predictive trends will emerge as well. For instance:

- Heating COP varies with relative loop sizing (ft per ton)
- Heating COP varies with heat pump sizing (sq ft per ton)
- Minimum loop temperature (EWT) varies with loop size
- Annual cost savings are proportional to house size
- Annual cost savings depend on base case fuel type
- Annual cost savings depend loop sizing

CDH will prepare a Validation Report summarizing our analysis from these 40 sites for the NYSERDA Residential HVAC program. The report will summarize the results and findings, and it will document the analysis procedures and per site characteristics and results. Survey results will also be summarized in the report, and detailed results from the web and phone surveys will be included in an appendix of the main report.

The on-site verification results for the four onsite visits will become appendices of the main report.

We will also combine the data from this 40 site study on Long Island with the results for the State-wide evaluation of 40 sites with WaterFurnace GHP systems. This separate analysis of the combined 80-site study will be included in separate section of the final report.

Validation Project Schedule

Project activities by CDH (green) and AEG (blue) are indicated in the two tables below.

Table 6. Validation Project Schedule - Individual Site

Task \ Month[1]	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Site Identification	🟦													
Web and Phone Survey 1	🟩	🟩												
GHP Installation and Envelope Retrofit		🟦												
Data Acquisition		🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩		
Validation Site Visit			🟩											
Site Report				🟩										
BTU Meter Data Collection		🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟦		
Web and Phone Survey 2												🟩	🟩	
Monitoring Data Analysis										🟩	🟩	🟩	🟩	🟩

[1] Month from identification of site by AEG

Table 7. Validation Project Schedule - After All Data Collection Complete

Task \ Month[1]	1	2	3
Final Survey Collected	🟩		
Monitoring Data Analysis	🟩	🟩	
Survey Analysis		🟩	
Survey Results Report			🟩
Validation Report			🟩

[1] Month from date CDH collects final survey

Appendix A. Draft Surveys

Pre-Retrofit Customer Survey

All questions are required to be answered unless specified otherwise. The survey is to be completed by homeowners and some non-owner occupants. CDH will elicit elaboration on answers during phone interviews.

Welcome to the Pre-Retrofit Customer Survey

This survey is being collected by CDH Energy on behalf of NYSERDA for their Emerging Technology and Accelerated Commercialization (ETAC) program to understand customer satisfaction with ground source heat pumps.

You are being asked to complete this survey because Applied Energy Group installed a WaterFurnace ground source heat pump at your home under NYSERDA PON 3127, Emerging Technologies Demonstration Projects – Residential HVAC.

You will receive two surveys: this one, around the time of installation, and one 9 to 12 months after the heat pump system is installed. Please answer both surveys as accurately as possible.

We will not release individual answers publicly. Rather, we will publish answers and analysis as an aggregate for all surveys collected together.

Note: we are collecting your address in this survey to use to correlate survey results with measured heat pump performance data, as well as ensure that we have survey results for each home. We will not release your address publicly, unless you give us explicit permission to do so.

General

Q1. What is the street address of the building or unit that the heat pump system is being/has been installed in? (e.g. 121 Genesee St Apt 1)

(text box)

Q2. Do you own this building/unit?

(yes/no)

Q3. Do you reside in this building/unit?

(yes/no)

Q4. (owners only) How important were the following in your decision to install a ground-source heat pump system?

(Not at All Important, Somewhat Important, Very Important)

a. Lower operating costs (save on energy bills)
b. Ability to both heat and cool
c. Quieter than existing heating/cooling system(s)
d. Reduced greenhouse gas emissions
e. Reduced peak load and need for more electric generating plants

f. Reduce or remove chance of carbon monoxide poisoning
g. Lower maintenance costs
h. Lower life cycle cost due to longer equipment lifetime
i. Dehumidification during summer
j. Consistent room temperature
k. Reduced installation costs compared to alternate HVAC system
l. Ability to control temperature separately in each room
m. Modern, trendy technology
n. Recommended by someone I trust
o. Financial incentives (e.g. rebate)

Heating

Q5. (owners & occupants) Overall, how satisfied or dissatisfied are/were you with your heating system prior to the heat pump upgrade?

a. Very satisfied
b. Somewhat satisfied
c. Neither satisfied nor dissatisfied
d. Somewhat dissatisfied
e. Very dissatisfied

Q6. (occupants only) How did your home heating system perform over the most recent winter, prior to the heat pump upgrade?

a. My desired temperature was maintained in all rooms of my home.
b. My desired temperature was maintained in some rooms, but not in others (i.e., it was warm enough in some rooms but too cold in others).
c. My desired temperature was not reached in any area of my home (i.e., it was too cold in every room).

Q7. (occupants only) Overall, how do you expect your heat pump will maintain desired temperatures throughout your home in the winter compared to before the heat pump upgrade?

a. Much better
b. Slightly better
c. About the same
d. Slightly worse
e. Much worse

Q8. (owners & occupants) How do/did you feel about the cost of energy from your heating system prior to the heat pump upgrade?

a. Very high
b. Slightly too high
c. About right
d. Slightly too low
e. Too low
f. I don't pay the heating energy bill.

Q9. (skip if answer f above) How do you expect your winter energy bills to change overall after the heat pump upgrade?

a. Increase
b. Little to no change

c. Decrease

Q10. (owners only) How do/did you feel about the level of effort needed to maintain your heating system prior to the heat pump upgrade?

a. Very easy
b. Moderately easy
c. Neither easy nor difficult
d. Moderately difficult
e. Very difficult

Cooling

Q11-Q16: Questions will be the same as for heating, but with the word “cooling” replacing “heating”, “cool” replacing “heat”, and “summer” replacing “winter”. Will also add options for “I did not have cooling prior to the heat pump system.”

Other

Q17. (owners only) How do you expect the level of effort required to maintain your heat pump system will compare to your old heating and cooling equipment?

a. Much easier
b. Slightly easier
c. About the same
d. Slightly more difficult
e. Much more difficult

Q18. (owners only) How satisfied or dissatisfied are you with the work carried out by the contractor?

a. Very satisfied
b. Somewhat satisfied
c. Neither satisfied nor dissatisfied
d. Somewhat dissatisfied
e. Very dissatisfied

Q19. (owners only) How likely is it that you would recommend the contractor to a friend or colleague? (Net Promoter Score)

0-10 scale, 0 is not at all likely, 10 is extremely likely

Q20. (owners & occupants) Did you receive written instructions on how to operate the heat pump?

