Investigation of Air Source Heat Pumps as a Replacement of Central Air Conditioning
Potential Benefits, Market Research and Technical Analysis

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Prepared by: Center for Energy and Environment
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<td>Air conditioning</td>
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<td>ASHP</td>
<td>Air source heat pump</td>
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<tr>
<td>CAC</td>
<td>Central air conditioning</td>
</tr>
<tr>
<td>CARD</td>
<td>Conservation Applied Research and Development program</td>
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<tr>
<td>CCASHP</td>
<td>Cold-climate air source heat pump</td>
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<tr>
<td>CEE</td>
<td>Center for Energy and Environment</td>
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<tr>
<td>CFM</td>
<td>Cubic feet per minute</td>
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<td>CIP</td>
<td>Conservation Improvement Program</td>
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<td>SSASHP</td>
<td>Single-speed air source heat pump</td>
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Investigation of Air Source Heat Pumps as a Replacement of Central Air Conditioning
Center for Energy and Environment
Executive Summary

Introduction

Air source heat pumps (ASHPs) have been recently touted as a technology for significant energy savings, as well as a potential pathway to space heating decarbonization. However, studies to date suggest that in cold climates like Minnesota all-electric ASHP systems bring these energy savings at higher upfront and ongoing energy costs compared to homes heated with natural gas furnaces. This study evaluates dual fuel (or hybrid heat) applications, in which an ASHP is paired with a natural gas furnace to mitigate the higher operating costs of all-electric ASHP systems. Dual fuel ASHP products can replace the central air conditioner (CAC) and integrate with existing natural gas furnaces. This configuration allows the operation of either the gas furnace or ASHP for space heating, depending on economic conditions and customer priorities. This product category can serve as a gateway application for ASHPs that familiarizes consumers and contractors with ASHP technology and enables most of the savings benefits of ASHP systems while minimizing the barriers exclusive to all-electric ASHP installations.

Study Objectives

1. Characterize ASHPs for CAC replacement.
2. Identify barriers and opportunities from the perspective of current CAC market participants.
3. Quantify savings and costs of different ASHP for CAC equipment types.
4. Review existing programs and recommend utility marketing and implementation strategies.

Methods

This study comprises market characterization work and detailed equipment performance modeling. Market characterization efforts featured 438 customer surveys and interviews with 30 contractors, 3 distributors, and 5 manufacturers to understand the existing and potential market for this application from perspectives ranging from consumers to manufacturers.

Equipment performance was modeled to show how costs and savings vary across the replace-on-fail market, where failed CAC systems are replaced with dual fuel ASHP equipment. This extensive modeling effort ran 8760 performance simulations over four types of ASHP equipment, nine baseline equipment configurations, four geographic locations, two replacement options, and utility costs ranging from 0.07 $/kWh to 0.2 $/kWh and 0.5 $/therm to 1.6 $/therm.
Market Findings

Lack of customer awareness is the main barrier to adoption; education efforts are necessary for contractors and consumers so they can make informed decisions during replacement cycles.

- CAC replacements are often made under duress by customers who are unfamiliar with ASHP technology, often following the advice of contractors who are unfamiliar with or who downplay ASHP options.

Today’s CAC replacements are locked in for 15 or more years. Thus, every CAC currently installed is a lost opportunity for:

- Significantly increased volumetric electricity sales,
- more efficiency,
future integration with increased statutory emissions and savings goals, and
expanding the flexibility of dual fuel space heating applications

Technical Findings

**ASHPs sized as CAC replacements offer most of the savings available from all-electric ASHP systems sized for the full heating load.**

- Single-speed ASHPs in dual fuel configurations can yield up to approximately 50% of the savings attributed to all-electric systems.
- Variable speed ASHPs offer better savings, at over 80% of all-electric savings potential.

**Current savings, when paired with existing utility incentives or lower upfront costs realized at an increased market scale, meet customer cost expectations for higher performance and comfort.**

- Special dual fuel electric rates drive added customer cost savings.

<table>
<thead>
<tr>
<th>Single-speed ASHPs</th>
<th>Entry-level variable-speed ASHPs</th>
<th>Cold-climate variable-speed ASHPs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost-neutral operation under many utility rate combinations</td>
<td>Economic &quot;sweet spot&quot;, yields cost effective savings today</td>
<td>Offer flexibility for future cold weather operation</td>
</tr>
<tr>
<td>Low-cost entry to ASHP technology</td>
<td>Even better results when paired with high efficiency furnace upgrades</td>
<td>No significant performance advantages at current utility rates</td>
</tr>
</tbody>
</table>

Recommendations

**Utility rebate programs can overcome first-cost barriers at the point of CAC replacement and offer a selling tool for contractors.**

- The project team encourages an increased baseline in the CAC market shifting to entry level (SEER ≥ 15) ASHP.
- Phase out CAC rebates to send a clear signal to the market that heat pumps are the preferred technology for CAC and ensure that the gap between CAC and heat pump costs are as minimal as possible.
- Provide two tiers of heat pump rebates to incentivize as many heat pump installations as possible while also continuing to encourage the highest efficiency products.
Due to the rapidly evolving nature of ASHP technology, utilities should stay engaged with regional collaborative groups such as the Minnesota ASHP Collaborative (https://www.mnashp.org) and the MN Efficient Technology Accelerator (https://www.mncee.org/mi) to maintain rebate best practices and regional alignment.
Introduction

Recent national research highlights residential air source heat pumps (ASHPs) as a compelling efficiency and decarbonization measure across the entire country, even for cold climate Minnesota homes (Walker 2022, Nadel 2022, Malinowski 2022). Analyses consistently show energy, carbon, and customer cost savings for Minnesota’s housing stock that is heated by electric resistance or delivered fuels, which represents about 710,000 homes or 32% of all homes (EIA 2022). However, results are not as favorable for homes heated using natural gas furnaces. Many national studies show energy and carbon savings for Minnesota’s climate, but typically at higher customer costs compared to natural gas space heating systems (Walker 2022, Nadel 2022). The higher cost of ASHP compared to natural gas space heat is a major barrier for a state in which 68% of homes are heated via natural gas furnaces. Upon closer examination, cost conclusions to date are restricted to a relatively narrow set of assumptions about energy costs, weather details, or ASHP and baseline equipment performance levels.

Recognizing that higher operating costs of ASHPs are due to lower performance at the coldest outdoor conditions, this study looks at dual fuel (or hybrid heat) applications, whereby an ASHP is paired with a natural gas furnace. In this application, the ASHP displaces the central air conditioning (CAC) system to meet space cooling loads and while also some fraction of the space heating load. The natural gas furnace meets the remaining space heating load. In this context, ASHPs can be considered a CAC efficiency measure with additional benefits that include high efficiency heating at warmer outside temperatures and the flexibility to use either natural gas or electricity for heat in response to carbon goals, customer costs, or participation in utility load management programs.

Several Conservation Applied Research and Development (CARD) projects have focused on ASHP technologies, but those projects predominately target heating load. This project instead focuses on a new market opportunity where ASHP products are specifically designed to integrate with existing natural gas furnaces to displace CAC systems. The major advantage of this ASHP application is lower costs. First costs are lowered by using the existing furnace/air handler and smaller units sized for cooling loads. Operational costs are reduced because the system can heat with natural gas or electricity depending on energy costs and relative performance of the heating systems. Additionally, this gateway application familiarizes consumers and contractors with ASHP systems. And while Minnesota’s efficiency statute has since been updated to enable efficient fuel-switching, ASHP systems that displace CAC systems fit within an efficiency framework without fuel-switching. In the context of fuel-switching, these ASHP for CAC measures offer tremendous flexibility for electric savings, natural gas savings, or fuel-switching savings, which can be realized depending on specific customer objectives or utility program goals.

There are two major components of this project:

1. Market characterization efforts to engage contractors, distributors, and manufacturers through interviews and discussions to understand this application type and the key barriers and benefits in the market.
2. A technical modeling effort to understand how baselines, ASHP equipment specifications, energy, rates, and weather impact savings potential and customer costs.

This project also highlights current program strategies deployed statewide and nationally in this application space. The report concludes with recommendations that utilities and market actors can take to swiftly advance this energy savings and decarbonization opportunity.
Objectives

1. Characterize what defines a heat pump for CAC replacement.
2. Identify existing barriers and opportunities in the current CAC market with customers, contractors, distributors, and manufacturers.
3. Quantify the energy savings and customer costs of different ASHP for CAC equipment types.
4. Review existing programs or related programs and provide utility program recommendations and marketing/implementation strategies.

Background

Air Source Heat Pumps

ASHPs are a space heating and cooling technology similar to air conditioning systems except they have a valve and additional controls that enable them to operate in reverse. When this valve is engaged, the reverse cycle transfers energy from cold outside conditions into warm inside conditions to meet space heating needs. While heat pumps have been commercially available for decades and have a significant market share in warm climates, it is only in the last 10 years that technological developments yielded viability in very cold climates like Minnesota. These systems have very high energy savings and carbon reduction potential because, like air conditioners, they have efficiency greater than one. In fact, in mild conditions (47°F or more), the efficiency of ASHPs can approach 400% or more. These efficiency levels can bring 10 times or more space heating savings compared to conventional furnace upgrades, which are usually limited to less than 20%. This huge potential is the basis for Minnesota’s Air Source Heat Pump Collaborative, a utility funded initiative to accelerate ASHP adoptions. It is also led to ASHPs as one of the inaugural initiatives of Minnesota’s new market transformation initiative, the Efficiency Technology Accelerator.

ASHPs come in many different types and form factors. This study focuses exclusively on centrally ducted split heat pump systems paired with natural gas furnaces. These homes comprise a majority of Minnesota housing stock, and there is already a clear economic benefit for using ASHPs in homes with electric resistance heat or delivered fuels like propane. Mini-split, multi-split, and mini-ducted systems are not considered in this project scope. Centrally ducted, dual fuel (hybrid) heat pumps that are paired with propane furnaces and all-electric heat pump systems (those with electric resistance backup) are also excluded from consideration. Further, the systems considered here are sized for the space cooling loads, which means they are generally smaller than systems sized for heating. By design, these systems cannot meet winter heating loads in cold climates. Consequently, the natural gas furnace is an integral component for space heating in very cold outside conditions. These ASHPs come in variable efficiency levels and features, including both single speed and variable speed systems. Lastly, this application includes interoperable (non-communicating) ASHPs that, like a regular CACs, can usually be paired with existing furnaces, but it also includes non-interoperable (communicating) ASHPs that have proprietary controls and typically require a compatible furnace (typically from the same manufacturer). These system distinctions are highlighted in Figure 1.
These dual-fuel systems generally operate the ASHP down to a specific outside operating temperature called the switchover temperature. Below the switchover temperature, the ASHP is locked out by the thermostat and the natural gas furnace is used to meet the heating load. The capacity-based switchover temperature is the lowest temperature for which the ASHP capacity can meet the heating load. ASHPs operating below the capacity-based switchover temperature would not meet the thermostat setpoint. Switchover temperatures are usually set higher than the capacity-based switchover depending on cost benefits for the customer. The relationship between customer costs and ASHP efficiency is described in Appendix C.

### Minnesota Housing Stock

Most single-family (SF) homes in Minnesota are heated by centrally ducted natural gas furnaces. Most of these systems are also served by centrally ducted air conditioning systems. The recent Residential Energy Consumption Survey (RECS 2020) estimates that there are 1,080,000 of these homes in Minnesota. While RECS does not provide spatial fidelity below the state level, recent residential survey results from the 2018 Minnesota Potential Study are used to estimate how these homes are distributed throughout the state as shown in Table 1 and graphically in Figure 2. There are about 120,000 additional homes in the state that have centrally ducted natural gas furnaces, but no CAC. These homes also represent opportunities for the systems considered here.

<table>
<thead>
<tr>
<th>Quadrant</th>
<th>Count of Homes</th>
<th>Percent of Homes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Northeast</td>
<td>97,200</td>
<td>9%</td>
</tr>
<tr>
<td>Northwest</td>
<td>43,200</td>
<td>4%</td>
</tr>
<tr>
<td>Southwest</td>
<td>172,800</td>
<td>16%</td>
</tr>
<tr>
<td>Southeast</td>
<td>766,800</td>
<td>71%</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>1,080,000</strong></td>
<td><strong>100%</strong></td>
</tr>
</tbody>
</table>

Table 1: SF homes with natural gas furnaces and CACs (by quadrant), from 2020 Residential Energy Consumption Survey and 2018 Minnesota Potential Study
Figure 2: Map displaying the four regional quadrants used in this study, with the heating degree days (HDD) and cooling degree days (CDD) for each location representing each quadrant.

Figure 2 shows the distribution of SF homes across the state, including those without natural gas heating. The four quadrants signify distinct climates, represented by four specific locations and their typical annual heating and cooling degree days (HDD and CDD). Typical weather within Minnesota can vary broadly, from warmer temperatures and larger cooling loads in the southwest, to colder winters and milder summers in the northwest quadrant of the state. As the efficiency and capacity of an ASHP system depends heavily on outside air temperature and building heating and cooling loads can vary significantly between quadrants, capturing these differences is necessary to paint a complete picture of ASHP potential and customer cost impacts.
Market Investigation

To understand the existing CAC replacement market dynamics, market actors were engaged to collect data on existing attitudes, dynamics, barriers and opportunities. Online surveys, in-depth interviews, and roundtable discussions were conducted with customers, contractors, distributors, and manufacturers to paint a complete picture of the existing marketplace. This section describes the methodology, key findings, and takeaways from the market investigation portion of this project.

Methodology

The project team performed market research with the following audience types and methods:

- **438 online customer surveys** – The customer survey portion of this project was collaboratively designed by Center for Energy and Environment (CEE) and Leede Research. Leede Research performed the survey work and developed the analysis. Surveys were intended to identify motivations for replacing CAC and establish what homeowners value during replacement, when homeowners consider replacement, and what homeowners currently know about the technology.
- **30 in-depth contractor interviews** – CEE performed contractor interviews to understand perceptions, barriers, and opportunities for ASHP as CAC installations in Minnesota.
- **3 in-depth distributor interviews** – CEE performed distributor interviews to understand perceptions, barriers, and opportunities in the ASHP as CAC market.
- **5 in-depth manufacturer interviews** – CEE performed manufacturer interviews to understand product offerings, manufacturer perceptions of the product category (centrally ducted split heat pump systems paired with natural gas furnaces), barriers, and opportunities.

Results

The results of the surveys indicate positive conditions for heat pump adoption in CAC replacement scenarios with some barriers that can be overcome through utility or other program interventions including market transformation activities. Key takeaways follow, with complete results included in Appendix A.

Homeowner Interview Key Takeaways

- Most homeowners are happy with their existing CAC systems, but have a strong interest in:
  a. Upgrading to new and better technology.
  b. Lowering operational costs.
  c. Reducing environmental impact.
- There is a small segment of customers (early adopters) interested in making choices based on environmental drivers.
- Most customers replace their CAC units on failure. They want to shop carefully but may not have time.
Cooling performance, upfront cost, and operating cost are the most important purchasing decision factors.

The average customer’s response indicates that they are willing to pay more upfront to lower their operating costs and, on average, a six-year payback is attractive.

Rebates and financing are important tools for customers; contractors should be prepared to offer these financial tools.

Awareness of this technology is low to moderate; utilities and customer word-of-mouth can play a powerful role in increasing awareness.

Customers need to know that it will work in our climate and that the technology will make economic sense.

Contractor Interview Takeaways

- Customer demand for ASHPs as a CAC replacement is generally low. Education is needed to make the sale.
- There is a strong sense that ASHP business will increase in the future.
- Rebates that make ASHPs cost-competitive with traditional CACs are a key driver of installations.
- Many contractors consider the heating economics and viability of ASHPs when considering them as CAC replacements.

Distributor Interview Takeaways

- Most current sales are in the mini-split category.
- Demand for centrally ducted heat pumps to replace CAC comes from the utility and efficiency industry and not from customers.
- Contractors are receptive to but not yet actively selling the technology.
- Around 10% of customers always pick the best equipment presented — this would apply if heat pumps were offered over high efficiency CAC.

Manufacturer Interview Takeaways

- The market is transitioning away from fossil fuels (the pace of this transition depends on the manufacturer).
- Heat pump as CAC replacement products will be a helpful transitional technology to all-electric systems.
- Manufacturers see opportunities for the product to meet existing market needs.
- Four of the five manufacturers interviewed either already have a heat pump CAC replacement product on the market or were planning to launch one soon (within the next year).

The following is a more detailed summary of each market group’s current attitudes.

Customer Survey Results

Leede Research completed the data gathering and analysis for this portion of the market research. The project team completed 438 interviews with qualified homeowners in Minnesota. Homeowner demographics (age, race, sex, income, and location) represent typical Minnesota homeowner statistics,
according to 2019 US Census data¹. Home size and age varied by respondent, but survey participants were selected based on their homeowner status and their HVAC configuration (forced air heating via a ducted natural gas furnace and a CAC).

Homeowners were asked several questions intended to yield insights into customer attitudes toward energy efficiency, behavior during the CAC replacement process, and knowledge of ASHPs, both in general and as CAC replacements. An overview of the consumer survey questions available in Appendix A. The raw survey data are available on request.

**Baseline Attitudes**

To get a better sense of customers’ feelings regarding their current HVAC system, survey respondents were prompted to list one thing they would change about their heating/CAC system to improve overall home comfort. Many customers indicated they wouldn’t change what they have or were not experiencing issues, but other common responses included a desire for zoning capability or more consistent temperatures throughout the home, upgrading/updating to a new system, or reducing system operating costs.

These results suggest that while many customers may be satisfied with what they currently have, there are customers who are interested in new and better technology, especially something that will lower costs, be environmentally friendly, or provide better temperature control in the home.

