Residential Cold Climate Air Source Heat Pump Building Electrification Study:

NYSERDA-Specific Results

Final Report

Prepared for:

New York State Energy Research & Development Authority

Albany, NY

Victoria Engel-Fowles

Project Manager

Prepared by:

The Cadmus Group, LLC

Boulder, CO

Christie Amero

Associate

June 2022

CADMUS

Memorandum

To:	Victoria Engel-Fowles; NYSERDA
From:	Christie Amero, Jeremy Koo, John Walczyk; Cadmus
Subject:	Residential ccASHP Metering Study – NYSERDA Supplement
Date:	June 6, 2022

Introduction

In early 2020, E4TheFuture[1] engaged Cadmus to complete a research study to assess the in-field performance of cold climate air source heat pumps (ccASHPs) used as primary or sole sources of heating in single-family homes in Massachusetts and New York. The study also assessed customer satisfaction and contractor sales and installation practices through surveys and phone interviews.

MassCEC and NYSERDA provided Cadmus with historical residential ASHP program data to use for the onsite data collection sample and customer survey and contractor interview contacts. NYSERDA also provided additional study funding to enable Cadmus to conduct an in-depth winter peak demand analysis for the 19 metered sites in New York, as well as onsite blower door tests and Manual J heating load calculations.

This memo summarizes the results of these additional activities and is a supplement to the E4TheFuture PowerPoint slide deck deliverable. Additionally, this memo compares Cadmus' Manual J load calculations to contractor reported heating loads and measured energy savings to deemed and technical reference manual expected savings.

New York Customer Sample Frame Development

NYSERDA provided Cadmus with a full dataset of all ASHP projects rebated through the Air Source Heat Pump Program (Q4 2017 through Q1 2020), including customer name, address, and contact information, as well as information about the project equipment, incentive amount, and incentive type (e.g., base rebate or whole house incentive). Given the need to secure customer consent for collecting utility bills for analysis and metering, Cadmus developed and disseminated the customer survey to all rebate recipients both to assess customer satisfaction and behavior and to identify potential candidates for requesting utility data and installing meters.

While many NYSERDA rebate recipients were designated as having received a Whole-House Solution Incentive adder (designed for homes where the ccASHP is sized to serve 90% to 120% of the building's design heating load), there was insufficient information to determine whether customers intended to use their systems as primary or sole sources of heating. Survey responses were critical to identify

[1] E4TheFuture. Accessed January 2022. https://e4thefuture.org/

whether customers were deemed as using their ccASHPs for "supplemental," "primary with backup," or "whole-home" applications, with bill analysis and metering targeting the latter two cohorts. Follow-up recruitment calls with respondents who indicated interest in metering helped to confirm whether survey responses accurately captured customer usage.

While the scope of the study was focused on primary with backup and whole-home applications, Cadmus also captured and analyzed responses from customers who were deemed through the survey to be using their ASHPs in supplemental applications. While no utility billing data or metering was requested of these customers, supplemental applications account for the majority of the ASHP market in New York and comparing responses from primary with back and whole-home ccASHP users against supplemental ccASHP users may offer useful insights. Customer survey results are summarized in the slide deck accompanying this memo.

New York Site Sample Details

Table 1 summarizes key attributes of the 19 New York sites metered by Cadmus.

Table 1. New York Participating Site Details

Site ID	Zip Code	Home Age, years	Solar PV Onsite	ccASHP Application	ccASHP System Type	Total Conditioned Floor Area, sq. ft.	Primary Backup Fuel System Type	Home Weatherization Upgrade Timing
NY_01	14551	171	No	Whole-Home	Mixed	2,500	Electric resistance	No change/existing
NY_02	13485	2	No	Whole-Home	Ductless	2,100	None	During ASHP installation
NY_03	14850	65	No	Primary w/ Backup	Ducted	2,800	Natural gas	No change/existing
NY_04	12067	101	Yes	Primary w/ Backup	Ductless	2,700	Electric resistance	Pre-ASHP installation
NY_05	13903	29	Yes	Whole-Home	Ductless	2,100	None	Pre-ASHP installation
NY_06	12809	49	Yes	Whole-Home	Mixed	2,500	Wood	Pre-ASHP installation
NY_07	12401	20	No	Whole-Home	Mixed	1,500	Natural gas	Pre-ASHP installation
NY_08	12477	38	No	Whole-Home	Ductless	1,800	None	No change/existing
NY_09	10461	101	No	Primary w/ Backup	Ductless	1,300	Natural gas	Pre-ASHP installation
NY_10	12572	35	Yes	Primary w/ Backup	Ducted	3,200	Oil	No change/existing
NY_11	13905	74	No	Whole-Home	Ducted	1,380	None	Post-ASHP installation
NY_12	14850	119	Yes	Primary w/ Backup	Ductless	3,000	Natural gas	Pre-ASHP installation
NY_13	13865	3	No	Whole-Home	Ductless	2,000	None	Pre-ASHP installation
NY_14	13219	71	No	Primary w/ Backup	Ducted	1,800	Natural gas	Post-ASHP installation
NY_15	12060	81	No	Whole-Home	Ducted	1,440	Wood	Pre-ASHP installation
NY_16	14850	20	No	Whole-Home	Ductless	1,600	Wood	Pre-ASHP installation
NY_17	13040	3	No	Primary w/ Backup	Ducted	2,000	Wood	No change/existing
NY_18	14850	71	No	Whole-Home	Ducted	1,800	None	No change/existing
NY_19	14850	46	No	Whole-Home	Ductless	1,500	Wood	Pre-ASHP installation

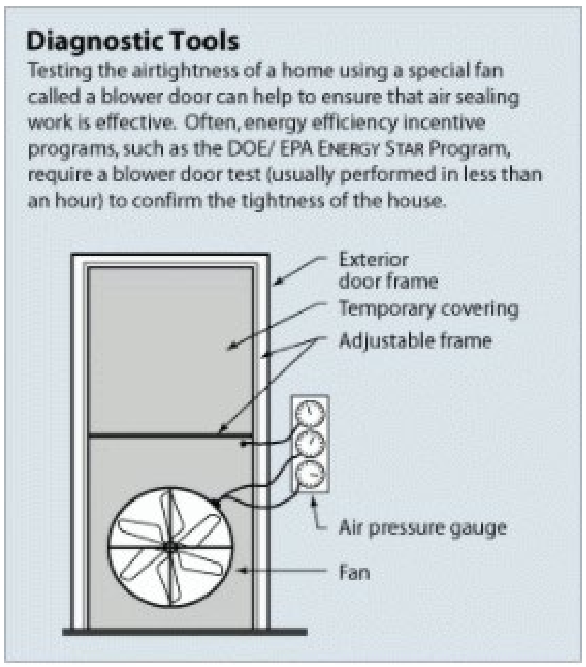
Blower Door Testing

Blower-door testing indicates the amount of air leakage for the structure, which is a primary determinant of thermal energy efficiency. Air leakage can also affect occupant comfort, indoor air quality, and building durability. The intention of collecting this data for sampled sites was to understand the correlation between the leakiness of a home, ccASHP performance, and customer comfort.

Methodology

The Cadmus technician used a two-point blower door test procedure, which strikes a balance between the expediency of single-point testing and the greater reliability and accuracy of multi-point testing. The two-point blower door test requires depressurizing the house to near 50 Pa and 25 Pa with respect to the outside. Figure 1 illustrates a blower door test setup and Figure 2 shows test measurements using a DG-700 Pressure and Flow Gauge.

Figure 1. Blower Door Test Illustration[2]



[2] Energy.gov. *Energy Saver – Blower Doors: What Are They and How Do They Work?* Accessed January 2022. https://www.energy.gov/energysaver/blower-door-tests

Figure 2. Blower Door Test Measurements

Blower door testing creates exaggerated pressure differences between the inside and outside of a structure in order measure air leakage. Indiscriminate use of blower door equipment in homes with combustion appliances and/or that contain hazardous materials (such as asbestos or mold) may create unsafe conditions inside a home. Accordingly, Cadmus did not perform a blower door test where the technician encountered one or more of these conditions onsite:

- A fire burning in any wood-burning fireplace or wood-burning or pellet stove, or there had been such a fire burning in the previous six hours.
- Asbestos was reported or observed in any area of the home.
- Mold was observed or suspected at the boundary of the conditioned and unconditioned areas of the home.
- One or more persons living in the home suffered from respiratory conditions such as severe asthma or chronic obstructive pulmonary disease.

Blower Door Test Sample

During onsite meter removals in Spring 2021, Cadmus attempted to perform onsite blower door tests and collect inputs for Manual J heating load calculations for all metered sites in New York. Of the 19 participating sites, 14 customers agreed to allow Cadmus' field technician to conduct a blower door test onsite and three provided blower door test reports from their contractor. Only two sites declined the onsite blower door test and did not provide a previous blower door test report.

Blower Door Test Results

Table 2 summarizes blower door test results, estimated equivalent leakage area (ELA), and ACH50 (the number of times per hour that the home air volume is replaced with outside air at a 50 Pa pressure difference) for the sampled New York sites. According to the National Association for State Community Services Programs, homes with ACH50 values less than 5 ACH50 are considered tight, moderate is between 5 and 10 ACH50, and leaky is greater than 10 ACH50.[3] On average, the sampled New York homes would fall into the 'moderate' category based on the results of these blower door tests.

Table 2. New York Blower Door Test Results by Site

Site	Construction Year	Home Weatherization Upgrade Timing	Measured Airflow at 50 Pa, CFM	Equivalent Leakage Area (ELA)	Approximate ACH50[1]
NY_01	1850	No change/existing	3,869	215	10.9
NY_02	2019	During ASHP installation	189	11	0.6
NY_03	1956	No change/existing	1,782	99	4.5
NY_04	1920	Pre-ASHP installation	2,462	137	6.4
NY_05	1992	Pre-ASHP installation	984	55	3.3
NY_06	1972	Pre-ASHP installation	3,144	175	8.9
NY_07	2001	Pre-ASHP installation	N/A	N/A	N/A
NY_08	1983	No change/existing	2,065	115	8.1
NY_09	1920	Pre-ASHP installation	2,100	117	11.4
NY_10	1986	No change/existing	4,888	272	10.8
NY_11	1947	Post-ASHP installation	1,283	71	6.6
NY_12	1902	Pre-ASHP installation	3,509	195	8.3
NY_13	2018	Pre-ASHP installation	707	39	2.7
NY_14	1950	Post-ASHP installation	1,452	81	5.7
NY_15	1940	Pre-ASHP installation	2,180	121	10.7
NY_16	2018	Pre-ASHP installation	1,838	102	8.1
NY_17	2018	No change/existing	2,681	149	9.5
NY_18	1975	No change/existing	N/A	N/A	N/A
NY_19	1950	Pre-ASHP installation	3,844	214	18.1
Average			**2,293**	**128**	**7.9**

[1] Cadmus assumed an average ceiling height of 8.5 feet.

Table 3 summarizes the blower door test results by home weatherization upgrade timing. Unsurprisingly, the homes with no weatherization upgrades had the highest measured airflow rates and the highest equivalent leakage area. The three homes that had weatherization upgrades performed during or after the ccASHP installation had the lowest leakage rates. However, this was a small sample of homes, and many variables factor into home leakiness, including the type and quality of existing and new insulation, home age, and test conditions.

Table 3. New York Blower Door Test Results by Weatherization Upgrade Timing

Home Weatherization Upgrade	Number of Homes	Measured Airflow, CFM		Equivalent Leakage Area, ELA
		50 Pa	25 Pa	
No change/existing	6	3,057	1,982	170.0

[3] National Association for State Community Services Programs. *Blower Door Testing.* Accessed February 2022. https://nascsp.org/wp-content/uploads/2018/02/van-der-meer_blower-door-testing.pdf

Home Weatherization Upgrade	Number of Homes	Measured Airflow, CFM		Equivalent Leakage Area, ELA
		50 Pa	25 Pa	
Pre-ASHP installation	10	2,308	1,735	128.3
During ASHP installation	1	189	N/A	11.0
Post-ASHP installation	2	1,368	840	76.0
Overall	**19**	**2,334**	**1,627**	**129.8**

Manual J Heat Load Calculations

Cadmus also collected onsite inputs to calculate expected heat load for each of the New York homes and compared results with the contractors' heat load calculations, where available to analyze whether there are any usage patterns, performance, or comfort issues related to over or under-sizing ccASHP systems.

Methodology

Cadmus worked with NYSERDA to collect the installation contractor's Manual J outputs for the New York sites, where available. Of the 19 participating sites, contractor Manual J heat load calculations were available for 13 sites.

During the heating season data download site visits in Spring 2021, Cadmus collected site-specific Manual J calculation inputs, such as home orientation, insulation levels, conditioned floor area, ceiling height, window area, number of above and below grade floors, occupants, and other internal space loads. Cadmus input these site-specific inputs and the blower door test results, where available, into CoolCalc[4] Manual J software, a web based, Air Conditioning Contractors of America (ACCA) approved heating and cooling load calculator to estimate the heating and cooling load at the design conditions for each home. An example CoolCalc report output for one of the New York sites is attached to this memo.

Results

Table 4 shows Cadmus' Manual J heating and cooling calculations for each of the New York sites, compared with the contractor's estimates where available. On average, Cadmus' calculated Manual J heating load including the blower door test result was 16% higher than the contractor estimates but varied from 83% to 152%. This does not necessarily indicate these systems were undersized on average; contractors size systems based on understanding of how a customer intends to use their systems. Cadmus' Manual J heating and cooling load calculations do not account for partial displacement operation.

Cadmus' calculated cooling load varied significantly from 56% to 159% of the contractor estimates. The rated cooling capacity for ccASHP systems will always be higher than the heating capacity, so if a system is selected to meet the required heating load in the Northeast, it will likely be oversized for the cooling load.

---

4 CoolCalc Manual J. Accessed January 2022. https://www.coolcalc.com/

Table 4. Manual J Heating and Cooling Load Comparison

Site	Measured Equivalent Leakage Area[1]	Heating Load			Cooling Load		
		Contractor, Btu/hr	Cadmus, Btu/hr	Cadmus / Contractor Ratio	Contractor, Btu/hr	Cadmus, Btu/hr	Cadmus / Contractor Ratio
NY_01	215	56,377	73,275	130%	22,468	23,687	105%
NY_02	11	36,776	30,645	83%	16,987	14,416	85%
NY_03	99	N/A	34,656	N/A	N/A	18,611	N/A
NY_04	137	N/A	83,037	N/A	N/A	31,596	N/A
NY_05	55	47,614	53,112	112%	13,158	16,906	128%
NY_06	175	57,948	88,294	152%	31,596	27,089	86%
NY_07	N/A	N/A	33,802	N/A	N/A	15,147	N/A
NY_08	115	N/A	36,756	N/A	N/A	16,980	N/A
NY_09	117	N/A	29,439	N/A	N/A	17,129	N/A
NY_10	272	84,427	97,469	115%	49,006	35,003	71%
NY_11	71	34,849	28,804	83%	N/A	15,164	N/A
NY_12	195	59,589	81,432	137%	25,089	27,512	110%
NY_13	39	N/A	28,712	N/A	N/A	11,732	N/A
NY_14	81	59,886	54,230	91%	27,387	19,376	71%
NY_15	121	41,838	48,346	116%	27,904	19,043	68%
NY_16	102	27,445	36,140	132%	22,918	12,889	56%
NY_17	149	50,305	55,778	111%	23,660	20,062	85%
NY_18	N/A	42,583	64,694	152%	15,894	25,332	159%
NY_19	214	50,571	49,024	97%	12,143	18,739	154%
Overall	**128**	**50,016**	**53,034**	**116%**	**24,018**	**20,338**	**98%**

[1] Equivalent Leakage Area measured by Cadmus.

While this small sample is not statistically significant, these results provide a preliminary indication that contractors are not over-sizing systems relative to a correctly performed Manual J with actual blower door test inputs. However, one member of the advisory committee for this study noted that the Manual J calculator default air infiltration values tend to be lower than field-tested conditions, whereas other assumptions in the calculator may pad the calculated loads, such that a Manual J done with field-tested blower door data is likely to result in a higher heating load than the home's true load.

Cadmus investigated this by comparing the measured average heating load served by each ccASHP system during extreme cold periods with the contractor estimates. Table 5 compares the installed system heating capacity (at NEEP rating conditions of 5°F), contractor and Cadmus Manual J heat load estimates, and measured heating load during all metered hours with average outdoor air temperatures between 0°F and 15°F and a particularly cold seven-hour period in mid-February 2021, referred to as the cold snap. On average, the measured average heat load provided by the ccASHP systems is less than 50% of the design capacity.

These averages do not represent the absolute maximum measured load during those periods but indicate that most of the ccASHP systems were operating below their rated capacity during the 2020/2021 heating season (noting that 2020/2021 was a relatively mild winter).

Table 5. Contractor, Cadmus Manual J, and Measured Heat Load Comparison

Site	NEEP Rated Capacity (5F), Btu/hr	Calculated/Estimated			Measured			
		Contractor, Btu/hr	Cadmus, Btu/hr	Cadmus / Contractor Ratio	0-15°F Average Heating Load, Btu/hr	0-15°F Measured / Capacity, %	Cold Snap[1] Average Heating Load, Btu/hr	Cold Snap Measured / Capacity, %
NY_01	54,000	56,377	73,275	130%	19,092	35%	16,201	30%
NY_02	50,000	36,776	30,645	83%	12,403	25%	13,120	26%
NY_03	26,340	N/A	34,656	N/A	6,295	24%	N/A	0%
NY_04	70,200	N/A	83,037	N/A	32,977	47%	33,435	48%
NY_05	47,000	47,614	53,112	112%	27,539	59%	23,336	50%
NY_06	81,840	57,948	88,294	152%	28,992	35%	29,732	36%
NY_07	51,600	N/A	33,802	N/A	21,151	41%	19,942	39%
NY_08	45,400	N/A	36,756	N/A	27,815	61%	22,505	50%
NY_09	50,600	N/A	29,439	N/A	17,229	34%	18,507	37%
NY_10	63,870	84,427	97,469	115%	38,185	60%	43,973	69%
NY_11	38,000	34,849	28,804	83%	17,708	47%	16,487	43%
NY_12	57,200	59,589	81,432	137%	28,648	50%	20,492	36%
NY_13	48,000	N/A	28,712	N/A	24,856	52%	19,568	41%
NY_14	30,100	59,886	54,230	91%	11,207	37%	7,640	25%
NY_15	48,000	41,838	48,346	116%	11,883	25%	12,423	26%
NY_16	28,600	27,445	36,140	132%	22,835	80%	21,995	77%
NY_17	34,000	50,305	55,778	111%	27,426	81%	13,903	41%
NY_18	48,000	42,583	64,694	152%	26,792	56%	19,528	41%
NY_19[2]	67,000	50,571	49,024	97%	N/A	N/A	N/A	N/A
Overall	**49,461**	**50,016**	**53,034**	**116%**	**22,391**	**47%**	**19,599**	**40%**

[1] The cold snap for the heat load analysis was selected as the coldest seven-hour period of the metered data collection, defined as February 12, 2021, midnight to 7:00 AM. The average outdoor air temperature for the 19 New York sites was 8.3°F.
[2] Cadmus was unable to collect indoor supply and return air temperatures for NY_19 due to customer concerns about COVID-19.

Winter-Peak Demand Analysis

Cadmus performed an additional cold snap analysis of ccASHP system energy use, peak demand, and performance for the 19 metered homes in New York during the three coldest consecutive days of the monitoring period. For this analysis, Cadmus selected the three-day period from February 11, 2021, through February 13th, 2021, when most New York sites experienced outdoor air temperatures in the single digits in the early morning hours. Figure 3, Figure 4, and Figure 5 show hourly profiles of average demand, maximum demand, and heating performance by application for the three-day period. In contrast to the traditional utility Winter Peak period of 1:00 PM to 5:00 PM, the maximum hourly demand for whole-home residential ccASHP systems is in the early morning hours when the outside air temperature is the coldest.

The sampled New York sites have a noticeable peak load compared to the daily average. Generally, a smoother load shape will be less problematic for the electric grid and easier for utilities to plan for. New York could consider expanding customer education programs around "set-it-and-forget-it," to encourage ccASHP owners to remove overnight setbacks and reduce morning warm up demand.

