Winter is Coming: Is the Northeast Ready for Residential Electrification?

Christie Amero, Conner Geery, Nathan Hinkle, Neil Veilleux, Cadmus

ABSTRACT

Achieving decarbonization goals requires significant reduction or elimination of fossil fuel heating systems in buildings, and strategic heating electrification has been identified as a primary pathway for decarbonizing residential buildings. To date, most market development programs have focused on installations of supplemental cold climate air source heat pumps (ccASHP), which typically serve less than 70% of a home's total heating load. However, achieving decarbonization targets in the Northeast will require widespread deployment of whole-home or primary with backup ccASHPs; that is, systems that serve 70% or more of the load. To design successful residential electrification programs, policymakers need to assess ccASHP customer satisfaction, technical performance, and electric grid impacts to ensure that customer experience and in-field performance achieve expected performance standards and determine the scale of necessary grid infrastructure upgrades.

In collaboration with E4TheFuture, Massachusetts Clean Energy Center (MassCEC), New York State Energy Research & Development (NYSERDA), and U.S. Department of Energy, the Cadmus team conducted the Residential ccASHP Building Electrification Study. Key research included assessing customer satisfaction and collecting and analyzing detailed heating and cooling season metered data to compare utilization, delivered heating capacity, performance, and grid impacts of ccASHP systems. The team metered outdoor, supply, and return air temperatures and total system, supply fan, and backup electric resistance power for 73 ccASHP systems in 43 homes, calculating an average overall heating season performance of 2.34 sCOP.

This paper explains the data collection and analysis methodology, describes study findings on five key objectives, and presents conclusions and program recommendations to address winter peak demand impacts and encourage greater adoption of whole-home ccASHPs.

Introduction

Utilities and energy agencies know that carbon reduction targets in the Northeast require transformation of the built environment. Massachusetts is seeking 50% GHG reductions by 2030 and 85% by 2050 (Commonwealth of Massachusetts 2021), and New York is aiming for a 40% reduction by 2030 and an 85% reduction by 2050 (New York State 2021). It is also estimated that direct emissions from fossil fuel combustion for building space and water heating account for approximately 30% of emissions (Leung 2018). Achieving these targets will require widespread electrification of thermal loads, improved thermal performance of building envelope, the ability to store or shift energy use using grid integration, and the supplying of energy loads from zero emissions resources.

Across the Northeast, most building thermal loads are served by fossil fuels, that is, oil, gas, propane, or wood (Mass.gov). Though increasingly used for heating, heat pumps are still primarily a supplemental heat source. Greater adoption of whole-home heat pumps—or heat pumps serving as the primary heating source—will be necessary to decarbonize building stock. While some cold climate air source heat pumps (ccASHP) can function in temperatures as low as

-22°F (NEEP), there is still debate about fully displacing fossil fuel heating systems with ccASHPs, including customer satisfaction and cost-effectiveness, grid reliability during winter storms, and whether the electric grid can support the added load from widescale electrification.

The results of this study (Cadmus 2022) are intended to inform policymakers and program administrators about customer experience, in-field performance, and electric grid impacts of ccASHPs used as primary residential heating sources. E4TheFuture was the primary funder, and the study has also received support from MassCEC, NYSERDA, and the U.S. Department of Energy's Building Technology Office. The study involved a mix of quantitative and qualitative data collection and analysis, including stakeholder and installation contractor phone interviews, customer surveys, utility billing data, and metered data for 43 homes across Massachusetts and New York.

For this study, the team defined whole-home, primary with backup, and supplemental ccASHP systems as follows:

- Whole-home systems serve at least 90% of the total heat load. These homes may have occasionally used a wood fireplace or electric strip heat in a bathroom or basement.
- Primary with backup systems are designed to serve at least 70% of the heat load. These homes had a backup fossil fuel system such as a furnace, boiler, or wood stove and used the fossil fuel heating source during cold periods.
- Supplemental systems are designed to serve less than 70% of the heat load. While still the most common application in the Northeast, these systems were excluded from this study.

There are many barriers to residential building electrification, including upfront costs, contractor training, and customer awareness, but this study focused on technology risks such as performance and customer comfort concerns during cold periods. The team also investigated the potential peak-period demand impacts on the electric grid from widescale residential electrification, comfort impacts from home weatherization, and any correlation between system type and performance. This paper highlights the data collection and analysis methodology, key observations, conclusions, and recommendations from the study.

Methodology

During fall 2020, Cadmus worked with MassCEC and NYSERDA to collect historical residential ASHP rebate program data for the customer survey, contractor interview contacts, and on-site data collection sample. MassCEC provided rebate data from its Whole-Home Air Source Heat Pump Pilot and its Clean Heating and Cooling Program, and NYSERDA provided data from its Air-Source Heat Pump Program. Customer survey responses helped to identify whether customers were using their ccASHPs for supplemental, primary with backup, or whole-home applications, with 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.

The final sample of 43 homes across Massachusetts and New York included a mix of whole-home and primary with backup applications and 73 individual heat pump systems of various types (Figure 1). The average total system installation cost per home was $20,255 and the average total rebate was $3,336 (Table 1). Thirty-two of the homes (74%) were in Climate Zone 5, 10 homes were in Zone 6, and one home was in Zone 1 (Figure 2). The rebated ccASHP systems at these homes were installed between July 2016 and December 2019.