Customers also shared how frequently they currently service their systems. As shown in Figure 3, roughly 30% of respondents serviced their heating or CAC at least once in the last year, which provides insight into how often customers think about servicing their units and how often a professional may have an opportunity to provide recommendations on an older unit.

Figure 3: Results for customer survey question H4: "How many times in the past year have you had to service your AC/Heating System?"

The survey also asked questions regarding customers’ general attitudes toward energy efficiency. 35% of homeowners surveyed look for information to help improve their homes’ comfort or energy efficiency. Of those who do seek additional information, online searches and utility-provided information (both what is available on their website and info they send directly to customers) are the most popular resources.

Figure 4 indicates that customers consider utilities as trusted sources for information, and that both web-based resources and customer-utility relationships can be leveraged to disseminate accurate heat pump information to customers.

**Figure 4: Results for customer survey questions H5: “Do you currently look for information to help you to improve the comfort or energy efficiency of your home?” and H5A: “If Yes: Please check any of the following sources that you would typically use for this type of information”**

![Pie chart showing survey results]

**Attitudes About the Purchase Process**

To better understand customers’ motivations to replace their existing CAC system, the survey included a question asking customers about what aspects they consider during the CAC replacement process. Knowing what motivates consumer interest in replacing their CAC system can help identify opportunities for when customers are more willing to consider converting to a heat pump.

Functionality is a deciding factor for system replacement, as shown in Figure 5. “Current AC unit fails” was the main consideration (strongest motivator) for 65% of respondents. This factor was the most common selection both for general and #1 considerations. The next most common consideration was “ongoing problems with AC unit” (32% of respondents ranked this item as their #2 consideration). Other significant motivators include having an old system, wanting to upgrade to a more energy efficient unit, and available financial incentives for new units.
Investigation of Air Source Heat Pumps as a Replacement of Central Air Conditioning
Center for Energy and Environment

These findings indicate customers who are experiencing issues with their current unit (unit failure, poor performance, etc.) are primed to consider purchasing a new system. To a lesser extent, customers are also interested in system efficiency, proactively upgrading their system, and opportunities to save on upfront costs. This existing dynamic in the CAC replacement market indicates that customers make replacement decisions under duress, without future planning and funding allocation and with urgency on replacement timeline.

To learn more about what customers consider during the replacement process, respondents were asked to rank various system aspects they consider when purchasing a new CAC unit as shown in Figure 6. Of the options provided, customers rated cooling performance as most important (8.4 out of 10), followed by costs (both equipment and operating) in second and third place. Homeowners indicated they also care about energy efficiency and potential cost savings of the unit compared to other options. The five highest ranking customer concerns are all related to either unit performance or cost/savings opportunities, indicating customers consider cost-driven factors very highly during the replacement process.
Figure 6: Results for customer survey question P6: “The following is a list of attributes that you might consider in the purchase of a new air conditioning unit or system. Please rate the importance of each item from 1 to 10, with 1 being Not at All Important to 10 being Very Important in your selection of an AC unit for your home needs.”

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cooling performance</td>
<td>8.4</td>
</tr>
<tr>
<td>Cost of the equipment</td>
<td>8.0</td>
</tr>
<tr>
<td>Operating costs</td>
<td>7.9</td>
</tr>
<tr>
<td>Energy efficiency</td>
<td>7.8</td>
</tr>
<tr>
<td>Savings during operation compared to other options</td>
<td>7.8</td>
</tr>
<tr>
<td>Warranty</td>
<td>7.6</td>
</tr>
</tbody>
</table>

Customers were also asked about their expected spending habits regarding system upgrades in the next two years, specifically to either reduce energy costs or improve in-home comfort. Figure 7 shows that 45% of customers are likely (ranked at least 7 on a scale of 1 to 10) to spend more upfront in exchange for lower energy costs when the cost premium is up to $500, compared to only 20% of customers who are as likely to spend more when the cost premium exceeds $1,000.

Figure 7: Results for customer survey question H6: “How likely would you be to spend the following amounts to reduce the energy costs of your heating and AC systems in the next two years?”

A similar trend is apparent when viewing customers’ willingness to pay a cost premium to improve in-home comfort, as shown in Figure 8. Customers’ willingness to spend additional money decreases as the...
expected premium goes up, from 43% willing to spend up to $500 down to only 18% willing to spend more than $1000.

Figure 8: Results for customer survey question H7: “How likely would you be to spend the following amounts to improve the overall comfort of your home through heating and AC systems in the next two years?”

The survey later grouped respondents into different categories based on their purchasing behaviors. “Recent Purchasers” are those who indicated they purchased their current heating system less than two years ago, whereas “Intenders” are those considering upgrading or replacing their current system in the next three years. Each group was asked questions to provide insight into their methodology (hypothetical or actual) during the air conditioning system evaluation and selection process. In the Recent Purchasers group, roughly two-thirds of homeowners replaced their heating system when they replaced the CAC. There are several potential reasons for this, such as contractor persuasion during the time of sale process, heating system is close to end-of-life anyway, or low incremental cost for furnace replacement, etc. One distinction observed here relates to household income; this dataset shows a strong correlation between annual household income and likelihood of replacing the heating system at the same time, as shown in Figure 9.
Of the households that did replace their heating system at the same time, households with higher income levels were more likely to do a full system replacement. Roughly 82% of respondents (37 of 45) had annual incomes of at least $50,000. In comparison, households that did not replace their heating systems at the same time had more variation in annual household income.

Both Recent Purchasers and Intenders were also asked about how many systems they would consider during the purchase process and whether they would consider purchasing a high-efficiency system as shown in Figure 10. During the purchase process, roughly half of Recent Purchasers considered just one unit and about 72% considered up to two units. At that time, most Recent Purchasers (68%) were offered high-efficiency units and most (88%) did purchase the high-efficiency unit. In comparison, almost 70% of Intenders claim they would consider at least three units during the selection process as shown in Figure 11. Nearly all Intenders (96%) would at least consider a high-efficiency option if it were offered to them. Of that 96%, all the Intenders said they would purchase the offered high-efficiency system.
Figure 10: Results for customer survey questions P2: "How many different AC units or systems did you consider in that process?", P2A: “Were you offered a high-efficiency option in these units?”, and P2AA: “Did you purchase the high-efficiency option?”

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<th></th>
<th>1</th>
<th>2</th>
<th>3 or more</th>
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<tbody>
<tr>
<td>Percentage</td>
<td>49%</td>
<td>23%</td>
<td>28%</td>
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Figure 11: Results for customer survey questions PP2: “How many different AC units or system would you likely consider in [the installation] process?”, PP2A: “Would you consider a high-efficiency option in these units if offered?”, and PP2AA: “Would you purchase a high-efficiency option?”

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<tr>
<th></th>
<th>1</th>
<th>2</th>
<th>3 or more</th>
</tr>
</thead>
<tbody>
<tr>
<td>Percentage</td>
<td>24%</td>
<td>10%</td>
<td>67%</td>
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</table>

The disparity between Recent Purchasers and Intenders regarding how many systems were or would be considered during the selection process (67% of Intenders indicated they were willing to consider more than three systems compared to 24% of Recent Purchasers who did compare more than three systems) indicates customers may want more choice than they end up having, which could be for a variety of reasons (e.g., time constraints). However, the majority in both groups either were offered or would consider a high-efficiency unit, and either did or would buy a high-efficiency unit. These results speak to the importance of both choice and the availability of high-efficiency units for CAC replacement consumers.
Regarding system operating costs, slightly more than half of Recent Purchasers would be willing to pay a premium for an CAC system with lower operating costs, compared to roughly 80% of Intenders as shown in Figure 12. In addition, Recent Purchasers were willing to pay an average of 15% more with an average payback period of roughly six years, whereas Intenders would be willing to pay an average of 21% more. The data indicate a larger proportion of Intenders would be willing to pay more (as well as a higher percentage more on average) upfront in exchange for lower ongoing system costs compared to Recent Purchasers.

![Figure 12: Results for customer survey questions P12 and PP12: "Would you be more willing to pay more for an air conditioner system that offered a lower cost to operate on an ongoing basis?"
](image)

**Awareness of Heat Pumps as ACs**

Survey results indicate customers have minimal experience with heat pumps. The number of respondents who have heard of heat pumps was roughly the same as those who have not (44% vs. 46%) as shown in Figure 13.

![Figure 13: Results for customer survey question T1: “Have you heard of heat pumps as they are related to heating and air conditioning?”
](image)

Of those who have heard of the technology, only 38% consider themselves familiar with the technology, and just 29% personally know someone who owns a heat pump, compared to more than twice as many who do not (61%) (Figure 14). In general, the surveyed homeowners appear to have minimal familiarity with or knowledge of heat pumps, even among customers who have heard of the technology. These results indicate more consumer education is needed for the average customer to feel knowledgeable about the technology.
When asked to list the advantages of heat pumps for cooling, many customers identified cost savings, along with unit efficiency and environmental benefits. However, many respondents felt they didn’t know, were not sure, or needed more information before they could address the question, echoing the minimal customer heat pump knowledge expressed in other responses.

Homeowners were also asked about what information would be helpful for learning about heat pumps as CACs. One common response was that homeowners wanted to have more tangible experience with heat pumps (including seeing how they work or hearing about others’ experience with heat pumps). Homeowners also want a better idea of what to expect regarding system costs and expected savings. However, even with the perceived lack of knowledge about heat pumps, Figure 15 shows that more than half of the surveyed homeowners (57%) indicated they were likely to consider heat pumps as an alternative to traditional AC replacements.
Contractor Interview Results

The research team conducted interviews with 30 local contractors to gain insight into how contractors perceive heat pumps, as well as the benefits and barriers they have identified regarding the technology. The survey uncovered perceptions about the future of ASHPs, gauging customer demand, replacement motivators for customers, current selling practices for ASHP as CAC replacement, and issues and benefits for ASHP as CAC replacement. Full results can be viewed in Appendix A with key results below.

53% of contractors reported a belief that business will increase for ducted ASHPs. A few top sentiments emerged for contractors who believed ASHP business would grow:

- They are optimistic that good ASHP rebates would continue and build demand.
- They are encountering more customers who are interested in environmentally friendlier options.
- They hold a nearer-term prediction that increasing natural gas prices will push customers towards ASHPs.

A belief that ASHPs would continue to have a high upfront cost was the main reason contractors said business would stay the same.

43% of contractors reported low or no demand for ducted ASHPs while 33% reported some demand. The critical importance of good rebates was a top sentiment to explain demand. For responses indicating low or no demand, the main issue was a lack of customer awareness of ASHPs as a CAC replacement option.
Contractors typically reported replacing CACs on failure, which was identified as the more economical choice for most customers. Contractors reported urging customers to purchase a new furnace along with the new CAC or vice versa if the furnace failure was the point of replacement.

83% of contractors have recommended a ducted ASHP when replacing a furnace or CAC. While many contractors said they had recommended an ASHP, most shared (sometimes narrow) qualifiers and situations in which they would make a recommendation. The main reason contractors would recommend an ASHP is when a customer is on propane, followed by scenarios where generous rebates make ASHPs comparable or nearly the same price as CACs. Negative responses cited foremost the high initial cost of ASHPs, then the high operational cost versus natural gas and few customers expressing interest in the systems.

Savings in one form or another were the top benefits reported by contractors. Along these lines, multiple contractors said that good rebates could make higher-end ASHPs cost competitive with CACs. This makes ASHPs an attractive choice for customers to commit to a system with more benefits, like greater efficiency, functionality, and fuel choice, around the same price as a CAC. Contractors also reported that environmentally minded customers liked ASHPs.

Most contractors did not report issues with ASHPs as products or issues that cause customer callbacks beyond the normal range. Of those who did report issues, challenges with the defrost cycle, controls, shorter or more error-prone lifespan, and a generally more complicated installation were cited. Issues resulting in customer callbacks were mainly about the low supply air temperatures and confusion with controls.

Distributor Interview Results

The team performed three distributor discussion meetings and gathered valuable information about perception and interest concerning this technology. Each meeting included multiple staff from different roles in each organization to provide market and technology perspectives. Companies are currently selling significantly more mini-split heat pumps than centrally ducted heat pumps. However, they do believe that with demand coming from the energy industry and leanings toward electrification, this application type will become a bigger opportunity in the future. Distributors interviewed are companies that have previously demonstrated significant interest in ASHP technology. Distributors reported the following perceived benefits and barriers to this application type:

Benefits:

- Customer benefits
  - Fuel choice
  - System flexibility
  - Shoulder season comfort
  - Reduced environmental impact
  - Higher tier product: quieter, better dehumidification, longer life, better warranties
- Contractor benefits
  - Stay competitive in the sales process
  - Better margin product with little technical difference
  - Good differentiator for contractors: forward-thinking and innovative services
- Distributor benefits
  - Be the lead innovator
Barriers:

- The higher product cost makes it harder to craft a compelling value proposition to customers. Distributors reported 50% or even significantly higher cost for ASHPs over baseline CACs. This incremental cost varies depending on the volume of the contractor and the type of product.
- Consumers have low awareness of and interest in these products. Contractors need to have a more engaging educational sales process to be successful with this application. However, this has the potential to slow down sales, making the products less attractive to contractors.
- Distributors reported that it is difficult to plan proper inventory buying patterns because utility program specifications are so variable. Distributors operate in larger territories, so this inconsistency is a barrier to selecting what stock to carry and in what volumes.

Manufacturer Interview Results

CEE conducted interviews with five manufacturers to help identify equipment that fits the product category for this research (ASHPs and CAC replacements), as well as opportunities and barriers for this product category. The interviewed manufacturers were generally interested in this product category, and several planned to increase their product offerings for this market segment in 2022. Three of the five manufacturers interviewed only offer variable-speed heat pumps, while the remaining manufacturers also offer one-stage and two-stage systems. While manufacturers generally offer both ducted and ductless products, current marketing efforts focus more on mini-split systems. Manufacturers consider their versions of the product to be cost-competitive with 16 SEER CACs, with similar installation needs and labor costs.

Benefits:

- CAC replacement is a key opportunity for heat pumps with gas furnaces, especially as the retrofit market transitions away from fossil fuels.
  - Dual use capability – ASHPs can be used for both cooling and heating, and dual fuel systems (heat pumps with gas backup furnaces) are a common application type, especially during shoulder seasons.
  - Homeowner peace of mind – Dual fuel systems enable ASHPs while retaining the gas furnace as a backup fuel source.
  - Price optimization between electricity and gas – Homeowners can use ASHPs when they are most cost-effective.

Barriers:

- Unfamiliarity with ASHPs – Contractors and customers may not understand how ASHPs work and how they differ from traditional furnaces (e.g., differences in supply air temperature). This is a significant barrier because customers may have concerns or expectations about ASHP operation that contractors cannot address due to both parties’ limited exposure to the technology.
- Contractors’ limited heat pump experience – Contractors might have difficulty completing complex load calculations to properly size the system or an underdeveloped framework to present the product as an option to customers.
- Negative perception of ASHPs – Customers and contractors may have had bad prior experiences with heat pumps or may be unaware of new product improvements and innovations.
Investigation of Air Source Heat Pumps as a Replacement of Central Air Conditioning  
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Energy and Cost Modeling

Methodology

The purpose of the technical and cost evaluation is to understand energy and cost savings in the ASHP market segment focused on dual fuel ASHP systems for CAC replace-on-fail opportunities. The modeling results consider a representative home with a natural gas furnace and a failed CAC in need of replacement. The base case of the representative home has a 75 kBtu/hr, 80% furnace with PSC blower an oversized 2.5 ton CAC. ASHP equipment specifications, baseline equipment types, weather, energy costs (utility rates), and replacement types were all varied, as indicated in the following, to understand their impact on energy savings and costs. Additional modeling details are provided in Appendix B.

ASHP for CAC Equipment

Following a review of currently available ASHP equipment, four types of ASHP systems were selected to represent the range of equipment available for direct CAC replacement. Each heat pump archetype represents a different ASHP system with its own performance and capacity profile. The key distinction of these systems is that they are universally compatible with existing air handlers and furnaces because that is assumed to be a requirement for replacing CAC-only and integrating with existing furnaces. These non-proprietary systems, also called non-communicating systems, interact with thermostats and furnaces through conventional analog thermostat wiring (e.g., R, W, Y, C, G). In some cases, additional control wires are possible for multi-stage compatible equipment (e.g., W2, Y2), but this is not a requirement, only a potential efficiency benefit in some configurations. The second key distinction is that these systems are sized for the cooling load. They cannot meet winter design loads; thus, they require a backup system (the natural gas furnace). The four heat pump archetypes are detailed as follows and their specifications given in Table 2.

Single speed ASHP (ssASHP)

- An entry level, low-cost, single speed option
- Closest parallel to code minimum SEER 13 CAC, the most frequently installed CAC system
- Good mild weather efficiency, but capacity and efficiency fall off in cold conditions more so than other archetypes
- Available in 2-ton size

Entry-level variable speed ASHP (vsASHP)

- An entry level, low-cost, variable speed option
- Entry level variable speed equipment, marketed as low-cost entry to variable speed equipment
- Very high COP potential at mild outside air temperatures, but capacity and efficiency fall off in cold conditions more than other variable speed systems
- Available in 2-ton size

Average vsASHP

• A variable speed unit with good performance across a broad temperature range
• The second most costly system considered
• Highest weather-weighted efficiency of options considered
• Not available smaller than 3-ton

Cold climate vs ASHP
• The highest cost option
• Lower mild weather efficiency in favor of capacity maintenance at cold conditions
• Provides nameplate space heating capacity down to 5°F and is typically synonymous with “cold climate” product
• Not available smaller than 2.5-ton

In addition to having varying performance profiles, these four system types are differentiated by their turndown ratio, HSPF, and SEER ratings. The turndown ratio is the ratio of a heat pump’s rated maximum capacity to its minimum capacity. In single speed units, the capacity cannot be adjusted or turned down to match reduced load, resulting in a turndown ratio of 1.0. The Heating Seasonal Performance Factor (HSPF) is the heating efficiency metric, and it represents the ratio of total heating load delivered (in Btu) to the total energy consumed by the unit (in Watt-hours) in space heating mode, where a higher value represents a more efficient unit. The Seasonal Energy Efficiency Ratio (SEER) is the common metric for cooling efficiency. It is a ratio of heat removed (in Btu) to energy consumed (in Watt-hours) by the unit in cooling mode. Both HSPF and SEER ratings attempt to account for varying weather conditions, but neither are tailored to specific climates and they generally lead to overestimation of savings when used to estimate energy consumption or as-operated efficiency in Minnesota use cases.

