Air Source Heat Pump Efficiency Gains from Low Ambient Temperature Operation Using Supplemental Electric Heating

Final Study Report

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Prepared by:

Franklin Energy
Experience. Delivery. Results.

Principal Authors:

Mark Brown
Franklin Energy Services, LLC

Max Burke-Scoll
Franklin Energy Services, LLC

Jim Stebnicki
Franklin Energy Services, LLC

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Please send inquiries to: mbrown@franklinenergy.com or jstebnicki@franklinenergy.com

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Executive Summary

This report highlights the opportunity for hybrid heating systems coupling air source heat pumps (ASHPs) with supplemental variable electric heating to contribute to improved electric heating efficiency. While ASHPs have typically been more common in warmer climates as an efficient cooling system, advances in technology and the availability of thermal electric storage and variable electric furnaces continue to make air source heat pumps a viable means for efficient heating in cold climates. Given the electric efficiency potential, hybrid ASHP systems present an opportunity for ratepayer-funded energy efficiency programs to support adoption and associated energy savings.

The team conducted a study that involves three discrete paths of investigation. First, the research team coordinated with utility partners to collect electric utility billing data to evaluate the impact of hybrid ASHP system installation on energy use. Second, a customer satisfaction survey was executed to gain greater insight on user satisfaction and decision making related to the installation of hybrid ASHP electric heating systems. Finally, data was collected over several months in multiple residential installations to provide actual system operation and metering data over a range of temperature in order to confirm actual system performance and efficiency.

Among the key findings explored in the body of this report are the following:

1. Independent research has verified the ability of air source heat pumps to maintain energy efficiency well above other electric heating systems, with coefficients of performance (COP) of between 2 to 3, in temperatures as low as -15^{o} F. Multiple manufacturers have developed ASHPs designed for cold-climate operation, incorporating features such as two-stage compressors and advanced defrost capabilities.
2. Where data is available to evaluate the energy savings impacts of customers moving from less efficient electric heating systems, the energy savings associated with the heating demand served by the hybrid ASHP systems is found to be in the range from 10% to more than 40%, with median savings of around 22%
3. Overall, customers are highly satisfied with their system's performance. Surveyed customers provide an average rating of 4.3 on a 5-point scale (1 = 'Poor', 5 = 'Excellent') across all dimensions of their hybrid system performance.
4. Because of customers moving away from other heating fuels to adopt electric heating with hybrid ASHP systems, electricity consumption actually increases among a majority of adopters. Among more than 100 Minnesota customers adopting hybrid ASHP systems with sufficient data to evaluate weather-normalized pre and post-installation results, the large majority of customers (77%) show an increase in kWh/HDD electricity consumption intensity following system installation. Over 40% of customers are found to have experienced a more than 50% increase in electricity consumption with the new systems. Close to 30% of customers experienced more than a doubling of electricity consumption once the hybrid systems were installed.
5. In order to advance the goals of Minnesota’s Conservation Improvement Program (CIP) in achieving energy savings, program sponsors should seek ways to maximize the adoption of more efficient systems including hybrid ASHP systems among customers using primary electric heating. Appropriate considerations should be made in program eligibility requirements that ensure energy savings will be achieved.

1. Background

This study aims to investigate the potential for supplemental, variable electric heating systems to enable energy savings by operating an air source heat pump (ASHP) to lower ambient temperatures.

The findings shared in this report are intended to inform electric utilities, particularly those Minnesota utilities with a high saturation of homes that utilize electricity for space heating, about the applicability of these hybrid systems as potential measures under ratepayer-funded Conservation Improvement Programs (CIP).

2. Methodology

This study consists of three discrete paths of investigation. First, the research team coordinated with utility partners to collect electric utility billing data to evaluate the impact of hybrid ASHP system installation on electric consumption, though limited visibility was available with respect to the previously installed systems. Second, a customer satisfaction survey was executed to gain greater insight on user satisfaction and decision making related to the installation of hybrid ASHP electric heating systems. Finally, data was collected over several months in multiple residential installations to provide actual system operation and metering data over a range of temperature in order to confirm actual system performance and efficiency.

This study is limited to evaluation of electric energy use and does not aim to quantify impacts across all potential fuel sources. The focus was to gain insight into the energy savings associated with transitioning from less efficient electric heating systems to systems that employ an ASHP for primary heating in order to increase system efficiency.

In addition to those customers transitioning from existing electric systems, the findings of this study highlight that a significant proportion of customers adopting hybrid ASHP electric heating systems are transitioning from other primary heating sources such as propane, fuel oil, or natural gas. Customers also have the option to take advantage of attractive rate structures including off-peak rates where electric heating can be sourced at a substantial discount to normal retail rates. Electric thermal storage systems charged during off-peak hours can provide a continuous source of primary heating, often coupled with an ASHP for increased efficiency. Alternatively, customers may employ a dual fuel system where electricity is the primary heating fuel during normal off-peak conditions and a non-electric backup system, such as a fossil fuel furnace or boiler, supplies heat during energy control periods with electric utilities sending radio signals to automatically switch from one fuel to the other.

2.1 Billing Data Analysis

In coordination with utility partners, the team was able to obtain billing data on a population of unidentified customers with known installations of air source heat pumps, with a subset having also installed either a thermal electric storage (TES) or variable electric furnace that would allow the hybrid ASHP system to serve as a primary heating system.Monthly utility billing data over several years allowed the team to make year-over-year comparisons of energy use including changes subsequent to the installation of the hybrid system. The billing data analysis focuses on the heating season and does not incorporate consumption data on natural gas or other fuel sources for home heating.

2.2 Customer Survey

The team was able to conduct in-depth interviews with ten customers using hybrid ASHP systems. Insights were gleaned on customer characteristics, satisfaction with system performance, decision making for system selection and a number of other dimensions.

2.3 In-Home Testing

The team collected detailed data on system performance in two Minnesota homes utilizing a hybrid ASHP system involving a variable electric furnace. The study monitored outside air temperature, supply and return air temperatures, and control sequences for a 12-week period during the 2010/11 heating season to specifically understand the heating contribution of the ASHP at temperatures below 30° F.

3. Overview of Hybrid Electric Heating Systems

Typical home heating systems utilize a single technology for the primary space heating. However, in many cases it is common for home heating systems to make use of supplemental heating technology separate from the primary heating system. This study compares electric consumption of homes with space conditioned either with an ASHP as the only primary electric heating source and homes using a hybrid approach that supplements heat from the ASHP with an additional source such as a variable electric furnace or thermal storage system. Throughout the report we use the following definitions: ASHP Only: Residences which utilize an ASHP as a primary and exclusive electric space heating technology.

Hybrid ASHP: Residences which utilize an ASHP as a primary heating technology and under some conditions simultaneously utilize a supplemental electric heating technology in order to meet the heating demand. Examples of supplemental heating technologies include electric heat storage furnaces and modulating plenum heaters.

It is important to recognize that included in this definition is simultaneous use: both systems operating at the same time, and not as alternatives for primary home heating.

We limit the definition to a supplemental electric heating system for a couple reasons. First, feedback from industry professionals suggests that electric resistance heat was the only viable technology for economically modulating the heat and controls required to be a supplemental heating source for air source heat pumps. Secondly, the scope of the project included investigation of electrical efficiency gains by running an ASHP at a lower temperature range.

Over the past decade, air source heat pump technology advancements have yielded systems with the capability to run at temperatures as low as -10° F or colder. Coupled with this technical advancement, residential building shell weatherization and insulation continues to improve, creating a viable market for ASHP heating, which typically involves lower supply air temperatures applied over a longer period to maintain desired room air temperatures.

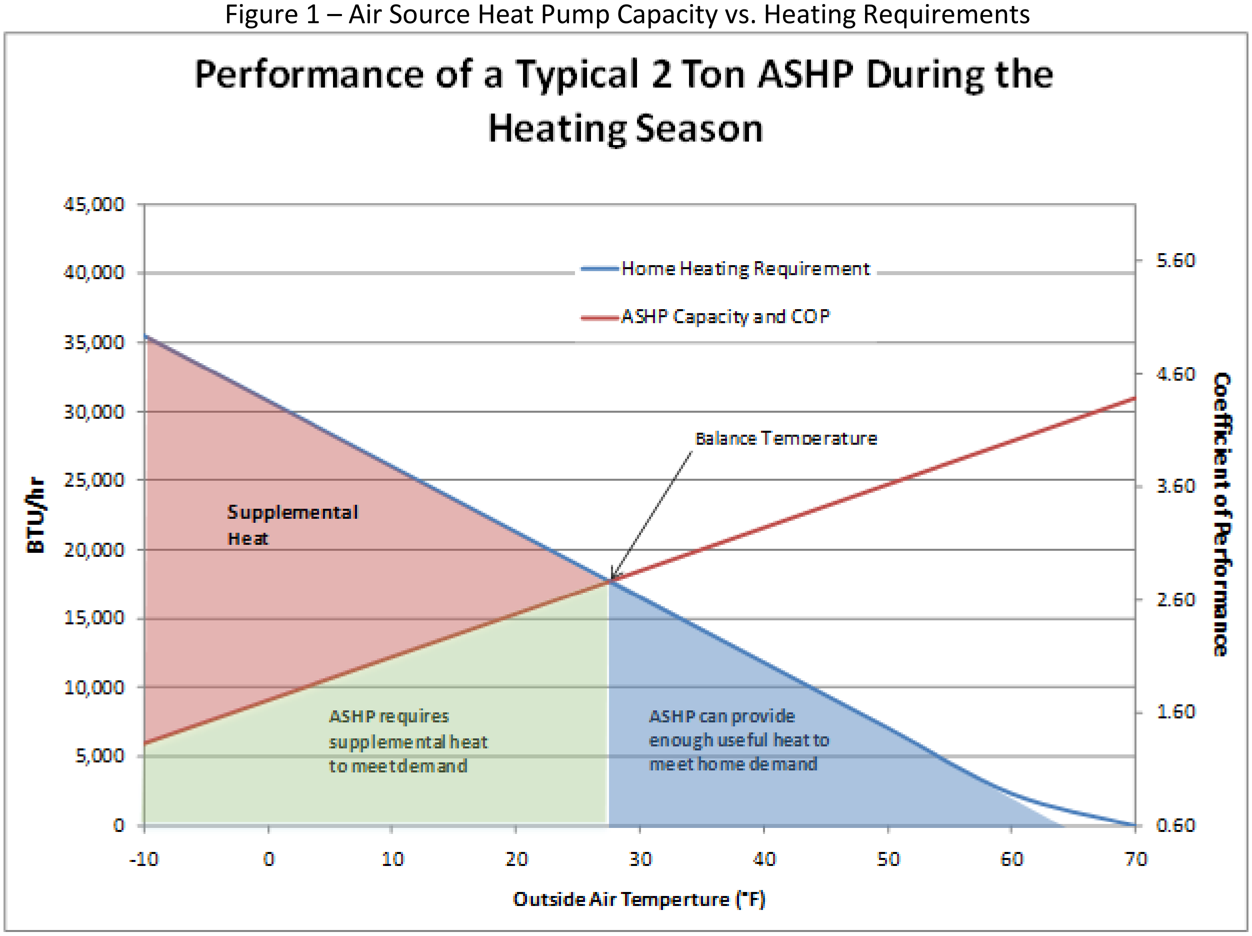
Figure 1 illustrates the opportunity for electrical efficiency using ASHP's. The graph depicts a typical home's heating requirement across a heating season temperature range, as well as the capacity and coefficient of performance (COP) of a typical ASHP. Where the lines cross marks the balance point where the capacity of the ASHP and heating requirement are equal, meaning that at temperatures below that point, the ASHP would not be able to produce enough heat to properly maintain indoor temperature.

Based on the HVAC industry sizing standards for ASHP's, particularly when sizing for the required cooling load, the balance temperature typically falls around or slightly below 30° F. Because of this, it is common industry practice when installing ASHPs for the cut-off point to be set to 30° F. This means that in a baseline configuration, the ASHP no longer runs below the cut-off and the primary heating switches to another primary heating system such as an electric furnace, baseboard heat, propane/fuel oil/natural gas furnace, etc.

Also illustrated in Figure 1 is the effect of outside air temperature on the COP of a typical ASHP. At the balance point, a typical ASHP is still operating at a COP around 2.8 and still able to produce efficient heat.

ASHPs face another performance limitation with respect to supply air temperatures at colder temperatures. As it gets colder outside, eventually the ASHP is no longer capable of producing supply air temperature that is warm enough for comfortable use. Supply air temperatures below the lower range of 90° F to 95° F is typically where supply air is judged not to feel warm to the home occupants, and is no longer viable for comfortable space heating.