Figure 3. Cold Snap Average Site Demand per Hour

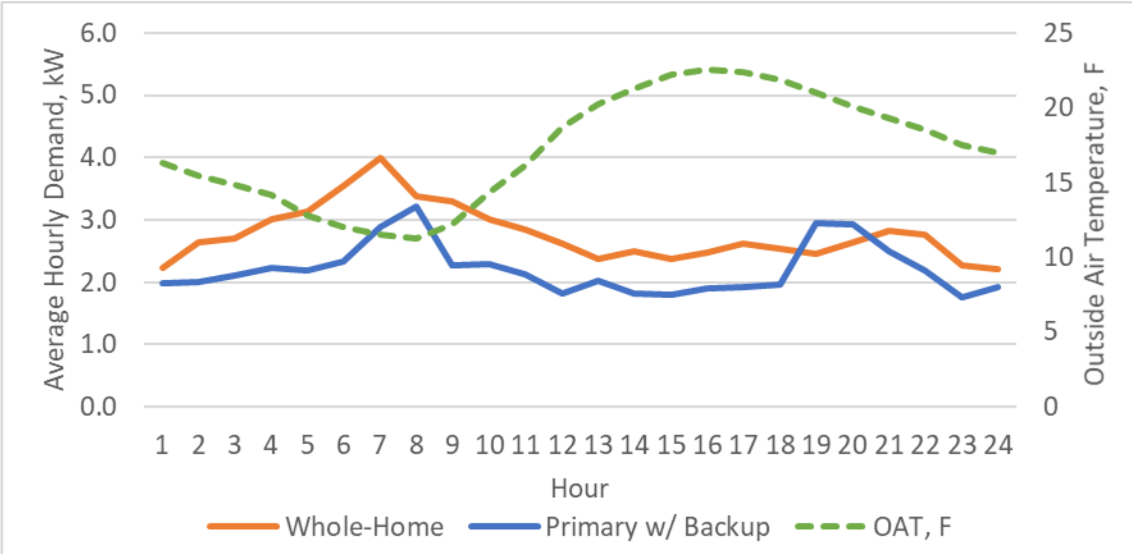


Figure 4. Cold Snap Average Site Maximum 2-Minute Demand per Hour

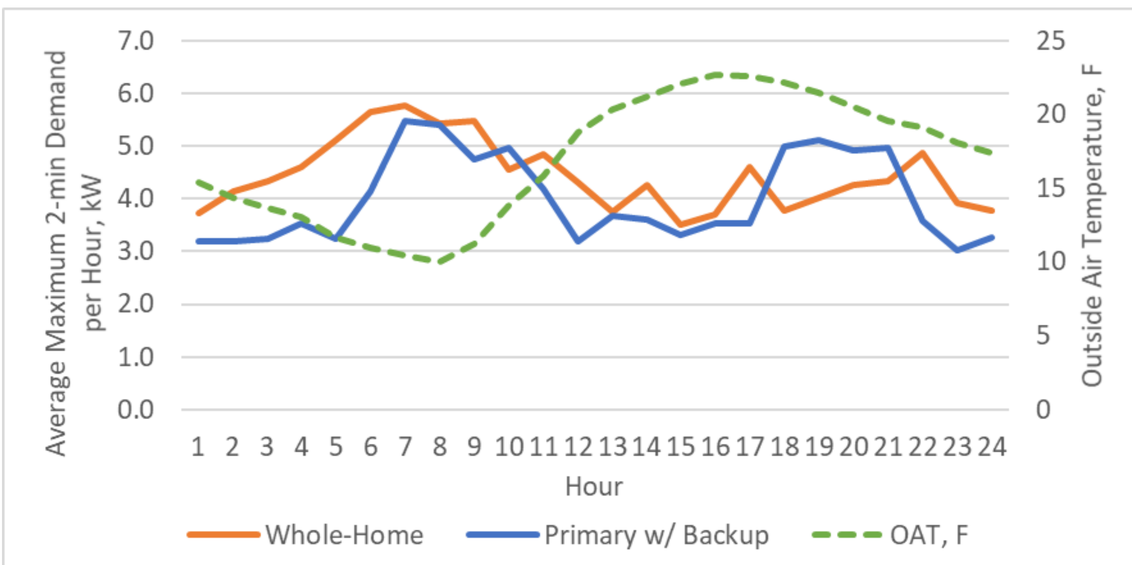


Figure 5. Cold Snap Average Site Heating Performance

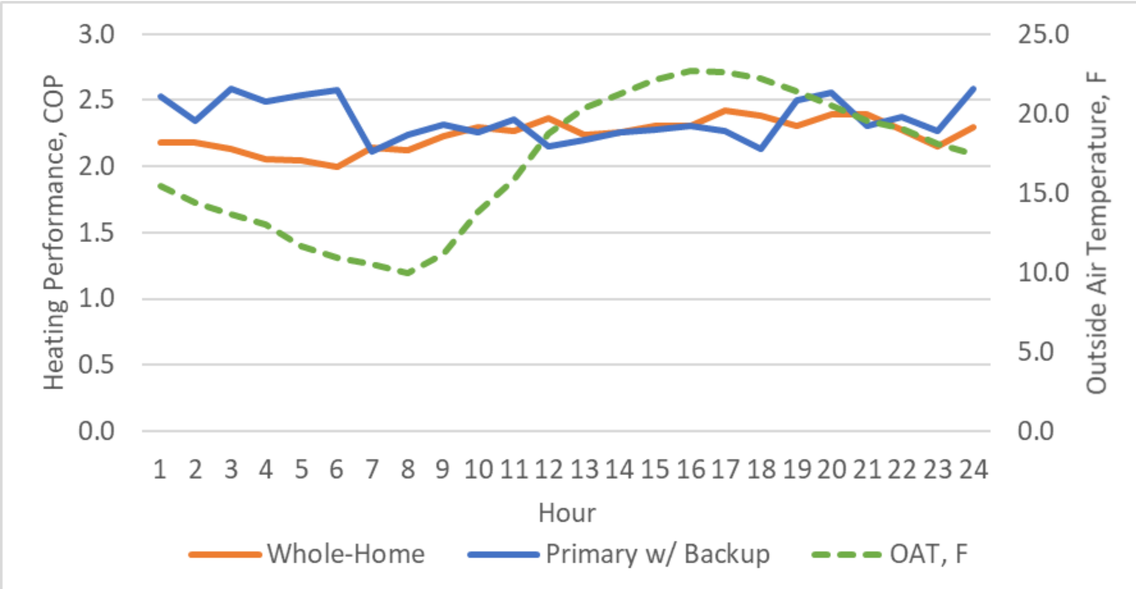


Table 6 summarizes average metered data results for various parameters during the three-day cold snap period by application. The average and maximum demand and heating load for whole-home systems was higher than primary with backup systems, as expected. However, the average heating performance for primary with backup systems was slightly higher than whole-home systems, likely due to the use of backup electric resistance elements by ducted systems in whole-home applications. While the measured average site-level maximum demand was only 4.45 kW for whole-home sites, the instantaneous maximum two-minute interval demand for whole-home sites with electric resistance elements ranged as high as 17.25 kW.

Table 6. New York Cold Snap Measured Data Summary by Application

Parameter	Application	
	Whole-Home	Primary with Backup
Number of Homes	12	7
Average Metered Demand, kW	2.77	2.21
Average Maximum Demand per Hour, kW	4.45	4.00
Maximum Site-Level Demand (2-min interval), kW [1]	17.25	14.11
Average Measured ccASHP Heating Load, Btu/hr [2]	18,881	19,859
Average Heating Performance, COP [2,3]	2.24	2.36
Average Outdoor Air Temperature, °F	17.2	16.9
Average Windspeed, mph	4.9	5.4

[1] This is the overall maximum measured site-level demand during a 2-minute interval of all sites per application.
[2] Load and performance data for NY_19 is not included in the cold snap analysis because the site contact declined indoor air temperature monitoring due to COVID-19 concerns.
[3] The calculated performance does not include electric resistance backup demand for three whole-home, ducted sites in New York.

New York Site Performance and Energy Savings Analysis

Cadmus also evaluated the in-field performance of the New York sites against both the original deemed savings estimate reported to the Clean Energy Fund (CEF) for projects incentivized through the NYSERDA Air Source Heat Pump Program (as established in 2017)[5] and the estimated energy savings approach for ccASHPs developed for Version 8 of the New York State Technical Resource Manual (TRM 8).[6]

- **Deemed savings estimate.** As part of the Air Source Heat Pump Program, NYSERDA established a deemed savings estimate for all projects incentivized under the program as reported to the CEF. All projects were assumed to offset 34.9 MMBtus of oil with a net increase of 2,320 kWh per outdoor unit installed, regardless of the heating fuel offset or the capacity of the outdoor unit(s) installed. This deemed savings estimate did not change with the introduction of the Whole-House Incentive.
- **TRM 8 savings estimate.** The TRM 8 approach for estimating ccASHP savings greatly expanded on previous TRM approaches for estimating ccASHP savings by accounting for fossil fuel savings and leveraging results from an in-depth analysis of manufacturer data completed for NYSERDA and the New York Department of Public Service seeking to model the performance of various ccASHP applications installed under different scenarios and in different geographic regions of the state. The TRM 8 approach was developed as part of the New York State Clean Heat Program implemented by the Joint Utilities as of April 2020.

Cadmus used the TRM 8 approach to calculate energy savings estimates for each metered site, using site-specific parameters. However, there are several caveats about the use of the TRM 8 savings estimates:

- **Inadequate TRM scenarios for ducted ccASHP installations through NYSERDA program.** The TRM 8 approach relies on modeling done for 19 installation scenarios to estimate system sizing and the percentage of the annual heating and cooling load offset by the ccASHP installation. All centrally ducted systems installed through the program must be sized to a minimum of 90% of the building heating load for incentive eligibility, and thus no scenarios are available for ducted ccASHPs that are sized for less than 90% of the building heating load. Four of the eight ducted ccASHP installations metered by Cadmus had heat pump sizing ratios of 56% to 78% of the building heating load and, due to scenario limitations, were assumed to have been sized at 90% of building heating load, which is expected to overestimate ccASHP load factor and existing fuel displacement.

---

[5] Information provided by NYSERDA Air Source Heat Pump Program manager.

[6] New York State Joint Utilities. (2020, July 31). *New York Standard Approach for Estimating Energy Savings from Energy Efficiency Programs – Residential, Multi-Family, and Commercial/Industrial Measures. Version 8.* Retrieved from https://www3.dps.ny.gov/W/PSCWeb.nsf/96f0fec0b45a3c6485257688006a701a/72c23decff52920a85257f1100671bdd/$FILE/NYS%20TRM%20V8.pdf

- **Wood backup heat.** A significant number of homes in the study used wood stoves for supplemental heating. Wood heating usage and its impact on ccASHP utilization is difficult to quantify in in-situ monitoring and was not part of this scope of work. The TRM 8 methodology does not include any information regarding use of wood backup heating and its impacts on estimated savings. As such, ccASHP load factor and estimated savings are likely to be overestimated by the TRM 8 methodology in homes continuing to use wood heat even after ccASHP installation.
- **No scenarios for mixed systems.** Four of the 19 New York sites metered included a mix of ductless and ducted equipment—either as multizone systems with both a ducted and ductless air handler or with separate ducted and ductless systems. None of the 19 TRM 8 scenarios account for mixed ducted/ductless systems. Cadmus selected either ducted or ductless multi-split scenarios based on the system/indoor unit with the largest proportion of capacity.

Cadmus used meters for supply airflow and air temperature as well as electricity consumption to estimate annual electricity used by the heat pump as well as heat delivered. As Cadmus was unable to meter backup system heating output and utility—and delivered fuel data provided by customers was often insufficient to establish an effective baseline—the team assumed heat delivered by the heat pump was equivalent to heat offset from the previous heating system for purposes of estimating energy savings.

Please note that the comparison of metered savings to savings calculated through deemed and TRM 8 approaches is for illustrative purposes only. Given the sample sizes available, this analysis is not a statistically significant assessment of either NYSERDA's deemed savings values or the TRM 8 methodology.

Energy Savings Analysis

Table 7 compares the deemed, TRM 8, and metered/calculated energy savings estimates for each site. While NYSERDA's deemed energy savings estimates do not vary substantially between whole-home and primary, TRM 8 estimates vary significantly, primarily due to the differences between the sampled sites. Homes with primary with backup ccASHP systems were significantly larger on average (30% higher) and had higher Manual J heating loads (44% higher) than whole-home sites.

Table 7. Summary of Site-Level Deemed, TRM 8, and Metered Energy Savings Estimates

Site	Site Attributes			NYSERDA Deemed Savings Estimates		TRM 8 Energy Savings Estimates		Metered Energy Savings Estimates	
	Application	System Type	Prior Primary Heating Fuel	Non-Electric, MMBtu	Electric, kWh	Non-Electric, MMBtu	Electric, kWh	Non-Electric, MMBtu	Electric, kWh
NY_01	Whole-Home	Mixed	Propane	34.9	-2,320	138.1	-11,791	69.6	-10,113
NY_02	Whole-Home	Ductless	Electric	69.8	-4,640		3,532		2,609
NY_03	Primary	Ducted	Propane	34.9	-2,320	76.7	-6,146	31.7	-1,722
NY_04	Primary	Mixed	Oil	104.7	-6,960	187.1	-14,725	120.6	-8,955
NY_05	Whole-Home	Ductless	Propane[1]	69.8	-4,640	110.6	-10,684	91.4	-6,920
NY_06	Primary	Mixed	Oil[1]	69.8	-4,640	136.0	-12,008	91.0	-11,595
NY_07	Whole-Home	Mixed	Gas	69.8	-4,640	80.8	-6,494	55.7	-6,524
NY_08	Whole-Home	Ductless	Oil	104.7	-6,960	87.8	-7,622	63.7	-4,635
NY_09	Primary	Ductless	Gas	34.9	-2,320	51.8	-3,832	28.1	-3,610
NY_10	Primary	Ducted	Oil*	69.8	-4,640	195.7	-14,924	104.6	-7,268
NY_11	Whole-Home	Ducted	Gas	34.9	-2,320	89.7	-7,384	20.7	-2,783
NY_12	Primary	Ductless	Gas	69.8	-4,640	144.2	-11,518	138.5	-10,752
NY_13	Whole-Home	Ductless	Gas[2]	34.9	-2,320	64.7	-5,806	69.0	-5,413
NY_14	Primary	Ducted	Gas	34.9	-2,320	132.0	-11,136	17.9	-2,169
NY_15	Whole-Home	Ducted	Oil[1]	34.9	-2,320	98.2	-8,250	41.8	-3,693
NY_16	Whole-Home	Ductless	Gas	34.9	-2,320	61.9	-4,643	50.8	-3,441
NY_17	Primary	Ducted	Propane[1]	34.9	-2,320	113.4	-10,636	22.4	-2,124
NY_18	Whole-Home	Ducted	Gas[1]	34.9	-2,320	109.7	-9,070	20.8	-2,102
NY_19	Whole-Home	Ductless	Electric	69.8	-4,640		8,219	N/A	N/A
Average				**55.1**	**-3,663**	**98.9**	**-7,627**	**61.1**	**-5,067**

[1] Site had additional supplemental wood or electric resistance heating. Heating displaced by ccASHP is assumed to be the primary system, as Cadmus was unable to meter usage from the supplemental source.
[2] Site was recently built with ccASHP as the sole source of heating. Gas is used as a baseline comparison.

Table 8 aggregates the measured and deemed/estimated savings by whole-home and primary with backup sites.

Table 8. Comparison of Estimated Energy Savings Methodologies by Application

Site Attributes		A NYSERDA Deemed Savings Estimates		B TRM 8 Energy Savings Estimates		C Metered Energy Savings Estimates		Comparison			
Application	Average Condit. Area, sq. ft.	Non-Electric, MMBtu	Electric, kWh	Non-Electric, MMBtu	Electric, kWh	Non-Electric, MMBtu	Electric, kWh	C / A, % MMBtu	C / A, % kWh	C / B, % MMBtu	C / B, % kWh
Primary w/ Backup	2,400	54.8	-3,646	128.7	-10,417	66.3	-5,229	121%	143%	51%	50%
Whole-Home	1,852	55.3	-3,673	81.5	-6,000	57.4	-4,965	104%	135%	71%	83%
Average	**2,054**	**55.1**	**-3,663**	**98.9**	**-7,627**	**61.1**	**-5,067**	**111%**	**138%**	**62%**	**66%**

On average, metered sites exceeded both the fossil fuel savings estimated through the NYSERDA deemed savings approach by 11% as well as the net increase in electricity consumption through electrification (38%). This was likely due to the number of centrally ducted and multi-zone ductless systems installed in the homes metered, which typically exceeded the deemed savings estimates for a single outdoor unit.

By contrast, the metered sites achieved only 62% of the savings estimated by the TRM 8 and 66% of the net increase in electricity consumption through electrification. Whole-home sites achieved 71% of estimated MMBtu savings compared to 51% of estimated savings achieved in primary homes. In addition to the factors discussed previously, this discrepancy may also be explained by a combination of factors:

- Manual J building heating load and heating load factor ($F_{load,heating}$) are two of the primary factors in estimating fossil fuel savings.
- Heating load factor in the TRM is determined by heat pump sizing relative to building heating load and geographic location. Using the displacement scenarios best aligned with the heat pump sizing ratios and closest geographic proxy locations, the TRM estimated that the heat pumps in primary homes would serve approximately 94% of the building's annual heating load. As most of the primary with backup homes used delivered fuels, Cadmus was not able to estimate the percent of heating load likely served by the backup system, but based on customer responses, Cadmus expects that heat pumps served significantly less the estimated annual heating load.
- As indicated in the peak heating analysis (Table 5), at near design conditions during cold snaps, the heat pumps metered were not providing heat capacity at close to design loads or maximum rated capacity, suggesting that Manual J loads are overestimating the actual heat required by the home. As such, relying on Manual Js to estimate annual fossil fuel consumption displaced may lead to overestimation.

System Efficiency Analysis

Heating Seasonal Performance Factor (HSPF) is the standard AHRI metric for estimating heat pump annual heating efficiency, though gaps in testing methodology for temperatures below 17°F led to the development of alternative certifications such as the NEEP Cold Climate Air Source Heat Pump Specification. While previous versions of the New York TRM used rated HSPF as the efficiency factor for estimating energy savings, TRM 8 aims to derate system HSPF (to $COP_{season,ee}$) to better estimate the expected seasonal coefficient of performance (sCOP) of the system depending on the geographic location and installation scenario. Across the 19 sites, the TRM-derived sCOP was over 10% lower than the manufacturer rated sCOP (as derived from HSPF).

Table 9 compares manufacturer-rated, TRM-derived, and measured seasonal heating performance for all New York sites. Table 10 shows the average manufacturer, TRM, and measured seasonal heating performance by application.

Table 9. Comparison of Manufacturer, TRM, and Measured ccASHP Seasonal Heating Performance

Site	Site Attributes			Manufacturer sCOP (HSPF – weighted avg)[1]	TRM Estimate, sCOP	Measured Performance, sCOP	Measured / Manuf. Rating sCOP, %	Measured / TRM sCOP, %
	Application	System Type	Prior Primary Heating Fuel					
NY_01	Whole-Home	Mixed	Propane	3.08	2.73	1.49	48%	55%
NY_02	Whole-Home	Ductless	Electric	2.93	2.41	1.51	52%	63%
NY_03	Primary	Ducted	Propane	3.08	2.90	4.32	140%	149%
NY_04	Primary	Mixed	Oil	3.50	3.38	3.16	90%	93%
NY_05	Whole-Home	Ductless	Propane[2]	2.94	2.43	3.10	105%	128%
NY_06	Primary	Mixed	Oil[3]	3.03	2.56	1.84	61%	72%
NY_07	Whole-Home	Mixed	Gas	3.34	2.96	2.00	60%	68%
NY_08	Whole-Home	Ductless	Oil	3.37	2.97	3.22	96%	109%
NY_09	Primary	Ductless	Gas	3.11	3.11	1.83	59%	59%
NY_10	Primary	Ducted	Oil[3]	3.35	3.00	3.38	101%	112%
NY_11	Whole-Home	Ducted	Gas	3.22	2.83	1.60	50%	57%
NY_12	Primary	Ductless	Gas	3.22	2.93	3.02	94%	103%
NY_13	Whole-Home	Ductless	Gas[3]	3.22	2.92	2.99	92%	102%
NY_14	Primary	Ducted	Gas	2.93	2.75	1.93	66%	70%
NY_15	Whole-Home	Ducted	Oil[3]	3.22	2.79	2.65	82%	95%
NY_16	Whole-Home	Ductless	Gas	3.22	2.93	3.46	107%	118%
NY_17	Primary	Ducted	Propane[2]	2.78	2.49	0.99	36%	40%
NY_18	Whole-Home	Ducted	Gas[2]	3.22	2.83	2.32	72%	82%
NY_19	Whole-Home	Ductless	Electric	3.28	3.02	N/A	N/A	N/A
Average				**3.16**	**2.84**	**2.59**	**82%**	**91%**

[1] Converted to seasonal COP through rated HSPF. For sites with multiple units, HSPF values were weighted based on total capacity of system at 5°F.
[2] Site had additional supplemental wood or electric resistance heating. Heating displaced by ccASHP is assumed to be the primary system, as Cadmus was unable to meter usage from the supplemental sources.
[3] Site was recently built with ccASHP as the sole source of heating. Gas is used as a baseline comparison.

Table 10. Manufacturer, TRM 8, and Measured Seasonal Heating Performance Comparison by Application

Application	Manufacturer Rating, sCOP (from HSPF)	TRM 8 Estimate, sCOP	Measured Performance, sCOP	Measured / Manufacturer sCOP, %	Measured / TRM sCOP, %
Primary	3.14	2.94	2.66	85%	91%
Whole-Home	3.17	2.78	2.38	75%	86%
Overall	**3.16**	**2.84**	**2.49**	**79%**	**88%**

Seasonal heating performance varied significantly across metered sites, from a minimum of 0.99 sCOP to a maximum of 4.32 sCOP, with an average of 2.49 sCOP. Measured seasonal heating performance was higher in homes with primary with backup systems than in homes with whole-home systems (2.66 sCOP vs. 2.38 sCOP). On average, primary with backup homes performed at 91% of the TRM-estimated seasonal heating performance while whole-home systems performed at 86% of TRM-estimated sCOP.