Table 2: Performance metrics for ASHP archetypes

<table>
<thead>
<tr>
<th>ASHP Archetype</th>
<th>Nameplate Heating &amp; Cooling Capacity (Btu/hour) [tons]</th>
<th>HSPF</th>
<th>SEER</th>
<th>Turndown Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>ssASHP</td>
<td>24,000 [2]</td>
<td>9</td>
<td>14</td>
<td>1.00</td>
</tr>
<tr>
<td>Entry-Level vsASHP</td>
<td>24,000 [2]</td>
<td>13</td>
<td>20</td>
<td>2.18</td>
</tr>
<tr>
<td>Average vsASHP</td>
<td>36,000 [3]</td>
<td>10.5</td>
<td>20</td>
<td>1.92</td>
</tr>
<tr>
<td>Cold Climate vsASHP</td>
<td>30,000 [2.5]</td>
<td>10</td>
<td>18</td>
<td>2.04</td>
</tr>
</tbody>
</table>

Costs

Two approaches were used to bookend current incremental cost estimates for ASHPs as CAC replacement. The costs for CAC-only and full (CAC + furnace) replacement are shown in Table 3. The incremental cost is the ASHP system relative to a SEER 13 CAC. For the full replacement, the incremental cost of an 80% PSC to a 95%+ two-stage ECM furnace is added. In the first approach, the low end of incremental cost is established from wholesale prices of comparable equipment with installation upcharges for venting and low voltage controls where necessary. An equipment margin of 40% was assumed on top of wholesale equipment cost differences. In the second approach, installation bids were gathered over the past two years for comparable equipment. Fifty-four recent (2022) bids for 2- to 3-ton
heat pumps were analyzed and deemed comparable to the archetypes considered here. Incremental costs determined from contractor bids are significantly higher than equipment-based bids, even for box-in replacement scenarios, where installation and ancillary costs should be comparable. Very large variations between bids across this sample set voided any relationship between cost and capacity for equipment sized 2, 2.5, and 3 ton. In general, a majority of the entry-Level vsASHP and average vsASHP systems bid have lower performance specifications than those of archetypes in this study.

Table 3: Incremental cost estimates for ASHP archetypes

<table>
<thead>
<tr>
<th></th>
<th>Wholesale-Based a</th>
<th>Average Project Bids</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>ASHP</td>
<td>CAC-Only</td>
</tr>
<tr>
<td>ssASHP</td>
<td>$700</td>
<td>$1,000</td>
</tr>
<tr>
<td>Entry level vsASHP c</td>
<td>$2,100</td>
<td>$3,000</td>
</tr>
<tr>
<td>Average vsASHP c</td>
<td>$3,500</td>
<td>$4,900</td>
</tr>
<tr>
<td>Cold Climate vsASHP c</td>
<td>$4,620</td>
<td>$7,300</td>
</tr>
</tbody>
</table>

a) 40% margin added to wholesale cost-based estimates  
b) + $1,000 for sealed vent (where applicable)  
c) + $500 for wiring (for multi-stage wiring)

Other Variables

Baselines

Nine baselines with different combinations of combustion efficiency (80% to 95%), blower efficiency (0.2 W/cfm to 0.5 W/cfm), and CAC efficiency (SEER 10 to SEER 12) are considered.

Weather

Four areas in the state: Minneapolis-St. Paul, Duluth, Thief River Falls, and Worthington were modeled to represent different weather throughout the state.

Utility Rates

Different combinations of electric and gas rates were considered as well as special dual fuel electric rates that may be available to customers with dual fuel ASHP systems. Gas rates varied from 0.5 $/therm to 1.6 $/therm. Electric rates varied from 0.09 to 0.20 $/kWh. Dual fuel rates of 0.07 $/kWh were also modeled.

Replacement Type

The modeling considers two types of replacements. The original focus was on ASHP products that could replace a failed CAC and keep the existing furnace. Market research indicates a customer preference toward full replacement (furnace and CAC) so these full replacement options were considered as well.

Outputs

A representative building is subject to combinations of the preceding parameters (ASHP archetype, baseline, weather, replacement type, utility rates, and switchover temperature) representing about 1.3 million combinations. Each scenario yields an hourly simulation of energy use and cost for each
combination of variables. The results presented focus on annual heating and cooling savings and operating strategies that maximize energy savings and cost savings/payback.

Results

Cooling Savings

Heat pumps as CAC replacements are predicated on their potential cooling electricity savings. Cooling savings depend on the baseline cooling system efficiency (SEER), the air handler fan efficiency (W/cfm), and the replacement ASHP cooling efficiency (SEER), but in general are the same as existing high efficiency CAC systems. The advantages of ASHPs over CAC systems are the additional savings and operational flexibility.

Cooling savings for the ssASHP (SEER 14) and the Average vsASHP (SEER 20) are shown for CAC-only and full replacements in Figure 16 for Minneapolis as a function of relevant baseline fan and CAC efficiency. These two systems offer the lowest and highest cooling savings respectively. Savings figures for all four ASHP measures are given in Appendix B for each baseline.

Cooling savings vary substantially based on the baseline equipment. When the oversized (2.5-ton) baseline CAC is replaced with this 2-ton ssASHP, any cooling savings are negated when paired with the existing inefficient 0.5W/cfm PSC fan due to the increased runtime of the lower capacity (right-sized) ssASHP system. However, all other baseline combinations yield positive savings, ranging from 20 kWh to 276 kWh. When the furnace is replaced with the CAC (full replacement), overall cooling savings increase from 107 kWh to 385 kWh.

Cooling savings are much higher for the Average vsASHP (SEER 20) due to the inherent efficiency advantage of the variable speed compressor. While cooling savings are diminished for variable speed equipment paired with PSC fans, the cooling efficiency benefit still yields 168 kWh of savings against a SEER 13 baseline. Savings over 400 kWh are possible compared to an older SEER 10 system with PSC fan and over 700 kWh for a full replacement. Up to an additional 140 kWh savings are possible when the variable speed ASHP leverages the lower fan speed in a multi-stage furnace. The entry level vsASHP shows very similar figures, whereas the cold climate ASHP has slightly smaller savings due to its heating-focused performance.
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Figure 16: Cooling savings for CAC-only and full AHU replacements for different baseline fan and cooling systems in Minneapolis (a) with SEER 14 ssASHP and (b) with SEER 20 average variable speed ASHP.

Gas Heating Savings

In addition to cooling savings, most full-replacement scenarios increase furnace and fan efficiency to realize additional electricity and natural gas savings. Figure 17 shows additional natural gas and fan electricity savings for different baseline furnace and fan efficiency combinations. Two-stage 95% furnace achieves no potential savings since the underlying furnace and fan efficiency are unchanged, whereas relatively large natural gas savings (150 therms) and fan energy savings (260 kWh) are possible when replacing a less efficient furnace. Lesser savings, 40 therms and 100 kWh, are available when replacing a better 90% furnace with ECM fan. These savings will decrease in proportion to ASHP runtime for space heating but serve as a valuable baseline. ASHP runtime will offer an additional heating energy savings profile that will depend on ASHP equipment specifications and heating climate. While not considered here, there are additional savings from full replacements when the air handler is used continuously for ventilation.
Maximum ASHP Heating Savings

ASHP systems, even at their most inefficient operating conditions (very cold outside air temperatures) have higher efficiency than natural gas furnaces. Therefore, site energy savings for space heating are the largest when ASHP runs as often as possible. ASHP runtime is mainly a factor of the equipment capacity compared to the space heating load. The ASHP archetypes studied here have different nameplate capacities, as well as different capacity and efficiency curves, thus they have different absolute saving limits tied to these specifications. These limits are shown in Table 4 for each ASHP archetype and climate for a fixed baseline of a 90% furnace with ECM fan.

The capacity-based switchover temperature is a function of the relationship between equipment (ASHP type) and the space heating load. It is the same for all climate regions. The variable speed systems have capacity-based switchovers ranging from -5°F to 5°F. None of the systems sized for CAC can meet the entire heating load. Incidentally, the largest capacity system (3-ton average vsASHP) has a higher capacity-based switchover temperature than other variable speed systems, indicating that its capacity maintenance is less than both the 2-ton entry-level vsASHP and the 2.5-ton cold climate vsASHP archetypes. Despite variances in capacity-based switchover temperature, overall savings for the variable speed systems are within about 10% for each MN climate region. Across all four climates, there is a 20% difference in total maximum space heating savings. The 2-ton ssASHP has a much higher capacity-based switchover temperature, 25°F, than the variable speed systems, but still manages to save about half to two-thirds as much energy for space heating as the variable speed systems. For the single speed system, these savings are about 50% of those available from an all-electric ASHP system, and for the variable speed systems, the savings range between 80% to 90% of an all-electric ASHP systems. These results
suggest that even when sized for cooling, dual fuel ASHP systems have the flexibility to claim half or more of all ASHP savings potential.

Table 4: Maximum savings from different ASHP archetypes in Minnesota climates paired with a 90% ECM furnace

<table>
<thead>
<tr>
<th>Location</th>
<th>ASHP Equipment</th>
<th>Capacity Switchover (°F)</th>
<th>Maximum Heating Savings (MMBtu)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Duluth 399 CDD 9,034 HDD</td>
<td>ssASHP</td>
<td>25</td>
<td>32.9</td>
</tr>
<tr>
<td>Entry-Level vsASHP</td>
<td>0</td>
<td>53.1</td>
<td></td>
</tr>
<tr>
<td>Average vsASHP</td>
<td>5</td>
<td>57.5</td>
<td></td>
</tr>
<tr>
<td>Cold Climate vsASHP</td>
<td>-5</td>
<td>58.1</td>
<td></td>
</tr>
<tr>
<td>Minneapolis 706 CDD 8,385 HDD</td>
<td>ssASHP</td>
<td>25</td>
<td>28.9</td>
</tr>
<tr>
<td>Entry-Level vsASHP</td>
<td>0</td>
<td>46.1</td>
<td></td>
</tr>
<tr>
<td>Average vsASHP</td>
<td>5</td>
<td>49.7</td>
<td></td>
</tr>
<tr>
<td>Cold Climate vsASHP</td>
<td>-5</td>
<td>51.0</td>
<td></td>
</tr>
<tr>
<td>Thief River Falls 555 CDD 9,704 HDD</td>
<td>ssASHP</td>
<td>25</td>
<td>28.3</td>
</tr>
<tr>
<td>Entry-Level vsASHP</td>
<td>0</td>
<td>50.5</td>
<td></td>
</tr>
<tr>
<td>Average vsASHP</td>
<td>5</td>
<td>54.5</td>
<td></td>
</tr>
<tr>
<td>Cold Climate vsASHP</td>
<td>-5</td>
<td>55.6</td>
<td></td>
</tr>
<tr>
<td>Worthington 692 CDD 7,680 HDD</td>
<td>ssASHP</td>
<td>25</td>
<td>32.7</td>
</tr>
<tr>
<td>Entry-Level vsASHP</td>
<td>0</td>
<td>47.6</td>
<td></td>
</tr>
<tr>
<td>Average vsASHP</td>
<td>5</td>
<td>51.3</td>
<td></td>
</tr>
<tr>
<td>Cold Climate vsASHP</td>
<td>-5</td>
<td>50.3</td>
<td></td>
</tr>
</tbody>
</table>

Cost Savings and Payback

As described previously, modeling results were produced for many different combinations of variables. In order to highlight the variances in customer costs, results are shown for three scenarios that feature three potential replacement possibilities under a large parametric space of rate combinations. Savings results show a range of outputs. These different replace-on-fail scenarios were emphasized to demonstrate the broad range of cost outcomes observed in this analysis. They are described in the following and summarized in Table 5. Additional results for the other ASHP archetypes, baselines, and climates are available in Appendix C.

Scenario 1 features a relatively modern furnace with 90% combustion efficiency and an ECM fan. In this case, either the furnace has significant lifetime remaining or a consumer is not currently opting for a full replacement. Thus, this cost-conscious customer is considering an entry-level single speed ASHP as an alternative to a baseline a SEER 13 CAC.

Scenario 2 features an older furnace with 80% combustion efficiency and a PSC fan that is near or beyond end of life, likely installed at the same time as the failed CAC. Due to the older furnace, this
customer is more enthusiastic about replacing the furnace and air conditioner simultaneously and interested in the potential comfort and operating benefits of higher performance equipment. In this scenario, the existing 80% furnace and baseline SEER 13 CAC are compared against a 95% two-stage furnace paired with a SEER 20 entry-level variable speed ASHP.

Scenario 3 is the same as scenario 2, except the customer has access to a special rate reserved for dual fuel customers (those with electric and non-electric space heating systems) or electric heat (those customers who use electricity for their primary heating system). In this case, the installation of the ASHP and furnace combination from scenario 2 enables a lower electricity rate. In this scenario, that rate was fixed at 0.07 $/kWh.

<table>
<thead>
<tr>
<th>Scenario 1: Newer existing furnace with low entry cost for heat pump and no rate change</th>
<th>Baseline Furnace and CAC</th>
<th>90% furnace with ECM motor and SEER 13 CAC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Replacement Heat Pump Type</td>
<td>Single speed</td>
<td></td>
</tr>
<tr>
<td>CAC only vs. full furnace and CAC replacement</td>
<td>CAC only</td>
<td></td>
</tr>
<tr>
<td>Rate</td>
<td>Standard rate</td>
<td></td>
</tr>
<tr>
<td>Region</td>
<td>Southeast</td>
<td></td>
</tr>
<tr>
<td>Notes:</td>
<td>Lower replacement costs due to only installing a single piece of equipment and lower cost heat pump option</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Scenario 2: Older existing furnace with mid-level heat pump and no rate change</th>
<th>Baseline Furnace and CAC</th>
<th>80% furnace with PSC fan and SEER 13 CAC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Replacement Heat Pump Type</td>
<td>Entry-level variable speed</td>
<td></td>
</tr>
<tr>
<td>CAC only vs. full furnace and CAC replacement</td>
<td>Full furnace and CAC</td>
<td></td>
</tr>
<tr>
<td>Rate</td>
<td>Standard rate</td>
<td></td>
</tr>
<tr>
<td>Region</td>
<td>Southeast</td>
<td></td>
</tr>
<tr>
<td>Notes:</td>
<td>Slightly higher cost of replacement due to full system replacement and upgrade to variable speed equipment.</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Scenario 3: Older existing furnace with mid-level heat pump and change to dual fuel electric rate</th>
<th>Baseline Furnace and CAC</th>
<th>80% furnace with PSC fan and SEER 13 CAC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Replacement Heat Pump Type</td>
<td>Entry-level variable speed</td>
<td></td>
</tr>
<tr>
<td>CAC only vs. full furnace and CAC replacement</td>
<td>Full furnace and CAC</td>
<td></td>
</tr>
<tr>
<td>Rate</td>
<td>Dual fuel rate (0.07 $/kWh)</td>
<td></td>
</tr>
<tr>
<td>Region</td>
<td>Southeast</td>
<td></td>
</tr>
<tr>
<td>Notes:</td>
<td>Higher cost of replacement due to full system replacement and upgrade to variable speed equipment.</td>
<td></td>
</tr>
</tbody>
</table>
These scenario results are presented using contour gradient plots. In these figures, each region of color corresponds to switchover temperatures and energy cost savings associated with each combination of electric rate (y-axis) and gas rate (x-axis). The black lines demarcate the border between these regions because sharp gradients are occasionally difficult to identify. Each contour plot examines a range of gas prices, 0.5 $/therm to 1.6 $/therm, a range of electric prices, 0.09 $/kWh to 0.2 $/kWh, and the switchover temperatures varying from the capacity-based switchover up to 65°F. In general, economic switchover temperatures decrease with decreasing electric rates and increase with decreasing gas rates. Annual energy cost savings increase with increasing gas rates and decrease with increasing electric rates.

These results are shown for Scenario 1 in Figure 18. On the top plot, the regions are mainly split between yellow and purple. The yellow region shows where cost savings are maximized at 60°F switchover and purple region where cost savings are maximized at 25°F, which is also the capacity-based switchover. In other words, the electric cost relative to the gas cost determines which switchover temperatures yield the most savings. As a baseline CAC replacement, the single speed system ASHP doesn’t offer much flexibility in terms of switchover optimization. The cost savings ($/yr) associated with these switchover temperatures and energy rates are shown on the bottom plot. Operating the system as a CAC only results in about $25/yr to $35/yr in savings. As electric and gas rates move up or down together, the outcomes are invariant. However, for fixed electric rates and increasing gas costs, savings increase dramatically. Therefore at higher gas prices (>1.0 $/therm) cost savings increase and the system can be operated down to the capacity-based switchover.

Scenario 1 represents a relatively conservative outcome for baseline ASHP technology. This entry-level single speed ASHP yields annual cost savings, while improving cooling comfort due to equipment right-sizing. Alternatively, if the baseline was a right-sized CAC, savings would increase by about $50/yr. Consistent with consumer preferences articulated in the market outreach work, this scenario emphasized ASHPs as a measure that can provide cooling savings even when configured for comfort instead of maximizing energy savings.