Figure 1 – Air Source Heat Pump Capacity vs. Heating Requirements

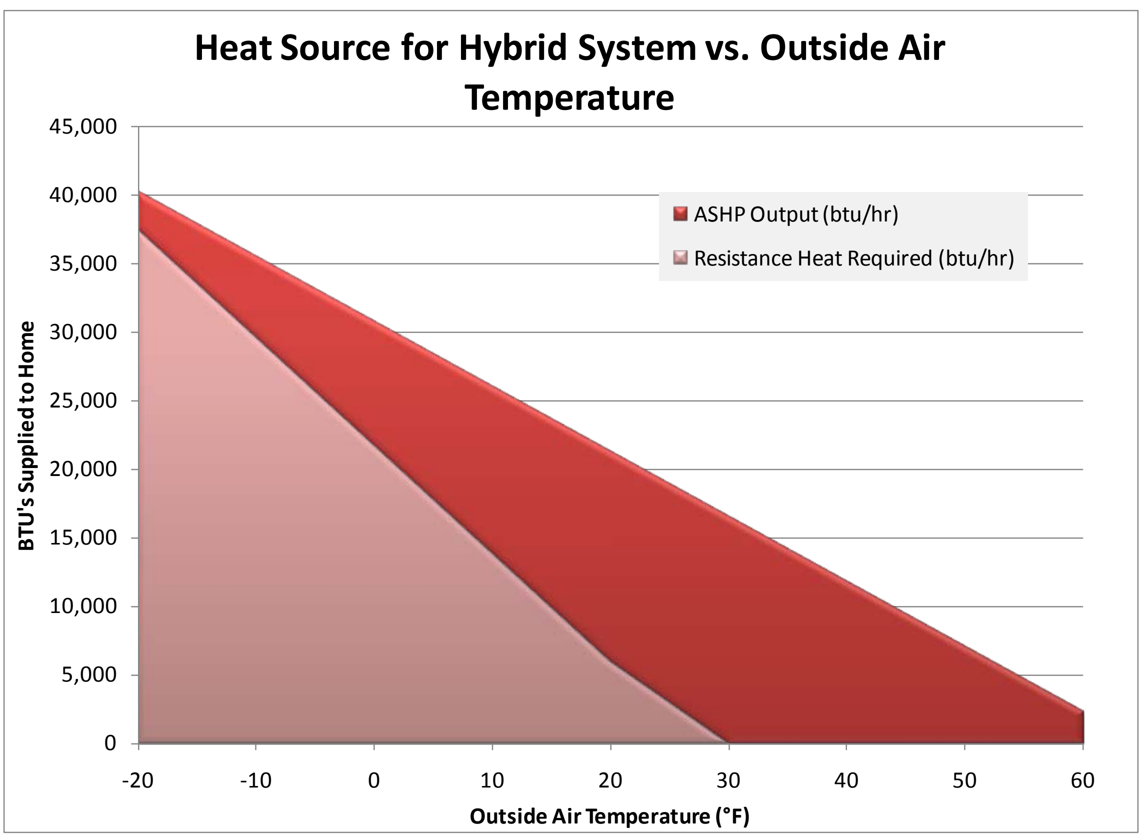


To solve the supply air temperature and capacity deficiencies, in order for an ASHP to effectively run in temperatures below their traditional cut-off temperatures, it is often necessary to supplement the supply air with additional heat. In doing so, the primary heating system can utilize the favorable COP of the ASHP to produce more efficient heating than could otherwise be achieved. Maximizing the system's utilization of the ASHP and minimizing the heat being supplied by the supplemental heating source requires a well-planned control system and fast responding modulation for the supplemental heat source. The following control concepts serve as guidelines for hybrid ASHP operation:

1. The supply air temperature must be supplied at a minimum of 95°F. A feedback control must be in place to assure the supply air temperature is comfortable.
2. A second control must be in place to assure that enough heat is being delivered to the space. In most cases this would require the supply air temperature to be higher than 95°F as the outside air temperature decreases. There are a variety of control concepts which can be incorporated including pre-calculating a supply air target based on outside air temperature and ASHP capacity, or tying a second feedback to return air temperature, making sure the return air temp increases at a sufficient rate during heating run time.

Figure 2 illustrates the typical heating volume supplied by an ASHP and the supplemental heating source taking into consideration the required controls across a range of outdoor air temperatures. The ASHP heat contribution in temperatures below 30° F can be considered efficiency improvements for an electrically heated home as electric resistance heaters would have a COP of 1 while the ASHP would be significantly higher.

Figure 2 – Hybrid System Btu Contribution by Source vs. Temperature



3.1 Thermal Storage Supplemental Heating Systems

Thermal storage solutions can be an effective supplemental heating solution for hybrid systems. Most commonly, an electric thermal storage (ETS) system uses electric resistance heat, typically harvested during off-peak hours (to take advantage of lower billing rates), to heat a volume of high density ceramic bricks stored in an insulated vessel. To harvest the heat, a controlled volume of supply air can be circulated across the bricks to supplement the temperature of the total supply air. A simple damper control can be utilized to control how much heating energy is being extracted from the bricks. Steffes Corporation is a leading provider of ETS systems and has made utility marketing programs a major focus of its promotional efforts.[1]

3.2 Variable Electric Systems

Various "on demand" modulating electric heating systems can also be deployed as supplemental heating systems. The most important requirement of these systems is to have are the ability to modulate the amount of resistance heat the devices supply, and to have fine enough modulation adjustments so the ASHP run time can be maximized. Examples of these heating systems include electric furnaces and modulating plenum heaters.

3.3 Insights from Research on Heat Pumps in Cold Climates

Various studies in recent years have examined the performance, efficiency, and cost effectiveness of air source heat pumps in cold climates. The following is a summary of findings from this research:

Independent research has verified the ability of at least some air source heat pumps to maintain high COPs (above 200%) even in temperatures as low as -15^{o} F. In 2007 the *EnergyIdeas Clearinghouse,* a publication of the Washington State University Extension Energy Program in partnership with the Northwest Energy Efficiency Alliance, summarized the findings of several relevant studies.[2] Multiple accounts are provided highlighting use of ASHPs for heating in temperatures well below 0^{o} F, in many cases without the need for supplemental heating. The research focuses on systems optimized for cold climate performance such as those manufactured by Nyle Systems and Hallowell International, the latter having just recently gone out of business in mid-2011.[3] Low supply temperatures and system failure due to icing are cited among the major issues encountered with air source heat pumps at low temperatures.

A 2009 *ASHRAE Journal* article summarizes the findings of an analysis comparing the performance of a two-stage cold-climate ASHP to three conventional heating options – an 80% AFUE natural gas furnace,

[1] Steffes Corporation: http://www.steffes.com/Home.htm

[2] Meredith, C. and D. Hales, *EnergyIdeas Clearinghouse, Product & Technology Review: Acadia™ Heat Pump*, PTR #19, Washington State University Extension Energy Program, December 2007: http://www.energyideas.org/documents/Factsheets/PTR/AcadiaHeatPump.pdf

[3] Hallowell International was reported in May of 2011 to be in the process of liquidating its assets, going out of business; see Bangor Daily News story here: http://bangordailynews.com/2011/05/24/business/auction-notice-indicates-bangor-heat-pump-firm-out-of-business/

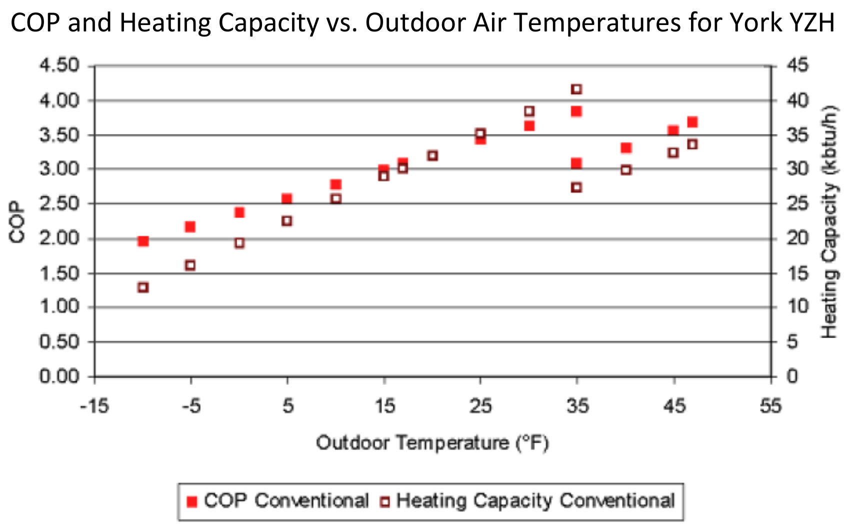
a 90% AFUE natural gas furnace, and an 85% fuel oil furnace in order to examine primary energy efficiency. The analysis was conducted using inputs for homes constructed in 2000 and experiencing the climates in Chicago, Minneapolis, and New York respectively. In the Minneapolis scenario, the heat pump was found to have negligible primary energy savings relative to the 80% AFUE gas furnace and 85% AFUE fuel oil furnace. Compared to the 90% AFUE gas furnace, the cold-climate optimized ASHP was found to consume around 9% more primary energy.[4]

The authors also highlight several other factors relevant to adoption of ASHPs in cold climates:

- In order to lower balance points and avoid significant supplemental heating requirements, ASHP can be sized for heating rather than cooling loads. One downside of this approach could be the excessive cycling that would occur in the cooling season and under moderate heating requirements, lowering efficiency and decreasing dehumidification effectiveness.
- Use of CO_2 as a refrigerant is identified as a potential technology innovation with advantages for ASHP heating loads. One study has shown that CO_2 refrigerant cycles yield close to a 35% increase in system capacity at 17 °F compared to conventional systems.
- Relative to conventional ASHPs, the newer two-stage cold-climate ASHPs (e.g., the Hallowell Acadia) are noted to have an installed cost premium of around $3,000 to $4,000. The cost premium relative to a 90% AFUE gas furnace is identified to be around $3,900 to $4,900.

A characterization study from Caneta Research completed in March of 2010 highlights the pros and cons of various ASHP designs in weighing their viability and economics for heating loads in Canada's Yukon Territory. The study outlined the COP profiles of two-stage ASHPs designed for cold-climate heating:

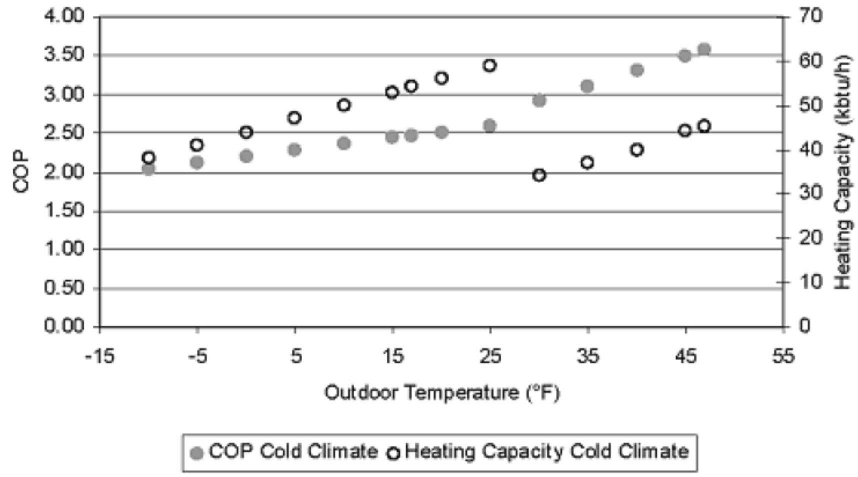
Figure 3 – COP Profiles for Cold-Climate ASHPs (*Source: Caneta Research*[5])



[4] Roth, K., J. Dieckmann, and J. Brodrick, "Heat Pumps for Cold Climates," American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc., *ASHRAE Journal*, February 2009: http://www.tiaxllc.com/publications/ashrae/february2009.pdf

[5] Caneta Research Inc., *Heat Pump Characterization Study*, Prepared for Energy Solutions Centre, March 2010: http://www.energy.gov.yk.ca/pdf/yukon_airsource_heatpump_mar_2010.pdf

COP and Heating Capacity vs. Outdoor Air Temperatures for Acadia Heat Pump



The study concludes that sizing a system to have a heating capacity at 0° F of 25% to 35% of a home's heating load would supply 60% to 75% of the annual heating load and can be economical.

4. Energy Use Profiles – Billing Data Analysis

Working with its utility partners, the research team was able to gather historical billing data for several hundred electricity customers identified to have installed an air source heat pump in combination with a supplemental electric heating system such as a variable electric furnace or thermal electric storage system. Using the monthly electric consumption data in combination with heating degree day (HDD) data from weather stations in the local Western Minnesota territory, the team was able to perform weather normalized analyses in order to understand the distribution of changes in energy savings impacts among the population of customers adopting hybrid ASHP systems.[6] The data was provided with customers remaining anonymous. No information was provided identifying the legacy heating systems in place prior to the upgrade to the new ASHP or Hybrid system. Additionally, for residences with multiple meters, the research team combined all metered electricity and used the total consumption values in this study.

The investigation yields insights into the patterns of energy use both pre and post installation of hybrid heating systems. In particular it is shown that a significant majority of system adoption is from customers that are moving away from other fuel alternatives in order to pursue an efficient and cost effective electric heating system. The cost of electricity, along with a variety of rate plan options, coupled with the efficiency of ASHP's makes electric heating financially competitive with other fuel options such as propane and natural gas.

Where data is available to evaluate the energy savings impacts of customers moving from less efficient electric heating systems, the energy savings associated with the heating demand served by the hybrid ASHP systems is found to be in the range from 10% to more than 40%.

[6] Heating degree day data sourced from the National Oceanic and Atmospheric Administration's (NOAA's) National Climatic Data Center (NCDC): http://www.ncdc.noaa.gov/oa/documentlibrary/hcs/hcs.html

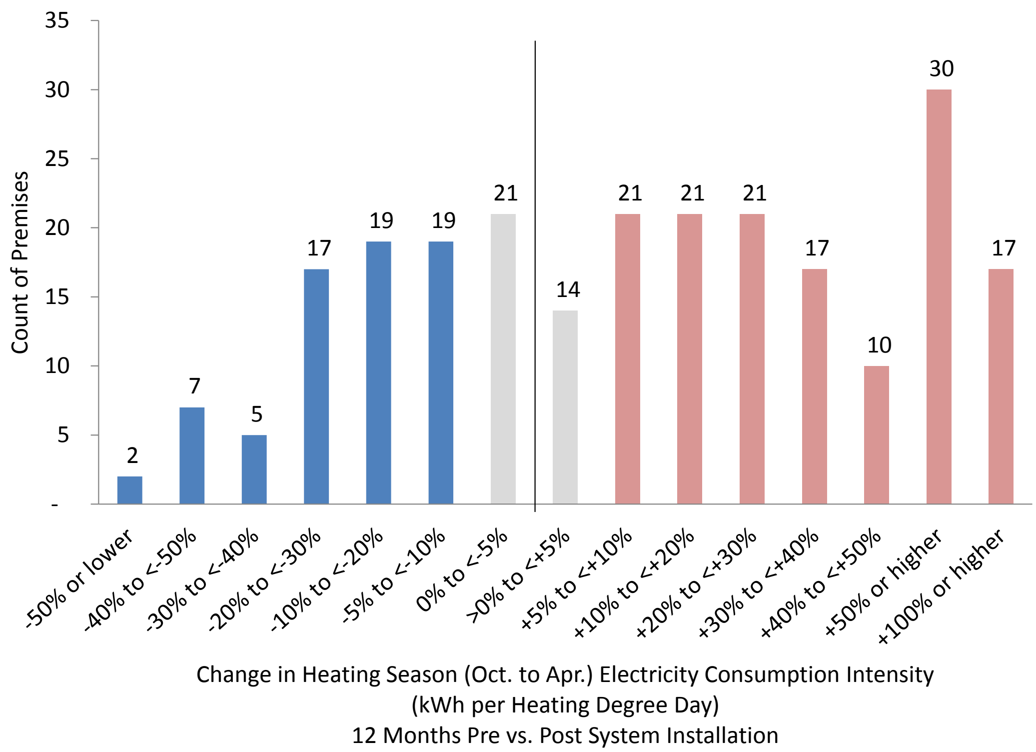
4.1 Magnitude of Changes in Energy Use

In order to understand changes in energy use associated with the installation of hybrid ASHP systems, the team first sought to establish a baseline for comparison by examining the energy consumption patterns of customers only installing an air source heat pump, absent any supplemental electric heating system that would allow for efficient heating beyond typical ASHP cut out temperatures (30^{o} F).