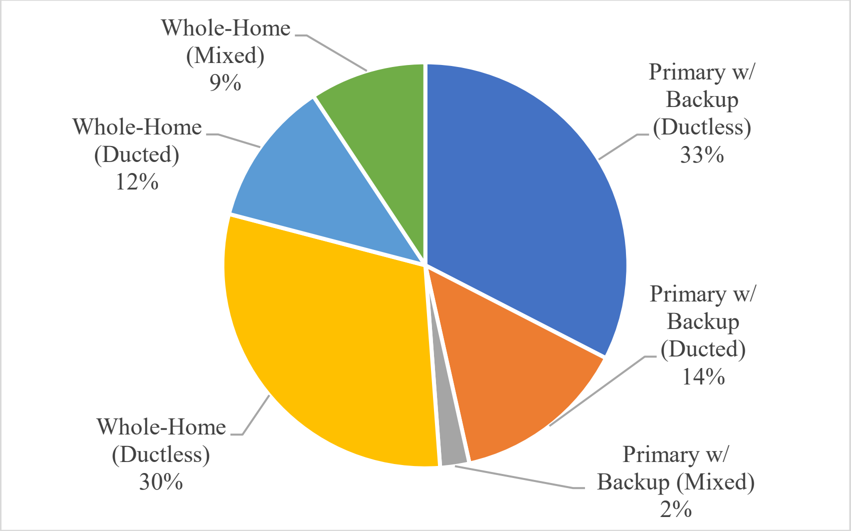

Figure 1. Site Sample Distribution by Application and System Type

Table 1. Site Sample Average System Installation Cost and Rebate

Application	System Type	Average Total System Installation Cost per Home	Average Total Rebate per Home
Primary w/ Backup	Ducted	$20,454	$5,013
	Ductless	$24,663	$1,000
	Overall	$22,258	$3,293
Whole-Home	Ducted	$17,843	$3,333
	Ductless	$16,415	$2,833
	Mixed	$28,390	$5,000
	Overall	$18,981	$3,364
Overall Average		$20,255	$3,336

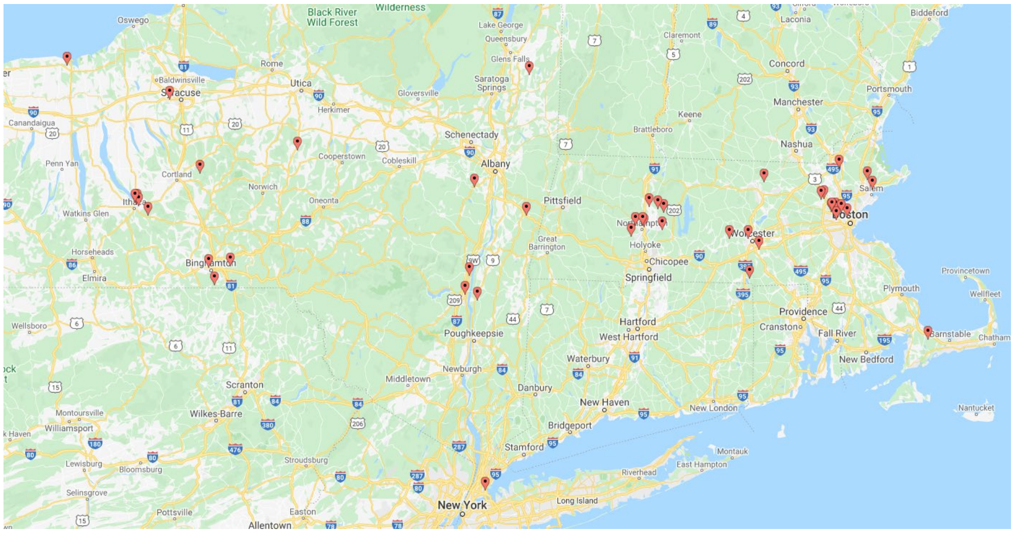

Figure 2. Geographic Site Distribution

Metered data collection. Meter installations began in October 2020, and all meters were installed by early February 2021. The team removed all meters in October 2021. The team configured all loggers to record at two-minute intervals to collect highly granular data on energy consumption, demand, heating performance, and what, if any, backup heating systems were used. During the heating season, in addition to power meters on the ccASHP systems, the team also installed interior supply and return temperature sensors and recorded the indoor heat pump head fan power to estimate the delivered heat capacity. During the cooling season, the team collected data for system power only, since the primary objective was to understand cooling season electric grid impact, not cooling season performance.

For ductless systems, the team estimated the airflow based on measured fan power and manufacturers' specifications and fan curves. For ducted systems, the team recorded any backup electric resistance heat and performed on-site airflow testing to refine the fan curves relating fan power and airflow. A variety of sensors collected operating hours on any backup heating equipment (such as boilers, furnaces, wood stoves, and electric resistance strip heaters).

Metered data analysis. The team sourced data from installed loggers; equipment and building metadata, including age, conditioned area, zip code, weatherization upgrades, and leakiness; National Oceanic and Atmospheric Administration (NOAA) weather data; and AHRI system specifications such as rated capacity and performance. The team installed anywhere from five to 20 sensors per home, resulting in millions of data points from 43 sites. The team selected NOAA weather data from local stations over outdoor air temperatures collected onsite due to the greater accuracy of NOAA weather data. Weather data collected onsite may be impacted by direct solar load, shading, and warmer or cooler heat pump exhaust air.

Due to the granularity of the logger data, the team developed Python scripts to automate data retrieval, standardize data formats, and insert the data into a SQL Server data warehouse. This robust solution allowed simultaneous analysis of all sites rather than pulling static outputs into a summary file after performing manual analysis on individual sites. Automating the analysis for such a large volume of data also improved quality control and data manipulation.

Figure 3 shows an overview of the data sources and tools involved in populating the data warehouse used for the meter data analysis.

