Better than a Dupe: How to Use Heat Pumps for AC Replacements

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ABSTRACT

Heat pumps can do everything an air conditioner (AC) can do and more. So, why replace old ACs with the same old AC technology when heat pumps can do better? This idea is quickly moving from concept to reality for more customers as a new variable speed heat pump (VSHP) product class emerges. VSHPs that can be installed directly as central AC replacements are now available for the residential heating market. These systems include outdoor condensers paired with a specific indoor A-coil rather than a specific air handling unit or furnace to enable mix-and-match or non-communicating dual fuel heating systems. Potential benefits include wide applicability, lower upfront costs, and improved efficiency over standard ACs. In this paper, we evaluate VSHPs as AC replacements through a field study of 36 installations of these coil-only VSHPs in occupied single-family homes in cold climates. We uncover barriers and opportunities for this new product class in the context of field-measured performance and occupant feedback. While these coil-only heat pumps are quite like traditional ACs, our field work has identified subtle yet important differences that can significantly impact realized performance. These factors include optimizing sizing, thermostat selection, and controls settings. Applying the lessons learned from this field study could help cost-effectively accelerate the displacement of outdated ACs in favor of beneficial heat pumps.

Introduction

Air source heat pumps (ASHPs) are advanced air conditioners (ACs) that provide space cooling and heating. For residential applications, ASHPs offer an opportunity to significantly electrify heating loads in virtually any climate and provide heating fuel flexibility when integrated with centrally ducted furnaces in dual fuel applications (Malinowski et al.). Despite the benefits, ASHPs have struggled to displace central ACs in all cases. This paper explores how recent ASHP advances can be leveraged in cold climate, centrally ducted, dual fuel applications at the time of central AC replacement. Two main types of ASHPs may be used in central AC replacements: single-stage heat pumps (SSHPs) and variable speed heat pumps (VSHPs). SSHPs are entry-level products much like entry-level ACs with the addition of an inexpensive reversing valve to switch between heating and cooling modes. SSHP adoption is limited in cold climates due to their low heating capacity in weather below about 40°F. In contrast, VSHPs use multi-stage or inverter-driven compressors and often pair with variable speed air handlers to maximize their efficiency and capacity to temperatures near 0°F or lower (Gibb et al. 2023).

Centrally ducted ASHPs and ACs of any type essentially comprise an outdoor unit paired with an indoor coil mounted on a furnace or air handler unit (AHU), as illustrated in Figure 1. At the time of AC replacement, only the outdoor unit and indoor coil necessarily need to be replaced, but efficiency ratings are assigned to the entire system, including the furnace and its AHU. Entry-level ACs and SSHPs are offered by every major manufacturer of ducted systems and are often rated in many combinations of their existing product lines. As a result, finding a rated pairing option for existing furnaces is often possible, reducing the need to replace the existing furnace in the event of an AC replacement with an entry-level AC or SSHP.

In contrast, VSHPs have developed as premium products to pair with premium furnaces that enable advanced, communicating controls that coordinate modulation of the indoor and outdoor units to truly maximize performance. Thus, installation of VSHPs typically requires a complete replacement of both the existing AC and furnace. The incremental costs of the higher efficiency VSHP combined with the replacement cost of the furnace has been a major barrier for upgrading ACs to VSHPs (Wilson 2024). However, a new VSHP product class is emerging that does not require simultaneous furnace replacement at the time of installation (Schoenbauer et al. 2022). These VSHPs may be described as coil-only, non-communicating, or AC replacement VSHPs. They are a new option of particular interest to homeowners who wish to upgrade their centrally ducted AC without simultaneously replacing their furnace.

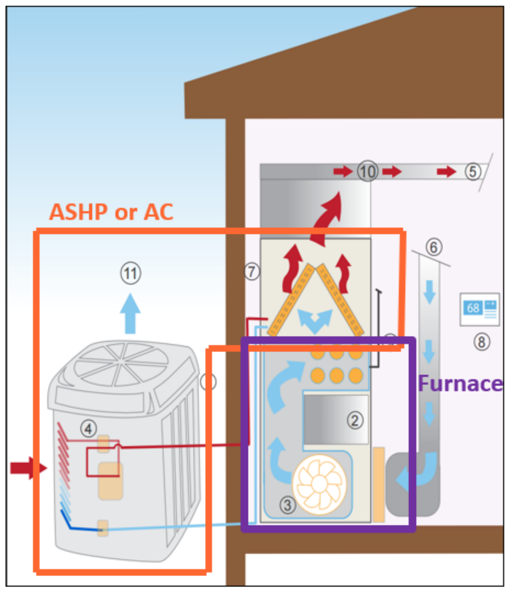

Figure 1. Diagram of centrally ducted air source heat pump or air conditioner paired with a furnace.

Coil-only VSHPs promise to reduce the total installation costs of efficient ASHP systems but their field performance has not been previously studied. Furthermore, existing efficiency rating methods are expected to underestimate their average performance. Rating methods defined by the Air-Conditioning, Heating, and Refrigeration Institute (AHRI) assume coil-only VSHPs are paired with the worst performing furnaces possible, rather than an average or typical furnace (AHRI 2020). Field data is therefore necessary to improve estimations of typical coil-only VSHP performance and support program development. To that end, we report here the field evaluation results of thirty-six VSHPs installed as AC replacements in cold climates. Most of the research was completed in northern Illinois in ComEd's service area. Thirty-three installations were monitored with ComEd's support. An additional six installations were monitored with Xcel Energy's support, evenly split between Minneapolis, MN, and Denver, CO. Three of the sites in IL were installed with single-stage heat pumps (SSHPs) for comparison.

Methodology

To better understand ASHPs for AC replacement applications, market actors were interviewed about their perspectives. Interviews were conducted by phone and conference call between fall 2021 and spring 2022. Several HVAC manufacturers, distributors, and contractors were reached. A significant focus of the interviews was to identify available VSHP as AC replacement products and contractors willing to recruit for the project. Some participating homeowners were recruited via newsletters, social media, or rebate data, but most were recruited directly by installers offering AC replacement bids who were aware of the project.