The team screened available data to identify customers where at least twelve months of data was available both pre and post installation of the ASHP. Focusing only on heating months, identified as October to April, the team sought to examine the change in energy consumption relative to heating load as provided by HDD data.

Examination of the population of ASHP installations showed a bi-modal distribution as shown in Figure 4. On the one hand, the majority of data points for the change in year-over-year energy consumption intensity (kWh/HDD) fell evenly around a no-change central measure. However, a noticeably large proportion showed substantially larger electricity consumption with an increase in the kWh/HDD ratio of more than 50%.

FIGURE 4 – Change in Heating Season Electricity Consumption – ASHP Only Homes (N=241)



These findings are fairly intuitive. It is likely, particularly in a climate like Minnesota, that air source heat pumps are less likely to have a significant impact on electric load in the heating season, particularly for customers that rely on natural gas, fuel oil or propane as a primary heating system to operate during the below-freezing conditions that constitute much of the Western Minnesota heating season.

The spike in consumption intensity among a smaller proportion of customers reflects a population that is making use of the ASHP to supplement its heating requirements, particularly in periods around the shoulder months when temperatures are likely to remain above 30^{o} Fahrenheit.

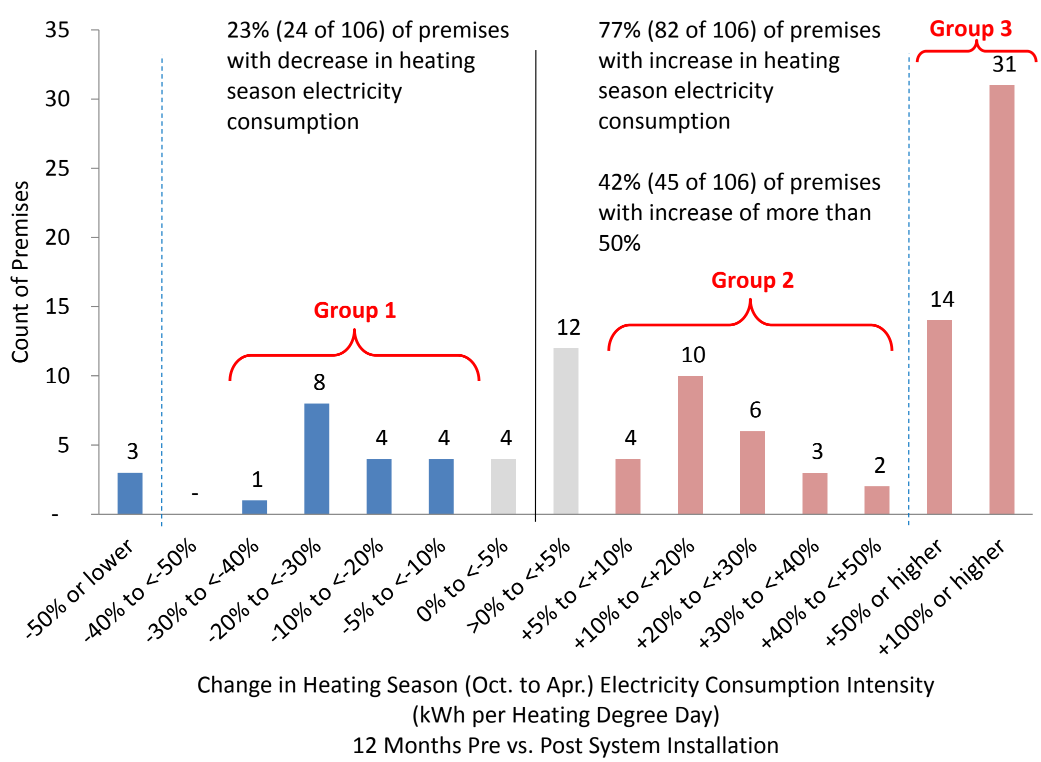
By comparison, the targeted population of customers employing an ASHP in combination with a supplemental variable electric heating appliance shows a significantly different distribution of electric consumption intensity changes after installation of the hybrid system.

Figure 5 provides a distribution of 106 customers with sufficient data to compare the heating season in the 12 months prior to installation of the hybrid ASHP system to the heating season in the 12 months following installation. In comparison to the ASHP-only distribution the biggest difference is in the large majority of customers (77%) that show an increase in kWh/HDD electricity consumption intensity following system installation.

Over 40% of customers are found to have experienced a more than 50% increase in electricity consumption with the new systems. Close to 30% of customers experienced more than a doubling of electricity consumption once the hybrid systems were installed.

In total, the 106 customers installing hybrid systems had an 18% net increase in kWh consumed in the 12 months after system installation compared to in the 12 months prior to the new system installation.

FIGURE 5 – Change in Heating Season Electricity Consumption – Hybrid ASHP Homes (N=241)



These findings point to a significant proportion of customers that are transitioning away from other fossil fuel heating sources in order to take advantage of the efficiency and cost effectiveness of the electric ASHP hybrid system. It is a minority of system adopters that are found to be transitioning away from less efficient electric heating systems and realizing electricity savings as a result of installing the hybrid ASHP systems (see blue bars on left of Figure 5).

Looking closer at the three groups of homes identified in Figure 5 provides additional insights.

TABLE 1 – Comparison of Electricity Consumption Changes by Group

Group	Group 1	Group 2	Group 3
# Homes	17	25	45
# Homes with Significant Electric Heating Load Prior to New System Installation	12	17	11
Share of Homes w/ Significant Electric Heating Load Prior to New System Installation	71%	68%	23%
Median Change in Heating Season Electricity Use After Hybrid ASHP System Installation (Homes with Significant Electric Heating in Old System)	-22%	+17%	+94%
Median Change in Heating Season Electricity Use After Hybrid ASHP System Installation (Homes without Significant Electric Heating in Old System)	-13%	+23%	+169%

Billing data from the twelve months prior to installation of the new hybrid ASHP system provides an indication of whether there is significant seasonality in electricity consumption that would indicate electricity consumption related to space heating. We identified homes with significant electric heating load prior to the installation of a new system as homes in which the electricity consumption in peak heating months was more than double the electricity consumption in shoulder months (May and September). In Group 1, 12 of 17 (71%) of homes were found to have significant pre-existing electric heating loads.

Somewhat surprisingly, a similar percentage (68%, 17 of 25 homes) of homes within Group 2 were found to have significant pre-existing electric heating loads. This is likely an indicator that electric space heating was used to a significant degree in combination with space heating with another fuel source prior to installation of the new ASHP hybrid system.

For the homes experiencing consumption increases of more than 50%, only 23% of homes were found to demonstrate a significant electric heating load prior to the new system installation.

The median savings of 22% for Group 1 homes is an indicator of average expected savings among homes where conversion from an existing primary electric heating system to a more efficient hybrid ASHP system can yield electricity savings. This is the population and efficiency potential that should be the focus of CIP program incentives in order to achieve electric savings.

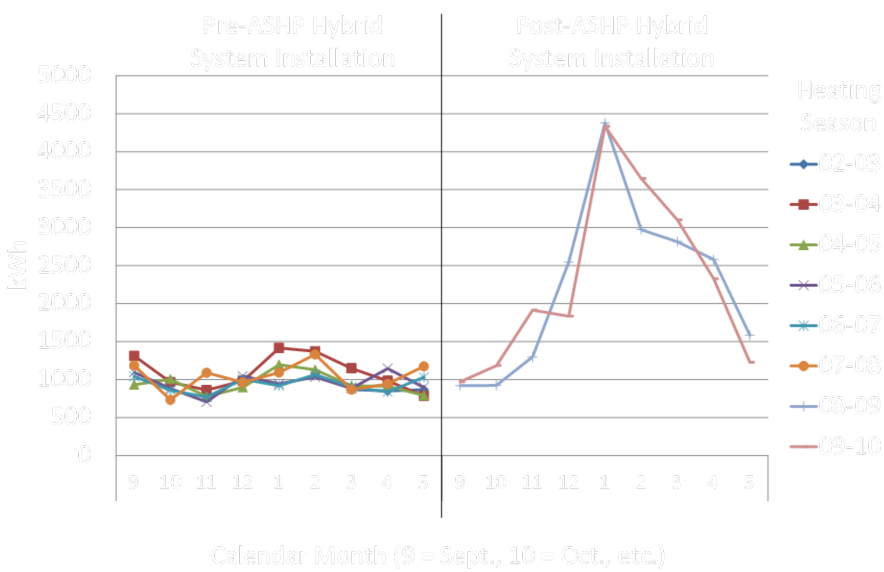
4.2 Examining Electricity Consumption Profiles – Individual Homes

Examining energy consumption data at the individual premise level highlights consumption variability and provides a means to examine the magnitude of energy savings.

As noted, for a large proportion of premises not presently using legacy electric heating systems, energy consumption increases with the adoption of air source heat pumps and supplemental variable electric heating systems.

Figure 6 provides actual consumption data for a typical home adopting a hybrid ASHP system and switching to electric heating. While the heating season and shoulder months (September to May) shows fairly level consumption prior to the ASHP installation, following system installation consumption increases significantly in peak winter months with monthly kWh growing to as much as four times previous average monthly consumption.

FIGURE 6 – Monthly Consumption Profile Pre and Post ASHP Hybrid System Installation
Example Non-Electric Heating Home

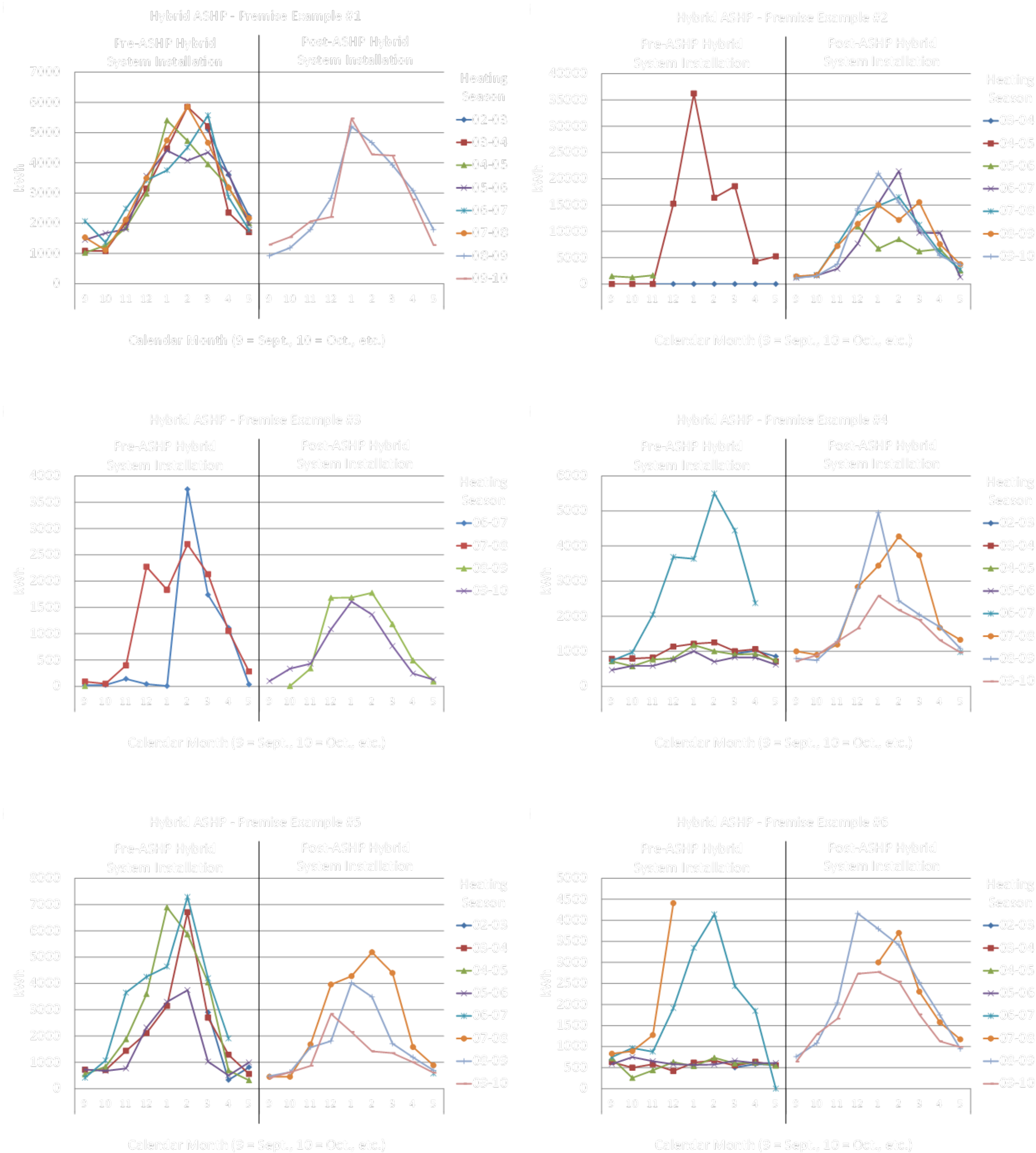


While this profile may be typical for many homes adopting hybrid ASHP systems, a sizable proportion of homes install hybrid systems to replace or enhance an existing electric heating system. Among this segment of the population, there is clear evidence of energy savings.

Figure 7 provides six examples of actual Minnesota households whose electricity consumption has declined following installation of hybrid ASHP heating systems. These profiles demonstrate both the improved efficiency under the hybrid ASHP system, but also some of the challenges in performing year-over-year analysis. Included in these challenges is not only the variability in climate that requires weather normalization, but also variability resulting from factors including occupancy and use of backup fossil fuel systems.

For instance, Premise Example #5 highlights at least two challenges to making year-over-year comparisons. First, the pre-ASHP period shows significant variability, with the 05-06 heating season lacking the February and March peaks observed in surrounding years. Likewise, the 09-10 season in the post-ASHP hybrid system installation period has a profile that suggests either minimal January-February heating related to occupancy or perhaps the use of an alternative/backup system.

