Cold Climate Air Source Heat Pumps (ccASHPs) Technology

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National Renewable Energy Laboratory

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List of Acronyms

AHRI	Air Conditioning, Heating, and Refrigeration Institute
ASHP	air source heat pump
ccASHP	cold climate air source heat pump
DOE	U.S. Department of Energy
HSPF	Heating Seasonal Performance Factor
NEEP	Northeast Energy Efficiency Partnership
SIR	savings-to-investment ratio
WAP	Weatherization Assistance Program

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1 Detailed Description of Technology

Cold climate air source heat pumps (ccASHPs) are a variation of an existing air conditioning technology—heat pumps—that are designed to heat homes adequately in very cold weather (usually at or below 5°F) and, as a secondary function, cool these homes during warm weather. They represent an efficient way to heat and cool dwellings. Heat pumps move thermal energy from inside to outside for cooling and from outside to inside for heating, without the combustion of fossil fuels (Goldberg et al. 2018). If heat pumps are not designed properly, they are likely to struggle to provide the heat required during cold weather, leading to increased operating costs and occupant discomfort.

When heating, the efficiency and capacity of a heat pump diminishes as the outdoor temperature drops. If the temperature outdoors continues to drop, the heat pump will reach a point at which it is no longer able to extract enough useful heat from the outdoor air; at this point, the backup or supplemental heat[1] must take over. Because of this, when heat pumps are installed, either in new or existing dwellings, backup heat is also required (Goldberg et al. 2018). When installing a ccASHP in an existing home, the existing heating system can be left in place to serve as the backup (Subgrantee 4).

The Northeast Energy Efficiency Partnership (NEEP) has developed a set of voluntary performance requirements for ccASHPs (NEEP Performance Requirements 2019). The scope of these requirements includes air-to-air, split system heat pumps and does not include ground-source, water-source, or air-to-water heat pump systems. Importantly, the heat pump must have a variable capacity compressor (described in the next section) as well as the capability for application in both nonducted (single- or multizone) or ducted (centrally ducted, single-, or multizone) systems.

NEEP also lists the following performance requirements: nonducted systems must have a Heating Seasonal Performance Factor (HSPF)[2] of at least 10; ducted systems must have an HSPF of at least 9; the heat pump must have a coefficient of performance[3] at 5°F of at least 1.75, and the heat pump must have a Seasonal Energy Efficiency Ratio[4] of at least 15 (NEEP Performance Requirements 2019). NEEP also has a ccASHPs product list compiled from manufacturers (NEEP Product List). Table 1 shows performance ratings for different categories of ccASHPs within this product list (Kounkdakjian 2021).

[1] Backup refers to a heating system that can be used if the heat pump fails entirely while supplemental refers to a heating system that supports the heat pump when it is deficient in meeting all heating needs.
[2] HSPF is a heating efficiency rating for heat pumps.
[3] Coefficient of performance is the ratio of useful heating or cooling done relative to work required.
[4] Seasonal Energy Efficiency Ratio is the cooling output during a typical cooling-season divided by the total electric energy input during the same period.

Table 1. Performance Ratings of ccASHPs in NEEP Product List by Configuration

Source: Kounkdakjian 2021

CONFIGURATION	Average HSPF	Average COP (at 5°F)	Average EER	Average SEER
All Products	9.9	2.13	11.6	18.0
All Multi zone	11.8	2.08	11.8	19.6
Single Zone – Centrally Ducted	9.7	2.13	11.5	17.6
Single Zone – Compact Ducted	10.8	2.16	11.6	18.9
Single Zone – Non-Ducted	11.2	2.11	12.8	22.1

2 How Heat Pumps Work

Heat pumps have several important technological characteristics, including a variable capacity compressor and the possibility for minisplit installations for homes with no ducts.

Air source heat pumps (ASHPs) use a compression cycle refrigeration system to transfer heat between locations (Schoenbauer et al. 2016). ASHP systems include an outdoor unit, which includes a fan, outdoor coil, and compressor, and an indoor unit, which includes an indoor coil and a fan. In heating mode, the outdoor unit's fan draws outside air through a heat exchanger to absorb the heat by evaporating the liquid refrigerant (Government of Canada). The vaporized refrigerant then passes through the reversing valve and moves to the compressor, where it is further compressed into a gas (and thus heated up further) (Government of Canada). The gas refrigerant then passes through the reversing valve again and goes to the indoor coil, which transfers the heat from the gas refrigerant into the house (Government of Canada). This causes the refrigerant to condensate back into a liquid and allows the process to repeat. Figure 1 depicts this process. Users can switch the heat pump into cooling mode with a control on the thermostat, which slides the reversing valve and enables the heat pump to transfer indoor heat outside and provide cooling in summer months (reversing the process described above). Figure 2 depicts this cooling process.

