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Cold Climate Air Source Heat Pump

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Center for Energy and Environment

Prepared by:
Ben Schoenbauer, Nicole Kessler, Alex Haynor, and David Bohac
Center for Energy and Environment
212 3rd Ave N, Suite 560
Minneapolis, MN, 55401

Marty Kushler
ACEEE
529 14th Street N.W., Suite 600
Washington, D.C. 20045-1000

Contract Number: 86417

Prepared for Minnesota Department of Commerce, Division of Energy Resources:
Jessica Looman, Commissioner, Department of Commerce
Bill Grant, Deputy Commissioner, Department of Commerce, Division of Energy Resources

Mark Garofano, Project Manager
651-539-1864
mark.garofano@state.mn.us

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DISCLAIMER

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Definition of Terms and Acronyms

AFUE	annual fuel utilization efficiency
ASHP	air source heat pump
ccASHP	cold-climate air source heat pump
COP	coefficient of performance
HSPF	heating seasonal performance factor
SEER	seasonal energy efficiency ratio
COP	coefficient of performance

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Executive Summary

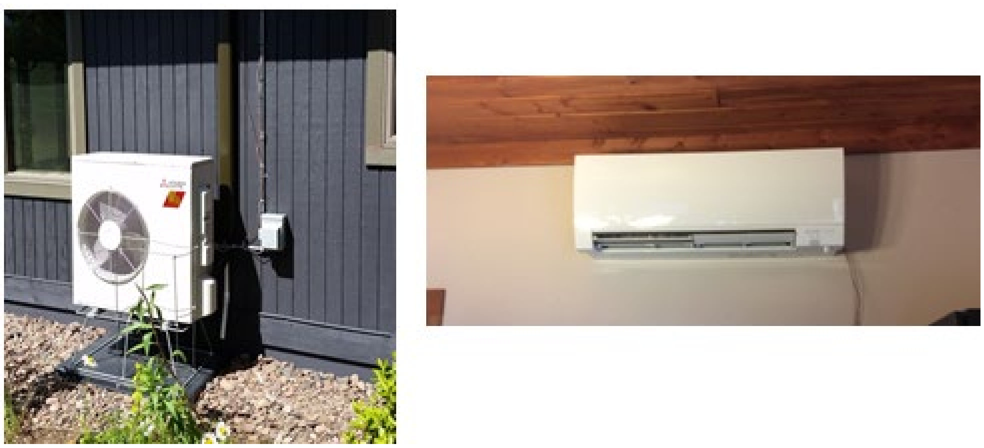
High-efficiency technologies like air source heat pumps (ASHPs) have significant potential to improve space heating efficiency and reduce energy costs for houses in cold climates. ASHP technology has been available for many years, but until recently, technological limitations caused concern about efficiency and reliability during the coldest months of the year in climate zones 6 and 7. Recent generations of ASHP have improved with the addition of an inverter-driven compressor and updates to the refrigerant, making the systems better suited for cold-climate heating. The inverter-driven compressor allows the compressor speed to modulate and increase capacity during periods of colder outdoor air temperatures. The increase in efficiency and operating capacities of cold-climate air source heat pumps (ccASHP) provide an opportunity for energy efficient space heating for homes without access to natural gas heating, a market typically underserved.

Cold-climate air source heat pumps are available as both central-ducted systems (Figure 1) and ductless systems (Figure 6). Both system types are available with single and multi-zone indoor units. While this project focused on single-zone systems, multi-zone systems are expected to perform similarly.

Central-ducted systems are designed and installed to meet the full load of the home by distributing heat through forced air ductwork. Ductless systems deliver heat to a specific area of a home through a single interior head with no ductwork. In cold-climate applications, air source heat pumps typically require a backup system to provide heat when cold outdoor air temperatures limit the heat pump capacity of ccASHPs, or prevent the system from operating. The integration between the heat pump and the backup systems are important design and installation considerations that can drastically impact the performance of a system. Ducted systems typically use a propane furnace as a backup. These backups take over the load of the system at an outdoor air temperature when heat pump capacity is no longer sufficient. This temperature, about 10^{o}F, is based on the house load and system size. Homes with ductless systems typically do not have central ductwork. These homes often rely on electric resistance baseboards for backup heating.

Figure 1. Whole home-ducted cold-climate air source heat pump

Figure 2. Ductless cold-climate air source heat pump



The Center for Energy and Environment conducts field research on emerging technologies with the potential to reduce energy use in Minnesota. Air source heat pumps have been of particular interest due to their potential to significantly improve energy efficiency. A field study was necessary to evaluate this new technology and understand how the system would perform in actual installations. In 2015, CEE started its field assessment with a CARD grant and additional support from Great River Energy and the Electric Power Research Institute (EPRI).

CEE developed a field test methodology to characterize ccASHP and understand their potential in Conservation Improvement Programs (CIP). The methodology focused on several key phases. First, Minnesota characterization data was used to develop site selection criterion to best represent the Minnesota market for ASHPs. Once the sites were identified, equipment was selected from a range of manufacturer and installation types to look at the full range of available technology. Detailed monitoring equipment was then installed with the ASHP system to characterize the systems performance in the real world. Finally, data was collected and analyzed to characterize equipment performance and compared to the performance of baseline systems. The analysis included energy consumption, operating costs, impact of the cold-climate on system performance, occupant comfort, and a characterization of system efficiency over the range of Minnesota temperatures.

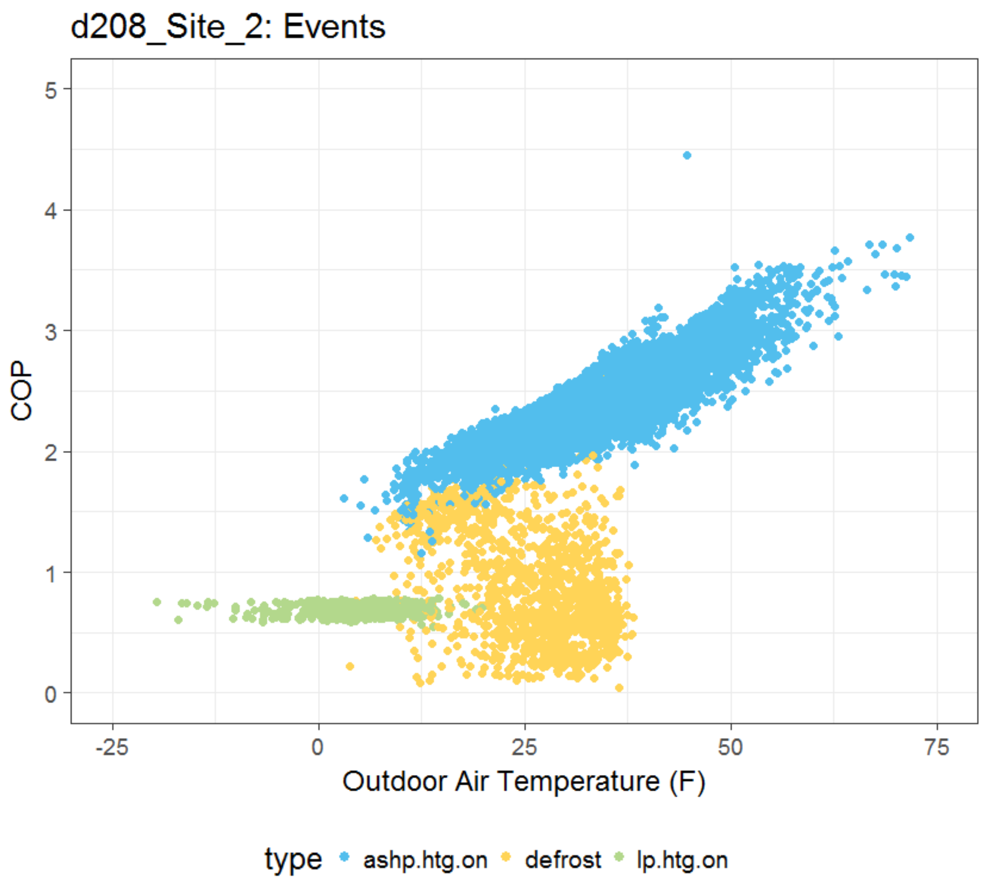
Cold-climate air source heat pumps have three types of heating operation. Figure 3 shows the operation of the ducted ccASHP in one of the monitored sites. The plot shows the coefficient of performance (COP) or the ratio of energy delivered to the home to energy consumed in electricity or propane. The three modes of operation are heat pump heating (ashp.htg.on), backup heating (lp.htg.on), and defrost mode.

Heating events where only the heat pump was used typically had the highest COPs, around 1.3 at the lower temperature change point (10^{o}F) and increasing to about 3.5 in the shoulder heating seasons (around 50^{o}F to 60^{o}F). While the outdoor air temperature has the largest impact on the COP, as the figure shows, heating cycles at the same OAT did have a range of COPs. Secondary factors on cycle COP include the rates of operation of components in both the indoor and outdoor units.

The second type of heating operation was the backup furnace mode. These events occurred at outdoor temperatures below the point where the ASHP was expected to meet the full load of the home (10 ^{o}F for how these systems were sized).

The final mode of operation was defrost. When the ccASHP is operational and outdoor conditions are below freezing, there is a risk that frost can form on the outdoor coil. To prevent this, ccASHP systems run in defrost mode by reversing the system and transferring a small amount of indoor heat back to the outside. There is a lot of variation in the defrost performance, because defrost can turn on mid-heating cycle. There are also times in an event when only the defrost is running, and almost no heat is provided to the home. This results in a COP near 0, because almost all of the heat goes to the outdoor unit to keep it from frosting. Some events have higher COPs because the heat pump has been on for a long time, and is only active for a small fraction of the event run time.

Figure 3. Heating performance of the ducted ccASHP at Site 01



The high-resolution data was compiled to determine the annual system performance. The findings from this research show opportunities for residents and utilities to reduce total site energy by 35% to 50%. These savings may be attributed to climate, ASHP type, and the system the heat pump replaced, but in all cases, ccASHPs saved homeowners and renters significant amounts of energy and money. Figure 4 shows reductions in site energy consumption from switching to a ccASHP. Detailed data collection at each site allowed system performance curves to be developed. The performance data allowed for estimates of ccASHP savings across a range of baseline heating systems and installation locations. Table 1 summarizes those results.

Figure 4. Propane and electricity use for the ccASHP and baseline heating systems at each site

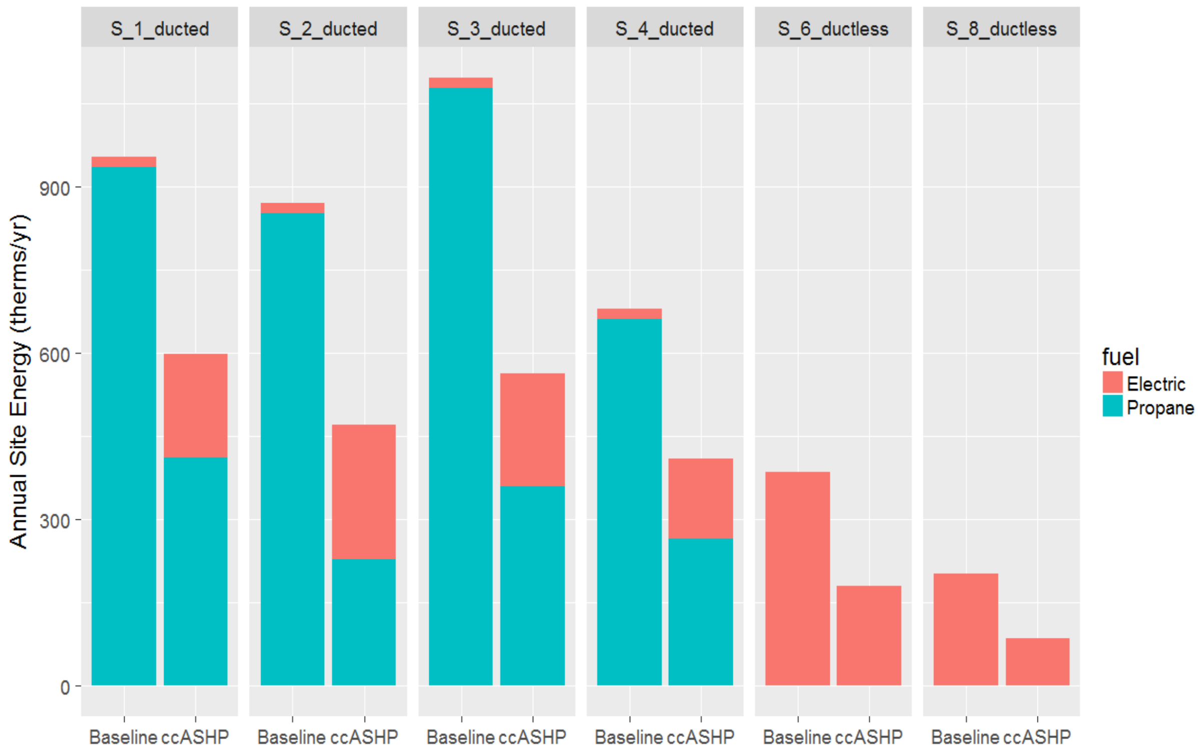


Table 1. Summary of savings for MN homes

Air Source Heat Pump	Baseline	Location	Site Energy Reduction	Cost Reduction	Propane Reduction
Ducted	Condensing LP Furnace	Metro	**41%**	30%	63%
Ducted	82% LP Furnace	Metro	**49%**	40%	67%
Ductless	Elect. Resistance	Metro	**56%**	56%	N/A
Ducted	Condensing LP Furnace	Northern MN	**36%**	26%	55%
Ducted	82% LP Furnace	Northern MN	**44%**	36%	61%
Ductless	Elect. Resistance	Northern MN	**53%**	53%	N/A

Overall, CEE research found that ccASHP performed to their rated specifications for both system capacity and efficiency (coefficient of performance or heating seasonal performance factor). With proper sizing, installation, and integration with backup heating systems, ccASHPs are an attractive heating system replacement for homes with propane or electric heating.

Many electric utilities and co-ops in Minnesota have existing ASHP rebate programs that can be modified to include the benefits of heating with ccASHPs. The project recommends that these programs consider installation requirements to ensure the desired heating performance is met. One method would be to provide a tiered rebate structure. For example, a low rebate could be provided for ASHP systems installed only for cooling, a middle level rebate for systems designed for cooling and shoulder season heating, and the highest level rebate for systems designed for cooling and heating through the winter.

Background

Introduction

This report describes the Center for Energy and Environment's (CEE) cold climate air source heat pump (ccASHP) field assessment that was supported by a grant from the Minnesota Department of Commerce, Division of Energy Resources, through the Conservation Applied Research and Development (CARD) program. Great River Energy and the Electric Power Research Institute provided additional support. The findings presented here are from six sites monitored during the 2015 to 2016 and 2016 to 2017 heating seasons. ASHP systems are widely used for space heating in climates with mild heating seasons, and with recent upgrades these systems can also meet the majority of a home's heat load in colder climates. The greatest potential for ASHP adoption is in cold-climate regions where natural gas is not available for space heating because ASHPs can offset the use of more expensive delivered fuels. For homes with electric resistance heat, ASHPs can result in a significant reduction in electrical use.

ASHP technology has improved with the addition of an inverter-driven compressor and updates to the refrigerant, making the systems better suited for cold-climate heating. The inverter-driven compressor allows the compressor speed to modulate and increase capacity during periods of colder outdoor air temperatures. Manufacturers claim that these new, cold-climate systems are able to transfer heat into homes at outdoor air temperatures at and below 0°F. The Northeast Energy Efficiency Partnerships (NEEP) has created a set of specifications to identify ccASHPs, which include variable capacity compressor, coefficient of performance (COP) at 5°F ≥ 1.75 at maximum capacity, and a heat system performance factor (HSPF) ≥ 9[1] (Northeast Energy Efficiency Partnerships 2017).

Cold-climate air source heat pumps are available as both central ducted systems (Figure 5) and ductless systems (Figure 6). Both system types are available with single- and multi-zone indoor units. While focus of this project was single-zone systems, multi-zone systems are expected to have similar performance. Central-ducted systems are designed and installed to meet the full load of the home by distributing heat through forced air ductwork. Ductless systems deliver heat to a specific area of a home through a single interior head with no ductwork. In cold-climate applications, air source heat pumps typically require a backup system to provide heat when the cold outdoor air temperatures limit the heat pump capacity of ccASHPs, or prevent the system from operating. The integration between the heat pump and the backup systems are important design and installation considerations that can drastically impact the performance of a system.

[1] Some system types require an HSPF ≥ 10.

Figure 5 Central ducted air soure heat pump system

Figure 6 Ductless mini-split heat pump system

A ccASHP has three basic heating modes of operation. The first mode is heat pump operation. In this mode the heat pump transfers heat from the outdoors into the home, heating the house in the most efficient manner. The second mode is backup heating. For propane based central systems, the backup heating mode is the operation of a propane furnace. These systems are often called flex fuel heat pumps. For ductless systems the most common backup option is electric resistance baseboard heat. The final mode is the defrost mode. This mode is engaged when outdoor conditions are cold enough that the condensate on the outdoor coil may freeze and ice up the coil. The furnace and the heat pump fire up simultaneously to prevent frosting, with the refrigerant running in the reverse mode. This moves heat from the furnace into the refrigerant and through the outdoor coil, warming the outdoor unit and preventing frost. For ductless systems or other systems with only an electric backup option, a ceramic heater in the outdoor unit warms the coils to prevent frost. This mode of operation is the least efficient because the backup heating is less efficient than the heat pump, and it uses output from the backup heat to warm the exterior coils instead of the home. It is important to characterize the amount of time operating in each of these modes to understand the actual installed performance of these systems.

Figure 7 Heating capacity and coefficient of performance for Trane's ducted ccASHP

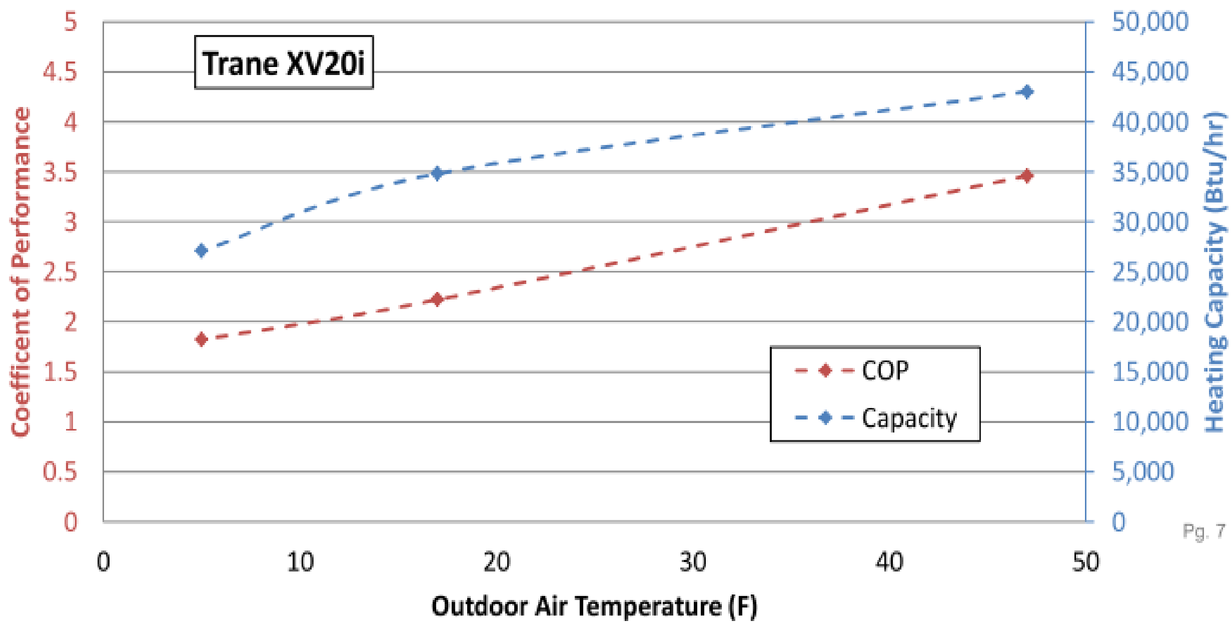


Figure 5 shows the heating capacity and COP values provided by Trane for the XV20i model of ccASHP which has a reported HSPF = 10 (Northeast Energy Efficiency Partnerships 2017). This system can deliver 63% of the design condition capacity at 5°F. A traditional ASHP without a variable capacity compressor cannot reach this COP and heating capacity at similar outdoor air temperatures.