Homeowners were offered participation incentives equal to the incremental cost of installing a VSHP compared to installing a new AC, up to $4,000 maximum. Recruiting contractors were offered up to $200 per lead successfully recruited to the project. Participating homeowners were not required to work with particular contractors or obtain competitive bids but were required to install a coil-only ASHP. Sites were screened for eligibility primarily by HVAC equipment age, home type, and location. The final study pool was demographically biased, with nearly all sites being White households earning middle to upper incomes. As accounted in Table 1, the Bosch BOVA and BOVB models were the most represented VSHPs in the study. Installers in the study regions were somewhat familiar with these models. The eligibility of Bosch systems was ultimately capped to improve product variety. Eight Ducane Lynx were included as a result, though no participating installers in the project areas had previous experience installing them as AC replacements. Three systems from Mitsubishi were provided for the study, slightly ahead of the Intelli-HEAT line's official product release. Installers were not required to follow any special project-specific procedures so typical installation practices could be observed.

Following installation, each HVAC system was instrumented with a continuous monitoring package developed in previous works (Schoenbauer et al. 2017). The package included power monitoring of the VSHP and AHU via an Emporia Vue 2 power monitor, air temperature thermocouples mounted in the supply and return ducts of the AHU, and current transformers monitoring the blower fan and gas valve amperages. A series of discrete airflow measurements were taken by a TrueFlow meter to correlate the continuous fan amperage to total airflow in the AHU during various operating modes. Outdoor weather data was downloaded from the nearest NOAA weather station with hourly dry bulb temperature data. Ten sites in Illinois were fitted with humidity sensors in the supply and return ducts to estimate the summer average sensible heat ratio (SHR) and improve cooling season coefficient of performance (COP) measurements. The power, temperature, and airflow measurements were sufficient to calculate the systems' COPs as a function of weather. For analysis, continuous data was summarized by time-weighted averaging over individual heat pump cycles or in daily averages.

Table 1. Number of each type of coil-only ASHPs included in the study

Heat Pump Model	Size [tons]	Number in Study
Bosch BOVB	3	6
Bosch BOVB	5	1
Bosch BOVA	3	14
Bosch BOVA	5	3
Ducane Lynx	3	6
Mitsubishi Intelli-HEAT Hyperheat	3	1
Mitsubishi Intelli-HEAT	2	1
York HMH7	4	1
Ducane Single Stage	3	1
Ducane Single Stage	3.5	2
Lennox Single Stage	2.5	1

ASHPs vs. ACs: The Major Market Differences

The selection of AHRI-rated coil-only VSHP products was limited during the recruitment phase of this project for reasons ranging from supply chain delays to changing AHRI rating methods. Feedback from a few manufacturers indicated that more coil-only VSHPs for AC replacements will be available with efficiency ratings soon. More product options should help increase contractor awareness of the market segment, particularly for those who specialize in a limited number of HVAC brands. However, contractors rarely recommend heat pumps of any type as a replacement option for ACs in Illinois, Minnesota, or Colorado. Contractors still struggle to articulate the value proposition of ASHPs in an AC replacement scenario. Contractors reported that they frequently suggest full system replacements to customers who only ask for an AC replacement bid, but not usually with a heat pump included. Instead, VSHPs are more commonly installed in ductless residential applications in cold climates well served by natural gas lines. SSHPs are not usually recommended in these areas due to a reputation for poor performance in cold climates.

Still, positive experiences with coil-only VSHPs proved influential with contractors. All three contractors who provided feedback after completing installations for the project said they now always offer ASHPs for AC replacements. High incremental costs were cited by contractors as the usual reason a homeowner would choose an AC over a VSHP when offered, but rebate programs can help bridge the price gap. The average incremental cost for a 3-ton VSHP over an AC replacement was $3,569 — a 3-ton VSHP cost $9,201 on average. Prices were most strongly influenced by the bidding contractor and regional price differences were also observed (see Table 2). Prices may have been influenced by the participation incentives offered to homeowners by the project. In comparison, the SSHPs installed in IL had an average incremental cost of only $512. The low incremental cost of SSHPs warrants their further investigation.

Table 2. Average VSHP installation cost by region and size

Location	VSHP Size	VSHP Cost	Incremental Cost
Illinois	3	$8,621	$3,194
Minnesota	3	$10,231	$3,807
Colorado	3	$12,033	$5,831
Illinois	5	$10,322	$4,039

During market interviews, a small number of contractors and distributors estimated the equipment cost difference between ACs and VSHPs as approximately $500 to $1,500. The incremental costs calculated from the project bids include those cost differences related to the VSHP equipment itself, its mounting hardware, and, in about half of the installs, new thermostats. Labor cost increases, if present, are also included. Extra labor costs may be due to multiple factors such as the time required for thermostat set up, perceived risk of the new product category, or the bidding contractor’s low familiarity with the product. The bids received for this project’s installations did not include the line-item costs of these contributing factors. As ASHPs for AC replacements become more common, incremental costs related to labor are expected to decrease because the installation is essentially like other AC replacements. Only three significant differences appear in retrofitting a VSHP as compared to an AC. These include:

1. **Thermostats.** While almost any thermostat can control a ducted AC, ASHPs require some additional thermostat features. These involve both thermostat hardware and software capabilities related to controlling the switch between heating, cooling, and supplemental heating modes. Especially for ASHPs sized for cooling loads in cold climates, dual fuel thermostat controls are needed. Many dual fuel capable thermostats are available, but their importance remains easy to overlook. Thermostat best practices will be discussed in more detail later in this report.

2. **Siting.** Because ASHPs operate in the winter, outdoor ASHP units should be thoughtfully placed with snow stands to mitigate ice and snow build up. Considering winter site conditions is already a best practice for cold climate ASHPs. Emphasizing this practice is important for AC replacements as it can more easily be overlooked when the previous AC was placed without concern for winter conditions.

3. **Segmentation.** The best practices for selecting and sizing ASHPs as AC replacements should be segmented based on the priorities of the customer and economics of their supplemental heat source rather than according to cooling loads alone. For example, customers with high-cost heating fuels like propane usually achieve lifetime cost savings from higher capacity and efficiency VSHPs, while customers with inexpensive natural gas heat may find an SSHP more cost-effective. Value propositions from VSHPs related to comfort should not be overlooked, however, as contractors report that improved comfort can justify increased installation costs in many scenarios.