At incremental costs of $700 to $2,000, these measures require $45/yr to $125/yr savings in order to pay back within their lifetime. These paybacks are possible with only sustained gas prices exceeding 0.9 to 1.0 $/therms; however, even relatively low utility rebates and/or improved market efficiency are likely to have major positive impacts on consumer payback.
Figure 18: Scenario 1: Comparing an entry-level ssASHP to a SEER 13 CAC with a baseline 90% ECM furnace in Minneapolis on regular residential electric rates.
The results are shown for Scenario 2 in Figure 19. In this case, the furnace and CAC are replaced with the entry-level vsASHP system and a 95% ECM furnace following customer preferences. The top plot shows switchover temperature, while the bottom shows the cost savings. The variable speed system offers much higher potential for optimizing switchover temperatures as shown by the variation of potential switchover temperatures between 0°F and 60°F. This translates to increased operational flexibility compared to the ssASHP in Scenario 1. In current rate environments, 0.12 $/kWh to 0.14 $/kWh and 0.8 &/therm to 1.0 $/therm, switchover temperatures vary anywhere between 35°F and 60°F for cost savings ranging from around $200/yr to $250/yr. Despite much higher cost savings than Scenario 1, higher incremental costs of these systems ($3,000 to $6,000) yield a similar situation for consumer payback. At the lower range of estimated incremental costs, these systems can pay back within their lifetime, but utility rebates and/or improved ASHP market efficiency are likely to have major positive impacts on consumer payback. However, along with these savings this system provides improved humidity control and probably quieter indoor and outdoor operation, likely impacting consumer notions of cost-effectiveness.

Scenario 3 results are shown in Figure 20. The third scenario is the same as Scenario 2, except the addition of the ASHP as a heating system qualifies the customer for a dual fuel or a special rate of 0.07 $/kWh. Consequently, there are cost savings associated with the rate change that stack with the cost savings of improved heating and cooling efficiency. The vertical regions on the top switchover plot show that, due to the fixed dual fuel rate, the optimum switchover temperature is now only a function of the gas rate. At a dual fuel rate of 0.07 $/kWh, switchover temperatures are such that this vsASHP system should meet most of the heating load even at gas rates as low as 0.8 $/therm. At prices higher than 1.0 $/therm, this vsASHP system should be operated down to capacity switchover (and perhaps introduce the possibility of upsizing the ASHP to increase savings.) In this scenario, the lower dual fuel electric rates increase savings from $350/yr to $500/yr at typical rates, which enables these systems to reliably pay off their incremental cost within their lifetime and, with the introduction of incentives, potentially within the six-year window identified as attractive by customers.

These three scenarios show that entry-level ssASHP and vsASHP can provide comfort benefits and savings opportunities for customers and that, generally, with utility incentives and increasing market efficiency, these savings can be cost-effective for customers. However, the main outcome relayed by these results is that outcomes are highly sensitive to electric and gas rates. Variable speed systems have more operational flexibility to accommodate rates or changes in rates to realize savings. The higher end variable speed systems offer additional energy and cost savings beyond those shown, but these savings are not commensurate with their higher incremental costs at this time. In other words, they have lower cost-effectiveness when used in CAC replacement applications.
Figure 19: Scenario 2: Comparing an entry-level vsASHP with 95% ECM furnace to a SEER 13 CAC with a baseline 80% PSC furnace in Minneapolis on regular residential electric rates.
Figure 20: Scenario 3: Comparing an entry-level vsASHP with 95% ECM furnace to a SEER 13 CAC with a baseline 80% PSC furnace in Minneapolis on dual fuel electric rates.
Program Strategies and Recommendations

Methodology

Review of Existing Programs

To understand how utilities present heat pumps and CACs to consumer audiences, the project team reviewed existing heat pump incentive offerings, both in Minnesota and nationally. In Minnesota, the project team reviewed programs offered by the state’s three electric investor-owned utilities (IOUs): Minnesota Power (MP), Otter Tail Power (OTP), and Xcel Energy (Xcel). Nationally, the project team focused on markets that are actively promoting heat pumps or allow fuel switching in policy.

The project team collected information regarding what product types are eligible for incentives (e.g., ducted or ductless), incentive levels per product type, required product spec (SEER/HSPF, etc.), and whether programs also offered a rebate for (centrally ducted) ACs. The results of this research provide insight into where heat pumps are being promoted, as well as whether heat pumps are being considered and marketed by utilities as an option for cooling in addition to heating.

Results

Minnesota

Table 6 shows the information gathered regarding heat pump incentive programs in Minnesota.

<table>
<thead>
<tr>
<th>Utility</th>
<th>Rebate Amount (Ducted)</th>
<th>System Specifications (Ducted)</th>
<th>Rebate Amount (Mini-Split)</th>
<th>System Specifications (Mini-Split)</th>
<th>CAC Rebate Available?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minnesota Power</td>
<td>$400 (ASHP)</td>
<td>ASHP: Energy Star, SEER 15+, HSPF 8.5+</td>
<td>$400</td>
<td>SEER 15+, HSPF 8.5+</td>
<td>No</td>
</tr>
<tr>
<td></td>
<td>$1000 (ccASHP)</td>
<td>ccASHP: SEER 15+, HSPF 9+, and 1.75+ COP @ 5°F</td>
<td>$1200 (cold-climate mini-split heat pump)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Otter Tail Power</td>
<td>$600–$700/ton</td>
<td>HSPF 9+ (Energy Star or SEER 15+ for higher rebate)</td>
<td>$400–$500/ton</td>
<td>HSPF 9+ (Energy STAR or SEER 15+ for higher rebate)</td>
<td>No</td>
</tr>
</tbody>
</table>
Minnesota’s IOU heat pump incentive programs have a clear focus on a heat pumps’ ability to function in cold climates, as shown by MP’s much higher incentive for products with cold-climate capability and OTP’s incentives that are exclusively for cold-climate, inverter-driven products (defined on the program website as products that “operate with nearly 200% efficiency at 0°F and up to 400% efficiency at temperatures of 40°F and higher”\(^3\)). Xcel’s ducted incentives do not target ASHPs, but the utility does incentivize mini-split air source heat pumps that can provide heat at low temperatures. Each incentive webpage notes that heat pumps can also offer cooling benefits.

Each utility has a different approach to cooling incentives. MP does not offer a separate cooling incentive, whereas OTP offers a demand-side-management cooling incentive but no downstream rebate. In contrast, Xcel offers a rebate for centrally ducted cooling units, which explicitly includes heat pumps.

**Nationwide**

Table 7 shows the information gathered regarding heat pump incentive programs across the country.

*Table 7: Overview of Heat Pump Incentive Programs offered Nationally (Wisconsin, Colorado, Massachusetts, Maine, New York, Vermont, and California) as of August 2022*

<table>
<thead>
<tr>
<th>Rebate Provider</th>
<th>Rebate Amount (Ducted)</th>
<th>System Specifications (Ducted)</th>
<th>Rebate Amount (Mini-Split)</th>
<th>System Specifications (Mini-Split)</th>
<th>CAC Rebate Available?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Focus on Energy (Wisconsin)</td>
<td>$300 (propane/oil backup)</td>
<td>SEER 15+, HSPF 8.5+</td>
<td>$300</td>
<td>SEER 16+, HSPF 8.4+ (centrally ducted)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>$1000 (gas backup)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>$300 (centrally ducted unit)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

---

<table>
<thead>
<tr>
<th>Provider</th>
<th>(Ducted)</th>
<th>Specifications (Ducted)</th>
<th>(Mini-Split)</th>
<th>Specifications (Mini-Split)</th>
<th>Available?</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Xcel Energy Colorado</strong></td>
<td>$800 (ASHP)</td>
<td>ASHP: SEER 15+, EER 12.5+, HSPF 9+</td>
<td>$500</td>
<td>SEER 15+, EER 11+, HSPF 9+</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>$1000 (ccASHP)</td>
<td>ccASHP: SEER 18+, 12.5+ EER, 10.5+ HSPF, NEEP QPL, capacity ratio (5°F/47°F) ≥ 70%</td>
<td>$600 (ccMSHP)</td>
<td>N/A</td>
<td></td>
</tr>
<tr>
<td><strong>Mass Save (Massachusetts)</strong></td>
<td>$10,000 per home</td>
<td>SEER 16+, HSPF 9.5+, capacity ratio (17°F/47°F) ≥ 60%</td>
<td>$1,250/ton, up to $10,000</td>
<td>SEER 18+, HSPF 10+, capacity ratio (17°F/47°F) ≥ 58%</td>
<td>No (room AC only)</td>
</tr>
<tr>
<td><strong>Efficiency Maine</strong></td>
<td>Tier 1: $400 for 1st unit, $200 for 2nd unit</td>
<td>Tier 1: HSPF 10+ (multiple indoor units OR ducted system)</td>
<td>Same as ducted</td>
<td>Tier 1: HSPF 12+ (single indoor unit)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Tier 2: $600 for 1st unit, $400 for 2nd unit</td>
<td>Tier 2: HSPF 12.5+, no gas utility account</td>
<td>Tier 2: same as ducted</td>
<td>Tier 2: same as ducted</td>
<td></td>
</tr>
<tr>
<td><strong>NYS Clean Heat (New York)</strong></td>
<td>$500–$1000 per 10,000BTU/hr heat load (@ 5°F)</td>
<td>NEEP QPL</td>
<td>$200–$500/outdoor condenser unit</td>
<td>NEEP QPL</td>
<td>No</td>
</tr>
<tr>
<td><strong>Efficiency Vermont</strong></td>
<td>$1000–$2000</td>
<td>NEEP QPL; min 2ton</td>
<td>$350–$450</td>
<td>NEEP QPL; min 2ton</td>
<td>No</td>
</tr>
<tr>
<td><strong>SMUD (California)</strong></td>
<td>$3000</td>
<td>SEER 16+, HSPF 9.04+; HVAC gas-to-electric conversion</td>
<td>N/A</td>
<td>N/A</td>
<td>No</td>
</tr>
</tbody>
</table>
In general, the heat pump incentive programs surveyed do not offer a separate CAC incentive. This could be because most of these programs are for utilities in colder climates (in the Northeast and Midwest parts of the country), where not as much cooling is needed. These areas also tend to experience lower temperatures than other parts of the country (i.e., more days below 0°F), which makes system functionality at low temperatures a higher priority.

Reviewed programs are generally more focused on heating, as indicated by certain heating-specific program eligibility requirements that were common throughout the programs. Those eligibility requirements are as follows.

- Included on the Northeast Energy Efficiency Partnership Qualified Product List (NEEP QPL)
- Have a high HSPF rating (9-10+, compared to the 8.5 minimum requirement for Energy Star v6.1 rated heat pumps)
- Require certain minimum capacity ratios at lower temperatures (e.g., at 17°F the heat pump must produce at least 60% of its capacity at 47°F).

One exception is Xcel, which offers broader cooling incentives (for both CACs and heat pumps) in Minnesota and Colorado. While CAC products are also eligible for this incentive, the program explicitly acknowledges the cooling capability of heat pumps and implies that the cooling needed in these markets can be satisfied by a heat pump.

**Barriers**

- Heat pump markets are more focused on heating, with little or no mention of heat pump cooling capability.
- Minimal cooling benefits are available in these markets.
- Utilities are hesitant to move away from CAC rebates due to losing visibility into sales and therefore savings, as well as concerns with upsetting the contractor network.

**Opportunities**

- Utilities can also market additional heat pump benefits (cooling/dehumidification capability, reduced noise, etc.).
- For locations with minimal cooling needs, increased cost savings from greater heat pump use during heating and shoulder seasons can make up for comparatively lower cost savings during cooling season.
- Develop more advanced and heat-pump specific rate structures.
- Some utilities offer higher rebates or other financing options for low-income customers.
Conclusions

Market Readiness

As evidenced by the market research, education efforts are necessary for contractors and consumers so they can make adequate decisions during replacement cycles. These decisions are often made under duress by customers who are generally unfamiliar with heat pumps, then locked in for 15 or more years. Hence, every CAC currently installed is a significant lost opportunity for:

- Significantly increased volumetric electricity sales,
- major efficiency opportunity, and
- future integration with strengthening emissions and savings targets

The study team’s research shows that customers are open to more efficient equipment that makes economic sense if given the option. In fact, simply providing the option to customers will result in significant uptake given trends described in the high efficiency air conditioning market. The supply chain wants to see increased customer awareness and demand before they invest more into the technology in their business models. Consequently, utilities should be justified in spending significant resources through all available channels to raise awareness about these options.

Technical Research/Savings

Cooling savings from ASHP systems depend on the baseline cooling system efficiency (SEER), the air handler fan efficiency (W/cfm), and the replacement ASHP cooling efficiency (SEER), but in general are the same as existing high efficiency CAC systems. The advantages of ASHPs over CAC systems are the additional savings on the heating side and operational flexibility of two heating systems.

ASHPs sized as CAC replacements cannot meet the design heating load, but still offer sizable potential savings (~50% for ssASHP and 80%+ for vsASHP) compared to full electrification with ASHP systems sized for heating loads. Today’s entry level ssASHP and vsASHP systems offer a compelling alternative to CAC systems. They offer savings that, when paired with existing utility incentives or lower upfront costs that come with increasing market scale, meet customer cost expectations for higher performance and comfort.

Performance beyond entry-level variable speed equipment does bring more efficient operation and added savings, but at a significantly higher cost. The cold weather performance improvements do not confer significant advantages at today’s utility rates because customer costs drive switchover to fossil fuel systems before this performance is realized. While variable speed systems designed for cold weather performance may offer significantly more flexibility for future cold weather operation, their incremental cost cannot be justified in dual fuel applications without substantially higher customer incentives.

Utility Programs

Utility rebate programs can overcome first-cost barriers at the point of CAC replacement and offer a selling tool for contractors. The structure of utility rebates signal to the market what application types and product specifications to focus on. The conclusions of this report encourage an increased baseline in
the CAC market shifting from CAC to at a minimum, an entry level (SEER ≤ 15) heat pump. Utility rebates have a role to play in advancing this shift, however, will not be able to address the entry level heat pump category or heat pumps with SEER ratings less than 15 because there would not be enough incremental (cooling) savings to justify a rebate of any significant amount. However, utility rebates can promote mid and high tier heat pump products which yield significantly more savings and will have the effect of increasing market momentum. To truly transform the heat pump replacing CAC baseline, there will need to be a change to codes or standards to capture the full energy and carbon savings opportunities revealed in this report. In other words, there is still reason to transform the less than SEER 15 market, but utility rebates are not the right tool.

Utilities can also serve to advance the market by offering a high tier rebate with a larger rebate amount on more advanced equipment to motivate customers willing to pursue efficiency and decarbonization more aggressively. Another key point is that utility rebates across the state should maintain alignment to the extent possible to better motivate market engagement. With the Inflation Reduction Act provisions and new roll out of Energy Star specifications, options for product specification are rapidly evolving. As of today, some key sources of specification are unknown. Based on what is known at the time of this report rebate recommendations include:

- **Phase out AC rebates to send a clear signal to the market that heat pumps are the preferred technology for CAC and additionally that the gap between CAC and heat pump costs are as minimal as possible.**
- **Provide two tiers of HP rebates to both incentivize as many heat pump installations as possible while also continuing to encourage advanced and highest efficiency products**
  - **Tier 1:** Low-cost AC replacement market; this tier will yield lower energy savings per install and therefore a lower rebate amount. The Tier 1 rebate will help promote high volume of heat pump sales for technology that is most accessible to a larger number of customers.
  - **Tier 2:** Cold-climate ASHPs; this tier is meant to incentivize the most advanced product that will meet the highest fraction of the heating load. This rebate would be most applicable for customers looking to go all electric or mostly electric with space heating or customers who have existing electric or propane heat where a higher performance product will produce more cost savings and therefore a more attractive payback.
- **Product Specifications**
  - **Tier 1:** Consortium for Energy Efficiency (CEE1) heat pump specification (excluding advanced tier)
  - CEE1 specifications are currently under revision and will likely be finalized at the end of 2022. This specification will be the qualification for the $2000 tax credits offered through the Inflation Reduction Act.
  - **Tier 1** rebate offered at a lower amount but anticipate higher volume of sales.
  - **Tier 2:** ENERGY STAR v6.1 Cold Climate specification
  - Provide higher rebate amount to encourage advanced product adoption and encourage homeowners who are motivated to decarbonize more aggressively or who have most costly existing fuel types.
- **Both Tiers: Quality Install Incentive**
  - Provide higher rebate levels for contractors participating in a quality installation program to increase energy efficiency of installations.
Scan for future options for enhanced quality installation programming through connected diagnostic tools which can provide utilities with data on system operation and detect faults that could degrade energy savings.

- Avoid rebate structures that are built on a rebate amount offered on a per/ton basis as this may lead to oversizing equipment.

Due to the rapidly evolving nature of heat pump product specifications, utilities should stay engaged with regional collaborative groups such as the Minnesota ASHP Collaborative and/or the MN Efficient Technology Accelerator to stay engaged on rebate best practices and regional alignment.

**Recommendations**

**Manufacturer**

- **Increase consumer awareness** — Market research indicates many consumers are not aware of ASHP technology or their options at critical periods such as the time of CAC failures. Consumer awareness is key to marketplace acceptance.

- **Provide opportunities for distributor and contractor product ownership** — Skepticism over ASHP systems as CAC alternatives and space heating systems in cold climates exists throughout the supply chain because ASHP are either new technology or represent a radical improvement compared to prior heat pump technologies, which were marketed as appropriate only for warm climates. Personal familiarity with systems will reduce supply chain friction and demonstrate advances in technology.

