

Field Test Results from Cold Climate Air Source Heat Pump Installations in New York State: Performance, Savings and More

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ABSTRACT

Determining and improving the performance of cold climate air source heat pumps (ccASHP) is key to efficiently electrifying our buildings. The Hudson Valley Heat Pump Pilot (HVHPP), a field demonstration project, sought to demonstrate the energy, cost and greenhouse gas (GHG) savings achievable from ccASHPs installed in New York State homes beginning in late 2017 through early 2019. The twenty participating residences represented diverse building types, with most, but not all, installing ductless systems. Pre-retrofit heating fuels included: fuel oil (7), natural gas (4), electric resistance (5), and propane (4). Contractors received training regarding heat pump sizing and installation, customers were educated regarding efficient operation, with quality assurance visits at each site. Power measurements were collected at 15-minute intervals in the post-retrofit period to quantify electric use for the ccASHPs, the total house, any direct electric resistance heating, and other loads. Fuel readings from utility bills and delivery logs from pre- and post-retrofit periods were collected, allowing a comparison of weather-normalized pre- and post-retrofit energy use. The ccASHPs displaced an average of 85% of the original heating system fuel use (ranging from 34% to 100%); average estimated seasonal average heating efficiency was 2.1 (ranging from 1.6 to 2.9). Cost savings per nominal installed ton of cooling capacity averaged +\$113 (depending heavily on the type of fuel displaced). Annual GHG savings averaged 1,100 to 1,300 of CO₂ equivalent per nominal ton. 80% of the homeowners reported that they are “very satisfied” with their air-source heat pump systems, and all were either “somewhat satisfied” or “very satisfied”.

Project Goals and Overview

Thermal energy usage in the residential and commercial sectors in New York state accounts for approximately 32% of all combustion-based greenhouse gas (GHG) emissions in New York state.¹ As part of State policy to address these impacts, the New York State Energy and Research Development Authority (NYSERDA) sponsored the HVHPP, a field demonstration effort led by Energy Futures Group (EFG).² Two primary goals of the HVHPP included (1) demonstrating the energy and greenhouse gas savings reductions achievable by incorporating ccASHPs into existing homes, and (2) further understanding New York-specific building needs and barriers to full market adoption of ccASHPs.

The HVHPP Program worked with six contractors to install ductless and ducted Mitsubishi ccASHPs in twenty homes located in the Hudson Valley area of New York State.

¹ <https://www.nyserda.ny.gov/-/media/Files/Publications/PPSER/NYSERDA/RHC-Framework.ashx>

² The EFG team was comprised of EFG providing program management, Bruce Harley Energy Consulting (BHEC) and Integral Building and Design (IBD) providing technical, analytical, contractor liaison, site installation, and quality assurance expertise and support.

Contractors were given support regarding sizing, design and application of heat pumps, provided customer-facing materials to optimize heat pump operation by homeowners, and each site received a quality assurance (QA) visit with follow up required by contractors to correct any identified issues. Both homeowners and contractors participated in a series of pre- and post-surveys to assist in better understanding various barriers to ccASHP market adoption.

Development of a “Performance Validation Plan”, installation of data collection systems, and monitoring and analysis of heat pump performance was completed by Frontier Energy (FE) and Owahgena Consulting under separate contract with NYSERDA to assess energy/cost savings.

Contractors were recruited through homeowner referrals and by reaching out to NYSERDA- and utility-approved contractor lists, and received a \$500 incentive bonus for each completed project. The participating contractors varied in their service offerings; two specialized in ductless ccASHP installations, one focused on whole home building analysis and efficiency retrofits, and three provided an array of heating and cooling services across multiple fuel types.

Customers were recruited through utility announcements, contractor referrals and presentations by the EFG team at local energy and climate events. Customers received a \$350/ton discount (based on the size of the heat pump unit) courtesy of Mitsubishi. Customers were also informed of other utility incentives and low-cost financing offers and were offered the opportunity to keep an eGauge monitoring unit after project completion.³ Customers were able to receive technical advice and support from the EFG team, in addition to their contractor.

Home Characteristics and Equipment Details

Home styles varied, with three colonials, four ranches, four split levels, five contemporaries, two capes and two “other”. All but one home was built after 1950. Multiple heating fuels are represented including fuel oil, natural gas, liquid propane (LP), wood, and electricity. Heating systems also varied and included electric baseboard and radiant heat, furnaces, boilers (with baseboard and steam radiators), existing heat pumps, and wood stoves. Three homes had existing working central air conditioning; the rest relied upon window units or did not have cooling. Table 1 presents a summary of site information including original equipment and ccASHP equipment installed between November 2017 through January 2019.



Figure 1. Pictorial collage of HVHPP homes.