Sizing Matters

Detailed sizing calculations are not typically performed at the time of AC replacement despite best practice recommendations. Instead, installers usually match the replacement product to the size of the pre-existing AC even though oversizing is common in the existing building stock. We calculated heat load curves at each study site using the average total daily heat output measured as a function of temperature, seen in Figure 2a. These best fit lines of daily load data can be used to calculate the heating design load for each home by evaluating the load line at the design temperature. Design temperatures vary by location and are typically defined by the temperature at which the location is warmer than 99% of the time or more.

Comparing 99% design loads to nameplate equipment capacities at each site, we found the average HVAC system studied was more than three times larger than necessary (see Figure 2b). Existing oversized furnaces lead to oversized ACs. Unless regularly updated and detailed load calculations become industry standard, the average ASHP installed as an AC replacement will likely have more heating capacity than would be expected for right-sized systems. Importantly, while the nameplate capacity of a furnace is a fair estimate of its maximum output, the same is not true for ASHPs. A standard definition for ASHP nameplate capacity does not exist but manufacturers often report it as the system's approximate cooling capacity near 95°F. It is unsurprising then that the ASHPs monitored here have a similar distribution of nameplate capacities as the sites' preexisting ACs.

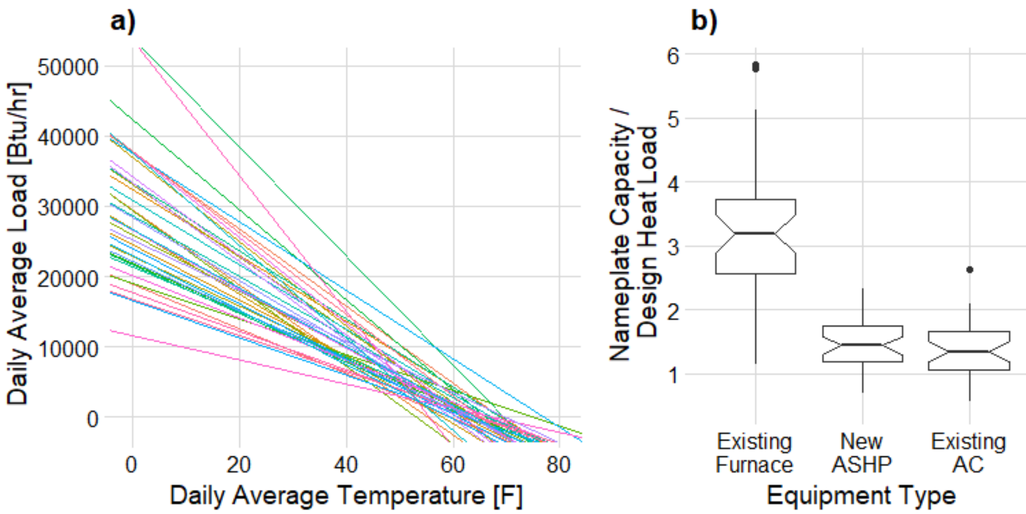

Figure 2. a) Linear load lines fit to measured daily heating load at each study site as a function of temperature and b) the ratio of equipment nameplate capacity to home design load. Right-sized equipment will have a ratio near one.

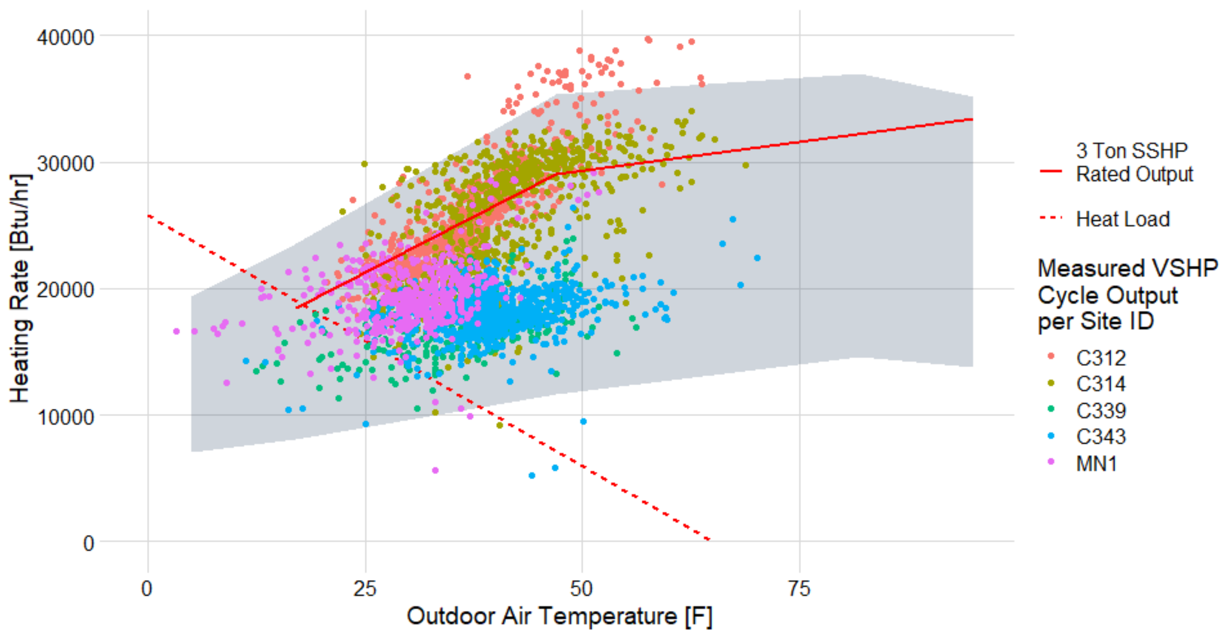

Figure 3. Comparison of 3-ton ASHP rated capacity data for a VSHP (grey), SSHP (solid red line) with cycle-level field data (points) measured at five different sites with a VSHP, and their average home heat load (dashed red line) as a function of temperature. Data is filtered to include only heating cycles longer than 15 minutes without a defrost event.

The ASHP capacities measured in this project generally aligned with AHRI capacity ratings despite differences between laboratory and field-testing conditions. Figure 3 compares the rated heating capacity range of a 3-ton coil-only VSHP model (AHRI #203377014) and the field-measured cycle average output of this specific system installed in five different sites. For reference, the rated heating capacity of a typical 3-ton SSHP is plotted in a solid red line and the average home heating load of the five VSHP sites is plotted in a dashed red line. Efficiency and comfort are maximized when VSHPs modulate output to closely match the home heating load. In practice, ideal operation is not achieved but some output modulation is observed at temperatures where the heating load is well contained within the rated VSHP output capacity range. When VSHP capacity far exceeds daily heating loads, thermostat calls are likely satisfied quickly before the VSHP modulates its output. More intelligent control algorithms might improve part load output.