Cold-climate air source heat pumps have the potential to meet a large fraction of home space heating loads. However, in a climate as cold as Minnesota's, especially in the northern regions of the state, there are significant fractions of the heating load that cannot be met by the heat pump alone.

Justification

Cold-climate air source heat pump technology has advanced significantly in the five years since the last CARD study of the technology. Therefore, a precise and detailed field assessment of new advancements in this technology was necessary. The characterization of the installed performance and energy savings in Minnesota as well as an economic analysis of the technology were also necessary to achieve the full, state-wide, energy savings potential of this equipment. In addition, funding to study these aspects of ccASHPs is needed to help Minnesota's electric municipals, and cooperative utilities take full advantage of a technology that has the potential to provide significant energy savings to their customer base.

Cold-climate air source heat pumps can improve the space heating of many homes, with the potential to increase the efficiency from 80% to 100% with a furnace or electric resistance heater to 130% or greater. This potential improvement represents a large opportunity for utility conservation programs. As with any new technology, there are several real world problems that need to be understood to truly assess this technology, and these issues are discussed in detail throughout this report to shed light on these technical issues with ccASHPs and their impact on actual energy use and savings in Minnesota homes.

The advancements in commercially available ASHP technology in the past five years allow a new-generation ASHPs to provide a much larger fraction of the heating load than previous generations. A field study was needed to verify the amount of the heating load that ASHPs actually meet. While manufacturer specifications and system sizing should allow for reasonable estimation and protection, there were issues such as freeze protection and the actual functionality of the ASHP lock-out temperature that need to be verified in the field to determine actual performance, as this type of characterization was difficult to predict without real world experiences. The heating performance of this technology has been studied and shown promising in more moderate heating climates such as the pacific northwest (Larson et al. 2013 and Davis and Robison 2008) and the northeast (Williamson and Aldrich 2015). This work shows the potential of ccASHPs to heat efficiently and meet large fractions of the space heating needs of homes, but detailed testing in Minnesota's colder climate in necessary to validate that performance under those conditions.

In addition to technical issues, there are also broader policy and utility program issues that impact adoption of ccASHPs. The significant improvement in system efficiency that comes with ASHPs make these systems ideal candidates to replace less efficient baseboard heating. These systems also have the potential to replace heating systems with other fuel types and, while this project looked at replacing systems using delivered fuels, natural gas supplementation or replacement is also possible. Fuel switching and beneficial electrification are becoming an increased area of interest to policy makers and utility managers, especially with changing energy sources of the electrical grid, commonly referred to as the "greening" of the grid. Because ASHPs could contribute to this, it is important to understand the performance of ASHPs in the field and how they integrate with the gird and the backup systems of other fuel types as it comes time to make important decision around electrification. This project provides the technical knowledge based on the installed performance of these systems to help characterize the expected performance of ccASHPs under a broad range of conditions requires to make those decisions in the future.

Relevance to CIP Goals

In Minnesota, 16% of homes are heated with either propane or heating oil (U.S. Census Bureau 2010). Price increases and shortages in delivered fuels create a market demand to reduce reliance on delivered fuel for space heating. During the 2013 to 2014 heating season, propane prices spiked from $1.67 to $4.61 per gallon in Minnesota (EIA 2016) due to a shortage that was attributed to cold weather, a large damp corn crop that required more propane than in other years for drying, and fuel transportation constraints (Levenson-Faulk 2015). When prices increase and shortages occur, the only alternative to delivered fuels for many rural residents is the use of portable electric heaters. In extreme cases, a large increase in the number of homes using electric resistance space heaters can cause increases in electric use and peak demand. The high efficiency of ccASHPs can help reduce reliance on delivered fuels for space heating in cold weather states such as Minnesota. During periods of very cold temperatures when some ccASHPS do not have adequate capacity to meet heating load, a furnace or electric resistant heat can be used as backup.

Minnesota's Conservation Improvement Program (CIP) benefits Minnesotans by identifying and incentivizing effective measures that decrease emissions and reduce energy costs. Several utilities across the state offer rebates through CIP for ASHPs based entirely on their seasonal energy efficiency ratio (SEER) rating. However, the current rebates do not reflect the full benefit of the heating capabilities of the new ccASHPs. Much of the savings from ccASHPs come from replacing other space heating systems that are less efficient but go unrecognized under state policy because they also use other fuels (i.e. not electricity) and current policy excludes savings associated with fuel switching. Under current Minnesota regulations, with the exception of certain low-income customers, there is no way to credit savings in deliverable fuels towards utility CIP goals. Furthermore, historically CIP programs have not encouraged customers to switch fuel sources in order to achieve increased efficiency. While CIP provides an excellent policy structure for achieving electric and natural gas savings, Minnesota has no comparable structure or funding in place for achieving heating oil and propane savings.

Methodology

Several key research questions need to be answered before the potential of ASHP can be achieved. The methodology of this field study was designed specifically to address these research questions and provide answers and guidance for facilitating the inclusion of ASHPs in Minnesota's CIP programs.

The methodology focused on several key phases. First, generic Minnesota characterization data was used to develop site selection criterion to best represent the Minnesota market for ASHPs. Once the sites were identified, equipment was selected from a range of manufacturer and installation types to look at the full range of available technology. Detailed monitoring equipment was then installed with the ASHP system to characterize the systems performance in the real world. Finally, data was collected and analyzed to characterize the equipment performance and address each research question.

Research Questions

The unresolved issues for ccASHPs fell into two categories. The first was cold weather performance and the second was the policy and programmatic aspects of ASHPs. Recent changes to the refrigerant system of ccASHPs allow for operation down to 0°F and even operation of some systems down to -13 °F. This new generation of equipment improves the capacity and effectiveness of ASHPs to operate under a greater portion of heating conditions in Minnesota, considerably reducing electricity use and further limiting the need for backup heating use. Previous field studies in locations with heating seasons that are comparable to Minnesota were limited to short-term, basic measurements on older equipment. Increasing the application of ASHPs in utility CIP offerings required more comprehensive field testing to assess the performance and measured energy usage compared to the baseline system in Minnesota. For that reason this study was needed to access the reliability of ASHPs with different backup heating system types as well as installation costs, annual fuel savings, and operations/maintenance. This data would be able to support utility incentive programs and encourage increased market growth.

In terms of the unresolved issues related to policy and programs, ASHPs have the potential to be a good option to offset delivered fuels that are used for space heating. Reduced reliance on delivered fuels has several large benefits that are especially important when there is a shortage of delivered fuels. For homeowners, the benefit is that ASHPs can significantly reduce their use of delivered fuels in the time of highest demands, saving a considerable amount of money. For utilities, the benefit is that ASHPs can reduce the use of electric resistance space heaters at times when delivered fuel costs are high or fuel supply is low. Current incentive programs focus on ASHPs as a replacement to electric space heating, and many of the additional benefits of ASHPs are difficult to evaluate with traditional policies, incentive, and CIP structure. To begin this, the primary analysis in this study focused on replacing electric resistance heat and reducing delivered fuel consumption.

Site Selection

Site selection was based on two factors. The first factor was whether a home was a good fit for a cold climate air source heat pump. The second factor focused on selecting sites that were as representative of the potential market as possible. Based on these two factors, six sites were chosen for field monitoring.

While cold-climate air source heat pumps have a wider range of applications, not all Minnesota homes were a good fit for this technology and this project. Homes were excluded either because of issues with the installation or operation of a heat pump system of for a project specific reason, such as inability to instrument the home, additional heating sources what could not be measured, or unique housing characteristics that made the site unrepresentative. Table 2 summarizes the selection criteria as well as the homes that were ultimately selected.

Table 2. Site Selection Criteria

Requirement	Parameter	Ducted System Criteria	Ductless System Criteria	Installed
ccASHP requirement	Heating Distribution	Forced Air	Electric Resistance or Hydronic	Ducted: 4 Forced air Ductless: 2 ER
ccASHP requirement	Heating Load	4ton or less	No Criteria	Ducted: 536, 606, 652, and 799 Therms/yr Ductless: NA
ccASHP requirement	Floor Plan	No Criteria	Open enough for ductless install	Ducted: NA Ductless: Yes and Yes
Project Requirement	Heating Fuel	Propane	Electric	Ducted: 4 Propane Ductless: 2 Electric
Project Requirement	Cooling	Have of need cooling	Have of need cooling	Ducted: 4 had AC Ductless: 1 had AC, 1 wanted AC
Project Requirement	Additional sources of heating (ie fireplaces, space heaters,etc)	Minimal	Minimal	Ducted: 4 None Ductless: 1 None, 1 minimal
market representation	Electric utilities	Range of munis/co-ops/utlities represented		Dakota Electric (x2), Goodhue County, Lake Regional Elec, Arrowhead, East Central
market representation		Range of heating loads		Yes
market representation	Location	Northern and Central/Southern Homes		Metro (x2), South, Northeast (x2)

Equipment

ASHP systems were installed in six Minnesota homes. The ASHPs selected were designed for cold climate operation with a traditional heating system as backup (either a propane furnace or electric resistance heat). Each system was installed so that the ccASHP could be deactivated and bypassed allowing the system to be run as either (1) a ccASHP with the existing heating system as backup or (2) an existing traditional system (the baseline system, without the ASHP). These two modes of operation were alternated through a full heating season to allow for a direct comparison of the two systems over the full range of outdoor conditions

A total of six ccASHP were installed. Four of the systems were centrally ducted whole house units (Figure 5) and two were ductless systems (Figure 6). All of the systems used variable speed compressors, often described as inverter driven technology, allowing the system to change operation speeds and modulation rates depending on temperatures and heating loads. This allows for increased capacities and colder temperature operation.

For this study each of the four ducted systems were designed with a propane furnace as back-up for both the alternate mode operation as well as to meet the load of the home at the coldest outside temperatures. The indoor coil of these systems was installed in the furnace duct-work much like a traditional air conditioning system. The ducted systems relied on the furnace air handler fan to move air over the heat pump indoor coil to transfer heat to the ductwork and then the home.

The two ductless systems were designed and installed to meet only a fraction of the homes' total load; each home had electric resistance baseboard heat in addition to the ductless system. The ductless units were sized to meet the load of the room or series of rooms with open air flow between them and the ductless unit's indoor head. As would be the case for most installs, both of these homes had bedrooms that were typically closed off to the location with the heat pump head and were primarily heated by the supplemental baseboard.

The equipment that was selected for installation is described inTable 3. These systems were selected because the manufacturers are well established with large shares of the residential HVAC market and the most local contractors familiar with the systems. All systems meet the inverter driven requirements of ccASHPs and have heating ratings (HSPFs) in the highest levels available (at least 8.5 HSPF for all systems).

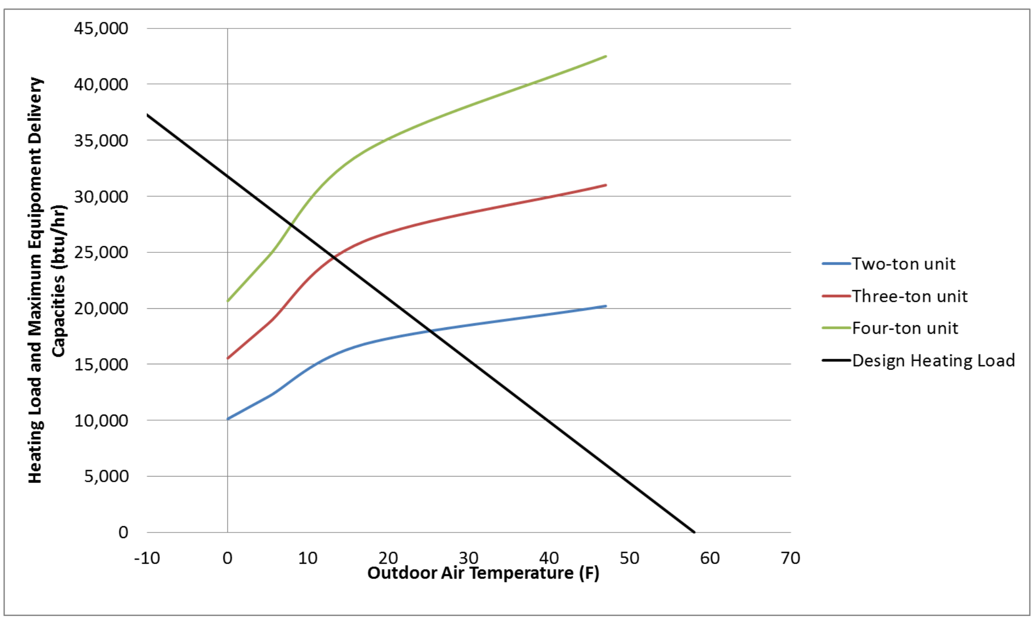
Table 3. ASHP equipment installed for the field characterization

Site Number	ASHP System	ASHP Size	ASHP Type	Backup
1	Carrier Infinity with Greenspeed [25VNA048A003]	4 ton	Ducted	LP Cond. Furnace
2	Bryant Extreme Heat Pump [280ANV048]	4 ton	Ducted	LP Cond. Furnace
3	Carrier Infinity with Greenspeed [25VNA036A003]	3 ton	Ducted	LP 80% Furnace
4	Trane XV20i [4TWV0036A]	3 ton	Ducted	LP Cond. Furnace
6	Mitsibishi Ductless Hyper Heat [MUZ-FH18NAH]	1.5 ton	Ductless	Electric Resistance
8	Mitsibishi Ductless Hyper Heat [MSZ-FH12NA]	1 ton	Ductless	Electric Resistance

Sizing

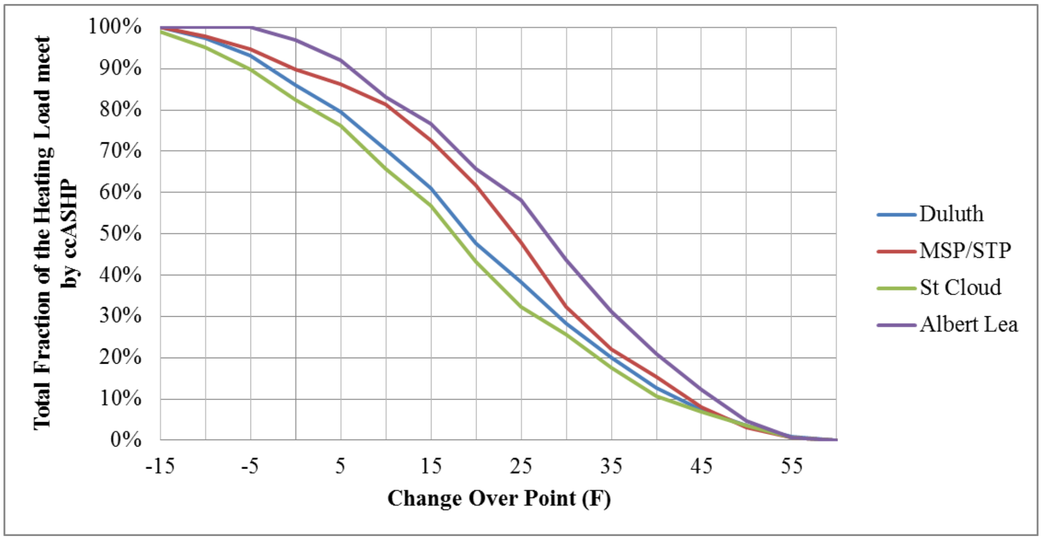
Cold-climate air source heat pumps were sized for each home's heating load (as opposed to the cooling load), which typically led to an increase in capacity (or "tonnage") of the system by one ton. This meant that where a home sized for cooling would install a two-ton heat pump, the same home sized for ccASHP heating would install a three-ton system. In cold climates, sizing the heat pump for a home's heating load is important in order to take full advantage of the system's variable capacity, thus minimizing the use of backup heating. Figure 8 shows the equipment output for a two-ton, three-town, and four-ton ccASHP, all of which have a furnace for backup, charted against the outdoor air temperature. The house heating load must be calculated in order to properly size the heat pump. Comparing the house heating load curve to the equipment capacity curve shows the crossover temperature where the heat pump capacity matched the house heating load. Figure 8 shows the comparison of a TRANE ccASHP and a home with a 38,000 btu/hr heating load at -11^{o}F outdoor air temperature. The outdoor air temperature at which the heat pump capacity matched the house load is at 5°F for the four-ton, 14°F for the three-ton, and 27°F for the two-ton unit. These temperatures indicate that point at which the heat pump can no longer meet the load of the home independently and back up is required. If the two-ton heat pump were to have been chosen for this home, the furnace would have to take over heating the home at 27°F, significantly limiting the fraction of the heating load met by the ccASHP. The three-ton and four-ton switchover points are lower, allowing the system to take advantage of the variable capacity to provide heat to the home at low temperatures. Sizing the system for the heating load resulted in a heat pump that was one ton larger than sizing for cooling. However, this is not a concern because the variable capacity of the system will allow the heat pump to match the cooling load required, by firing at a lower rate.

Figure 8. Heating sizing chart for an ccASHP system



The temperature at which the heat pump no longer meets the full heating load of the home and requires back up heat, or the changeover point, determines the fraction of the heating load the ccASHP will deliver. Figure 9 shows that fraction of heating load met by the ccASHP for a range of change pover points for four Minnesota cities. The figure shows that in colder locations, such as Duluth, a switch over point of 10 ^{o}F would allow the heat pump to meet 71% of the space heating load. In the slightly warmer climate zone, such as Minneapolis, a 10^{o}F change over point will meet 81% of the heating load.

Figure 9. Fraction of the heating load by set point for several MN locations



Controls allow the installer to program a switchover set point that locks out the ccASHP. For this study, the change over point that resulted in meeting approximately 80% of the heating load was targeted.. Based on how the systems were sized for each home, a 10°F chang over was slightly warmer metro and southern MN sites and a 5 °F temperature was selected for colder homes application. In Minnesota, it is common practice for installers to set this point around 25°F to 35°F for ASHPs that are not designed for cold-climate heating. This is done to prevent the ASHP from operating at cold outdoor temperatures where the capacity, efficiency, and delivered air temperatures are unfavorable. In addition to being the coldest point where the ASHP could meet the full load, the 10°F set point was a conservative midpoint between the coldest theoretical operating temperature of the system and a point the installers' were comfortable with. Setting the switchover point to a higher value would have locked out the heat pump at a point where it still had the capability to meet the heating load of the house, preventing the homeowner from taking full advantage of the system benefits.

Integrating ccASHPs with backup heating systems

The original intent of this project was to integrate ccASHPs with the existing heat source as backup. However, there are issues that make integrating a ducted ccASHP with the existing furnace complicated. The two primary issues are 1) the furnace and heat pump require communicating capabilities and 2) a multi-stage fan is necessary to achieve the full benefit of the ccASHP. To deal with these issues, manufacturers and installers specify that the furnace and ccASHP must be the same brand. This ensures that the controls for the ccASHP and the furnace can communicate. Integrated controls are required for the switchover set point and the furnace fan speed. With the variable capacity capabilities of ccASHPs, manufacturers require that the fan in the air handler unit also be variable speed for ideal performance of the system. Unfortunately, most 80% AFUE and older condensing furnaces have single stage fans. While it is expected that a wider range of options will become available, at the present time only recently installed and higher end furnaces would have the controls and fan characteristics desired for integration.