(yes/no)

Q21. (owners & occupants) Were you trained on how to use your new system?

(yes/no)

Q22. (owners & occupants) Was the information provided to you sufficient for you to operate your heat pump?

(yes/no, please explain why not)

Q23. (owners & occupants) If you have any further information you would like to share, or comments about the survey, please enter them here.

(text box, optional)

Post-Retrofit Customer Survey

(9-12 months after retrofit)

All questions are required to be answered unless specified otherwise.

Q1. What is the street address of the building or unit that the heat pump system was installed in? (e.g. 121 Genesee St Apt 1)

(text box)

Q2. Do you own this building/unit?

(yes/no)

Q3. Do you live in this building/unit?

(yes/no)

Q4. (owners & occupants) Overall, how satisfied or dissatisfied are you with your ground-source heat pump system?

(same options as corresponding question from Survey 1)

Q5. (occupants only) How easy is it to operate your heat pump?

a. Extremely easy
b. Very easy
c. Somewhat easy
d. Not so easy
e. Not at all easy

Q6. (occupants only) How did your heat pump system perform during the first winter after the heat pump upgrade?

(same options as corresponding question from Survey 1)

Q7. (occupants only) How do you feel your new heat pump system maintained desired temperatures throughout your home during winter compared to your old heating system?

(same options as corresponding question from Survey 1)

Q8. (owners & occupants) How did your heating energy bills over the first winter after the heat pump upgrade compare to what you expected prior to the heat pump upgrade?

a. Much higher than expected
b. Higher than expected
c. As expected
d. Lower than expected
e. Much lower than expected
f. I don’t pay the heating energy bill

Q9. (occupants only) How did your heat pump system perform during the first summer after the heat pump upgrade?

(same options as corresponding question from Survey 1)

Q10. (occupants only) How do you feel your new heat pump system maintained desired temperatures throughout your home during summer compared to your old cooling system?

(same options as corresponding question from Survey 1)

Q11. (owners & occupants) How did your cooling energy bills over the first winter after the heat pump upgrade compare to what you expected prior to the heat pump upgrade?

a. Much higher than expected
b. Higher than expected
c. As expected
d. Lower than expected
e. Much lower than expected
f. I don't pay the cooling energy bill

Q12. (owners only) How do you feel about the level of effort required to maintain your new heat pump system compared to your old heating and cooling equipment?

(same options as corresponding question from Survey 1)

Q13. (owners & occupants) Briefly describe any unexpected benefits that you have gained from your new heat pump system, if any.

(text box, optional)

Q14. (owners & occupants) Briefly describe any unexpected problems that you have gained from your new heat pump system, if any.

(text box, optional)

Q15. (owners & occupants) Briefly describe any unexpected benefits that you have gained from the building envelope retrofit, if any (e.g., impacts or changes in comfort, aesthetic (visual) changes).

(text box, optional)

Q16. (owners & occupants) Briefly describe any unexpected problems that you have experienced with the building envelope retrofit, if any (e.g., impacts or changes in comfort, aesthetic (visual) changes).

(text box, optional)

Q17. (occupants only) Have you noticed any change in the temperature of your basement since your heat pump was installed?

a. No
b. Yes (describe)

Q18. (owners & occupants) Have there been any changes in the number of people residing in the building in the past two years? If yes, please give any details of any changes (number of occupants increased/decreased and approximate date).

a. No
b. Yes (give details)

Q19. (owners & occupants) Have there been any changes to heating or cooling controls or settings (e.g. desired temperature set on thermostat) since installation? If yes, please briefly describe.

a. No
b. Yes (describe)

Q20. (owners & occupants) How did you feel about the installation process compared to an equipment replacement (e.g. replacing your old boiler with a new boiler)?

a. It was less invasive
b. There was little to no difference
c. It was more invasive

Q21. (owners & occupants) Was the level of effort you put into this project worth the achieved benefits of your heat pump system?

a. No
b. Yes

Q22. (owners & occupants) Would you switch back to your old heating and cooling systems? If yes, please explain why.

a. No
b. Yes (please explain why)