³ <https://www.egauge.net/>

Table 1 Site Information: Original Equipment, ccASHP Installation and Cost Details

Site #	Original Space Heating Fuel & System Type	Original Water Heating Fuel & System Type	Heat Pump Strategy* for Heating	Heat Pump: Ducted or Ductless	HP (#out / # in / tons)	HP Installed Costs – W/O and W Incentives	Installed \$/ton – W/O and W Incentives
S1	Gas boiler	Gas-fired tank	Partial	Ductless	1 / 1 / 1.5	\$5,898 \$4,873	\$3,932 \$3,249
S2	Electric baseboard	Electric tank	Partial	Ductless	1 / 2 / 2.5	\$9,770 \$8,495	\$3,908 \$3,398
S3	Oil boiler	Oil boiler HX	Partial	Ductless	1 / 3 / 3.0	\$12,500 \$11,450	\$4,167 \$3,817
S4	Electric baseboard	Electric	Partial	Ductless	1 / 1 / 1.25	\$5,454 \$4,499	\$4,363 \$3,599
S5	Gas steam boiler + (2) existing HPs	Gas-fired tank	Partial	Ductless	4 / 4 / 3.5		
S6	Gas furnace	Gas-fired tank	Full, remain	Ductless	3 / 3 / 3	\$12,100 \$8,950	\$4,033 \$2,983
S7	Gas boiler HW Baseboard	Gas-fired tankless	Full, remain	Ductless	2 / 6 / 4.0	\$26,400 \$22,600	\$6,600 \$5,650
S8	Oil boiler	Oil indirect tank & HPWH	Full, remain	Ductless	4 / 4 / 3.0	\$16,215 \$10,615	\$5,405 \$3,538
S9	Propane furnace	Propane tank	Partial	Ductless	2 / 2 / 2.5	\$8,830 \$5,105	\$3,532 \$2,042
S10	Oil boiler & existing HPs	Solar hot water & oil indirect tank	Full, remain	Ductless	6 / 6 / 5.25	\$8,450 \$5,450	\$1,610 \$1,038
S11	Electric baseboard & radiant	Electric HE tank	Full, remain	Ductless	5 / 5 / 4.25	\$18,980 \$12,493	\$4,466 \$2,939
S12	Oil boiler & wood stove	Oil indirect tank & HPWH	Partial	Ductless	1 / 1 / 0.75	\$3,750 \$2,488	\$5,000 \$3,317
S13	Oil boiler & wood fireplace	Indirect tank	Full, remain	Ductless	3 / 3 / 3.5	\$15,350 \$10,375	\$4,386 \$2,964
S14	Propane HE boiler	Propane indirect tank	Full	Ductless / Ducted	2 / Duct / 6.0	\$25,000 \$21,900	\$4,167 \$3,650
S15	Propane HE boiler & existing HPs	Propane indirect tank	Full, remain	Ductless	8 / 8 / 9.0		
S16	Electric baseboard & wood stove	Electric tanks (2)	Full	Ductless	3 / 3 / 4.0	\$14,450 \$10,650	\$3,613 \$2,663
S17	Oil boiler & wood stove	Electric HPWH	Partial	Ductless	1 / 1 / 1.5	\$3,950 \$2,550	\$2,633 \$1,700
S18	Oil boiler	Oil indirect tank	Full, remain	Centrally Ducted	1 / Duct / 3.0	\$11,450 \$9,400	\$3,817 \$3,133
S19	Electric baseboard	Electric tank	Full	Ductless	5 / 5 / 5.25	\$23,545 \$14,208	\$4,485 \$2,706
S20	Propane furnace	Propane tankless	Full	Ductless	5 / 5 / 5.5	24,040 \$12,615	\$4,371 \$2,294

*Definitions for “HP Strategies”:

“Partial” means partial load heating: the HP meets only part of heating load.

“Full” means full load heating: the HP is intended to meet all the heating load, and the original heating system is removed.

“Full, remain” is the same as full load heating, but the original heating systems remained in place.

** These heat pumps were installed prior to the HVHPP.

Monitoring and Analysis Methodology

The overall monitoring approach used a pre- and post-retrofit comparison to quantify the impact of installing the ccASHP in each home. Inherent in this approach is the assumption that the occupants maintain similar temperature conditions and generally have similar behavior in the pre- and post-periods.

For the post-retrofit period, metering was installed to measure ccASHP electric use, which was then correlated to outdoor temperature data from a nearby weather station in the region. Similarly, fuel delivery logs and/or monthly utility fuel bills from before the ccASHP installation (pre-retrofit) were also correlated to outdoor temperatures after accounting for baseline fuel use by non-space-heating uses. These pre- and post-retrofit trends were then applied to a temperature bin analysis using typical year weather data for the same local weather station. From this bin analysis, the following was determined:

- Pre-retrofit and post-retrofit fuel use for space heating in a typical year
- ccASHP electric use for space heating (and cooling) in a typical year
- Annual cost savings
- The implied seasonal average efficiency of the heat pump
- Reductions in greenhouse gas emissions

At most houses, metering was also installed to collect total house electric use at regular intervals. This helped determine internal gains in the home and was used in a load-line analysis to discern the temperature dependent portions of the electric load for both heating and cooling. For electrically-heated homes, the difference between the temperature-dependent electric load in the pre- and post-retrofit periods provided an estimate of the net electric heating savings. For homes with pre-retrofit electric baseboard heat, the on-site metering also included the resistance electric heat use where possible. This allowed for separating the impact that the ccASHPs had on baseboard electric heater use in the post-retrofit period.