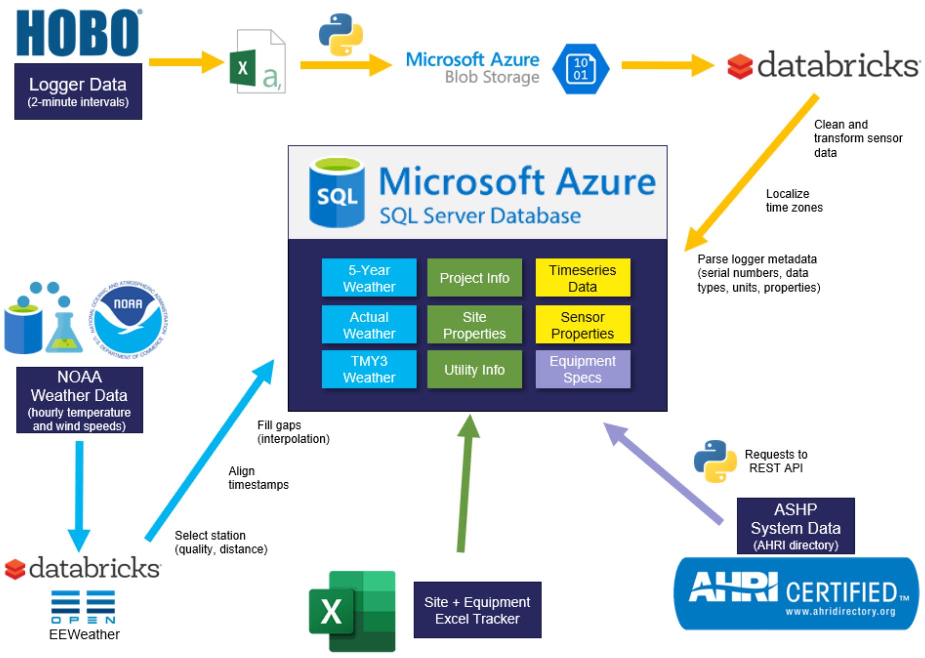

Figure 3. Data Analysis Framework

Key Objectives

Using the results of the metered data analysis, customer surveys, and phone interviews, the team investigated the following key objectives:

1. Are ccASHP systems meeting home comfort expectations?
2. Are ccASHPs efficiently delivering heating and cooling?
3. How does ccASHP system heating performance differ between applications?
4. What are the grid impacts of ccASHP market scale up?
5. What continued challenges with customer and contractor experience need to be addressed to scale the market?

1. Are ccASHP systems meeting home comfort expectations? In fall 2020, the team conducted an online customer survey using MassCEC and NYSERDA's rebate program data. Results were positive from the 628 customers who responded. However, customers with whole-home applications gave a slightly lower overall satisfaction rating due to lack of backup on extreme cold days. On a scale of 1 to 10, the likelihood to recommend a ccASHP to others was rated as 8.9 by whole-home customers and 9.3 by primary with backup customers. When asked about weatherization upgrades, 89% of survey respondents said they had completed upgrades either before, at the same time, or after their ASHP installation.

Figure 4 shows the average customer satisfaction survey scores, from 9.0 to 7.8, for a variety of questions. When asked about changes to their overall utility bills since installing an ASHP, 69% reported lower costs while 25% reported higher costs, likely leading to the score of 7.8 on the question regarding the cost of the customer's energy bill since installing the ASHP.

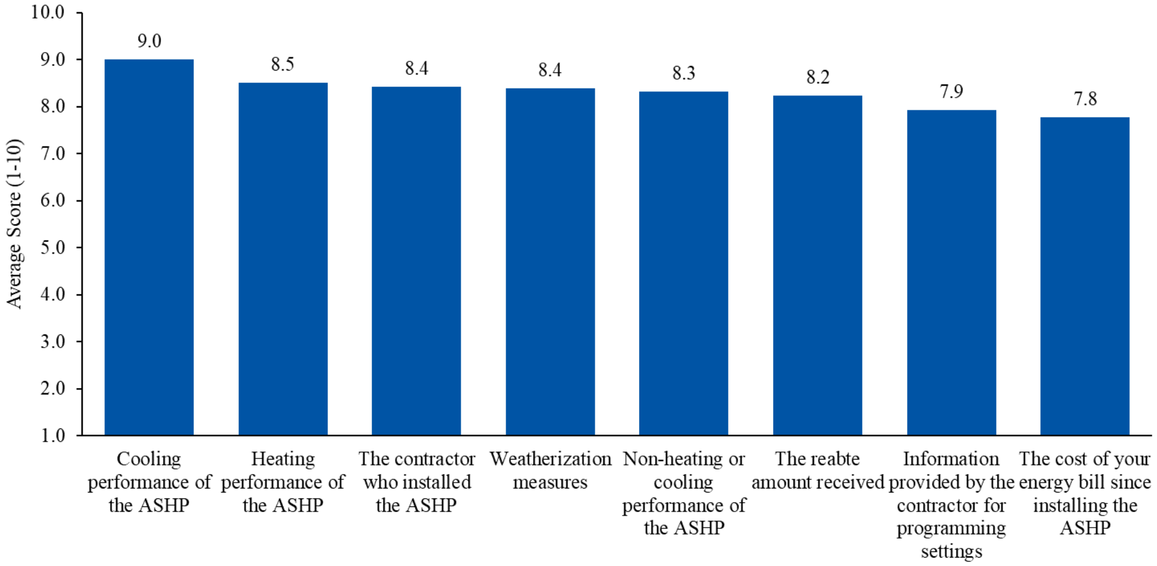

Figure 4. Customer Satisfaction Survey Response

After the metered data collection period, the team conducted an in-depth follow-up phone interview with 42 of the 43 metering participants to gather more detailed data on satisfaction and challenges. All phone interview participants indicated some level of satisfaction, and 32 were very satisfied. Reasons for being very satisfied included improved comfort and temperature maintenance (n=10), less costly to run (n=9), reducing their carbon footprint (n=7), easy to use (n=3), and quiet and clean (n=2).