- **Help dispel skepticism through increased contractor training and customer experience** — Manufacturers are well positioned to provide increased training on this ASHP application via distribution channels. By focusing on both technical and sales training for the ASHP as CAC replacement market, this will provide knowledge transfer and support to the contractor and customer markets.

- **Market systems as AC replacement (clear distinction between their equipment) and communicate the benefits** — ASHPs as CAC replacements minimize the two largest barriers to ASHP adoption in Minnesota, cost and sizing. Systems sized for CAC are cheaper and systems designed for use with backup are cheaper. Sizing systems for CAC replacements avoids the technical and cost challenges of sizing systems for peak heating loads, while in many cases offering most of the benefits.

- **Offer competitive pricing and ample production of ASHP equipment** — First cost and product availability are barriers to customer and contractor adoption of ASHP equipment.

- **Phase out manufacturing of CAC equipment** — CACs are a dead end. Manufacturers should strongly consider sunsetting CAC production in favor of ASHP systems.

- **Increase consumer awareness** — Market research indicates many consumers are not aware of ASHP technology or their options at critical periods such as the time of CAC failures. Consumer awareness is key to acceptance in the marketplace.

**Distributor**

- **Build stock of heat pump equipment and reduce stock of AC equipment** — Product stock becomes a large barrier in CAC replace-on-fail scenarios where both contractors and consumers may prioritize fast service over efficiency or NEB benefits of heat pumps over CACs.
• Continue to ramp up contractor engagement and training for AC replacement application type — The central theme of these recommendations is that the entire supply chain needs to be engaged on ASHP technology’s benefits and potential.

**Contractor**

• **Training and first-hand experience with this application** — Despite enthusiasm for ASHP, most contractors are not installing ASHPs, and many still steer customers away from these options.

• **Promotion of non-energy benefits to customers** — These benefits are key to upselling high efficiency CAC systems translated to ASHP systems. Plus, these systems have climate benefits, resiliency benefits, and more flexibility to changing energy prices.

• **Begin pricing for higher scale of installation and be competitive in bidding (increased transparency in bidding)** — Consumers need consistent and transparent pricing to make good decisions. Some contractors excel at this, while others do not.

• **Offer good, better, best with entry-level heat pump as the “good” option** — Simple choices that distinguish between ASHP systems according to upfront cost, operational savings, and non-energy benefits will help consumers make informed decisions based on their needs.

• **Replacing CAC only vs. whole system replacement** — Clear guidance should be offered to consumers about whether their furnace should be replaced.

• **Product selection and sizing** — Track rebate program requirements and select product and size according to customer needs and optimized cost considerations.

**Utility**

• **Rebate design** — Optimize rebate design to increase the baseline of ASHP adoption in CAC replacement and promote advanced technology in a higher tier rebate (see Utility Program Recommendations).

• **Replacing AC only vs. whole system replacement** — Full replacements bring more savings at added cost and most customers indicate preference for full system replacements. They also provide direct natural gas savings that could enable realization of additional efficiency incentives.

• **Product selection** — Align product specifications for consistency with other rebate funding sources and tax credits, as well as with other utility programs across the state (see Utility Program Recommendations).

• **Rate design** — ASHP as CAC replacements offer the opportunity to build significant new load (~1,000 to 8,000 kWh/customer) while lowering current summer peaks and avoiding potential winter peaks. Existing dual fuel programs demonstrate the ability to lower rates in these scenarios.

• **Increase consumer awareness** — All existing outreach efforts serve as additional opportunities to let consumers know about ASHP options they have during replacement scenarios. Utilities can recommend contractors, recommend questions for consumers to ask contractors, and point consumers to additional resources.

• **Aligning rebate design to increase distributor stocking practices** — If utility programs have consistent product specifications, distributors will be better able to predict demand, build stock, and optimize pricing to better serve utility rebate program needs.
Other Considerations

In addition to the key recommendations for the primary audiences in this report, there are other audiences and levers to reach the end goal of raising the baseline in the furnace/CAC market. Municipalities, statewide investments, and regulatory action can help advance this efficiency and decarbonization opportunity.

Municipalities

- **Permitting incentives** — Municipal control over permitting costs and timelines offers an opportunity to influence the types of systems that are considered during heating or cooling system replacement.
- **Sustainability action plan** — Incorporate this opportunity in city-lead sustainability action plans and focus on customer awareness to promote early retirement of old CAC and replacement with ASHPs or general awareness of ASHPs.
- **Licensure** — Licensure is an additional opportunity for municipalities to influence the types of equipment that are installed and information presented to consumers.
- **Increase consumer awareness** — All existing outreach efforts serve as additional opportunities to let consumers know about the ASHP options they have during replacement scenarios and/or as options to facilitate municipal decarbonization plans. Municipalities can recommend contractors, questions for consumers to ask contractors, and additional resources for consumers.

State

- **Continue investing in statewide initiatives** — Currently, the ASHP collaborative in Minnesota is a statewide effort to increase adoption of ASHP technology, and the Minnesota Efficient Technology Accelerator will also serve as a statewide vehicle for market transformation of the heat pump market.
- **Codes and standards** — State authorities can investigate how to implement appliance efficiency standards or other avenues to enact state appliance standards and require reversing valves in CAC equipment so that all systems sold in the state must be heat pump systems.
- **Increase consumer awareness** — All existing outreach efforts serve as additional opportunities for consumers to learn about the ASHP options they have during replacement scenarios and/or as options to facilitate municipal decarbonization plans. Municipalities can recommend contractors, questions for consumers to ask contractors, and additional resources for consumers.

Regulatory

- **Approving better rate structures** — Without drastic changes in the relative costs of electricity and natural gas, utilities’ flexibility to lower rates for natural gas customers who adopt ASHPs is the most impactful lever to accelerate ASHP adoptions in pursuit of state decarbonization goals.

Future Work

This work provides comprehensive estimates of the cost to operate ASHP systems when they are installed as CAC replacements based on manufacturer specifications and reasonable assumptions about
real world performance. However, field work to date from all over the country has demonstrated that
that the installed performance of specific ASHP systems varies considerably due to a large number of
building, occupant, and HVAC system variables. This inherent uncertainty extends to forecasts of
individual customer costs and is not captured here. In order that we can accurately predict customer
savings, significantly more field work is necessary. As ASHP adoption continues to accelerate, the project
team recommends expansion of detailed measurement and verification projects that not only verify
savings, but systematically investigate ASHP performance as a function of the many building, occupant,
and system variables that impact performance.
References

Matt Malinowski, Max Dupuy, David Farnsworth, Dara Torre, Combating High Fuel Prices with Hybrid Heating: The Case for Swapping Air Conditioners for Heat Pumps, CLASP, 2022, https://www.clasp.ngo/research/all/ac-to-heat-pumps/


Appendix A: Market Research Survey Results

Complete Customer Surveys

Customer survey raw data and codebook are available upon request.

Summary Contractor Survey Results

1) Do you think you will be selling more ASHPs in the future or the same amount as now?

Table 8: Count of responses to the contractor survey question, "Do you think you will be selling more ASHPs in the future or the same amount as now?", itemized for ducted and ductless units

<table>
<thead>
<tr>
<th>Response</th>
<th>Count for Ducted Systems</th>
<th>Percent for Ducted Systems</th>
<th>Count for Ductless Systems</th>
<th>Percent for Ductless Systems</th>
</tr>
</thead>
<tbody>
<tr>
<td>Business will increase</td>
<td>16</td>
<td>53%</td>
<td>18</td>
<td>60%</td>
</tr>
<tr>
<td>Business will stay the same</td>
<td>11</td>
<td>37%</td>
<td>8</td>
<td>27%</td>
</tr>
<tr>
<td>Not sure</td>
<td>3</td>
<td>10%</td>
<td>3</td>
<td>10%</td>
</tr>
</tbody>
</table>

A few top sentiments emerged for contractors who believed ASHP business would grow.

- Optimism that good ASHP rebates would continue and build demand
- Encountering more customers interested in environmentally friendlier options
- A nearer-term prediction that increasing natural gas prices will push customers toward ASHPs

A belief that ASHPs would continue to have a high upfront cost was the main reason contractors said business would stay the same.

2) What is the customer demand like for ASHPs? Is there a difference in demand between ducted and ductless?

Table 9: Count of responses to the contractor survey question, "What is the customer demand like for ASHPs?" itemized for ducted and ductless systems

<table>
<thead>
<tr>
<th>Response</th>
<th>Count for Ducted Systems</th>
<th>Percent for Ducted Systems</th>
<th>Count for Ductless Systems</th>
<th>Percent for Ductless Systems</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very high demand</td>
<td>1</td>
<td>3%</td>
<td>0</td>
<td>0%</td>
</tr>
</tbody>
</table>
Appendix A: Market Research Survey Results

<table>
<thead>
<tr>
<th>Response</th>
<th>Count for Ducted Systems</th>
<th>Percent for Ducted Systems</th>
<th>Count for Ductless Systems</th>
<th>Percent for Ductless Systems</th>
</tr>
</thead>
<tbody>
<tr>
<td>High demand</td>
<td>4</td>
<td>13%</td>
<td>7</td>
<td>23%</td>
</tr>
<tr>
<td>Some demand</td>
<td>10</td>
<td>33%</td>
<td>7</td>
<td>23%</td>
</tr>
<tr>
<td>Low demand</td>
<td>12</td>
<td>40%</td>
<td>11</td>
<td>37%</td>
</tr>
<tr>
<td>No demand</td>
<td>1</td>
<td>3%</td>
<td>1</td>
<td>3%</td>
</tr>
</tbody>
</table>

The critical importance of good rebates was a top sentiment to explain demand. There were also several notes about the attractiveness of ductless systems for houses with hydronic heat or hard-to-condition areas. For responses indicating low or no demand, a lack of customer awareness of ASHPs as options was the main issue.

3) How often do you replace equipment on failure? How often do you replace both the heating and cooling systems at the same time?

Table 10: Responses to the contractor survey questions, "How often do you replace equipment on failure? How often do you replace both the heating and cooling systems at the same time?"

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Average frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>“How often do you replace an AC when it has failed?”</td>
<td>67% of the time</td>
</tr>
<tr>
<td>“When an AC has failed, how often do you also replace the furnace?”</td>
<td>50% of the time</td>
</tr>
<tr>
<td>“When a furnace has failed, how often do you also replace the AC?”</td>
<td>51% of the time</td>
</tr>
</tbody>
</table>

Contractors typically reported replacing ACs on failure, which was said to be the more economical choice for most customers. A common reason that contractors would also sell a customer a new furnace (or a new AC if the furnace failed) was that both existing systems were installed at the same time, opening homeowners to the argument that the other piece of equipment could also soon fail, and it might be better to replace both at the same time.
4) Do you ever recommend a ducted ASHP when replacing a furnace or AC?

Table 11: Responses to the contractor question, "Do you ever recommend a ducted ASHP when replacing a furnace or AC?"

<table>
<thead>
<tr>
<th>Response</th>
<th>Count of Responses</th>
<th>Percent of Responses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yes</td>
<td>25</td>
<td>83%</td>
</tr>
<tr>
<td>No</td>
<td>5</td>
<td>17%</td>
</tr>
</tbody>
</table>

While many contractors said they had recommended an ASHP, most shared (sometimes narrow) qualifiers and situations when they would make a recommendation. The biggest reason contractors would recommend an ASHP is when a customer is on propane, followed by scenarios in which generous rebates make ASHPs comparable or nearly the same price as ACs. Negative responses cited foremost the high initial cost of ASHPs, then the high operational cost versus natural gas and a lack of customer awareness.

5) What is the customer demand for replacing an AC with an ASHP?

Table 12: Count of responses to the contractor survey question, "What is the customer demand for replacing an AC with an ASHP?"

<table>
<thead>
<tr>
<th>Response</th>
<th>Count of Responses</th>
<th>Percent of Responses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very high demand</td>
<td>1</td>
<td>3%</td>
</tr>
<tr>
<td>High demand</td>
<td>2</td>
<td>7%</td>
</tr>
<tr>
<td>Some demand</td>
<td>8</td>
<td>27%</td>
</tr>
<tr>
<td>Low demand</td>
<td>12</td>
<td>40%</td>
</tr>
<tr>
<td>No demand</td>
<td>7</td>
<td>23%</td>
</tr>
</tbody>
</table>

Contractors broadly reported little customer demand for ASHP as an AC replacement. However, many contractors, including those who reported little to no demand, also noted that if anybody did ask, it was because a utility rebate got their attention.

6) Are there any issues selling and installing ASHPs as AC replacements?
### Table 13: Responses to the contractor survey question, "Are there any issues selling and installing ASHPs as AC replacements?"

<table>
<thead>
<tr>
<th>Issue Reported</th>
<th>Count of Responses</th>
<th>Percent of Responses</th>
</tr>
</thead>
<tbody>
<tr>
<td>No issues</td>
<td>44</td>
<td>51%</td>
</tr>
<tr>
<td>Installations and systems more complicated and finicky</td>
<td>14</td>
<td>16%</td>
</tr>
<tr>
<td>Too expensive</td>
<td>10</td>
<td>11%</td>
</tr>
<tr>
<td>Lack of customer education</td>
<td>8</td>
<td>9%</td>
</tr>
<tr>
<td>Not as comfortable</td>
<td>6</td>
<td>7%</td>
</tr>
<tr>
<td>Service technicians need more training</td>
<td>3</td>
<td>3%</td>
</tr>
<tr>
<td>Don't perform well in cold</td>
<td>2</td>
<td>2%</td>
</tr>
</tbody>
</table>

### 7) What are the benefits to installing ASHPs as AC replacements?

### Table 14: Responses to the contractor survey question, "What are the benefits to installing ASHPs as AC replacements?"

<table>
<thead>
<tr>
<th>Benefit Reported</th>
<th>Count of Responses</th>
<th>Percent of Responses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operational savings vs ACs</td>
<td>10</td>
<td>18%</td>
</tr>
<tr>
<td>Savings for propane, electric resistance users</td>
<td>10</td>
<td>18%</td>
</tr>
<tr>
<td>No benefit or other issues</td>
<td>10</td>
<td>18%</td>
</tr>
<tr>
<td>Appealing to environmentally minded customers</td>
<td>6</td>
<td>11%</td>
</tr>
<tr>
<td>Taking advantage of rebates</td>
<td>5</td>
<td>9%</td>
</tr>
<tr>
<td>Increasing fuel choice for customers</td>
<td>5</td>
<td>9%</td>
</tr>
<tr>
<td>ASHPs offer more functionality than ACs</td>
<td>5</td>
<td>9%</td>
</tr>
</tbody>
</table>
Appendix A: Market Research Survey Results

<table>
<thead>
<tr>
<th>Benefit Reported</th>
<th>Count of Responses</th>
<th>Percent of Responses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Good for business and revenue</td>
<td>4</td>
<td>7%</td>
</tr>
<tr>
<td>More comfortable</td>
<td>2</td>
<td>4%</td>
</tr>
</tbody>
</table>

Savings in one form or another were the top benefits reported by contractors: savings for customers on propane or electric resistance heat and savings versus traditional ACs. Along this theme, multiple contractors said that good rebates could make higher end ASHPs cost competitive with ACs. Rebates could make ASHPs an attractive choice for customers to switch to a system with more benefits, like greater efficiency, functionality, and fuel choice, for close to the same price as an AC. Contractors also reported that environmentally minded customers liked ASHPs. However, another top response was that there weren’t benefits to or there were issues with installing ASHPs as an AC replacement.

8) Are there customer call backs or product issues for installing ASHPs as AC replacements?

Table 15: List of responses to the customer survey question, “Are there customer call backs or product issues for installing ASHPs as AC replacements?”

<table>
<thead>
<tr>
<th>Response</th>
<th>Count of Responses</th>
<th>Percent of Responses</th>
</tr>
</thead>
<tbody>
<tr>
<td>No issues</td>
<td>23</td>
<td>56%</td>
</tr>
<tr>
<td>Comfort issues</td>
<td>3</td>
<td>7%</td>
</tr>
<tr>
<td>Assorted product issues beyond installation</td>
<td>6</td>
<td>15%</td>
</tr>
<tr>
<td>Installation more challenging</td>
<td>5</td>
<td>12%</td>
</tr>
<tr>
<td>Lack of customer education</td>
<td>4</td>
<td>10%</td>
</tr>
</tbody>
</table>

Most contractors didn’t report issues with ASHPs as products or issues that cause customer callbacks beyond the normal range. Challenges with the defrost cycle, controls, shorter or more error-prone lifespan, and a generally more complicated installation process were cited as issues. Issues resulting in customer callbacks were mainly about the low supply air temperatures and confusion with controls.
Appendix B: Modeling Methodology

The Representative Building

The ASHP archetypes are considered options for CAC replacement at the time of CAC failure for a specific baseline building. The building has characteristics broadly consistent with a 1950s Minneapolis home that has natural gas forced air heating and a failed CAC. The home is 1,800 square feet and has been renovated over its life, including partial weatherization. The heating design load is 33 kBtu/hr at a design outside air temperature (OAT) of -11°F, which is lower than about 75% of existing homes in MN, but not quite at the level of homes built after 1990. The cooling load is around 21 kBtu/hr, which has been designed to match an average cooling load according to the Minnesota TRM version 3.3.4

Air Source Heat Pumps

This analysis eschews HSFP and SEER values in favor of adjusted performance models generated using manufacturer-reported coefficients of performance (COPs) and capacity values (Btu/hr) at several outside air temperatures to model unit heating efficiency. Performance adjustments include a cycling penalty, which occurs when the load is below the equipment capacity; defrost adjustments, when the systems must enter defrost mode; and standby energy, which includes energy consumption not associated with meeting heating or cooling load.