An eGauge power metering system was installed to measure electric power use at each home; each system could accommodate up to 12 current transducers (CTs) that could be used to measure individual circuits in the electrical panel. Different measurements were taken at each house, with prioritization of measurements as follows: 1) all ccASHPs in the home, 2) resistance electric heat circuits that might run for supplemental heating, 3) total house power, 4) boiler/furnace power (to infer runtime), 5) solar PV system output (if present), and 6) electric water heater power. Fifteen minute interval readings were automatically transferred to a cloud server via wireless internet which was then saved in a database for each site. Each site was associated with a nearby weather station as were local utility costs, as shown in Table 2.

Table 2. Weather Data and Utility Fuel Costs

Weather / Utility Region	Electric Cost (\$/kWh)	Natural Gas Cost (\$/therm)	Fuel Oil Cost (\$/gal)	Propane Cost (\$/gal)
Albany / National Grid	0.117	0.83	2.49	2.67
Newburg / Central Hudson	0.15	1.47	2.68	2.44
NY LGA / Con Ed	0.20	1.40	2.45	2.24

Results: Energy Impacts and Cost Savings

Table 3 compares key characteristics for each site to higher-level calculated results.⁴ The nominal capacity of the installed heat pumps is shown along with the number of outdoor and indoor sections (# out / # in / tons). The annual space heating load is determined using the pre-retrofit fuel use trends in the bin analysis to isolate the portion of the annual fuel use that is attributable to space heating in a typical year. The result is normalized per square foot of floor area. The space heating loads range from 12.8 to 77.1 Mbtu per sq ft per year, with an average of 32 and a median of 31. Other results include:

- The normalized annual electric consumption of the ccASHP for heating per installed ton are shown. Consumption for heating ranged from 563 to 4,201 kWh per nominal ton, with an average of 1,805 and a median of 1,369.
- The percentage in heating fuel reduction before and after ccASHP installation is also given and compared to the original replacement strategy. For consistent comparison across heating fuels, the electric fuel reduction is only for the resistance heating and does not include the impact of added electric use by the heat pump. In a few cases the ccASHP was expected to displace all of the fuel use but did not (S8). In other cases, the ccASHP system was only intended to displace part of the fuel-fired system but ending up displacing all fuel use (S12).
- The heat pumps at S8 did not run as much as expected for the 1st winter, only displacing 33% of fuel use. In the 2nd winter, the homeowners changed their boiler thermostat settings (based on coaching by the EFG team) so that the ccASHPs met more of the heating load and displaced 61% of fuel use. Therefore, the table shows three separate values for S8 for all the data, and for the first and second winters.

Five sites (S5, S9, S12, S15 and S17) had issues with the pre- or post-retrofit results and therefore some of the calculated values for implied COP, percent heating seasonal performance factor (HSPF) and cost savings are not given.⁵ The data given for the fifteen included sites show that:

- The implied heating COP is calculated using the change in fuel consumption, the assumed fuel conversion efficiency and the ccASHP power use. This approximate value ranges from 1.6 to 2.9 for the 15 sites with an average of 2.1. Two of the ccASHPs were ducted units with resistance heating elements (S14 and S18). In these cases resistance use were included with ccASHP power.
- The implied heating COP is divided by the rated HSPF value for each site to determine the percent of HSPF. HSPF is known to be a poor predictor of seasonal heating efficiency, especially in colder climates such as NYS. The values range from 48 to 80%, with an average of 63%.

⁴ Note that installations began in late 2017 and continued through 2019. Therefore, while all analyses of energy and cost savings captured at least one full heating and cooling season, the time frame varied. For example, analyses of the earlier installations cover the 2017 – 2019 time frame, and analyses of the later installations cover the 2019 – 2020 time frame.

⁵ Reasons for excluding the results for these sites include changes in ownership and occupancy which resulted in a very poor pre-post comparison due to differences in setpoints and usage patterns, changes in secondary fuel use (wood) between pre- and post-periods, and inconsistent fuel delivery data.

- Cost savings are also given in Table 3. These are calculated using the regional utility and fuel costs. Cost savings are highest for the sites with expensive fuels (electric, propane, and fuel oil). Savings compared to natural gas, for the 2017 – 2020 time frame, are typically less than zero.