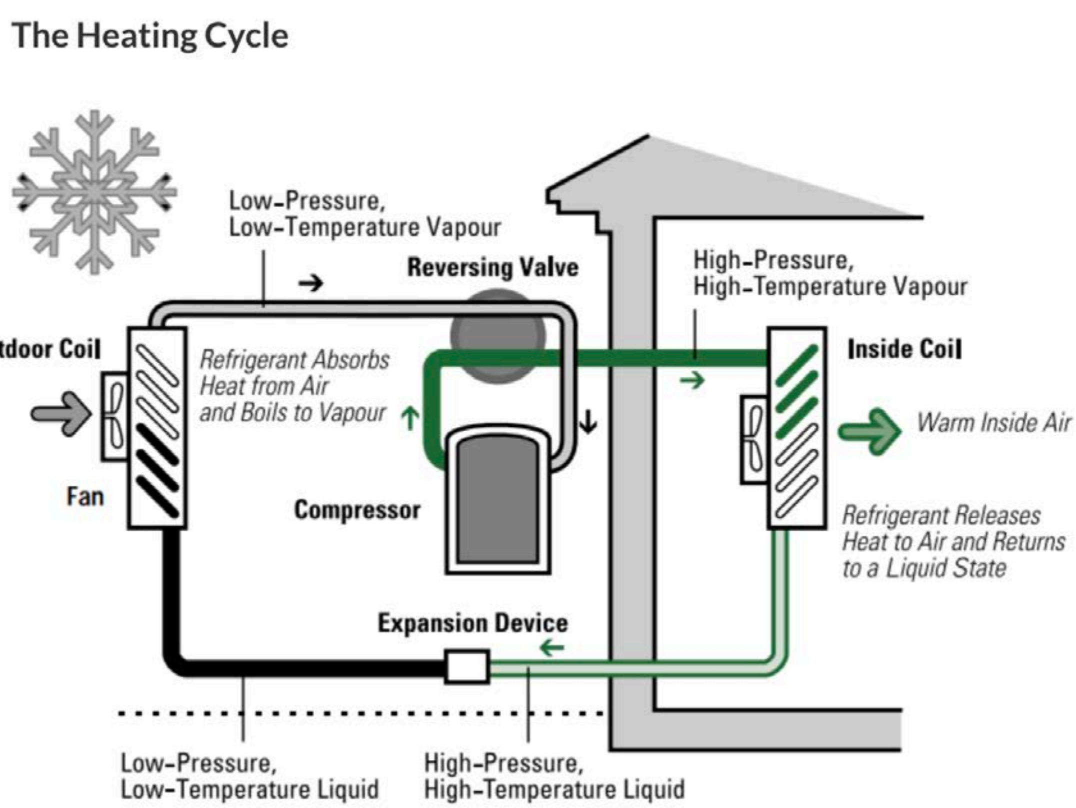

Figure 1. Overview of heat pump components in heating mode

Source: Government of Canada

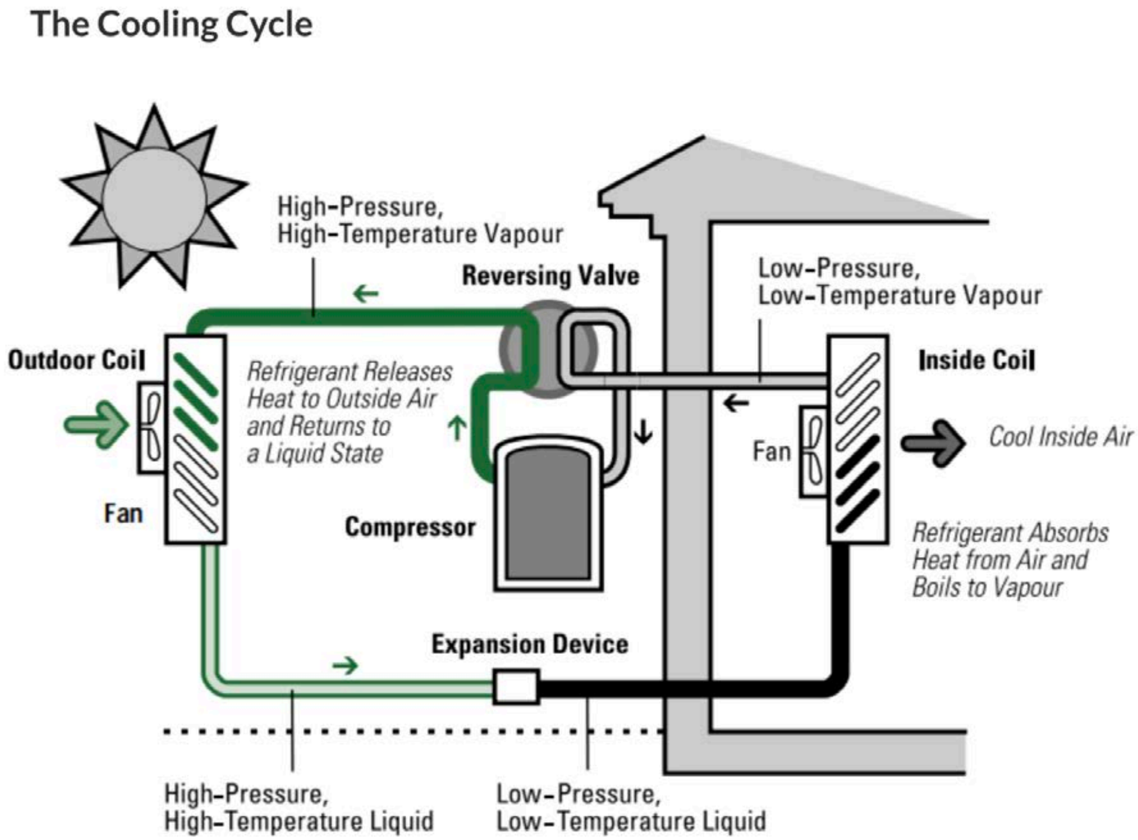

Figure 2. Overview of heat pump components in cooling mode

Source: Government of Canada

Most modern heat pumps use variable capacity compressors. Most air conditioning systems have compressors with only two settings, on or off. On the other hand, variable capacity compressors operate on a gradient, increasing efficiency and performance. They function better in colder temperatures because they more efficiently utilize the lower amounts of thermal energy present in the outdoor air (Training Center 1).

Furthermore, ccASHP installation configurations include centrally ducted and minisplit systems. Homes with ducts can install ccASHPs in a manner that uses the existing duct system. Homes without ducts (or projects choosing to bypass ductwork) can utilize a minisplit ccASHP installation configuration where one or more indoor units are strategically located to condition a particular space (Hawkins et al. 2017). Figure 3 depicts these two configurations.

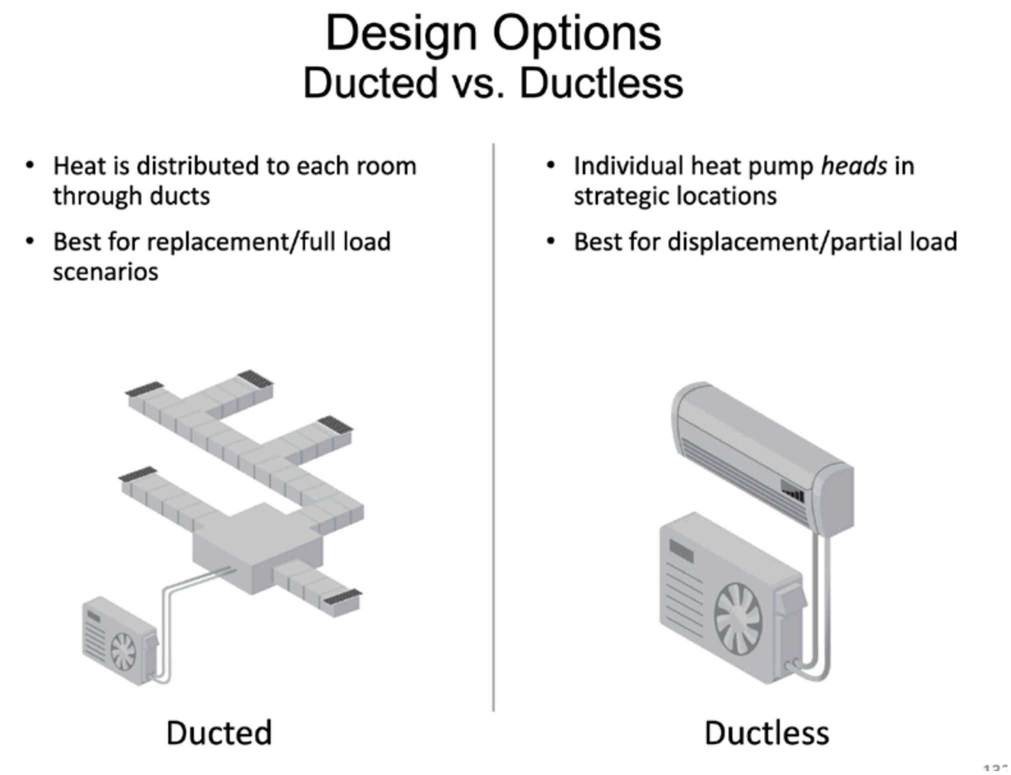

Figure 3. Overview of ducted vs. ductless applications

Source: Energy Smart Academy 2021

Furthermore, both types of systems can be expanded to allow for multizone conditioning. Multiple indoor units can be installed in a ductless application to allow for greater control of air conditioning within different parts of the home, but doing this also requires more careful sizing and zone conditioning requirements (Energy Smart Academy 2021). Generally, for minisplit configurations, one outdoor and one indoor unit are enough to heat homes between 1,000–1,200 square feet (Subgrantee 5, Subgrantee 2). Ultimately, the variety of system types and applications shows that ccASHPs have potential regardless of whether the home is ducted or requires multiple heating zones. Although these differences do matter when evaluating costs and benefits (discussed later in the document), they do not preclude the use of ccASHPs for different types of homes. Table 2 shows the breakdown of ccASHPs on NEEP’s product list by ducting configuration (Kounkdakjian 2021).