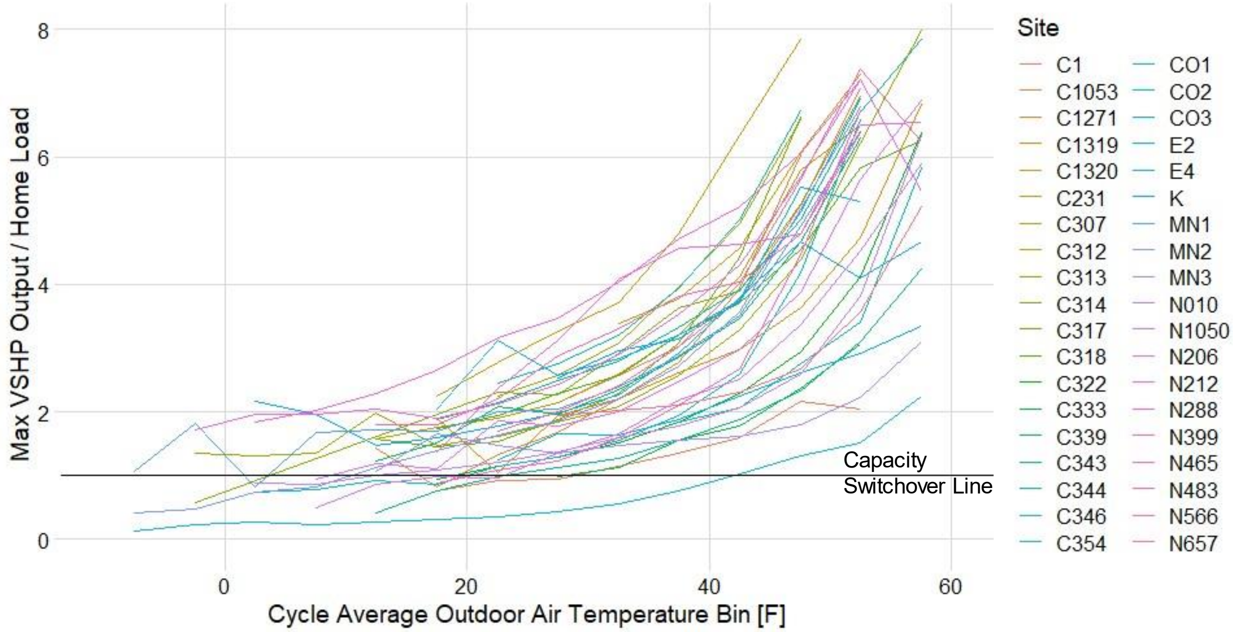

Figure 4. Ratio of average heating cycle maximum ASHP output to total home heating load as a function of outdoor air temperature per site.

The temperature at which the ASHP maximum output capacity is equal to the home heating load is known as the capacity switchover. In dual fuel applications, the capacity switchover defines the temperature below which the system will usually need to switch from the ASHP to the supplemental heat source to satisfy the load. The capacity switchover for all sites studied in this project are available in Figure 4, where we show the average maximum observed ASHP capacity divided by the site's average home heating load as a function of outdoor air temperature. This ratio will become equal to one when the capacity is equal to the load, so a horizontal line at a ratio of one is included for reference in the figure. In most cases, the systems studied here had the ability to meet daily average heating loads down to freezing temperatures, with some having capacity as cold as 0°F or lower. These data show that the average ASHP installed as an AC replacement has sufficient heating capacity to displace all heating loads above freezing, and sometimes significantly more, due to chronic oversizing of existing HVAC equipment in the study regions. In temperatures below the capacity switchover, the pre-existing furnace was able to support the home heating load at all study sites.

Efficiency Varies

A wide range of COP values were measured across the study sites as seen in Figure 5. For this population, the rated heating seasonal performance factor (HSPF) did not correlate with measured COP. In fact, no standardly available equipment specification provided statistically significant correlation to the COP of studied systems. Coil-only VSHPs installed with higher HSPF ratings, higher efficiency rated furnaces, newer furnaces, or furnaces with efficient fan types were not predictably more efficient for heating with statistical significance, given the sample size of 39 ASHPs here. These results do not prove that these specifications do not have an impact but show that their influence is not stronger than other interacting factors at play. Interestingly, the COPs observed from VSHPs do not necessarily exceed that of the small number of SSHPs monitored. More research is needed to evaluate the average field performance of SSHPs as AC replacements in cold climates.