Feedback from participants who rated themselves as satisfied or somewhat satisfied included inconsistent distribution of heat to specific rooms (n=3), ccASHP system requires more attention than previous system (n=2), outdoor unit is too loud (n=1), settings are not maintained and fan is consistently on (n=1), and the unit does not stay warm as long and does not heat enough when it is cold outside (n=1).

The team also conducted blower door tests to measure the leakiness of each home and investigate any correlation with customer satisfaction and performance. ACH50 is the measured CFM at 50 Pa normalized for conditioned building volume. According to the National Association for State Community Services Programs, homes with an ACH50 score of less than 5 are considered tight, between 5 and 10 are considered moderate, and greater than 10 are considered leaky. On average, participating homes fell into a moderately leaky category.

As Table 2 shows, leakiness did not correlate with the timing of the weatherization upgrades. This result was unsurprising since the level of weatherization performed or the condition of the existing insulation was unknown. This was also a small sample of homes, and many confounding variables factor into home leakiness, including the type and quality of existing and new insulation, home age, occupant behavior, and test conditions.

Table 2. Blower Door Test Results

Home Weatherization Upgrade	Number of Homes[1]	Measured Airflow, CFM		Equivalent Leakage Area, ELA	Approximate ACH50
		50 Pa	25 Pa		
No change/existing	8	2,889	1,848	160.6	9.5
Pre-ASHP Installation	18	2,521	1,775	140.1	9.1
During ASHP Installation	4	2,567	1,429	142.8	10.1
Post-ASHP Installation	4	1,928	1,138	107.0	8.5
Overall	34	2,543	1,676	141.4	9.2

[1] Cadmus conducted blower door tests or collected contractor blower door test reports for 34 of the 43 sites.

2. Are ccASHP systems efficiently delivering heating and cooling? Table 3 summarizes the results of electric heating and cooling metered data energy use intensity (EUI). Based on the metered data, whole-home ccASHP systems were 23% more energy intensive than primary with backup applications during the heating season. On average, heating EUI is almost 10 times higher than cooling EUI.

Table 3. Metered Heat Pump System Heating and Cooling Energy Use Intensity

Application	Conditioned Area, sq. ft	Number of Homes	Heating		Cooling	
			Avg. ASHP System Energy Use, kWh	EUI, kWh/sq. ft.	Avg. ASHP System Energy Use, kWh	EUI, kWh/sq. ft.
Primary w/ Backup	500 to 1,000	1	4,018	4.46	765	0.38
	1,000 to 1,500	3	3,889	3.14	348	0.23
	1,500 to 2,000	6	3,154	1.64	326	0.17
	2,000 to 2,500	5	4,589	1.89	434	0.25
	2,500 to 3,000	3	7,143	2.51	206	0.14
	3,000 to 3,500	1	7,268	2.27	125	0.06
	3,500 to 4,000	1	6,244	1.73	2,330	0.78
	Overall	20	4,625	2.24	450	0.23
Whole-Home	500 to 1,000	1	3,603	3.60	340	0.26
	1,000 to 1,500	8	3,882	2.73	563	0.29
	1,500 to 2,000	8	4,336	2.41	462	0.24
	2,000 to 2,500	4	8,433	3.60	665	0.38
	2,500 to 3,000	1	11,802	3.93	1,704	1.22
	3,000 to 3,500	1	454	0.15	101	0.04
	Overall	23	5,015	2.75	565	0.31
Overall	-	43	4,833	2.51	512	0.27

Table 4 summarizes metered utilization hours during the heating and cooling seasons, where utilization refers to the percent of time during the metering period that the ccASHP system was running, not the percent of total heat load served by the system. Utilization was highly variable but was higher on average in whole-home applications, which operated 68% of metered hours during the heating season and 42% more than primary with backup systems. Primary with backup systems were used 48% of the time.

Average cooling season utilization per outdoor unit was 56% less than heating season utilization. Systems installed in whole-home applications were used 13% more than primary with backup systems, but overall average utilization was only 26%. This result indicates that these participants may be using their ASHP systems primarily for heating, rather than for cooling.

Table 4. Heating and Cooling Season Utilization per Outdoor Unit

Application	System Type	Number of Outdoor Units	Average Utilization	
			Heating	Cooling
Primary with Backup	Single-zone, Ductless	8	36%	18%
	Single-zone, Ducted	9	35%	26%
	Multizone, Ductless	18	60%	26%
	Overall	35	48%	24%
Whole-Home	Single-zone, Ductless	13	73%	20%
	Single-zone Ducted	7	43%	26%
	Multi-zone, Ductless	16	74%	33%
	Multi-zone, Ducted	1	49%	55%
	Multi-zone Ductless and Ducted	1	98%	9%
	Overall	38	68%	27%
Overall		73	58%	26%

In terms of performance, ductless multi-zone systems with more than three indoor heads (some with branch-box control) had the lowest average seasonal heating performance during the metering period (Table 5). In contrast, ductless single-zone systems had the highest measured performance. Ductless, single-zone, wall- and floor-mounted systems had the highest metered average seasonal heating performance in both applications. Ducted systems in primary with backup applications performed better than in whole-home applications, likely due in part to being used for heating less often during the coldest times of the year.