Solutions to the integration issues include 1) install a new communicating condensing furnace; 2) install a new 80% AFUE communicating furnace with a multi-stage fan; 3) retrofit the existing fan and furnace controls; or 4) install a plenum electric resistance heater. Option 3 was eliminated, as it is complicated and not practical for integration into an energy efficiency program. Option 4 was also eliminated since eliminating the need for a furnace would require a plenum heater to meet the full heating load of the home. In large homes this would require a very large plenum heater and an air handler to eliminate the furnace. Options 1 and 2 were both selected as viable solutions that could be easily implemented by installers and used in a utility rebate program. While the HVAC installers working on this study preferred option 1, it is a much more expensive options. In the Minneapolis/St, Paul metro area, a homeowner would pay about $4,250 for a condensing furnace and only $1,875 for the same size non-condensing furnace. With a properly sized ccASHP, it is expected that the furnace would have to meet less than 30% of the heating load, and this percentage can be reduced further for homes with lower heating loads. Given that the furnace would only be running for a small portion of the heating season, it is likely to be more cost effective to install an 80% AFUE furnace. An 80% AFUE unit was installed at site 3 where the proper vent was available.

Electric resistance baseboard heating can also be an effective method of providing back-up heating. Electric resistance systems are primarily used as back up for ductless heat pump systems, but can also be used with fully ducted ccASHPs. Typical back-up applications of electric resistance baseboards are used with their own independent controls (thermostat). The integration between the primary and back-up systems are done through the thermostat set points. For example, the primary thermostat is set to the desired room temperature and the back-up system is set a couple degrees cooler. When the primary system is not able to meet the demand the temperature in the space drops and the back-up thermostat will call for heat.

Monitoring equipment

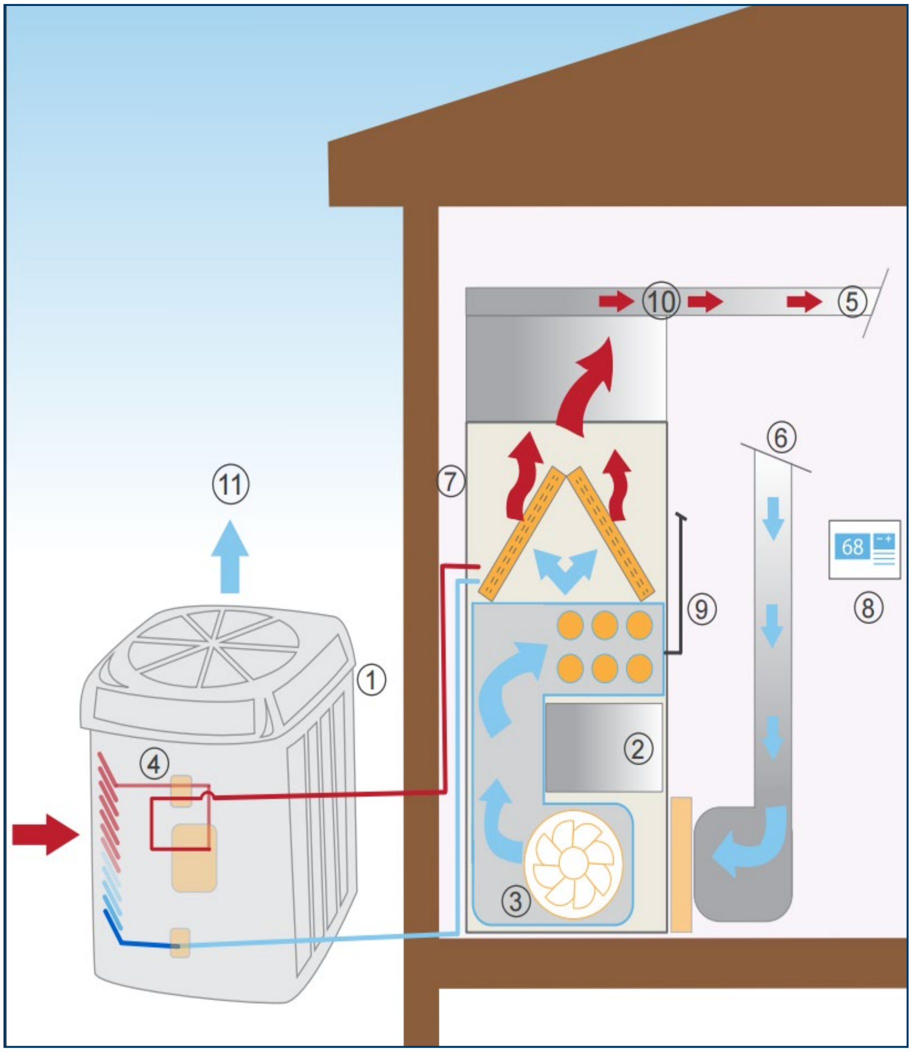
Each home was fully instrumented with a residential HVAC data acquisition system that was developed by CEE and successfully used on other field test projects. The system utilizes a Campbell Scientific acquisition system customized to collect HVAC data. The data collection interval was adjusted for high-resolution (one second) data when systems are active and lower resolution data when systems are inactive. This logging interval strategy allows for the efficient use of short-term storage on the data logger with daily transmission by cellular modem or internet connection each night. Table 4 details the data collection system used at each site.

Table 4. Instrumentation

Number	Measurement	Instrument	Location
1	Power measurement	Current transformer	Outdoor unit
2	Power measurement	Current transformer	Indoor unit
3	Power measurement	Current transformer	Indoor Fan
4	Status (on/off)	Relay	Reversing valve
5	Air temperature	Thermocouple array	Supply air outlet
6	Air temperature	Thermocouple array	Return air inlet
7	Air temperature	Thermocouple	Mechanical ambient
8	Air temperature	Thermocouple	Conditioned space
9	Ducted: Gas use Ductless: Electric power	Ducted: Gas meter Ductless: Power meter	Ducted: Furnace Ductless: ER circuits
10	Airflow	Current transformer[1]	Air handler fan
11	Weather data	NOAA weather station	Nearby
12	Air temperature	thermocouple	Outdoors

Note 1: Air handler fan amperage was measured during the field test. This value was related to airflow through on-site testing at least two site visits. Airflow was measured with Trueflow plate for ducted systems and a Ductblaster for ductless systems. See Appendix A for a full test methodology.

Figure 10. Instrumateation diagram for a ducted ccASHP



Data Collection

The data was transmitted to CEE servers and then processed and validated. This involved three steps: 1) integrating the data with external weather data, 2) filtering the data for repeated or omitted data, and 3) range checking the data.

In addition to the outdoor air temperature data collected at the field site, CEE integrated weather station data from the nearest available source in the analysis. Hourly weather station data was used, and the data was interpolated for high-resolution analysis and aggregated for a longer time period analysis. Outdoor dry bulb temperature was the primary measurement used.

The data timestamps were checked to ensure that data had not been repeated and/or omitted. Automated range checking was performed, and a warning was output when values outside of a specified range were detected. Aggregate data was also compared over time to ensure accuracy. For example, the daily electric use of the outdoor unit was compared day by day, and if the daily values were outside of the expected daily variance they were tagged for further analysis. This process allowed for quick and regular data validation and was used to indicate data acquisition system errors. Although errors were rare, it was important to identify and correct them quickly to avoid data loss.

With the exception of airflow, measurements were made directly by the data collection system. The system airflow was determined through measurements of the supply fan current draw and calibrated to short-term measurements at each site. For ducted systems, short-term airflow measurements were made using a TrueFlow for each mode of system operation. System airflow measurements were made following the standard TrueFlow procedure for measuring at the furnace filter slot (The Energy Conservatory 2005). The continuously monitored current measurements were then correlated to short-term airflow measurements, which allowed the fan measurements to be used as a stand in for airflow throughout the monitoring period. For ductless systems, a powered flow hood was used to make airflow measurements in each mode of operation. These measurements were made following the methodology used by (Christensen et al. 2011), which is explained in detail in Appendix A. Then using the same process that was used for ducted systems, these short-term airflow measurements were calibrated to continuous indoor fan current draws. With that calibration, the fan current draw measurements were used to determine the continuous airflow of the system.

These short-term airflow measurements were made at the start and conclusion of the heating season, and were used to create the fan power and airflow correlation and to verify measurement accuracy. A series of temperature traverses were used to ensure an accurate mixed supply. Return temperature was measured in all modes of operation, and the steady-state energy output and energy input measurements for both the ASHP and the propane furnace were compared to expected values for each system.

Analysis

Annual Energy Use

The annual energy use analysis was based on creating a heating load model and a system performance model for each site. These models were used with typical medological data to determine normalized annual performance. This approach has been used for many CEE research projects in the past, including field evaluations of tankless water heaters, combined space and water heating systems, and other HVAC technologies.

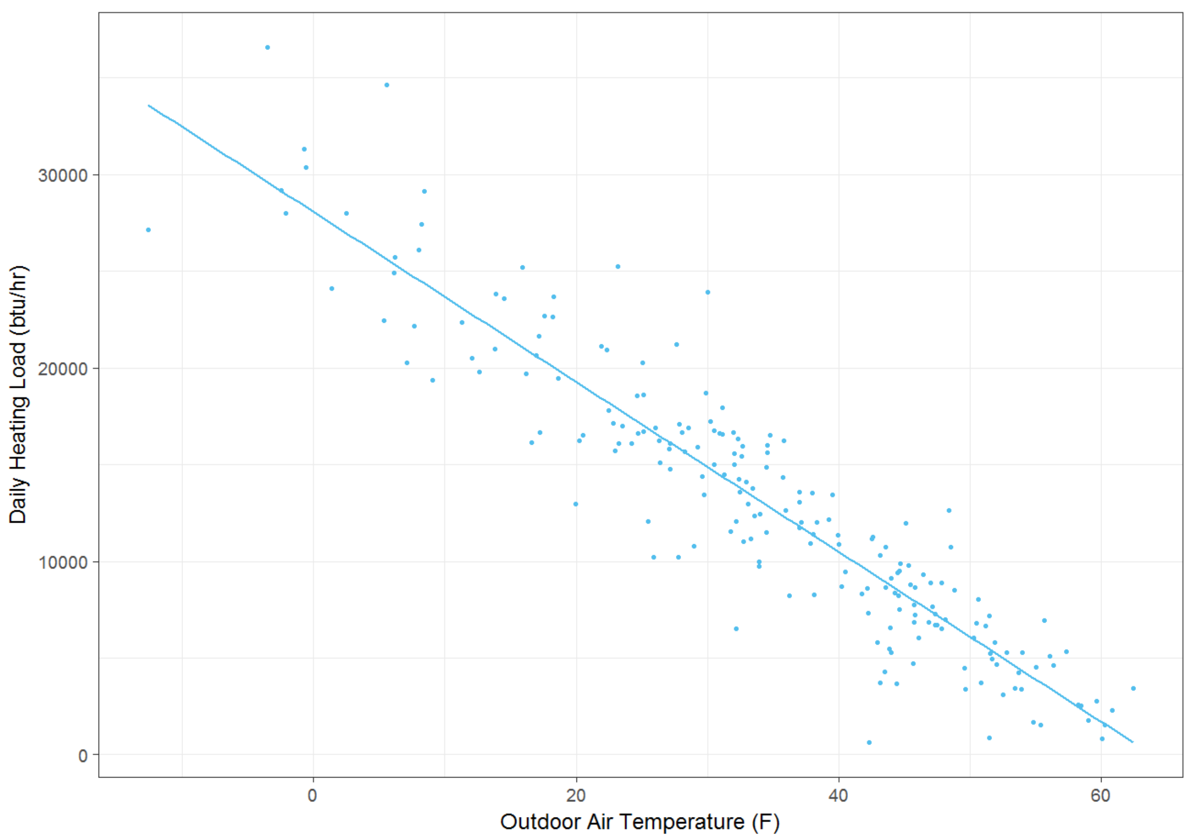
The first step was to create a heating load model for each home. These models characterized the ammount of energy the heating system must deliver to keep the home comfortable at vairous outdoor air temperatures. The measured data were used to calculate the delivered heating capacity (load or output).

$$Q_{out} = C_1 CFM\left(T_{Supply} - T_{Return}\right) \quad (1)$$

Where Q_{out} is the delivered heating capactiy in Btu/hr that is calculated from the measured system air flow, CFM, and the difference between the supply, T_{Supply}, and return, T_{Return}, thermocouple arraies. C_1 was a conversion factor (~1.08 for typical air properties) that included the temperature depenedent characteristics, density and specifc heat of air, and unit conversions.

The delivered heating capacity was calculated on a daily bases with the daily average outdoor air temperature. This data was fit to a linear regression model to characterize the homes heating load. Figure 11 shows that heating load characterization on Site_01_ducted. For wach site, the house heating load model was used to calculate the deisgn heating load (the required energy necessary at the design heating temperature) and the balace point temperature (the outdoor temperature at which heat was no longer required). For Site_01_ducted the design heating load was 35,468 Btu/hr at -11 ^{o}F, the design temperature for the metro area. The balance point was 64.5 ^{o}F.

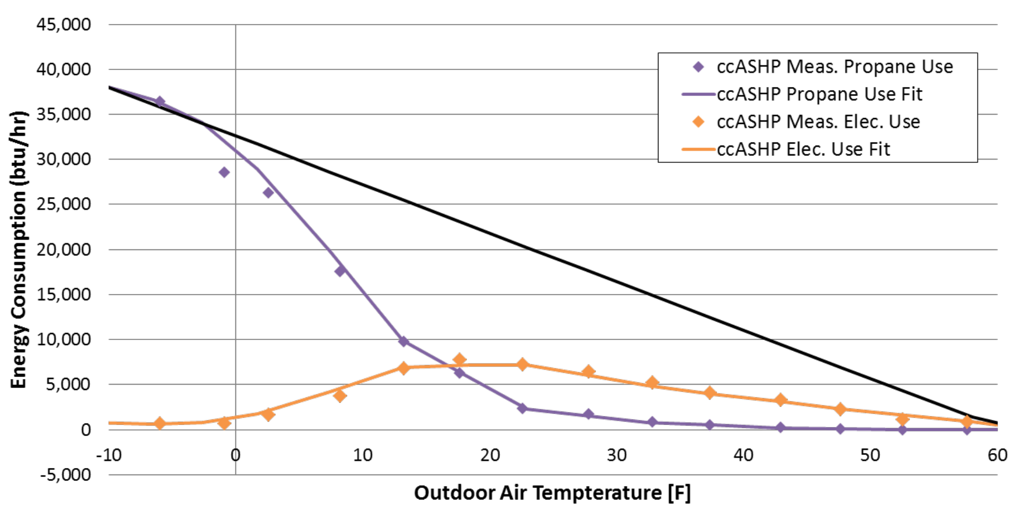
Figure 11. Heating load characterized by outdoor air temperature for daily data from Site_01_ducted



A system performance model was also developed from the field data. Energy consumption data was measured directly. For ducted systems both the electricity from the indoor and outdoor units and the back-up propane use from the furnace were measured. For the ductless systems, electricity was measured from the indoor and outdoor heat pump units, and also from the back-up electric resistance baseboards. The energy usage data was compared to the outdoor air temperature to develop the energy use models.

Figure 12 shows the system performance model for the ducted systems at site_02. The model was created by averaging the energy use for each 5°F outdoor air bin. Table 5 shows the binned results for site_02. Averages were taken for both the propane use (purple in Figure 12) and indoor and outdoor unit electricity use (total electricity use shown in orange in Figure 12) per day during ccASHP operation. Additionally, the alternating mode methodology of the test allowed for data collection of furnace only operation (black in Figure 12), which was used as a baseline. As outdoor air temperatures approached the balance point (typically between 55°F and 65°F) heating energy use approached zero for all modes of operation. In moderate temperature conditions during ccASHP mode, the electricity use from the heat pump was larger than the propane use from the backup furnace. As outdoor air temperature approached the changeover point (10°F), propane usage increased. This analysis was conducted on the energy consumption data. The difference in efficiency between the heat pump (with COPs greater than 1.5) and the backup systems (with efficiency around 80%) mean that electricity delivered a proportionally larger amount of energy to the home compared to the equivalent Btus of propane. For example, on a shoulder season day where propane accounted for about 25% of energy consumption (measured in Btus), the respective energy delivered from propane would be around 10% of the total energy delivered.

Figure 12. Energy use for ccASHP and baseline propane furnace at Site_02_ducted



When temperatures were below zero the backup propane use from the ccASHP was similar to the propane use in the baseline only mode. Air temperature bins below the ccASHP system change point had some heat pump operation due to the range of daily temperatures. For example, a day when the average air temperature of 0^{o}F appears to prohibit heat pump operation because it is below the ccASHP change point of 10^{o}F, the maximum temperature of that day may have been above the change point, allowing the heat pump to meet part of the daily load.

Table 5. Binned analysis for site_02_ducted

OAT Bin	Avg. OAT	Energy Delivered to Home (Heating Load) Btu/hr	Propane Use Btu/hr	Electricity Use Outdoor Unit Btu/hr	Electricity Use Indoor Unit Btu/hr	Avg. System COP
-10 to -5	-6.0	27,240	36,382	NA	4.4	0.7
-5 to 0	-0.9	21,627	28,513	0.4	4.2	0.7
0 to 5	2.6	21,858	26,234	6.8	4.4	0.8
5 to 10	8.2	19,245	17,538	21.8	4.2	0.9
10 to 15	13.2	19,160	9,794	43.4	4.5	1.2
15 to 20	17.6	18,606	6,265	50.0	4.4	1.3
20 to 25	22.6	15,489	2,301	46.9	4.0	1.6
25 to 30	27.8	14,401	1,711	41.5	4.0	1.8
30 to 35	32.8	12,173	879	33.1	3.3	2.0
35 to 40	37.4	9,966	520	25.7	3.2	2.2
40 to 45	42.9	7,710	220	19.5	3.5	2.2
45 to 50	47.6	5,322	60	12.1	3.7	2.3
50 to 55	52.5	2,311	NA	4.5	3.4	2.1

The average measured field data per OAT bin (diamond shapes in Figure 12) were used to calculate the average system performance at any outdoor air temperature through interpolation. The interpolated energy use calculations were used to determine the annual energy use based on the typical meteorological weather data (TMY3) from the nearest available site. The first step was to calculate the number of days in each OAT bin based on the daily average TMY3 OAT. Next, the daily average TMY3 OAT per bin was calculated. Then, the electricity used by both the indoor and outdoor units, as well as the propane used by the backup system, was calculated from the daily average TMY3 OAT and an interpolation of the measured field data. Finally, the consumption data was totaled for the correct number of days per bin to determine the annual heating energy used by the ccASHP system. This process was repeated using the propane only baseline system to determine baseline operation.

Coefficient of Performance (COP)

The data collection methodology employed at each site allowed for several additional analyses beyond the annual energy use methodology described previously. One additional analysis that was performed was a calculation of the coefficient of performance (COP) and/or system efficiencies. Both system efficiency and COP are a measurement of the ratio of the energy output (or energy delivered) to the energy input (or energy consumption). For energy transferring devices, like a heat pump, the ratio is called a COP. For energy conversion devices, such as a furnace with a propane burner, the ratio is called efficiency. For energy conversion, the output can only be a portion of the input and the efficiency must be less than 100% by the laws of thermodynamics. For an energy transfer system, the energy output is the energy extracted from the source, such as outdoor air for an ASHP, and it can exceed the input without breaking the laws of thermodynamics. Therefor COPs can be higher than 100%.

Both the energy output and the energy inputs of the heat pump and backup propane system were measured directly. This allowed calculation of the COP or efficiency of the systems. COPs or efficiencies were calculated for various intervals, including instantaneous, one second, daily, and seasonal.

Cycle based analysis

In addition to measuring energy input and energy output, the data collection systems measured many other system parameters at each site. These parameters included delivered air temperature, return air temperature, airflow rate, component runtimes, ambient temperatures, and temperatures inside the outdoor unit of the heat pump. All of these parameters were used for additional calculations.

Cyclical performance was determined for each system. The runtime of three components was used to determine the heating cycle start and stop times. The runtimes of the indoor unit fan, the outdoor unit, and the propane furnace were used to determine the start and stop of each heating cycle and the mode (i.e. heat pump heating, backup heating, defrost, fan only, or cooling) that was active. Data from each cycle was used to diagnose and characterize system performance.