FIGURE 7 – Monthly Consumption Profile Pre and Post ASHP Hybrid System Installation
Example Electric Heating Homes – Heating Season Months (Sept. to May)

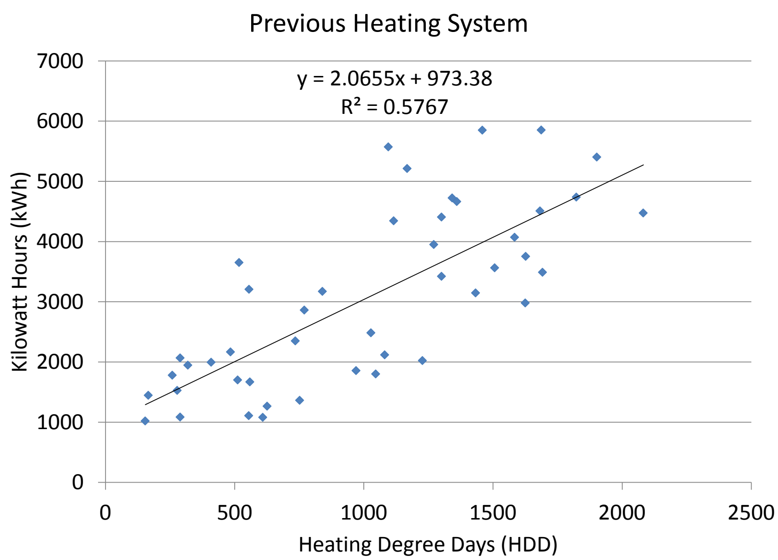


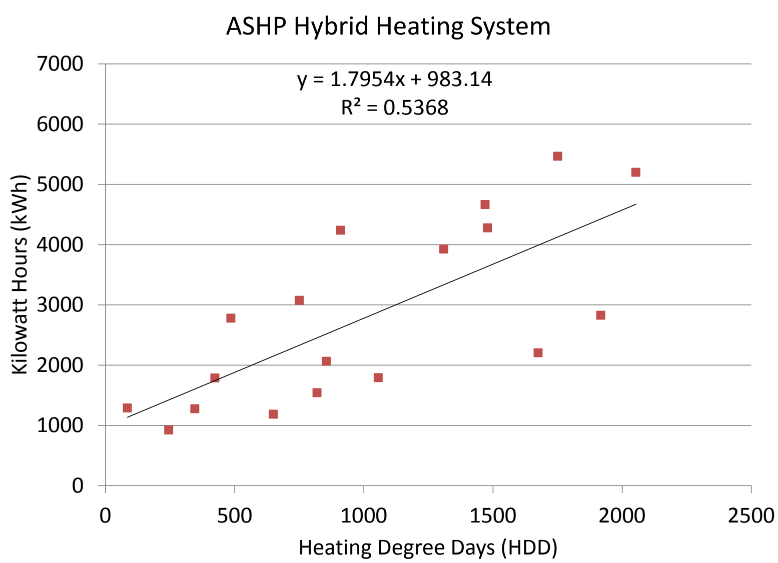
Quantifying Energy Savings Benefits

Applying regression analysis to examine the correlation between monthly electricity consumption and heating load provides an even closer look into the efficiency gains of the hybrid ASHP systems. As illustrated in Figure 8 below, while there is still significant variability in energy use relative to heating degree days (HDDs), the regression model yields a significant difference in temperature-dependent energy consumption.

The slope coefficient for the hybrid ASHP system installed at Example Premise #1 (1.8 kWh/HDD), is around 13% lower than the relationship under the previous system (2.1 kWh/HDD).

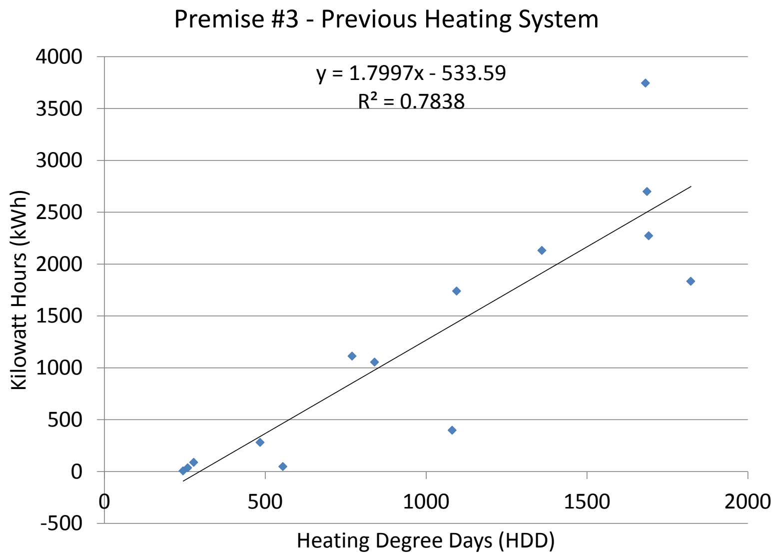
FIGURE 8 – Linear Regression of Monthly Electricity Use to HDD – Example Premise #1

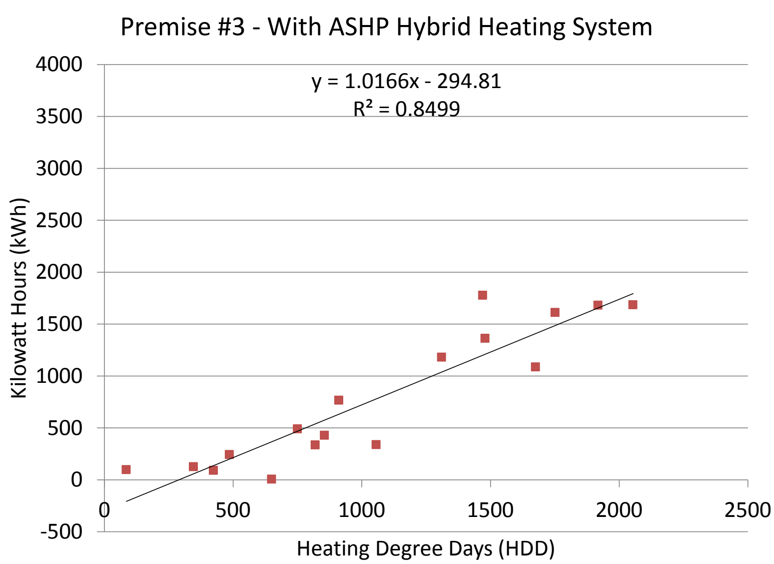




Separately, a similar analysis on Example Premise #3 yields a more substantial decrease in the observed kWh/HDD energy intensity. Based on data from February 2007 to May 2010, the required energy consumption moved from an average of 1.8 kWh/HDD to 1.0 kWh/HDD in moving from the old system to the new hybrid ASHP system. This is a reduction in energy use of around 44%.

FIGURE 9 – Linear Regression of Monthly Electricity Use to HDD – Example Premise #3





While these findings are compelling, it is important to note that the observed energy savings are the result of the unique circumstances of the individual household. The observed change in system efficiency is subject to a large number of influences including legacy system design and efficiency, new system capabilities, and additional renovations and modifications to building shell and temperature control measures. Nonetheless, these findings demonstrate that energy savings on the order of 10% to 40% are achievable with the installation of hybrid ASHP electric heating systems.

5. Insights from Customer Feedback

5.1 Background

In cooperation with Otter Tail Power Company, the research team gathered feedback from homeowners that had participated in Otter Tail Power Company's air source heat pump rebate program for new heating system installations. In particular, the team focused on homeowners' experiences with air source heat pumps used in combination with other heating systems such as electric thermal storage systems or plenum heaters. A prepared survey instrument was developed in coordination with Otter Tail Power Company's team. The survey guide template used by the interviewer is provided as Appendix C.

Homeowners who had participated in the program and received incentives were sent a mailer inviting them to participate in the ASHP survey. The letter explained the intentions of the survey and included a toll-free phone number for customers to schedule their survey participation and notice that the research team planned on reaching out by phone to request their participation. 112 letters were sent in total, yielding 23 respondents who engaged in some portion of the survey and 10 respondents completing the survey in its entirety.

Findings from the survey are discussed in detail below. A table of survey responses for the ten completed interviews is provided in Appendix B.

5.2 Characterization of the Respondent Population

The ten respondents who provide in-depth survey feedback included seven respondents who coupled an air source heat pump with a plenum heater (electric furnace) for supplemental electric resistance heating, two respondents combined an ASHP with a thermal electric storage (TES) heater and one respondent uses an ASHP for primary heating until lower ambient temperatures (below 10^{o} F) trigger a cutover to a forced-air natural gas furnace.

Home size among respondents ranged from 1,100 to 2,800 square feet with an average of 1,810 sq. ft. and a median of 1,650 sq. ft. Original home construction vintage dates back to 1914 and as recent as 2009 with average and median vintages on the order of 1986 to 1987.

In terms of backup systems, 40% of respondents indicate having a natural gas furnace serving as backup to their hybrid electric system with 2 of 10 respondents indicating that utility load management controls can trigger use of the natural gas furnace. Other backup systems include wood furnaces while two respondents indicate not having a backup heating system (outside of a wood-burning fireplace).

Three of the ten (30%) respondents indicate having additional room-specific electric resistance heating elements such as baseboard and/or cove heating elements. The use of these non-central electric heating elements ranged among respondents from near daily use to use in only a few instances a year.

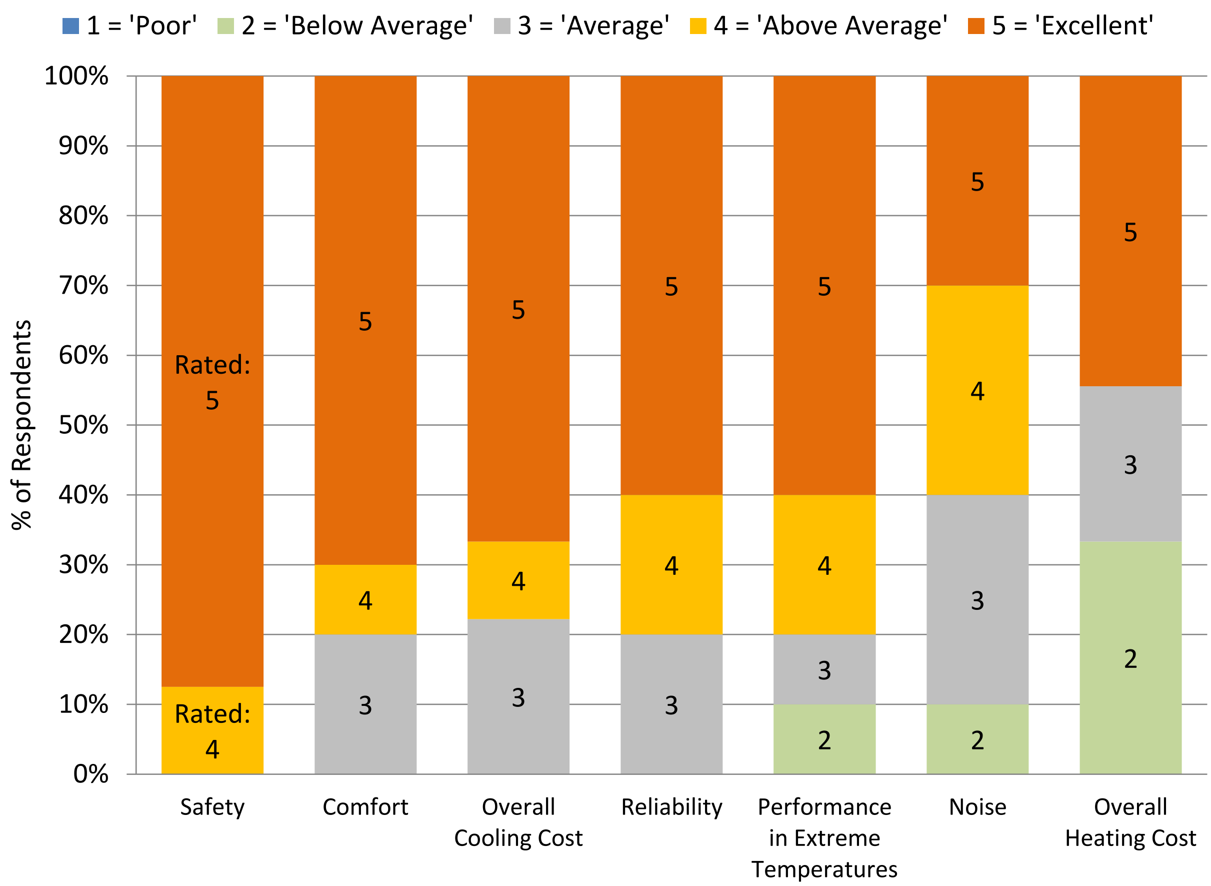
5.3 System Performance and Comfort

In general, respondents have a positive experience with the overall performance of their hybrid ASHP system, providing an average rating of 4.3 on a five-point scale across all performance dimensions. Seven out of ten respondents would choose the same system if they were choosing again today.

Systems receive large majority ‘Excellent’ ratings in categories including comfort, safety, and cooling cost effectiveness.

A minority of respondents note concerns with noise and performance in extreme temperatures, with only 1 in 10 respondents providing a ‘Below Average’ rating in these categories. Overall heating costs also receives some lower marks, though this is viewed to be a reflection of the generally high heating load and associated heating bills that place a significant burden on nearly all Minnesota households.

FIGURE 10 – Respondent Ratings on System Performance (N=10)



Average Rating: 4.2 3.7 3.4 2.8 2.6 2.4 2.0

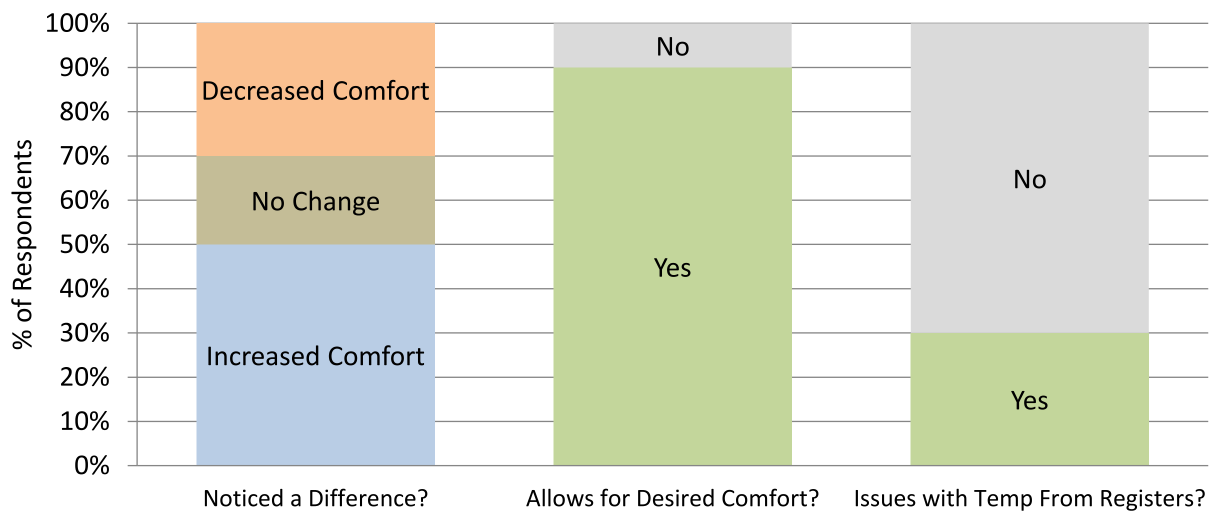
System Comfort

With respect to system comfort, half of respondents report increased comfort as a result of their new hybrid ASHP system with multiple respondents reporting improved temperature control. However 3 in 10 respondents report decreased comfort compared to their previous system performance with 1 in 10 respondents having issues maintaining a desired level of comfort.