Most ASHP specifications are listed for matched systems, that is a combination of indoor unit and outdoor unit fixed operating assumptions. Since each product considered here can be paired with existing furnaces, reported data are adjusted to account for unmatched configurations, where heat pump outside units are paired with existing furnaces. The process is as follows. The first step is to remove the impact of the matched indoor component so that it can be replaced with a different baseline furnace. We assume indoor power is represented by the blower, calculate the fan power necessary to supply the rated air flow at 0.5” w.g. static pressure, and recalculate energy input into the system. Absent indoor blower power, the COP increases by between 7% and 29% for the selected archetypes. System COP for these archetypes will decrease based on the baseline blower to which they are paired.

Demonstrative COP values alongside system heating capacity as a function of outside air temperature are given in Figure 21. Each archetype also has a different minimum outside operating temperature. The three variable speed systems each have a large capacity range due to their variable compressor speed, whereas the single speed system is represented by a single curve.

For a fixed load, varying heat pump capacity can have significant effects on system energy consumption. The capacity of a single speed unit is fixed for any given outside air temperature as the ASHP is unable to modulate its capacity to match the load, as shown in Figure 23. If the ASHP is delivering a capacity that is too high for the needs of the home at that outside air temperature, it will begin to cycle on and off more frequently and incur efficiency penalties. An ASHP that can deliver exactly the capacity that is needed can avoid these cycling penalties but will be subject to much longer runtimes and will consume more fan power as a result. More efficient fans can help minimize this effect. With variable speed units, the ASHP

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4 Available from mn.gov/commerce-stat/pdfs/mn-trm-3-3.pdf
Appendix B: Modeling Methodology

can modulate down to its minimum capacity, determined by the turndown ratio, creating a range in which the heat pump can provide exactly the load required for any given temperature. In all cases, if the required load is higher than the heat pump’s capacity at that outside air temperature, the system switches over to the natural gas backup to provide heating. The temperature at which this occurs is called the capacity-based switchover temperature. Switchover temperatures can be set higher than the capacity-based switchover temperature. For example, they can be set higher to increase bill savings under specific combinations of electricity and natural gas costs.

![Figure 21: Coefficient of performance vs. outside air temperature for each ASHP archetype.](image)

**Building HVAC Energy Model**

The representative building is shown in an hourly energy conservation model to estimate the input energy necessary to meet the heating and cooling load of the building subject to specific weather and HVAC performance data in each hour of the year. In this exercise, building characteristics (e.g., parameters determining heating and cooling load) and occupant variables (e.g., thermostat settings) are constant. With these variables constant, ASHP equipment, furnace and CAC baseline, weather, and utility rates are varied to understand their role in energy and cost savings of ASHP for CAC replacement.
Baseline furnace and CAC configurations were selected from recent field data to represent CAC systems likely for near-term replacement. These baselines range in furnace efficiency (AFUE), heating stages, CAC efficiency (SEER), and fan type. The resulting baseline scenarios are then used as reference for each of the four selected heat pumps, representing four distinct ASHP performance behaviors or archetypes. These 36 ASHP baseline combinations are then iterated over 17 switchover temperatures between -15°F and 65°F, at which the system switches from heat pump to backup furnace operation. This is repeated for four weather models, representing distinct climates across Minnesota. Additional calculations are made for full replacement cases, in which the baseline furnace is upgraded to a 95% efficient 2-stage ECM unit alongside the ASHP installation. These scenarios are then each iterated over several electricity and natural gas rate combinations.

**Baselines**

Baselines selected to represent broad natural gas furnace types, ranging from 80% to 95% efficiency, combined with several CAC efficiencies. The baseline CAC model is a single-speed, 2.5-ton SEER 13 unit.

Baselines include the following blower motor types:

- PSC fixed speed motor
- ECM fixed speed motor
- Two-stage (heating) ECM motor
- Two-stage (heating and cooling) ECM motor

The list of baselines considered for this analysis is presented in Table 16.

<table>
<thead>
<tr>
<th>Baseline</th>
<th>Furnace</th>
<th>CAC SEER</th>
<th>Fan Motor</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>80% – 75 kBu</td>
<td>10</td>
<td>PSC Fixed</td>
</tr>
<tr>
<td>2</td>
<td>90% – 65 kBu</td>
<td>10</td>
<td>PSC Fixed</td>
</tr>
<tr>
<td>3</td>
<td>80% – 75 kBu</td>
<td>12</td>
<td>PSC Fixed</td>
</tr>
<tr>
<td>4</td>
<td>90% – 65 kBu</td>
<td>12</td>
<td>PSC Fixed</td>
</tr>
<tr>
<td>5</td>
<td>80% – 75 kBu</td>
<td>13</td>
<td>PSC Fixed</td>
</tr>
<tr>
<td>6</td>
<td>90% – 65 kBu</td>
<td>13</td>
<td>PSC Fixed</td>
</tr>
<tr>
<td>7</td>
<td>90% – 65 kBu</td>
<td>13</td>
<td>ECM Fixed</td>
</tr>
<tr>
<td>8</td>
<td>95% 60 kBu</td>
<td>13</td>
<td>ECM two-stage heating</td>
</tr>
<tr>
<td>9</td>
<td>95% 60 kBu</td>
<td>13</td>
<td>ECM two-stage heating &amp; cooling</td>
</tr>
</tbody>
</table>
Appendix B: Modeling Methodology

Rates

This analysis varies electric and gas rates independently. Electricity rates vary from 0.09 to 0.20 $/kWh. Natural gas rates vary from 0.5 $/therm to 1.6 $/therm. Special electric dual fuel rates were also considered. Dual fuel rates represent scenarios in which the installation of an ASHP operated with a gas backup grants eligibility for special utility rate programs designed for dual fuel heating customers. Some dual fuel rates come with additional riders. The selected dual fuel rate cases have been adjusted so that the volumetric rates used account for the effect of these riders. Rates were determined from a survey of electric and gas utilities statewide and represent annual average energy rates, inclusive of seasonal fluctuations. Considering fuel price volatility and pending rate cases, higher gas and electric rates have been included to investigate the impact of future prices.

Natural gas rates are relatively uniform between utilities, but less constant from season to season due to more dynamic pricing. Regular and dual fuel electricity rates can vary significantly between providers. The energy model outputs are iterated to apply these rate scenarios, including those in which the measure is eligible for dual fuel rates, unlocking additional savings as the natural gas rates are held constant between the measure and baseline. These savings are calculated by fuel and by mode (heating or cooling), in addition to overall annual savings.

Weather

The building energy model was iterated across four locations, each selected to represent distinct climate zones across the state. These locations and quadrants are as defined in Figure 2, with each location’s heating and cooling degree days listed in Table 17.

<table>
<thead>
<tr>
<th>Location</th>
<th>Quadrant</th>
<th>CDD</th>
<th>HDD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thief River Falls</td>
<td>Northwest</td>
<td>550</td>
<td>9,700</td>
</tr>
<tr>
<td>Duluth</td>
<td>Northeast</td>
<td>400</td>
<td>9,000</td>
</tr>
<tr>
<td>Minneapolis – St. Paul</td>
<td>Southeast</td>
<td>700</td>
<td>8,400</td>
</tr>
<tr>
<td>Worthington</td>
<td>Southwest</td>
<td>700</td>
<td>7,700</td>
</tr>
</tbody>
</table>

Model runs for each location use a weather file specific to each climate. This model uses data for a typical meteorological year (TMY) as provided by the National Solar Radiation Database maintained by the National Renewable Energy Laboratory (NREL-NSRDB). This TMY data includes average hourly outside air temperature, humidity, and solar irradiation measurements presented for a typical year. Together, these metrics are used to estimate the hourly load characteristics of the representative home had it been situated in each of these four locations.

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5 An example dual-fuel rate from Minnesota Power is available [here](http://mnpower.com/ProgramsRebates/DualFuel)
6 The National Solar Radiation Database is available from NREL. [nsrdb.nrel.gov/data-viewer](http://nsrdb.nrel.gov/data-viewer)
While the intent of TMY data is to represent the average year, there are expected year-to-year fluctuations in weather metrics that can significantly alter the economics and operation of a heat pump system. For example, a milder summer would decrease energy expended in cooling, thereby decreasing cooling savings attributed to the heat pump system. Figure 22 illustrates these year-to-year differences by charting the annual heating and cooling degree days between 2012 and 2020 in comparison to those of the TMY data.

**Figure 22: Historical Weather variations compared to TMY3-2020 weather data**

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**Replacement Type**

In addition to the replacement of the baseline AC with an ASHP (CAC-only replacement), the model was iterated to consider the effects of replacing both the baseline furnace and the CAC (full replacement). The replacement unit was selected to be a 95% efficient, two-stage ECM furnace and air handler combination, with the added capability of two-stage cooling, representing a high efficiency choice for the replacement of an aging or inefficient baseline furnace. While a new furnace will garner added savings compared to low efficiency baselines, full replacement scenarios also introduce added...
incremental costs associated with the replacement of both the AC and gas heating system. Full replacement scenarios are created for all combinations of baselines, ASHPs, rates, switchovers, and locations.

**Switchover Temperature**

The switchover temperature is the outside air temperature at which the system is set to switch from the ASHP to the backup heating system. In a dual fuel system, the minimum switchover is dependent on the heat pump’s ability to provide the whole home load. If the load demanded at a low outdoor temperature is higher than the ASHP capacity at that temperature, the system must disable the ASHP and rely entirely on the backup to meet the whole load. While this maximizes the use of the heat pump, it also requires the heat pump to operate at colder temperatures in which it is least efficient and incurs higher electricity costs. The model is iterated through switchovers between -15°F and 65°F to capture the effects of running the heat pump throughout its useful range of operation. Table 18 shows the percentage of annual heating load occurring above each switchover temperature for each location.

<table>
<thead>
<tr>
<th>Switchover (°F)</th>
<th>Minneapolis – St. Paul</th>
<th>Duluth</th>
<th>Thief River Falls</th>
<th>Worthington</th>
</tr>
</thead>
<tbody>
<tr>
<td>-15</td>
<td>98%</td>
<td>100%</td>
<td>96%</td>
<td>100%</td>
</tr>
<tr>
<td>-10</td>
<td>96%</td>
<td>99%</td>
<td>91%</td>
<td>99%</td>
</tr>
<tr>
<td>-5</td>
<td>91%</td>
<td>96%</td>
<td>86%</td>
<td>96%</td>
</tr>
<tr>
<td>0</td>
<td>85%</td>
<td>90%</td>
<td>81%</td>
<td>93%</td>
</tr>
<tr>
<td>5</td>
<td>78%</td>
<td>83%</td>
<td>74%</td>
<td>88%</td>
</tr>
<tr>
<td>10</td>
<td>72%</td>
<td>79%</td>
<td>68%</td>
<td>82%</td>
</tr>
<tr>
<td>15</td>
<td>65%</td>
<td>70%</td>
<td>58%</td>
<td>77%</td>
</tr>
<tr>
<td>20</td>
<td>56%</td>
<td>61%</td>
<td>49%</td>
<td>69%</td>
</tr>
<tr>
<td>25</td>
<td>47%</td>
<td>49%</td>
<td>39%</td>
<td>58%</td>
</tr>
<tr>
<td>30</td>
<td>40%</td>
<td>42%</td>
<td>33%</td>
<td>49%</td>
</tr>
<tr>
<td>35</td>
<td>23%</td>
<td>26%</td>
<td>18%</td>
<td>26%</td>
</tr>
<tr>
<td>40</td>
<td>15%</td>
<td>17%</td>
<td>13%</td>
<td>17%</td>
</tr>
<tr>
<td>45</td>
<td>10%</td>
<td>11%</td>
<td>8%</td>
<td>10%</td>
</tr>
<tr>
<td>50</td>
<td>5%</td>
<td>6%</td>
<td>4%</td>
<td>6%</td>
</tr>
<tr>
<td>55</td>
<td>3%</td>
<td>3%</td>
<td>2%</td>
<td>3%</td>
</tr>
<tr>
<td>60</td>
<td>1%</td>
<td>1%</td>
<td>0%</td>
<td>1%</td>
</tr>
<tr>
<td>65</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
</tr>
</tbody>
</table>

The economics of operating a dual fuel ASHP system are broadly dependent on two relationships: the ratio between electricity rates and gas rates per unit of energy and the ratio between the efficiency of the ASHP and that of the baseline natural gas furnace. If electricity rates are much higher than gas rates, the heat pump must be able to provide a large efficiency benefit that decreases fuel consumption to operate economically. The caveat is that high efficiency ASHPs will often come with higher incremental
costs. Conversely, low electricity rates like those of special dual fuel programs allow cheaper, less efficient heat pumps to retain an economic advantage over the incumbent system.

This allows us to identify the economic switchover, the minimum switchover modeled that allows for no net costs nor savings compared to the operation of the chosen baseline system. For example, with fixed electric and gas rates, heat pumps with comparatively good cold climate COP retention will have a lower economic switchover as they can maintain their efficiency advantage over the natural gas furnace at colder temperatures.

Note that, while modeled switchovers go down to -15°F, this does not guarantee the ASHP system will be operated at that temperature. As ASHPs demonstrate decreased heating capacities at low outside air temperatures, they may not be capable of providing the entire home’s heating load in colder periods. When this occurs, the model disables the ASHP entirely and relies on the furnace alone to provide the heating load. This capacity switchover is respected in all cases and indicates cold climate heat pump performance. While the economic switchover is correlated with the heat pump’s ability to maintain a high COP at lower temperatures, the capacity switchover is an indicator of the system’s capability to retain capacity at lower temperatures. For example, a model with a set switchover of -15°F and an otherwise identical model with a -10°F switchover will display identical heating usage and savings if the heat pump’s capacity switchover is -5°F.
Appendix C: Additional Modeling Results

Additional Cooling Results

Figure 23 shows a summary of the cooling electricity savings as they vary according to baseline CAC efficiency (SEER), baseline fan efficiency (W/cfm), replacement type (CAC or full), ASHP type (ASHP measure), and location (cooling degree days). Each horizontal bar represents a scenario featuring a different combination of these variables. Scenarios with equivalent savings were removed where possible for clarity.
There are several key takeaways.

- For a fixed cooling load, the baseline cooling system efficiency is the most important determinant of cooling savings potential. While SEER 13 CACs are the code minimum for replacement, actual customer energy savings will be much higher when compared to older equipment with less efficiency.
- The furnace fan also plays an important role in cooling savings. More savings are possible when ASHP measures are paired with efficient ECM and two-stage ECM fans compared to older PSC fans. In fact, much (sometimes all) of the cooling savings of the ASHPs over the SEER 13 CAC are eliminated when used with an older PSC fan. While right-sized or variable speed ASHPs can run at lower power to meet small cooling loads, their runtime can be nearly double, increasing fan
energy, which is especially punitive with a low efficiency fan motor that increases fan energy and indirectly adds to cooling load.

- Full replacements carry equivalent or increased savings compared to CAC only replacement because they are paired with two-stage ECM fans. The variable speed systems benefit from this lower fan power during lower stages of modulation, offsetting their increased runtime. Additional fan energy savings are possible when variable speed systems leverage the second cooling stage.

- The single stage ASHP is capable of about half to two-thirds of the variable speed systems’ savings. Savings are similar for variable speed systems due to diminishing savings at very high efficiency (SEER18+). The variable speed ASHPs bring additional cooling savings compared to the single stage ASHP because they spend much of their time at low speed. Despite their nameplate capacity (2 to 3 ton), each variable speed system is capable of modulating to an output that is at least 25% less than the single stage ASHP and at least 40% less than the SEER 13 baseline CAC.

- As illustrated by the four different locations, absolute savings are also sensitive to the overall cooling load. In general, higher savings are possible with the larger cooling loads in the southern half of the state, where savings are about 20% higher than the northwest and about 50% higher than the northeast. These differences are also indicative of year-to-year savings variations due to weather. Savings will be higher than the given figures for cooling seasons with above average temperatures.