Though the sample for this study was small and not statistically significant, the average seasonal heating performance for the three ducted primary with backup systems was 2.65 sCOP compared to 2.67 sCOP for the four ductless systems. By contrast, the three ducted whole-home systems had a lower sCOP than the six ductless whole-home systems (2.19 sCOP vs. 2.86 sCOP, respectively). Additional observations by system type and application include:

- The metered ducted primary with backup systems used integrated controls to switch to a backup fuel-fired furnace during extreme cold periods instead of operating to lower temperatures and relying on backup electric resistance. Ducted primary with backup systems operated at higher temperatures on average (where ccASHPs are more efficient), whereas ducted whole-home systems had to operate at all hours and temperatures, and three of the whole-home ducted sites had integrated electric resistance backup.
- The average seasonal heating performance for ductless systems was similar between primary with backup and whole-home applications, but due to the limited sample of 10 sites, Cadmus cannot draw conclusions on the relatively minor difference in heating performance.
- While only three whole-home sites have mixed ductless and ducted systems,[7] the metered data shows that all three sites had an average seasonal heating performance less than 2.0 sCOP during the metering period (ranging from 1.61 sCOP to 2.00 sCOP). Given the sample size, it is challenging to draw conclusions about the performance of mixed systems and additional study is warranted.

[7] Two of these sites used mini-split outdoor units connected to both ducted and ductless indoor units, while one site used separate ducted and ductless systems.

Project Name: NY_01

Address:

OUTDOOR DESIGN CONDITIONS

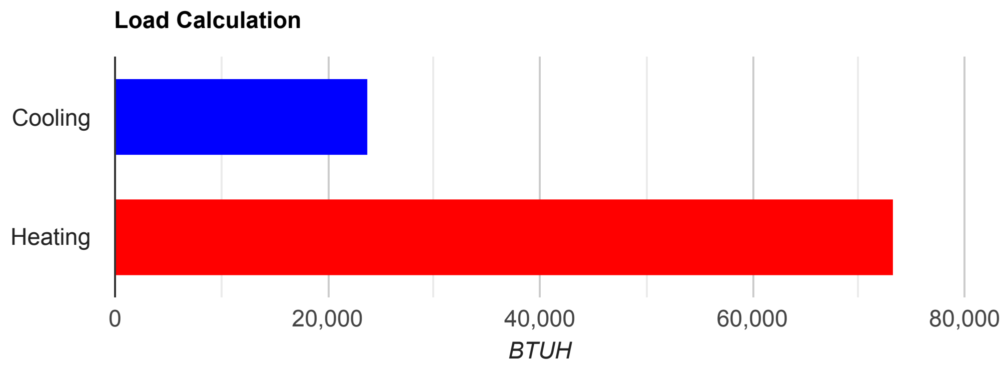
Weather station: Geneva

Summer Outdoor F:	87	Summer Indoor F:	75	Design Grains:	24	Daily Range:	Medium
Winter Outdoor F:	2	Winter Indoor F:	70	Cooling RH:	50	Elevation (Ft):	417

LOAD CALCULATION TOTALS

HVAC System: Primary

Heated square footage:	2,140	Heating BTUH:	73,275
Cooled square footage:	2,140	Cooling BTUH:	23,687
Heated volume (above grade CF):	16,858	CFM:	892
Cooled volume (above grade CF):	16,858	Sensible cooling:	19,646
Exposed wall area (SF):	1,899	Latent cooling:	4,041
		SHR:	0.829

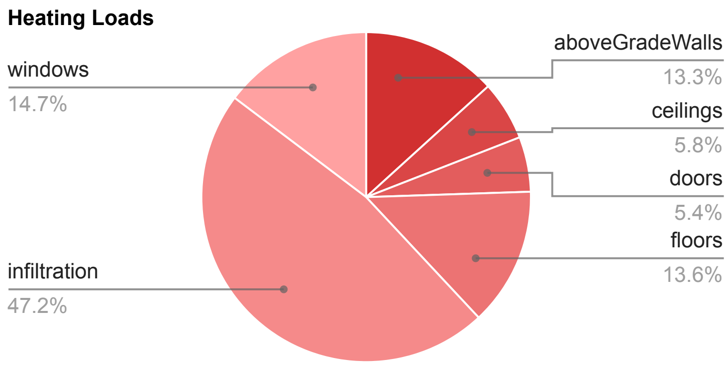


Approved ACCA MJ8 Calculations

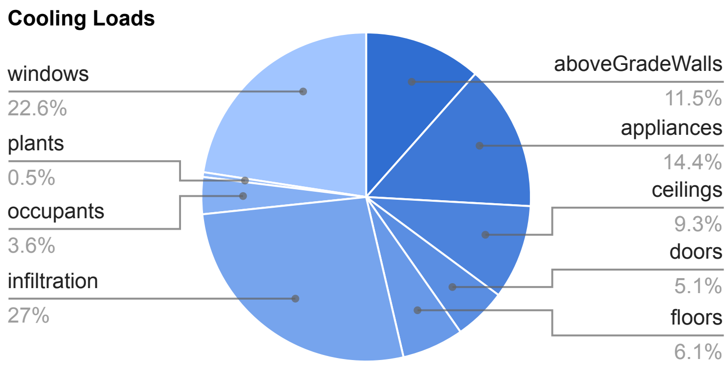
Calculations are based on the ACCA Manual J 8th Edition and are approved by ACCA. All computed calculations are estimates on building use, weather data, and inputted values such a R-Values, window types, duct loss, etc. Equipment selections should meet both the latent and sensible gain as well as building heat loss.

HEATING AND COOLING LOADS

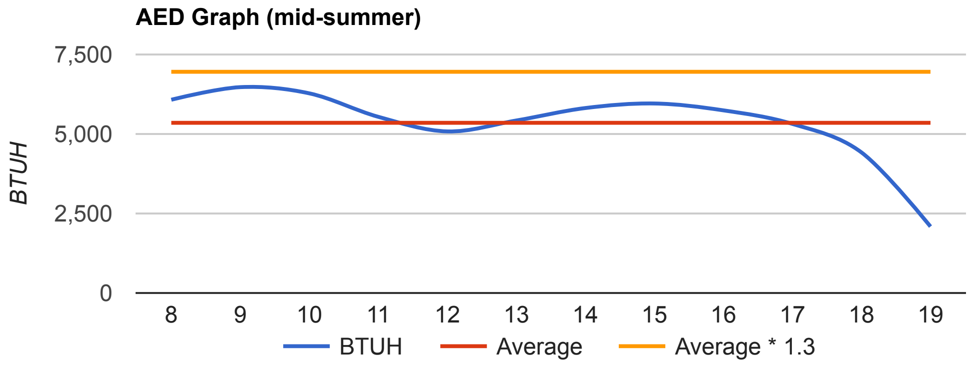
HEATING LOADS		
SECTION	AREA	HEAT LOSS
aboveGradeWalls	1,474.6	9,726
ceilings	1,280	4,265
doors	107.4	3,944
floors	1,280	9,931
infiltration	0	34,620
skylights	0	0
windows	317.3	10,788
Totals		73,275



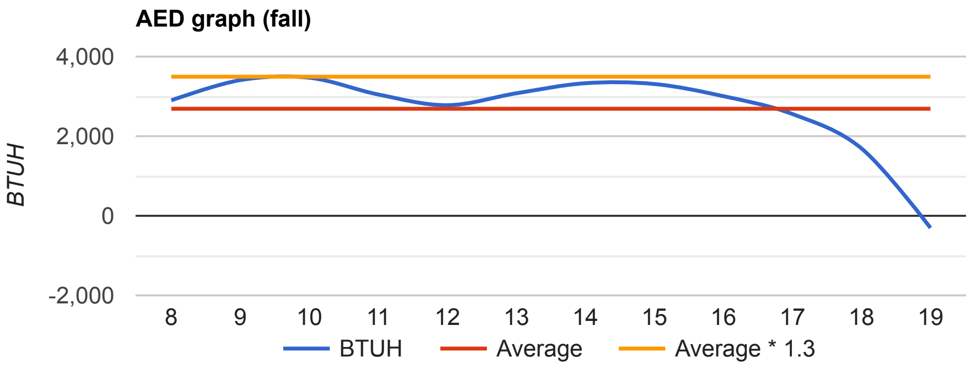
COOLING LOADS			
SECTION	AREA	SENSIBLE	LATENT
AEDExcursion	0	0	0
aboveGradeWalls	1,474.6	2,732	0
appliances	0	3,400	0
ceilings	1,280	2,195	0
doors	107.4	1,218	0
floors	1,280	1,435	0
infiltration	0	2,856	3,531
occupants	0	460	400
plants	0	0	110
skylights	0	0	0
windows	317.3	5,350	0
Totals		19,646	4,041



FENESTRATION LOADS



This graph represents hourly aggregrate fenestration loads in mid-summer.



This graph represents hourly aggregrate fenestration loads in October.

COMPONENT LOADS

ABOVE GRADE WALLS

System generated wall - N Frame Wall, Wood framing, R-11 cavity insulation, Stucco or Siding.	Construction nr: U Value:	12B-0s w 0.097	Exposure: Area:	N 6	Heating BTUH: Cooling BTUH:	40 11
System generated wall - E Frame Wall, Wood framing, R-11 cavity insulation, Stucco or Siding.	Construction nr: U Value:	12B-0s w 0.097	Exposure: Area:	E 75.3	Heating BTUH: Cooling BTUH:	497 140
System generated wall - E Frame Wall, Wood framing, R-11 cavity insulation, Stucco or Siding.	Construction nr: U Value:	12B-0s w 0.097	Exposure: Area:	E 128.9	Heating BTUH: Cooling BTUH:	850 239
System generated wall - S Frame Wall, Wood framing, R-11 cavity insulation, Stucco or Siding.	Construction nr: U Value:	12B-0s w 0.097	Exposure: Area:	S 132	Heating BTUH: Cooling BTUH:	871 245
System generated wall - W Frame Wall, Wood framing, R-11 cavity insulation, Stucco or Siding.	Construction nr: U Value:	12B-0s w 0.097	Exposure: Area:	W 155.2	Heating BTUH: Cooling BTUH:	1,024 288
System generated wall - N Frame Wall, Wood framing, R-11 cavity insulation, Stucco or Siding.	Construction nr: U Value:	12B-0s w 0.097	Exposure: Area:	N 115.8	Heating BTUH: Cooling BTUH:	764 215
System generated wall - E Frame Wall, Wood framing, R-11 cavity insulation, Stucco or Siding.	Construction nr: U Value:	12B-0s w 0.097	Exposure: Area:	E 119.3	Heating BTUH: Cooling BTUH:	787 221
System generated wall - N Frame Wall, Wood framing, R-11 cavity insulation, Stucco or Siding.	Construction nr: U Value:	12B-0s w 0.097	Exposure: Area:	N 121.6	Heating BTUH: Cooling BTUH:	802 225
System generated wall - W Frame Wall, Wood framing, R-11 cavity insulation, Stucco or Siding.	Construction nr: U Value:	12B-0s w 0.097	Exposure: Area:	W 100.5	Heating BTUH: Cooling BTUH:	663 186
System generated wall - E Frame Wall, Wood framing, R-11 cavity insulation, Stucco or Siding.	Construction nr: U Value:	12B-0s w 0.097	Exposure: Area:	E 165	Heating BTUH: Cooling BTUH:	1,088 306
System generated wall - S Frame Wall, Wood framing, R-11 cavity insulation, Stucco or Siding.	Construction nr: U Value:	12B-0s w 0.097	Exposure: Area:	S 180	Heating BTUH: Cooling BTUH:	1,187 333
System generated wall - W Frame Wall, Wood framing, R-11 cavity insulation, Stucco or Siding.	Construction nr: U Value:	12B-0s w 0.097	Exposure: Area:	W 175	Heating BTUH: Cooling BTUH:	1,154 324

BELOW GRADE WALLS

There are no components for this section.

WINDOWS

Default medium windows for wall id 1078916 Window, NFRC rated, Clear glass.	Construction nr: Area: Exposure:	1G 34 N	U Value: SHGC:	0.5 0.4	Heating BTUH: Cooling BTUH:	1,156 325

WINDOWS

Default small windows for wall id 1079562 Window, NFRC rated, Clear glass.	Construction nr: 1G Area: 14.7 Exposure: E	U Value: 0.5 SHGC: 0.4	Heating BTUH: 500 Cooling BTUH: 289
Default medium windows for wall id 1079334 Window, NFRC rated, Clear glass.	Construction nr: 1G Area: 34 Exposure: E	U Value: 0.5 SHGC: 0.4	Heating BTUH: 1,156 Cooling BTUH: 668
Default medium windows for wall id 1079335 Window, NFRC rated, Clear glass.	Construction nr: 1G Area: 34 Exposure: S	U Value: 0.5 SHGC: 0.4	Heating BTUH: 1,156 Cooling BTUH: 656
Default small windows for wall id 1079336 Window, NFRC rated, Clear glass.	Construction nr: 1G Area: 17 Exposure: W	U Value: 0.5 SHGC: 0.4	Heating BTUH: 578 Cooling BTUH: 381
Default medium windows for wall id 1079326 Window, NFRC rated, Clear glass.	Construction nr: 1G Area: 30.2 Exposure: N	U Value: 0.5 SHGC: 0.4	Heating BTUH: 1,027 Cooling BTUH: 288
Default small windows for wall id 1079327 Window, NFRC rated, Clear glass.	Construction nr: 1G Area: 13.7 Exposure: E	U Value: 0.5 SHGC: 0.4	Heating BTUH: 466 Cooling BTUH: 269
Default medium windows for wall id 1079327 Window, NFRC rated, Clear glass.	Construction nr: 1G Area: 28.3 Exposure: E	U Value: 0.5 SHGC: 0.4	Heating BTUH: 962 Cooling BTUH: 556
Default medium windows for wall id 1078895 Window, NFRC rated, Clear glass.	Construction nr: 1G Area: 15.1 Exposure: N	U Value: 0.5 SHGC: 0.4	Heating BTUH: 513 Cooling BTUH: 144
Default large windows for wall id 1078895 Window, NFRC rated, Clear glass.	Construction nr: 1G Area: 20.8 Exposure: N	U Value: 0.5 SHGC: 0.4	Heating BTUH: 707 Cooling BTUH: 199
Default large windows for wall id 1079319 Window, NFRC rated, Clear glass.	Construction nr: 1G Area: 24.5 Exposure: W	U Value: 0.5 SHGC: 0.4	Heating BTUH: 833 Cooling BTUH: 548
Default small windows for wall id 1079517 Window, NFRC rated, Clear glass.	Construction nr: 1G Area: 6 Exposure: E	U Value: 0.5 SHGC: 0.4	Heating BTUH: 204 Cooling BTUH: 118
Default medium windows for wall id 1079517 Window, NFRC rated, Clear glass.	Construction nr: 1G Area: 36 Exposure: E	U Value: 0.5 SHGC: 0.4	Heating BTUH: 1,224 Cooling BTUH: 707
Default small windows for wall id 1079515 Window, NFRC rated, Clear glass.	Construction nr: 1G Area: 9 Exposure: W	U Value: 0.5 SHGC: 0.4	Heating BTUH: 306 Cooling BTUH: 201

Window cooling BTUHs shown here are daily average values. See AED graphs for details of fenestration loads during the day.

CEILINGS

System generated ceiling. Ceiling under attic or attic knee wall, Asphalt shingles, Light, R-19.	Construction nr: 16C-19 al U Value: 0.049	Area: 400	Heating BTUH: 1,333 Cooling BTUH: 686
System generated ceiling. Ceiling under attic or attic knee wall, Asphalt shingles, Light, R-19.	Construction nr: 16C-19 al U Value: 0.049	Area: 420	Heating BTUH: 1,399 Cooling BTUH: 720
System generated ceiling. Ceiling under attic or attic knee wall, Asphalt shingles, Light, R-19.	Construction nr: 16C-19 al U Value: 0.049	Area: 460	Heating BTUH: 1,533 Cooling BTUH: 789

SKYLIGHTS

There are no components for this section.

Skylight cooling BTUHs shown here are daily average values. See AED graphs for details of fenestration loads during the day.

DOORS

DOORS

Default doors for wall id 1079334 Wood Door, Panel.	Construction nr: U Value:	11 0.54	Area: Exposure:	28 E	Heating BTUH: Cooling BTUH:	1,028 318
Default doors for wall id 1079336 Wood Door, Panel.	Construction nr: U Value:	11 0.54	Area: Exposure:	18.7 W	Heating BTUH: Cooling BTUH:	687 212
Default doors for wall id 1079327 Wood Door, Panel.	Construction nr: U Value:	11 0.54	Area: Exposure:	18.7 E	Heating BTUH: Cooling BTUH:	687 212
Default doors for wall id 1078895 Wood Door, Panel.	Construction nr: U Value:	11 0.54	Area: Exposure:	21 N	Heating BTUH: Cooling BTUH:	771 238
Default doors for wall id 1079319 Wood Door, Panel.	Construction nr: U Value:	11 0.54	Area: Exposure:	21 W	Heating BTUH: Cooling BTUH:	771 238

FLOORS

System generated floor. Floor over enclosed unconditioned crawl space or basement, no floor insulation, Carpet or hardwood.	Construction nr: Area:	19A-0cp 460	Heating U Value:0.295 Cooling U Value:0.295	Heating BTUH: Cooling BTUH: F Value:	3,569 516 N/A
System generated floor. Floor over enclosed unconditioned crawl space or basement, no floor insulation, Carpet or hardwood.	Construction nr: Area:	19A-0cp 400	Heating U Value:0.295 Cooling U Value:0.295	Heating BTUH: Cooling BTUH: F Value:	3,103 448 N/A
System generated floor. Floor over enclosed unconditioned crawl space or basement, no floor insulation, Carpet or hardwood.	Construction nr: Area:	19A-0cp 420	Heating U Value:0.295 Cooling U Value:0.295	Heating BTUH: Cooling BTUH: F Value:	3,259 471 N/A

VENTILATION

There are no components for this section.

HOT WATER PIPING

There are no components for this section.

DUCTS

There are no components for this section.

INFILTRATION

Leakage Category:	NCFM Heating: NCFM Cooling:	469 219	Heating BTUH: Sensible BTUH: Latent BTUH:	34,620 2,856 3,531

BLOWER MOTOR

There are no components for this section.

WINTER HUMIDIFICATION

There are no components for this section.