30% of respondents note having some issues with cool-feeling air temperatures coming from the heating ventilation registers.

Multiple respondents also make note of concerns due to the furnace fans having to run nearly continuously.

FIGURE 11 – Respondent Feedback on System Comfort (N=10)



Performance Over Temperature Range

Only half of respondents were able to identify the temperature set point at which their air source heat pump would cut out. All of these respondents identified a 10-degree Fahrenheit setting. Of the ten respondents, eight indicate that their hybrid system provides adequate heating performance in even the most extreme cold temperatures. Of the two respondents that regularly turn to backup systems in extreme temperatures, one supplements heating with a natural gas furnace while the other uses a wood furnace, with the wood furnace user noting it is less to maintain temperature as to provide a warmer-feeling heating source.

5.4 Perceptions of Energy Savings and Value of Investment

When asked if they have noticed a difference in their overall heating bill with the new heating system compared to the previous system, 50% of respondents note a significantly lower bill. Reductions in bills range from 10% to 45% over the course of the heating season. The largest savings are reported by respondents switching from a fuel oil furnace system.

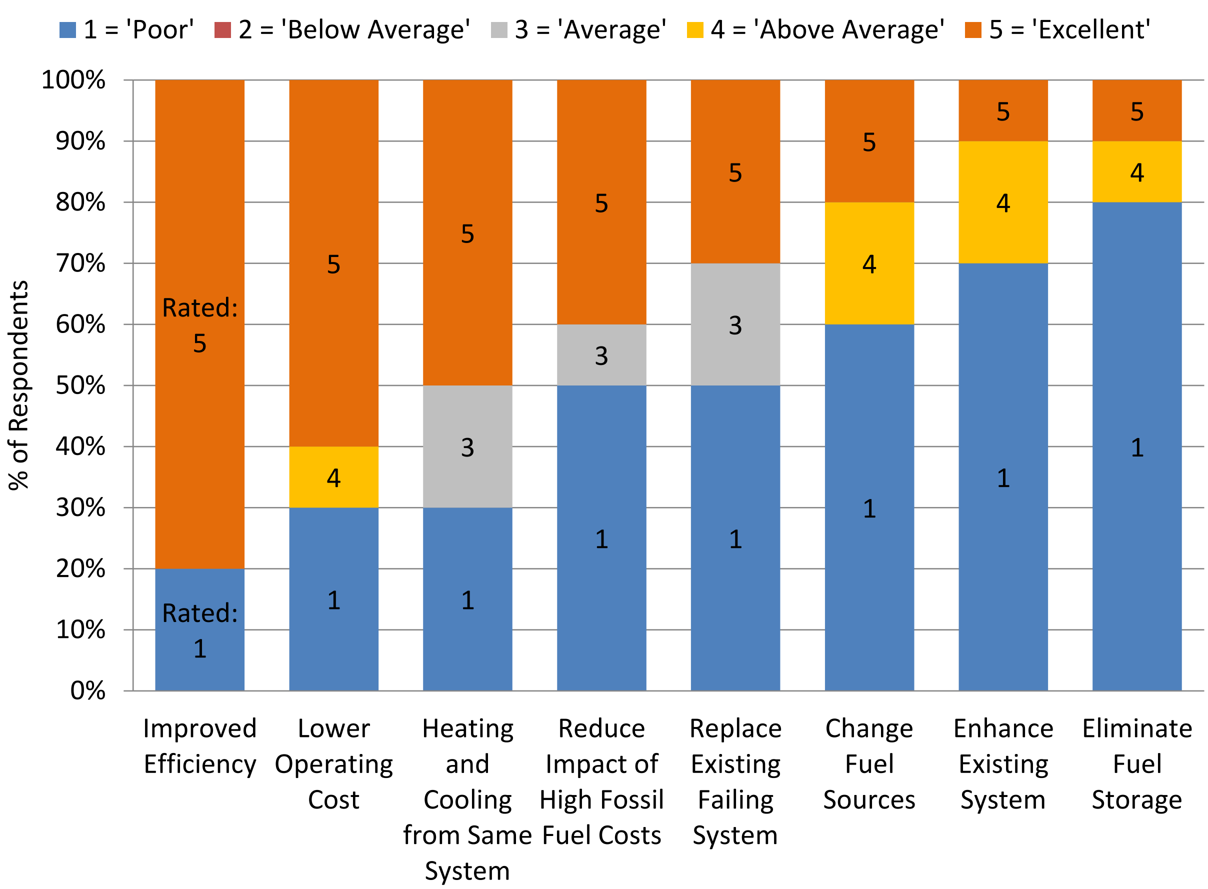
2 in 10 respondents using hybrid heating systems report a notable increase in heating bills, with both respondents comparing their experience to use of a natural gas furnace as their previous primary heating system.

When asked about comparison of the system's performance to expectations, 9 out of 10 respondents report the system has either met or exceeded their expectations. One respondent was unsatisfied with the installation of the supplemental plenum heater, noting it does not effectively activate to automatically provide supplemental heating in lower temperature conditions. Multiple respondents also note advantages and cost savings associated with cooling performance.

5.6 Decision Making Process

In terms of the motivations driving decisions to install an air source heat pump system as a primary heating system, respondents most often point to system efficiency and operating costs as major motivating factors. Around half of respondents indicate that a failing existing system was at least part of their decision making process. The opportunity to move away from higher cost fossil fuel systems and change fuel sources was at least a somewhat major motivating factor for 4 in 10 respondents.

FIGURE 12 – Respondent Ratings on Motivating Factors for System Installation (N=10)



Average Rating: 4.2 3.7 3.4 2.8 2.6 2.4 2.0 1.7

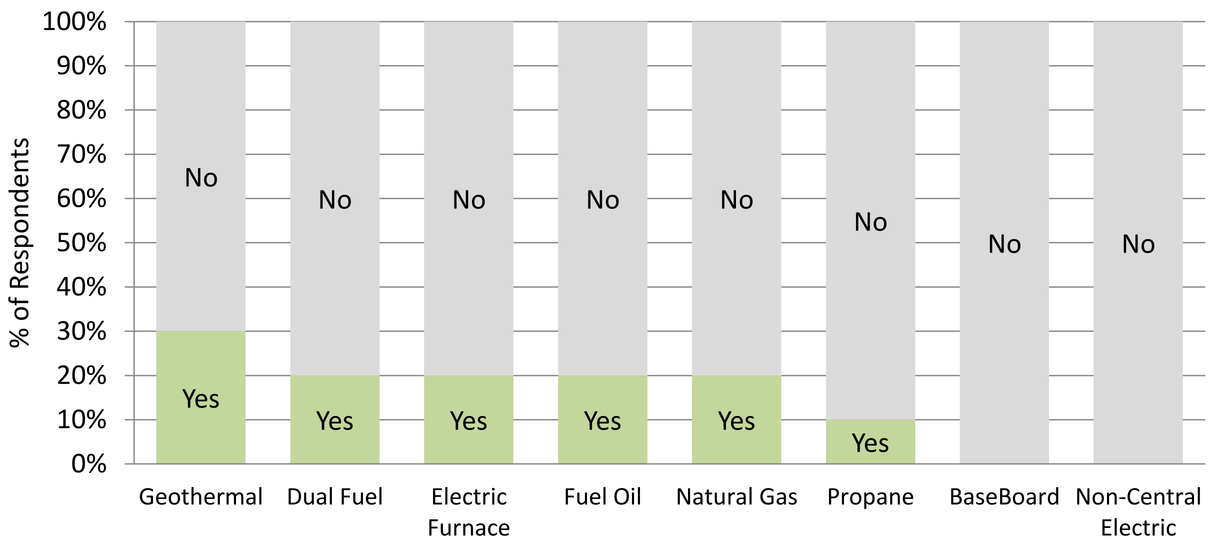
Impact of Off-Peak Rates on Decision Making

Half of respondents indicate that the installation of the new system allows them to take advantage of off-peak electric rate plans that contribute to greater savings on energy costs. 80% of these respondents indicate that the availability of off-peak rates had a significant impact on their decision. Multiple respondents indicate discussions with their electric utility and available incentives shaped their decision making.

Alternative Heating Systems Considered

In terms of the alternative heating systems considered by respondents with hybrid ASHP systems, geothermal systems were the most commonly mentioned, with 3 in 10 respondents indicating having considered a ground source heat pump. Dual-fuel systems and electric furnaces were considered by 1 in 5 respondents, as were fuel oil and natural gas furnaces respectively. 1 in 10 respondents also considered a propane furnace. No non-central electric heating systems, including baseboard electric resistance heaters, were considered by any respondents as a viable alternative for the home's primary heating system.

FIGURE 13 – Alternative Primary Heating System Replacements Considered by Respondents (N=10)



Influence of Utility Programs

A number of respondents indicated they heard of program opportunities including rebates and off-peak rates through Ottertail Power Company staff. They also indicated an appreciation for the electric utility customer service experience, in some cases contrasting it with previous gas utility experience.

Utility and Vendor programs from Steffes and Trane are among the common market channels into the program for respondents.

6. In-Home Testing

To validate that typical field installations of hybrid ASHP systems can functionally achieve the theoretical energy savings, the research team monitored system performance on site at two homes in Minnesota. The study monitored outside air temperature, supply and return air temperatures, and control sequences for a 12-week period during the 2010/11 heating season to specifically understand the heating contribution of the ASHP at temperatures below 30° F. Both hybrid systems in this study were plenum heaters; however, from an energy consumption standpoint, the results would be the same as systems using thermal storage technologies, as the control and function of the systems are similar.

6.1 Testing Protocol

In coordination with our utility partners, the team identified two customer sites with primary heating provided by an air source heat pump in combination with supplemental electric heating.

Variables Measured/Monitored:

1. Outside Air Temperature: °F
2. Supply Air Temperature from ASHP: °F
3. Supply Air Temperature mixed with Supplemental heat: °F
4. Return Air Temperature: °F
5. Thermostat Call for Heat
6. Power at Air Handler Motor (on/off)
7. Power at ASHP pump (on/off)
8. Air flow in return duct (CFM)

Apparatus:
HOBO H22 Energy Logger
HOBO S-TMB-M006 Smart Tip Sensor
HOBO S-FS-TRMSA Module, CT
HOBO T-MAG 0400-050 AC Split Core CT
HOBO S-FS-CVIA Logger
T-DCI-F900-L-O Sensor
HOBO U9-001 Logger
Veris H300, CT
HOBO U23-001, Sensor
HOBO Base U4 Interface
HOBOware PRO v.3.x software

The sensors and data loggers were installed on two properties from the date range of March 4th, 2011 to May 26th, 2011. Both homes were heated by an ASHP with supplemental modulating resistance heat provided by plenum heaters.

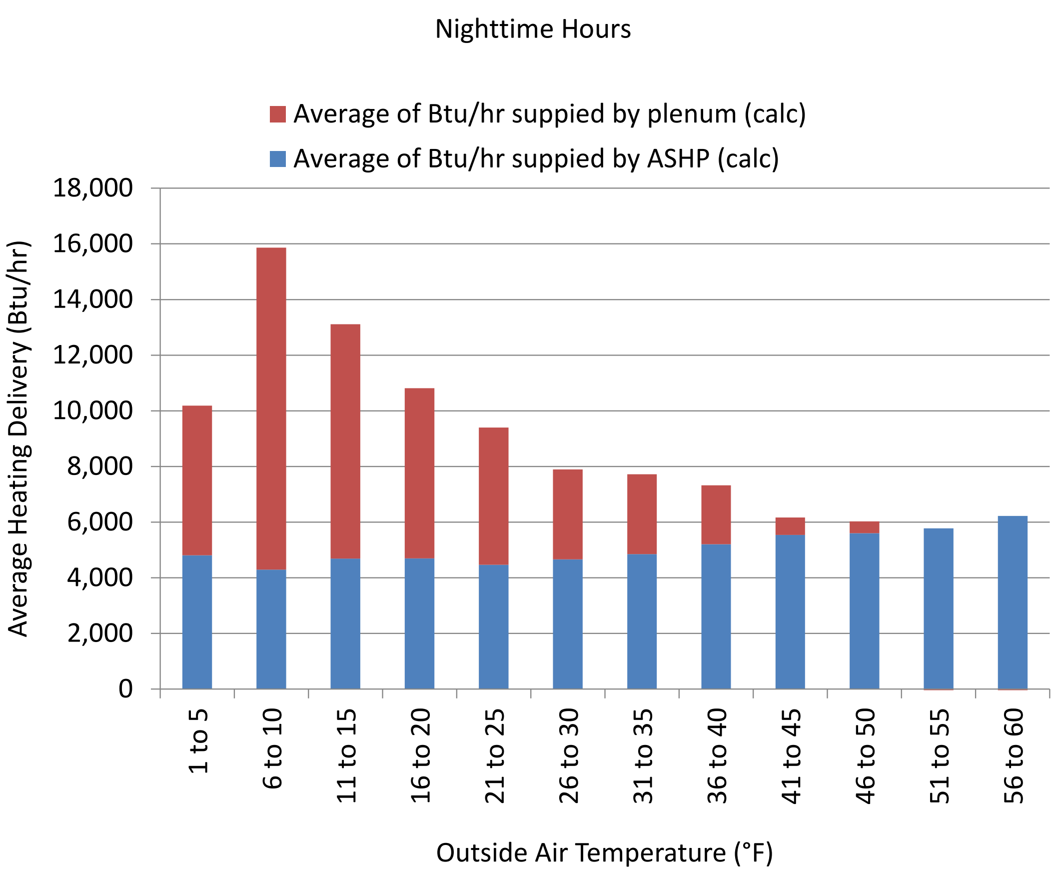
Data was captured on one-minute intervals and recorded on local data loggers. Data extracts were performed on April 4th and May 26th.