Table 5. Comparison of Heating Performance by System Type and Indoor Heads

System Type	Description	Indoor Heads per Unit	Number of Outdoor Units	Average Utilization, %	Average Seasonal Heating Performance, sCOP
Ductless	Single-zone	1	21	59%	3.16
	Multi-zone	2	15	66%	2.24
	Multi-zone	3	13	72%	2.57
	Multi-zone	4	3	45%	1.12

System Type	Description	Indoor Heads per Unit	Number of Outdoor Units	Average Utilization, %	Average Seasonal Heating Performance, sCOP
	Multi-zone	5	3	70%	1.52
Mixed	Multi-zone Non-ducted and Ducted	3	1	98%	1.97
Ducted	Single-zone	1	16	39%	2.25
	Multi-zone	2	1	49%	2.29
Individual Outdoor Unit			73	58%	2.50
Overall Site-Level			43	-	2.34

Figure 6 compares the overall average heating season performance for all 43 sites with outdoor air temperature. As expected, the overall average heating performance for the sampled homes peaked between 40°F to 50°F, with a pronounced decrease at 10°F.

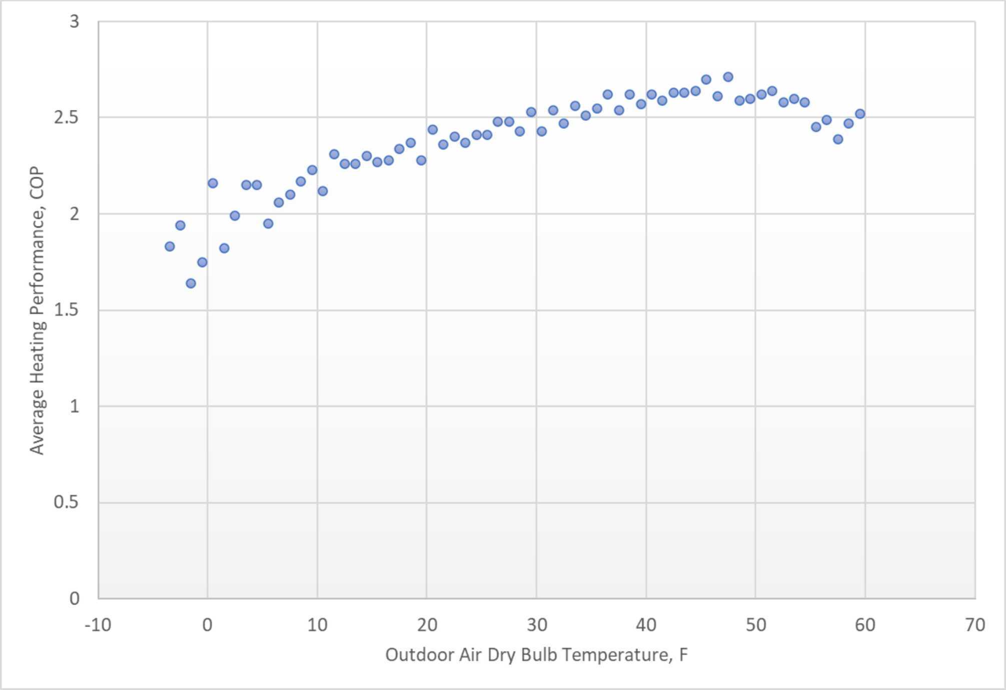

Figure 6. Overall Average Seasonal Heating Performance by Outdoor Air Temperature

Table 6 compares the estimated cost-effectiveness for 40 of the participating homes by application and fuel type. Average installation costs were 22% higher in whole-home sites than primary with backup relative to square footage. Energy cost savings were higher for whole-home sites, though this was driven in part by differences in energy costs between states and more whole-home sites in New York than in Massachusetts.

The team estimated an energy cost penalty for natural gas customers in this sample due to the high cost of electricity and relatively low cost of natural gas in the Northeast. The result of applying the penalty supports targeting customers with delivered fuel and electric resistance heating for ccASHP systems first where economics are a priority.

Table 6. Estimated Cost-Effectiveness Comparison

Application	Fuel Type	N	Sq. Ft.	Avg. Installation Cost[1]	Avg. Installed Cost per Sq. Ft.	Annual Cost Savings[1]	Annual Cost Savings per Sq. Ft.
Primary w/ Backup	All	20	2,167	$17,695	$8.50	$280	$0.20
	Non-Gas	15	2,156	$17,031	$7.90	$461	$0.32
	Gas	5	2,200	$19,686	$8.95	-$262	-$0.15
Whole-Home[1]	All	20	1,891	$18,755	$10.31	$264	$0.17
	Non-Gas	10[1]	1,815	$20,207	$11.13	$682	$0.42
	Gas	10	1,968	$17,142	$9.18	-$153	-$0.09
Total		40	2,029	$18,211	$9.38	$272	$0.18

[1] Program reported total installation cost data was missing for one whole-home site, and energy savings could not be estimated for three whole-home sites.

The online survey asked customers about energy bill impacts, and 90% of respondents reported a change in their overall energy bills since installing an ASHP and 76% said the change was the same as what they had expected. Respondents who installed weatherization measures were more likely to see a decrease of $100 or more per month compared to respondents who did not. Respondents who had electric resistance heat prior to installing their ASHP were more likely to see a decrease of at least $50 per month compared to respondents with gas and delivered fuel.

3. How does ccASHP system heating performance differ between whole-home and primary with backup applications? Table 7 summarizes the calculated heating season demand intensity and seasonal heating performance for the 43 participating homes by application and system type. Though, on average, there was no significant difference in seasonal heating performance between whole-home and primary with backup applications, ductless systems tended to perform better in whole-home applications while ducted systems performed better in primary with backup applications. However, the ccASHP systems used in whole-home applications were 40% to 50% more demand-intensive by conditioned square footage than in primary with backup applications.