Table 3. Summary of Heating Results for All Sites

Site	Pre-Retrofit Fuel	ASHP (#out / #in / tons)	Original Replacement Strategy	Space Htg Load (MBtu/ft2-yr)	ASHP Heating Use (kWh/ton)	Percent Fuel Reduction	Implied COP	Percent of HSPF	Annual Costs Savings
S1	Gas	1 / 1 / 1.5	Partial	37.0	2,570	57%	2.4	80%	-\$119
S2	Electric	1 / 2 / 2.5	Partial	16.3	1,895	92%	1.8	55%	\$604
S3	Oil	1 / 3 / 3.0	Partial	27.6	1,369	67%	2.6	80%	\$359
S4	Electric	1 / 1 / 1.25	Partial	28.1	4,201	93%	2.3	65%	\$802
S5	Gas	4 / 4 / 3.5	Partial	77.1	563	34%			
S6	Gas (HE)	3 / 3 / 3	Full, remain	24.1	1,560	94%	2.4	65%	-\$194
S7	Gas	2 / 6 / 4.0	Full, remain	44.3	2,581	100%	2.2	75%	-\$686
S8	Oil	4 / 4 / 3.0	Full, remain	38.0	1,304 1,073 1,748	42% (all data) 33% (1st winter) 61% (2nd winter)	1.9 1.7 1.9	50% 45% 50%	\$89 \$11 \$100
S9	Propane	2 / 2 / 2.5	Partial	12.8	897	34%			
S10	Oil	6 / 6 / 5.25	Full, remain	15.2	978	100%	1.9	52%	\$8
S11	Electric	5 / 5 / 4.25	Full, remain	32.3	1,199	100%	2.4	63%	\$1,011
S12	Oil	1 / 1 / 0.75	Partial	37.5	3,791	100%			
S13	Oil	3 / 3 / 3.5	Full, remain	22.8	1,369	69%	1.9	52%	-\$10
S14	Propane (HE)	2 / Duct / 6.0	Full	34.8	1,549	100%	2.9	98%	\$1,331
S15	Propane (HE)	8 / 8 / 9.0	Full, remain	14.9	1,297	100%			
S16	Electric	3 / 3 / 4.0	Full	24.1	3,319	98%	1.6	46%	\$1,277
S17	Oil	1 / 1 / 1.5	Partial	57.0	1,174	23%			
S18	Oil	1 / Duct / 3.0	Full, remain	41.2	2,083	64%	1.8	56%	-\$95
S19	Electric	5 / 5 / 5.25	Full	34.8	1,221	92%	1.9	52%	\$839
S20	Propane	5 / 5 / 5.5	Full	29.3	1,170	100%	1.8	49%	\$369

The breakdown by pre-retrofit fuel is shown in Table 4 for the 15 included sites where COP and savings could be determined. The homes that use more expensive fuels tended to displace more of their fuel use. The average implied COP is 2.1 and there is no significant variation in the implied COP with fuel type. As mentioned above, cost savings depend mostly on the cost of the pre-retrofit fuel, and on the degree of fuel reduction as a secondary effect. Cost savings per ton were highest for the electric sites, followed by propane and fuel oil. Natural gas does not result in positive savings because of its low cost.

Table 4. Results by Fuel Type – 15 Included Sites (where savings could be calculated)

Pre-Retrofit Fuel	No of Sites	Percent Fuel Reduction	Implied COP	Percent of HSPF	Cost Savings per ton
Oil	5	68%	2.0	58%	\$23.30
Natural Gas	3	84%	2.3	73%	-\$105.30
Electricity	5	95%	2.1	58%	\$320.10
Propane	2	100%	2.3	73%	\$144.50
Total / Avg	15	85%	2.1	63%	\$112.70

The heating analysis described above was careful to only consider the change in space heating fuel use. However, in some cases we did note that when the fuel-fired boiler was fully removed—and a new electric DHW system was installed to replace it—there was a significant drop in baseline or non-space-heating fuel use. For the propane sites, baseline use averaged 1.8 gallons per day and ranged as high as 2.8 gallons per day. For natural gas, the average baseline use was 0.7 therms per day with a maximum of 1.4 therms per day. For both propane and natural gas, the baseline use may have also served other loads in addition to DHW such cooking, clothes driers, etc. For oil, where the baseline use could only be associated with DHW, the average was 0.4 gallons per day with a maximum of 0.7 gallons per day. In contrast, the hypothetical fuel use to make 50 gallons of hot water per day would be 0.4 therms of gas, 0.4 gallons of propane, and 0.3 gallons of oil. While it is difficult to make a definitive judgement because actual hot water use was not measured, it appears that removing a fuel-fired boiler entirely may eliminate significant standby losses on an annual basis and provide even greater annual savings.

Table 5 shows the installation costs (after incentives) and compares it to the annual cost savings to determine simple payback. The simple payback for the five sites replacing electric heat ranged from 6 to 14 years, with an average of 12 years. For the two oil-heated sites the best payback was 32 years with an average over 200 years. The average simple payback for the two propane sites was 25 years. None of the three gas sites had a simple payback that was positive because none of the sites had positive savings.