Table 2. Number of ccASHP Products in NEEP Product List by Configuration

Source: Kounkdakjian 2021

AHRI Indoor Type	Ducting Configuration on NEEP List	# Products on ccASHP Product List
Mini-Splits	Singlezone Non-ducted, Floor Placement	121
	Singlezone Non-ducted, Ceiling Placement	427
	Singlezone Non-ducted Wall Placement	1024
	Singlezone Ducted, "Compact Ducted"	413
Non-Ducted Indoor Units	Multizone All Non-ducted	412
Ducted Indoor Units	Multizone All Ducted	182
Mixed Ducted and Non-Ducted Indoor Units	Multizone Mix of Non-ducted and Ducted	157
Centrally Ducted	Singlezone Ducted, Centrally Ducted	18851

NOTE: AHRI is the Air Conditioning, Heating, and Refrigeration Institute, a North American trade association of manufacturers of air conditioning, heating, and commercial refrigeration equipment.

3 The Market for This technology

ccASHPs have seen increasing attention from the market, due to heat pumps in general increasing in popularity country-wide, as well as specific interest in the cold-climate benefits of ccASHPs. Customers (within the Weatherization Assistance Program [WAP] network) have described heat pumps as quiet and more efficient (Subgrantee 3). Furthermore, heat pumps are a key component in the push for heating electrification across the country (Subgrantee 3). At the same time, research, deployment, and development of ccASHPs has increased in recent years. The U.S. Department of Energy's (DOE's) Building Technologies Office put together a pilot project in Ohio that showed 40% energy savings (BTO 2017). NEEP has increased market transformation and coordination to increase adoption (BTO 2017).

However, from a WAP perspective, multiple barriers to increased uptake of ccASHPs still exist. First, grantees are responsible for administering fuel-switching jobs if proven cost-effective, which can make it very difficult to get the approvals needed to replace a fossil fuel system with ccASHPs (even with high savings potential). Grantees have two options for enabling fuel-switching jobs: first, they can defer decision-making to DOE, and second, they can administer fuel switching themselves, but they must submit documents to DOE demonstrating that their fuel switching rules comply with WAP program rules, and they have the necessary expertise to make decisions on fuel-switching jobs (Department of Energy 2015). Both routes could delay project work. Second, many stakeholders reported that savings-to-investment ratio (SIR) calculations for ccASHPs (and for heat pumps in general) can be complex to determine because projects often implement other measures in conjunction with installing the heat pump. Finally, ccASHPs have a high installed cost (materials and labor), which means they are usually too expensive to install with DOE funds alone (Subgrantee 2, Subgrantee 4).

Stakeholders have found many ways to bypass these barriers, including using other funding sources (such as the Low-Income Energy Assistance Program) for all or part of the installation, using WAP funds for ductwork while using utility funds for the heat pump, and implementing pilot projects that do not have SIR restrictions (Subgrantee 3, Subgrantee 2, Subgrantee 4). NEEP has published a list of utility rebate programs in the Northeast (NEEP 2021).

Despite these workarounds, WAP subgrantees might face difficulty implementing the installation of more ccASHPs across the network if these barriers persist. For example, in Massachusetts, utility rebates for heat pumps only incentivize partial switching, which is when backup or supplementary heating is unnecessarily left in place, leading many consumers to end up with more energy-intensive heating (Subgrantee 1). Although ccASHPs have great potential to make an impact, they still face significant regulatory and market barriers.

3.1 Using This Technology

The process for installing ccASHPs has two significant stages: preparation and installation.

Preparation includes inspecting the various supporting functions for the heat pump and upgrading if necessary. These preparation steps include testing and inspections of electrical wiring, gauges (note that if installing a new heat pump system, gauge inspection would be needed), and voltage, piping (Subgrantee 2). Furthermore, the areas where the outdoor and indoor units will sit must be inspected for space and appropriateness (such as ensuring snowfall does not cover the outdoor unit). Any weatherization upgrades made that impact heating or cooling loads should be done before sizing and installing the heat pump to ensure that load calculations done before installation remain accurate, especially given that leakage and improper sizing can cause losses of more than 25% of conditioned air (Energy Smart Academy 2021).

Design and installation includes calculating the heating load of the home, sizing and installing the ccASHP, and checking on its performance. Accurately calculating the heating load is key to determining the right size of the heat pump, and software based on the Manual J (Residential Load Calculation) method developed by Air Conditioning Contractors of America, can make these calculations (Grantee 1, ACCA). Installers can then use the heating load results, which usually include a BTU and/or kW requirement and airflow calculations, to size the heat pump (and ductwork as necessary), where the Goldilocks Principle can serve as a useful guide: the heat pump should not be too small, or it will not keep the house warm on coldest day and risk poor comfort for the resident. The heat pump also should not be too big, or the system will cycle on and off and be inefficient (and thus too expensive). Instead, the heat pump should be sized just right to ensure comfort, efficiency, and durability (Energy Smart Academy 2021). Refer to the Air Conditioning Contractors of America Manual S (Residential Equipment Selection) on how to select and size heating and cooling equipment to meet loads for a particular home, which are based on local climate and home construction specifics. Figure 4 shows a recommended practice for the sizing process.