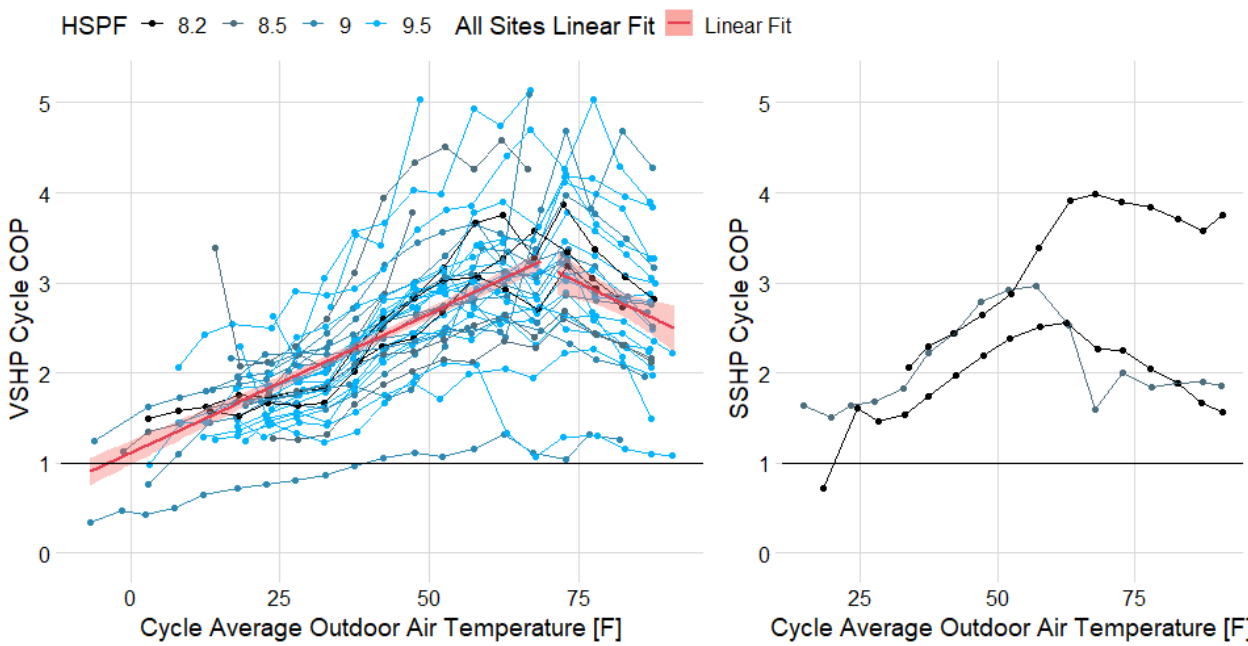

Figure 5. ASHP coefficient of performance at each site as a function of outdoor air temperature with color indicating the system's HSPF rating.

The observed factors that best correlated with a system's COP included how oversized the existing furnace was to the actual home heating load, the furnace blower fan efficiency, and the average ASHP cycle length. These correlations are provided in Figure 6 where the average COP at each site is plotted for heating events occurring within a 5°F band centered at 47°F. Figure 6 shows that COPs at 47°F tend to increase with fan efficiency, cycle runtime, and right-sizing, while HSPF, furnace efficiency (AFUE), and fan type lack predictive power for these study sites. Electronically commutated motor (ECM) fans are generally more efficient than permanent split capacitor (PSC) fans. However, multiple subtypes of ECM fans exist, and actual fan performance is a function of its speed setting and the static pressure of the ductwork, which is not easily predicted from existing equipment specifications.

Cycle runtime is influenced by system design factors including sizing and thermostat controls. Of these two factors, thermostat controls are easiest to correct. Unfortunately, more research is needed to determine the feasibility of right-sizing only part of an HVAC system at once. The airflow rates available from existing oversized furnace and ductwork might not readily be matched to the airflow requirements of a smaller, right-sized ASHP coil. Given the importance of right sizing on overall HVAC performance, installers should not overlook load calculations when bidding AC replacement options. Right sizing the entire HVAC system is a major opportunity to improve all-around performance for full system replacements.

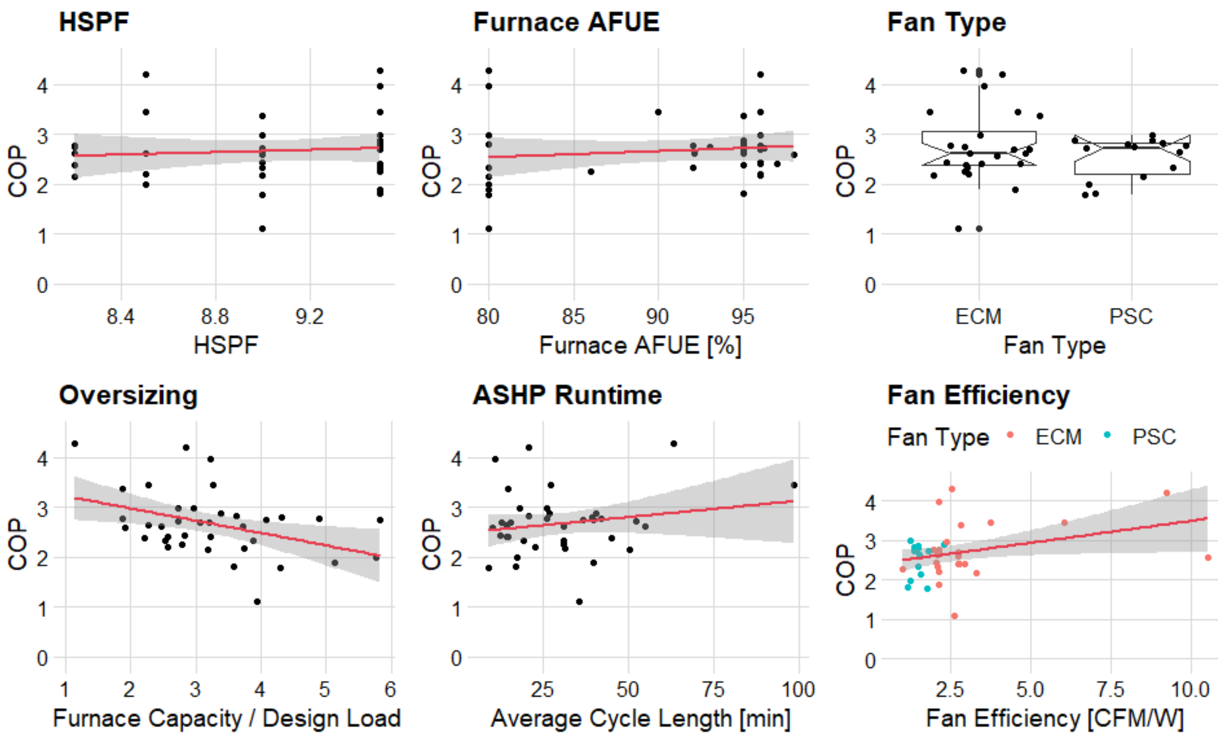

Figure 6. Average COP at 47°F at each study site as a function of various factors expected to impact performance.

Thermostat Configuration is Critical

Thermostats can impact COPs by controlling ASHP runtimes, and they also critically affect total system behavior and overall customer savings. As previously mentioned, coil-only ASHPs require dual fuel capable thermostats to operate with a second supplemental heat source. These thermostats offer at least four control wires (or remote connectivity) to switch the heat pump from heating to cooling mode and have software algorithms that distinguish between ASHP and supplemental heat source operating modes, ideally with feedback on outdoor air temperature via local sensors or Wi-Fi connection to local weather. Selecting and configuring a dual fuel thermostat is critical for a successful ASHP as AC replacement installation in cold climates. Unfortunately, contractors are not always aware of these required thermostat features. Four study sites in Illinois required a follow-up visit to install a dual fuel thermostat after the ASHP installation missed this critical upgrade. Some thermostats were also found that could operate ASHPs but not in conjunction with a supplemental heat source. To avoid these issues, installers and programs should ensure they promote only dual fuel capable thermostats. Heat pump capable thermostats without dual fuel controls are not broadly suitable in cold regions.