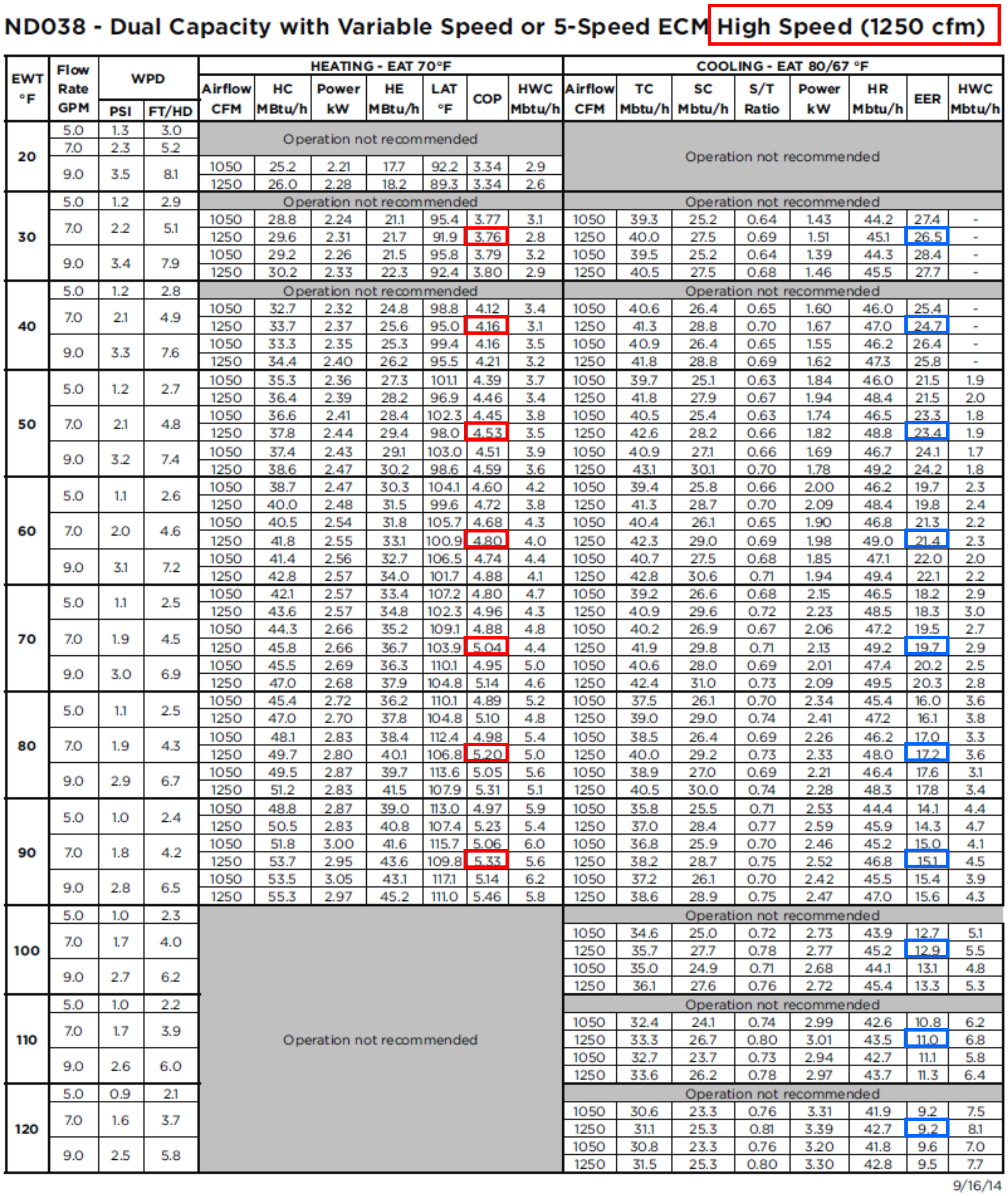
Q23. If you have any other comments about the survey and/or about your ground-source heat pump system, please enter them here.

(text box, optional)

Appendix B. Expected Performance Data from Water Furnace Units

Water Furnace provides performance data in tables of the following form. The Table B-1 corresponds to high speed and Table B-2 to low speed compressor operation for one of the dual speed units.

Table B-1. Published Performance Data for Water Furnace ND038 with High Speed Fan



ND038 - Dual Capacity with Variable Speed or 5-Speed ECM High Speed (1250 cfm)