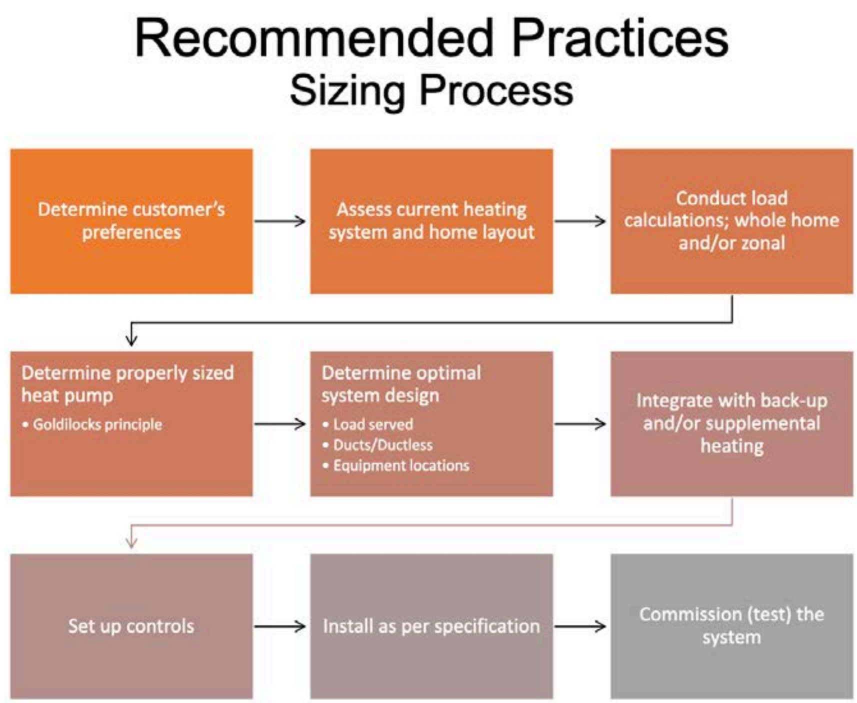

Figure 4. Recommended practices for sizing heat pumps

Source: Energy Smart Academy 2021

Procurement (described in Section 4) and installation follow. Installation takes approximately a day for ductless systems and one to three days for ducted systems, including off-site preparation work (Subgrantee 1). Installation includes laying down and insulating the line set, refrigerant charging, routing the condensate drain, and installing the indoor and outdoor units; NEEP provides a list of best practices surrounding these installation steps (NEEP Guide). Along with installing the physical ccASHP system, installers should make sure to meet other needs of the home based on the specific project, which can include snow shields or wind screens for the outdoor unit as well as thermostats or wireless handheld remotes based on customer preferences (LEAN 2021, NEEP Guide). These specifics should also account for homes opting for partial displacement (where the backup heating source still provides heat for some of the home), as the installer should ensure rooms with low coverage from the heat pump can still access backup and/or supplemental heating sources (Subgrantee 2).[5] All these steps demonstrate that installing ccASHPs is extremely home-specific, and installers should always ensure they can meet customer needs fully.

Finally, if possible, subgrantees should record performance data from the ccASHP to evaluate its performance. Heat pumps can last 15–20 years, according to industry estimates (HomeGuide 2021, Manufacturer 1).

3.2 Advantages of This Technology

The primary benefit of ccASHPs is their ability to bring the efficiency benefits of heat pumps to cold climates where ordinary heat pumps cannot adequately function, allowing more homes to access energy savings. Furthermore, given that heat pumps themselves are not a new technology, the WAP network can benefit from the existing contractor and manufacturer networks that already exist in those areas where ASHPs have been historically used. Heat pumps also bring convenience to the customers; they have a long working life, as they can function for 15–20 years and are very quiet. Finally, heat pumps enable greater electrification of space heating.

3.3 Disadvantages of This Technology

CcASHPs also have some disadvantages. Despite their potential to generate energy savings, they are expensive, which can drive down the SIR. Furthermore, ccASHP installation requires supporting measures to ensure the heat pump can function effectively, which can introduce complications. This factor can create several disadvantages: first, the supporting measures increase the cost of the job as a whole. Second, the high cost of ccASHPs can push the SIR of the of the project as a whole below one, which can complicate how projects get funded. Finally, ccASHP projects are very home-specific, which means subgrantees may have difficulties with bulk procurement, which can increase costs. Furthermore, the efforts spent correctly sizing the heat pump, combined with the relative lack of expertise of the nuances of home-specific system installation, can drive up the cost of the project.

3.4 Which Region(s) Is This Technology Best Suited For?

CcASHPs are best suited for cold regions where a high proportion of residential space heating is done with electrical resistance, propane, or oil heating. Areas with colder climates generally have higher electricity consumption in the winter, which increases the possibility that ccASHPs can be cost-justified when being installed when there is no fuel switching involved (Subgrantee 4). In fact, the NEEP, the only organization which has published specifications for ccASHPs, indicated

[5] Backup refers to heating sources that can be used when the heat pump fails, and supplemental refers to heating sources in conjunction with heat pumps.

that areas within International Energy Conservation Code Climate Zone 4 or colder are the optimal areas for using this technology (NEEP Performance Requirements 2019).

3.5 Which Dwelling Types Benefit Most?

Sizing a heat pump correctly for installation requires understanding the home's characteristics. The installer must understand the heating requirements of the home, including the total heating load and the number of heating zones that require conditioning (LEAN 2021). These calculations can be done using software which can calculate heating load (Subgrantee 3, Subgrantee 2). These evaluations can determine whether houses comply with the manufacturer's standards for installing and sizing the heat pump. For example, if the heating load is too high and/or the number of zones for conditioning too great, then ccASHPs will not effectively displace all of the capacity of the previous heating system and thus may only be appropriate for a partial replacement of the previous heating system (LEAN 2021). In fact, some heat pump incentive programs utilize the "warm room" concept, where the heat pump is installed to heat/cool a major room in the dwelling while the existing heating system heats the rest of the rooms.

A utility program in Ohio focuses on houses which have more than 4,500 kWh annual use and more than 2,000 kWh of winter use as the basic criteria for heat pump projects (Subgrantee 4). This demonstrates the importance of understanding heating loads when selecting dwellings for implementing this technology. Stakeholders note that more focus on how to size heat pumps for different homes as well as understanding how they interact with supplementary heating systems is needed.

Two home characteristics are key for evaluating the effectiveness of heat pumps: whether it has ducts or not, and what its current heating system is. Subsections 3.5.1 and 3.5.2 below discuss these items in greater detail.

3.5.1 Impact of Different Types of Heat Pump Configurations (Ducted vs. Ductless, Central vs. Minisplit)

Whether a home has ducted space conditioning or not is an important factor for determining whether to install a cold climate heat pump and how to go about doing so. Ducted systems generally enable better heat pump performance because they control heat distribution better than ductless systems. However, the presence of a ducted system in a house can complicate heating load calculations, which can make sizing heat pumps more difficult (Training Center 1). These complications may also explain why stakeholders have mentioned the lack of a systematic approach to sizing heat pumps as a barrier to increasing installations.

Furthermore, the complexity of ducted systems has led some stakeholders, such as those in Ohio and Indiana, to simply avoid ducted systems and install minisplit heat pump systems (Subgrantee 4, Subgrantee 2). In Indiana, a large majority of installations use minisplit heat pumps, especially for smaller houses, to avoid dealing with ductwork. However, despite these efforts to avoid ductwork, bypassing the duct system entirely can also be very expensive due to difficulties in distributing heating to all rooms, which means multiple indoor units would be required as opposed to a single central air handler. This might result in comfort issues due to uneven distribution throughout the home (Training Center 1).

3.5.2 Impact of Existing Heating System

When replacing widely used heating systems (electric resistance, propane/oil heating, and natural gas), ccASHPs are most appropriate for replacing electric resistance and propane/oil heating. A study done by Boston ABCD shows that the SIR for heat pump installations is greater than 1 when replacing electric resistance and propane heating, but it is less than 1 when replacing natural gas. For a WAP heat pump pilot project in Colorado, only homes with electric resistance or propane heating were eligible for the switch to heat pumps (Subgrantee 3). Furthermore, heat pumps are even more cost-effective in mobile homes that are electrically heated (Subgrantee 4). However, these analyses assume total replacement of the existing heating system. Stakeholders point out that more research needs to be done regarding the impact on total heating costs when the old heating system is kept as a backup.