Including a dual fuel thermostat in an AC replacement is not enough to optimize ASHP performance — it must also be programmed appropriately. Most currently available coil-only ASHPs do not require proprietary thermostats and advertise their compatibility with most 24 V third-party thermostats. The features and control options available from dual fuel thermostats vary widely, so Table 3 outlines the most important settings to properly configure for a coil-only

ASHP installation. If these four settings are not configured correctly, the system could perpetually lock out the ASHP from heating mode or even cause equipment damage. Notably, reversing valve and simultaneous heat settings might be new to ASHP installers as proprietary thermostats will usually have correct default settings for matched systems. Third-party thermostats can't predict the design features of the connected equipment, however, so their default settings must always be checked.

Table 3. Critical dual fuel thermostat controls and their recommended settings

Setting (alias)	**Possible Settings**	**Recommended Setting**	**Notes**
Switchover (compressor lockout, lockout, compressor minimum temperature, balance point, changeover, switch point)	A continuous or discrete range of temperatures, off, or auto	Use latest available cost of heat guide or calculator designed for the home's location	High switchovers can prevent the ASHP from heating entirely. When economics favor maximizing ASHP usage, use capacity switchover or ensure suitable staging controls.
Reversing valve	On heat or on cool	Refer to equipment manual	Depending on the ASHP, the reversing valve should be energized on heating or cooling calls. Often not accessible to homeowner; selected at install.
Simultaneous heat pump and aux heat (aux heat may be called backup, supplemental, auxiliary, or furnace)	Disable or enable, on/off	Disable, off (except if aux heat is downstream of ASHP coil)	Must be disabled for heating calls when the ASHP coil is downstream of the furnace to avoid damage to ASHP. Often not accessible to homeowner; selected at install.
Em heat (emergency heat mode)	Disable or enable, on/off	Disable, off	Temporarily forces supplemental heat for troubleshooting. Needs to be manually turned back off to unlock the ASHP and resume normal dual fuel operation.

A switchover setting with local temperature monitoring is a preferred defining feature of any dual fuel thermostat, though manuals may describe it using many different names. Existing ASHP best practices specific to climate regions should be used to select appropriate switchover settings. These guides usually consider equipment size, supplemental fuel source, and local utility costs to estimate economic and capacity switchover recommendations. Including local outdoor air temperature sensors with a thermostat installation may be a barrier for some sites and installers. In that case, Wi-Fi connected thermostats that download local weather data are an option if reliable signal is available.

If a switchover is not programmed or the thermostat cannot determine the outdoor air temperature, staged heat controls are likely to take precedence if available. Typical settings related to staged heat, plus other optional settings commonly found in dual fuel thermostats, are summarized in Table 4. Staged heat controls allow the supplemental heat source to take over any time the ASHP does not easily meet the heat load as measured by the difference in space temperature and setpoint or as inferred by runtime.

Table 4. Important but optional dual fuel thermostat controls and their recommended settings

Optional Settings (alias)	Possible Settings	Recommended Setting	Notes
Aux lockout (backup or supplemental heat lockout, aux heat max temperature)	A continuous or discrete range of outdoor air temperatures, off, or auto	Greater than capacity switchover and equal to or up to 10°F greater than economic switchover temperature	Prevents supplemental heat use in warm weather. The closer it is to the switchover the less staged heat occurs. Not to be confused with switchover.
Upstage droop (stage 2 droop, heat differential, compressor to aux temperature delta, upstage temp delta, or stage 2 heat delta)	A continuous or discrete range of temperature differences, off, or auto	2.1°F to 3.5°F	Defines how far setpoint can be missed before calling second stage heat.
Upstage timer (compressor to aux runtime, second stage timer, or compressor or stage one max runtime)	A continuous or discrete range of time, off, or auto	Disable, off, or maximum allowable value if no disable option	Limiting compressor runtime reduces efficiency but a timer control may be used for staging if a temperature droop control is unavailable.
Heat/cool/auto	Heat, cool, or auto choose mode	Heat or cool only, depending on season	Switch between heating and cooling modes manually when able; auto controls can lead to inefficient oscillations between modes.
Compressor minimum cycle off time	A continuous or discrete range of time, off, or auto	5 to 10 minutes	Reduces risk of short cycling from temporary temperature fluctuations at the thermostat and protects the compressor. Longer delays are more protective at the cost of responsivity.
Scheduled setback	Any number of scheduled time periods paired with setpoint adjustments	Setpoint changes of +1°F to +2°F spaced by 30+ minutes	Sudden increases in setpoint in the winter increase supplemental heat use when paired with staged heat controls. Scheduling gradual setpoint increases over time reduces supplemental heat use.

Since long heating cycles are most efficient, staged heating algorithms that rely on timers are not recommended. Instead, staging should be controlled according to setpoint droops of at least 2 to 3°F. While not all dual fuel thermostats have staged heat control options, they may provide some peace of mind to installers and customers alike, knowing that the system can always call the supplemental heat source in case of an ASHP failure or capacity limitation. On the other hand, staged controls biased toward comfort may prevent occupants from noticing potential issues with their ASHP and limit savings due to excess supplemental heat use.

Most of these important thermostat settings are rarely adjusted by homeowners or occupants, but some knowledge of their thermostat's features and options may go a long way to support customer satisfaction. Customer-facing thermostat guidance could be a significant tool in supporting successful adoption of ASHPs as AC replacements. Setpoint schedules and emergency heat mode are important controls that occupants more frequently modify that can impact ASHP performance. Deep setback schedules can result in unexpected supplemental heat use well above the usual switchover temperature if they are combined with staged heating controls. Using gradual setpoint changes can avoid this inefficient behavior. As for emergency heat mode, this setting should only be used in times of troubleshooting, but it is sometimes available on the main thermostat screen. Several participating homeowners turned on emergency heat mode during the research study without realizing they would need to turn it back off to resume normal ASHP heating operation. This resulted in suboptimal seasonal performance.