Table 5. Installed Costs and Simple Payback

Site	Pre-Retrofit Fuel	Annual Costs Savings	Installed Cost after Incentives	Simple Payback
S1	Gas	-\$119	\$4,873	<0
S2	Electric	\$604	\$8,495	14
S3	Oil	\$359	\$11,450	32
S4	Electric	\$802	\$4,490	6
S5	Gas			
S6	Gas (HE)	-\$194	\$8,950	<0
S7	Gas	-\$686	\$22,600	<0
S8	Oil	\$100	\$10,615	106
S9	Propane		\$5,105	
S10	Oil	\$8	\$5,450	681
S11	Electric	\$1,011	\$12,493	12
S12	Oil		\$2,488	
S13	Oil	-\$10	\$10,375	<0
S14	Propane (HE)	\$1,331	\$21,900	16
S15	Propane (HE)			
S16	Electric	\$1,277	\$10,650	8
S17	Oil		\$2,550	
S18	Oil	-\$95	\$9,400	<0
S19	Electric	\$839	\$14,208	17
S20	Propane	\$369	\$12,615	34

We used the measured energy savings, combined with eGrid⁶ 2018 data for upstate New York, to determine GHG emissions from electricity use. eGrid publishes the overall average emissions rate as well as the non-baseload emissions rate. Generally, in GHG analyses for building efficiency technologies, we use the non-baseload emissions factors to determine the impact of the marginal change in energy use. The non-baseload factors are higher than the overall average emissions factors, because they reflect the impact of incremental or marginal changes in energy use. For upstate New York, the overall average factor is 0.254 lb of CO₂ equivalent for each kWh. The non-baseload factor is 0.924 lb of CO₂ equivalent per kWh. GHG CO₂ equivalent factors for the fossil fuels are 11.7 lb/therm for natural gas, 12.8 lb/gal for propane and 22.4 lb/gal for fuel oil.

Table 6 shows the resulting GHG emission reductions for each site, in absolute terms as well as per ton, using both the overall average and non-baseload GHG emissions factors. GHG savings are only shown for the 15 sites where savings could be calculated. The average GHG savings are 4,499 lb CO₂ equivalent per year using the overall average emissions factor (0.254 lb/kWh). The average value normalized for heat pump size is 1,304 lb/ton-yr. The average GHG

⁶ https://www.epa.gov/sites/production/files/2020-01/documents/egrid2018_summary_tables.pdf

savings are 3,274 lb CO₂ equivalent per year using the non-baseload factor (0.924 lb/kWh). The average value normalized for heat pump size is 1,093 lb/ton-yr.

Table 6. GHG Emission Savings at 15 Included Sites

				GHG Savings (lb/yr)		Normalized GHG Savings (lb/yr per installed ton)	
Site	Pre-Retrofit Fuel	Annual Fuel Savings	Annual HP Electric Use (kWh)	Overall Avg based on 0.254 lb/kWh	Non-baseload based on 0.924 lb/kWh	Overall Avg based on 0.254 lb/kWh	Non-baseload based on 0.924 lb/kWh
S1	therms	400	3,854	3,700	1,078	2,466	719
S2	kWh	4,025	4,739	1,022	3,760	409	1,504
S3	gallons oil	337	4,107	6,512	3,719	2,171	1,240
S4	kWh	6,875	5,251	1,746	6,421	1,396	5,137
S6	therms	426	4,679	3,794	612	1,265	204
S7	Therms	983	10,325	8,875	1,853	2,219	463
S8	gallons oil	219	3,912	3,921	1,261	1,307	420
S10	gallons oil	290	5,136	5,195	1,702	990	324
S11	kWh	6,740	5,095	1,711	6,295	403	1,481
S13	gallons oil	264	4,791	4,698	1,439	1,342	411
S14	propane	1,117	9,293	11,925	5,605	1,987	934
S16	kWh	8,517	13,277	2,162	7,954	541	1,989
S18	gallons oil	314	6,250	5,449	1,198	1,816	399
S19	kWh	5,593	6,409	1,420	5,224	270	995
S20	propane	547	6,433	5,359	984	974	179
AVG				4,499	3,274	1,304	1,093

Note: Results only given for 15 sites where savings could be calculated. GHG CO₂ equivalent factors for the fossil fuels are 11.7 lb/therm for natural gas, 12.8 lb/gal for propane and 22.4 lb/gal for fuel oil.

GHG savings for fuels = [fuel savings] x K_f – [HP electric] x K_e. GHG savings for electric = [Net electric savings] x K_e

Table 7 summarizes the GHG savings by base fuel type normalized per installed ton. Using the overall average GHG factor (0.254 lb/kWh) results in greater savings for the fossil fuel cases and smaller savings when ccASHPs replace resistance electric heat. The non-baseload GHG emissions factor (0.924 lb/kWh) results in higher GHG savings for the electric heat cases, because more carbon is associated with the electric grid. Because New York law mandates the grid be carbon neutral by 2040, emissions associated with the electric grid should drop to zero.