Table 7. Heating Season Metered Data Results

Application	System Type	Homes	Avg. Use	Avg. ccASHP System Heating Season Demand (kW/1,000 sq. ft.)	Avg. ccASHP System Utility Winter Peak Demand[1] (kW/1,000 sq. ft.)	Measured Average sCOP	AHRI Rated sCOP (from HSPF)	Measured sCOP/ Rated sCOP
Primary w/ Backup	Ductless	14	50%	0.60	0.77	2.23	3.23	69%
	Ducted	5	38%	0.38	0.64	2.46	3.06	63%
	Mixed	1	48%	0.42	0.29	2.55	3.02	84%
	Total	20	48%	0.54	0.71	2.30	3.18	68%
Whole-Home	Ductless	13	75%	0.89	1.12	2.80	3.28	84%
	Ducted	6	43%	0.54	0.70	2.03	3.16	57%

	Mixed	4	69%	0.99	1.15	1.87	3.33	56%
	Total	23	68%	0.82	1.03	2.38	3.26	71%
Total		43	58%	0.69	0.88	2.34	3.22	70%

[1] Utility Winter Peak defined as 5:00 p.m. to 7:00 p.m. daily, December, January, and February.

The overall average seasonal heating performance was 2.34 coefficient of performance (COP). Though, on average, there was no significant difference in performance between whole-home and primary with backup applications (2.38 sCOP and 2.30 COP, respectively), the ductless systems in this sample tended to perform better in whole-home applications and ducted systems performed better in primary with backup applications. This was likely due in part to the fact that ducted systems in primary with backup applications tend not to have or to use electric resistance elements during cold periods.

The team used the AHRI-rated heating seasonal performance factor (HSPF) as a rough comparison metric for metered seasonal heating performance and found that metered performance was 30% lower than expected performance. However, HSPF is not a perfect comparison, so for New York sites, the team calculated the expected seasonal heating performance using the methodology in the New York State Technical Reference Manual (TRM). On average, those sites would have been expected to have a seasonal COP (sCOP) of 2.84, which meant metered seasonal heating performance was 17% lower than expected.

The team drew tentative conclusions from this small sample. In-field performance was lower than expected if AHRI ratings are normalized for the Northeast's climate. Ductless whole-home systems in this sample performed better than ductless primary with backup systems because they likely operate more continuously instead of more cycling during hours below peak heating needs and may also be better sized for actual heating loads. On the other hand, ducted systems perform less efficiently in whole-home configurations. This is possibly because of high electric resistance usage compared to primary with backup systems since the backup fuel system would operate during many of the hours when electric resistance would be used.

4. What are the potential electric grid impacts of wide-scale residential heating electrification? Table 8 summarizes heating season demand impacts by system type, including backup electric resistance demand for five ducted sites. Though average demand during the current utility winter peak period was only 0.88 kW/1,000 square feet, the average hourly maximum demand was as high as 3.48 kW/1,000 square feet for mixed sites (both ducted and ductless systems), and instantaneous site-level demand for one mixed site was 9.12 kW/1,000 square feet.

Table 8. Heating Season Demand Impacts

System Type	Number of Homes	Average Conditioned Area, sq. ft.	Total System Electric Energy Use, kWh/ 1,000 sq. ft	Average ASHP Operating Demand, kW/1,000 sq. ft.	Average Maximum Hourly Demand, kW/1,000 sq. ft.	Average Utility Winter Peak Demand, kW/1,000 sq. ft.	Site-Level Maximum 2-Minute Interval Demand, kW/1,000 sq. ft.
Ductless	27	1,878	2,728	0.91	2.11	0.90	5.47
Ducted	11	2,281	1,453	1.10	3.04	0.64	8.47

Mixed	5	1,907	3,468	1.05	3.48	1.04	9.12
Overall	43	1,984	2,436	0.98	2.52	0.88	-

[1] Utility Winter Peak demand period defined as 5:00 p.m. to 7:00 p.m. daily during December, January, and February.

To further investigate electric grid impacts, the team analyzed a three-day (midnight to midnight) cold period for both states to compare demand loadshapes across applications. For sites in New York, the cold snap period was defined as February 11 to 13, 2021, and for sites in Massachusetts, as January 29 to 31, 2021. Note that the outdoor air temperatures between sites varied greatly, especially in New York, but on average these were the coldest days of the metering period.

The results for both states show that electric demand from widescale residential heating electrification will typically peak in the early morning hours when outdoor temperatures are coldest and customers raise space setpoints. Figure 7 and Figure 8 compare the average cold snap demand loadshapes by application for the New York and Massachusetts sites, respectively.