More broadly, some point out, and as mentioned above, that bureaucracy surrounding fuel-switching rules have inhibited the widespread implementation of heat pumps within the network, forgoing possible health and environmental benefits (Training Center 1). In fact, some programs report delays when trying to switch homes from a natural gas furnace to a heat pump, as well as the need to use other funding sources, like the Low-Income Energy Assistance Program, due to low cost-effectiveness (Subgrantee 2). These testimonies illustrate some of the challenges of implementing ccASHPs in the WAP.

4 Savings and Costs Data From Past Case Studies and Testimonies

4.1 Costs

The cost of ccASHP systems vary widely for a number of reasons, including the complex nature of heat pump technology, the wide range of regional price differences, the design and installation expertise available in any particular area or region, and the home-specific nature of ccASHP installation (discussed earlier). The key components of cost include the cost of the equipment itself, the cost for installing the equipment, and the cost for other home upgrades needed to ensure the heat pump functions at maximum effectiveness.

The cost of the equipment can range from $4,000 up to $8,000 depending on the sizing and model as well as whether the heat pump is intended to replace the existing heating method fully or only partially (Subgrantee 3, Subgrantee 4, Subgrantee 5, Subgrantee 2). The labor cost of installing the heat pump can range from $2,000 to $4,000, which can be influenced by labor costs in the region as well as whether the subgrantee has a crew-based or contractor-based work model (Subgrantee 3, BOSCH document). Finally, the cost of other home upgrades varies widely based on the specific nature of each project, but overall, stakeholders noted the cost of an entire project (equipment, labor, additional upgrades) can range from $7,000 all the way up to $20,000 (Subgrantee 3, Grantee 1, Subgrantee 1, LEAN 2021, HomeGuide 2021). For example, a study done on homes weatherized by Brightpoint in Indiana indicated average total costs of about $15,000, with the cost of home upgrades making up about $7,000 of this total (Brightpoint Savings 2021).

4.2 Savings

Savings (as well as SIR) are difficult to calculate because heat pumps are often installed with other measures, making it difficult to determine how much savings to attribute to the heat pump. The range of savings can vary from $150–$900 annually based on the specifics of the project, but generally, savings are higher for homes when replacing a propane-based heating source (when accounting for lower costs from reduced fuel usage) compared to electric resistance systems (Subgrantee 1, Brightpoint 2019, THRHA 2021, Goldberg et al. 2018). For example, Boston ABCD reported average annual savings between $300–$400 for over 1,000 heat pumps installed over the past 5 to 6 years (Subgrantee 1). NEEP found that when replacing entire heating units in the Northeast and Mid-Atlantic regions, the annual savings from a heat pump can be more than $450 when replacing electric resistance heaters or over $900 when replacing oil systems. Further details on savings are mentioned later in this report (Section 11).

Stakeholders have varying opinions regarding the SIR of heat pumps, with some saying that extra contractor costs led to an SIR below 0.5 and others saying heat pumps generally have an SIR above 1 (Subgrantee 1, Grantee 1). One stakeholder noted that SIR is generally greater when replacing propane, oil, and electric resistance systems, but not when replacing natural gas (Subgrantee 1). Another mentioned that heat pumps have led to increased savings, but because of their high efficiency, it causes the SIRs of other measures installed concurrently to drop below 1 (Subgrantee 5). In fact, the Brightpoint analysis (include the reference here) reported an average SIR of 0.3 when including the heat pump installation costs, but it reported an SIR of 1.2 when accounting for the home upgrade costs (Brightpoint Savings 2021). These results demonstrate that SIR values can vary significantly as a result of additional home upgrades being done at the same time, varying gas and electricity prices in different regions, and whether the heat pump fully or partially replaces the existing heating system (Training Center 1).

5 Specifications Needed for Procurement

5.1 Materials

Procurement of heat pump materials is very project-specific because the subgrantee must consider the specific characteristics of the home when deciding which heat pump to use and how to procure it. For example, minisplit configurations may have more choices than central configurations (which may be influenced by the existing heating system) (Subgrantee 3). Mobile homes may have limited options for heat pump systems due to space limitations (Subgrantee 3). In the end, it is critical for all the heat pump system parts to match with each other and satisfy the requirements of the house (Subgrantee 4).

Potential in the future for bulk purchases of heat pump systems (which would decrease costs) by the WAP network does exist (Subgrantee 3). As subgrantees install more heat pumps, they will better understand the broader characteristics for different situations where heat pumps are used, increasing the possibility of bulk purchases for similar projects. In addition, multifamily projects might also allow for more bulk purchasing, leading to significant savings.

Stakeholders have noted the importance of using specifications (sometimes through requests for proposals) to procure heat pump systems. Many interviewed stakeholders had a contractor-based method of procuring services, so contractors propose lowest-cost ways to the subgrantee for installing heat pumps that meet their requirements. However, the specifications do not require a specific brand of heat pump, instead leaving these specifics to the contractors. This process is described in greater detail later in this report (distributors/installers section). The specifications themselves often have many similarities with the NEEP ccASHP performance requirements discussed earlier. Aside from basic manufacturer, brand and AHRI certification information, key components include the metrics of HSPF, Seasonal Energy Efficiency Ratio, Energy Efficiency Ratio, and certifications such as ENERGY STAR®.

Furthermore, the specifications should also include installation configurations for the heat pump (multizone/single zone, ducted/ductless), lab testing results on the heat pumps' performance at standard test temperatures (preferably below 5°F to meet ccASHP specifications), and information on supporting factors, such as whether the heat pump can be integrated with backup or supplemental heating and what kind of refrigerant to use. Finally, specifications should require disclosure of labor and parts warranty. Figure 5 shows these specifications included in a NEEP template on procurement guidelines for ccASHPs; several stakeholders have shared request for proposal documents with similar types of procurement guidelines (THRHA RFP 2021, NEEP Performance Requirements 2019). These templates and examples may help subgrantees streamline the procurement process.

Cold Climate Air-Source Heat Pump Performance Information Tables

Manufacturers must complete the following "Cold Climate Heat Pump Performance Information Tables" for each qualifying system. This information will support the cold climate specification and aid in appropriate equipment selection for installations in cold climates.