Table 7. Normalized GHG Savings by Fuel Type – 15 Included Sites

Pre-Retrofit Fuel	No of Sites	Normalized GHG Savings (lb/yr per installed ton)	
		Overall Avg based on 0.254 lb/kWh	Non-baseload based on 0.924 lb/kWh
Oil	5	1,525	559
Natural Gas	3	1,983	462
Electricity	5	604	2,221
Propane	2	1,481	556
Avg	15	1,304	1,093

Findings & Lessons Learned

Lessons from Measured Performance Data

The energy cost savings and implied heating efficiency of the heat pump installations were determined for fifteen of the twenty sites using measured heat pump electricity use data as well as pre- and post-retrofit utility bills and fuel delivery logs. At the other five sites savings estimates were confounded by behavioral or occupancy changes between pre- and post-retrofit periods as well as other issues with secondary fuels, such as irregular wood stove use. These issues occurred even though the project team carefully screened potential sites up front in an effort to minimize these risks. The findings from this study show that pre-post savings analysis methods are still subject to uncertainties and unknowns that cannot always be foreseen – even with careful upfront screening of sites. The savings analysis from this study point to several key findings and lessons:

- The implied seasonal heating COP of the fifteen HPs ranged from 1.6 to 2.9 with an average of 2.1. The seasonal average heating efficiency averaged 63% of the published heating seasonal performance factor (HSPF) for each ccASHP unit. This provides an approximate metric to gauge what heating efficiency (and savings) might be expected in in this climate region of New York based on the manufacturer’s published HSPF values.
- Cost savings were highest when the displaced fuel was electric, propane, or fuel oil. Cost savings were either negative or very small when the displaced fuel was natural gas. The normalized heating savings per installed ton averaged \$300 when the displaced fuel was electric and averaged -\$100 when the displace fuel was natural gas. The survey results demonstrated that reducing fossil fuel use and greenhouse gas emissions was a primary motivator for many homeowners in this study. It seems reasonable to assume that large scale adoption of ccASHPs may depend on homeowners realizing at least some positive cost savings to offset higher capital costs.
- In this study, most ccASHP systems were designed and installed to displace, but not fully replace, the original heating system. On average the ccASHP systems displaced 85% of the original fuel use. In most cases the fuel reduction at each site were fairly

well aligned with the original design intentions. However, three sites that intended to fully replace the original heating system still had significant fuel use (between 30-40% of pre-retrofit fuel use). This experience (along with observations from other pilots), resulted in New York State adding design and sizing to the Clean Heat Program mandatory trainings required of participating contractors.

- Full replacement of boilers with high standby losses could increase the savings significantly for some homes.
- Customer behavior has a significant effect: at one site where the homeowner had intended to fully heat the home with heat pumps, the oil heating only dropped by 33% the first winter. After program staff coached the homeowner about thermostat settings, the fuel reduction for the second winter increased substantially to 62%. This highlights the importance of occupant education.

Lessons from QA Site Visits

Contractors received pre-project training, additional training materials for contractors and customers, and post-install QA site visits.⁷ Units were generally installed well, and when issues were identified, contractors were required to return to the site to address the issue to the degree possible.

Regarding outdoor units, the few identified issues included:

- The lack of surge protectors, which is a recommended Northeast Energy Efficiency Partnerships (NEEP) “best practice” but was not a HVHPP requirement (17 out of 20 sites had this issue);
- Units that were not installed plumb or were missing fasteners (3 out of 20 sites had this issue);
- Units not placed adequately above the expected snow line (3 out of 20); and,
- Units that were not adequately installed away from walkways or other areas such that refreezing defrost meltwater might cause a hazard (4 out of 20 sites had this issue).

Proper refrigerant charge procedures that could have a critical impact on performance were questionable, including evacuation, pressure testing and charging. Some of the field QA challenges included the fact that it is impractical to field check proper procedures at time of installation, or to field test for proper refrigerant charge post-installation. Some recommended QA actions to consider in the future include photo-documentation of actual refrigerant charging procedures for each system and developing, standardizing and implementing alternate testing and measuring protocols.

Line sets had few issues. A few homes had thermal insulation that was disturbed by the installation that was not returned to its original condition, and one had issues with the insulation not running all the way to the outdoor unit (this was corrected).

⁷ https://neep.org/sites/default/files/resources/ASHP%20Sizing%20%26%20Selecting%20-%208x11_edits.pdf
<https://neep.org/sites/default/files/GettingTheMostFromYourHeatPumpConsumerGuide.pdf>

Indoor unit installations were rarely problematic with the exception being clearance of ductless units to the ceiling. At the time of the writing of this report, the NEEP recommendation is a minimum of 6 inches when possible. While this was not physically possible at some sites, at the sites where it was possible it was clear that contractors prefer to install the units as close to the ceiling as they possibly can, typically as close as 3 inches (as allowed by manufacturer recommendations). This reduces heating efficiency by increasing return air temperature, and while it's not a critical requirement it is certainly a lesson to share moving forward as contractors continue to install ccASHPs in NY State.