EWT °F	Flow Rate GPM	WPD		HEATING - EAT 70°F							COOLING - EAT 80/67 °F							
		PSI	FT/HD	Airflow CFM	HC MBtu/h	Power kW	HE MBtu/h	LAT °F	COP	HWC Mbtu/h	Airflow CFM	TC Mbtu/h	SC Mbtu/h	S/T Ratio	Power kW	HR Mbtu/h	EER	HWC Mbtu/h
20	5.0	1.3	3.0	Operation not recommended							Operation not recommended							
	7.0	2.3	5.2	Operation not recommended														
	9.0	3.5	8.1	1050	25.2	2.21	17.7	92.2	3.34	2.9								
				1250	26.0	2.28	18.2	89.3	3.34	2.6								
30	5.0	1.2	2.9	Operation not recommended							Operation not recommended							
	7.0	2.2	5.1	1050	28.8	2.24	21.1	95.4	3.77	3.1	1050	39.3	25.2	0.64	1.43	44.2	27.4	-
				1250	29.6	2.31	21.7	91.9	3.76	2.8	1250	40.0	27.5	0.69	1.51	45.1	26.5	-
	9.0	3.4	7.9	1050	29.2	2.26	21.5	95.8	3.79	3.2	1050	39.5	25.2	0.64	1.39	44.3	28.4	-
				1250	30.2	2.33	22.3	92.4	3.80	2.9	1250	40.5	27.5	0.68	1.46	45.5	27.7	-
40	5.0	1.2	2.8	Operation not recommended							Operation not recommended							
	7.0	2.1	4.9	1050	32.7	2.32	24.8	98.8	4.12	3.4	1050	40.6	26.4	0.65	1.60	46.0	25.4	-
				1250	33.7	2.37	25.6	95.0	4.16	3.1	1250	41.3	28.8	0.70	1.67	47.0	24.7	-
	9.0	3.3	7.6	1050	33.3	2.35	25.3	99.4	4.16	3.5	1050	40.9	26.4	0.65	1.55	46.2	26.4	-
				1250	34.4	2.40	26.2	95.5	4.21	3.2	1250	41.8	28.8	0.69	1.62	47.3	25.8	-
50	5.0	1.2	2.7	1050	35.3	2.36	27.3	101.1	4.39	3.7	1050	39.7	25.1	0.63	1.84	46.0	21.5	1.9
				1250	36.4	2.39	28.2	96.9	4.46	3.4	1250	41.8	27.9	0.67	1.94	48.4	21.5	2.0
	7.0	2.1	4.8	1050	36.6	2.41	28.4	102.3	4.45	3.8	1050	40.5	25.4	0.63	1.74	46.5	23.3	1.8
				1250	37.8	2.44	29.4	98.0	4.53	3.5	1250	42.6	28.2	0.66	1.82	48.8	23.4	1.9
	9.0	3.2	7.4	1050	37.4	2.43	29.1	103.0	4.51	3.9	1050	40.9	27.1	0.66	1.69	46.7	24.1	1.7
				1250	38.6	2.47	30.2	98.6	4.59	3.6	1250	43.1	30.1	0.70	1.78	49.2	24.2	1.8
60	5.0	1.1	2.6	1050	38.7	2.47	30.3	104.1	4.60	4.2	1050	39.4	25.8	0.66	2.00	46.2	19.7	2.3
				1250	40.0	2.48	31.5	99.6	4.72	3.8	1250	41.3	28.7	0.70	2.09	48.4	19.8	2.4
	7.0	2.0	4.6	1050	40.5	2.54	31.8	105.7	4.68	4.3	1050	40.4	26.1	0.65	1.90	46.8	21.3	2.2
				1250	41.8	2.55	33.1	100.9	4.80	4.0	1250	42.3	29.0	0.69	1.98	49.0	21.4	2.3
	9.0	3.1	7.2	1050	41.4	2.56	32.7	106.5	4.74	4.4	1050	40.7	27.5	0.68	1.85	47.1	22.0	2.0
				1250	42.8	2.57	34.0	101.7	4.88	4.1	1250	42.8	30.6	0.71	1.94	49.4	22.1	2.2
70	5.0	1.1	2.5	1050	42.1	2.57	33.4	107.2	4.80	4.7	1050	39.2	26.6	0.68	2.15	46.5	18.2	2.9
				1250	43.6	2.57	34.8	102.3	4.96	4.3	1250	40.9	29.6	0.72	2.23	48.5	18.3	3.0
	7.0	1.9	4.5	1050	44.3	2.66	35.2	109.1	4.88	4.8	1050	40.2	26.9	0.67	2.06	47.2	19.5	2.7
				1250	45.8	2.66	36.7	103.9	5.04	4.4	1250	41.9	29.8	0.71	2.13	49.2	19.7	2.9
	9.0	3.0	6.9	1050	45.5	2.69	36.3	110.1	4.95	5.0	1050	40.6	28.0	0.69	2.01	47.4	20.2	2.5
				1250	47.0	2.68	37.9	104.8	5.14	4.6	1250	42.4	31.0	0.73	2.09	49.5	20.3	2.8
80	5.0	1.1	2.5	1050	45.4	2.72	36.2	110.1	4.89	5.2	1050	37.5	26.1	0.70	2.34	45.4	16.0	3.6
				1250	47.0	2.70	37.8	104.8	5.10	4.8	1250	39.0	29.0	0.74	2.41	47.2	16.1	3.8
	7.0	1.9	4.3	1050	48.1	2.83	38.4	112.4	4.98	5.4	1050	38.5	26.4	0.69	2.26	46.2	17.0	3.3
				1250	49.7	2.80	40.1	106.8	5.20	5.0	1250	40.0	29.2	0.73	2.33	48.0	17.2	3.6
	9.0	2.9	6.7	1050	49.5	2.87	39.7	113.6	5.05	5.6	1050	38.9	27.0	0.69	2.21	46.4	17.6	3.1
				1250	51.2	2.83	41.5	107.9	5.31	5.1	1250	40.5	30.0	0.74	2.28	48.3	17.8	3.4
90	5.0	1.0	2.4	1050	48.8	2.87	39.0	113.0	4.97	5.9	1050	35.8	25.5	0.71	2.53	44.4	14.1	4.4
				1250	50.5	2.83	40.8	107.4	5.23	5.4	1250	37.0	28.4	0.77	2.59	45.9	14.3	4.7
	7.0	1.8	4.2	1050	51.8	3.00	41.6	115.7	5.06	6.0	1050	36.8	25.9	0.70	2.46	45.2	15.0	4.1
				1250	53.7	2.95	43.6	109.8	5.33	5.6	1250	38.2	28.7	0.75	2.52	46.8	15.1	4.5
	9.0	2.8	6.5	1050	53.5	3.05	43.1	117.1	5.14	6.2	1050	37.2	26.1	0.70	2.42	45.5	15.4	3.9
				1250	55.3	2.97	45.2	111.0	5.46	5.8	1250	38.6	28.9	0.75	2.47	47.0	15.6	4.3
100	5.0	1.0	2.3	Operation not recommended							Operation not recommended							
	7.0	1.7	4.0								1050	34.6	25.0	0.72	2.73	43.9	12.7	5.1
											1250	35.7	27.7	0.78	2.77	45.2	12.9	5.5
	9.0	2.7	6.2								1050	35.0	24.9	0.71	2.68	44.1	13.1	4.8
											1250	36.1	27.6	0.76	2.72	45.4	13.3	5.3
110	5.0	1.0	2.2								Operation not recommended							
	7.0	1.7	3.9								1050	32.4	24.1	0.74	2.99	42.6	10.8	6.2
											1250	33.3	26.7	0.80	3.01	43.5	11.0	6.8
	9.0	2.6	6.0								1050	32.7	23.7	0.73	2.94	42.7	11.1	5.8
											1250	33.6	26.2	0.78	2.97	43.7	11.3	6.4
120	5.0	0.9	2.1								Operation not recommended							
	7.0	1.6	3.7								1050	30.6	23.3	0.76	3.31	41.9	9.2	7.5
											1250	31.1	25.3	0.81	3.39	42.7	9.2	8.1
	9.0	2.5	5.8								1050	30.8	23.3	0.76	3.20	41.8	9.6	7.0
											1250	31.5	25.3	0.80	3.30	42.8	9.5	7.7