Manufacturer	
Brand	
Model Name/Product Line (if applicable)	
AHRI Certified Reference Number	
AHRI Type	
Outdoor Unit Model Number:	
Indoor Unit Model(s)[3] Number:	
Variable-Capacity (Yes/No)	
HSPF (Region IV):	
SEER:	
EER (@ 95°F):	
ENERGY STAR Certified (Yes/No)	
Single-zone or Multi-zone configuration?	
Indoor Unit type/configuration? If Single-zone, select: centrally-ducted, compact-ducted, non-ducted: wall, non-ducted: floor, non-ducted: ceiling cassette If Multi-zone, select: non-ducted, ducted or mixed indoor	
If the system utilizes any form of air ducts for distribution (compact or central for single-zone, or ducted or mixed for multi-zone configurations), please classify as DUCTED. Otherwise, please classify as NON-DUCTED	

Provide laboratory testing data or engineering data for the conditions shown below. "Minimum" and "Maximum" refer to the steady-state heating (and cooling) capacities and input power at each condition that the rated *outdoor equipment* model can deliver *continuously (without cycling)*, during normal operation using the equipment's built-in controls (e.g. not using fixed-speed test modes). Capacities in the "Rated" column should correspond to those listed on the AHRI certificate at 47°F and 17°F ODB for heating and 95°F ODB for cooling. (In some cases these may be equal to the "Maximum" capacity values, but shall still be reported.) Btu/h is total heat or cooling capacity, and kW is power input. Do not include the power required for defrost cycling or drain pan heater operation in the table.

Heating Performance

			Capacity Level		
Outdoor Dry Bulb (°F)	Indoor Dry Bulb (°F)		Minimum	Rated	Maximum
47°F	70°F	Btu/h			
		kW			
		COP			
17°F	70°F	Btu/h			
		kW			
		COP			
5°F	70°F	Btu/h			
		kW			
		COP			

Cooling Performance

			Capacity Level		
Outdoor Dry Bulb (°F)	Indoor Dry Bulb (°F)		Minimum	Rated	Maximum
95°F	80°F	Btu/h			
		kW			
		COP			
82°F	80°F	Btu/h			
		kW			
		COP			

OPTIONAL- If engineering data are available for operation at lower temperatures (below 5°F), provide this information below.

			Capacity Level		
Outdoor Dry Bulb (°F)	Indoor Dry Bulb (°F)		Minimum	Rated	Maximum
	70°F	Btu/h			
		kW			
		COP			

OPTIONAL- Manufacturers are strongly encouraged to provide additional information related to the following capabilities/functionalities:

Integration- Describe any capabilities this ASHP system or its controller(s) have related to integration other heating systems/third-party thermostats including "works with", etc.	
Connectivity- Describe any capabilities this ASHP system or its controller(s) have related to communication with the consumer or utility (i.e. Does the system/controller have an interface that allows for remote communication with the consumer or utility, wi-fi connected, etc.)	
Operational diagnostics- Describe any capabilities of the ASHP System to self-report or self-diagnose its operation or the quality of its installation	
Refrigerant- List the refrigerant(s) used	

Figure 5. NEEP model specifications report for heat pumps

Source: NEEP 2019

5.2 Training

Opportunities for heat pump installation training can come from the manufacturers as well as other private- or state-sponsored programs. Some can be taken online, and others can be attended in person, but generally, prospective participants have many options for training. Typically, training involves courses on HVAC installation and maintenance, as well as supporting measures, such as handling refrigerant (Subgrantee 3, Manufacturer training brochure).

Manufacturers have invested resources into training due to the anticipated demand for heat pumps, and some subgrantees have sent technicians to participate to build in-house installation capabilities (Subgrantee 3). Manufacturers wish to alleviate a potential implementation gap as well as to create demand for their own products.

Regarding training delivery (online or in-person), some stakeholders have mentioned the difficulty of accessing training due to limited availability (Subgrantee 5, Manufacturer training brochure). It is unclear how much of an impact online access to training has made in alleviating training gaps. Manufacturers usually administer in-person learning at their own training centers or they certify licensed contractors within their distribution network to conduct training (Manufacturer 1).

Training content usually focuses on a number of areas. The product component focuses on helping participants understand the manufacturer's product lines, while the technical component focuses on basic installation procedure, maintenance, and greater details surrounding materials and technology needed to ensure high-quality installation (Manufacturer training brochure). Figure 6 and Figure 7 provide examples of a product and technical training, respectively.

Category	Market Served	Class Name	Points	Product Line Covered
Sales	Residential	Residential Selling Skills	1	M&P
Sales	Residential	Residential Product Overview	2	M&P
Sales	Residential	**Module 1: HVAC Technology and Competitive Advantages	0.33	M&P
Sales	Residential	**Module 2: M-Series Single-zone Products	0.34	M&P
Sales	Residential	**Module 3: M-Series Multi-zone Products	0.33	M&P
Sales	Residential	**Module 4: P-Series Products	0.34	M&P
Sales	Residential	**Module 5: M- and P-Series Controls	0.33	M&P
Sales	Residential	**Module 6: M- and P-Series Accessories	0.33	M&P
Sales	Residential	Overcoming Residential Selling Obstacles	1	M&P
Sales	Both	Introduction to LinkDrive	1	M&P
Sales	Residential	Booking an Appointment	1	M&P
Sales	Residential	Ductless Business Development Vol. 1	1	M&P
Sales	Both	Why Mitsubishi Electric Trane HVAC US	1	M&P
		Points earned for Completing all =	10	

**Required for a Diamond Contractor (DC) to earn DC Standard Tier status. Highly recommended for salespeople.

Figure 6. Product training series

Source: Manufacturer

Category	Market Served	Class Name	Points	Product Line Covered
Tech	**Residential**	**MSZ Preventative Maintenance**	**1**	**M&P**
Tech	**Residential**	**MFZ Preventative Maintenance**	**1**	**M&P**
Tech	**Residential**	**MLZ Preventative Maintenance**	**1**	**M&P**
Tech	**Both**	**Diamond System Builder - Design to As-Built**	**1**	**M&P**
Tech	**Residential**	**Normal Operation**	**1**	**M&P**
Tech	**Residential**	**Failure Mode Recall**	**1**	**M&P**
Tech	**Residential**	**kumo cloud Installation and Setup**	**1**	**M&P**
Tech	**Residential**	**MXZ and Branch Box Port Assignment Setup**	**1**	**M&P**
Tech	**Residential**	**Multi-zone System Startup**	**1**	**M&P**
		Points earned for Completing all =	9	

Service Techs and Installers would also benefit from the six required Modules that are listed on the Salesperson sheet.

Those modules are required for anyone that it going to attend the Service and Installation class for M&P-series equipment

Figure 7. Technical training series

Source: Manufacturer course

Some private- and state-sponsored programs also provide training, with a mix of private contractors and WAP personnel participating (Training Center 1, Subgrantee 2).

5.3 Distributors/Installers

5.3.1 Contractor-Based Approach:

As noted above, the contractor-based approach to installing heat pumps is generally more expensive than the crew-based approach because of contractor fees. At the same time, contractors might have incentives to install specific brands and models due to franchise-like licensing benefits. However, licensing does not dictate what brands or models a contractor may install. Subgrantees sometimes issue requests for proposals for projects, including brand-neutral specifications, and contractors bid on these proposals at the lowest cost (THRHA RFP 2021). This method simplifies material procurement for the subgrantee, and it can increase the speed of procurement because contractors may have access to manufacturer supply houses, which exclusively sell equipment to licensed contractors (Subgrantee 4). However, the high cost of this approach has led some to use non-WAP funds for heat pumps while using WAP funds for related weatherization work (electric upgrades, etc.) (Subgrantee 3).