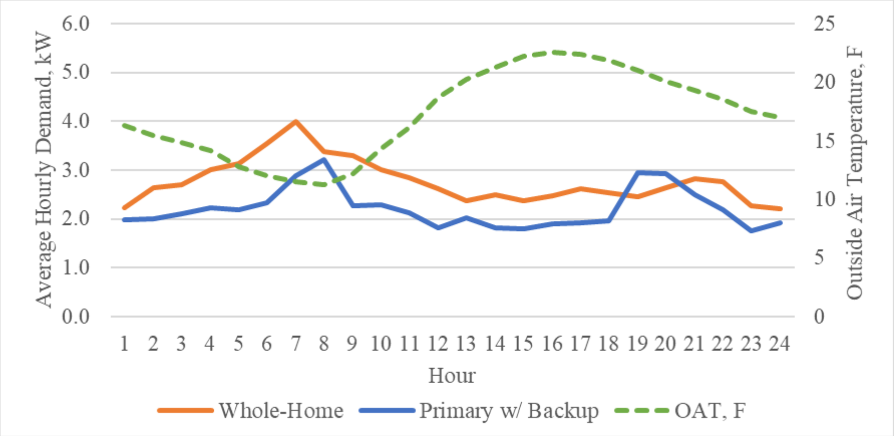

Figure 7. New York Cold Snap Average Hourly Demand Loadshape

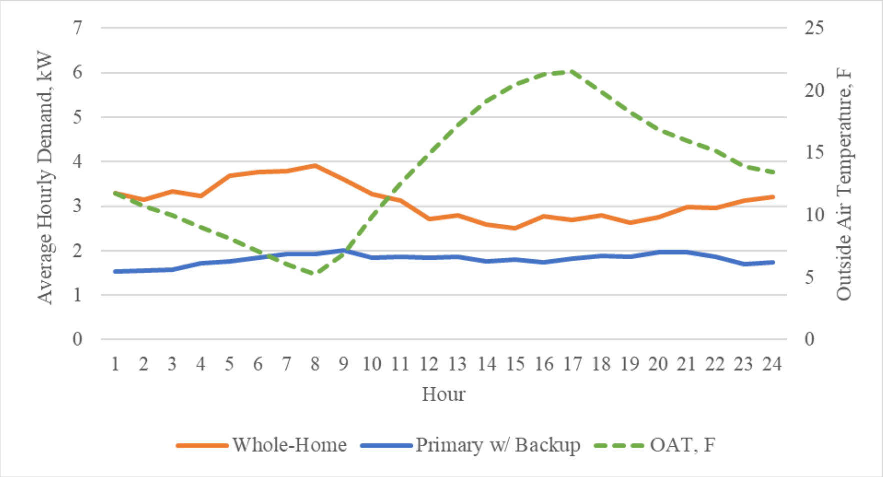

Figure 8. Massachusetts Cold Snap Average Hourly Demand Loadshape

Table 9 compares cold snap analysis summary parameters by state and application. On average, ccASHP systems in whole-home applications will have a greater peak demand impact. Heating performance is relatively steady throughout the day. Systems with electric resistance elements will have the greatest peak demand impact.

Table 9. Comparison of Cold Snap Metered Data by State and Application

	New York		Massachusetts	
Summary Parameter	Whole-Home	Primary w/ Backup	Whole-Home	Primary w/ Backup
Number of Homes	12	7	9	13
Average Metered Demand, kW	2.77	2.21	3.11	1.81
Average Measured ASHP Heating Delivered Capacity, Btu/hr	20,598	19,859	20,265	10,701
Average Heating Performance, COP	2.24[1]	2.36	2.55[1]	1.67
Average Outside Air Temperature, °F	17.2	16.9	13.6	12.5
Average Windspeed, mph	4.9	5.4	8.2	9.2

[1] The calculated cold snap average heating performance for five ducted whole-home systems (two in Massachusetts and one in New York) excludes electric resistance demand.

Table 10 summarizes cooling season demand impacts by system type. The metered average utility summer peak demand impact from ccASHPs in cooling mode of 0.21 kW/1,000 square feet was almost 76% less than the average utility winter peak demand in heating mode.

Table 10. Cooling Season Demand Impacts

System Type	Number of Homes	Average Conditioned Area, sq. ft.	Total System Electric Energy Use, kWh/ 1,000 sq. ft	Average ASHP Operating Demand,[1] kW/1,000 sq. ft.	Average Maximum Hourly Demand,[2] kW/1,000 sq. ft.	Average Utility Summer Peak Demand,[3] kW/1,000 sq. ft.	Site-Level Maximum 2-Minute Interval Demand, kW/1,000 sq. ft.
Ductless	27	1,878	293	0.44	1.16	0.21	6.52
Ducted	11	2,281	217	0.56	1.27	0.23	2.43
Mixed	5	1,907	181	0.46	1.52	0.17	3.54
Overall	43	1,984	258	0.49	1.23	0.21	-

[1] The average operating demand excludes metered hours when the system was not running.

[2] The maximum hourly demand occurred at different hours across sites. This value represents the average maximum hourly demand across sites.

[3] Utility Summer Peak demand period defined as 1:00 p.m. to 5:00 p.m. daily during June, July, and August.

In summary, whole-home applications with integral electric resistance elements will have the greatest impact on the electric grid during extreme cold periods, and heating demand impacts will be greater than cooling demand impacts. Residential heat pumps are likely to shift the utility winter peak demand from the traditional 5 p.m. to 7 p.m. period to the 5 a.m. to 8 a.m. period.

5. What continued challenges with customer and contractor experience need to be addressed for market scale-up? To address this question, the team conducted phone interviews with heat pump installation contractors and utility and program stakeholders. Contractors cited equipment and installation cost, aesthetics, technology misconceptions, and building logistics as the top adoption barriers. According to participating contractors, customer demand for ASHPs has increased in recent years, driven by improved technology, widespread adoption, and rebates. With customers, contractors most often discussed the benefits of the higher efficiency and lower environmental impact of ASHPs. However, many contractors said their customers still did not believe ccASHPs could heat their homes effectively, and they recommend designing more customer training around equipment controls and proper maintenance to improve efficiency.

According to the interview results, contractors are overwhelmingly recommending cold-climate models and ductless mini-split heat pumps still dominate over ducted systems. The main barriers for ducted systems are higher costs and logistical limitations based on home features. Contractors said their customers reported few performance issues with cold-climate models.

Contractors recommended several tactics to overcome barriers to ASHP adoption, including showing a demo ASHP to customers at their shop; marketing different ASHP styles to overcome aesthetic concerns; educating customers to overcome misconceptions on performance and understand benefits; sharing case studies and/or customer testimonials from successful past projects; and connecting customers to relevant rebates and clean energy programs.