6.2 Findings – Hybrid System Operation

In both homes in the study, the team found the share of provided heating btus across the heating technologies to be consistent with the theoretcal case (outlined in Section 3). In order to more accurately quantify the relationship, the team focused on time periods across two major parameters. First, to mitigate the effect of solar gain contribution, nightime data was isolated. Additionally, the data set was limited to periods concurrent with system fan operation, ignoring the contribution of convective flow through the ducting.

Based on these observations, the team calculated the average heat delivery by appliance across temperature ranges for each of the two residences. In both cases, the data highlight the ASHP's declining heating capacity across lower temperatures. Figure 14 shows the plenum heater growing from just 7% (425 of 6,000 Btu/hr) of required heating for Home "A" in the 46 to 50° F range to over 70% (11,570 of 15,860 Btu/hr) of provided heating at temperatures between 6 and 10° F. Beginning at 5° F an additional heating technology (natural gas furnace) is activated, reducing the contribution of the plenum heater.

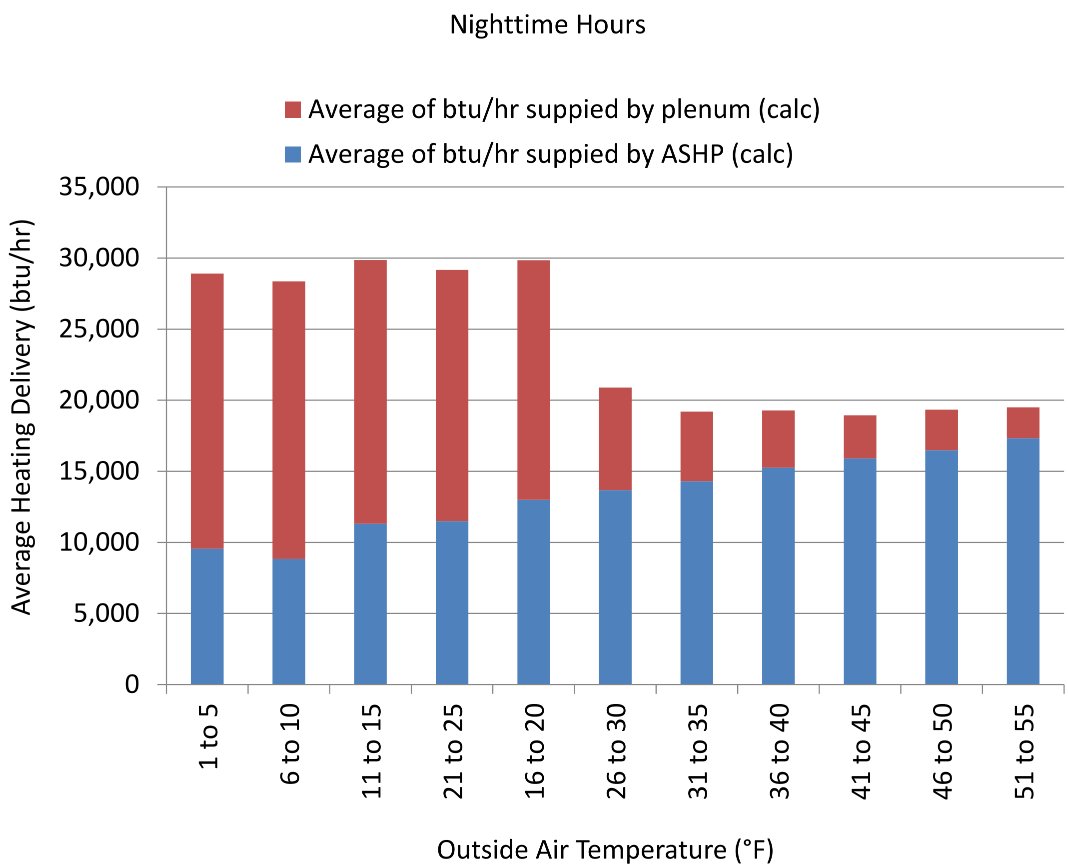
FIGURE 14 – Home "A" Heat Delivery by System Component vs. Outside Air Temperature



The controls in Home "A" are shown to allow for finer control of modulating electric heat across temperature ranges when compared to Home "N". As Figure 15 illustrates, the plenum heater contribution to Home "N" is more stepwise (increasing significantly below 20° F), showing the system is less able to precisely deliver the optimal quantity of supplemental heat to maximize the ASHP contribution. In the 6 to 10° F range, Home "N's" plenum heater contributes 69% of heating requirements, consistent with the 70% observed for Home "A".

As apparent in the scale, Home "N" has a higher heating requirement than Home "A", with average Btu/hr delivery nearly twice as large. Some factors that typically cause a differeince in the heating requirement are home insulation, temperature set point, size of home, and environmental conditions such as exposure to wind.

FIGURE 15 – Home "N" Heat Delivery by System Component vs. Outside Air Temperature



6.3 Findings – System Achieved Efficiency

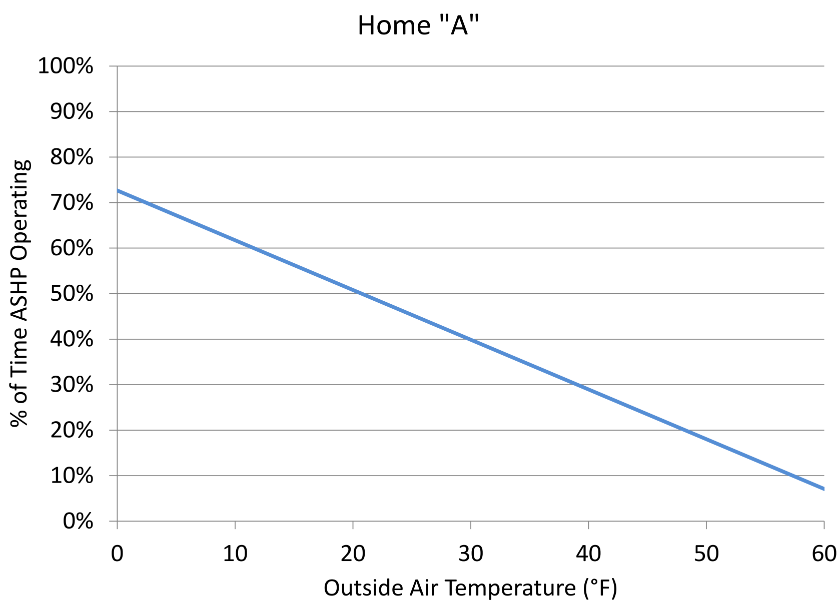
While the in-home testing data did not allow for precise calculation of the system coefficient of performance (COP) due to challenges with air flow measurement, clear conclusions can still be drawn.

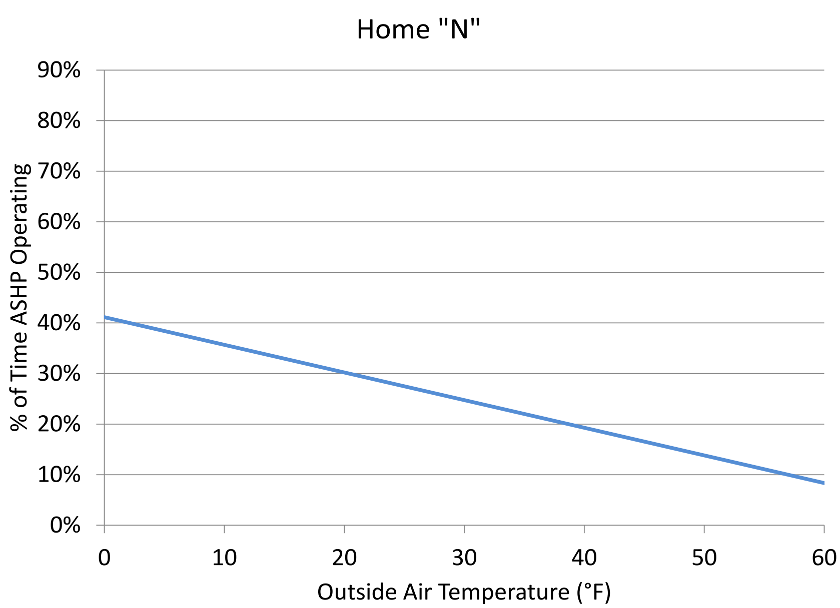
The field results demonstrate that it is feasible to utilize an ASHP for residential heating at temperatures below 30°F, and that in the temperature range between 0° and 30° a significant portion of the heating energy is supplied by the ASHP and the overall system efficiency is improved over using resistance heat alone. From an electric heating standpoint, a hybrid system of electric resistance heat and ASHP is an efficient heating solution.

6.4 Observations on System Cycling

Available data on fan operation provides insight into the proportion of time the ASHP system is running in order to supply adequate heated supply air to the home. Aggregating data to calculate a % of operating time across temperature ranges shows that, as expected, the propotion of time the system is running increases in proportion to the heating load (as given by outdoor air temperature). Somewhat surprising is the significant difference in performance across the two systems. As Figure 16 illustrates, Home "A" is found to have its system running close to 50% more of the time than Home "N". For example, at a temperature in the range of 20^{o} F Home "A" is found to have its system running around half of the time. By comparison, Home "N" is only operating around 30% of the time.

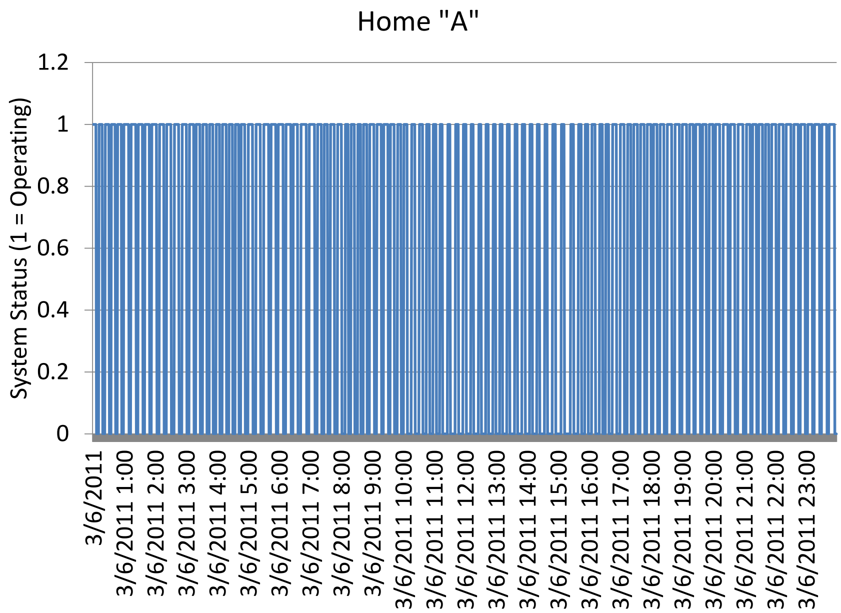
FIGURE 16 – Comparison of Operating Time across Temperature Ranges – Home "A" vs. Home "N"
Nighttime Hours – Fan Operating Status

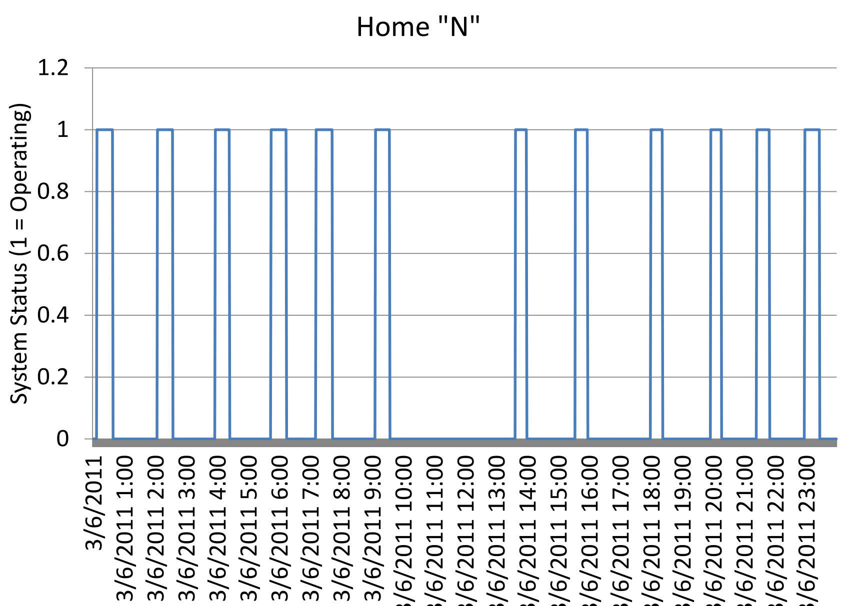




Examining system cycling also reveals some interesting insights. Figure 17 below shows system status over the course of 24 hours on March 6, 2011. Home "A" is observed to have a system that is cycling on for between 5 to 10 minutes of every 15-minute interval. In contrast, the system in Home "N" cycles just 12 times in the entire 24-hour period, typically for between 15 to 30 minutes. The data highlight a signficant differences in system performance between the two homes, likely reflecting both heat loss rates, but also system control parameters including temperature bands.