OCCUPANTS

Nr. Occupants:	2	Sensible BTUH:	460	Latent BTUH:	400

APPLIANCES

APPLIANCES

Kitchen, utility room, additional fridge, lighting: 3,400 BTUH	Quantity:	Sensible BTUH: Latent BTUH:	3,400

PLANTS

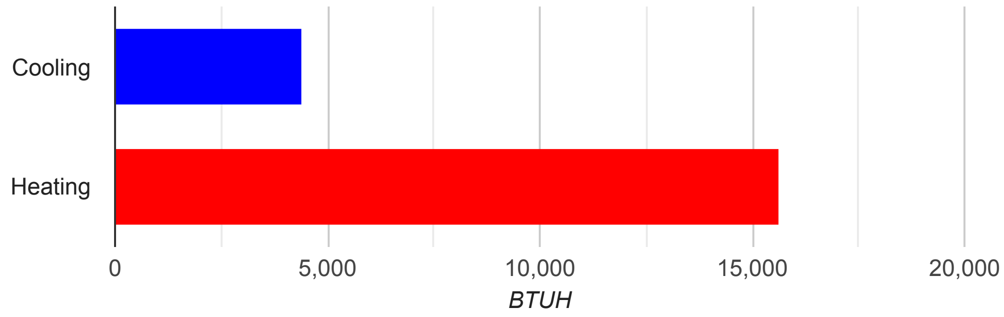
Plant Size:	small	Quantity:	4	Latent BTUH:	40
Plant Size:	medium	Quantity:	2	Latent BTUH:	40
Plant Size:	large	Quantity:	1	Latent BTUH:	30

ROOM DETAIL

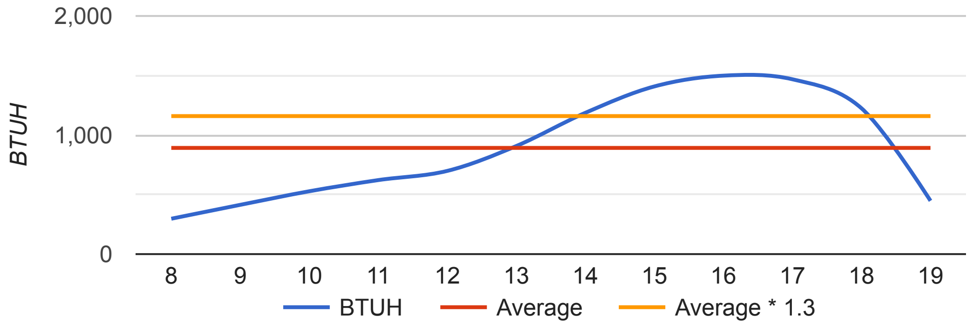
Room name: First Floor 1975

Heated square footage:	420	Total Cooling BTUH:	4,401
Cooled square footage:	420	Total Heating BTUH:	15,634
Heated volume (above grade CF):	3,360	CFM:	191
Cooled volume (above grade CF):	3,360		
Exposed wall area (SF):	325		

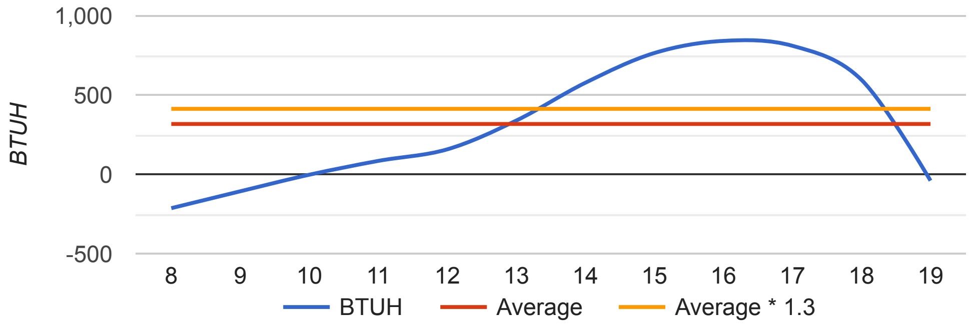
Load Calculation



AED Graph (mid-summer)



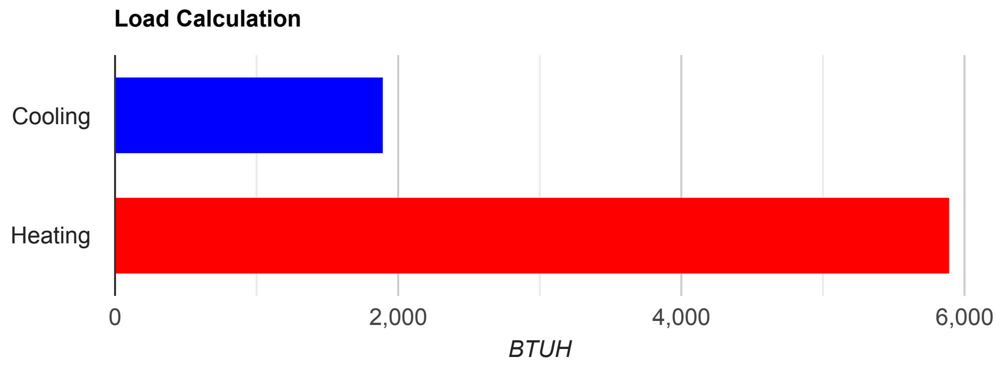
AED graph (fall)

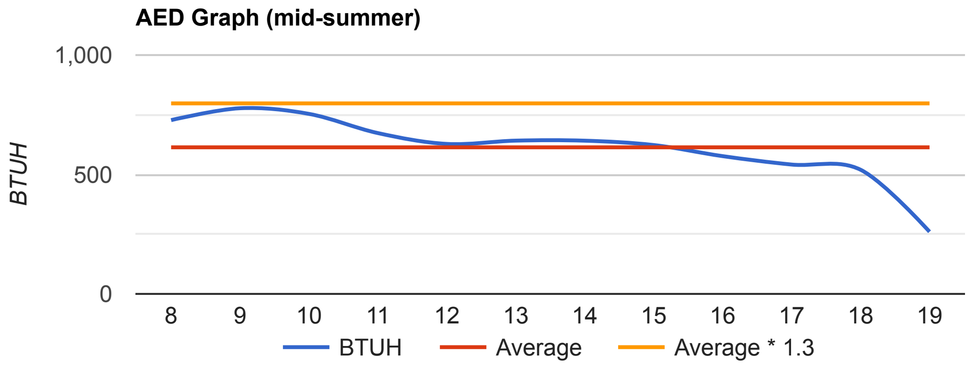


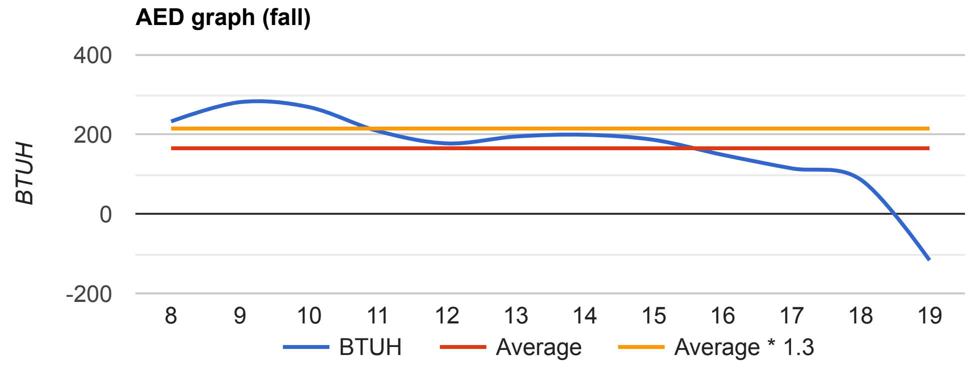
ROOM DETAIL

Room name: Second Floor 1900

Heated square footage:	400	Total Cooling BTUH:	1,887
Cooled square footage:	400	Total Heating BTUH:	5,894
Heated volume (above grade CF):	2,920	CFM:	83
Cooled volume (above grade CF):	2,920		
Exposed wall area (SF):	130		





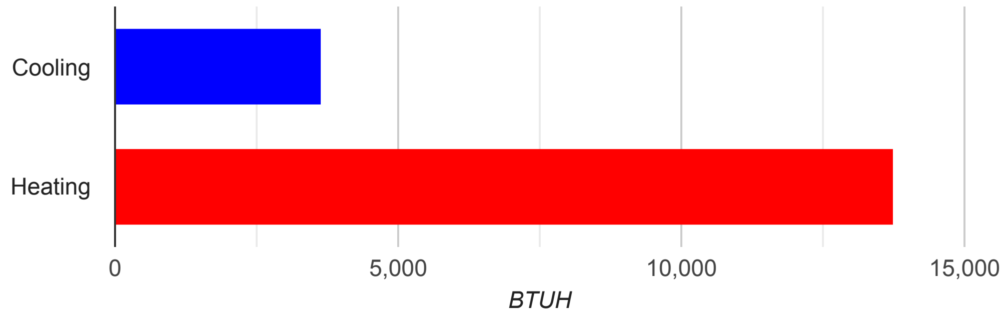


ROOM DETAIL

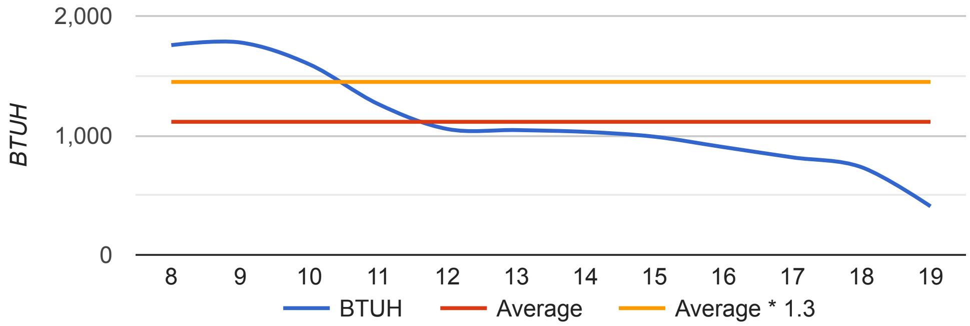
Room name: First Floor 1900

Heated square footage:	400	Total Cooling BTUH:	3,636
Cooled square footage:	400	Total Heating BTUH:	13,738
Heated volume (above grade CF):	3,080	CFM:	137
Cooled volume (above grade CF):	3,080		
Exposed wall area (SF):	326		

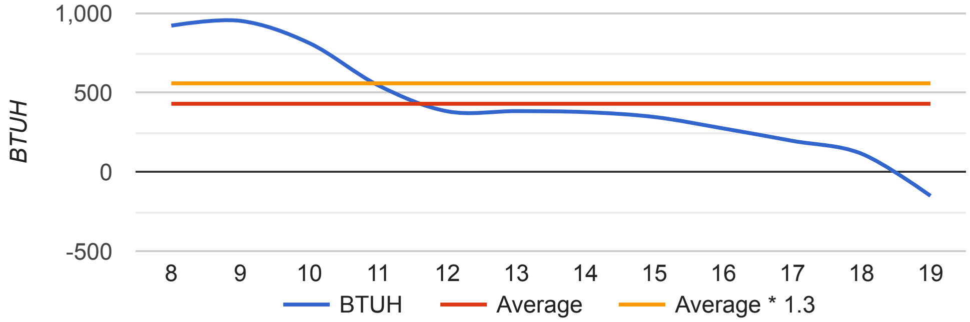
Load Calculation



AED Graph (mid-summer)



AED graph (fall)

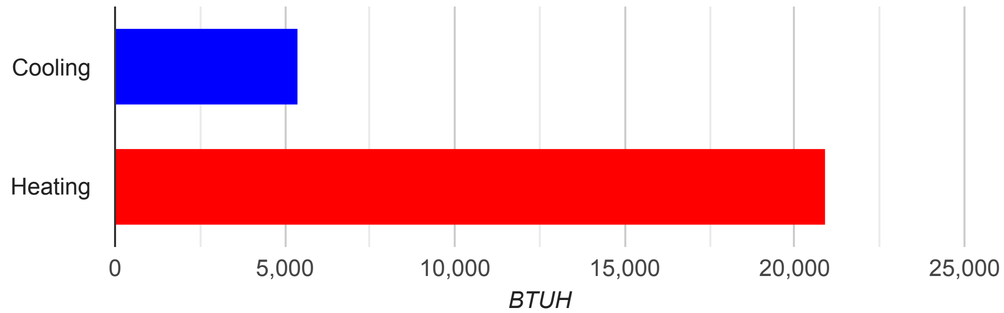


ROOM DETAIL

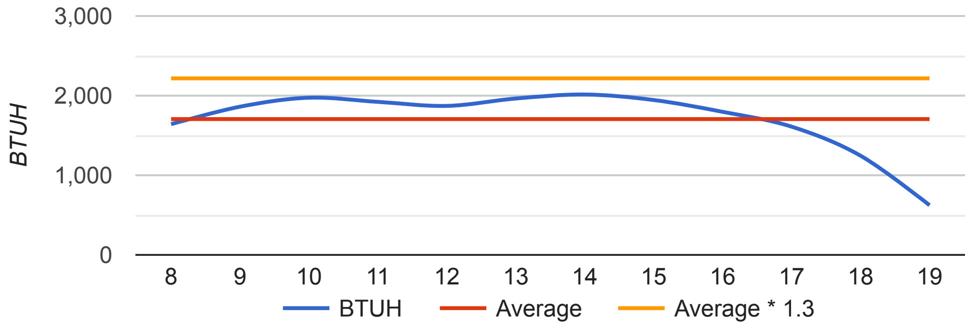
Room name: First Floor 1850

Heated square footage:	460	Total Cooling BTUH:	5,363
Cooled square footage:	460	Total Heating BTUH:	20,904
Heated volume (above grade CF):	3,358	CFM:	197
Cooled volume (above grade CF):	3,358		
Exposed wall area (SF):	548		

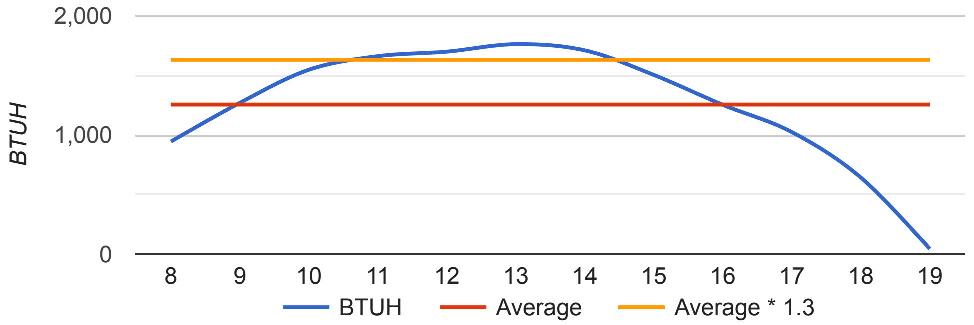
Load Calculation



AED Graph (mid-summer)



AED graph (fall)

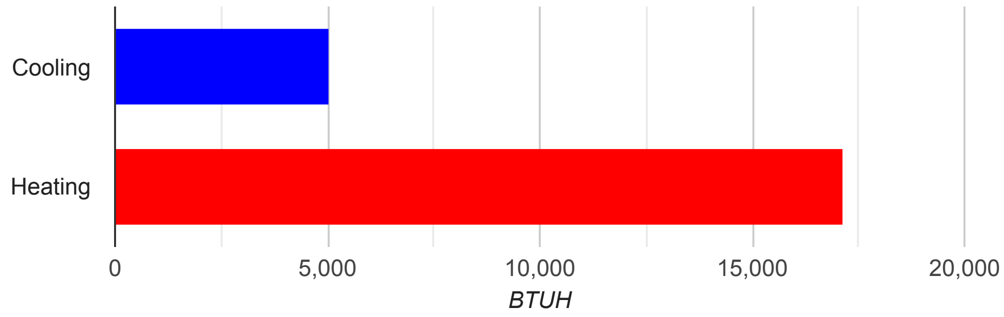


ROOM DETAIL

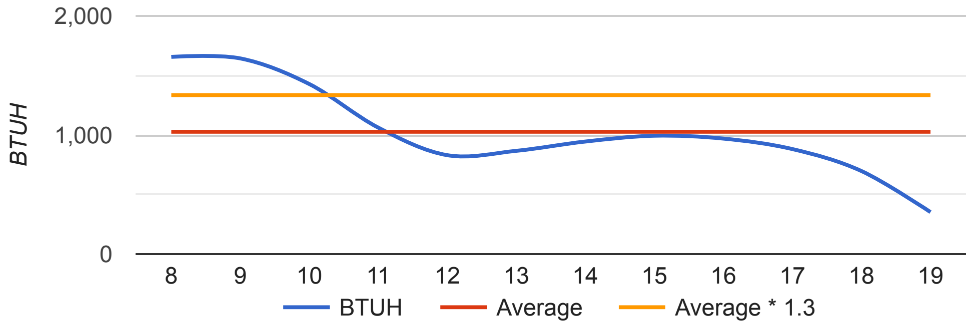
Room name: Second Floor 1850

Heated square footage:	460	Total Cooling BTUH:	5,020
Cooled square footage:	460	Total Heating BTUH:	17,105
Heated volume (above grade CF):	4,140	CFM:	163
Cooled volume (above grade CF):	4,140		
Exposed wall area (SF):	571		

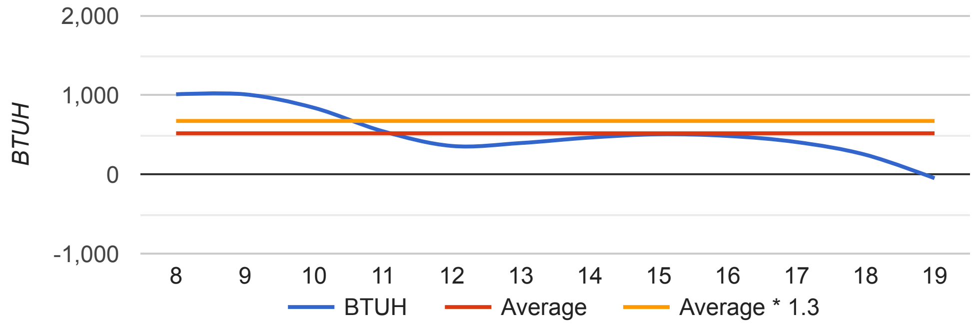
Load Calculation



AED Graph (mid-summer)



AED graph (fall)



CADMUS

E4TheFuture ccASHP Customer Survey Findings – New York

February 10, 2021

Agenda

Objectives and Methodology

Key Findings

Customer Motivations

Installation Experience

Weatherization

ASHP Behaviors

Satisfaction

Objectives and Methodology

Research Objectives	• Identify customer motivations for specific heating applications (i.e., whole-home, primary w/ backup, supplemental) • Assess customer experience with ccASHP installation • Understand customer behavior using ASHP and managing back-up heating (e.g. controls, thermostat adjustments) • Assess customer satisfaction with ccASHP and any performance issues experienced • Understand weatherization measures installed with ccASHP and satisfaction with weatherization performance • Collect information on utility and fuel bills and recruit for *in-situ* monitoring
Method	Cadmus fielded survey via two sources, NYSERDA rebate list and Qualtrics panel, with the following responses: • NYSERDA rebate data: **275** • Qualtrics panel: **74** Cadmus used the Qualtrics panel to increase total sample size beyond what could be achieved through rebate data alone. Qualtrics is a nationwide research firm that maintains a database of survey respondents

Methodology

In this research, the Cadmus team stratified respondents into three categories based on their ASHP usage.

Whole-Home	Primary w/ Backup	Supplemental
• Use ASHP for all heating needs • ASHP can heat/cool at least 75% of home • 98 respondents in final survey sample	• Use ASHP for nearly all heating needs but a backup system occasionally • ASHP can heat/cool at least 75% of home • 108 respondents in final survey sample	• Use other heating system as primary • 143 respondents in final survey sample

Key Findings

- Customers primarily installed ASHPs to **increase home comfort** and **save money on energy bills.** Customers with a whole-home configuration are especially likely to be motivated by environmental impacts: eliminating fossil fuel usage for heating.
- **Word-of-mouth** was the most common way that customers learned about ASHPs and found their contractor.

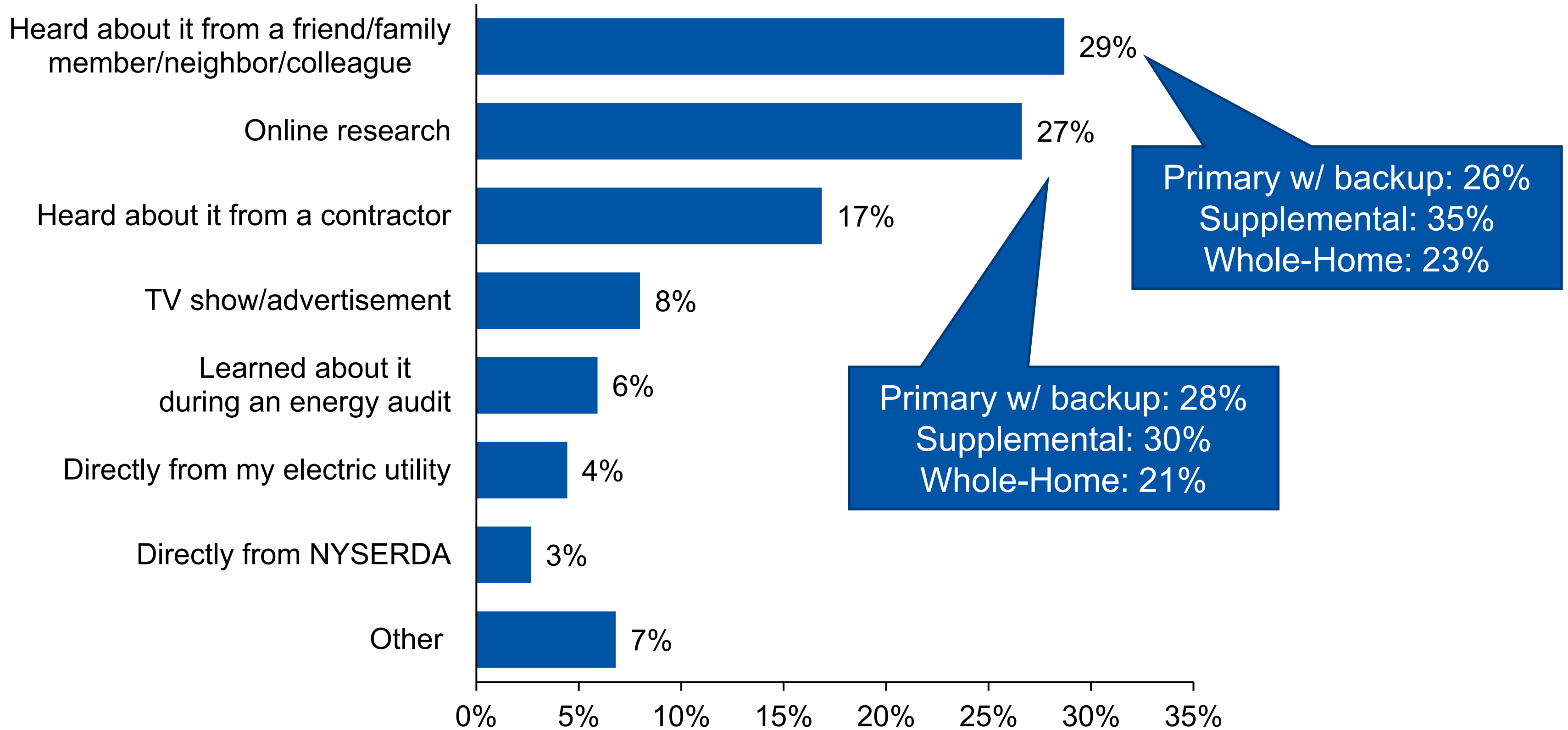
- **Weatherization upgrades** were usually completed before installing **ASHPs.** This was especially true among those that had an energy audit completed and customers installing whole-home systems.
- Contractors were a key knowledge conduit, as **contractors are how most customers learned how to use their ASHP**.

- Performance issues were uncommon with ASHPs.
- Nearly all customers reported lower bills, leading to an **extremely high likelihood to recommend an ASHP** to others.