Other system impacts

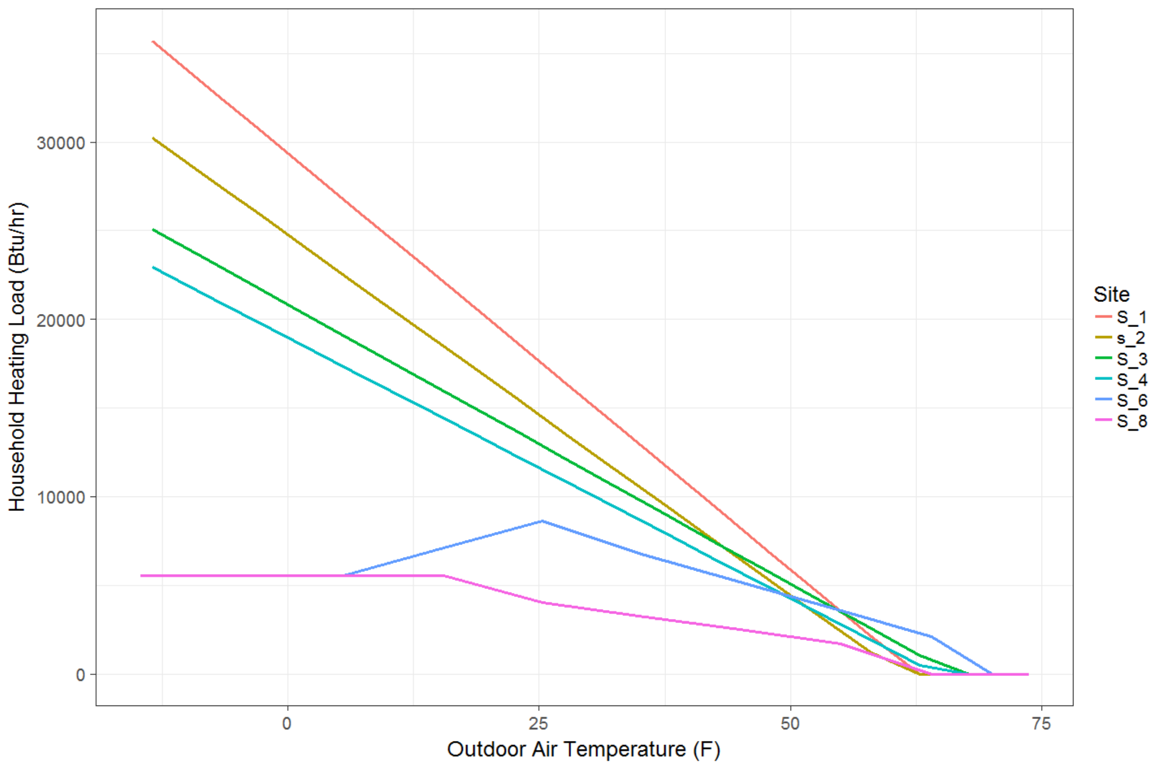
Detailed, high-resolution field data was also used to perform several other calculations and characterizations discussed in the results section. For example, data on when the system was in defrost mode was collected for each system. From this data the impact of defrost was calculated, including the reduction in system COP due to locking out the heat pump and the penalty from using the furnace to defrost the outdoor unit.

Results

Heating loads

The direct measurement of supply and return air temperatures and calculated airflow rates allowed for the calculation of the heating energy delivered to each home. The model of heating energy and outdoor air temperature was discussed previously in this report. Figure 13 shows the relationship between delivered heating load from each system and the outdoor air temperature for each site.

Figure 13. Heating load models for each site



For the ducted systems (s_1, s_2, s_3, and S_4), the ccASHP delivered energy was the only source of heating, meaning that the energy delivered by the heat pump was the full household heating load. For the ductless systems (s_6 and s_8), there were additional heat sources, such as electric resistance baseboards and fireplaces. For these homes, the delivered energy from the ductless systems was used as the systems load, which would be a fraction of the total household load. The delivered load of the ductless systems were limited by two factors, the capacity range of the ductless system and the heating load the ductless system interacted with due to the installation location and control settings. . The parameters of that regression were used to characterize each site's heating load. Table 6 shows the heating load parameters of each ducted ccASHP site based on the homes location (design heating temperature) and house characteristics (balance point temperature and design heating load). The design heating load of the ductless systems was not at the actual delivered capacity of these systems at design temperature; rather, it was a characterization number used to compare the size of the load to the ducted central systems. The design load was calculated using the balance point temperature and the annual heating load of each site, and calculating what the design load would have been if the system followed the typical linear heating load shape of sites 1 through 4. Additionally, the table shows the annual heating load for each site, as calculated from the load characteristics and the nearby typical weather profiles (TMY3 data).

Table 6. Heating load characteristics of each field test site

Site	Design Heating Temperature, °F	Balance Point Temperature, °F	Design Heating Load, Btu/hr	Annual Heating Load, Therms/year
S_01	-10.6	62.6	34,341	799
S_02	-8.8	60.9	28,339	652
S_03	-12.4	66.1	24,734	562
S_04	-18.2	64.5	24,306	664
S_06_ductless	-17.2	70.1	11,950*	442
S_08_ductless	-17.2	59.1	8,400*	244

* 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.

Annual Energy Use

The system performance and annual energy use of each ccASHP and baseline system were analyzed using the methodology previously described. The following section summarizes the energy use and savings, reduction of reliance on delivered fuels, system COPs, and ability of the ccASHP to meet the homes' load.

The annual energy consumption for both the baseline (furnace only) and the ccASHP with backup systems was determined with a binned analysis of the heating system energy consumption versus outdoor air temperature. Figure 14 shows the site energy use, in propane and electricity, for each site with the baseline (furnace or electric baseboard) and the ccASHP. Table 7 shows the relative reductions in energy and cost at each site. Significant site energy reduction, between 37% and 54%, was measured for all sites. The figure also illustrates the switch from a delivered fuel dominated heating system to a primarily electricity-based system for the flex fuel sites. In baseline, furnace-only operation, 97% to 98% of site energy use was from propane. The air handler fan operation was the only electricity use, and this was a small fraction at 2% to 3%, of total site energy use. In the ducted ccASHP system operation, between 48% and 69% of site energy use was electricity. While the air handler fan (the indoor unit) accounted for the same fraction of energy use, the addition of the outdoor unit (the heat pump) accounted for almost half the total site energy use. For the ductless systems, it was assumed that the load met by the heat pump system would have been meet by an electric resistance heater in the baseline case. These systems saw a 53% reduction in electrical use with the ductless system. Along with these energy savings, there are substantial cost savings for the homeowner. There was an average cost savings of 33% for ducted ccASHPs and 53% for ductless. Ducted systems saved between $377 and $764 per year and ductless systems saved $369 and $610.

Figure 14. Propane and electricity use for each the ccASHP and baseline heating system at each site

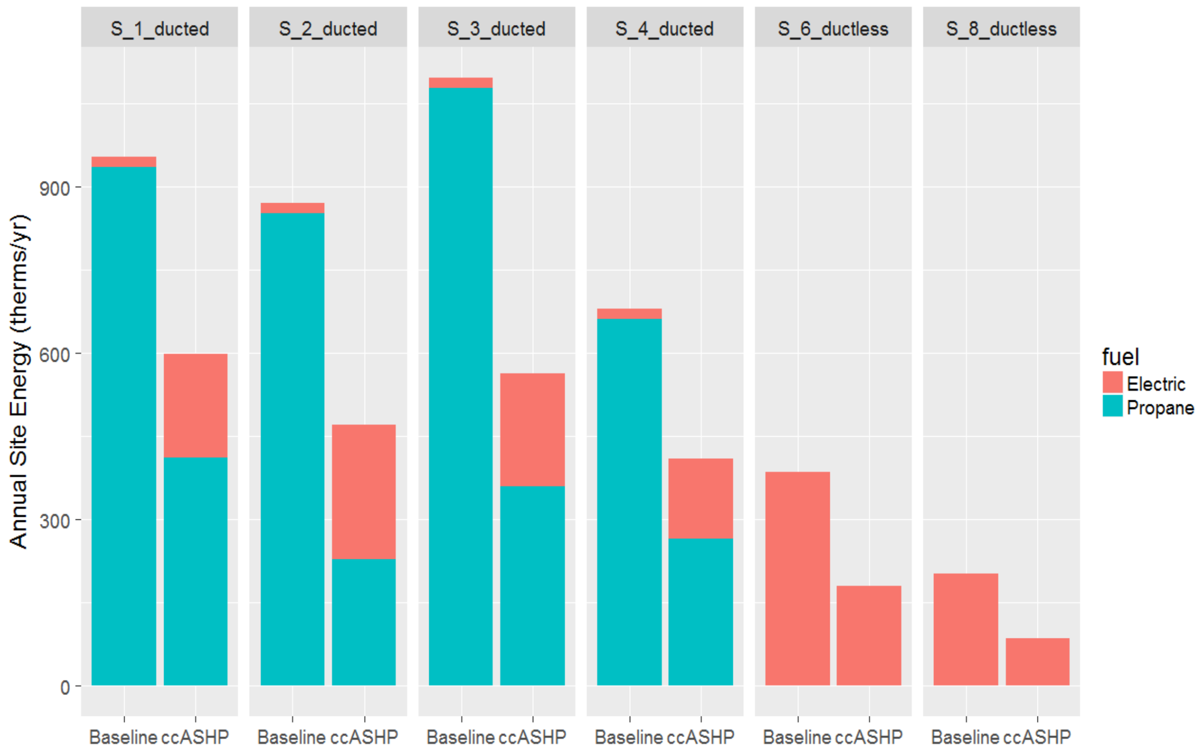


Table 7. Savings from ccASHPs over baseline furnace at each site

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

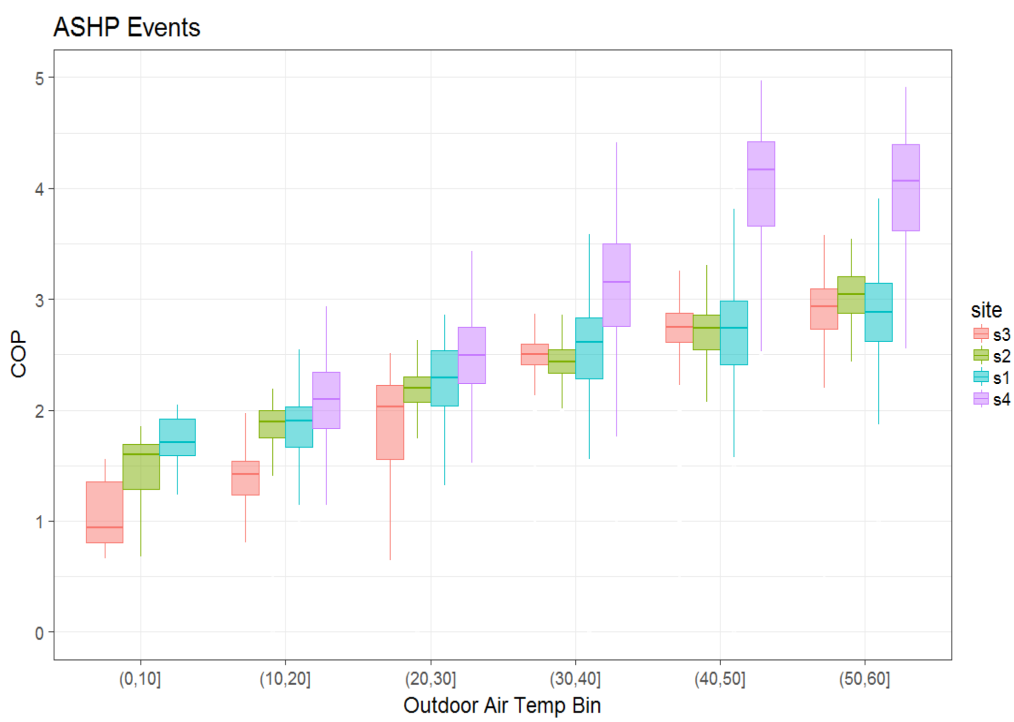
Propane Reduction

On average there was a 64% reduction in propane use for the ccASHP systems with propane furnace backups. These sites saw their annual consumption reduced from an average of 967 gallons per year to 346 gallons when using the ccASHP. All four sites used less than 500 gallons of propane per year. A typical residential home has a 500-gallon storage tank; therefore all the homes monitored would be able to avoid costly heating season propane deliveries, and most homes in the metro, central, and southern regions of the state would avoid mid-heating season refills with 500 gallons of storage. In the northern regions, propane use with ASHPs would still be greater than 500 gallons for homes with design heating loads greater than 25,000 Btu/hr.

ccASHP Performance

The large reductions in site energy consumption were possible because of the significant COP increase with the ccASHP systems compared to baseline systems. Heating events where only the heat pump was used typically had COPs around 1.3 at the lower temperature change point (10°F), and COPs increased to around 3.0 to 4.5 in the shoulder heating seasons (around 50°F to 60°F).

Figure 15. Heat pump only cycle COPs by outdoor air temperature bin



While the outdoor air temperature has the largest impact on the COP, as Figure 15 shows, heating cycles at the same OAT did have a range of COPs. Secondary factors on cycle COP include the levels of modulation of components in both the indoor and outdoor units. The largest impacts are the modulation of the heat pump outdoor unit (i.e. the compressor) and the flow rate of the indoor circulation fan. For example, Site 4 showed much higher COPs (~4.0) in the shoulder seasons than the other three ducted systems (~3.0). This was due in part to higher performance equipment at these conditions, and also in part because Site 4 reduced the modulation and capacity to increase the amount of heat transfer. The weather-normalized, annual ccASHP-only (no backup fuel use included) COPs were 2.75, 2.78, and 2.51 for Sites 1 through 3 respectively.

Figure 16. Coefficient of performance for each heating cycle at each central ducted site

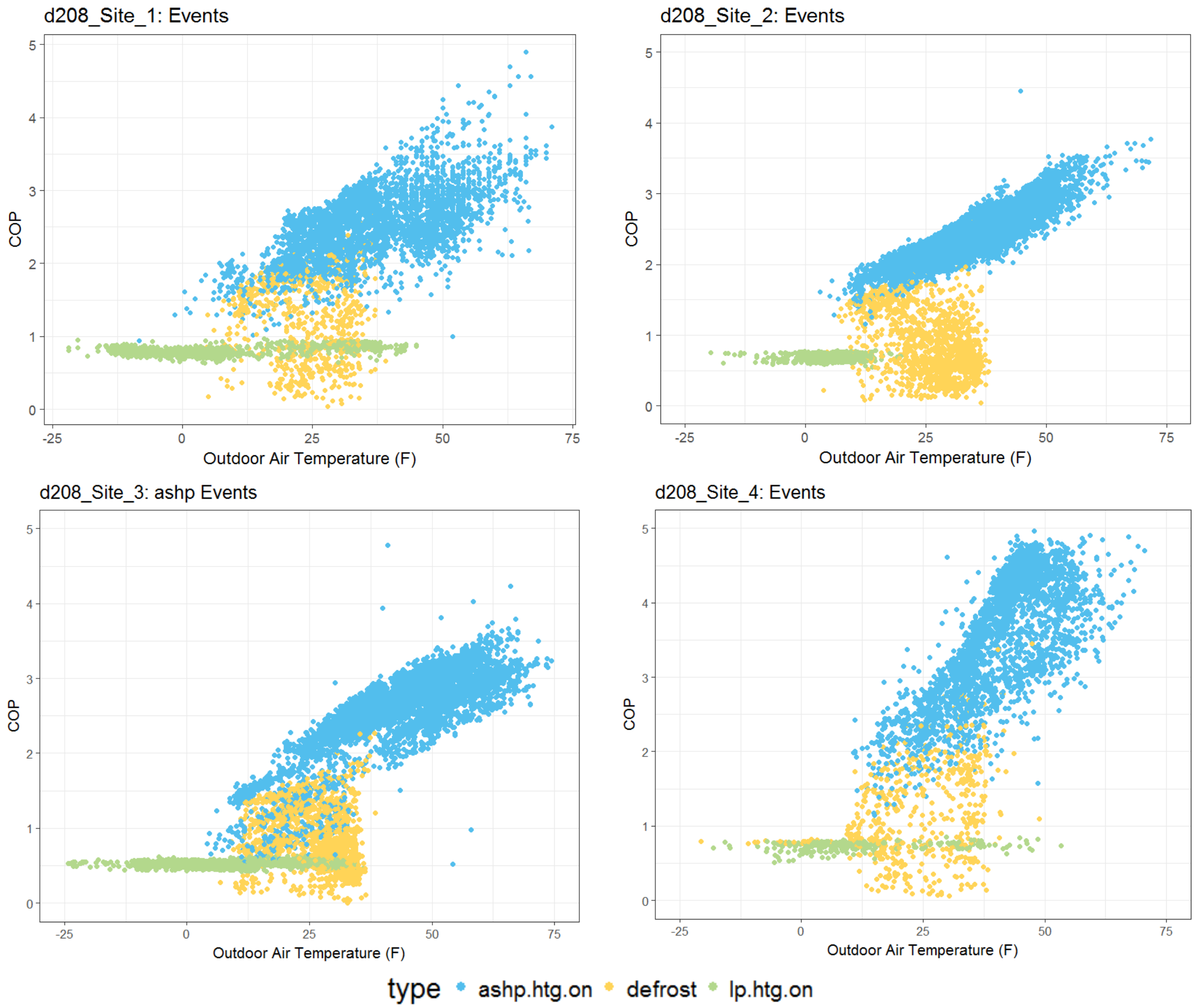


Figure 16 shows the performance of each ducted system by heating mode. This figure shows the individual cycle data represented in Figure 15 as well as the efficiency of the furnace-only cycles. These events were typically between 70% and 85%, or 8 to 15 percentage points below the rated AFUEs for the condensing units. The non-condensing furnace was typically firing around 57%, 13 percentage points below the rated efficiency. These efficiencies were below the rated efficiencies due at least partially to the cycle length. Figure 17 shows the instantaneous and cumulative event efficiency for a typical furnace event with a condensing furnace. This event took 14 minutes for the instantaneous efficiency to reach the condensing level (>90%), and it didn't reach steady-state operation for an additional six minutes. Looking at the cumulative efficiency of this event, the 25-minute draw concluded before these transient state-up effects were made insignificant. These impacts contribute to the annual efficiency in the baseline mode as well as the efficiency of the backup propane system for ccASHPs. Note that it is very common for installed efficiencies to be lower than the rated performance. This is because ratings are conducted at a specific set of operating conditions, which are often not directly recreated in the field. Additionally, the method of tests for HVAC equipment, including AFUE and HSPF, are intended to compare unit performance, and they are not intended to represent the installed efficiency of any specific installation.