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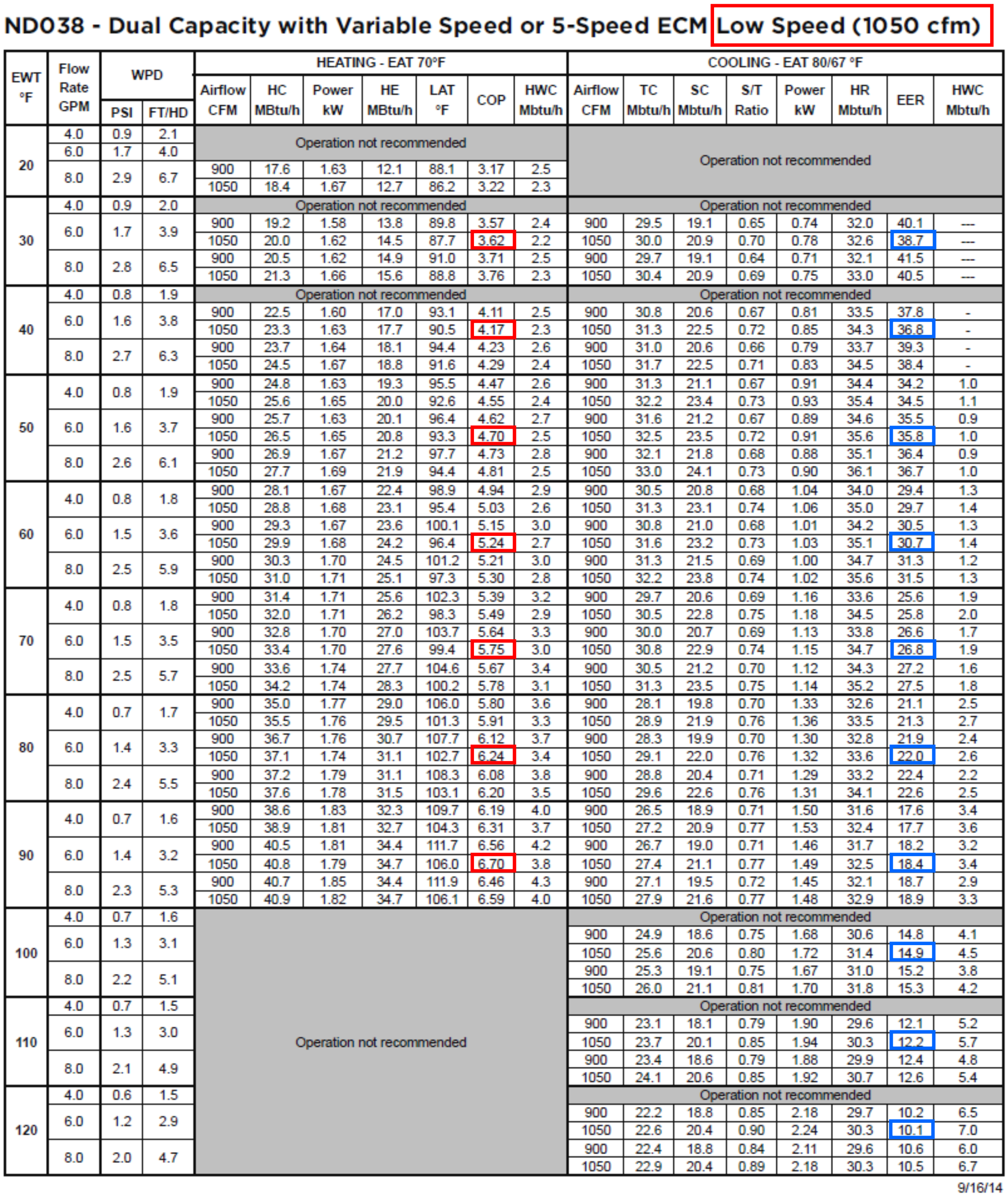
Figure B-2. Published Performance Data for Water Furnace ND038 with Low Speed Fan



ND038 - Dual Capacity with Variable Speed or 5-Speed ECM Low Speed (1050 cfm)