5.3.2 Crew-Based Approach:

The crew-based approach focuses on training in-house personnel to install heat pumps and procure materials directly. It has received mixed reviews from stakeholders, with some saying in-house personnel training is not worth the time, and others saying training all technicians may save money in the long run as they do not have to pay contractor fees (Subgrantee 3, Subgrantee 4). However, it is likely that only subgrantees with large staffs and many homes to weatherize can cost-effectively train people as heat pump specialists to unlock the aforementioned long-run savings. With a crew-based approach, subgrantees can separately procure heat pumps without being restricted by contractors' brand limitations, giving subgrantees greater choice on which and how many heat pumps to purchase, opening the door to bulk procurement and greater savings.

6 Lessons Learned/Challenges

Finally, lessons learned from ccASHP installation and usage across the network include the importance of geographic factors, sizing the heat pumps, and post-installation procedures.

For geographic factors, some stakeholders mentioned that heat pump specifications are listed for sea level, but performance, especially in places with notably high elevation (a heat pump's capacity decreases about 3%–4% per 1,000 feet increase in elevation) could experience significant reductions in operation efficiency. (Subgrantee 3, Fujitsu 2016). Furthermore, installers should be careful when purchasing from overseas, as they may have difficulty acquiring replacement parts. (Subgrantee 3).

Stakeholders also faced challenges in sizing heat pumps, probably the most important stage of installation. First, stakeholders mentioned that sizing and matching the equipment for each project simply requires practice, and that many challenges are likely to come up (Subgrantee 3). For example, some energy modeling software does not include a room-by-room feature for calculating heating loads, which makes it difficult to size minisplit systems (Training Center 1).

Furthermore, some stakeholders have faced challenges integrating ducted ccASHPs with existing furnaces (Schoenbauer et al. 2016). These obstacles include integrating controls for the furnace and the heat pump, as well as the lack of multistage fans on many furnaces, which reduces the effectiveness of the heat pump's variable capacity compressor. In fact, AHRI ratings for ccASHPs are based on having a matched air handler system fan to reach the rated efficiency level, indicating the air handler system fan/furnace must be part of the replacement. In addition, duct system integration remains an obstacle for ducted ccASHPs because either the heat pump does not fit the duct system, or the duct system costs too much to modify. Both issues have caused confusion among installers who are unsure whether to bypass the duct system completely or try to integrate the heat pump with the duct system (Training Center 1).

Finally, the high cost of maintenance remains an issue for ccASHPs as it costs about $300 a year, according to industry estimates, and requires coordinating with the customer ahead of the time to ensure availability, causing possible scheduling issues and potentially annoying customers (Subgrantee 1, HomeGuide 2021).

7 Past Evaluations/Case Studies

Action for Boston Community Development

Overview: The organization installed about 100 heat pumps in single-family homes in the last year and about 1,000 in multifamily homes in the past 5–6 years using utility funding. Consultants use HEAT software for sizing, but most of the calculations can be done using the Massachusetts technical reference manual.

Costs: $15,000–$18,000 per installation.

Savings: $300–$400 per unit per year (actual utility savings data).

Brightpoint Dwellings

Overview: Seventy-six dwellings (single-family and mobile homes) with an average square footage of 1,200 in Indiana. Ductless minisplit heat pumps were installed. The heat pump installations were also coupled with other weatherization measures, and not all the homes are 100% heated by the heat pump. All the homes also had electric heating systems partially or fully replaced by heat pumps. The savings and cost data account for all WAP measures installed *(and does not separate out heat pump impacts)*.

Costs: Average cost of the heat pump itself is approximately $8,000 (Total Job Cost subtracting Energy Efficiency Costs).

Savings: Average net present value of savings is $4,854, which includes both the value of natural gas savings and electricity savings.

Table 3. Costs and Net Present Value of Savings for Sample Houses That Received Both Weatherization and Heat Pumps

Dwelling Typ	Square Footage	Fuel Type	Total Job Cost ($)	EE Costs ($)	DOC	Economics: Natural Gas Present Value of Savings ($)	Electricity Present Value of Savings ($)	Total Net Present Value of Savings ($)	SIR Efficiency Exp	SIR Total Exp
Average	1,187		15,212	6,993		4,991	637	4,854	1.2	0.4
Median	1,130		10,950	4,245		3,721	301	3,466	0.8	0.3
Count	74		76	76		49	58	58	58	58
SB	1720	N	35,054	9,010	3/4/2017	10,102	301	10,402	1.2	0.3
SB	1625	N	8,949	4,836	4/26/2016					
SB	892	N	22,426	2,618	5/13/2016	2,884	301	3,185	1.2	0.1
MH	576	N	6,997	2,966	5/4/2016	3,130	301	3,431	1.2	0.5
SB	2028	N	12,614	7,734	5/24/2016					
MH	784	N	3,515	1,817	6/20/2016					
SB	1420	N	17,206	1,520	6/17/2016					
SB	1896	N	12,890	6,128	7/15/2016	14,078	301	14,378	2.3	1.1
SB	1580	N	5,725	4,391	7/26/2016	1,689	-3,549	-1,861	-0.4	-0.3
SB	1620	N	10,644	5,776	5/26/2016	3,700	301	4,000	0.7	0.4
SB	1589	P	12,999	2,253	6/17/2016					
MH	900	P	8,340	3,064	6/16/2016					
MH	980	N	9,915	3,993	8/2/2016	323	301	624	0.2	0.1
SB	950	N	14,516	9,536	8/11/2016	4,912	745	5,657	0.6	0.4
MH	792	N	6,887	2,231	9/30/2016	6,661	3,251	9,911	4.4	1.4
MH	980	N	6,022	1,018	9/29/2016	643	289	932	0.9	0.2
SB	1056	N	5,428	2,017	8/30/2016	1,661	570	2,231	1.1	0.4
SB	1184	N	5,077	1,624	9/13/2016	1,276	301	1,577	1.0	0.3
SB	1488	E	3,234	2,004	8/24/2016		5,621	5,621	2.8	1.7
MH	980	P	16,287	11,112	8/1/2016					
SB	1156	N	4,237	2,487	9/28/2016	3,042	41	3,083	1.2	0.7
SB	1008	N	8,556	2,031	9/27/2016	5,458	-1,082	4,376	2.2	0.5
SB	725	N	5,752	1,706	9/7/2016	1,029	301	1,330	0.8	0.2
SB	1386	E	2,962	1,647	9/13/2016		567	567	0.3	0.2
SB	988	N	3,524	1,380	9/22/2016					

NOTE: Top three rows of numbers represent mean, median, and number of instances for the column headers below them, respectively.

Legend

N = Natural Gas

P = Propane

E = Electric Resistance

SB = Site-built

MH = Mobile Home

EE Costs = cost of weatherization measures (does not include heat pumps)

Brightpoint Example Houses Modeled Results in National Energy Audit Tool

Overview: Individual data on costs and savings for five single-family homes. Included measures beyond installation of heat pump.

House 1: Baseboard electric

Costs: $9,000 for heat pump, $4,000 for supporting measures

Savings: $715 annual savings, ($588 heating, $126 cooling).