Customer Motivations

ASHP Awareness

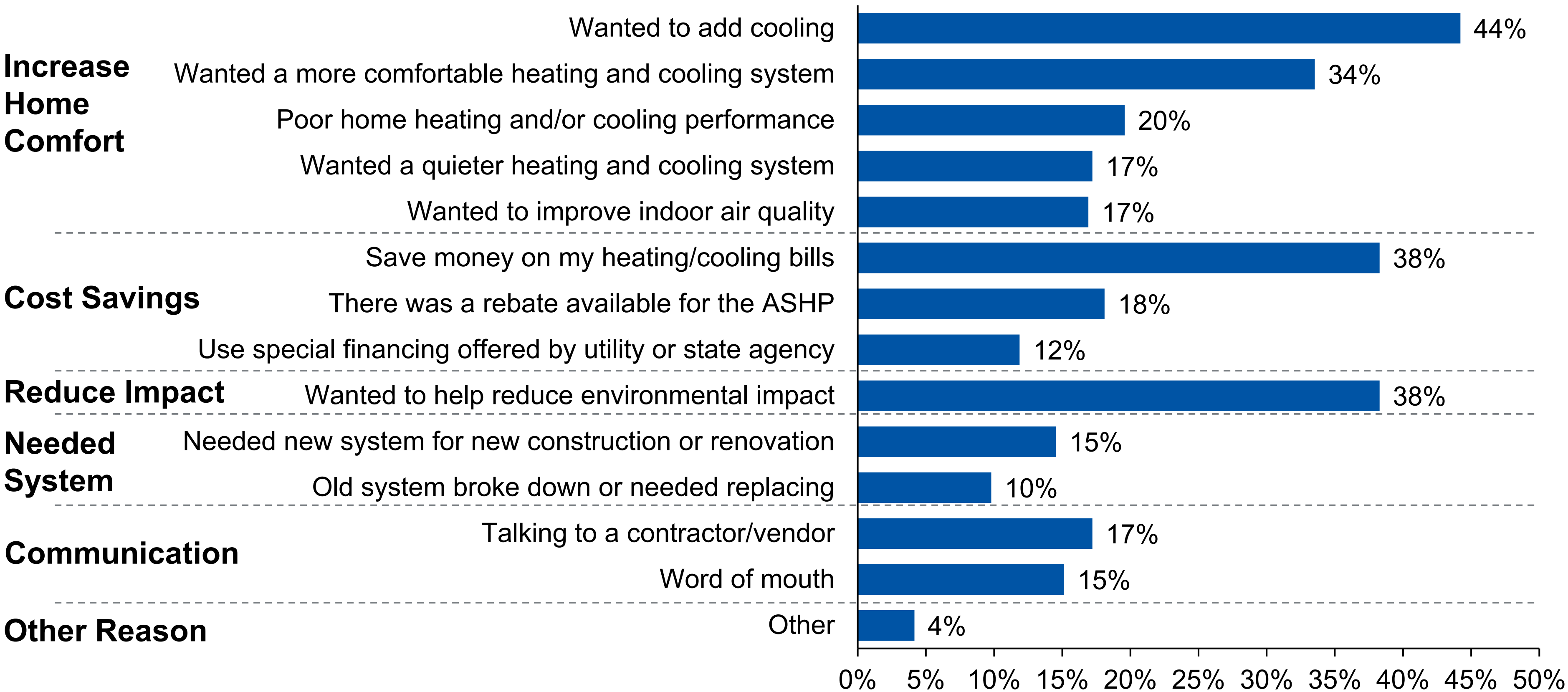
Most respondents learned about ASHPs through word of mouth; customers with a primary with backup system were more likely to learn about ASHPs through online research than whole-home customers.



Source: E4TheFuture Customer survey question B1. How did you first learn about air source heat pumps? Please select only one response. (n=338)

Decision to install ASHP

Most respondents installed an ASHP to increase home comfort, save money, and reduce environmental impact.



Sources: E4TheFuture Customer survey questions B2. What led you to your decision to install an air source heat pump? (n=337)

Decision to install ASHP

Customers across the three configuration types had different reasons that led them to their decision to install an ASHP. Specifically, primary w/ backup and supplemental customers were more likely to be looking to add cooling.

	Configuration		
	Whole-Home	Primary w/ Backup	Supplemental
Wanted to add cooling	25%	47%	55%
Save money on my heating/ cooling bills	27%	52%	35%
Wanted to help reduce environmental impact	34%	48%	34%
Needed new system for new construction or renovation	20%	16%	9%
Talking to contractor/vendor	23%	17%	14%

Sources: E4TheFuture Customer survey questions B2. What led you to your decision to install an air source heat pump? (n=337) Respondents could select multiple answers.

Decision to install ASHP

Delivered fuel customers were more likely to install an ASHP to add cooling snd reduce their environmental impact.

	Prior Heating Fuel Type		
	Electric	Natural Gas	Delivered Fuel
Save money on heating/cooling bills	37%	35%	42%
Wanted to add cooling	33%	40%	56%
Reduce environmental impact	31%	32%	47%
More comfortable heating/cooling system	35%	33%	33%
There was a rebate available	13%	24%	18%

Sources: E4TheFuture Customer survey questions B2. What led you to your decision to install an air source heat pump? (n=337) Respondents could select multiple answers.

Motivators for Configuration

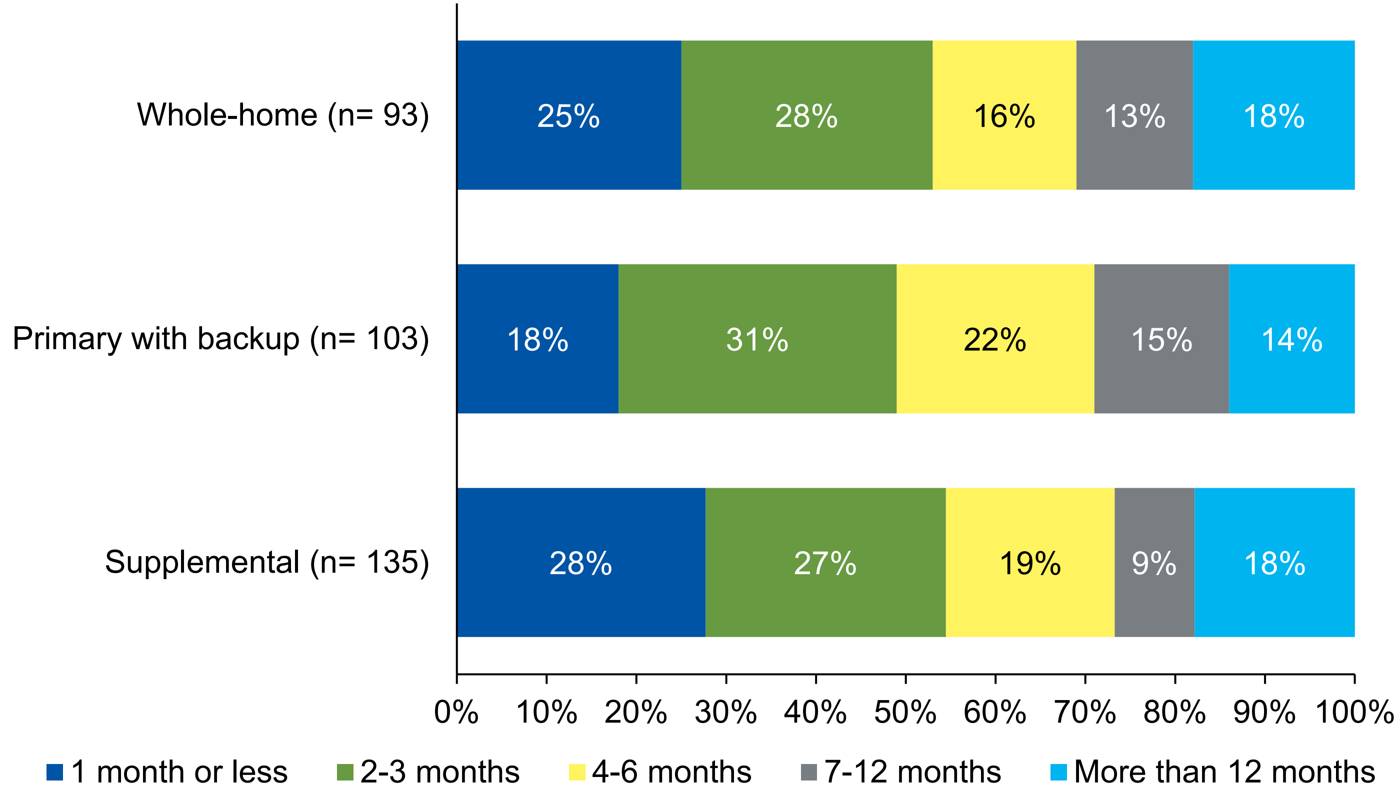
Customers using their ASHP in a whole-home configuration were most influenced by environmental benefits, while primary w/ backup and supplemental customers were focused on keeping both systems.

Whole-Home	Primary w/ Backup & Supplemental
Wanted to eliminate fossil fuel usage for heating (29%)	Previous system did not need to be replaced (37%)
Needed new system for new construction or renovation project (23%)	Recommended by contractor (32%)
Wanted to maximize energy savings (22%)	Wanted 2 heating systems in case of emergencies (21%)

Sources: E4TheFuture Customer survey questions B6. & B7. When you were deciding to purchase an air source heat pump, why did you select the specific configuration that you now have installed? (B6. n=92, B7. n=241) Primary with backup and supplemental configuration customers were asked the same set of answer options.

Length of Consideration

Over half of respondents considered installing an ASHP for 3 months or fewer before having the work completed.



Source: E4TheFuture Customer survey question B5. How long did you consider installing an air source heat pump before having the work completed? (n=331)

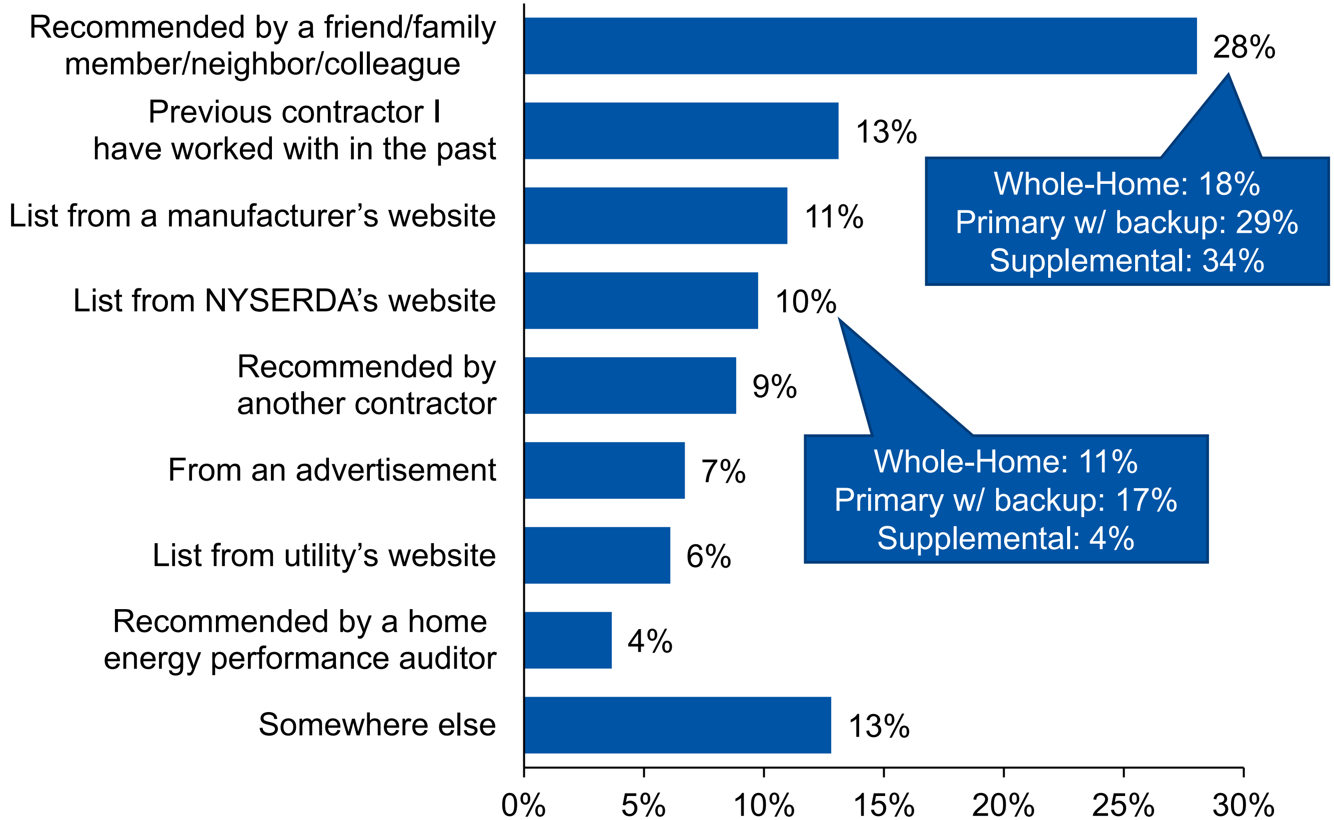
CADMUS

Installation Experience

CADMUS

Finding a contractor

Most respondents contacted 2 to 3 contractors about ASHP installations and found their contractor through (1) word of mouth or (2) because they had worked with the contractor in the past.



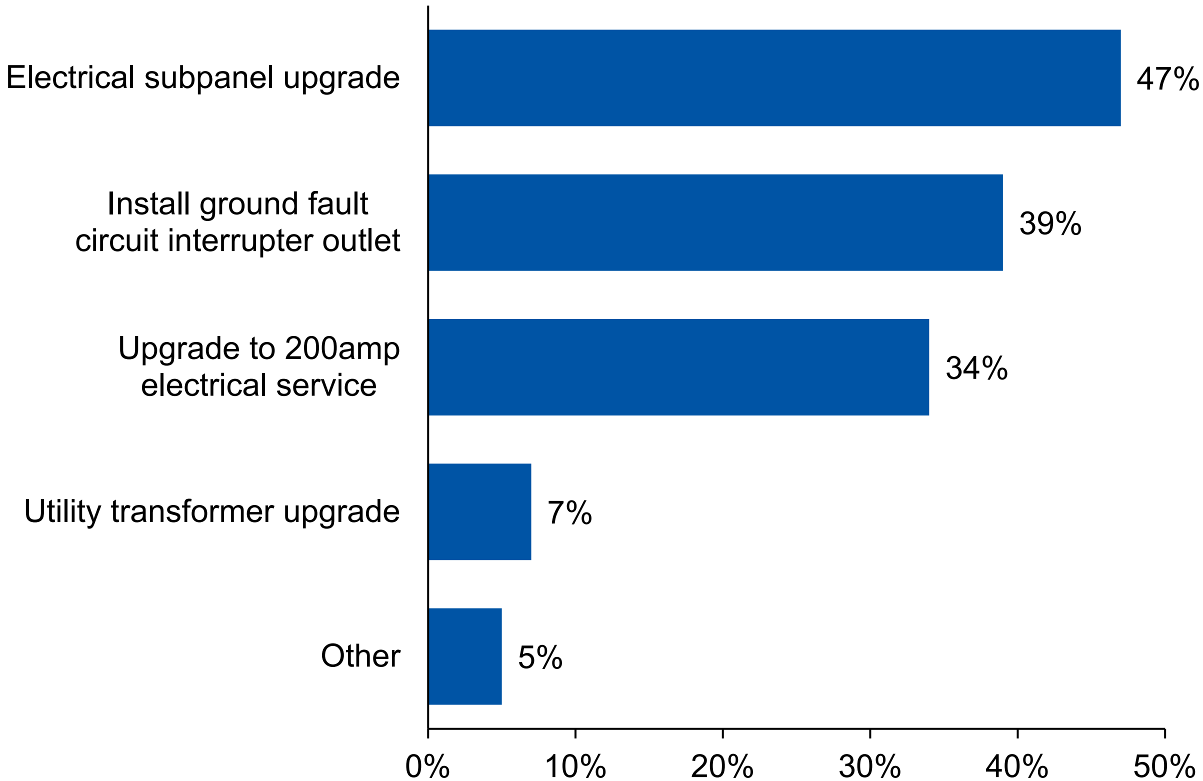
Respondents contacted, on average, **2.8** contractors about the ASHP installation.

Respondents received a quote or bid from an average of **2.3** contractors.

Sources: E4TheFuture Customer survey questions C8. How did you find the contractor who installed your air source heat pump? (n=328), C9. How many contractors did you contact about the air source heat pump installation? (n=262), & C10. Of these contractors you contacted, how many did you receive a quote/bid from? (n=257)

Required Upgrades

Whole-home respondents were more likely to require home upgrades to support their new system; the main upgrades that were required for respondents were electrical subpanel upgrades and installing ground fault circuit interrupter outlets.

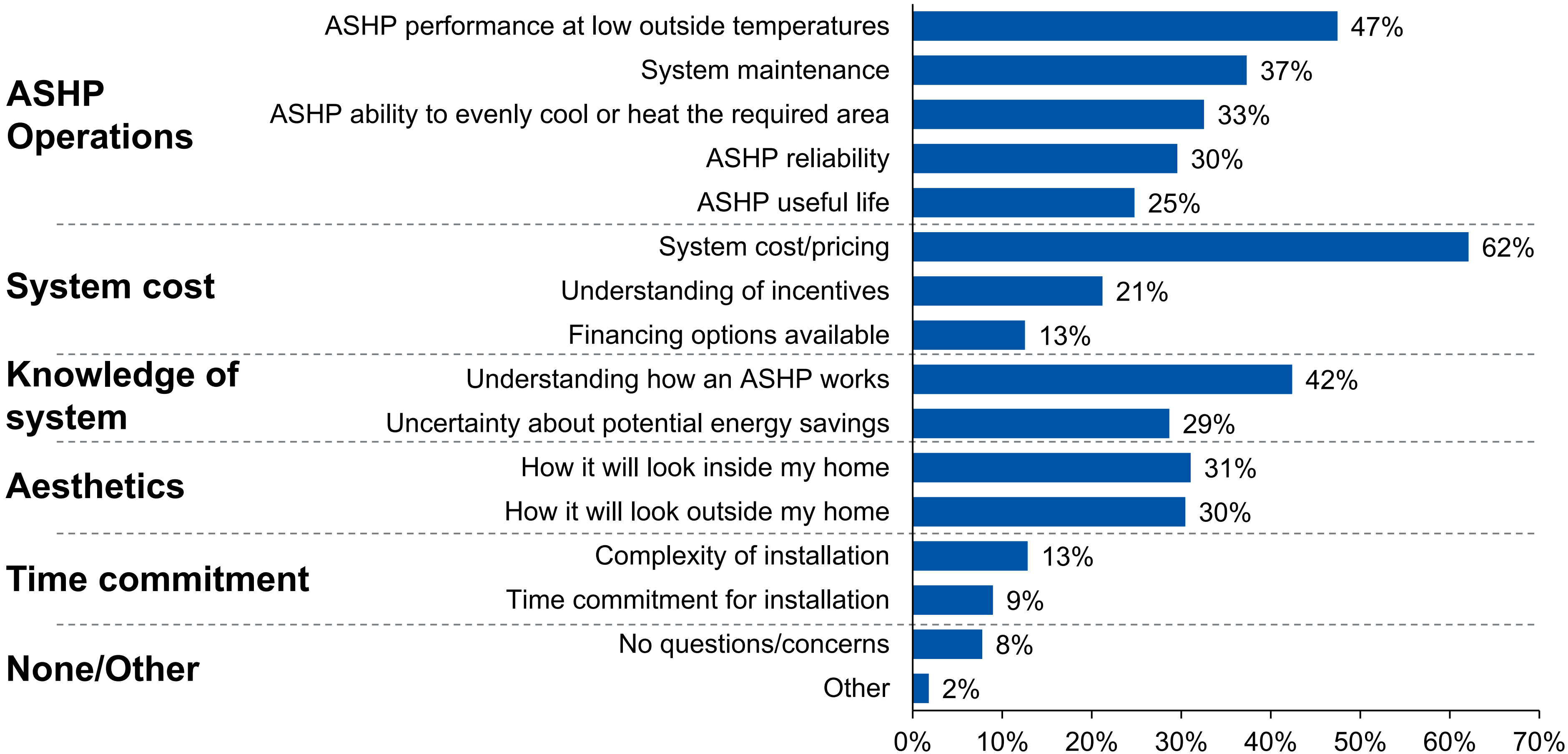


36% of respondents with a primary with backup configuration, **28% of respondents** with a supplemental configuration, and **54% of respondents** with a whole-home configuration required home upgrades.

Sources: E4TheFuture Customer survey questions C11. Did your home require any upgrades to your electrical system to install the air sources heat pump? (n=331) & C12. What upgrade(s) were required? (n=116)

Concerns

Most of the questions and concerns among survey respondents were related to system cost and ASHP system operations.