Utility and program stakeholders also identified educational gaps and recommended training programs to educate customers on the benefits of ccASHP systems for heating and to instruct contractors on the best methods to select and size systems for various applications. From a program perspective, energy efficiency and building weatherization measures should still be emphasized. They also recommended that utilities and program administrators consider increasing incentives for whole-home ccASHP systems, shifting incentives to an upstream model, and developing electric heating rates to encourage off-peak energy use.

Interestingly, several program stakeholders discouraged policies on integrated controls (controls that transition between multiple HVAC system types, such as heat pumps and boilers) and supplemental ccASHP systems, since recommending integrated controls may encourage customers to retain backup fuel systems. Integrated controls are also costly and difficult to install and even more difficult to program correctly. Nevertheless, stakeholders recognize that retaining existing systems may be the simplest and most cost-effective way to get customers to invest in ccASHP systems.

Conclusion and Recommendations

Study caveats. This research study focused on a small sample of homes from rebated installations in Massachusetts and New York. The team used a sample of convenience and did not select the participant sample with the intent to be statistically significant or representative of the population. Findings and conclusions from this study indicate possible trends. The team recommends collecting additional data from a broader sample to draw firm conclusions about ccASHP operation in the Northeast.

The 2020/2021 winter was mild with few data points around design conditions. Cold snap periods were warmer and shorter than design conditions and did not reflect periods of prolonged extreme cold that could have greater impacts on customer comfort and grid demand. Further study with a larger sample during such a weather event would provide more definitive conclusions on comfort, performance, and grid impact that could influence policymakers and program administrators. This study was also performed during the height of the COVID-19 pandemic, and system utilization may not reflect typical operation because customers were working from home.

Key takeaways. In summary, key takeaways from the sample in this study include these:

- Customers were highly satisfied with ccASHP performance. Comfort differences between primary with backup and whole-home systems were minimal.
- Whole-home systems tended to be more expensive to install than primary with backup.
- A customer's existing fuel type is an important factor to cost-effectiveness. Natural gas customers will likely see an increase in overall utility bills by switching to ccASHP systems for heating because electricity costs more per delivered BTU than natural gas in the Northeast.
- The overall average seasonal heating performance for all measured systems was 2.34 sCOP.
- On average, seasonal heating performance was similar between primary with backup and whole-home applications, but it varied significantly by home and system type and was influenced by many factors, including system type, size, and utilization.
- Winter peak demand impacts of widescale ccASHP adoption will likely occur during early morning hours (5 a.m. to 8 a.m.), not during traditional evening utility peak periods.
- Electrical demand was higher for whole-home systems during cold periods. Whole-home applications with electric resistance elements will have the greatest electric grid impact during extreme cold periods.
- Heating season demand impacts will be greater than cooling season demand impacts.
- Contractors reported installation costs, aesthetics, customer misconceptions, and building logistics as the top barriers to widescale ccASHP deployment.

Program and policy recommendations. The following program and policy recommendations should be considered to scale up the market:

- **Adjust regulatory policies and utility rates.** The utility winter peak demand period will switch from the evening to early morning hours (i.e., 5 a.m. to 8 a.m.). Electric grid operators and policymakers will need to update policies and rates to address this change.
- **Increase incentive levels**. Most of the participating sites in the study will not achieve a payback during the system lifetime based on the received rebate. Since then, incentive levels have increased substantially for many New York and Massachusetts customers, which may enable greater savings for future ccASHP installations.
- **Focus on applications with highest energy cost savings.** Participating electric resistance, propane, and fuel oil customers in New York were most likely to see significant energy savings. High electricity costs limit energy savings in Massachusetts. Utility rate structures with lower volumetric costs to reflect higher grid utilization (particularly in Massachusetts) may improve economics, though such structures may be inappropriate in the long term with increasing electrification and winter peak concerns.

While the data collected for this study do not suggest any significant trends that would warrant policy and/or program decisions to encourage or discourage whole-home systems, the observed difference in electrical grid impacts (particularly peak-use time of day in the context of mass market adoption) may be a more important factor for policymakers and utilities to consider for informing policy and programmatic decisions.

References

Cadmus. June 2022. "Residential ccASHP Building Electrification Study." https://cadmusgroup.com/wp-content/uploads/2022/06/Residential-ccASHP-Building-Electrification-Study_Cadmus_Final_060322_Public.pdf

Commonwealth of Massachusetts. 2021. "Chapter 8: An Act Creating a Next-Generation Roadmap for Massachusetts Climate Policy." The 192nd General Court of the Commonwealth of Massachusetts. https://malegislature.gov/Laws/SessionLaws/Acts/2021/Chapter8

Leung, Jessica. July 2018. *Decarbonizing U.S. Buildings: C2ES Climate Innovation 2050.* Prepared for Center for Climate and Energy Solutions. https://www.c2es.org/document/decarbonizing-u-s-buildings/

Mass.gov. *How Massachusetts Households Heat Their Homes.* https://www.mass.gov/service-details/how-massachusetts-households-heat-their-homes

NEEP. *Cold Climate Air-Source Heat Pump Specification (Version 3.1).* Effective August 1, 2021. https://neep.org/sites/default/files/media-files/cold_climate_air-source_heat_pump_specification-version_3.1_update_.pdf

New York State. 2021. *2021 Statewide GHG Emissions Report.* Department of Environmental Conservation. https://www.dec.ny.gov/energy/99223.html

Van der Meer, Bill. 2018. *Builder Brief BB0201. Blower Door Testing.* Prepared for the Pennsylvania Housing Research Resource Center. Cited on National Association for State Community Services Programs website. Accessed February 2022. https://nascsp.org/wp-content/uploads/2018/02/van-der-meer_blower-door-testing.pdf