EWT °F	Flow Rate GPM	WPD		HEATING - EAT 70°F							COOLING - EAT 80/67 °F							
		PSI	FT/HD	Airflow CFM	HC MBtu/h	Power kW	HE MBtu/h	LAT °F	COP	HWC Mbtu/h	Airflow CFM	TC Mbtu/h	SC Mbtu/h	S/T Ratio	Power kW	HR Mbtu/h	EER	HWC Mbtu/h
20	4.0	0.9	2.1	Operation not recommended							Operation not recommended							
	6.0	1.7	4.0															
	8.0	2.9	6.7	900	17.6	1.63	12.1	88.1	3.17	2.5								
				1050	18.4	1.67	12.7	86.2	3.22	2.3								
30	4.0	0.9	2.0	Operation not recommended							Operation not recommended							
	6.0	1.7	3.9	900	19.2	1.58	13.8	89.8	3.57	2.4	900	29.5	19.1	0.65	0.74	32.0	40.1	---
				1050	20.0	1.62	14.5	87.7	3.62	2.2	1050	30.0	20.9	0.70	0.78	32.6	38.7	---
	8.0	2.8	6.5	900	20.5	1.62	14.9	91.0	3.71	2.5	900	29.7	19.1	0.64	0.71	32.1	41.5	---
				1050	21.3	1.66	15.6	88.8	3.76	2.3	1050	30.4	20.9	0.69	0.75	33.0	40.5	---
40	4.0	0.8	1.9	Operation not recommended							Operation not recommended							
	6.0	1.6	3.8	900	22.5	1.60	17.0	93.1	4.11	2.5	900	30.8	20.6	0.67	0.81	33.5	37.8	-
				1050	23.3	1.63	17.7	90.5	4.17	2.3	1050	31.3	22.5	0.72	0.85	34.3	36.8	-
	8.0	2.7	6.3	900	23.7	1.64	18.1	94.4	4.23	2.6	900	31.0	20.6	0.66	0.79	33.7	39.3	-
				1050	24.5	1.67	18.8	91.6	4.29	2.4	1050	31.7	22.5	0.71	0.83	34.5	38.4	-
50	4.0	0.8	1.9	900	24.8	1.63	19.3	95.5	4.47	2.6	900	31.3	21.1	0.67	0.91	34.4	34.2	1.0
				1050	25.6	1.65	20.0	92.6	4.55	2.4	1050	32.2	23.4	0.73	0.93	35.4	34.5	1.1
	6.0	1.6	3.7	900	25.7	1.63	20.1	96.4	4.62	2.7	900	31.6	21.2	0.67	0.89	34.6	35.5	0.9
				1050	26.5	1.65	20.8	93.3	4.70	2.5	1050	32.5	23.5	0.72	0.91	35.6	35.8	1.0
	8.0	2.6	6.1	900	26.9	1.67	21.2	97.7	4.73	2.8	900	32.1	21.8	0.68	0.88	35.1	36.4	0.9
				1050	27.7	1.69	21.9	94.4	4.81	2.5	1050	33.0	24.1	0.73	0.90	36.1	36.7	1.0
60	4.0	0.8	1.8	900	28.1	1.67	22.4	98.9	4.94	2.9	900	30.5	20.8	0.68	1.04	34.0	29.4	1.3
				1050	28.8	1.68	23.1	95.4	5.03	2.6	1050	31.3	23.1	0.74	1.06	35.0	29.7	1.4
	6.0	1.5	3.6	900	29.3	1.67	23.6	100.1	5.15	3.0	900	30.8	21.0	0.68	1.01	34.2	30.5	1.3
				1050	29.9	1.68	24.2	96.4	5.24	2.7	1050	31.6	23.2	0.73	1.03	35.1	30.7	1.4
	8.0	2.5	5.9	900	30.3	1.70	24.5	101.2	5.21	3.0	900	31.3	21.5	0.69	1.00	34.7	31.3	1.2
				1050	31.0	1.71	25.1	97.3	5.30	2.8	1050	32.2	23.8	0.74	1.02	35.6	31.5	1.3
70	4.0	0.8	1.8	900	31.4	1.71	25.6	102.3	5.39	3.2	900	29.7	20.6	0.69	1.16	33.6	25.6	1.9
				1050	32.0	1.71	26.2	98.3	5.49	2.9	1050	30.5	22.8	0.75	1.18	34.5	25.8	2.0
	6.0	1.5	3.5	900	32.8	1.70	27.0	103.7	5.64	3.3	900	30.0	20.7	0.69	1.13	33.8	26.6	1.7
				1050	33.4	1.70	27.6	99.4	5.75	3.0	1050	30.8	22.9	0.74	1.15	34.7	26.8	1.9
	8.0	2.5	5.7	900	33.6	1.74	27.7	104.6	5.67	3.4	900	30.5	21.2	0.70	1.12	34.3	27.2	1.6
				1050	34.2	1.74	28.3	100.2	5.78	3.1	1050	31.3	23.5	0.75	1.14	35.2	27.5	1.8
80	4.0	0.7	1.7	900	35.0	1.77	29.0	106.0	5.80	3.6	900	28.1	19.8	0.70	1.33	32.6	21.1	2.5
				1050	35.5	1.76	29.5	101.3	5.91	3.3	1050	28.9	21.9	0.76	1.36	33.5	21.3	2.7
	6.0	1.4	3.3	900	36.7	1.76	30.7	107.7	6.12	3.7	900	28.3	19.9	0.70	1.30	32.8	21.9	2.4
				1050	37.1	1.74	31.1	102.7	6.24	3.4	1050	29.1	22.0	0.76	1.32	33.6	22.0	2.6
	8.0	2.4	5.5	900	37.2	1.79	31.1	108.3	6.08	3.8	900	28.8	20.4	0.71	1.29	33.2	22.4	2.2
				1050	37.6	1.78	31.5	103.1	6.20	3.5	1050	29.6	22.6	0.76	1.31	34.1	22.6	2.5
90	4.0	0.7	1.6	900	38.6	1.83	32.3	109.7	6.19	4.0	900	26.5	18.9	0.71	1.50	31.6	17.6	3.4
				1050	38.9	1.81	32.7	104.3	6.31	3.7	1050	27.2	20.9	0.77	1.53	32.4	17.7	3.6
	6.0	1.4	3.2	900	40.5	1.81	34.4	111.7	6.56	4.2	900	26.7	19.0	0.71	1.46	31.7	18.2	3.2
				1050	40.8	1.79	34.7	106.0	6.70	3.8	1050	27.4	21.1	0.77	1.49	32.5	18.4	3.4
	8.0	2.3	5.3	900	40.7	1.85	34.4	111.9	6.46	4.3	900	27.1	19.5	0.72	1.45	32.1	18.7	2.9
				1050	40.9	1.82	34.7	106.1	6.59	4.0	1050	27.9	21.6	0.77	1.48	32.9	18.9	3.3
100	4.0	0.7	1.6	Operation not recommended							Operation not recommended							
	6.0	1.3	3.1								900	24.9	18.6	0.75	1.68	30.6	14.8	4.1
											1050	25.6	20.6	0.80	1.72	31.4	14.9	4.5
	8.0	2.2	5.1								900	25.3	19.1	0.75	1.67	31.0	15.2	3.8
											1050	26.0	21.1	0.81	1.70	31.8	15.3	4.2
110	4.0	0.7	1.5								Operation not recommended							
	6.0	1.3	3.0								900	23.1	18.1	0.79	1.90	29.6	12.1	5.2
											1050	23.7	20.1	0.85	1.94	30.3	12.2	5.7
	8.0	2.1	4.9								900	23.4	18.6	0.79	1.88	29.9	12.4	4.8
											1050	24.1	20.6	0.85	1.92	30.7	12.6	5.4
120	4.0	0.6	1.5								Operation not recommended							
	6.0	1.2	2.9								900	22.2	18.8	0.85	2.18	29.7	10.2	6.5
											1050	22.6	20.4	0.90	2.24	30.3	10.1	7.0
	8.0	2.0	4.7								900	22.4	18.8	0.84	2.11	29.6	10.6	6.0
											1050	22.9	20.4	0.89	2.18	30.3	10.5	6.7

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Figure B-1 and Figure B-2 show the resulting performance curves for heating COP and cooling EER for the heat pump unit (compressor and fan, assuming the stated airflow at zero static). The units are shown with different colors while the low speed and high speed performance are shown with different symbols.

Figure B-3 and Figure B-4 show same performance data for the variable speed (series 7) units at 100% Full Load and 50% Part Load.

Figure B-1. Performance Curves for Heating COP for Water Furnace Dual Stage Units