Table 19: Cooling savings for heat pump measures for different baseline systems for Minneapolis, MN

<table>
<thead>
<tr>
<th>Baseline</th>
<th>Replacement</th>
<th>ssASHP</th>
<th>Entry-Level vsASHP</th>
<th>Cold Climate vsASHP</th>
<th>Avg. vsASHP</th>
</tr>
</thead>
<tbody>
<tr>
<td>SEER10 0.5W/cfm</td>
<td>CAC-only</td>
<td>276</td>
<td>304</td>
<td>292</td>
<td>445</td>
</tr>
<tr>
<td>SEER10 0.5W/cfm</td>
<td>Full</td>
<td>385</td>
<td>616</td>
<td>640</td>
<td>706</td>
</tr>
<tr>
<td>SEER12 0.5W/cfm</td>
<td>CAC-only</td>
<td>74</td>
<td>102</td>
<td>90</td>
<td>243</td>
</tr>
<tr>
<td>SEER12 0.5W/cfm</td>
<td>Full</td>
<td>183</td>
<td>414</td>
<td>438</td>
<td>504</td>
</tr>
<tr>
<td>SEER13 0.5W/cfm</td>
<td>CAC-only</td>
<td>-1</td>
<td>26</td>
<td>14</td>
<td>168</td>
</tr>
<tr>
<td>SEER13 0.5W/cfm</td>
<td>Full</td>
<td>107</td>
<td>338</td>
<td>363</td>
<td>428</td>
</tr>
<tr>
<td>SEER13 0.4W/cfm</td>
<td>CAC-only</td>
<td>20</td>
<td>91</td>
<td>100</td>
<td>204</td>
</tr>
<tr>
<td>SEER13 0.4W/cfm</td>
<td>Full</td>
<td>20</td>
<td>252</td>
<td>276</td>
<td>341</td>
</tr>
<tr>
<td>SEER13 0.3W/cfm (2 stage both)</td>
<td>CAC-only</td>
<td>20</td>
<td>252</td>
<td>276</td>
<td>341</td>
</tr>
<tr>
<td>SEER13 0.3W/cfm (2 stage both)</td>
<td>Full</td>
<td>20</td>
<td>251</td>
<td>276</td>
<td>341</td>
</tr>
<tr>
<td>SEER13 0.3W/cfm (2 stage heat)</td>
<td>CAC-only</td>
<td>20</td>
<td>91</td>
<td>100</td>
<td>204</td>
</tr>
<tr>
<td>SEER13 0.3W/cfm (2 stage heat)</td>
<td>Full</td>
<td>20</td>
<td>251</td>
<td>276</td>
<td>341</td>
</tr>
</tbody>
</table>
Savings from Furnace Replacement

Table 20: Heating gas and electric savings for furnace replacement (no ASHP runtime)

<table>
<thead>
<tr>
<th>Baseline</th>
<th>Maximum natural gas savings (therms)</th>
<th>Fan savings (kWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>80% SEER10 0.5W/cfm</td>
<td>150</td>
<td>199</td>
</tr>
<tr>
<td>90% SEER10 0.5W/cfm</td>
<td>37</td>
<td>263</td>
</tr>
<tr>
<td>80% SEER12 0.5W/cfm</td>
<td>150</td>
<td>199</td>
</tr>
<tr>
<td>90% SEER12 0.5W/cfm</td>
<td>37</td>
<td>263</td>
</tr>
<tr>
<td>80% SEER13 0.5W/cfm</td>
<td>150</td>
<td>199</td>
</tr>
<tr>
<td>90% SEER13 0.5W/cfm</td>
<td>37</td>
<td>263</td>
</tr>
<tr>
<td>90% SEER13 0.4W/cfm</td>
<td>43</td>
<td>105</td>
</tr>
<tr>
<td>95% SEER13 0.3W/cfm (2 stage heat)</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>95% SEER13 0.3W/cfm (2 stage both)</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

Full Cost Results

Entry Level Variable Speed Heat Pump

Dual Fuel Rate

Baseline 80% Furnace with PSC Blower

Full Furnace & CAC Replacement
Figure 24: Entry level vs ASHP (Full replacement) vs 80% furnace with SEER 13 CAC on 0.07 $/kWh dual fuel rate in Minneapolis.
Figure 25: Entry level vs ASHP (Full replacement) vs 80% furnace with SEER 13 CAC on 0.07 $/kWh dual fuel rate in Duluth
Figure 26: Entry level vs ASHP (Full replacement) vs 80% furnace with SEER 13 CAC on 0.07 $/kWh dual fuel rate in Thief River Falls
Figure 27: Entry level vs ASHP (Full replacement) vs 80% furnace with SEER 13 CAC on 0.07 $/kWh dual fuel rate in Worthington.
Appendix C: Additional Modeling Results

**CAC-Only Replacement**

Figure 28: Entry level vs ASHP (CAC-only replacement) vs 80% furnace with SEER 13 CAC on 0.07 $/kWh dual fuel rate in Minneapolis

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Investigation of Air Source Heat Pumps as a Replacement of Central Air Conditioning
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Figure 29: Entry level vs ASHP (CAC-only replacement) vs 80% furnace with SEER 13 CAC on 0.07 $/kWh dual fuel rate in Duluth
Figure 30: Entry level vsASHP (CAC-only replacement) vs 80% furnace with SEER 13 CAC on 0.07 $/kWh dual fuel rate in Thief River Falls
Figure 31: Entry level vs ASHP (CAC-only replacement) vs 80% furnace with SEER 13 CAC on 0.07 $/kWh dual fuel rate in Worthington
Appendix C: Additional Modeling Results

Baseline 90% Furnace with ECM Blower

*Full Furnace & CAC Replacement*

**Figure 32:** Entry level vs ASHP (Full replacement) vs 90% furnace with SEER 13 CAC on 0.07 $/kWh dual fuel rate in Minneapolis
Figure 33: Entry level vs ASHP (Full replacement) vs 90% furnace with SEER 13 CAC on 0.07 $/kWh dual fuel rate in Duluth.
Figure 34: Entry level vs ASHP (Full replacement) vs 90% furnace with SEER 13 CAC on 0.07 $/kWh dual fuel rate in Thief River Falls.
Figure 35: Entry level vs ASHP (Full replacement) vs 90% furnace with SEER 13 CAC on 0.07 $/kWh dual fuel rate in Worthington
CAC-Only Replacement

Figure 36: Entry level vs ASHP (CAC-only replacement) vs 90% furnace with SEER 13 CAC on 0.07 $/kWh dual fuel rate in Minneapolis
Figure 37: Entry level vs ASHP (CAC-only replacement) vs 90% furnace with SEER 13 CAC on 0.07 $/kWh dual fuel rate in Duluth
Figure 38: Entry level vs ASHP (CAC-only replacement) vs 90% furnace with SEER 13 CAC on 0.07 $/kWh dual fuel rate in Thief River Falls.
Figure 39: Entry level vsASHP (CAC-only replacement) vs 90% furnace with SEER 13 CAC on 0.07 $/kWh dual fuel rate in Worthington

Regular Electric Rates

Baseline 80% Furnace with PSC Blower

Full Furnace & CAC Replacement
Figure 40: Entry level vs ASHP (Full replacement) vs 80% furnace with SEER 13 CAC at regular electric rates in Minneapolis
Figure 41: Entry level vs ASHP (Full replacement) vs 80% furnace with SEER 13 CAC at regular electric rates in Duluth.
Figure 42: Entry level vs ASHP (Full replacement) vs 80% furnace with SEER 13 CAC at regular electric rates in Thief River Falls.
Figure 43: Entry level vs ASHP (Full replacement) vs 80% furnace with SEER 13 CAC at regular electric rates in Worthington.
CAC-Only Replacement

Figure 44: Entry level vs ASHP (CAC-only replacement) vs 80% furnace with SEER 13 CAC at regular electric rates in Minneapolis
Figure 45: Entry level vs ASHP (CAC-only replacement) vs 80% furnace with SEER 13 CAC at regular electric rates in Duluth
Figure 46: Entry level vs ASHP (CAC-only replacement) vs 80% furnace with SEER 13 CAC at regular electric rates in Thief River Falls.
Figure 47: Entry level vs ASHP (CAC-only replacement) vs 80% furnace with SEER 13 CAC at regular electric rates in Worthington.

### Switchover

- 0°F
- 5°F
- 10°F
- 15°F
- 20°F
- 25°F
- 30°F
- 35°F
- 40°F
- 45°F
- 50°F
- 55°F
- 60°F

### Cost Savings

- $0 - 66$
- $66 - 132$
- $132 - 198$
- $198 - 264$
- $264 - 330$
- $330 - 396$
- $396 - 462$
- $462 - 528$
- $528 - 594$
- $594 - 660$
Baseline 90% Furnace with ECM Blower

Full Furnace & CAC Replacement

Figure 48: Entry level vsASHP (Full replacement) vs 90% furnace with SEER 13 CAC at regular electric rates in Minneapolis

Switchover
(°F)

Cost Savings
($/yr)

Baseline 90% Furnace with ECM Blower

Full Furnace & CAC Replacement
Figure 49: Entry level vs ASHP (Full replacement) vs 90% furnace with SEER 13 CAC at regular electric rates in Duluth

Switchover (°F)
- 0
- 5
- 10
- 15
- 20
- 25
- 30
- 35
- 40
- 45
- 50
- 55
- 60

Cost Savings ($/yr)
- [0, 60]
- [60, 120]
- [120, 180]
- [180, 240]
- [240, 300]
- [300, 360]
- [360, 420]
- [420, 480]
- [480, 540]
- [540, 600]
Figure 50: Entry level vs ASHP (Full replacement) vs 90% furnace with SEER 13 CAC at regular electric rates in Thief River Falls

Switchover
(°F)
0
5
10
15
20
25
30
35
40
45
50
55
60

Cost Savings
($/yr)
(0, 60]
(60, 120]
(120, 180]
(180, 240]
(240, 300]
(300, 360]
(360, 420]
(420, 480]
(480, 540]
(540, 600]
Figure 51: Entry level vs ASHP (Full replacement) vs 90% furnace with SEER 13 CAC at regular electric rates in Worthington.
Appendix C: Additional Modeling Results

**CAC-Only Replacement**

Figure 52: Entry level vs ASHP (CAC-only replacement) vs 90% furnace with SEER 13 CAC at regular electric rates in Minneapolis
Figure 53: Entry level vs ASHP (CAC-only replacement) vs 90% furnace with SEER 13 CAC at regular electric rates in Duluth.
Appendix C: Additional Modeling Results

Figure 54: Entry level vs ASHP (CAC-only replacement) vs 90% furnace with SEER 13 CAC at regular electric rates in Thief River Falls
Appendix C: Additional Modeling Results

Figure 55: Entry level vs ASHP (CAC-only replacement) vs 90% furnace with SEER 13 CAC at regular electric rates in Worthington.
Entry Level Single Speed Heat Pump

Dual Fuel Rate

Baseline 80% Furnace with PSC Blower

Full Furnace & CAC Replacement

Figure 56: Entry level ssASHP (Full replacement) vs 80% furnace with SEER 13 CAC at 0.07 $/kWh dual fuel rate in Minneapolis
Figure 57: Entry level ssASHP (Full replacement) vs 80% furnace with SEER 13 CAC at 0.07 $/kWh dual fuel rate in Duluth
Appendix C: Additional Modeling Results

Figure 58: Entry level ssASHP (Full replacement) vs 80% furnace with SEER 13 CAC at 0.07 $/kWh dual fuel rate in Thief River Falls

Baseline Electric Rate ($/kWh)

Switchover
(°F)

- 25
- 30
- 35
- 40

Gas Rate ($/therm)

Cost Savings
($/yr)

- [97.8, 195.6]
- [195.6, 293.3]
- [293.3, 391.1]
- [391.1, 488.9]
- [488.9, 586.7]
- [586.7, 684.4]
- [684.4, 782.2]
- [782.2, 880.0]
- [880.0, 977.8]
Figure 59: Entry level ssASHP (Full replacement) vs 80% furnace with SEER 13 CAC at 0.07 $/kWh dual fuel rate in Worthington
**CAC-Only Replacement**

Figure 60: Entry level ssASHP (CAC-only replacement) vs 80% furnace with SEER 13 CAC at 0.07 $/kWh dual fuel rate in Minneapolis
Figure 61: Entry level ssASHP (CAC-only replacement) vs 80% furnace with SEER 13 CAC at 0.07 $/kWh dual fuel rate in Duluth
Figure 62: Entry level ssASHP (CAC-only replacement) vs 80% furnace with SEER 13 CAC at 0.07 $/kWh dual fuel rate in Thief River Falls
Figure 63: Entry level ssASHP (CAC-only replacement) vs 80% furnace with SEER 13 CAC at 0.07 $/kWh dual fuel rate in Worthington.
Baseline 90% Furnace with ECM Blower

Full Furnace & CAC Replacement

Figure 64: Entry level ssASHP (Full replacement) vs 90% furnace with SEER 13 CAC at 0.07 $/kWh dual fuel rate in Minneapolis
Figure 65: Entry level ssASHP (Full replacement) vs 90% furnace with SEER 13 CAC at 0.07 $/kWh dual fuel rate in Duluth
Figure 66: Entry level ssASHP (Full replacement) vs 90% furnace with SEER 13 CAC at 0.07 $/kWh dual fuel rate in Thief River Falls.
Figure 67: Entry level ssASHP (Full replacement) vs 90% furnace with SEER 13 CAC at 0.07 $/kWh dual fuel rate in Worthington.

Switchover
(°F)

- 25
- 30
- 35
- 40

Cost Savings
($/yr)

- (0, 77]
- (77, 154]
- (154, 231]
- (231, 308]
- (308, 385]
- (385, 462]
- (462, 539]
- (539, 616]
- (616, 693]
- (693, 770]
**CAC-Only Replacement**

Figure 68: Entry level ssASHP (CAC-only replacement) vs 90% furnace with SEER 13 CAC at 0.07 $/kWh dual fuel rate in Minneapolis
Figure 69: Entry level ssASHP (CAC-only replacement) vs 90% furnace with SEER 13 CAC at 0.07 $/kWh dual fuel rate in Duluth
Figure 70: Entry level ssASHP (CAC-only replacement) vs 90% furnace with SEER 13 CAC at 0.07 $/kWh dual fuel rate in Thief River Falls

Switchover (°F)
- 25
- 30
- 35
- 40

Cost Savings ($/yr)
- (0, 66]
- (66, 132]
- (132, 198]
- (198, 264]
- (264, 330]
- (330, 396]
- (396, 462]
- (462, 528]
- (528, 594]
- (594, 660]
Figure 71: Entry level ssASHP (CAC-only replacement) vs 90% furnace with SEER 13 CAC at 0.07 $/kWh dual fuel rate in Worthington
Regular Electric Rates

Baseline 80% Furnace with PSC Blower

Full Furnace & CAC Replacement

Figure 72: Entry level ssASHP (Full replacement) vs 80% furnace with SEER 13 CAC at regular electric rates in Minneapolis
Figure 73: Entry level ssASHP (Full replacement) vs 80% furnace with SEER 13 CAC at regular electric rates in Duluth.
Figure 74: Entry level ssASHP (Full replacement) vs 80% furnace with SEER 13 CAC at regular electric rates in Thief River Falls

Switchover
(°F)

- 25
- 30
- 35
- 40

Cost Savings
($/yr)

- (611.1, 672]
- (488.9, 550]
- (550.0, 611]
- (611.1, 672]
- (427.8, 489]
- (366.7, 428]
- (305.6, 367]
- (244.4, 306]
- (183.3, 244]
- (122.2, 183]
- (61.1, 122]

Electric Rate ($/kWh)

Gas Rate ($/therm)
Figure 75: Entry level ssASHP (Full replacement) vs 80% furnace with SEER 13 CAC at regular electric rates in Worthington.

Switchover
°F
- 25
- 30
- 35
- 40

Cost Savings
($/yr)
- (61.1, 122.2]
- (122.2, 183.3]
- (183.3, 244.4]
- (244.4, 305.6]
- (305.6, 366.7]
- (366.7, 427.8]
- (427.8, 488.9]
- (488.9, 550.0]
- (550.0, 611.1]
CAC-Only Replacement

Figure 76: Entry level ssASHP (CAC-only replacement) vs 80% furnace with SEER 13 CAC at regular electric rates in Minneapolis
Figure 77: Entry level ssASHP (CAC-only replacement) vs 80% furnace with SEER 13 CAC at regular electric rates in Duluth

Switchover

°F

25
30
35
40

Cost Savings

$/yr

[0, 50]
(50, 100]
(100, 150]
(150, 200]
(200, 250]
(250, 300]
(300, 350]
(350, 400]
(400, 450]
(450, 500]
Figure 78: Entry level ssASHP (CAC-only replacement) vs 80% furnace with SEER 13 CAC at regular electric rates in Thief River Falls

Switchover
(°F)

<table>
<thead>
<tr>
<th>Value</th>
<th>Color</th>
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</thead>
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<td>25</td>
<td>Purple</td>
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<td>30</td>
<td>Blue</td>
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<tr>
<td>35</td>
<td>Green</td>
</tr>
<tr>
<td>40</td>
<td>Yellow</td>
</tr>
</tbody>
</table>

Cost Savings
($/yr)

<table>
<thead>
<tr>
<th>Range</th>
<th>Color</th>
</tr>
</thead>
<tbody>
<tr>
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<td>Dark Purple</td>
</tr>
<tr>
<td>(44, 88]</td>
<td>Dark Blue</td>
</tr>
<tr>
<td>(88, 132]</td>
<td>Blue</td>
</tr>
<tr>
<td>(132, 178]</td>
<td>Green</td>
</tr>
<tr>
<td>(176, 220]</td>
<td>Light Green</td>
</tr>
<tr>
<td>(220, 264]</td>
<td>Yellow</td>
</tr>
<tr>
<td>(264, 308]</td>
<td>Light Blue</td>
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<tr>
<td>(308, 352]</td>
<td>Blue</td>
</tr>
<tr>
<td>(352, 396]</td>
<td>Green</td>
</tr>
<tr>
<td>(396, 440]</td>
<td>Dark Green</td>
</tr>
</tbody>
</table>
Figure 79: Entry level ssASHP (CAC-only replacement) vs 80% furnace with SEER 13 CAC at regular electric rates in Worthington
Baseline 90% Furnace with ECM Blower

Full Furnace & CAC Replacement

Figure 80: Entry level ssASHP (Full replacement) vs 90% furnace with SEER 13 CAC at regular electric rates in Minneapolis
Appendix C: Additional Modeling Results

Figure 81: Entry level ssASHP (Full replacement) vs 90% furnace with SEER 13 CAC at regular electric rates in Duluth
Figure 82: Entry level ssASHP (Full replacement) vs 90% furnace with SEER 13 CAC at regular electric rates in Thief River Falls.
Figure 83: Entry level ssASHP (Full replacement) vs 90% furnace with SEER 13 CAC at regular electric rates in Worthington

Switchover
(°F)
- 25
- 30
- 35
- 40

Cost Savings
($/yr)
- (0, 44]
- (44, 88]
- (88, 132]
- (132, 176]
- (176, 220]
- (220, 264]
- (264, 308]
- (308, 352]
- (352, 396]
- (396, 440]
CAC-Only Replacement

Figure 84: Entry level ssASHP (CAC-only replacement) vs 90% furnace with SEER 13 CAC at regular electric rates in Minneapolis
Figure 85: Entry level ssASHP (CAC-only replacement) vs 90% furnace with SEER 13 CAC at regular electric rates in Duluth