FIGURE 17 – Comparison of System Cycling – March 6, 2011

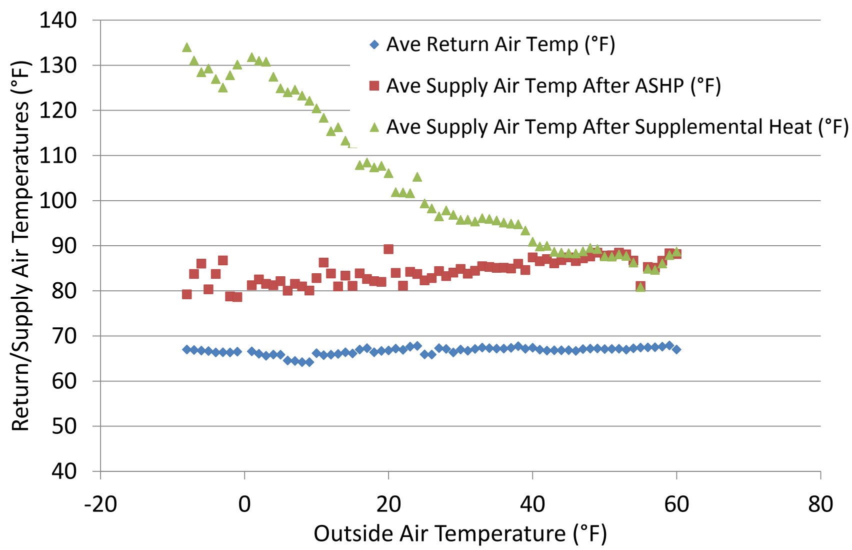




6.4 Observations on Supply Air Temperatures

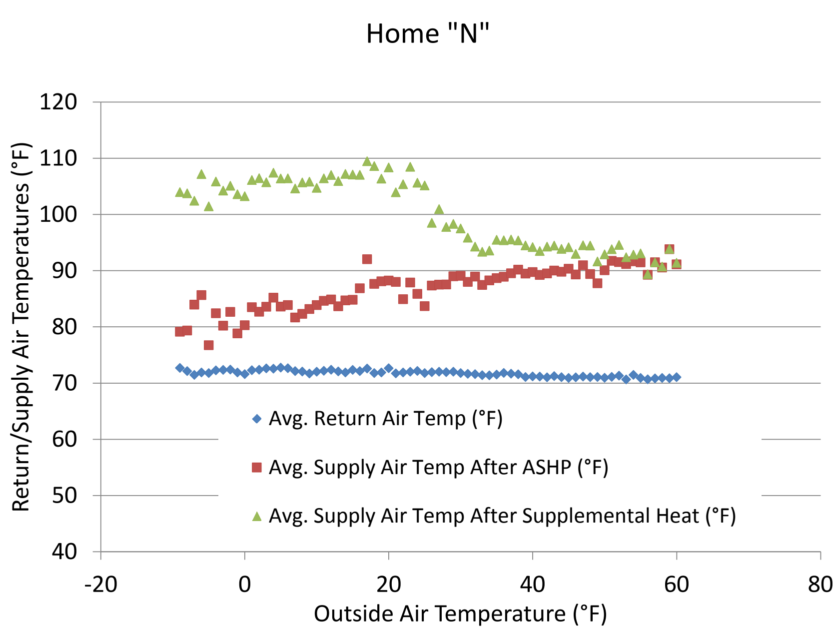
Data on supply air temperatures highlight how the ASHP supply temperature drops across the lower temperature ranges, requiring supplemental heating from the plenum heater in order to maintain comfort and system performance.

FIGURE 18 – Supply Air Temperatures vs. Outside Air Temperature – Home "A"



As with the calculated heat delivery, Home "N" is shown to have less modulation in the supply air temperature output as compared to Home "A". Supply air temperatures increase from around 95^{o} F to around 100^{o} F beginning at outside air temperatures of around 25^{o} F.

FIGURE 19 – Supply Air Temperatures vs. Outside Air Temperature – Home "N"



7. Conclusions – CIP Program Considerations

This study highlights several important considerations for utility program sponsors to consider in weighing incentive strategies for air source heat pumps, including for Conservation Improvement Program (CIP) offerings in Minnesota:

1. ASHPs, typically operating in combination supplemental electric resistance heating, are a viable and economical means to improve electric heating efficiency. Independent research shows ASHPs will maintain a coefficient of performance (COP) well above 1, and often between 2 to 3, in cold-climate conditions (as compared to a COP of 1 for electric resistance heat).
2. Converting from less efficient electric systems to heat pump-only or hybrid electric systems offers significant opportunity for energy savings. Billing data analysis of individual homes highlights examples of electrically-heating homes that have realized as much as 40% electricity consumption reductions through the adoption of hybrid ASHP systems.
3. Coupling systems with a thermal electric storage system can present a win-win where customers are able to lower electric energy costs by taking advantage of off-peak rates and utilities are able to benefit from a load management perspective with reductions to peak demand.
4. Overall, customers are highly satisfied with their system's performance. Surveyed customers provide an average rating of 4.3 on a 5-point scale (1 = 'Poor', 5 = 'Excellent') across all dimensions of their hybrid system performance.
5. A large majority of customers adopting hybrid ASHPs are found to be converting from other heating fuel sources. In reviewing billing data, over three quarters of Minnesota premises in our study installing systems were found to have an increase in heating season electricity consumption with more than half of these homes having an increase in kWh consumption of more than 50%. In total, an 18% increase in kWh consumption was observed for system adopters.

In order to advance the goals of the CIP program in achieving energy savings, program sponsors should seek ways to maximize the adoption of more efficient systems including hybrid ASHP systems among customers using primary electric heating. Appropriate considerations should be made in program eligibility requirements that ensure energy savings will be achieved.

More broadly, given the economic attractiveness of hybrid ASHP systems for customers that may be moving away from fossil fuel heating sources or adopting a dual-fuel approach, additional research into efficiency across all fuel types – pre and post installation – would provide valuable insights. Investigation from ASHRAE members has shown there may not be primary energy savings benefits for Minnesota customers as compared to high efficiency gas systems.[7] However, the reality is that many customers will be moving away from less efficient systems from a variety of fuel sources (including fuel oil, propane, natural gas, etc.). It is important to characterize the impacts of these system adoptions and ensure that incentives are aligned from an energy-savings cost effectiveness standpoint.

[7] Roth, K., J. Dieckmann, and J. Brodrick, "Heat Pumps for Cold Climates," American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc., *ASHRAE Journal*, February 2009: http://www.tiaxllc.com/publications/ashrae/february2009.pdf

Appendix A – References and Resources

Caneta Research Inc. 2010. *Heat Pump Characterization Study*. Prepared for Energy Solutions Centre. March.
http://www.energy.gov.yk.ca/pdf/yukon_airsource_heatpump_mar_2010.pdf

Ecotope. 2009. *Analysis of Hallowell Cold Climate Heat Pump Data McCall, ID and Portland, OR.* Submitted to Northwest Power and Conservation Council and Regional Technical Forum, Bonneville Power Administration. December.
http://www.bpa.gov/energy/n/emerging_technology/pdf/Hallowell_Cold_Climate_Heat_Pump_Data_121409.pdf

Meredith, C. and D. Hales. 2007. *EnergyIdeas Clearinghouse, Product & Technology Review: Acadia™ Heat Pump*, PTR #19. Washington State University Extension Energy Program. December.
http://www.energyideas.org/documents/Factsheets/PTR/AcadiaHeatPump.pdf

Roth, K., J. Dieckmann, and J. Brodrick. 2009. *Heat Pumps for Cold Climates.* American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc. *ASHRAE Journal*. February. 69-72.
http://www.tiaxllc.com/publications/ashrae/february2009.pdf

Appendix B – Customer Survey – Respondent Feedback Summary

Question:	Respondent ID#	1	2	3	4	5	6	72	8	9	10
	System Type	ASHP/Plenum	ASHP/Thermal Storage	ASHP	ASHP/Thermal Storage	ASHP/Plenum	ASHP/Plenum	ASHP/Plenum	ASHP/Plenum	ASHP/Plenum	ASHP/Plenum
1.a. Is It correct to assume that you are using the air source heat pump as part of your home's primary heating system?	Heat Pump is Primary	Heat Pump	Heat Pump	Heat Pump	Heat Pump	Other System	Heat Pump	Heat Pump	Heat Pump	Heat Pump	Heat Pump
1.b. What other equipment do you consider to be part of your home's primary heating system?	Other Equipment	Plenum Heater/Electric Furnace	Brick Storage Heating	None	Brick Storage Heating	Electric Boiler	Baseboard	Plenum Heater/Electric Furnace	Plenum Heater/Electric Furnace	None	Plenum Heater/Electric Furnace
1.c.i Do you have a system that you consider your backup heating system? How would you describe your backup heating system?	Backup Heating System	Wood Furnace	Other	NG Furnace	None	Heat Pump	Other	NG Furnace	NG Furnace	NG Furnace	None
1.c.ii What are the conditions that require you to utilize your backup heating system?	Backup Decision	Local Space Heat	Other	Heatpump Cutout	None	Utility Controls	Price of Gas	Utility Controls		None	None
1.d. Does your home have any baseboard, cove, or ceiling electric heating elements or space heaters that are not part of your central primary heating system and may be used less frequently to provide heat in specific areas?	Specific Area Heat	No	Yes Weekly	No	No	No	Yes Daily	Yes A Few Times a Year	No	No	No
1.e.Do you have under-floor electric heating in your garage or other parts of your home?	Electric Underfloor Heating	Yes, Other	No	Yes, Garage	No	No	No	No		No	No
1.f.i Do you have a sense for the approximate square footage of your home?	Square Footage	2800	1500	1640	2000	1100	N/A	1900	1650	2600	1100
1.f.ii Do you have a sense for the approximate age of your home? (Year of Construction)	Year of Construction	2009	1914	2001	1950's	1978	N/A	1987	2008	1984	2009
2 Prior to the installation of your current heating system, what did you use as your primary heating system?	Previous System	New Construction	Gas Furnace	Air Source Heat Pump	Fuel Oil Furnace	Gas Furnace	Air Source Heat Pump	Gas Furnace	Fuel Oil Furnace	Gas Furnace	New construction
3.i With the previous system did you have a backup system?	Previous Backup	None	None	NG Furnace	Wood Furnace	None	Other	NG Furnace	None	Wood Furnace	None
3.ii If yes what are the conditions thatt require you to utilize your backup heating system?	Previous Backup Conditions	None	None	Heat Pump Cut-Out	Other	None	Heat Pump Cut-Out	None			None
4.b. Next I'd like to understand what motivated you to install your new system. Please rate on a scale of 1-5 with 5 being a 'Major Motivator' and 1 being 'No motivator', how the following factors have motivated your decision?	Replace Existing Failing System	1	3	1	1	3	5	5	1	5	1
4.c	Enhance Existing System	1	1	1	1	1	4	4	1	5	1
4.d.	Replace Existing System with More Efficient	5	5	5	5	5	5	5	5	1	1
4.e.	Replace Existing System with Lower Operating Cost	5	1	5	5	5	5	5	4	1	1
4.f.	Heating and Cooling from Same System	1	5	1	5	5	5	5	3	3	1
4.g.	Change Fuel Sources	1	4	1	5	5	1	1	4	1	1
4.h.	Eliminate Fuel Storage	1	5	1	1	4	1	1	1	1	1
4.i.	Reduce Impact of High Fossil Fuel Costs	5	1	1	5	3	5	1	5	1	1
4.j.	Other Selection Influence	Environmental Impacts	Home Improvement	Vendor/ Contractor Program	Rebate Available	Vendor/ Contractor Program			Discussion with Ottertail	Discussion with Ottertail	Home Improvement
5.a. In addition to the rebate you received, did the installation of the new system allow you to take advantage of other energy or money saving programs offered by your power company, such as off-peak rates, financing, or dual fuel programs?	Other Incentives	Yes, Off Peaking	Yes, Off Peaking	Yes, Off Peaking	Yes, Off Peaking	Yes, Financing			No	Yes, Off Peaking	No
5.b. If yes did this have a significant impact on your decision to install the system?	Significant Impact	Yes	Yes	Yes	Yes	Yes			No	No	No

Question:	Respondent ID#	1	2	3	4	5	6	72	8	9	10
6.a. In evaluating your options for the new system, do you recall considering any of the following alternatives before purchasing your existing airsource heat pump system?	Considered: Electric Furnace	No	No	No	Yes	Yes	No	No	No	No	No
6.b.	Dual Fuel	No	No	No	Yes	No	No	Yes	No	No	No
6.c.	Baseboard	No	No	No	No	No	No	No	No	No	No
6.d.	Non-Central Electric	No	No	No	N/A	No	No	No	No	No	No
6.e.	Geothermal	Yes	No	No	No	No	No	Yes	No	Yes	No
6.f.	Propane	No	No	No	No	No	No	Yes	No	No	No
6.g.	Fuel Oil	No	No	No	Yes	No	No	No	Yes	No	No
6.h.	Natural Gas	No	Yes	No	N/A	No	No	No	Yes	No	No
7.a. How did you select the air source heat pump and supplemental (explain as thermal storage furnace or plenum heater) over other electric resistance heating options you may have considered? Please rate on a scale from 1 to 5 with 1 being not at all and 5 being very high the following factors in influencing your decision?	ASHP vs Electric: Operating Cost	N/A	5	N/A	5	5	N/A	5	5	N/A	1
7.b.	Off-Peak Rates	N/A	5	N/A	5	5	N/A	5	1	N/A	1
7.c.	Maintenance	N/A	5	N/A	3	1	N/A	3	1	N/A	1
7.d.	System Cost	N/A	5	N/A	1	1	N/A	5	1	N/A	1
7.e.	Rebates and Incentives	N/A	5	N/A	5	3	N/A	5	1	N/A	5
7.f.	Heating and Cooling in One System	N/A	5	N/A	5	5	N/A	5	1	N/A	5
7.g.	Anticipated Comfort	N/A	5	N/A	1	5	N/A	5	5	N/A	5
7.h.	Safety	N/A	5	N/A	2	4	N/A	2	1	N/A	1
8.a Have you noticed a difference in your overall heating bill with the new heating system compared to your previous system?	Notable Difference in Heating bill	N/A	Yes Lower	Yes Higher	Yes Lower	Yes Higher	Yes Lower	Yes Lower	Yes Lower	Yes Higher	N/A
9.a If #8 yes, Can you estimate the order of magnitude change you are seeing in your bill during the heating system?	Estimated Change		0.2		0.25	0.15	0.1		0.45		N/A
10.a Does your heating systems energy use match with your expectations at the tme of system installation?	Does system performance match expectations?	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	N/A
10. Comments	Comments	Unsatisfied with installation of plenum, doesNot effectively kick on in the cold	Meets expectations "Pretty well."	Increased the temperature I keep the house at.		cooling is significantly cheaper	better able to cool during hot weather		it exceeds expectations		
11.a. Have you noticed any difference in the comfort of the heating in your home as a result of the new system?	Difference in comfort of home:	Decreased Comfort	No Change	Improved Comfort	Decreased Comfort	Improved Comfort	Improved Comfort	Improved Comfort	Improved Comfort	Decreased Comfort	No Change
11. Comments	Comments on comfort change:	cooler than they'd like: cold register temps	no draft,no register issues	the variable speed on the furnace saves money and increased comfort	air from registers feels cooler	better temperature control	even temerature throughout	likes the feel of the heat from electric		it hadn't been adjusted, it had to be programed with the plenum heaters	
12.a Does the system allow you to maintain the desired temperature throughout the house?	Desired Comfort:	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
13a. Are there any issues with air temperature from the registers?	Issues with Temp From Registers	Yes	No	No	Yes	Yes	No	No	No	No	No
13b. Have you done anything to address this?	Anything to Address this?	Yes	N/A	N/A	Yes	N/A	N/A	N/A	N/A	N/A	N/A
13. Comments	Comments	the registers get too cold, the airpump is freezing,		keeps the house at 73*	the furnace runs a lot, so they had the fans serviced	cooler register temperatures			register temp is 80* its comfortable	It ran 100% of the time this year it cycles correctly	