Total Savings

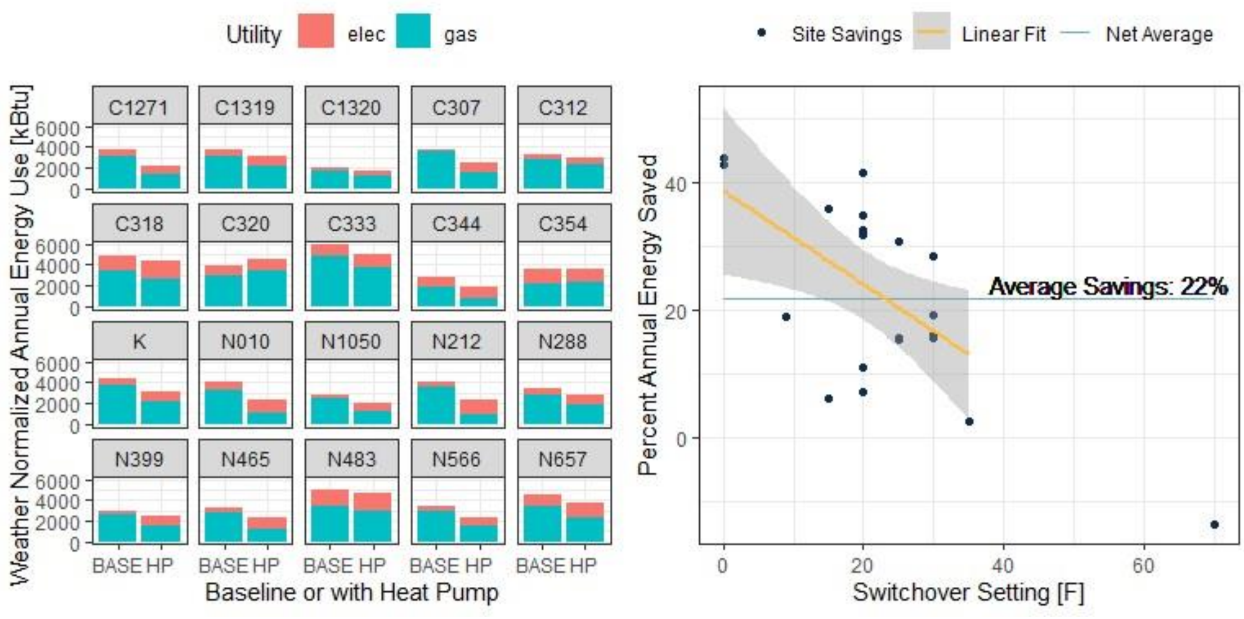

Figure 7. Annual site energy savings estimated via weather normalized utility billing data.

Total annual energy savings achieved by an ASHP as AC replacement can be estimated by comparing the total annual energy use before and after the ASHP was installed, normalized by the weather and home space conditioning load. This field evaluation did not include a baseline monitoring period to assess the performance of the pre-existing AC and furnace combinations, so savings have been estimated through a utility billing analysis. Most participants in Illinois provided at least two years' worth of electric and gas billing data to the research team. These data were split into pre- and post-ASHP installation periods, normalized to the sites' heating and cooling load, and weighted by local weather normalized to typical meteorological weather. Figure 7 shows that all but one site with available utility data realized net energy savings from their ASHP upgrade. The single site that did not save energy had an exceptionally high switchover setting at 70°F and likely changed their cooling season habits between the pre- and post-ASHP billing periods. On average, sites achieved 22% savings of their space conditioning energy use. A significant amount of natural gas was saved, with the average site reducing their natural gas use by 51%. However, gas savings are paired with an increase in electrical consumption. Net site energy savings were achieved because the ASHPs provided a significant efficiency boost compared to the baseline furnace heating systems.

Cost saving estimates are more challenging, given the volatility of natural gas prices and the potential for new electric rate structures over the course of the ASHP's lifetime. Assuming utility rates perpetually aligned with the year 2023 in ComEd's territory, the average participating site might see an annual bill increase of about 8%. Slight changes in rate assumptions significantly impact this estimate. The thermostat switchover setting is also important. Switchover settings in this study were strongly biased to lower temperatures than is usually recommended for economic operation to maximize collection of cold weather performance data. Under other circumstances, average bill impacts are expected to favor savings or cost-neutrality. More bill impacts research is warranted to evaluate how utilities can balance energy savings with customer costs.

Customer Feedback

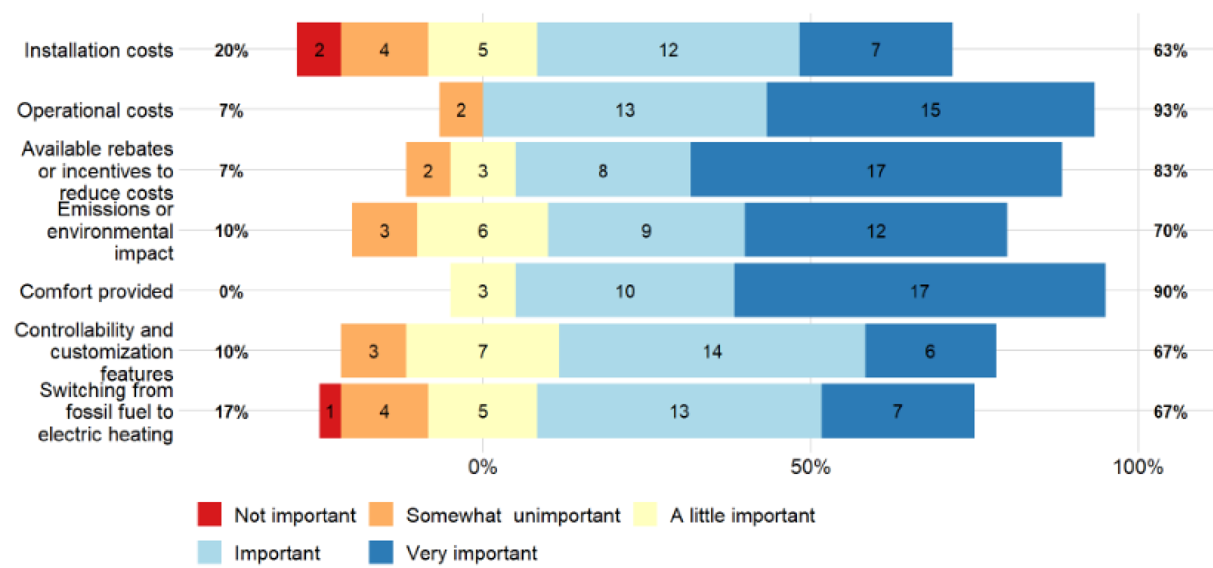

Figure 8. Responses to ranked choice question asking how important different factors were in homeowners' AC replacement purchase decisions.