Figure 17. Furnace efficiency

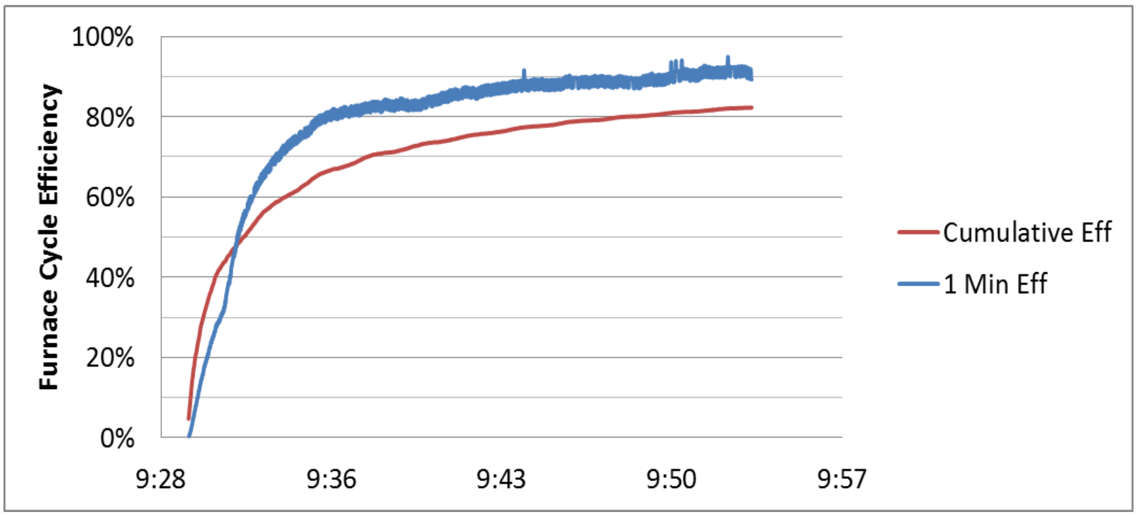
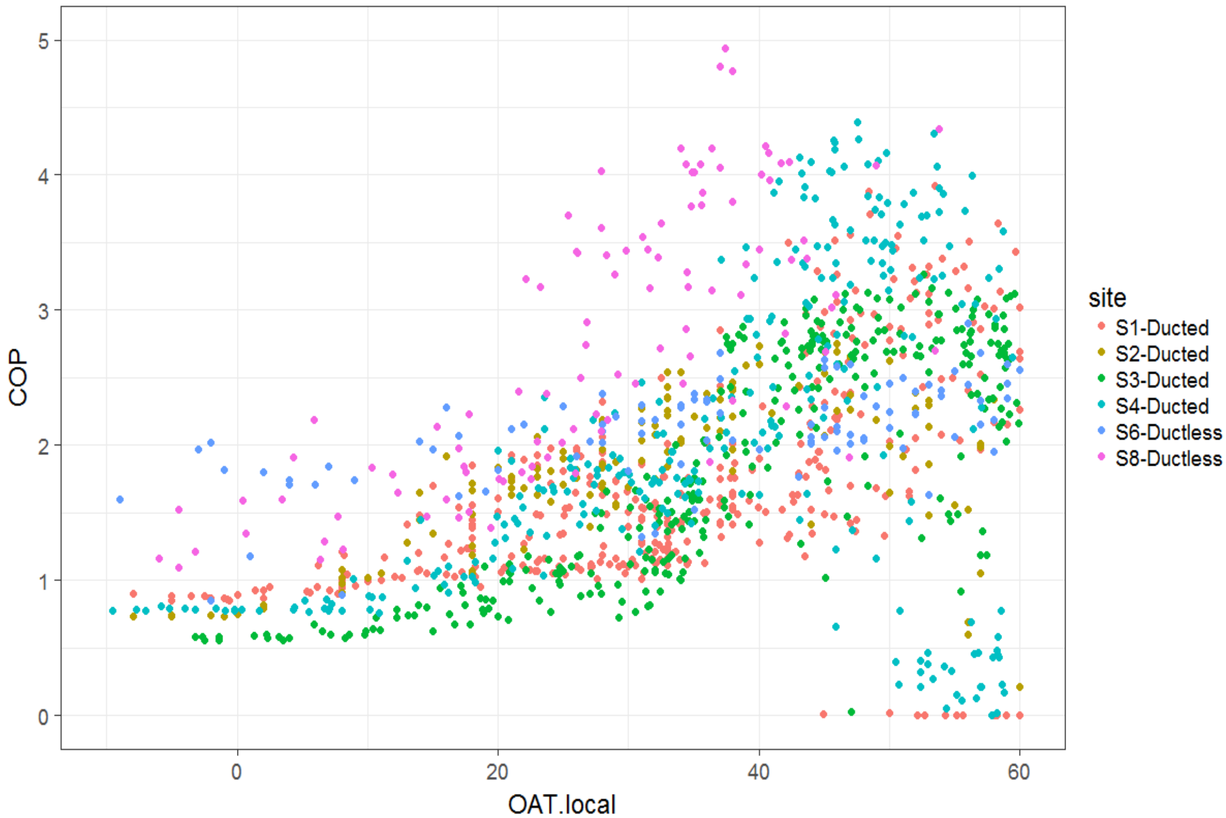


Figure 18 shows the overall of the performance of the ccASHP at each site, including system COPs for both ducted (S1, S2, S3, and S4) and ductless sites (S6 and S8). As the temperature increases from design temperatures well below 0 ^{o}F to shoulder season temperature, the COPs increase from 0.6/0.8 to 3.0/4.0 for the ducted systems and from 1.0/1.5 to 4.0/4.5 for the ductless systems. Below 0 ^{o}F, the ducted systems were operating at efficiencies comparable to the furnace-only performance (see Figure 16). This was because these systems were run with an outdoor temperature lockout at 10^{o}F so that below that temperature only the furnace would run. The ductless systems had higher efficiencies below 0^{o}F because the heat pump could run down to -13 OAT. Therefore, at OAT between 0^{o}F and -13^{o}F, Site 6 had an average daily COP of 1.7 and Site 8 had an average COP of 1.3. One of these ductless units operated evenly with COPs greater than 1.0 when the local outdoor temperature was -19 ^{o}F.

At outdoor temperatures at the warm end of the shoulder seasons some system COPs begin to decrease. These decreases were due to cooling operation, where the supply temperature was lower than the return temperature and the output of the system decreased the overall heat delivered. Because this project focused on the heating performance of the systems, the cooling events were typically ignored.

Figure 18. Daily ccASHP system performance.



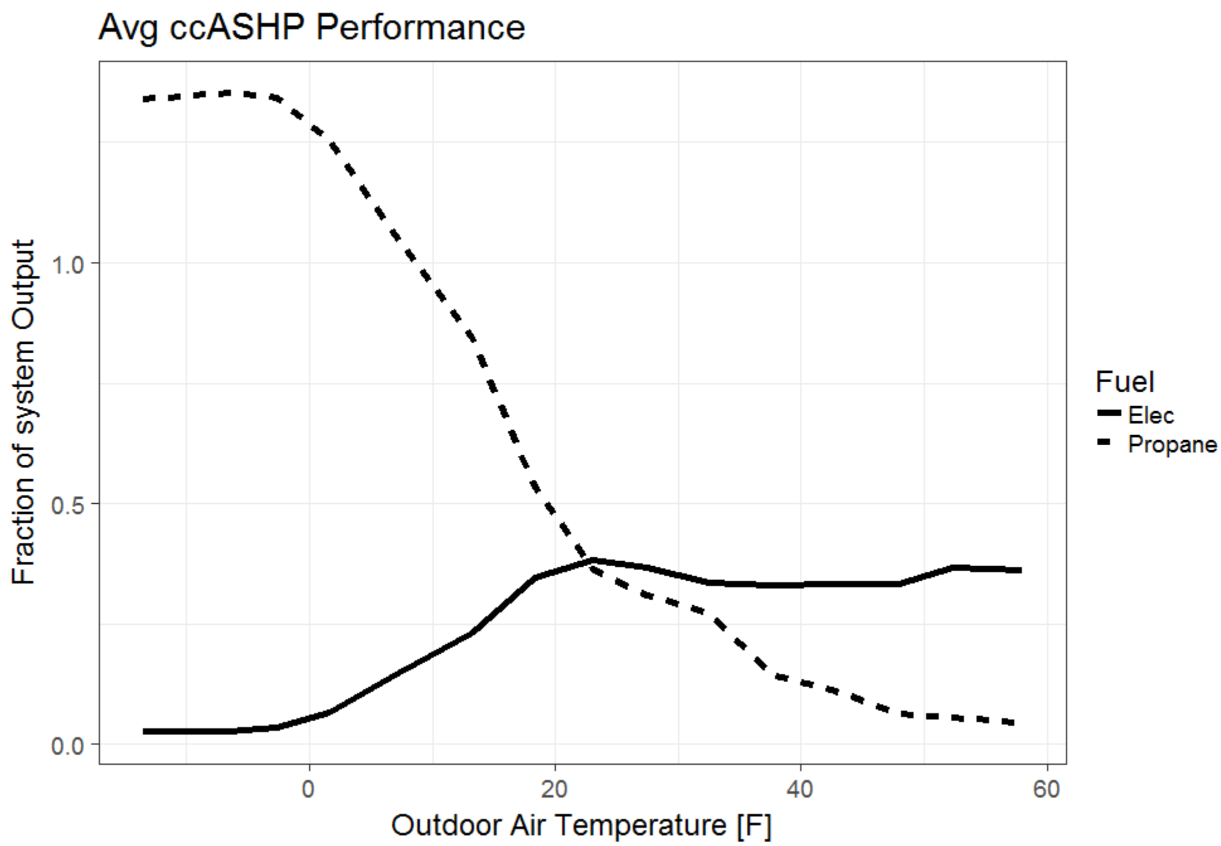
Note: Ducted installations include heat pump and furnace performance and ductless systems include the heat pump only.

Expected Savings across Minnesota

The data collected at each site in the study was used to create performance maps for ccASHP systems. These performance maps were then used to look at the changes in annual COP, energy use, savings, and reduction of delivered fuels, had the ccASHPs been installed in a different location or in a home with different load. This sensitivity analysis was also used as the bases for the calculation spreadsheet described in Appendix B.

Figure 19 shows the performance map for the average of the four ducted ccASHP systems. It was created through an average of the binned daily data shown in Figure 18. The energy usage in both propane and electricity was characterized as a fraction of the output to allow the model to scale with the size of the home. This performance model requires that the ducted heat pump meet the sizing criteria that this project used for its installations. The heat pump must also be able to meet the full load of the home at 10°F. The ccASHP performance model was used to look at the impact on annual energy use, savings, and system COP due to changes in house heating loads and locations in Minnesota.

Figure 19. The average performance map for the ducted ccASHPs characterized in the project

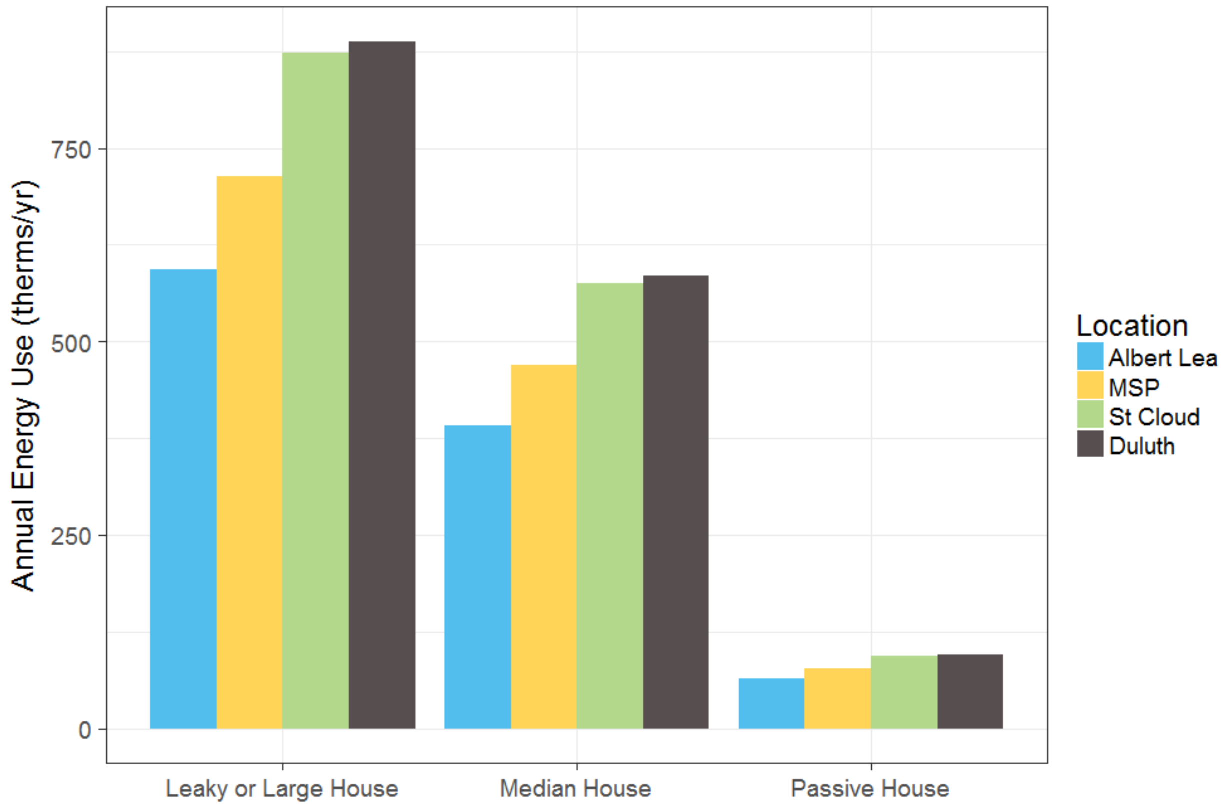


Three heating loads were defined to assess the impact of the house load on the ccASHP performance. The largest load represents either large or an especially leaky Minnesota home. The heating load was defined as the largest-sized home where a four-ton heat pump could be installed and still meet the proper sizing. Using this sizing criteria and the systems data for the ccASHP installed at Site 4, the largest load a four-ton heat pump can meet at 10 ^{o}F outdoor temperature is 28,507 Btu/hr. That home translates to a metro area design load (at -10.6 ^{o}F outdoor air design condition) of 40,252 Btu/hr.

The median home was developed to represent a typical Minnesota heating load. Based on data compiled from several resources (including the RECS, the U.S. Census, Minnesota utility rebate calculations, the Minnesota Technical Resource Manual calculations, and others), the average Minnesota home uses about 750 therms per year for heating. Assuming an average space heating efficiency of 80%, that is around 600 therms per year of heating load per home. With a typical balance point of 60^{o}F, the typical home would have a design load of 26,510 Btu/hr, with a design heating condition of -11 ^{o}F). This home was used as the median house. The U.S. passive house institute (PHIUS 2015) requires that the heating load of a passive house in Minnesota is below 7.6 kBtu/hr square feet of conditioned space. This requirement was used to generate the smallest heating load with a metro area design load of 4,325 Btu/hr at -10.6^{o}F.

The impact of a home's location was also analyzed. The ccASHP performance map was used to estimate the performance of the leaky/large, median, and small homes in four different Minnesota cities: Duluth, St. Cloud, Minneapolis/St. Paul, and Albert Lea. These cities were selected to represent the north, west, metro, and southern areas of Minnesota. Figure 20 shows the impact of changing locations. In northern areas, such as Duluth, the colder temperatures increase heating energy use because of the larger loads, and also because homes modeled there experience longer periods of time when it was too cold for the heat pump to operate. The heat pump lockout forces a higher fraction of the load be met by the back-up system, thus increasing the energy use.

Figure 20. Annual Energy Use for three house types in four different Minnesota cities



The annual system COP for these homes ranges from 1.09 to 1.33, depending on location. The heat pumps have an annual COP of between 1.9 and 2.1. The lower ASHP-only COPs are due to the lower temperatures while the heat pump is operating. The lower system COPs reflect impacts from the lower-ASHP COP and the longer periods of temperature below the heat pump lockout. Table 8 shows these effects for the 12 sample cases. St. Cloud had lower system COPs than Duluth, despite Duluth being a more northern city. St. Cloud only had 262 days below the heating balance point compared to 283 in Duluth. However, the average heating temperature in St. Cloud of 30.1^{o}F was actually lower than Duluth average temperature of 31.6^{o}F, which was likely the cause of a slightly lower COP.

The changes in operating performance and use resulting from location have a much smaller total impact on cost and energy savings that house type. The median house in southern Minnesota has an annual operation cost of $823 while the same house in northern Minnesota is $1,175.

Table 8. Impact of location and house load on system COP, energy use, and operating cost

House Type	Location	Space Heating Load, therms/yr	ccASHP Site Energy Use, therms/yr	Annual System COP	Operating Cost, $/yr	Savings over Cond Furnace, $/yr	Savings over 80% Furnace, $/yr
Passive	Duluth	108.0	95.4	1.13	$192	$50	$111
Median	Duluth	662.0	584.9	1.13	$1,175	$308	$680
Leaky/Large	Duluth	1005.1	888.1	1.13	$1,784	$467	$1,033
Passive	MSP	95.0	76.6	1.24	$158	$54	$107
Median	MSP	582.2	469.5	1.24	$971	$329	$654
Leaky/Large	MSP	884.0	712.8	1.24	$1,475	$500	$992
Passive	St Cloud	101.9	93.8	1.09	$186	$42	$100
Median	St Cloud	624.9	574.7	1.09	$1,141	$259	$612
Leaky/Large	St Cloud	948.8	872.6	1.09	$1,733	$394	$928
Passive	Albert Lea	85.1	63.8	1.33	$134	$56	$103
Median	Albert Lea	521.4	391.0	1.33	$823	$342	$633
Leaky/Large	Albert Lea	791.7	593.6	1.33	$1,250	$519	$962

Installation Costs and System Paybacks

The costs of installing the four ducted systems for this project may not be representative of typical installation costs for a couple of reasons. First, as part of the installations, contractors were required to install instrumentation packages, and two power transducers and a propane flow meter were installed by the contractor at each site. While the actual number varied with the contractor, it added some cost to the bid and labor at all sites. Second, it is likely there was an additional “risk” cost added into these installations because the contractors were unfamiliar with cold-climate operation, and the set up and change point temperatures were outside of their comfort zone. Additionally, each contractor knew they were participating in a research project, and there was likely additional set up, field visits, and other costs associated with the research. All of these potential costs likely increased the overall installation cost. Table 9 shows the installation costs that were a part of this project. Removing the estimated cost for instrumentation, the average project cost for instrumentation was $12,625 for a new ccASHP and a new propane furnace for backup. For the reasons listed above, and included in the table notes below, these costs may not be representative of actual costs of a typical installation. They are included here as a reference point, but the installation costs used for analysis were taken from a national database (National Renewable Energy Laboratory 2014) and discussed below.

Table 9. Installation sots for installs conducted as part of this project

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.

The National Residential Efficiency Laboratory (NREL) developed a database to provide a national database of residential building measures and their associated costs. The data was not intended for specific cost estimates; it was used to, compare the relative cost effectiveness of different energy efficiency options. Cost data was collected from four different sources: resources on construction cost estimates; web-based quote estimate resources; NREL's home performance industry partner and distributors cost figures; and data from published reports (National Renewable Energy Laboratory 2014). Table 10 shows the relevant database costs from this project.

Table 10. Cost estimates from the NREL National Residential Efficiency Measures Database

Measure	Cost of Baseline	Cost of Efficiency Option	Description
Air Source Heat Pump	$2,994	$5,550	Base: 7.7 HSPF / 13 SEER, Eff: 9.5 HSPF / 19 SEER
Air Conditioning	$3,164	$5,180	Base: 13 SEER, Eff: 19 SEER
Propane Furnace	$2,060	$3,900	Base: 80% AFUE, Eff: 96% AFUE

According to NREL database, the average ccASHP (9.5 HSPF/ 19 SEER) with propane furnace back-up (AFUE 96%) costs $9,450 installed. Assuming an 18 year life expectancy (ASHRAE 2017) and the median cost savings from the metro area for this project ($329 compared to a condensing furnace) has about a $6,000 life time savings for a condensing furnace that is a savings to investment ratio of 0.63. Or $11,800 lifetime savings compared to an 82% AFUE furnace ($654/year) for a savings to investment ratio of 1.24. This ratio shows that the ccASHP will pay for itself over the lifetime of the equipment compared to a baseline furnace system. Additionally, in retrofit applications, the necessary replacement at the time of HVAC failure is a good opportunity to upgrade. Table 11 shows the simple paybacks for ccASHP at the time of replacement for an existing forced air system. Heat pumps have installed costs very similar to that of traditional split system air conditions with the same SEER value. If both the furnace and air conditioner at a site need replacement, the ccASHP systems have a simple payback of less than one year.