Of the twenty sites, only one was entirely ducted while another included a mixture of ductless and ducted. One of these sites performed quite well with no installation issues of concern. However, there were installation issues with the other site, particularly related to the heat pump air-handlers in the existing ductwork.

Although 90% of the participating sites had ductless systems installed, it's not possible to generalize that outside this sample. The initial group of contractors who participated in the HVHPP training were a mix of contractors: some offered only ducted systems, some specialized in ductless while others offered both. Ultimately, the contractor who completed 14 out of the 20 installations only installed ductless systems in the HVHPP. Because of the dominance of installations by that one contractor, one cannot assume that generally contractors prefer to install ductless systems over ducted. However, the "plug-and-play" nature of ductless heat pumps does apparently lend itself to being a preferred technology for some installers.

The two primary issues regarding setup were both recommended "best practices" and not requirements. These pertained to the lack of wall-mounted thermostats or integrated controls, and the fact that the "continuous fan operation" setting was not disabled. To address the lack of wall-mounted thermostats/integrated controls, the EFG team ensured that for all 18 sites where this occurred, the homeowner was made aware of correct operation. The issue of disabling the continuous fan operation setting appears to be more challenging to address, as the manufacturer designed the ductless units with continuous fan operation and in order to disable that feature, a "non-standard" modification would need to be made to the indoor unit. This recommendation was not favorably received by the installing contractors, and customers were not advised of this option despite the fact that the modification was suggested by the factory representatives, is supported by the manufacturer, and does not void the warranty.

As part of the QA process, many homeowners took time to discuss their experience with the EFG team. From these conversations, it is clear that customers need greater training and orientation regarding the various controls and features (for example, the use of the "dry" mode) as well as how best to optimize ccASHP efficiency in relation to the pre-existing heating system. Alas, the results of the contractor surveys suggest that contractors believe they are adequately training homeowners in ccASHP operations. Addressing this gap between customers needing more education and contractors believing they are already providing the necessary training overview to homeowners, is critically necessary to ensure both efficient and effective use of ccASHPs, and customer satisfaction with the technology.

Finally, a significant lesson learned is the poor applicability of ccASHPs as a "displacement" strategy in a house with a steam boiler system. Steam-heat systems cannot be zoned, so heat is delivered to the entire house at once; any rooms where the heat pumps are installed are immediately heated and the heat pumps simply don't operate enough to offset a

significant amount of heat. S5 (the one home with steam heat) added two ductless units to two that were already in place (and previously ineffective), and based on the customer interview they were still unable to utilize the heat pumps effectively.

Lessons from Homeowner Perceptions and Motivations

First Energy (FE) administered a two-part survey (once at the time of installation and again, 12 months later) of participating residents using SurveyMonkey®, with some follow up phone surveys. The customer surveys revealed some key findings:

- This set of homeowners were driven to install heat pumps, in large part, by a desire to reduce fossil fuel use and greenhouse gas emissions. Energy cost savings and increased comfort was also a factor in their decision to install heat pumps.
- Customers were generally satisfied with the installation contractor and did not find the installation process to be more inconvenient than for conventional heating systems.
- Customers found maintenance and operation of the heat pumps to be relatively easy, and no more difficult to maintain than their original systems.

Participants had a range of satisfaction levels with their original heating systems and generally expected to see their desired temperatures improved by installing the heat pumps. However, desired temperatures were not always achieved in every room of the entire home, most likely due to the distribution limitations of ductless units. Two homeowners stated that their desired heating temperature had slightly worsened when compared to their previous heating system. Nevertheless, 80% of the homeowners in the final survey reported that they are “very satisfied” with their air-source heat pump systems, and all were either “somewhat satisfied” or “very satisfied”. The disparity between their overall satisfaction and their more mixed reports of comfort suggest that consumers need to be educated to better understand the benefits and limitations of ductless heat pumps that replace central heating systems –especially when converting a baseboard hydronic heating system to a ductless unit.

Generally, homeowners’ perception of energy and cost savings were in reasonable alignment with the actual measured savings. One exception was site S14, a homeowner that formerly used propane for heating, that had the highest cost savings of any home in the study. Their perception was that their electric bill increased more than they expected. Because heating with propane is more expensive than operating the heat pump, that represents a net *benefit* to the homeowner that they don’t seem to fully grasp. This highlights a key issue with heat pumps: preparing customers for the inevitable increase in wintertime electric bills that will accompany the anticipated decrease in their fuel bills. This is especially critical with delivered fuels, for which the decrease may take months to realize, while electric bills increase rapidly. A clear message for any existing heating fuel other than natural gas at the costs used in this analysis should be “the more you use the heat pump the more money you save.”

Lessons Learned on Contractor Perceptions and Motivations

The EFG team developed a survey in SurveyMonkey® to better understand contractors’ awareness of residential energy solutions such as efficiency as well as heat pumps, their approach to working with customers, and if (and how) the HVHPP might alter their business approach moving forward.