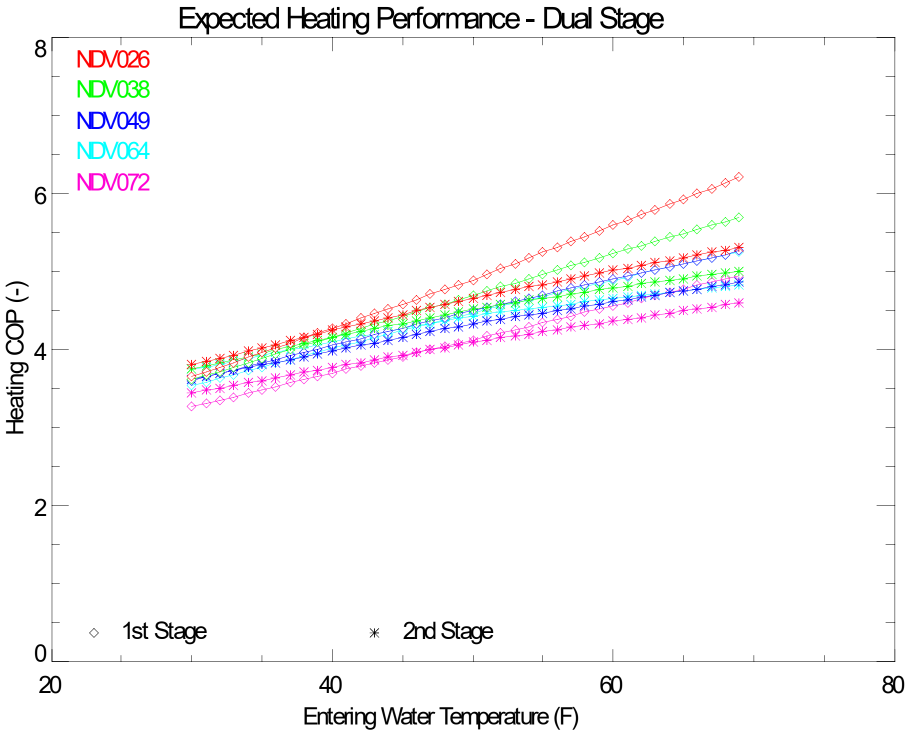


Figure B-2. Performance Curves for Cooling EER for Water Furnace Dual Stage Units

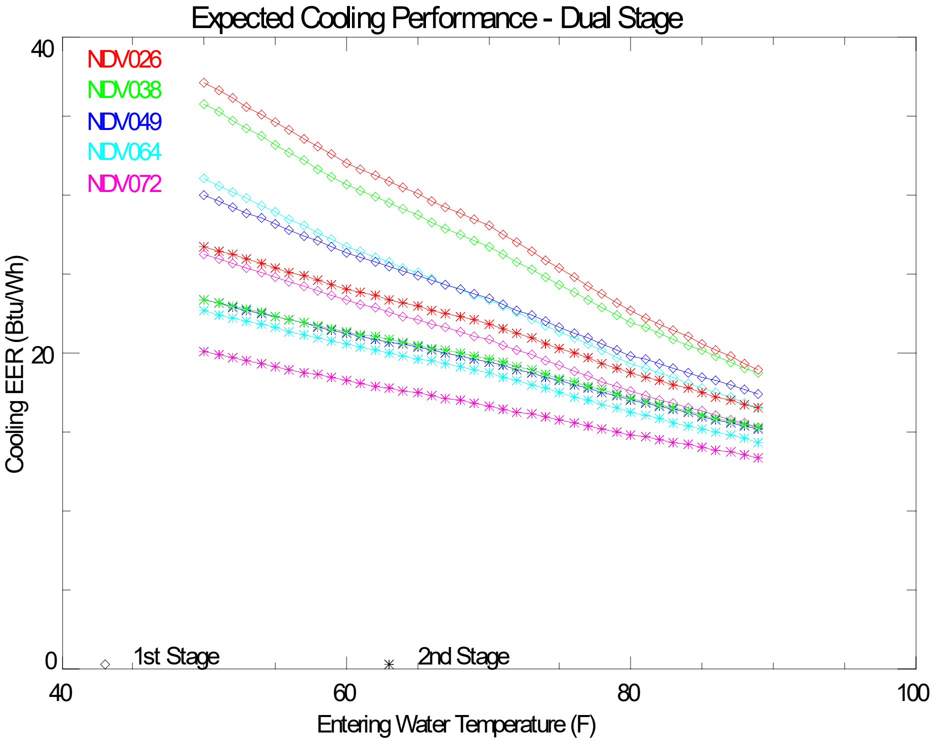


Figure B-3. Performance Curves for Heating COP for Water Furnace Variable Speed Units

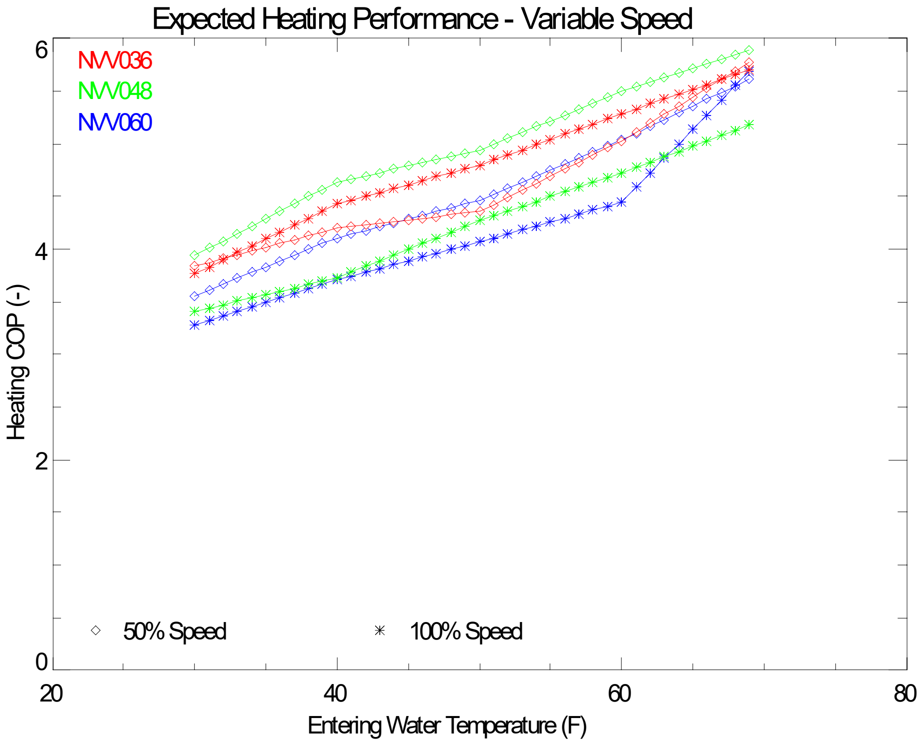


Figure B-4. Performance Curves for Cooling EER for Water Furnace Variable Speed Units