Table 11. Simple backup for ccASHP with a furnace backup

	Initial Cost	Incremental Cost	Simple Payback vs Cond. Furnace, years	Simple Payback vs 82% Furnace, years
No Failure	$9,450	$9,450	28.8	14.5
At A/C failure	$9,450	$4,270	13.0	6.5
At furnace failure	$9,450	$5,550	16.9	8.5
At furnace and A/C Failure	$9,450	$370	1.1	0.6

ccASHP Capacity

The capacity of each ducted ccASHP was compared to the heating load of the home. In general, the ccASHP ran at low capacity for long periods. Figure 21 shows the capacity of each ccASHP heating event compared to the daily heat load requirements of each site. Above 30ºF the ccASHPs typically operated in heat pump only mode at capacities greater that the heating load. Below the change point of 10 ^{o}F the backup system (Propane heating only) was used to meet the load. Between these temperature 30^{o}F and 10^{o}F the heat pump only events started to drop below the heating load of the home. In this temperature range there were also a large number of defrost events. These defrost cycles are any heating cycle where the defrost system was active. This includes events where the heat pump range for a period of time prior to the defrost event. Figure 21 shows that when OATs conditions were such that defrost was needed (10^{o}F to 30^{o}F) the heat pumps were running at higher capacity, but were also likely to require defrost operation for part of the heating event.

Figure 21. Heating capacity for each heating event compared the daily heating load of the home

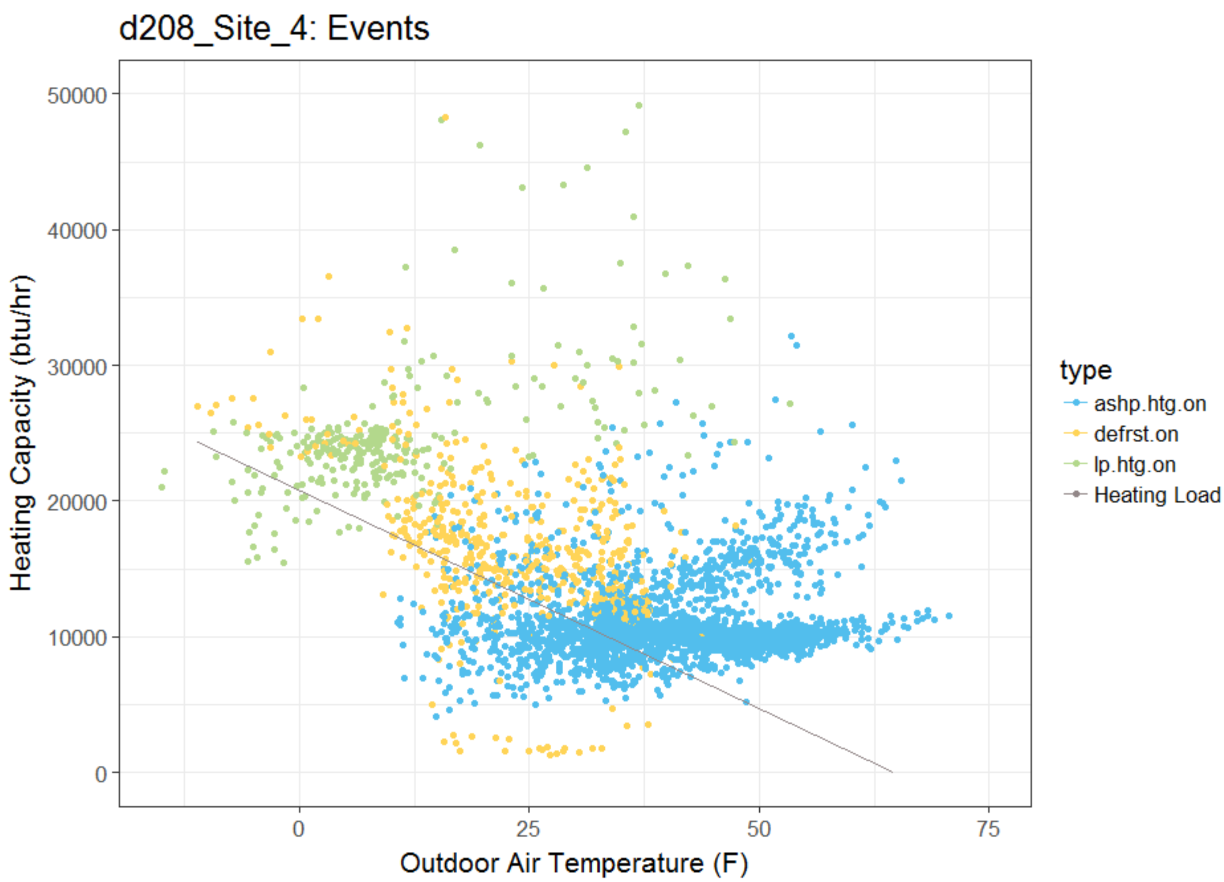


Figure 22. The fraction of heating system runtime met with the ASHP

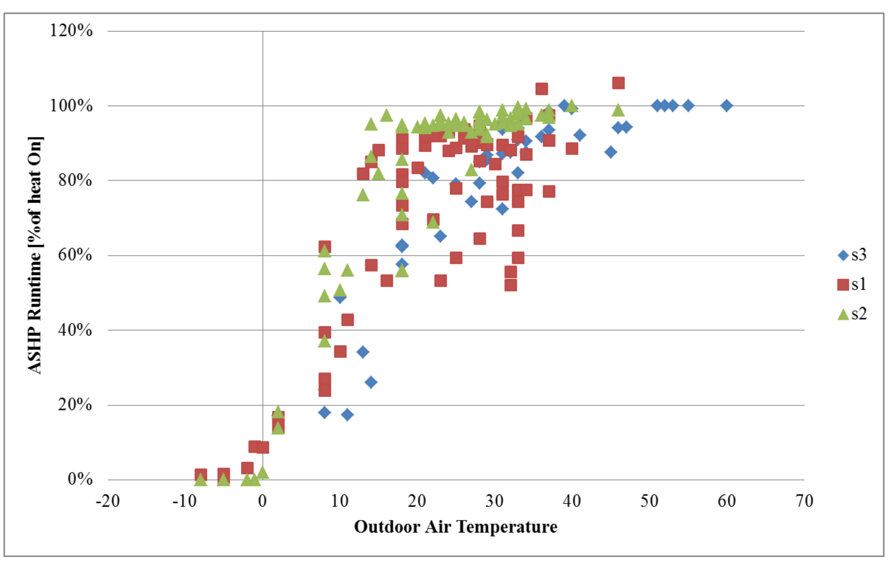
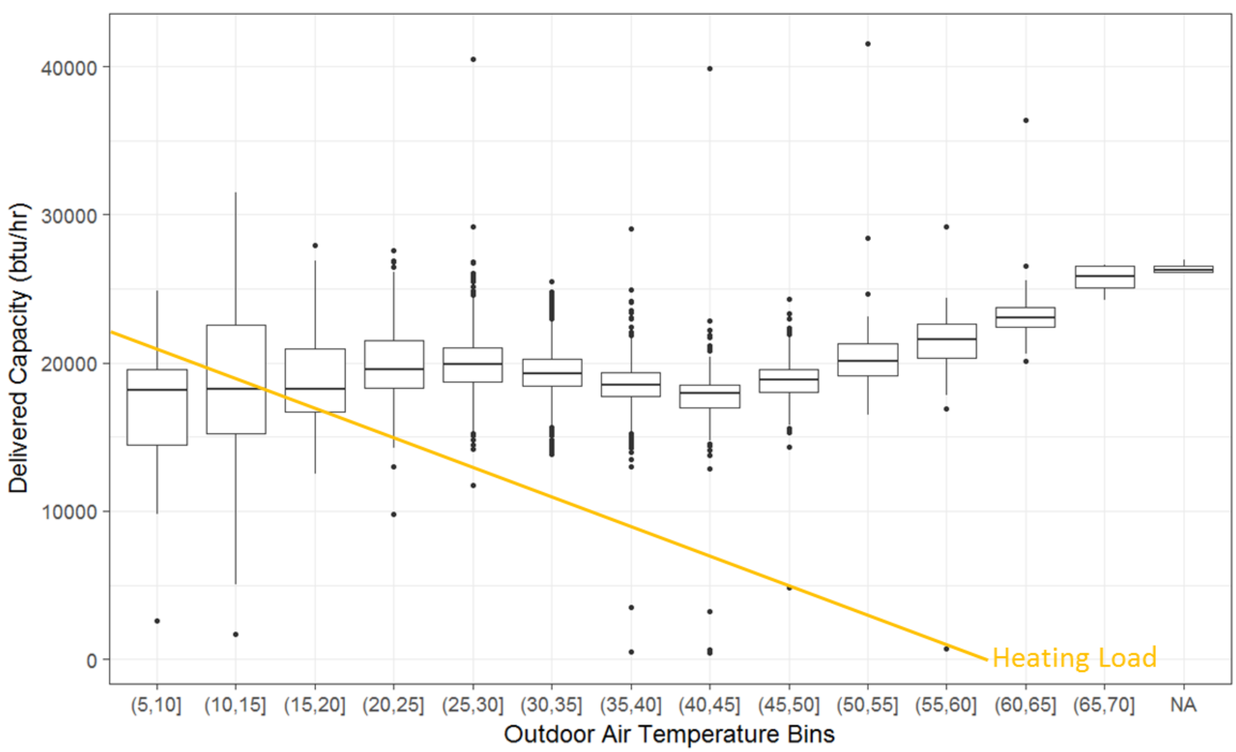


Figure 22 shows heat pump runtime as a percentage of the total heating system run time. There were two reasons for the backup system to operate instead of the ccASHP. The first was if the temperature dropped below the change-over point of 10ºF. The second was if for some reason the controls of the heating system preferred the backup over the ccASHP due to limited capacity, defrost, or some other reason. All six ccASHP rarely fired at maximum capacity, this was at least in part due to the heating loads of the homes being smaller than the load calculated from sizing. For example, the system installed using the heat pump specs in Figure 8 was sized based on a calculated design heating load of 35,500 Btu/hr (at -18^{o}F), but the analysis showed the actual heating load was only 24,306 at that condition. That was a 31% reduction in the necessary load, which meant that the system never needed to operate a maximum capacity. During the instrumentation verification the maximum capacities of the ccASHP were analyzed for each ccASHP. At each site the maximum capacity (determined by forcing high fire) was much greater that the highest capacities shown in typical heat pump only operation (Figure 21). The 4 Ton systems at Sites 1 and 2 fired at 55,000/hr Btu and 49,000 Btu/hr. The 3 Ton system at Site 3 delivered 38,000 Btu/hr during testing. Improved controls to prioritize ccASHP high capacity operation over backup heating would further increase the savings and reduction of delivered fuels. Additionally, lowering the switchover temperature for locking out the ccASHP could increase ccASHP usage.

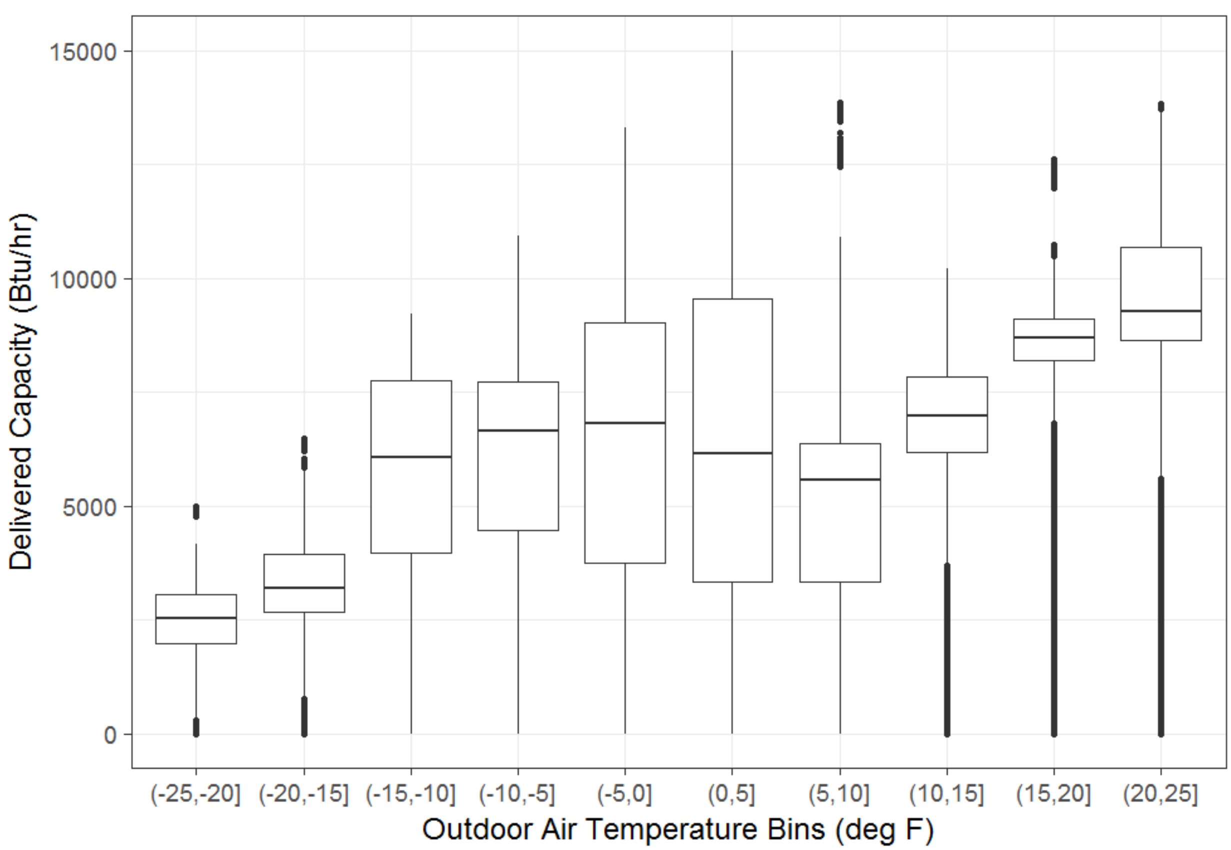
Figure 23. Heat pump delivered heating capacity compared to homes heating load for site_2_ducted



Comparing the heat pump's delivered capacity to the site's heating load was one way of looking at the ability of the heat pump to meet the load. Figure 23 shows this comparison for Site 2. When outdoor air temperatures were between 5^{o}F and 10^{o}F the heat pump delivered a median capacity of 19 kBtu/hr, with half of the cycles between 14kBtu/hr and 20 kBtu/hr and the system delivering capacity up to 25 kBtu/hr. At 10^{o}F the homes' heating load was 20.7 kBtu/hr. The heat pump had more capacity than necessary to heat the home at the changeover set point. The data was aggregated from the measured data in the field and should not be taken as an indication of the maximum capacity. Each system was able to meet the homes load at 10^{o}F, matching the design and sizing selections discussed in the installation section of this report. That is, the heat pump equipment performed as designed.

Figure 24 shows the same delivered capacity analysis for a ductless heat pump. It was difficult to determine the heating load of the ductless systems as the amount of electric resistance the system could offset was largely dependent on the installation. Because of this the comparison to the heating load was not conducted. As Figure 24 shows there was heating delivered by the heat pump, at Site 8, under very cold outdoor conditions, even below the systems rated range. While COP was lower in these conditions, the performance was still better than the electric resistance alternative. This unit had a capacity range up to 21,000 Btu/hr in moderate temperature conditions. At 5 ^{o}F the maximum capacity was 13,600 Btu/hr. Figure 24 shows between 0^{o}F and 5^{o}F the 1 ton ccASHP had a median capacity of 6,188 Btu/hr and a maximum capacity of 15,675 Btu/hr. Assuming that the heat pump was installed with proper sizing it was meeting the desired heating load. Additionally, the figure shows that the heat pump was still operational and delivering heat below the -13 ^{o}F minimum outdoor air temperature. This unit had an average output capacity of 3,735 btu/hr below -13 ^{o}F outdoor temps.

Figure 24. Cold weather capacity of a 1 ton ductless ccASHP at Site 8



Defrost

The defrost performance of cold climate air source heat pumps had a large impact on the heating performance of these system. Defrost is necessary to prevent frost build up in the outdoor unit. Frosting may lead to reduced performance and increased wear on the outdoor unit. All of these systems measured used air temperature measurements taken near the outdoor coil to determine when the defrost cycle should be run. For the systems monitored this meant the defrost came on whenever there was a potential for defrost which is much more conservative and consumes more energy than running only when defrost has actually started to accumulate.

Figure 16 shows the different operating efficiencies and temperature ranges of each mode of operation. In an ideal installation where defrost was not necessary the only back-up heating events would be the furnace events (in green) that occur below the changeover point of 10°F. This figure shows the fact that defrost cycles were creating back-up energy consumption between that change over point and 40 °F outdoor conditions.

Further analysis is necessary to determine the opportunity for reducing defrost runtime. Defrost cannot be completely eliminated, but there is room to reduce the operation. Any reduction in defrost runtime will result in an annual reduction of back-up energy use, operational cost, and site energy consumption. Table 12 shows the impact defrost operation has on the system's COP. These reduced COPs have a significant impact on the annual energy consumption at each site. On average the annual energy reduction would be reduced by 8.3% if defrost was eliminated from the ducted ccASHP systems (sites 1, 2, 3, and 4).

Table 12. Impact of defrost operation on COP at site 02

Outdoor Temperature Bins	COP of ccASHP only	COP of ccASHP with defrost
10°F to 20°F	1.86	1.65
20°F to 30°F	2.17	1.95
30°F to 40°F	2.44	2.31

Policy Analysis

Although there is currently no structure in place for achieving delivered fuel savings from ccASHPs for electric and natural gas utilities under CIP, Minnesota's policy commitment for energy efficiency goes well beyond CIP policy. There are several other Minnesota state policies that could help promote ccASHPs as a way for households using delivered fuels to save energy. For example, the Next Generation Energy Act of 2007 (Helty and Solon 2007), in addition to creating utility savings goals under CIP, set goals to reduce the use of fossil fuels per capita in Minnesota and outlined the state's interest in "increased efficiency in energy consumption" (Sec. 216c.05, subdiv. 1 and subdiv. 2) (Revisor of Statutes 2015). More recently, legislation enacted in 2015 commonly called the "Propane Bill" (HF 550) explicitly opened the door to displacing the use of fuels such as propane with a utility fuel source (natural gas). The "Propane Bill" defined an "energy improvement" as "the installation of infrastructure, machinery, and appliances that will allow natural gas to be used as a heating fuel on the premises of a building that was previously not connected to a source of natural gas" (Sec. 6, Subd. 5, (4)). This establishment of a public policy to allow expansion of a utility fuel source (natural gas) to displace propane and heating oil is analogous to allowing expansion of utility electric energy (via ccASHP equipment) to reduce reliance on the use of propane and heating oil. However, while there are several established state policies in Minnesota that support the concept of reducing the use of fossil fuels, such as propane and heating oil, there is still no established infrastructure or funding source for achieving savings. For ccASHPs, there is currently no way to recognize savings in the application of utility CIP savings goals.

There are areas in the CIP policy framework that could be amenable to recognizing delivered fuel savings from ccASHPs, even though there is no specific structure currently in place. The CIP statute defines "energy conservation" as "demand-side management of energy supplies resulting in a net reduction in energy use" [216B.241, subdivision 1(d)]. This does not restrict energy conservation to only electricity and natural gas. It goes on to define "energy conservation improvement" as "a project that results in energy efficiency ***or energy conservation***" [subdivision 1 (e), emphasis added]. Notably, the subsequent language in the statute setting minimum CIP spending requirements and energy savings goals all use the terminology "energy conservation improvement." This could open the door to some flexibility beyond direct electricity and natural gas savings. Additional components of the statue that would be supportive of fossil fuel savings include the requirement for inclusion of participant and "societal" benefits in determining cost-effectiveness [subdiv. 1c(f)], as well as the requirement for the Department of Commerce Commissioner to report "estimated carbon dioxide reductions" achieved by CIP programs [Subdiv. 1c(g)]. The DER has already allowed for a limited inclusion of savings from deliverable fossil fuels for electric utilities under CIP, in the case of low-income customers. In that policy guidance, DER included two particular rationales for allowing CIP to incorporate deliverable fuel savings: 1) an equity concern for ratepayers paying for CIP programs with little opportunity to benefit, and 2) benefits to customers and society from the "reduced consumption of fossil fuels (DER 2012)." These rationales would also apply to a ccASHP program under CIP.