House 2: Baseboard electric

Costs: $9,000 for heat pump, $3,500 for supporting measures

Savings: $832 (all heat) annual savings.

House 3: Baseboard electric

Costs: $6,000 for heat pump, $3,500 for supporting measures

Savings: $630 annual savings (all heat).

House 4: Baseboard electric

Costs: $9,000 for heat pump, $5,500 for supporting measures

Savings: $715 annual savings (all heat).

House 5- Baseboard electric

Costs: $5,000 for heat pump, $5,000 for supporting measures

Savings: $322 annual savings (all heat).

NOTE: These houses are different from the Brightpoint Dwellings costs and savings data mentioned immediately above.

Indiana Community Action Association 2016

Overview: The program weatherized 1,181 dwellings with heat pumps as an included measure. The average size of a weatherized dwelling was 1,287 square feet. Most weatherized dwelling units were single-family, site-built homes (74%). Nearly all the remaining units were mobile homes (with two being multifamily).

Costs: All weatherization (mostly heat pump), $11,844 for natural gas heated homes (65% of homes), $8,114 for electricity-heated homes (24% of homes), $9,407 for other forms of fuel (10% of homes)

Savings: 28% less energy (therms) consumed in natural gas homes; 7.5% electricity saved (kWh) for electricity-heated homes.

Minnesota Center for Energy and Environment

Overview: Three homes in Minnesota that relied on propane heating. This study focused specifically on ccASHPs and set a baseline temperature of 10°F for when the heat pump would shut off and the home would run on the backup propane heating. The heat pumps were also sized slightly larger than design load calculations to ensure they would meet heating needs (at the cost of being oversized for cooling purposes).

Costs: Not available

Savings: 39%–65% reduction in energy use, 14%–29% decrease in heating costs, reduced reliance on propane fuel for heating by 52%–89%.

Minnesota Department of Commerce Center for Energy and Environment

Overview: Six homes in Minnesota outfitted with ccASHPs in 2017. Four were previously propane-heated, and two were electric resistance heating.

Costs: See Table 4.

Table 4. Costs of Heat Pump Installations

Site	Location	size	furn	Total
S_1_ducted	Farmington	4 ton	96%	$11,149
S_2_ducted	Hastings	4 ton	98%	$15,864[1]
S_3_ducted	Kenyon	3 ton	80%	$15,970
S_4_ducted	Pelican Rapids	3 ton	96%	$13,520[2]
S_6_ductless	Lutsen		NA	$4,500[3]
S_8_ductless	Superior, WI	1.5 ton	NA	NA[3]

1. A about one third of the total cost (or $5,981) was for the condensing LP furnace
2. This contractor charge $1,763 for the electrical instrumentation. This was added cost for the research aspect of the project and does not count at added time and cost for the propane meter.
3. This is the installation costs only. The equipment was donated by the manufacturer.
4. This system was installed prior to CEE's involvement in with the site. It fit within the site selection criteria and the project team was able to install full instrumentation on the system.

Savings: Table 5 shows the savings from installing heat pumps at six homes.

Table 5. Savings From Heat Pump Installations

Site	Heating Design Load, Btu/hour	Site Energy Reduction	Cost Reduction	Propane Reduction	Savings, $/year
S_1_ducted	34,341	37%	28%	56%	$469
S_2_ducted	28,339	47%	34%	73%	$524
S_3_ducted	24,734	49%	40%	67%	$764
S_4_ducted	24,306	50%	31%	60%	$377
S_6_ductless	11,950*	52%	52%	NA	$610
S_8_ductless	8,400*	54%	54%	NA	$349

* The design heating load of the ductless systems should be used as a comparison to the ducted systems and was not the actually delivered capacity of these systems at design temperature.

8 Implementation Steps (Design, Installation, Post-Installation)

- Preparation:

  A. Test and inspect electrical wiring, refrigerant piping as well as ductwork if necessary.

  B. Inspect space where heat pump system will be placed and ensure space is adequate and outdoor unit is free of interference from weather.

  C. Perform necessary upgrades on inspected areas.

- Installation/Procurement:

  A. Calculate the heating load of the home using acceptable sizing software based on Air Conditioning Contractors of America's *Manual J: Residential Load Calculation:*

     i. CRITICAL: This calculation should reflect the post-weatherization state of the home. In other words, account for weatherization load reductions before sizing.

  B. Size heat pump according to load calculations and home specifications (Goldilocks Principle):

     i. Ensure the heat pump is not too small, or it will not keep the house warm on the coldest day and risk poor comfort for the resident.

     ii. Ensure the heat pump is not too big, or the system will cycle on and off and be inefficient (and thus too expensive).

     iii. Instead, ensure heat pump is sized just right to ensure comfort, efficiency, and durability.

     iv. Ensure all the home's specific needs are met (e.g., which rooms get adequately heated).

  C. Procure heat pump:

     i. Contractor-based:

        1. Issue request for proposals or notice about project with specifications for installation.
        2. Select contractor based on bids (he/she will choose and procure the heat pump).

     ii. Crew-based:

        1. Ensure in-house crew is trained and qualified to install heat pump (as well as possible supporting upgrades).
        2. Subgrantee can directly procure heat pumps from manufacturer or distributor.

  D. Install heat pump:

     i. Takes about a day for ductless and up to 3 days for ducted systems.

ii. Physical installation steps:

    1. Laying down and insulating line sets
    2. Refrigerant line sets and charging
    3. Routing condensate drain correctly
    4. Installation of indoor and outdoor units
    5. ***NOTE:*** *NEEP has provided a document with installation guide and best practices here.*

iii. Account for home-specific factors:

    1. Install snow shields or wind screens for outdoor units, if needed.
    2. Install thermostats and/or wireless remotes for indoor units based on customer and manufacturer preferences.
    3. Ensure rooms which require heat from pre-weatherization heating system (in partial replacement systems) can still access heat.

- Post-installation:

    A. Ensure heat pump system is properly inspected and commissioned by a trained professional:

    i. Balancing ducts where needed

    ii. Selecting appropriate filtration

    iii. Verifying air flow

    iv. Adjusting refrigerant levels based on this correct air flow.

    B. Educate customer so they understand aspects of the heat pump (for example variable capacity compressor is working although it is quiet).

    C. Record data from heat pump to monitor its performance over time.

    D. Advise client/customer to perform maintenance as needed.

9 Conclusion

Overall, ccASHPs represent an opportunity to improve the performance of more conventional heat pumps, which are already very efficient, and expand their range to colder climates. However, administrative, financial, and project-specific challenges remain as obstacles to implementing this technology more widely within the WAP network. Administrative challenges include potential bureaucracy surrounding fuel switching. Financial challenges include the high cost of heat pumps and contractor fees. Finally, project-specific challenges include the relative lack of expertise surrounding the details of heat pump installation, including the installation configuration (minisplit or central), whether the house has ducts, backup and supplementary heating system issues, and other factors. Subgrantees can overcome some of these challenges by utilizing non-WAP funds, training in-house installers, and purchasing ccASHPs in bulk, which in the long run could lead to wide usage of ccASHPs in the WAP network.

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