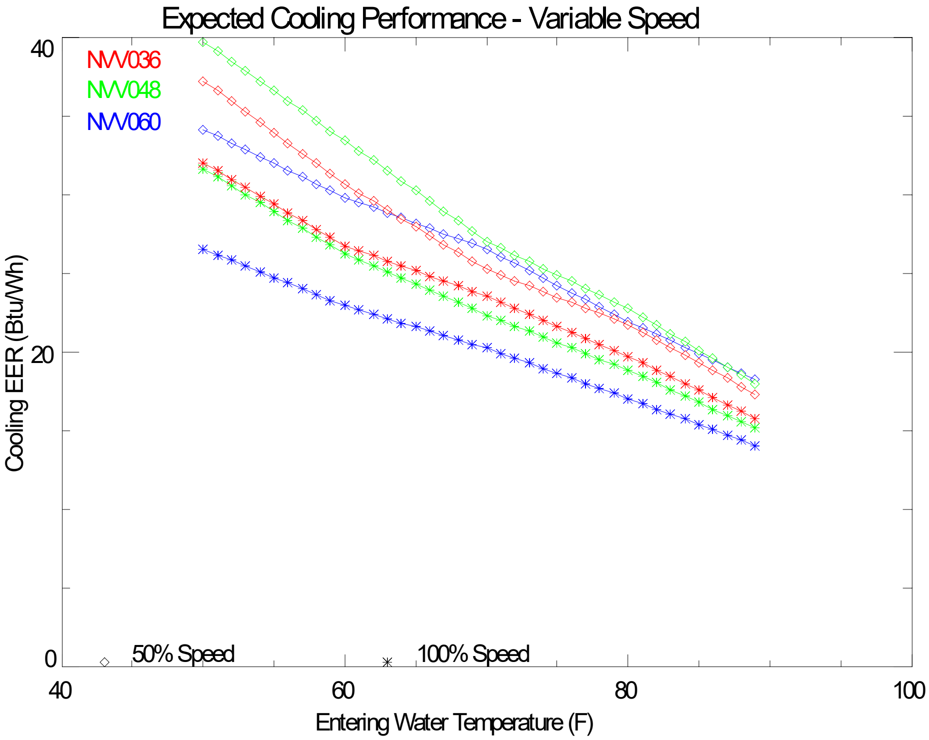
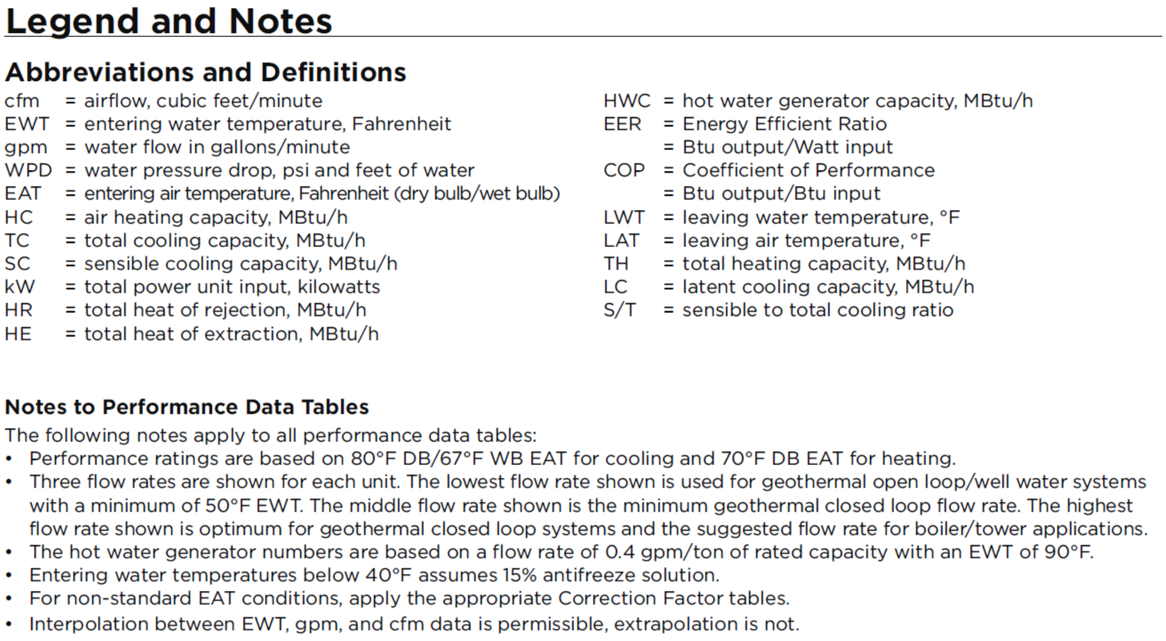


Table B-3. Detailed Notes for Water Furnace Performance Tables



Legend and Notes

Abbreviations and Definitions

cfm = airflow, cubic feet/minute
EWT = entering water temperature, Fahrenheit
gpm = water flow in gallons/minute
WPD = water pressure drop, psi and feet of water
EAT = entering air temperature, Fahrenheit (dry bulb/wet bulb)
HC = air heating capacity, MBtu/h
TC = total cooling capacity, MBtu/h
SC = sensible cooling capacity, MBtu/h
kW = total power unit input, kilowatts
HR = total heat of rejection, MBtu/h
HE = total heat of extraction, MBtu/h

HWC = hot water generator capacity, MBtu/h
EER = Energy Efficient Ratio
= Btu output/Watt input
COP = Coefficient of Performance
= Btu output/Btu input
LWT = leaving water temperature, °F
LAT = leaving air temperature, °F
TH = total heating capacity, MBtu/h
LC = latent cooling capacity, MBtu/h
S/T = sensible to total cooling ratio

Notes to Performance Data Tables

The following notes apply to all performance data tables:

- Performance ratings are based on 80°F DB/67°F WB EAT for cooling and 70°F DB EAT for heating.
- Three flow rates are shown for each unit. The lowest flow rate shown is used for geothermal open loop/well water systems with a minimum of 50°F EWT. The middle flow rate shown is the minimum geothermal closed loop flow rate. The highest flow rate shown is optimum for geothermal closed loop systems and the suggested flow rate for boiler/tower applications.
- The hot water generator numbers are based on a flow rate of 0.4 gpm/ton of rated capacity with an EWT of 90°F.
- Entering water temperatures below 40°F assumes 15% antifreeze solution.
- For non-standard EAT conditions, apply the appropriate Correction Factor tables.
- Interpolation between EWT, gpm, and cfm data is permissible, extrapolation is not.

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