CIP does allow for substantial authority for the Department of Commerce Commissioner to modify a utility's CIP energy savings goals. The pertinent language reads as follows: "In its energy conservation improvement plan filing, a utility or association may request the commissioner to adjust its annual energy-savings percentage goal based on its historical conservation investment experience, customer class makeup, load growth, a conservation potential study, *or other factors the commissioner determines warrants an adjustment*." [subdiv. 1c(d) emphasis added]. The statute does specify that a CIP plan must include savings of at least 1% of a utility's gross annual sales, and that these flexible elements would only apply above that 1% savings level. The statute goes on to list electric utility infrastructure projects and waste heat recovery as examples of types of additional projects that could be included under this flexibility. In summary, the existing CIP statute contains numerous elements that suggest it might be possible, and consistent with overall state policy objectives, to include delivered fuel savings from ccASHPs in a CIP program. Indeed, DER has already opened the door to that incorporation of delivered fuel savings in certain low-income programs.

As in many states, the potential for utilities promoting fuel-switching within an energy efficiency program has been a concern in Minnesota. The historical concerns focus on the possibility that a utility might use its energy efficiency programs as a means to lure customers away from a utility providing a different energy type, which could adversely affect the interests of the customers of the other utility (to whom regulators have some responsibility). These concerns are focused on the issue of fuel switching between electric and natural gas utilities (Docket No. G008/CIP-00-864.07), entities for which the state has specific regulatory responsibilities. An additional concern has been in regard to including cost-benefit analysis to ensure a net decrease in fuel consumption. Neither of these concerns should be an issue with a ccASHP program, as there is no second utility (i.e. on providing natural gas) involved and a new program would incorporate a net-Btu analysis. No specific rulings were found regarding programs that do not involve fuel switching between electric and natural gas utilities. Moreover, there is considerable support for the concept of using a multi-fuel net Btu savings basis for judging whether a project is desirable and cost-effective. Finally, as previously mentioned, Minnesota statute gives considerable discretion to the Department of Commerce Commissioner to approve alternative approaches in a utility CIP plan. The history of these issues in Minnesota suggests that it should be possible to avoid having the 'fuel switching' concern be a roadblock to the use of ccASHPs in the type of CIP program this study suggests.

Using the authority for flexibility provided in the CIP statute, a potential pilot program to promote ccASHPs may be feasible. The proposed programs should contain the following elements:

1. The program should target existing homes that use electricity, propane, or heating oil as their space heating fuel (not utility natural gas).
2. To help ensure that the program is genuinely focused on energy conservation, the program should include incentives and assistance to facilitate building shell conservation improvements (i.e., insulation and air sealing) in the homes that install ccASHPs.
3. Cost-effectiveness should be based on the total energy savings (electricity and heating fuel) of the package of measures installed in the home (ccASHPs plus any building shell conservation measures), net of any increase in electricity use from the ccASHP.
4. Any net electricity savings from the package should be directly credited toward the co-op's energy savings goal under CIP.

For full discussion of the policy of ccASHPs in Minnesota see ACEEE's full report in Appendix C.

Conclusions and Recommendations

Cold-climate air source heat pumps have been identified for their potential to provide significant energy and cost savings to homeowners without access to natural gas space heating. Additionally, ccASHP can reduce the reliance these homeowners have on delivered fuels, which can be costly in terms of price, emissions, and limited availability.

The project concluded that the measured performance of ccASHP installed in real homes confirms the potential to provide significant site energy savings (37% to 58% of space heating energy use) and cost savings (28% to 58% of space heating costs). Results also show that ccASHP reduce reliance on delivered fuels in 56% to 73% of homes. The reduced usage of propane could lead to even greater savings at times when limited availability makes propane unavailable or cost prohibitive.

Cold climate ASHP performance, in terms of efficiency and capacity, has made dramatic improvements in the last few years. These improvements opened new applications and system designs. More recently performance improvements have been incremental and future advances are likely to target improved applications with further improvement of the controls and integration with the backup systems which could result in increased utilization of the ccASHP. These improvements would provide less expensive installations leading to increased applications and even greater savings and further reductions of delivered fuel consumption.

Fuel switching considerations could have an impact on policies around ccASHP programs and market transformation. However, several precedents in affordable housing and emission reductions make programs feasible. Program managers are encouraged to look for opportunities were electrification, converting to an electric heating source, has significant benefits for the homeowner, utility and society.

For ccASHPs there are several important technical considerations. Because ccASHP performance is dependent on outdoor air temperature and how the system is integrated with the back-up it is important to carefully consider the savings for any program design.

Program options for CIP recommendations

- Consider additional metrics which account for benefits beyond site energy savings, including emission reductions, source energy savings, and costs.
- In instances where ccASHP are determined to be beneficial (ie switching off delivered fuels or replacing less efficient electric resistance heat) there are two options to ensure ccASHP installations that are capable of achieving good heating performance.
    - The program should specific installation requirements both on the technology as well as the installation.
- Technology: The heat pump shall be inverter drive, have a HSPF ≥ 8, and be sized to meet 100% of the homes heating load at outdoor temperatures ≤ 10 ^{o}F. If installation requires a back-up heating system to meet the homes load below 10 ^{o}F down to the design conditions (-11 ^{o}F in

metro area) the heat pump operation should be prioritized such that back up is only used when necessary.

- Or the program could take a tied approach where the expected savings and performance are based on a calculator or look-up table. Depending on the rated ccASHP performance, installation, and capacity of the ccASHP a tiered savings could be determined. The base level savings could be assumed for any heat pump installation, a larger second tier savings would be given if the equipment meet a minimum rated performance (i.e. HSPF ≥ 7) and the heat pump was installed such that it would meet the full load down to a heating moderate temperature (i.e OAT change point ≤ 25 ^{o}F), the largest savings tier would require the highest system performance (i.e. HSPF ≥ 9 and OAT change point ≤ 5 ^{o}F).These tiers and the performance metrics could be determined through the use of a calculator such as the one developed for this project should in Appendix B.

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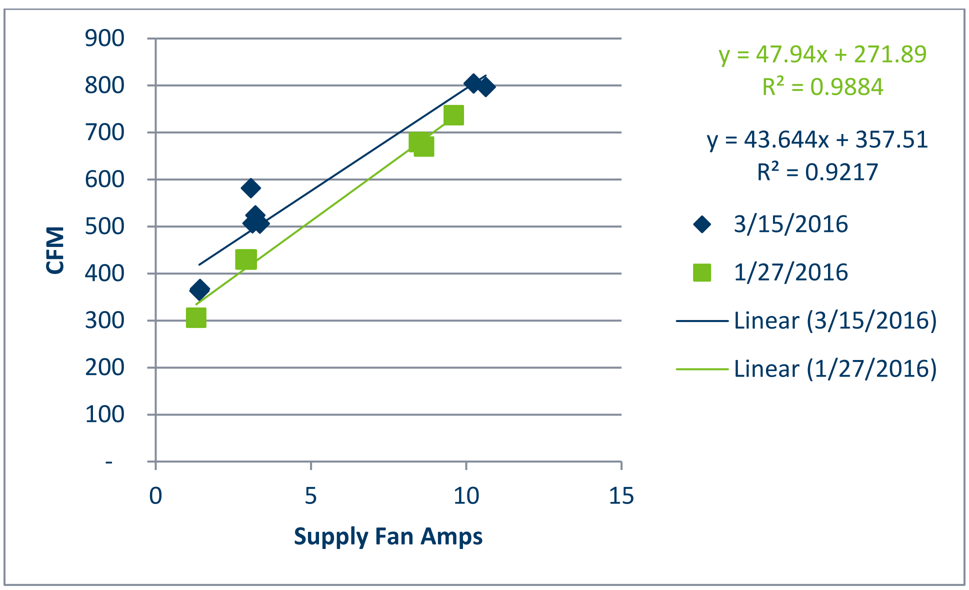
Appendix A: Airflow Methodology

Supply airflow is a crucial measurement for calculating ASHP COP and characterizing the performance of the system. It is difficult to get an accurate airflow value for the system due to the high variability of the flow at different parts of the system. CEE researchers have found that the most reliable way to get the accurate airflows is to correlate the flow to the current draw of the supply fan. A current transformer was installed on all systems to measure the current flowing to the supply fan and then correlated to spot airflow measurements that were taken at each site to create a fan curve.

Ducted systems

Spot airflow measurements were taken at the 4 sites with ducted systems with the system set to 'fan only'. Three speeds were tested; low, medium and high. The fan was turned on to each speed and a Trueflow plate was inserted into the filter slot to get the total system airflow in CFM. This value was recorded along with each supply fan current draw at all three speeds to create a fan curve for each site. Regression equations were then used to calculate the system airflow in CFM.

Figure 25. Measured airflow vs supply fan amps



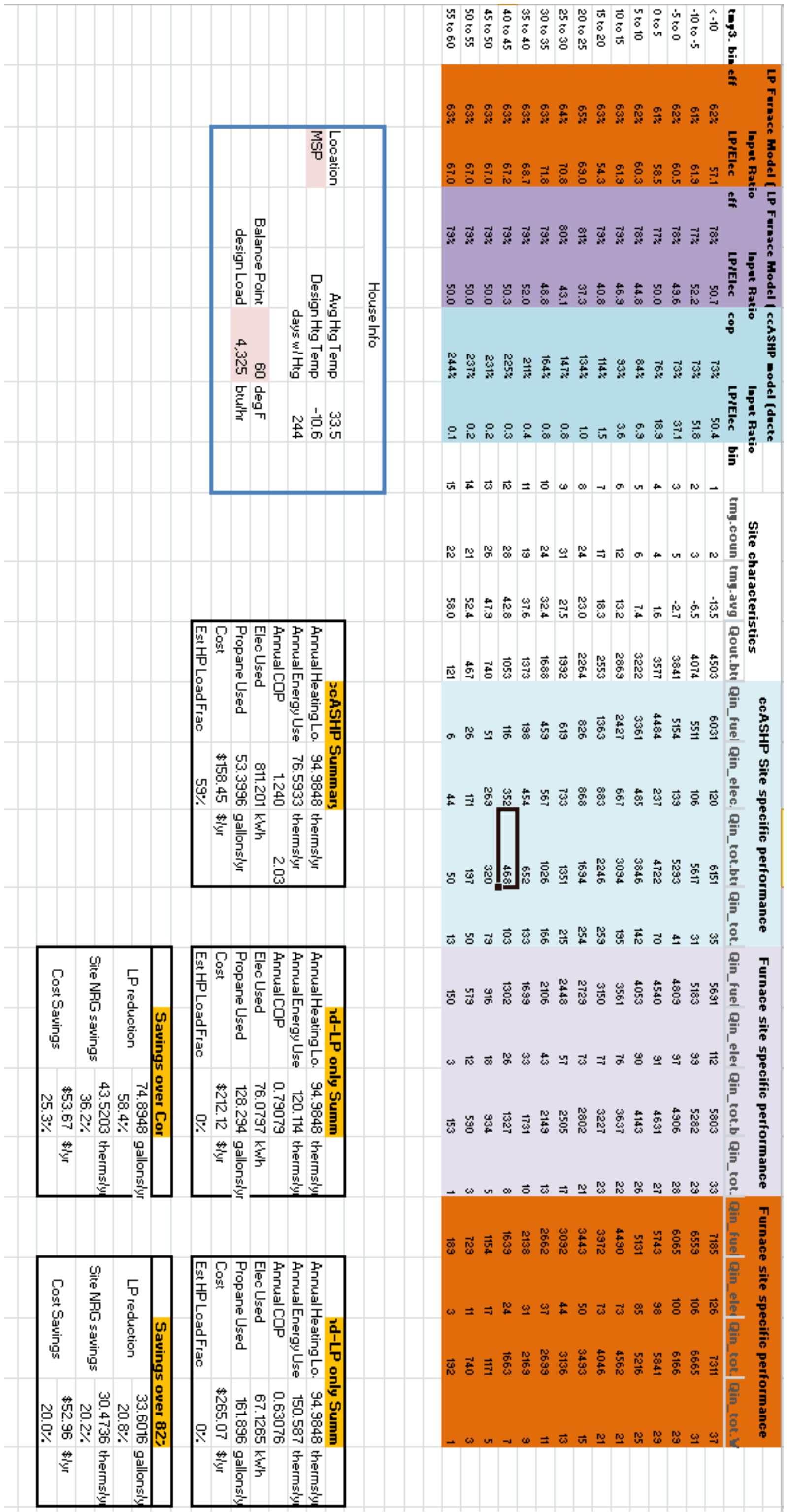
Ductless Systems

Two of the test sites have ductless systems which require a different process to determine the airflow of the system due to the fact that there is not a standard filter slot. The research team used a garbage bag and a Duct Blaster fan to measure the flow of the system. The bag was taped around the bottom of the unit to capture all of the supply airflow. The fan was turned on at one of the four speeds and the bag filled with air, meanwhile the Duct Blaster fan was turned on to depressurize the bag. Once the pressure in the bag reached zero, the airflow of the Duct Blaster fan equaled the overall flow of the system. This was repeated for all four fan speeds and system airflow was calculated using the same procedure as with the ducted systems.

Figure 26. Ductless airflow measurement

Appendix B: ccASHP Calculation Spreadsheet

Figure 27. Screen-shot of the ccASHP calculation sheet



	LP Furnace Model (		LP Furnace Model (		ccASHP model (ducte			Site characteristics			ccASHP Site specific performance			
		Input Ratio		Input Ratio		Input Ratio								
tmy3. bin	eff	LP/Elec	eff	LP/Elec	cop	LP/Elec	bin	tmy.coun	tmy.avg	Qout.btu	Qin_fuel	Qin_elec.	Qin_tot.btu	Qin_tot.
< -10	62%	57.1	78%	50.7	73%	50.4	1	2	-13.5	4503	6031	120	6151	35
-10 to -5	61%	61.9	77%	52.2	73%	51.8	2	3	-6.5	4074	5511	106	5617	31
-5 to 0	62%	60.5	78%	49.6	73%	37.1	3	5	-2.7	3841	5154	139	5293	41
0 to 5	61%	58.5	77%	50.0	76%	18.9	4	4	1.6	3577	4484	237	4722	70
5 to 10	62%	60.3	78%	44.8	84%	6.9	5	6	7.4	3222	3361	485	3846	142
10 to 15	63%	61.9	79%	46.9	93%	3.6	6	12	13.2	2869	2427	667	3094	195
15 to 20	63%	54.3	79%	40.8	114%	1.5	7	17	18.3	2553	1363	883	2246	259
20 to 25	65%	69.0	81%	37.3	134%	1.0	8	24	23.0	2264	826	868	1694	254
25 to 30	64%	70.8	80%	43.1	147%	0.8	9	31	27.5	1992	619	733	1351	215
30 to 35	63%	71.8	79%	48.8	164%	0.8	10	24	32.4	1688	459	567	1026	166
35 to 40	63%	68.7	79%	52.0	211%	0.4	11	19	37.6	1373	198	454	652	133
40 to 45	63%	67.2	79%	50.3	225%	0.3	12	28	42.8	1053	116	352	468	103
45 to 50	63%	67.0	79%	50.0	231%	0.2	13	26	47.9	740	51	269	320	79
50 to 55	63%	67.0	79%	50.0	237%	0.2	14	21	52.4	467	26	171	197	50
55 to 60	63%	67.0	79%	50.0	244%	0.1	15	22	58.0	121	6	44	50	13

	Furnace site specific performance				Furnace site specific performance			
tmy3. bin	Qin_fuel	Qin_elec	Qin_tot.b	Qin_tot.	Qin_fuel	Qin_elec	Qin_tot.	Qin_tot.W
< -10	5691	112	5803	33	7185	126	7311	37
-10 to -5	5183	99	5282	29	6559	106	6665	31
-5 to 0	4809	97	4906	28	6065	100	6166	29
0 to 5	4540	91	4631	27	5743	98	5841	29
5 to 10	4053	90	4143	26	5131	85	5216	25
10 to 15	3561	76	3637	22	4490	73	4562	21
15 to 20	3150	77	3227	23	3972	73	4046	21
20 to 25	2729	73	2802	21	3443	50	3493	15
25 to 30	2448	57	2505	17	3092	44	3136	13
30 to 35	2106	43	2149	13	2662	37	2699	11
35 to 40	1699	33	1731	10	2138	31	2169	9
40 to 45	1302	26	1327	8	1639	24	1663	7
45 to 50	916	18	934	5	1154	17	1171	5
50 to 55	579	12	590	3	729	11	740	3
55 to 60	150	3	153	1	189	3	192	1

House Info

Location	Avg Htg Temp	33.5	
MSP	Design Htg Temp	-10.6	
	days w/ Htg	244	
	Balance Point	60	deg F
	design Load	4,325	btu/hr

ccASHP Summary			
Annual Heating Lo.	94.9848	therms/yr	
Annual Energy Use	76.5933	therms/yr	
Annual COP	1.240		2.03
Elec Used	811.201	kWh	
Propane Used	53.3996	gallons/yr	
Cost	$158.45	$/yr	
Est HP Load Frac	59%		

nd-LP only Summ		
Annual Heating Lo.	94.9848	therms/yr
Annual Energy Use	120.114	therms/yr
Annual COP	0.79079	
Elec Used	76.0797	kWh
Propane Used	128.294	gallons/yr
Cost	$212.12	$/yr
Est HP Load Frac	0%	

nd-LP only Summ		
Annual Heating Lo.	94.9848	therms/y
Annual Energy Use	150.587	therms/y
Annual COP	0.63076	
Elec Used	67.1265	kWh
Propane Used	161.896	gallons/y
Cost	$265.07	$/yr
Est HP Load Frac	0%	

Savings over Cor		
LP reduction	74.8948	gallons/yr
	58.4%	
Site NRG savings	43.5203	therms/y
	36.2%	
Cost Savings	$53.67	$/yr
	25.3%	

Savings over 82%		
LP reduction	33.6016	gallons/y
	20.8%	
Site NRG savings	30.4736	therms/y
	20.2%	
Cost Savings	$52.96	$/yr
	20.0%	

Appendix C: Policy Analysis

Analysis of Policy and Potential for an Electric Co-Op Air Source Heat Pump Pilot Program to be Incorporated into Minnesota's CIP Structure

Technological Opportunity

Advancements in technology for Air Source Heat Pumps (ASHPs) create the potential for substantial energy efficiency gains in cold climate states such as Minnesota. Due to improvements in such areas as refrigerants and variable speed drives, the new cold-climate ASHPs can function at temperatures of 0 degrees Fahrenheit or below, and can save 60 to 80% of space heating fuel use or more.

The potential for ASHPs to contribute energy savings for Minnesota is very large. Over 12 % of Minnesota homes heat with electricity, and another 16% heat with either oil or propane. Together these represent over 547,000 Minnesota homes. For oil and propane alone, Minnesota homes spent over $660 million in 2013. The new advanced cold-climate ASHPs provide an opportunity for significant energy and dollar savings for Minnesota households, and for the state economy.

CEE is presently conducting field trials of ASHP units in a sample of Minnesota homes. If the results of the field trials document the potential for cost-effective energy efficiency gains, the question then becomes: what policies could be utilized to facilitate the capture of those energy efficiency savings for Minnesota?

State Policy Framework in Minnesota

The Conservation Improvement Program (CIP)

Minnesota has a long history of a strong policy commitment to energy efficiency. In many respects, the Conservation Improvement Program (CIP) policy for electric and natural gas utilities has been the cornerstone of energy efficiency policy in Minnesota.

CIP has been in operation since the 1980s and was incorporated by Governor Pawlenty into the Next Generation Energy Initiative of 2007. CIP serves utility ratepayers by avoiding unnecessary and expensive infrastructure investments. By all accounts, the Minnesota CIP policy has been very effective at achieving electricity and natural gas savings in Minnesota.