The four contractors who responded to the HVHPP Contractor Survey in its entirety, were generally confident in their business offerings and their awareness of heat pumps (sizing, installation, application, design, and customer training). Nevertheless, they still found some of the customer-facing NEEP materials as well as a few key “tricks” they learned through the program to be helpful and useful.⁸ Their approach to educating customers and explaining how to efficiently operate heat pumps was not significantly altered, but supported and slightly augmented by the HVHPP, and they plan on continuing to use the NEEP resources.

Their experience indicates that customers are interested in heat pumps for a range of reasons, but that comfort, convenience, energy and financial savings ultimately drive the customer’s decision to install. Their primary business development tool is “word of mouth”, although they all undertake other marketing efforts and initiatives such as attendance at home shows and other forms of advertising. While they are fairly confident about their heat pump knowledge and expertise, they generally feel that New Yorkers overall, as well as other residential HVAC contractors who do not currently offer ccASHPs, are not aware of the potential comfort and savings that ccASHPs can provide.

Of the three respondents to the question, “Do you recommend a comprehensive approach that pairs a heat pump installation with weatherization and/or solar to your clients?”, two said yes while one said no. The two that replied affirmatively explained that they suggest weatherization because it will improve ccASHP performance (and, by extension, customer satisfaction). The remaining respondent stated he focuses solely on heat pumps because otherwise it is “too much for a person to digest at once”.

Responding contractors mentioned two primary customer barriers to be upfront cost and lack of customer awareness. Three suggestions as to how to grow market interest included: (1) having more case studies showing energy and cost savings, (2) having more customer stories as well as customer experience with the technology that demonstrate the advantages and capabilities of ccASHPs in colder climates, (3) having these materials (and ccASHPs generally) widely promoted and shared by trusted resources such as NYSERDA and local utilities, (4) having greater rebate offers and access to low interest financing, and (5) having a savings tool, such as an annual energy savings calculator that would compare heating and cooling operating costs for ccASHPs to other common heating and cooling systems.

Lessons from Pilot Design

Prior to the HVHPP, the EFG team had designed and implemented a number of energy related pilot programs. As a result, many of the program design elements within the HVHPP worked smoothly and with few challenges. However, there were lessons learned regarding contractor and customer recruitment, and as a result of the recruitment process, the EFG team also experienced a different outcome from the initial goal of a mixture of ducted/ductless systems with and without solar.

For example, the EFG team had thought that customer recruitment would occur primarily through the contractors bringing interested customers into the HVHPP. This did not occur.

⁸ One contractor stated: “I will slightly under-size BTU capacity of multi-zone outdoor ccASHP condenser units by sizing total indoor unit BTU demand to ~130% of outdoor unit BTU capacity. This was a helpful tip. It increases the overall operating efficiency of the systems and also reduces our material costs slightly.” Another stated: “Mount head units lower from ceiling.”

Contractors are busy and the additional paperwork, monitoring and QA visits increased the amount of time required to complete a project for both the contractor and the customer, as well as increased the level of intrusion for the customer. While the EFG team did offer \$500 bonus incentives to contractors, as well as additional incentives for the homeowner, this was not enough to motivate contractors or participants. Ultimately, it fell to the EFG team to conduct significant targeted outreach via environmental volunteer groups, utilities and attendance at local events to recruit interested homeowners. Additionally, it fell to the EFG team (predominantly IBD and BHEC) to repeatedly follow up with contractors to ensure paperwork was completed and any identified QA issues were corrected prior to receipt of the \$500 bonus incentive. Fortunately, all projects were completed and customer satisfaction is generally high.

Regarding contractor recruitment, contractor excitement and interest was generally very strong at the start of the project, but waned as the program continued. Again, this is likely due to the mixture of contractors being busy, and the program requiring more of their time and effort. Fortunately, the EFG team's modified approach to address customer recruitment (explained above) also brought in new contractors. For example, upon learning about the HVHPP at various environmental events that the EFG team attended to recruit participants, homeowners who were already thinking about heat pumps and had chosen a contractor ended up asking those contractors to participate in the program.

It is clear that both a “pull” and a “push” is needed to move the market. Incentives and EFG team support did assist in ensuring projects were completed by contractors (the “pull”), but customers also needed to “push” their contractor, at times, to participate. It appears as though pilots such as the HVHPP, which require more time and a deep interest in detailing energy and cost savings, are a good fit for “early adopters,” among both contractors and homeowners.

Conclusion

The Hudson Valley Heat Pump Program highlighted the cost and energy savings possible through shifting to ccASHPs. Fuel offset overall was high (83%) and COPs reasonable (2.1). 80% of the homeowners reported that they are “very satisfied” with their air-source heat pump systems, and all were either “somewhat satisfied” or “very satisfied”. However, there are even greater opportunities to increase energy and cost savings by ensuring contractors receive sizing and installation training and customers receive training on how best to optimize heat pump usage.