Source: E4TheFuture Customer survey question C13. Did you have any questions/concerns about the air source heat pump prior to the installation? Please select all that apply. (n=335)

CADMUS

Concerns

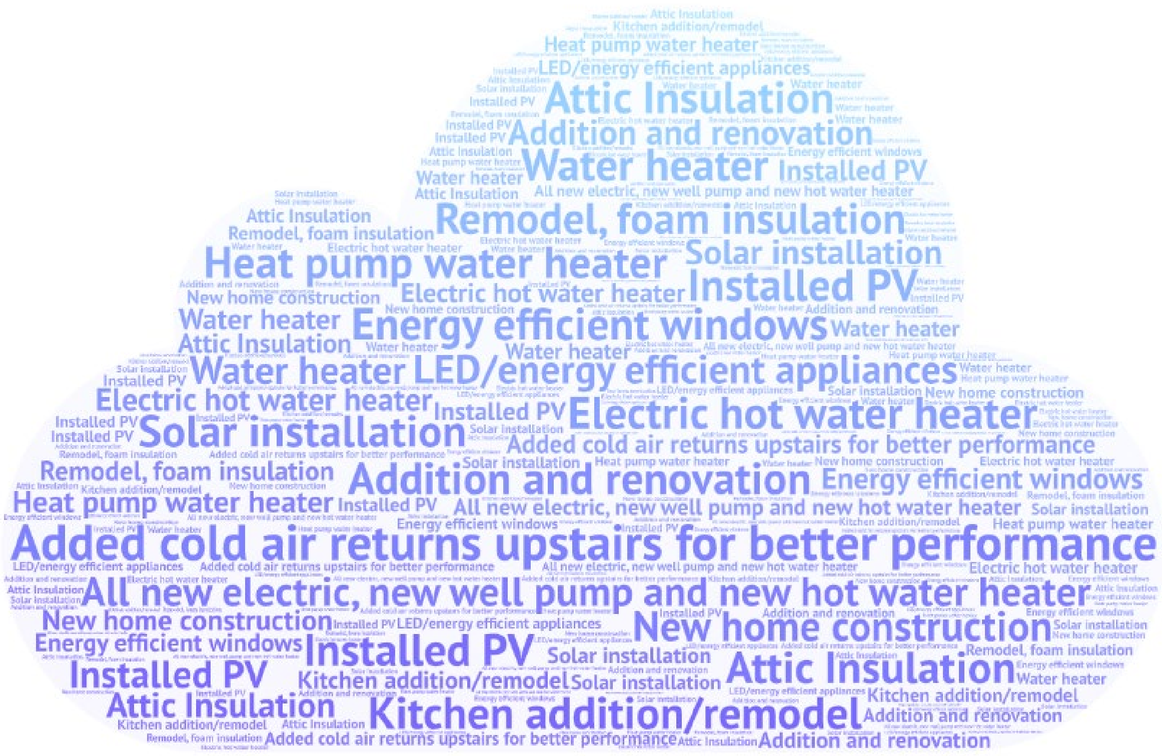
Whole-home customers noted fewer concerns than other customer types, but performance at lower outside temperatures was still top of mind.

Concerns about ASHPs	Whole-Home	Primary w/ Backup	Supplemental
ASHP performance at low outside temps	38%	62%	43%
System maintenance	22%	39%	47%
ASHP ability to evenly cool or heat the required area	21%	40%	35%
How it will look inside my home	24%	36%	32%
Complexity of installation	6%	22%	10%

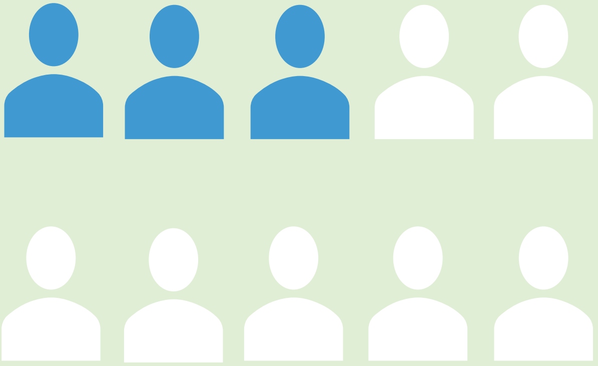
Source: E4TheFuture Customer survey question C13. Did you have any questions/concerns about the air source heat pump prior to the installation? Please select all that apply. (n=335)

Other Home Improvements

Some respondents paired their ASHP installation with other home improvements, typically adding solar panels, insulation, or general home remodels.



30% of respondents completed other home improvements as part of their ASHP installation.



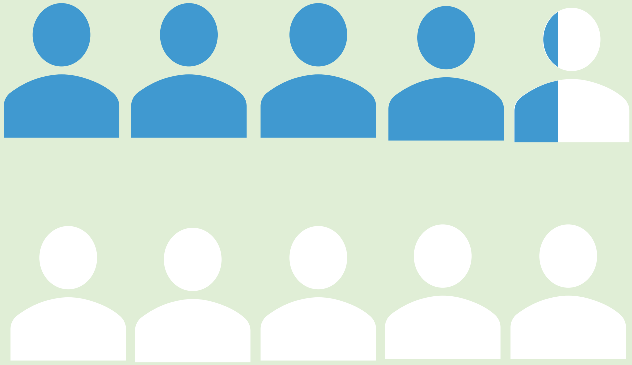
Source: E4TheFuture Customer survey question C14. Did you complete any other home improvements as part of the air source heat pump installation? (n=312)

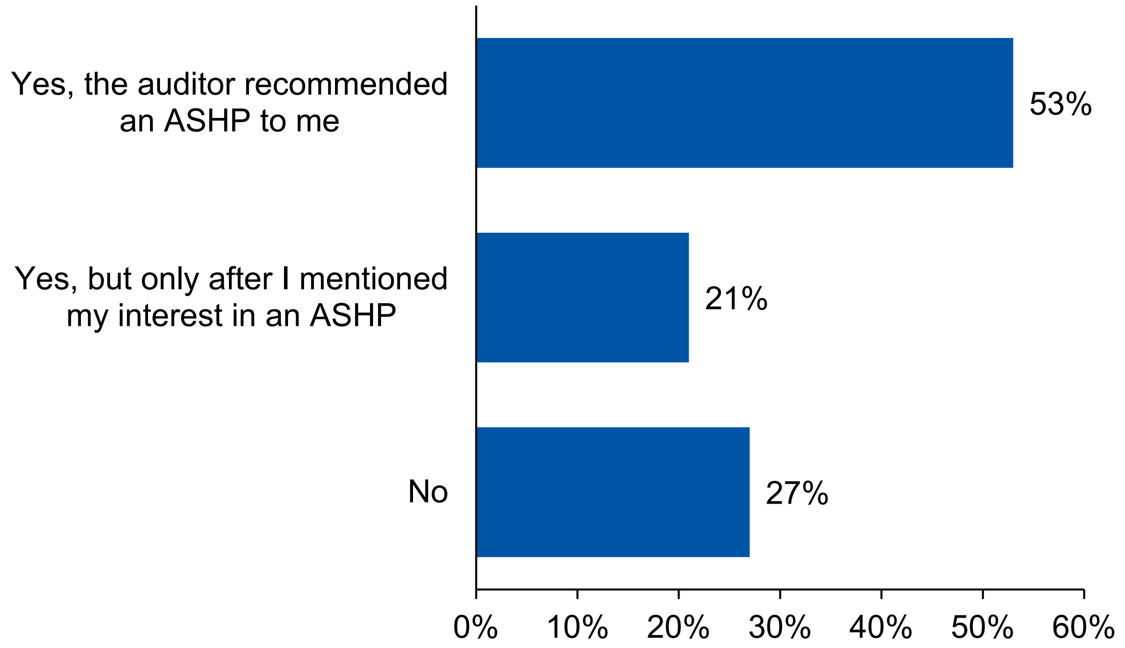
Weatherization

Energy Audits

73% of respondents had an ASHP recommended to them through an energy audit.

43% of respondents had an energy audit before installing their ASHP.



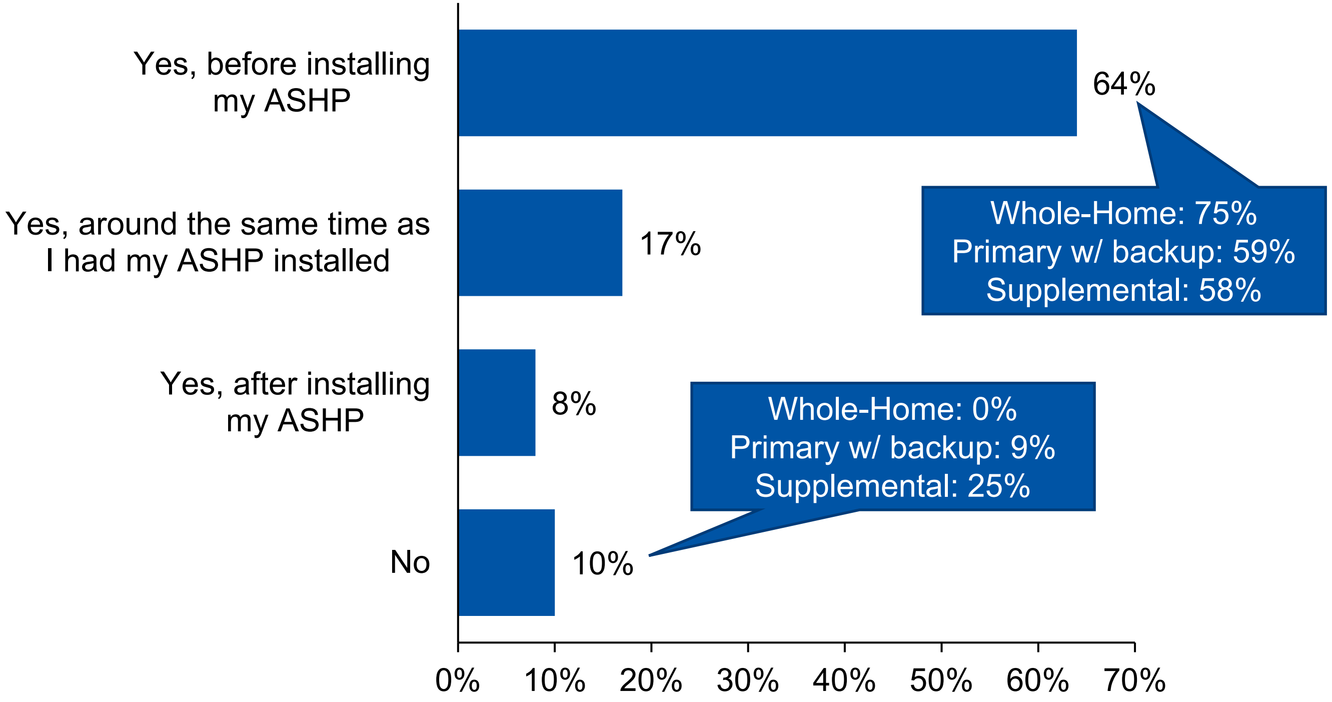


Source: E4TheFuture Customer survey question C2. Did the energy audit recommend you install an air source heat pump? (n=120)
Note: values do not add to 100% due to rounding.

Weatherization Measures

Most respondents reported that contractors recommended they complete weatherization upgrades before installing their ASHP, especially whole-home customers, with 100% reporting they had weatherization work completed.

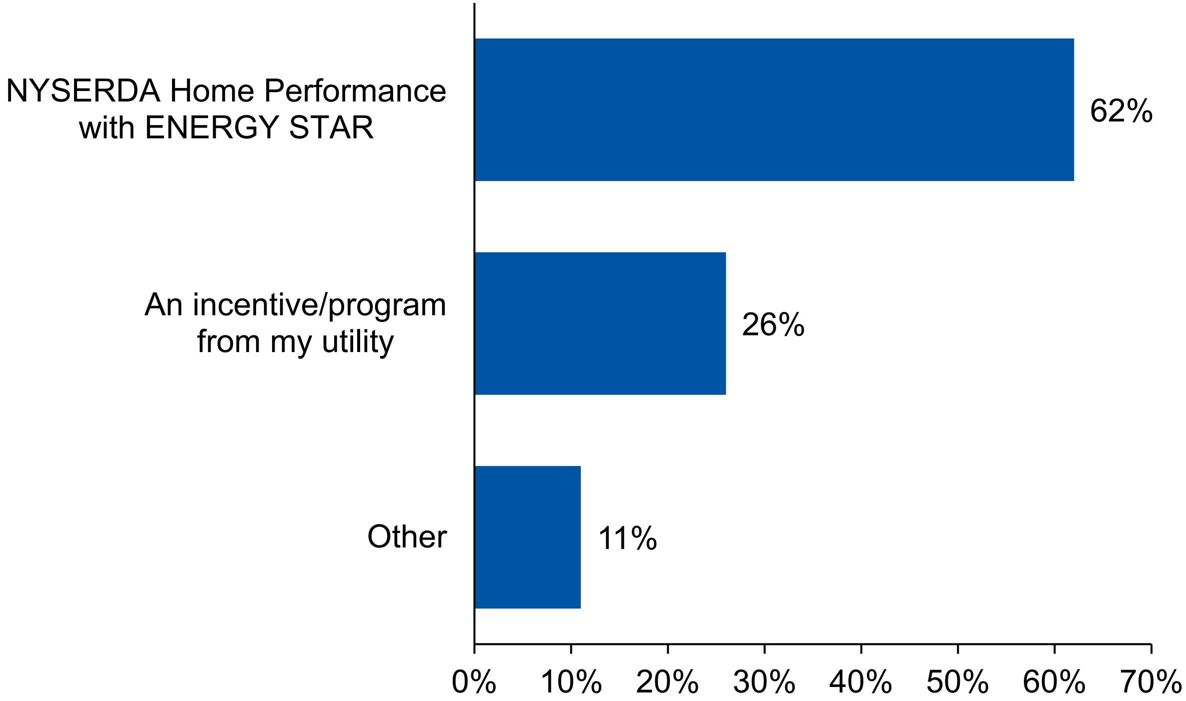
67% of respondents were recommended weatherization upgrades during their energy audit.



Sources: E4TheFuture Customer survey questions C3. Did the energy audit recommend you install any other weatherization upgrades (e.g., insulation and air sealing, duct sealing)? (n=128) & C4. Did you complete any of the recommended weatherization upgrades (e.g., insulation and air sealing, duct sealing)? (n=86)

Paying for Weatherization

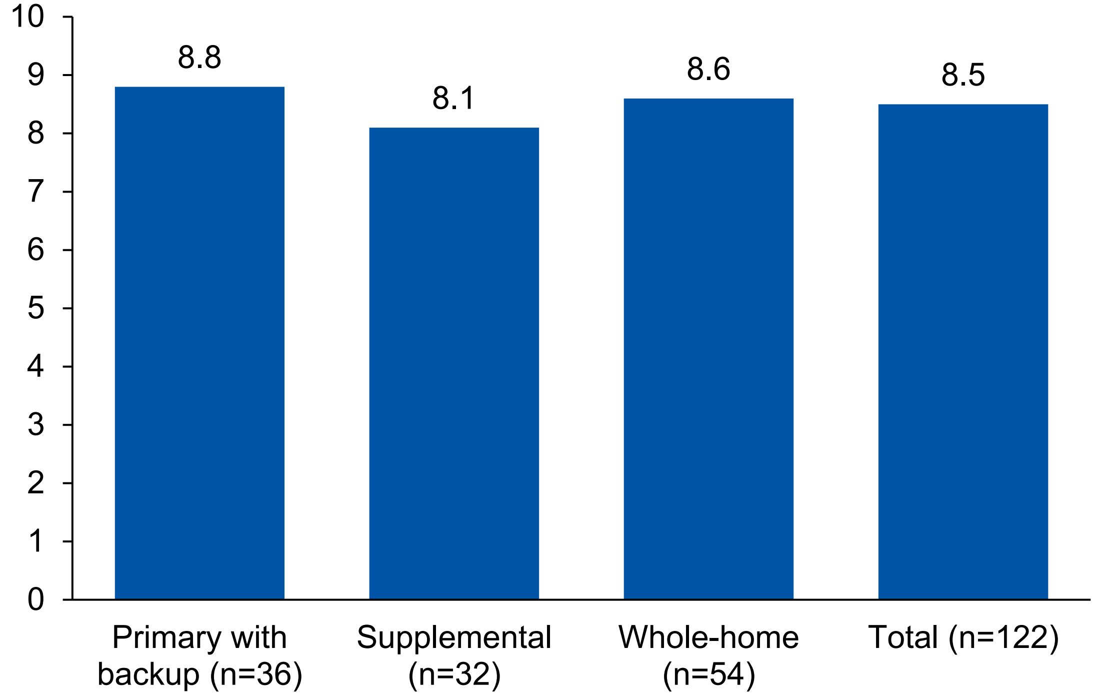
Most respondents used the NYSERDA Home Performance with ENERGY STAR program to help pay for their weatherization upgrades.



Source: E4TheFuture Customer survey question C5. Did you use any of the following programs to help pay for the weatherization upgrades (either through incentives or financing)? (n=53)

Satisfaction with Weatherization Measures

Respondents were highly satisfied with the performance of weatherization measures, giving an average rating of 8.5.



Recommended ways to increase satisfaction (n=3):

- Easier info on remote use of unit
- Better work provided by contractor
- Better performance from measure

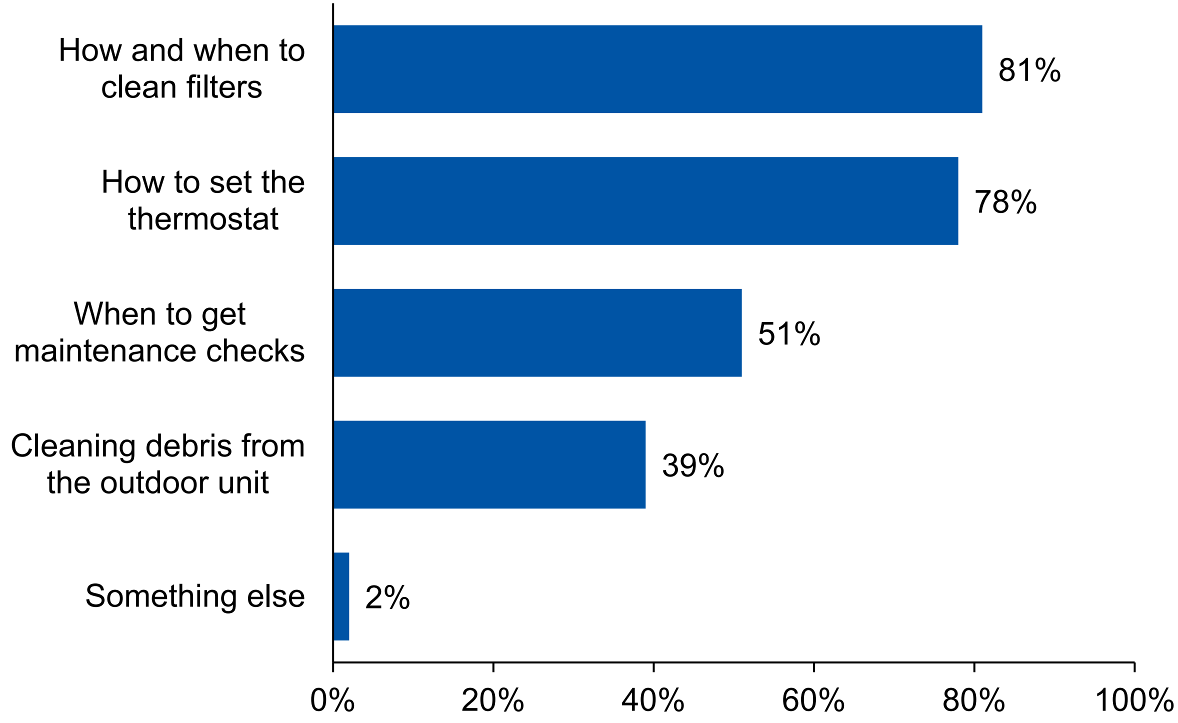
Source: E4TheFuture Customer survey question E1f. On a scale of 0 to 10, where 0 is not at all satisfied and 10 is extremely satisfied, how would your rate the following? – The performance of the weatherization measures that were installed with your air source heat pump.

ASHP Behaviors

Learning About the System

Most respondents were able to learn about their new system, specifically cleaning filters or setting the thermostat, with the help of their contractor.

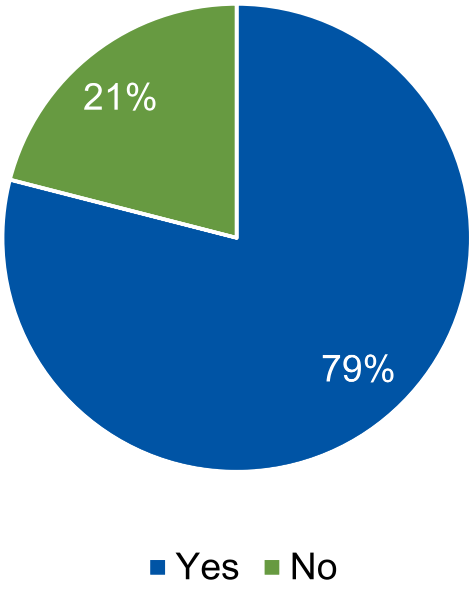
93% of respondents reported the contractor helped them understand how to use the new system.



Sources: E4TheFuture Customer survey questions D1. After the contractor finished installing the air source heat pump, did they spend time helping you understand how to use the new system? (n=341) & D2. What did you learn from the contractor about your air source heat pump? (n=307)

Learning About the System

Most respondents reported that their contractor left behind materials to help them understand their ASHP system.



95% of respondents said they used the materials to learn how to use their system.