Gaps in Minnesota's CIP Policy Framework with Regard to ASHPs

The Minnesota CIP policy is directed toward electric and natural gas utilities. While ASHPs do provide some electricity savings (from air conditioning load, and to the extent they replace other electric space heating technologies), much of their energy savings (and overall cost-effectiveness) comes from displacing other space heating fuels that are less efficient (e.g., oil, propane and natural gas). At present, with a limited exception for certain low-income customers[2], there is no way to credit savings in deliverable fuels (e.g., oil and propane) toward a utility's CIP goals.

A possible additional impediment to the use of ASHPs under CIP is the issue of fuel switching. Historically in Minnesota, using a CIP program to encourage a customer to switch fuel sources between electric and natural gas utilities is at least discouraged, if not prohibited. This issue will be discussed further in a later section.

To summarize, while CIP provides an excellent policy structure for achieving electricity and natural gas savings, Minnesota has no comparable structure or funding for achieving heating oil and propane savings. Yet as we've seen in recent years, heating oil and propane costs can be quite a burden on Minnesota customers.

Other Minnesota Policies for Energy Efficiency

Fortunately, it is the case that Minnesota's policy commitment for energy efficiency goes beyond just the CIP policy for those two utility energy sources (electricity and natural gas). Several of these other policies could be seen as providing support for the concept of encouraging the use of ASHPs to save energy fuels such as heating oil and propane.

For example, the Next Generation Energy Act of 2007 declared that "the state has a vital interest in providing for increased efficiency in energy consumption…", and established a goal for reduction in "per capita use of fossil fuel…" (Sec. 216c.05, subdiv. 1 and subdiv. 2).

In addition, Minnesota has established a very strong policy commitment regarding the reduction of greenhouse gases. As an example, that Next Generation Energy Act also established very aggressive goals for reduction in "statewide greenhouse gas emissions across all sectors" (Sec. 216H.02, subdiv. 1)

Most recently, in 2015 legislation was enacted (HF 550, commonly known as the "Propane bill") which explicitly opened the door to displacing the use of other fuels, such as propane, with a utility fuel source. For example, in the definition of "Energy improvement", it included: "the installation of infrastructure, machinery, and appliances that will allow natural gas to be used as a heating fuel on the premises of a

[2] In an August 3, 2012 policy guidance memorandum, DER declared that electric utilities could provide energy efficiency measures to low-income customers that used delivered fuels for space and water heat, in conjunction with the Weatherization Assistance Program, and claim electric savings toward their CIP goals.

building that was previously not connected to a source of natural gas." (Sec. 6, Subd. 5, (4)) This establishment of a public policy to allow expansion of a utility fuel source (natural gas) to displace propane (and heating oil) use would be analogous to allowing expansion of utility electric energy (via ASHP equipment) to similarly reduce reliance on propane and heating oil use.

Clearly, there are several established state policies in Minnesota that support the concept of reducing the use of fossil fuels such as propane and heating oil. The problem is that there is no established infrastructure and funding source for achieving those savings - - such as exists for electricity and natural gas under CIP. In the case of ASHPs, there is a technology that could achieve substantial savings in those fossil fuels (and their associated greenhouse gas emissions), but there is no present way to recognize those savings in the current application of utility CIP savings goals.

This raises the question: would it be possible to modify the CIP operating protocols such that the fossil fuel savings from ASHPs could be recognized and credited toward utility CIP goals?

Areas Where CIP Policy Framework Could be Amenable to Fossil Fuel Savings from ASHPs

To begin, the CIP statute defines "Energy conservation" as "demand-side management of energy supplies resulting in a net reduction in energy use" [216B.241, subdivision 1(d)]. This does not restrict energy conservation to only electricity and natural gas.[3] It goes on to define "Energy conservation improvement" as "a project that results in energy efficiency ***or energy conservation***" [subdivision 1 (e), emphasis added].

Notably, the subsequent language in the statute setting minimum CIP spending requirements and energy savings goals all uses the terminology "energy conservation improvement". This would seem to open the door to some flexibility beyond direct electricity and natural gas savings.

Indeed, there are several examples of just such flexibility. The statute allows for "waste heat recovery" to be an energy conservation improvement. [216B.241 subdivision 1(e) and subdivision 10]; allows for natural gas utilities to claim purchases of biomethane as a CIP measure [subdivision 5b]; and allows electric co-ops to count community solar projects toward their CIP savings goal [subdivision 5c(2)(c)].

Additional components of the statute that would be supportive of fossil fuel savings include the requirement for inclusion of participant and "societal" benefits in determining cost-effectiveness [subdiv. 1c(f)], and the requirement for the Commissioner to report "estimated carbon dioxide reductions" achieved by the CIP programs [Subdiv. 1c(g)].

[3] This is distinct from the subsequent definition of "energy efficiency", which does specifically mention "electric energy or natural gas".

Interestingly, as previously noted, the DER has already provided[4] for a limited inclusion of savings in deliverable fossil fuels for electric utilities under CIP, in the case of low-income customers. In that policy guidance, the DER included two particular rationales for allowing CIP to incorporate deliverable fuel savings:

1. An equity concern for ratepayers paying for CIP programs but with little opportunity to benefit:

> "First, electric utility customers that use delivered fuels for their space and water heating equipment do not have access to ratepayer-funded programs that address their space and water heating equipment because CIP requirements do not apply to delivered fuels providers." (p.1), and

2. Benefits to customers and society:

> "However, there is opportunity for these customers to benefit from reduced energy consumption and resulting reductions in fuel expenses, and there is opportunity for society to benefit from reduced consumption of fossil fuels." (p.2)

We would note that those two rationales provided by DER for allowing CIP credit for deliverable fuel savings would also apply to the ASHP program envisioned in this report.

Finally, as another example of "benefits to customers and society" - - with regard to the CIP statute mention of "demand side management" - - ASHP technology can be (and already is in some cases) incorporated into load management programs, whereby both summer and winter electric peak load management benefits can be obtained.

Authority for Further Flexibility Under CIP

Finally, it is important to recall that the statute explicitly provides substantial authority for the Commissioner to modify a utility's CIP energy savings goals. The pertinent language reads as follows:

"(d) In its energy conservation improvement plan filing, a utility or association may request the commissioner to adjust its annual energy-savings percentage goal based on its historical conservation investment experience, customer class makeup, load growth, a conservation potential study, ***or other factors the commissioner determines warrants an adjustment***." [subdiv. 1c(d) emphasis added]

Importantly, the statute does specify that a CIP plan must include savings of at least 1% of a utility's gross annual sales, and that these flexible elements would only apply above that 1% savings level. The statute goes on to list electric utility infrastructure projects and waste heat recovery as examples of types of additional projects that could be included under this flexibility.

[4] CIP Policy Guidelines: Energy Savings from Delivered Fuels, Minnesota Division of Energy Resources, August 3, 2012.

In summary, the existing CIP statute contains numerous elements that suggest it might be possible, and consistent with overall state policy objectives, to include fossil fuel savings from ASHPs in a CIP program. Indeed, the DER has already opened the door to that incorporation of fossil fuel savings in certain low-income programs.

The Fuel Switching Issue

As in many states, the potential for utilities promoting fuel-switching within an energy efficiency program has been a concern in Minnesota. The concern focuses on the possibility that a utility might use its energy efficiency programs as a means to lure customers away from a utility providing a different energy type, which could adversely affect the interests of the customers of the other utility (to whom regulators have some responsibility). That concern should not be an issue with the ASHP program being contemplated here, as there is no second utility involved. Moreover, a careful look at the history of this issue in Minnesota suggests that it should be possible to avoid having the 'fuel switching' concern be a roadblock to the use of ASHPs in the type of CIP program we are suggesting.

Our analysis of this issue begins with an October 29, 2003 Staff memorandum and accompanying report by the Minnesota Department of Commerce. The general issue at hand was "cross-fuel conservation", and the specific precipitating incident was a Minnegasco program to rebate electricity-driven equipment. The concern expressed was that Minnegasco did not net out the increase in one fuel that occurred with the decrease in the other fuel.

"…Advocacy Staff…noted that Minnegasco did not take into account the source Btus that were used to generate the electricity for the equipment" and recommended that "the Commissioner require Minnegasco to account for the increase in electric use as well as the decrease in gas use when performing a benefit-cost analysis." (p.1)

This concern would not be a problem for the ASHP program being contemplated here, as the program would be required to demonstrate cost-effectiveness considering the net impact on all fuels.

The precipitating incident led to a Commissioner request for a meeting of interested parties, which subsequently produced a report entitled "Report to the Commissioner of the Department of Commerce: BTU Comparison in a Benefit-Cost Analysis for the Conservation Improvement Program, Docket No. G008/CIP-00-864.07"

The report ultimately contained a recommendation against utility fuel switching programs, but opened the door to "fuel neutral conservation", which it defined as follows:

"Fuel-neutral conservation occurs when a utility provides a rebate for an energy-efficient measure regardless of the fuel source and of whether that utility is the provider of that fuel source." (p.2)

It also recognized that fuel switching could be cost-effective from a societal perspective:

"…fuel switching has been defined as "converting customers from one fuel to another when the costs of conversion are less than the costs to society of not converting." (p.2)

Thirdly, it called for the use of a "net Btu analysis" when a measure decreased the use of one utility's fuel and increased the use of another utility's fuel, and concluded:

"If the measure is cost-effective from a societal perspective, then a utility could issue a grant, loan or other incentive to the customer." (p.3)

The ASHP program being contemplated would be cost-effective from a societal perspective, and would incorporate a net Btu analysis.

Finally, it should be noted that the entire discussion focused on the issue of fuel switching regarding electric and natural gas utilities…entities for which the state has specific regulatory responsibilities. The ASHP program being contemplated does not involve any fuel switching between electric and gas utilities.

The next document considered in this review was the March 7, 2005 Commission Order in Docket No. G008/CIP-00-864.07. There the Commission stated that "Targeted fuel-switch projects are not allowed in the Conservation Improvement Program."

Here again, the order is explicitly in the context of fuel switching between electric and natural gas utilities. It does not broach the issue of fuel use changes involving other unregulated fuel sources. Moreover, the ASHP program being contemplated is not merely a "switch" of fuel types. It involves substantial conservation of the electric co-ops electricity, through dramatic improvement in air conditioning efficiency, and through the incorporation of building shell measures, where appropriate.

Furthermore, it is noteworthy that the Order does open the door to recognizing the value of projects that require saving more than one fuel type in order to be cost-effective.

"Projects that may deem it necessary to have a combination of natural gas and electric energy savings for the integrity of the project will submit that project to the Minnesota Department of Commerce for review. Upon completion of the review, the Deputy Commissioner will issue a decision on the project, including a limit on expenditures for the project." (p.2)

Finally, the order concludes with an explicit statement that the Department does not want to discourage programs that save multiple fuels.

"The intention of the Department is to encourage energy-saving projects that will continue to provide specific optimal energy savings while not discouraging programs that save both electricity and natural gas." (p.3)

The final document we would note is an October 8, 2013 posting by the Minnesota Department of Commerce[5], addressing the issue of combined heat and power systems and the implications for fuel neutrality and fuel switching. The document notes the historical prohibition on fuel switching in CIP, and that “unlike traditional natural gas efficiency programs, CHP will likely increase the natural gas consumption.”

Importantly, the entire focus of the discussion is once again on the effect of fuel switching between electric and natural gas utilities.

“How should fuel switching concerns be handled so that one utility customer of a specific fuel type (electric) is not subsidizing the cost of CHP project incentives or utility load building that may be provided to another utility customer for a different fuel type (natural gas)?” (p.4)

Clearly that electric vs. gas utility customer protection issue is not a concern for the ASHP program being contemplated here, as there is no natural gas utility involvement.

In addition, this document once again emphasizes the need to consider the net change in total energy consumption after considering any increases and decreases in the use of different types of fuels (p.4). That is what is being proposed for the ASHP program being contemplated here.

Lastly, the document also explicitly notes as a rationale for CHP that “these improvements can lead to a reduction in carbon emissions and greenhouse gases while helping Minnesota achieve its energy policy goals.” (p.2) That is a rationale that applies to the ASHP program as well.

In summary, while there is technically a history of prohibition against programs featuring targeted fuel switching between electric and natural gas utilities, we could find no specific rulings regarding programs that do not involve a fuel switch between electric and natural gas utilities. Moreover, we found considerable support for the concept of using a multi-fuel net Btu savings basis for judging whether a project is desirable and cost-effective. Finally, as previously noted, Minnesota statute gives considerable discretion for the Commissioner to approve alternative approaches in a utility’s CIP plans (e.g., waste heat recovery, biomethane gas production, community solar, etc.)

For all of these reasons, we believe that the historical concern regarding fuel switching between utilities should not be a barrier to the ASHP program being contemplated here.

Other Benefits to Minnesota

In addition to serving the broad state policies of reducing fossil fuel use and reducing greenhouse gas emissions, increasing the use of ASHPs can provide other economic benefits to the state as well. Data from the U.S. Energy Information Administration confirms that Minnesota has to import 100% of the heating oil and propane consumed in the state. In recent years, Minnesota households have spent over $660 million on heating oil and propane. To the extent that ASHPs can reduce that dollar drain, that

[5] MDOC DOER *Energy Savings Goal Study* call for comments.

would keep more money circulating in the Minnesota economy. This type of concern was no doubt part of the rationale for the "Propane Bill" HF 550 mentioned earlier.

There seems little doubt that reducing the importation of propane and heating oil from other states would be beneficial to the state of Minnesota. The pertinent question is: could the cornerstone energy conservation policy vehicle in Minnesota…the CIP program…be utilized to help achieve that objective?

Recommendations

Based on the results of our review, we would recommend the following.

Using the authority for flexibility provided in the CIP statute [216B.241, Subdivision 1c(d)], one or more electric co-ops should submit in their CIP plan filings, proposals for pilot programs to promote ASHPs. The proposed programs should contain the following elements.

1. The program should be targeted to existing homes that use electricity, propane or heating oil as their space heating fuel (not utility natural gas)[6]. All income levels would be eligible.
2. To help ensure that the program is genuinely focused on energy conservation, the program should include incentives and assistance to facilitate building shell conservation improvements (i.e., insulation and air sealing) in the homes that install ASHPs. (The Department may want to consider making the installation of any cost-effective shell improvements a pre-condition for receiving the ASHP incentive.)
3. Cost-effectiveness would be based on the total energy savings (electricity and heating fuel) of the package of measures installed in the home (ASHPs plus any building shell conservation measures), net of any increase in electricity use from the ASHP.
4. Any net electricity savings from the package would be directly credited toward the co-op's energy savings goal under CIP.
5. As long as the co-op meets the minimum 1% electricity savings from its normal CIP programs, any net savings in propane or heating oil from this ASHP program could be applied to the co-op's CIP energy savings goal above the 1% level (using an appropriate mmbtu to kWh conversion).

Attachment A provides a generic example description of the type of program envisioned in the above recommendation.

[6] Because Minnesota already has an effective policy structure and funding source for achieving natural gas savings, and because including natural gas would raise concerns about fuel switching between utilities, we are recommending that these pilot projects not target homes heated with utility natural gas.

Example Air Source Heat Pump (ASHP) Pilot Program[7]

Utility XYZ has a special energy saving program for customers that heat primarily with electricity, propane or fuel oil. Save on your heating and cooling bills by participating in our new high efficiency air source heat pump (ASHP) program.

Improve the comfort, safety and durability of your home with energy saving measures such as air source heat pumps, air sealing, ceiling insulation and wall insulation to earn rebates up to $__________.

Program	Amount	Product
Proper Installation Rebate	$50 rebate	Proper installation of ENERGY STAR® ASHP) **[e.g., ACCA MANUAL J AND MANUAL S REQUIREMENTS]**
ENERGY STAR® ASHP Rebate	$400 rebate	ENERGY STAR® ASHP **[MAY WANT TO SPECIFY DIFFERENT REBATE LEVELS FOR DIF. TIERS OF SEER, EER AND HSPF]**
Combo Rebate on ENERGY STAR® ASHP and ECM Fan Motor	$400 rebate for ENERGY STAR® ASHP (plus $200 rebate for new ECM Fan Motor)	Proper installation of ENERGY STAR ® ASHP with integrated all season, whole house applicable ECM Fan Motor on existing forced air furnace
Combo Rebate on New Forced Air Furnace with ECM Fan Motor and Properly Installed ENERGY STAR® ASHP	$600 rebate	New forced air furnace with ECM fan motor and properly installed ENERGY STAR® ASHP
Mini-Split Ductless ASHP System Rebate	$500 rebate	Mini-split ductless system for homes that do not have ducts **Note:** Electricity must be the existing primary heating source
Ceiling Insulation	$400 rebate	**[GIVE ANY DETAILS HERE]**

[6] This is just a generic program example. Specific details could vary, including rebate amount and equipment specification.

Wall Insulation	$400 rebate	**[GIVE ANY DETAILS HERE]**
Air Sealing with Blower Door Test	$200 rebate	**[GIVE ANY DETAILS HERE]**

IMPORTANT to advise customers: If an ASHP is the main heating source, customer will need a backup heat source when temperatures are below XX°F, typically mid-November through mid-March.

Additional Details on Program Rebates Available

(Note: homes heated with utility natural gas are not eligible for this special program.)

Proper Installation Rebate - $50

Offers a $50 rebate on the proper installation of an ENERGY STAR® Air Source Heat Pump (ASHP). The ASHP can be furnace integrated or mini-split ductless.

Customer must purchase and have installed a new ENERGY STAR® ASHP by **[DATE]**. Customer must use a program participating contractor to qualify for the rebate. Contractors will complete the paperwork necessary for the rebate.

ENERGY STAR® ASHP Rebate - $400

Offers a $400 rebate on ENERGY STAR® qualified, furnace integrated Air Source Heat Pumps (ASHP) with proper installation.

Customer must purchase and have installed a new ENERGY STAR® qualified, furnace integrated ASHP by date. Customer must use a program participating contractor to qualify for the rebate. Contractors will complete the paperwork necessary for the rebate.

Applies to both replacement of non-ENERGY STAR® ASHPs and new ASHPs.

Combo Rebate on ENERGY STAR® ASHP with New ECM Fan Motor - $600

Offers a $600 combo rebate on the proper installation of a new ENERGY STAR® qualified, furnace integrated Air Source Heat Pump (ASHP) plus an all season, whole house applicable Electronically Commutated Fan Motor (ECM) in an existing, non-electric forced air furnace.

Customer must purchase and have installed a new ENERGY STAR® qualified, furnace integrated ASHP plus an all season, whole house applicable ECM in an existing, non-electric forced air furnace by date. Customer must use a program participating contractor to qualify for the rebate. Contractors will complete the paperwork necessary for the rebate.

Applies to both replacement of non-ENERGY STAR® ASHPs and new ASHPs.

Combo Rebate on ENERGY STAR® ASHP and ECM Fan Motor in New Forced Air Furnaces - $600

Offers a $600 combo rebate on new forced air furnaces (gas, propane, or oil) with integrated Electronically Commutated Fan Motors (ECM) and properly installed of a new ENERGY STAR® qualified furnace integrated Air Source Heat Pump (ASHP).

Customer must purchase and have installed a new forced air furnace with an integrated ECM and properly installed new ENERGY STAR® qualified furnace integrated ASHP by date. Customer must use a program participating contractor to qualify for the rebate. Contractors will complete the paperwork necessary for the rebate.

New Mini-Split Ductless ASHPs for Homes with Electricity as the Primary Heating Source - $500

Offers a $500 rebate on Mini-Split Ductless Air Source Heat Pump (ASHP) systems for homes that do not have ducts and have electricity as the primary heating source and a minimum of two indoor units. Includes mini-split ductless heat pumps with electric baseboard/radiant heating, slab heating or electric boiler as the primary heating system. New installations only.

Customer must purchase and have installed a new qualifying Mini-Split Ductless ASHP (SEER $\geq$ 16 and HSPF $\geq$ 9). Customer must use a program participating contractor to qualify for the rebate. Contractors will complete the paperwork necessary for the rebate.