Switchover (°F)
- 25
- 30
- 35
- 40

Cost Savings ($/yr)
- (0, 40]
- (40, 80]
- (80, 120]
- (120, 160]
- (160, 200]
- (200, 240]
- (240, 280]
- (280, 320]
- (320, 360]
- (360, 400]
Figure 86: Entry level ssASHP (CAC-only replacement) vs 90% furnace with SEER 13 CAC at regular electric rates in Thief River Falls
Figure 87: Entry level ssASHP (CAC-only replacement) vs 90% furnace with SEER 13 CAC at regular electric rates in Worthington.
Average Variable Speed Heat Pump

Dual Fuel Rate

Baseline 80% Furnace with PSC Blower

Full Furnace & CAC Replacement

Figure 88: Average vs ASHP (Full replacement) vs 80% furnace with SEER 13 CAC at 0.07 $/kWh dual fuel rate in Minneapolis

Investigation of Air Source Heat Pumps as a Replacement of Central Air Conditioning
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Investigation of Air Source Heat Pumps as a Replacement of Central Air Conditioning

Figure 89: Average vs ASHP (Full replacement) vs 80% furnace with SEER 13 CAC at 0.07 $/kWh dual fuel rate in Duluth

Switchover (°F)
- 5
- 10
- 15
- 20
- 25
- 30
- 35

Cost Savings ($/yr)
- (133, 267)
- (267, 400)
- (400, 533)
- (533, 667)
- (667, 800)
- (800, 933)
- (933, 1067)
- (1067, 1200)
- (1200, 1333)
Figure 90: Average vs ASHP (Full replacement) vs 80% furnace with SEER 13 CAC at 0.07 $/kWh dual fuel rate in Thief River Falls.
CAC-Only Replacement

Figure 91: Average vs ASHP (Full replacement) vs 80% furnace with SEER 13 CAC at 0.07 $/kWh dual fuel rate in Worthington
Figure 92: Average vs ASHP (CAC-only replacement) vs 80% furnace with SEER 13 CAC at 0.07 $/kWh dual fuel rate in Minneapolis
Figure 93: Average vs ASHP (CAC-only replacement) vs 80% furnace with SEER 13 CAC at 0.07 $/kWh dual fuel rate in Duluth
Figure 94: Average vs ASHP (CAC-only replacement) vs 80% furnace with SEER 13 CAC at 0.07 $/kWh dual fuel rate in Thief River Falls.
Figure 95: Average vsASHP (CAC-only replacement) vs 80% furnace with SEER 13 CAC at 0.07 $/kWh dual fuel rate in Worthington.
Baseline 90% Furnace with ECM Blower

Full Furnace & CAC Replacement

Figure 96: Average vs ASHP (Full replacement) vs 90% furnace with SEER 13 CAC at 0.07 $/kWh dual fuel rate in Minneapolis
Appendix C: Additional Modeling Results

Figure 97: Average vs ASHP (Full replacement) vs 90% furnace with SEER 13 CAC at 0.07 $/kWh dual fuel rate in Duluth.
Figure 98: Average vs ASHP (Full replacement) vs 90% furnace with SEER 13 CAC at 0.07 $/kWh dual fuel rate in Thief River Falls
Figure 99: Average vs ASHP (Full replacement) vs 90% furnace with SEER 13 CAC at 0.07 $/kWh dual fuel rate in Worthington.
**CAC-Only Replacement**

Figure 100: Average vs ASHP (CAC-only replacement) vs 90% furnace with SEER 13 CAC at 0.07 $/kWh dual fuel rate in Minneapolis

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Investigation of Air Source Heat Pumps as a Replacement of Central Air Conditioning
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Figure 101: Average vs ASHP (CAC-only replacement) vs 90% furnace with SEER 13 CAC at 0.07 $/kWh dual fuel rate in Duluth
Figure 102: Average vs ASHP (CAC-only replacement) vs 90% furnace with SEER 13 CAC at 0.07 $/kWh dual fuel rate in Thief River Falls
Figure 103: Average vs ASHP (CAC-only replacement) vs 90% furnace with SEER 13 CAC at 0.07 $/kWh dual fuel rate in Worthington
Regular Electric Rates

Baseline 80% Furnace with PSC Blower

Full Furnace & CAC Replacement
Figure 105: Average vs ASHP (Full replacement) vs 80% furnace with SEER 13 CAC at regular electric rates in Duluth
Figure 106: Average vs ASHP (Full replacement) vs 80% furnace with SEER 13 CAC at regular electric rates in Thief River Falls.
Figure 107: Average vs ASHP (Full replacement) vs 80% furnace with SEER 13 CAC at regular electric rates in Worthington.
**CAC-Only Replacement**

Figure 108: Average vsASHP (CAC-only replacement) vs 80% furnace with SEER 13 CAC at regular electric rates in Minneapolis
Figure 109: Average vs ASHP (CAC-only replacement) vs 80% furnace with SEER 13 CAC at regular electric rates in Duluth

- **Switchover (°F):**
  - 5
  - 10
  - 15
  - 20
  - 25
  - 30
  - 35
  - 40
  - 45
  - 50

- **Cost Savings ($/yr):**
  - (0, 88]
  - (88, 176]
  - (176, 264]
  - (264, 352]
  - (352, 440]
  - (440, 528]
  - (528, 616]
  - (616, 704]
  - (704, 792]
  - (792, 880]
Figure 110: Average vs ASHP (CAC-only replacement) vs 80% furnace with SEER 13 CAC at regular electric rates in Thief River Falls
Figure 11: Average vs ASHP (CAC-only replacement) vs 80% furnace with SEER 13 CAC at regular electric rates in Worthington.
Appendix C: Additional Modeling Results

Baseline 90% Furnace with ECM Blower

Full Furnace & CAC Replacement

Figure 112: Average vs ASHP (Full replacement) vs 90% furnace with SEER 13 CAC at regular electric rates in Minneapolis

Investigation of Air Source Heat Pumps as a Replacement of Central Air Conditioning
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Figure 113: Average vs ASHP (Full replacement) vs 90% furnace with SEER 13 CAC at regular electric rates in Duluth.
Figure 114: Average vs ASHP (Full replacement) vs 90% furnace with SEER 13 CAC at regular electric rates in Thief River Falls.
Figure 115: Average vs ASHP (Full replacement) vs 90% furnace with SEER 13 CAC at regular electric rates in Worthington
Appendix C: Additional Modeling Results

**CAC Only Replacement**

Figure 116: Average vs ASHP (CAC-only replacement) vs 90% furnace with SEER 13 CAC at regular electric rates in Minneapolis
Figure 117: Average vs ASHP (CAC-only replacement) vs 90% furnace with SEER 13 CAC at regular electric rates in Duluth.
Appendix C: Additional Modeling Results

Figure 118: Average vsASHP (CAC-only replacement) vs 90% furnace with SEER 13 CAC at regular electric rates in Thief River Falls

Switchover
(°F)

5
10
15
20
25
30
35
40
45
50

Cost Savings
($/yr)

(0, 66]
(66, 132]
(132, 198]
(198, 264]
(264, 330]
(330, 396]
(396, 462]
(462, 528]
(528, 594]
(594, 660]

Investigation of Air Source Heat Pumps as a Replacement of Central Air Conditioning
Center for Energy and Environment
Figure 119: Average vsASHP (CAC-only replacement) vs 90% furnace with SEER 13 CAC at regular electric rates in Worthington
Cold Climate Variable Speed Heat Pump

*Dual Fuel Rate*

Baseline 80% Furnace with PSC Blower

*Full Furnace & CAC Replacement*

Figure 120: Cold climate vs ASHP (Full replacement) vs 80% furnace with SEER 13 CAC on 0.07 $/kWh dual fuel rate in Minneapolis
Figure 121: Cold climate vs ASHP (Full replacement) vs 80% furnace with SEER 13 CAC on 0.07 $/kWh dual fuel rate in Duluth

Switchover
(°F)

Cost Savings
($/yr)

Baseline Electric Rate ($/kWh)

Gas Rate ($/therm)
Figure 122: Cold climate vs ASHP (Full replacement) vs 80% furnace with SEER 13 CAC on 0.07 $/kWh dual fuel rate in Thief River Falls.
Figure 123: Cold climate vs ASHP (Full replacement) vs 80% furnace with SEER 13 CAC on 0.07 $/kWh dual fuel rate in Worthington
**CAC Only Replacement**

Figure 124: Cold climate vs ASHP (CAC-Only replacement) vs 80% furnace with SEER 13 CAC on 0.07 $/kWh dual fuel rate in Minneapolis
Figure 125: Cold climate vs ASHP (CAC-Only replacement) vs 80% furnace with SEER 13 CAC on 0.07 $/kWh dual fuel rate in Duluth.
Figure 126: Cold climate vs ASHP (CAC-Only replacement) vs 80% furnace with SEER 13 CAC on 0.07 $/kWh dual fuel rate in Thief River Falls.
Appendix C: Additional Modeling Results

Figure 127: Cold climate vs ASHP (CAC-Only replacement) vs 80% furnace with SEER 13 CAC on 0.07 $/kWh dual fuel rate in Worthington.
Appendix C: Additional Modeling Results

Baseline 90% Furnace with ECM Blower

Full Furnace & CAC Replacement

Figure 128: Cold climate vs ASHP (Full replacement) vs 90% furnace with SEER 13 CAC on 0.07 $/kWh dual fuel rate in Minneapolis
Figure 129: Cold climate vs ASHP (Full replacement) vs 90% furnace with SEER 13 CAC on 0.07 $/kWh dual fuel rate in Duluth.
Figure 130: Cold climate vs ASHP (Full replacement) vs 90% furnace with SEER 13 CAC on 0.07 $/kWh dual fuel rate in Thief River Falls
Figure 131: Cold climate vs ASHP (Full replacement) vs 90% furnace with SEER 13 CAC on 0.07 $/kWh dual fuel rate in Worthington.
**CAC-Only Replacement**

Figure 132: Cold climate vs ASHP (CAC-Only replacement) vs 90% furnace with SEER 13 CAC on 0.07 $/kWh dual fuel rate in Minneapolis
Figure 133: Cold climate vs ASHP (CAC-Only replacement) vs 90% furnace with SEER 13 CAC on 0.07 $/kWh dual fuel rate in Duluth
Figure 134: Cold climate vs ASHP (CAC-Only replacement) vs 90% furnace with SEER 13 CAC on 0.07 $/kWh dual fuel rate in Thief River Falls
Figure 135: Cold climate vs ASHP (CAC-Only replacement) vs 90% furnace with SEER 13 CAC on 0.07 $/kWh dual fuel rate in Worthington
Regular Electric Rates

Baseline 80% Furnace with PSC Blower

Full Furnace & CAC Replacement

Figure 136: Cold climate vs ASHP (Full replacement) vs 80% furnace with SEER 13 CAC at regular electric rates in Minneapolis
Figure 137: Cold climate vs ASHP (Full replacement) vs 80% furnace with SEER 13 CAC at regular electric rates in Duluth
Appendix C: Additional Modeling Results

Investigation of Air Source Heat Pumps as a Replacement of Central Air Conditioning

Center for Energy and Environment
Figure 139: Cold climate vs ASHP (Full replacement) vs 80% furnace with SEER 13 CAC at regular electric rates in Worthington.
CAC Only Replacement

Figure 140: Cold climate vs ASHP (CAC-Only replacement) vs 80% furnace with SEER 13 CAC at regular electric rates in Minneapolis

Investigation of Air Source Heat Pumps as a Replacement of Central Air Conditioning
Center for Energy and Environment
Investigation of Air Source Heat Pumps as a Replacement of Central Air Conditioning
Center for Energy and Environment
Figure 143: Cold climate vs ASHP (CAC-Only replacement) vs 80% furnace with SEER 13 CAC at regular electric rates in Worthington
Appendix C: Additional Modeling Results

Baseline 90% Furnace with ECM Blower

Full Furnace & CAC Replacement

Figure 144: Cold climate vs ASHP (Full replacement) vs 90% furnace with SEER 13 CAC at regular electric rates in Minneapolis

Investigation of Air Source Heat Pumps as a Replacement of Central Air Conditioning
Center for Energy and Environment
Figure 145: Cold climate vs ASHP (Full replacement) vs 90% furnace with SEER 13 CAC at regular electric rates in Duluth.
Figure 146: Cold climate vs ASHP (Full replacement) vs 90% furnace with SEER 13 CAC at regular electric rates in Thief River Falls
Appendix C: Additional Modeling Results

Figure 147: Cold climate vs ASHP (Full replacement) vs 90% furnace with SEER 13 CAC at regular electric rates in Worthington
Appendix C: Additional Modeling Results

CAC-Only Replacement

Figure 148: Cold climate vs ASHP (CAC-only replacement) vs 90% furnace with SEER 13 CAC at regular electric rates in Minneapolis

[Graph showing electric rate ($/kWh) vs gas rate ($/therm) for different switchovers (°F) and cost savings ($/yr) for different electric rates ($/kWh) and gas rates ($/therm).]
Figure 149: Cold climate vs ASHP (CAC-only replacement) vs 90% furnace with SEER 13 CAC at regular electric rates in Duluth
Figure 150: Cold climate vs ASHP (CAC-only replacement) vs 90% furnace with SEER 13 CAC at regular electric rates in Thief River Falls.
Figure 151: Cold climate vs ASHP (CAC-only replacement) vs 90% furnace with SEER 13 CAC at regular electric rates in Worthington.
Appendix D: Cost Effectiveness Sensitivity Primer

All ASHPs save site energy when operated down to their capacity-based switchover temperature because they have higher efficiency than the baseline technologies they replace. However, site energy savings are not a guarantee of cost savings because electricity is generally more expensive than natural gas. While not studied here, site savings are typically a proxy for cost savings when the baseline system is a propane or electric resistance furnace. Since natural gas is the predominant space heating fuel in Minnesota, our results will now focus on understanding how heat pump for CAC replacements can be operated to provide customer cost savings. Neglecting rate changes, the main levers for this are seasonal ASHP efficiency and switchover temperature. In this case, ASHP efficiency is fixed by the selection of specific ASHP equipment archetypes. Higher switchover temperatures are generally more economical because ASHP efficiency is higher at mild outside air temperatures, but this comes at the cost of reduced energy savings.

We define the economic switchover temperature as the lowest possible switchover temperature for which a customer can expect annual cost savings. This includes savings from the cooling season and, in the case of full replacements, any additional natural gas and fan energy savings from the new furnace. The economic switchover is a function of the ASHP type, the baseline system, the location/weather, and the utility rates. Generally, however, the concept is simple. ASHP systems are economical to operate for space heating when the equipment efficiency ratio (ASHP/baseline), exceeds the fuel-neutral utility cost ratio (electric/gas). This is illustrated in Table 21, below. The table is divided into three sections to demonstrate how ASHP efficiency, electric rates, and gas rates each affect the overall cost-effectiveness. Each example assumes a baseline furnace efficiency of 90%.

Table 21: ASHP cost-effectiveness depends on relative efficiency levels and utility rates

<table>
<thead>
<tr>
<th>#</th>
<th>Baseline Furnace Efficiency</th>
<th>Seasonal ASHP Efficiency</th>
<th>Equipment Efficiency Ratio</th>
<th>Gas Cost ($/MMBtu)</th>
<th>Elec Cost ($/kWh)</th>
<th>Elec Cost ($/MMbtu)</th>
<th>Utility Ratio</th>
<th>Cost effective?</th>
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</table>
Appendix D: Cost-Effectiveness Sensitivity Primer

In the first set of examples (1–4), gas cost is fixed at 7 $/MMBtu and electric cost at 0.11 $/kWh. The seasonal average annual ASHP efficiency varies from two to four, resulting in 220% to 440% improvement in equipment efficiency. However, at these fixed utility costs, none of these scenarios are cost effective because electricity is 460% the cost of natural gas.

In the second set of examples (5–8), the ASHP efficiency is fixed at 350% and gas costs are fixed at 7 $/MMBtu. The equipment efficiency ratio is 390%. The electric costs vary from 0.07 $/kWh to 0.1 $/kWh, yielding utility ratios where electricity is 290% to 420% as costly as natural gas. In this case, for electric rates less than 0.10 $/kWh, the ASHP is cost-effective (390% > 380%); however, at 0.10 $/kWh, the equipment efficiency ratio is less than the utility cost ratio (390% < 420%) and the ASHP is not cost-effective.

In the last set of examples (9–13), the ASHP efficiency is fixed at 300% and the electric costs are fixed at 0.11 $/kWh. The equipment efficiency ratio is 330%. The gas costs vary from 9 to 12 $/MMBtu, yielding utility ratios where electricity is 270% to 360% as costly as natural gas. In this case, for gas rates greater than 9 $/MMBtu, the ASHP is cost-effective (330% > 320%); however, at 9 $/MMBtu, the equipment efficiency ratio is less than the utility cost ratio (330% < 360%) and the ASHP is not cost-effective.

In practice, the most important takeaway is that the installed performance of ASHP systems is the only determinant of cost-effectiveness in a fixed rate environment with a known baseline. This reinforces the notion that equipment specific field performance measurements are critical, since even minor variations in field performance versus specifications (10%) can affect outcome. Field data to date has shown variable outcomes in field performance, typically significantly less (~30%) than predicted by ratings alone.

Secondly, this exercise highlights the extreme sensitivity of rates. A rate movement from 0.10 to 0.11 $/kWh (10%) is of the same order as change of 0.30 in annual average COP. Results are even more sensitive to changes in gas rates; a rate movement from 5 to 7 $/MMBtu (40%) is of the same order as a change of 1.2 in annual average COP. These sensitivities make it exceptionally difficult to develop reliable rules to guarantee cost-effective savings because in practice gas rates are volatile and average annual ASHP performance will vary year to year with changing weather.