Materials included:

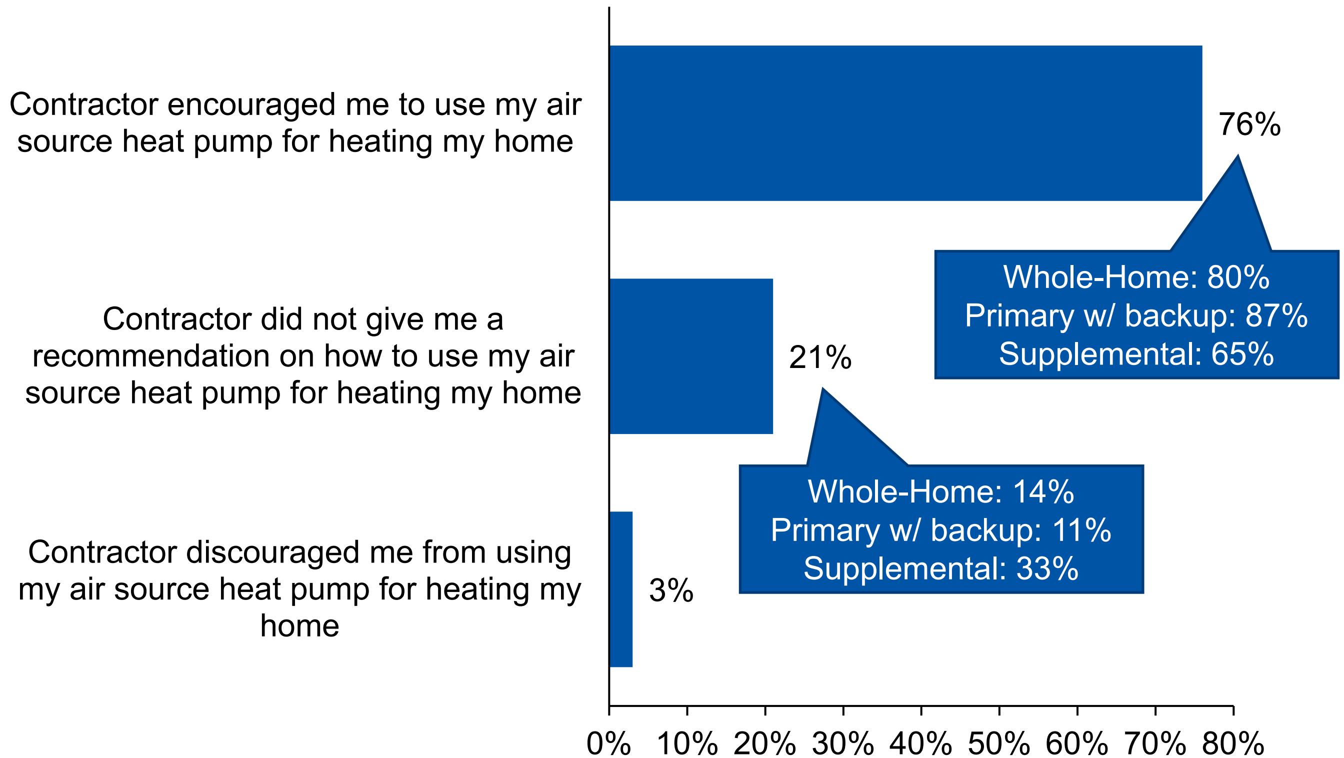
- Operating manuals
- Brochures
- Online resources

Sources: E4TheFuture Customer survey questions D3. Did the contractor leave behind any materials to help you understand your air source heat pump? (n=300) & D4. Did you use these materials to learn how to use the system? (n=237)

CADMUS

Encouragement to use ASHP for Heating

Most contractors encouraged respondents, specifically whole-home and primary w/ backup respondents, to use their ASHP for home heating.



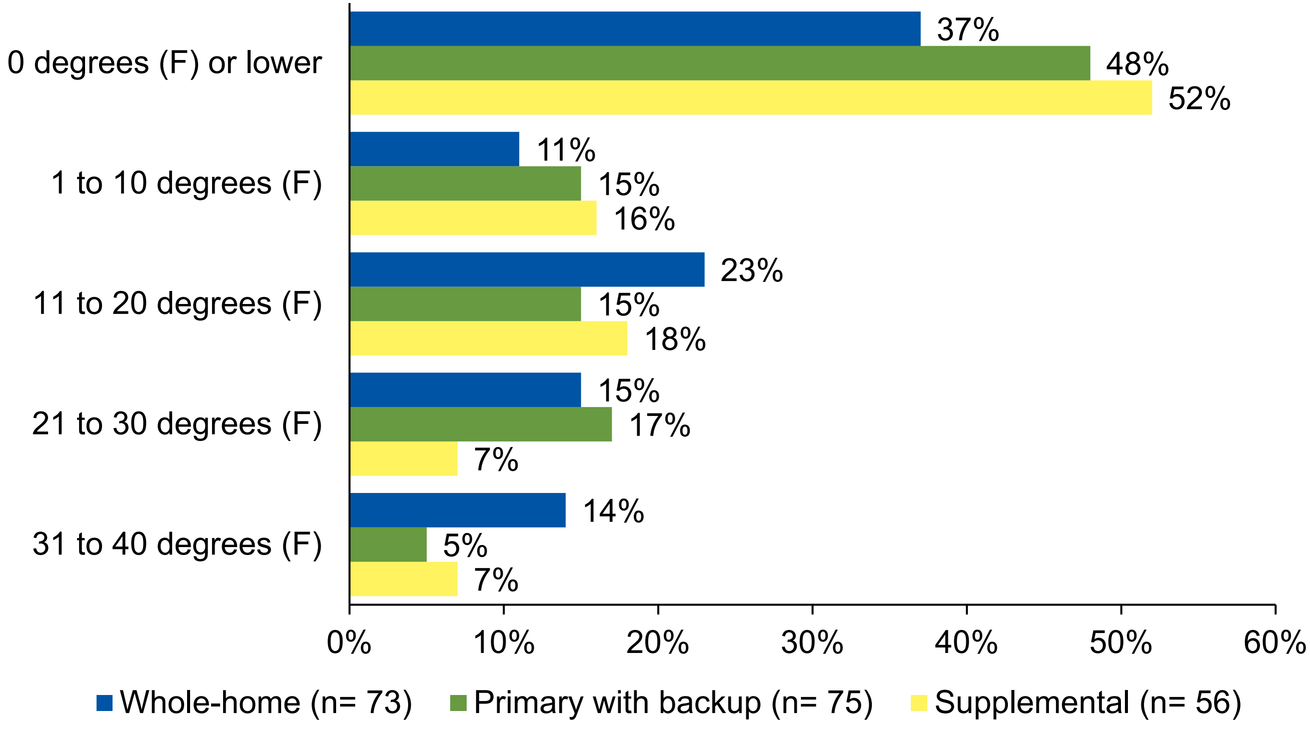
Efficiency (37%) and **cost savings (25%)** were the two main reasons why contractors recommended using an ASHP for home heating.

Sources: E4TheFuture Customer survey questions D5. When the contractor was helping you learn how to use your system, which of the following best describes their approach? (n=319) & D6a. You mentioned the contractor encouraged you to use your air source heat pump to heat your home. What reason did they give for this recommendation? (n= 225)

Cold Climate Usage

More than half of all respondents believe that their ASHP can function at outdoor temperatures of 10 degrees (F) or lower.

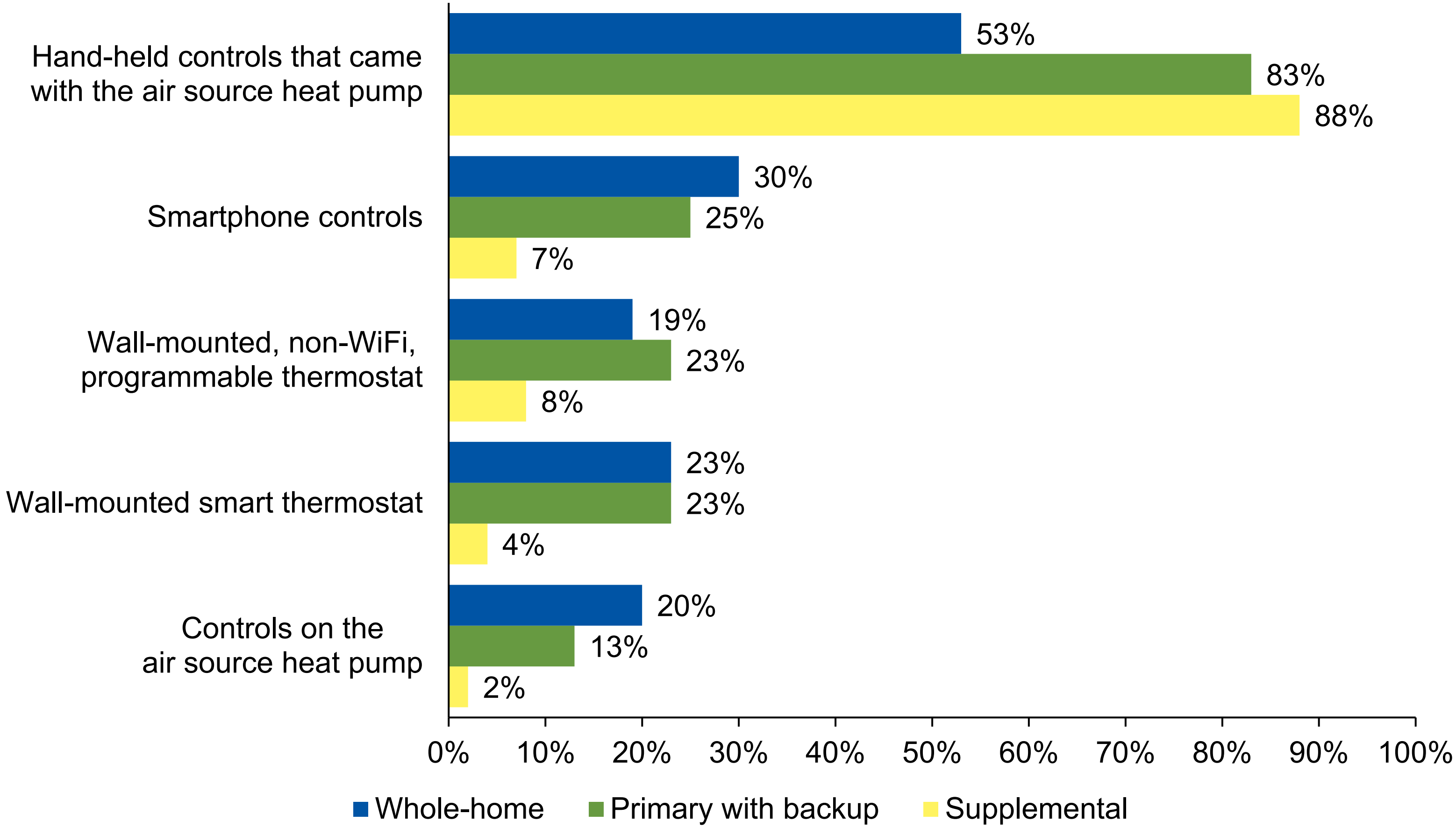
88% of respondents said their ASHP is designed to work in cold climates.



Sources: E4TheFuture Customer survey questions D7. Did your installer mention that your air source heat pump is specifically designed to work in cold climates? (n=292) & D8. What is the lowest outside temperature your installer said your air source heat pump would function? (n=204)

Controls Usage

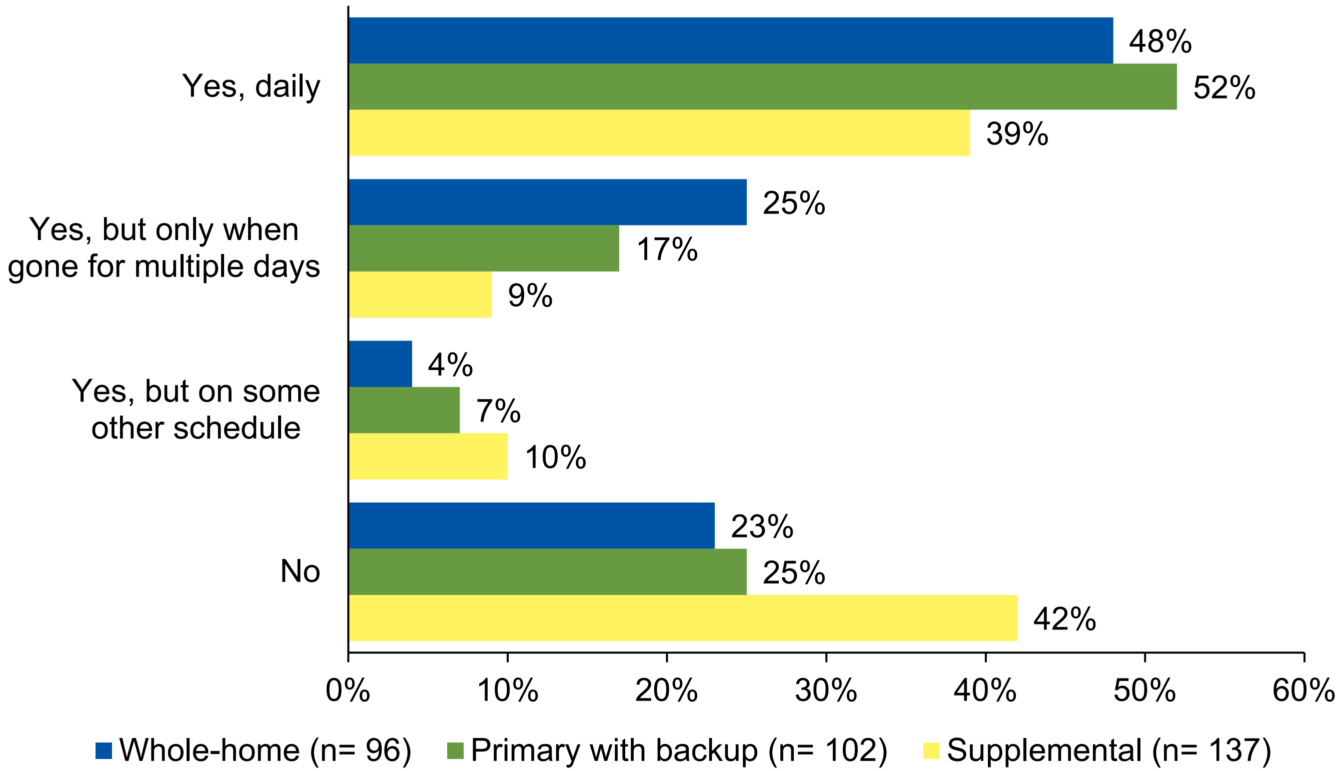
Most respondents use hand-held controls that came with their system to operate it.



Source: E4TheFuture Customer survey question D9. Which of the following controls do you use to control your air source heat pump? (n=336)

Thermostat Setback

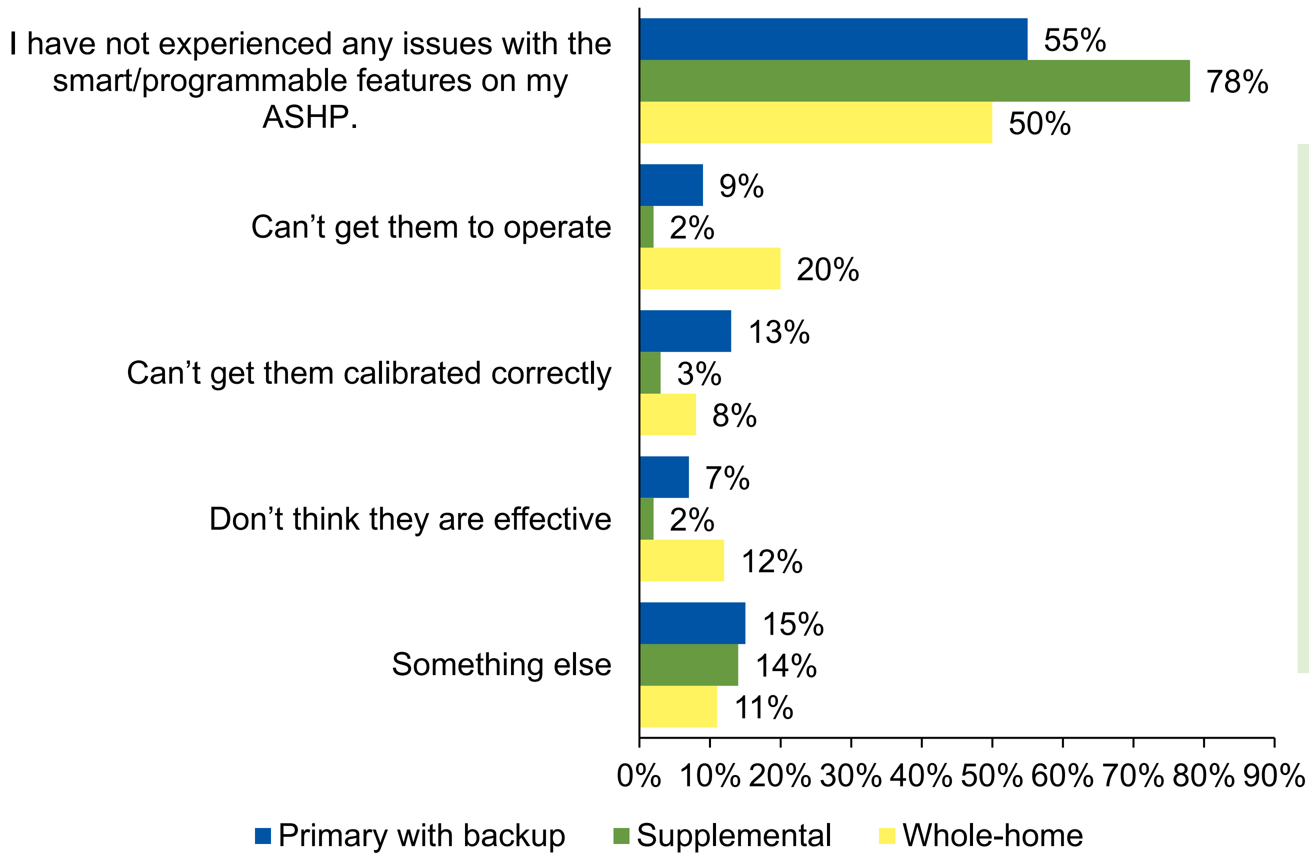
Most respondents reduce their thermostat temperature regularly, with almost half doing so daily.



Source: E4TheFuture Customer survey question D13. Do you regularly reduce the thermostat's temperature setpoint for your air source heat pump either automatically using a programmable thermostat (with pre-programmed setbacks) or manually? (n=335)

Smart Feature Issues and Usage

Most respondents have not experienced any issue with the smart or programmable features.



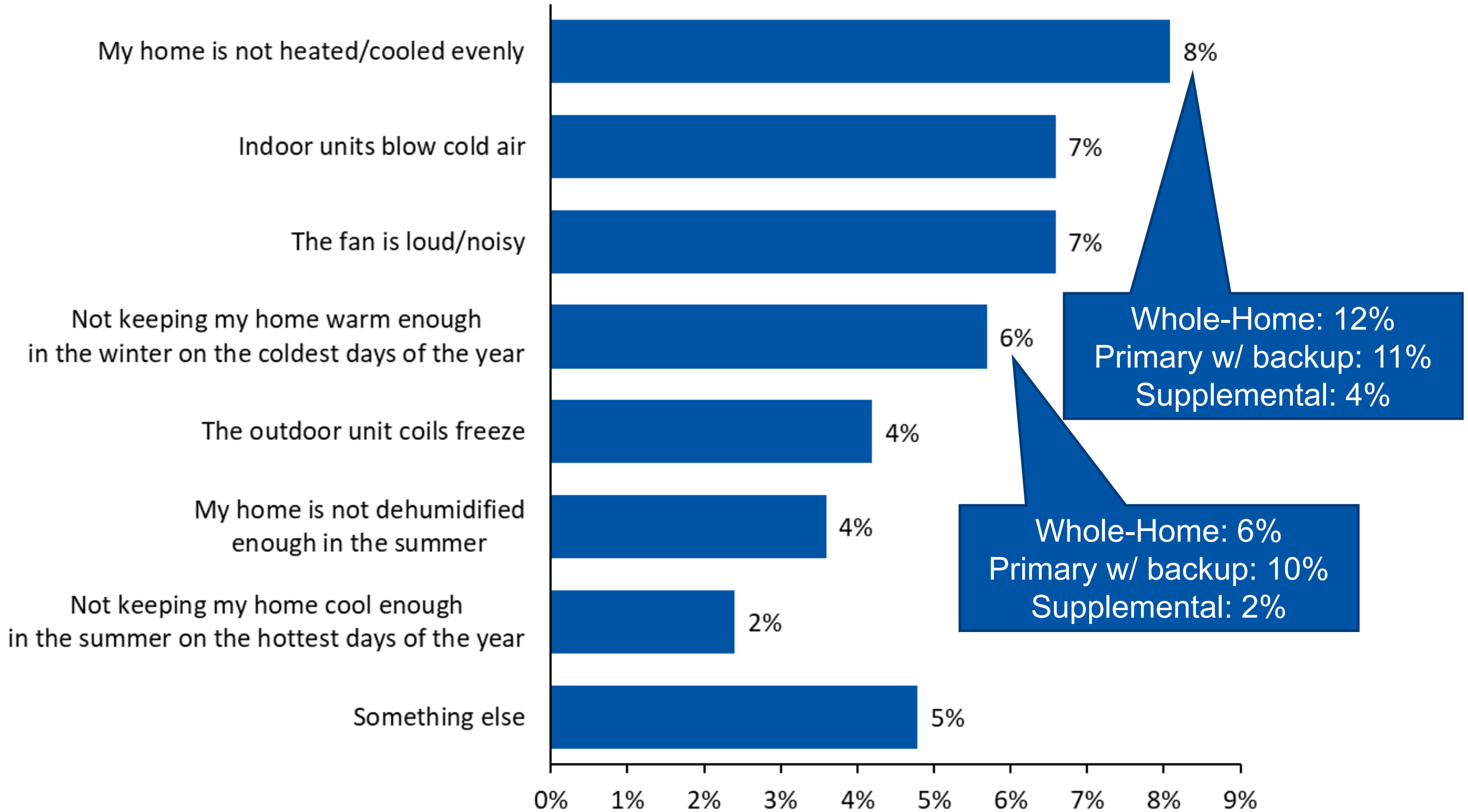
47% of Whole-home, **25% of Primary with backup**, and **8% of Supplemental** respondents said they control their system with **other smart technologies**.