Question:	Respondent ID#	1	2	3	4	5	6	72	8	9	10
14.a. how would you rate the heat pump system on the following dimensions on a scale from 1 to 5 with 1 being Poor and 5 being excellent? For comparison you can also provide a rating for your previous system	rating 1 poor-5 excellent: Comfort	3	4	5	3	5	5	5	5	5	5
14.b.	Noise	4	5	5	4	3	3	4	3	2	5
14.c.	Reliability	4	5	5	5	5	4	3	5	3	5
14.d.	overall heating cost	2	2	N/A	5	2	5	5	5	3	3
14.e.	overall cooling cost	N/A	3	5	5	5	5	5	4	3	5
14.f.	safety	4	5	N/A	5	5	5	5	5	5	N/A
14.g.	performance in extreme temperatures	4	5	5	4	2	5	5	5	3	5
14.h.	compatibility w/alternative systesm	N/A	N/A	N/A	N/A	5	5	5	3	N/A	N/A
	Total	21	29	25	31	32	37	37	35	24	28
Temperature: In most cases installers set an air source heat pump to stop operating once the outside air temperature reaches a certain level. Do you have a sense for the temperature at which your heat pump is set to cut out?	Do you have a sense for the temperature at which your heat pump is set to cut out?	No	No	10 Degrees	No	10 degrees	No	No	10 Degrees	20 Degrees	When OtterTail Controls
15.a. Is your primary electric heating system adequate for even the most extreme sub-zero temperatures, or do you need to supplement with other heating sources on the coldest days?	Is your primary heat system adequate for even the most extreme sub-zero temps or do you need to supplement?	No	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes
15. Comments	Comments	we turn to the wood stove in heavy winds, itsNot the temp it's the feel of wood heat				it will keep us warm			supliment with gas	it was the primary this year	
16.a. If you were replacing your heating system today, would you choose the same system? Why or why not?	Would you choose a heat pump again?	No	Yes	Yes	Yes	No	No	Yes	Yes	Yes	Yes
17.a. In addition to the heating system, have you made any significant changes to your home or other electric appliances in the last year or two; such as- list)	Have you made any significant changes to your home or other electric appliances in the last year or two?	windows, insulation, earth berm/passive solar, window shading, weatherization/air sealing	major renovations, lighting, wiring, gas water heat, HE windows, attic & basement insulation, washer and range, heated basement	no major changes	new roof with insulation, new refridgerator, new washer/dryer/new chest freezer	all new windows, refrigerator, dish-waher,range,freezer	go with geothermal heating		remodeled completely, all new windows, 28 inches of fiber-glass insulation in the ceiling and 3 1/2 to 5 1/2" of spray foam in the walls. refrigerator, washer, dryer, dish washer, range large tv.	no major changes but we'd like to make the system quieter	all new efficient construction
18.a. Is there anything else you would like to share?	Is there anything else?	"We don't want to use any more energy than we have to and this program made that an option."		very happy with the decision made; would promote the program to others.	the incentive was good enough to make up their minds at the time	Ottertail has much better customer service than the prior gas company.					

Appendix C – Customer Survey – Interview Guide Template

Air Source Heat Pump – Hybrid Heating System

Homeowner Questionnaire – Interviewer Guide

Respondent Name: ______________________ Interviewer: ______________________

Date: ______________________

System Type (check one): ASHP/Thermal Storage:___ ASHP/Plenum:___ ASHP(only)___

Respondent contact information (address, phone):

[Enter response]

<u>Introduction:</u>

If cold call:

Hi, _______. As part of a joint effort with Otter Tail Power Company, we are gathering feedback from homeowners that have participated in Otter Tail Power Company's air source heat pump rebate program for new heating system installations. In particular, we are hoping to learn more about homeowners' experience with air source heat pumps used in combination with other heating systems such as electric thermal storage systems or plenum heaters. We appreciate the opportunity to gather perspectives from homeowners like you that may have these systems in their home to learn about satisfaction with these systems and the impact on electric bills.

Our records show that a rebate application in the name of _____was processed on ___ (month/date) for the installation of a ____ system. Do you recall receiving a rebate from Otter Tail Power Company?

If Yes, proceed. If No:

"Thank you for taking the time to talk to us today. We apologize for the inconvenience. Have a great day."

Would you be willing to take a few minutes to share your thoughts on your home's heating system in a short phone interview? I will try to keep the call to ten minutes or less.

If Yes, proceed. If No

"Thank you for taking the time to talk to us today. We apologize for the inconvenience. Have a great day."

Great! Thank you. Your confidential responses to this survey will be used to develop better information about the advantages, and potential disadvantages of various heating and cooling systems. We recognize that most people may not be familiar with the details of their heating equipment. As we go through this survey please let me know if I can provide clarification on any of the terms I am using.

If customer has responded to request for interview (e.g., mailing):

Hi, _______. As part of a joint effort with Otter Tail Power Company, we are gathering feedback from homeowners that have participated in Otter Tail Power Company's air source heat pump rebate program for new heating system installations. We received your response and thank you for your willingness to take the time to talk with us.

Is this still a good time to talk? I will try to keep the call to ten minutes or less.

If Yes, proceed. If No:

> "Thank you for taking the time to talk to us today. We apologize for the inconvenience. Have a great day."

Great! Thank you. Your confidential responses to this survey will be used to develop better information about the advantages, and potential disadvantages of various heating and cooling systems. We recognize that most people may not be familiar with the details of their heating equipment. As we go through this survey please let me know if I can provide clarification on any of the terms I am using.

<u>Current Heating System</u>

1. First we'd like to get a little more information about your home and your current heating system.

   a. Is it correct to assume that you are using the air source heat pump as part of your home's primary heating system?

      ___ *Yes* ___ *No:* ____

   b. What other equipment do you consider to be part of your home's primary heating system?

      ___ *Underfloor electric thermal storage:* ____________________________

      ___ *Brick storage heating system:* ____________________________

      ___ *Plenum heater/electric furnace:* ____________________________

      ___ *Electric boiler:* ____________________________

      ___ *Non-central electric resistance (baseboard, cove, space heater, etc.):*

      ___ *baseboard* ___ *cove* ___*room space heater* ___ *other:* ________________

      ___ *Fossil fuel:* ___ *Furnace* __ *Boiler*

___ *Nat. gas* ___ *Fuel oil* ___ *Propane* ___ *Wood* ___*Other:*_________

___ *Ground source or geothermal heat pump:* ____________________________

___ *Other (hearth, stove, fireplace etc.):* ____________________________________

___ *Don't know*

c. Do you have a system that you consider your backup heating system? *[If Yes]* How would you describe your backup heating system?

___ *Yes* ___ *No*

i. If Yes:

___ *Furnace (non-electric):* ___ *Natural gas* ___ *Fuel oil* ___ *Propane*

___ *Wood*

___ *Boiler (non-electric):* ___ *Natural gas* ___ *Fuel oil* ___ *Propane* ___ *Wood*

___ *Other:* ____

ii. [*If Yes*] What are the conditions that require you to utilize your backup heating system?

[Enter description of backup system use]

d. Does your home have any baseboard, cove, or ceiling electric heating elements or space heaters that are not part of your central primary heating system and may be used less frequently to provide heat in s*pecific areas?*

___*No* ___*Yes*

i. [If Yes] How often*?*

___ *Daily* ___ *Weekly* ___ *Just a few times a year*

e. Do you have under-floor electric heating in your garage or other parts of your home?

___ *Yes* ___ *No*

___ *Garage* ___ *Other:* ____

f. Do you have a sense for the approximate square footage and age of your home?

____*sq. ft.*

Year of home construction: __________

[Enter response]

Previous System

2. Prior to the installation of your current heating system, what did you use as your primary heating system?

___ *Heat pump:* ___ *air source* ___ *geothermal:* _____________________________

___ *Electric thermal storage:* _____________________________

___ *Plenum heater/electric furnace:* _____________________________

___ *Electric boiler:* _____________________________

___ *Fossil fuel:* ___ *Furnace* __ *Boiler:* _____________________________

___ *Natural gas* ___ *Fuel oil* ___ *Propane*

___ *Wood*

____ *Other (hearth, stove, fireplace etc.):* _____________________________________

___ *Don't know*

___ *None – no previous system (e.g., new construction – Skip to question #5*

3. With the previous system, did you have a backup system?

___ *Yes* ___ *No*

i. *If Yes:*

___ *Furnace (non-electric):* ___ *Natural gas* ___ *Fuel oil* ___ *Propane*__ *Wood*

___ *Other:* ____

ii. [*If Yes*] What are the conditions that require you to utilize your backup heating system?

[Enter description of previous backup system use]

[Enter response]

Decision Making – System Selection

4. Next I'd like to understand what motivated you to install your new system. Please rate on a scale of 1-5 with 5 being a major motivator and 1 being no motivator, how the following factors may have motivated your decision:

   b. ___ Replace the existing system that was failing

   c. ___ Make enhancements to an existing system

   d. ___ Replace the existing system with a more efficient system

   e. ___ Replace the existing system with a lower operating cost system

   f. ___ Receive both heating and cooling in one system

   g. ___ Change fuel sources

   h. ___ Eliminate need for fuel storage or tanks

   i. ___ Eliminate high heating costs during periods of high fossil fuel prices

   j. ___ Other (mentioned by respondent): ________________________________

[Enter response]

5. In addition to the rebate you received, did the installation of the new system allow you to take advantage of other energy or money-saving programs offered by your power company, such as off-peak rates, financing, or dual fuel programs?

___ *Yes* ___ *No*

   a. [If Yes] Did this have a significant impact on your decision to install the system?

   ___ *Yes* ___ *No*

[Enter response]

6. In evaluating your options for the new system, do you recall considering any of the following alternatives before purchasing your existing air source heat pump system?

   a. electric furnaces?: ___Yes ___ No

b. Dual fuel furnaces?: ___Yes ___ No

c. Baseboard electric resistance?: ___Yes ___ No

d. Non-central electric heat such as baseboard, cove, or room space heaters? : ___Yes ___ No [If Yes, indicate below]

   ___ baseboard ___ cove ___room space heater ___ other: _________________

e. Geothermal heat pump systems?: ___Yes ___ No

f. Propane heating systems?: ___Yes ___ No

g. Fuel oil heating systems?: ___Yes ___ No

h. Natural gas heating systems?: ___Yes ___ No

[Enter response]

7. [If applicable] How did you select the air source heat pump and supplemental (explain as thermal storage furnace or plenum heater) over other electric resistance heating options you may have considered? Please rate on a scale from 1 to 5 with 1 being Not at All and 5 being Very High the following factors in influencing your decision?

   a. ___ Operating cost based on electric efficiency
   b. ___ Operating cost because of lower off-peak rates
   c. ___ Operating cost because of maintenance
   d. ___ System cost (equipment and installation)
   e. ___ Available rebates and incentives
   f. ___ Opportunity to have one system for both heating and cooling
   g. ___ Anticipated performance and comfort
   h. ___ Safety

[Enter response]

Energy Use Experience

8. Have you noticed a difference in your overall heating bill with the new heating system compared to your previous system?

___ *Yes* ___ *No*

   k. *[If Yes]:* ___ *Energy use is lower* ___ *Energy use is higher*

[Enter response]

9. *[If #8 Yes] Can you* estimate the order of magnitude change you are seeing in your bill during the heating season?
   a. *Magnitude of change:* ___% *to* ___%

[Enter response]

10. Does you heating system's energy use match with your expectations at the time of system installation?

___ *Yes* ___ *No*

[Enter response]

System Performance and Satisfaction

11. Have you noticed any difference in the comfort of the heating in your home as a result of the new system?

___*Improved* ___*Decreased*

[Enter response]

12. Does the system allow you to maintain the desired temperature throughout the house?

___ *Yes* ___ *No*

[Enter response]

13. Are there any issues with air temperature from the registers?

___ *Yes* ___ *No*

[*If* Yes] What types of issues? ___________________

Have you done anything to address this?

___ *Yes* ___ *No*

[Enter response]

14. How would you rate the heat pump system on the following dimensions, on a scale from 1 to 5 with 1 being Poor and 5 being Excellent? For comparison, you can also provide a rating for your previous system.

Criteria	New System	Old System
a. Comfort	_____	_____
b. Noise	_____	_____
c. Reliability	_____	_____
d. Overall heating costs (bill)	_____	_____
e. Overall cooling costs (bill)	_____	_____
f. Safety	_____	_____
g. Performance in extreme temperatures	_____	_____
h. Compatibility with alternative heating systems	_____	_____

Air Source Heat Pump Operation

In most cases, installers set an air source heat pump to stop operating once the outside air temperature reaches a certain level. Do you have a sense for the temperature at which your heat pump is set to cut out? ___*Yes:* _____*deg. F* ___*No*

[Enter response]

15. Is your primary electric heating system adequate for even the most extreme sub-zero temperatures, or do you need to supplement with other heating sources on the coldest days?

___ *Yes* ___*No, need other heating*

[Enter response]

<u>Other Questions (optional based on interviewee time sensitivity)</u>

16. If you were replacing your heating system today, would you choose the same system? Why, or why not?

___ Yes ___ No

[Enter response]

17. In addition to the heating system, have you made any significant changes to your home or other electric appliances in the last year or two, such as:?

    a. [Prompted by interviewer]

____ Additions or major renovations: ____________________________

____ Lighting: ___ CFLs ___ Other: ____________________________

____ Central Air Conditioning: ____________________________

____ Water Heating: ____________________________

____ Windows: ____________________________

____ Insulation: ____________________________

____ Weatherization/air sealing: ____________________________

____ Appliance: ___ A/C ___Rfg. ___Wash ___Dry ___DW ___Range

___ TV ___ Frz. ___Other:_______________________

_____ Pool/Spa: ___ Spa ___ Pool Pump ___ Sauna

_____ Resistance (baseboard/room) heating:____________________________

_____ Under-floor heating (garage, etc): _______________________________

_____ Other: ____

[Enter response]

18. Is there anything else you would like to share?

[Enter response]

Thank you for your willingness to take time to share your thoughts. We greatly appreciate your help!