Sources: E4TheFuture Customer survey questions D14. Have you experienced any of the following issues with the smart/programmable features on your air source heat pump? (n=324) & D15. Do you control your air source heat pump with any other smart home technologies (i.e. Nest, Google Home, Amazon Alexa, etc.)? (n=335)

ASHP Issues

Most respondents have not experienced performance issues with their ASHP, but whole-home and primary w/ backup respondents were more likely to experience inconsistent heating/cooling performance.

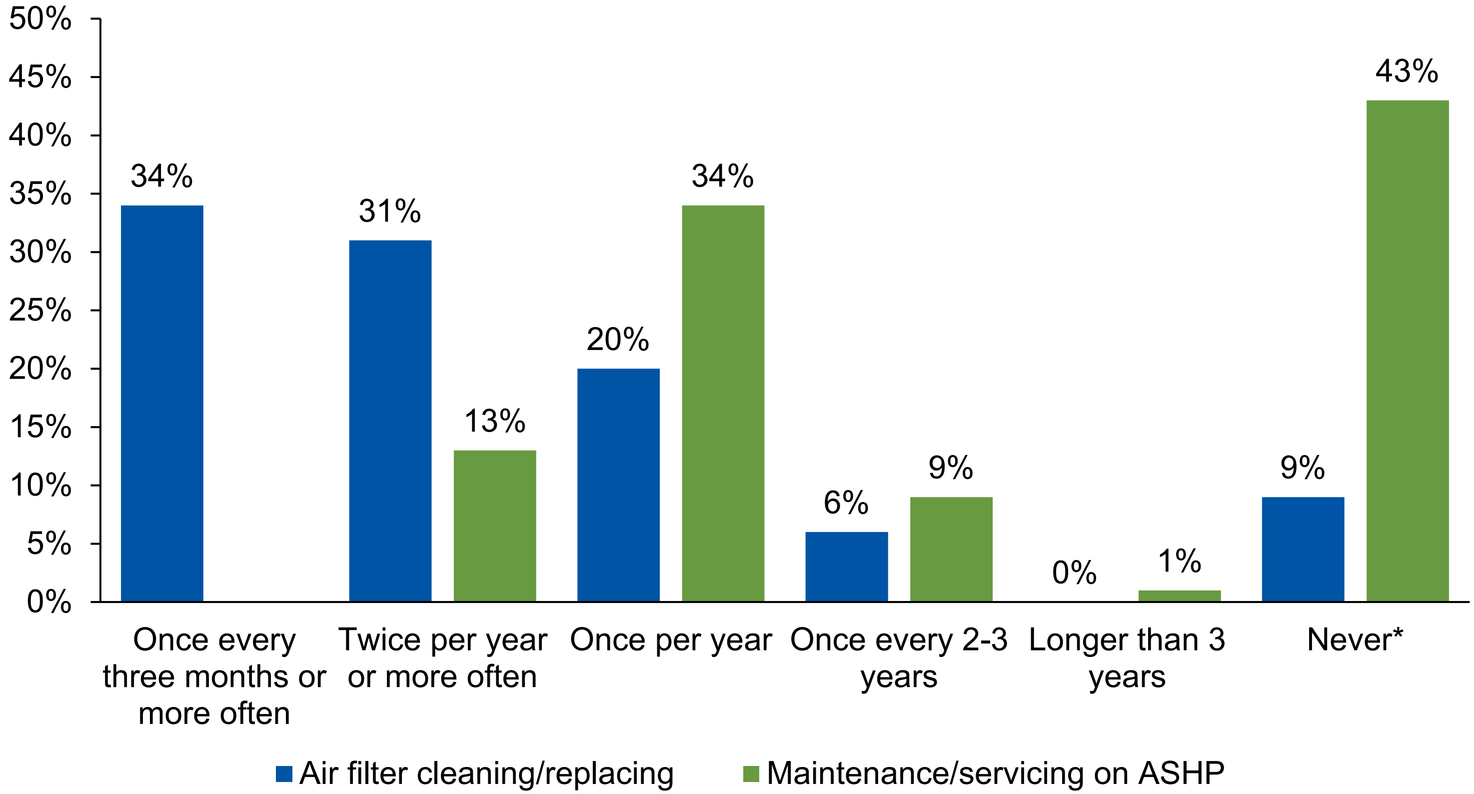
24% of respondents reported they **experienced performance issues** with their ASHP.



Sources: E4TheFuture Customer survey questions D16. Have you experienced any performance issue with your air source heat pump? (n=334) & D17. You mentioned you've experienced some performance issues with your air source heat pump. Which of the following have you experienced? Multiple responses accepted.

ASHP Maintenance

Most respondents clean or replace their air filters twice per year or more often and either receive maintenance from a contractor once per year or have never received maintenance.



Note: "Once every three months or more often" is exclusive to D18.

Sources: E4TheFuture Customer survey questions D18. How often do you clean/replace the air filters on your air source heat pump? (n=336) & D19. How often do you receive maintenance/servicing from a contractor on your air source heat pump? (n=334)

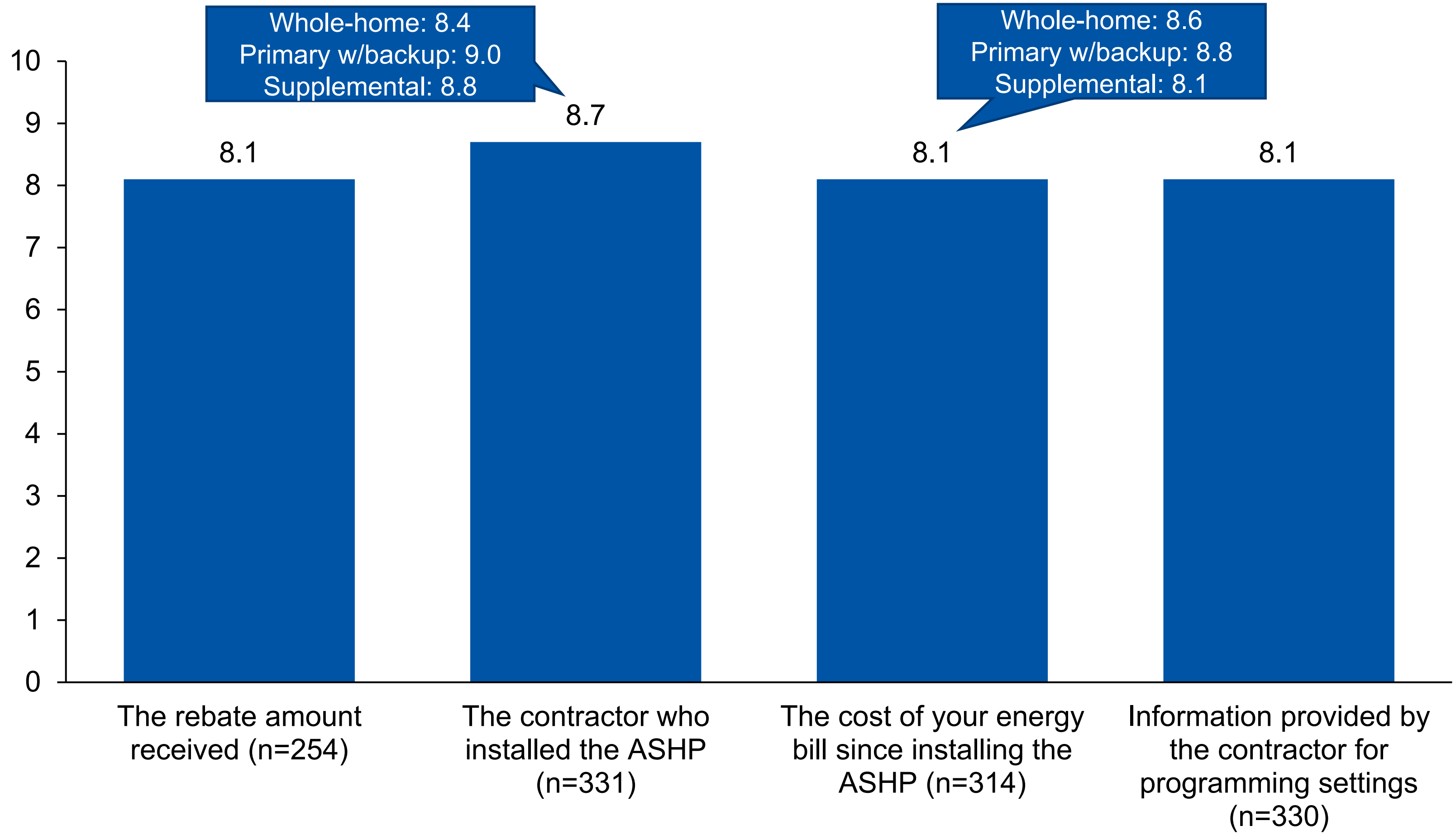
*72% of respondents who said "Never" received their rebate in 2019, which is likely driving this response.

CADMUS

Satisfaction

Satisfaction Ratings

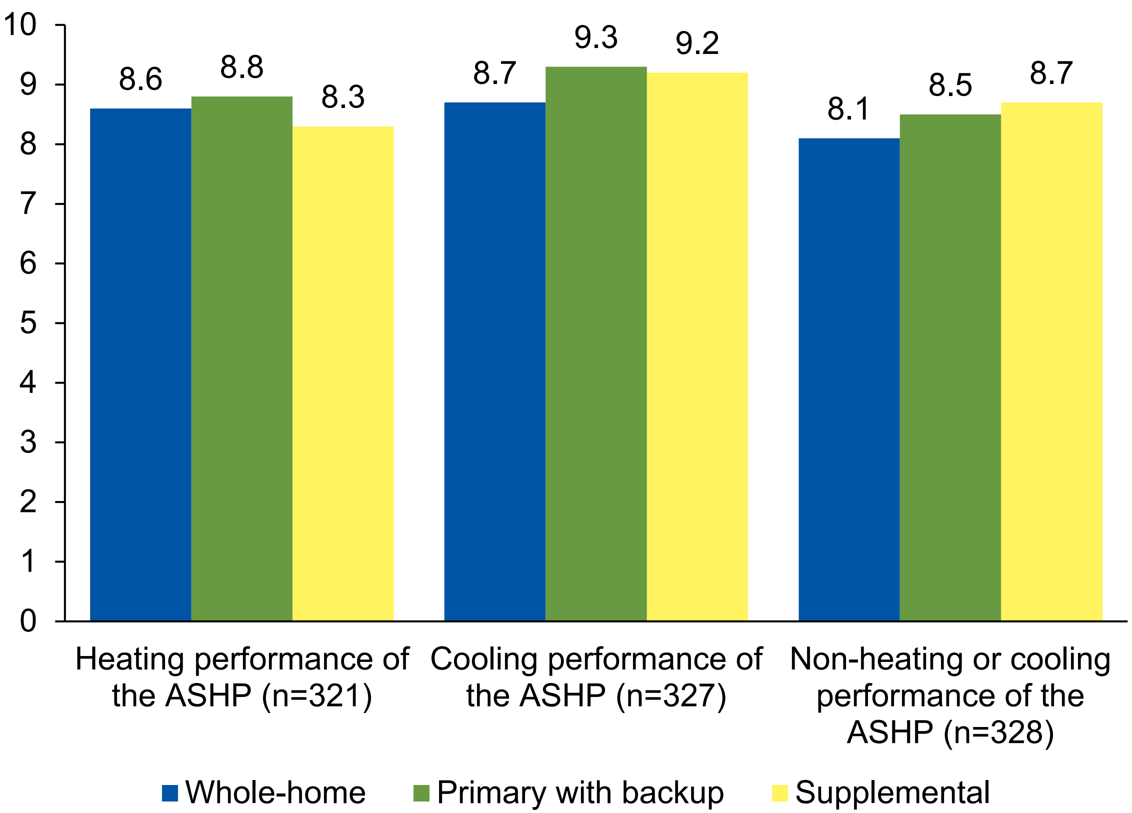
Customers were generally satisfied with their ASHP contractor.



Source: E4TheFuture Customer survey question E1. On a scale of 0 to 10, where 0 is not at all satisfied and 10 is extremely satisfied, how would you rate the following?

ASHP Performance Satisfaction

Customers were generally satisfied with ASHP performance, with satisfaction slightly lower among whole-home customers.



Ways to increase satisfaction with ASHP performance

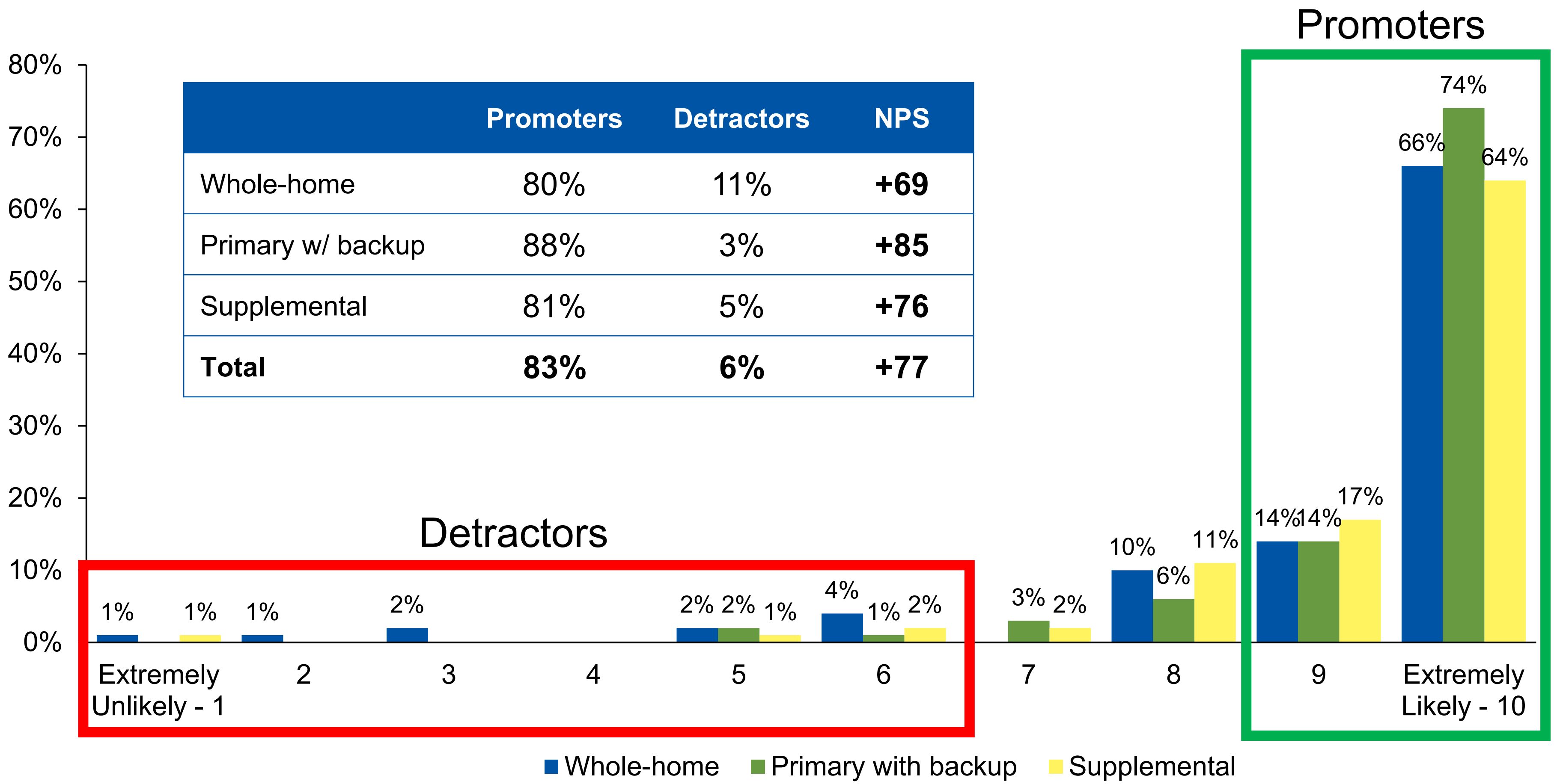
- More even temperatures (27%)
- Less Noise (12%)
- Better performance (12%)

Sources: E4TheFuture Customer survey questions E1. On a scale of 0 to 10, where 0 is not at all satisfied and 10 is extremely satisfied, how would you rate the following? & E2. What would make you more satisfied with the performance of your air source heat pump? (n=41)

ASHP Net Promoter Score (NPS)

Reflecting their high satisfaction, ASHP owners are highly likely to recommend an ASHP to others, leading to very strong Net Promoter Scores.

	Promoters	Detractors	NPS
Whole-home	80%	11%	**+69**
Primary w/ backup	88%	3%	**+85**
Supplemental	81%	5%	**+76**
Total	**83%**	**6%**	**+77**



Source: E4TheFuture Customer survey question E5. Based on your experience with your air source heat pump, how likely would you be to recommend an air source heat pump to a friend? (n=327)

The Net Promoter Score is calculated by subtracting the detractors (0-6) from the promoters (9-10).

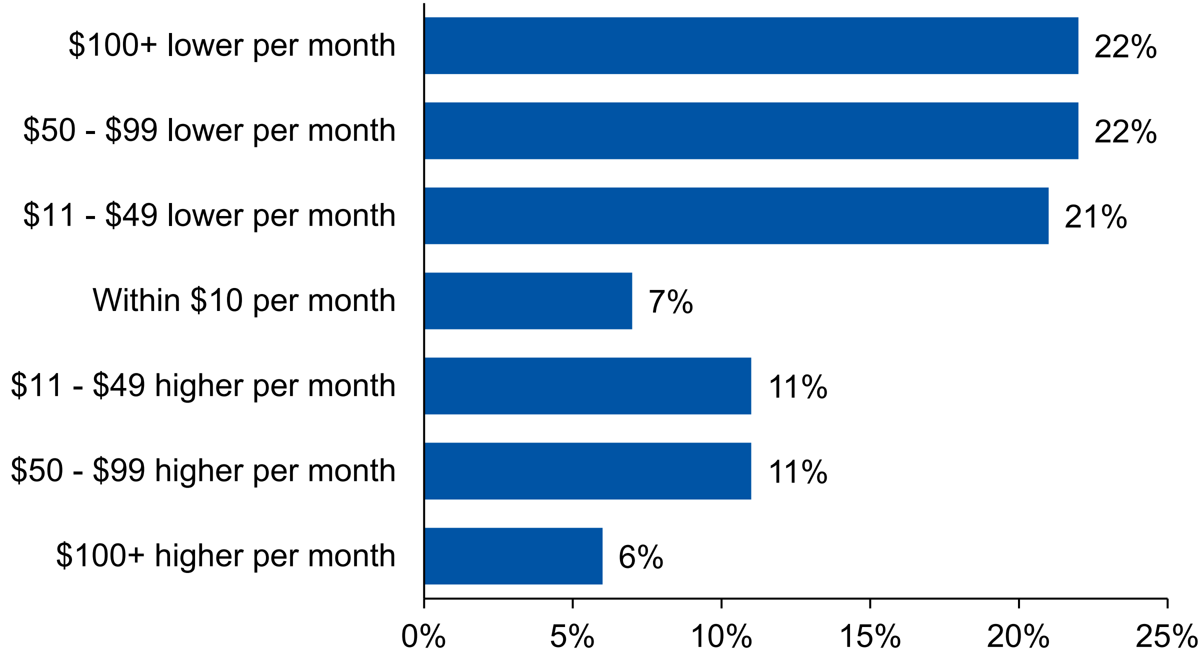
Energy Bills

Most respondents' utility bills were lower since installing an ASHP.

87% of respondents reported a change in their energy bills since installing an ASHP.

79% said the change was the same as what they expected.

57% of respondents with electric heat reported a monthly bill decrease of $50 or more, compared to **49%** of delivered fuel and **32%** of natural gas respondents.



Sources: E4TheFuture Customer survey questions E6. Have your energy bills changed since installing your air source heat pump? (n=271), E7. By how much have your average monthly energy bills for heating changed since installing your air source heat pump? (n=183), E8. Is the change in your energy bills the same or different than what you expected? (n=225), & E10. Did you expect a change in your energy bills? (n=33)

CADMUS

Thank You / Q&A