Homeowners who participated in this project provided positive feedback overall. All participants in Illinois were invited to provide feedback via online surveys sent at the start and end of the monitoring period. At the outset, half of respondents reported that they had not "heard about or had any experience with heat pumps" before they decided to replace their AC. Most participants did not seek an ASHP as AC replacement independently and were likely influenced by project incentives to make the upgrade. When asked to rate the importance of different AC replacement features, participant feedback aligned with contractors' belief that the comfort provided was important to all homeowners. Operational costs closely followed comfort in importance, as seen in Figure 8.

After at least half a year of experience with their ASHP, ninety-six percent of IL-based participants said they would recommend an ASHP to others. The single participant who said they wouldn't recommend a heat pump provided relatively neutral reasoning, stating that they "didn't see the difference to recommend it." More than half of homeowners reported being "very satisfied" with their heat pump and none reported being "dissatisfied" overall (see Figure 9). The most common reasons cited by homeowners for recommending an ASHP to others, in descending order of frequency, included cost savings (25 mentions), improved comfort (11 mentions), energy efficiency (11 mentions), and decreased noise (6 mentions). Comfort improvements reported by participants were related to both improved cooling season performance and more consistent or even temperatures throughout the year.

Most homeowners reported improvements in comfort, and nine respondents reported their home was "a lot more comfortable" since their VSHP installation (see Figure 9). If homeowners reported a change in comfort, they were able to provide more information on how their comfort changed in a free response question. Homeowners with improved comfort frequently mentioned "even" or "stable" home temperatures and more "consistent heating and cooling." Improved cooling overall was also commonly cited. One of the homeowners who reported "a little less comfort" said that their "heat pump takes longer to heat when first started" and was observed to use deep setbacks when away and at night. The second homeowner with less comfort found their home "a little less toasty warm in the winter and a little more humid in the summer." That home's HVAC system was especially oversized, with five times the furnace capacity to heating load ratio. Poor dehumidification is a known issue for oversized cooling systems.

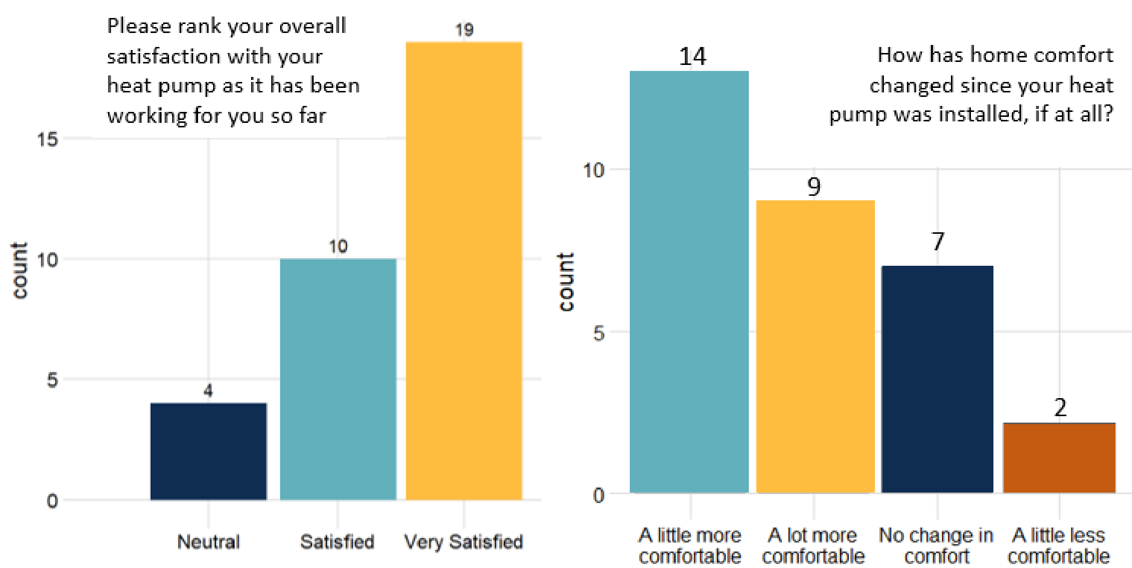

Figure 9. Homeowner responses regarding overall satisfaction with ASHP as AC replacement and how home comfort has changed since their installation.

Conclusions and Recommended Best Practices

New VSHPs are now available for AC replacement applications with features and performance exceeding that of traditional AC options. Coil-only VSHPs installed as AC replacements have impressive energy saving potential, with 22% average site energy savings observed in this study. While incremental costs remain, installation costs of VSHPs for AC replacements likely have room to shrink as the market matures. Incremental costs for SSHPs were comparatively small. While not the focus of this work, further research on SSHPs as AC replacements is warranted. Although SSHPs will not provide as much cold weather heating capacity as a coil-only VSHP, the capacity and COP performance of three SSHPs as AC replacements monitored in this work exceeded expectations. SSHPs may be the most cost-effective option for many customers, especially in areas with low-cost natural gas heating. There, economic operation of VSHPs is still limited, usually above 35°F. An SSHP could be a comparatively cost-effective alternative while still improving on the performance of a minimum efficiency AC.

Customer feedback suggests that VSHPs' ability to improve comfort through more consistent and even home temperatures may be worth the extra upfront costs to many homeowners. VSHPs are also an opportunity for customers to future-proof their HVAC systems against volatile natural gas prices. Since existing HVAC equipment is so commonly oversized, VSHPs tend to have significant cold-weather capacity, even when sized similarly to existing ACs. The average VSHP as AC replacement observed in this research had enough capacity to displace most of the annual heating loads in the cold climates of Illinois, Minnesota, and Colorado. Findings from this research study support the segmentation of the AC replacement market. Cost-conscious homeowners with low-cost natural gas might maximize their AC replacement by upgrading to an SSHP while customers with higher cost heating fuels like propane, or a desire to maximize comfort, reduce their carbon footprint, or future-proof their HVAC system should consider a coil-only VSHP or full system replacement, depending on their budget.

The market for centrally ducted ASHPs of any type in these regions remains immature, especially within the AC replacement segment. Performance of coil-only VSHPs in the field is currently influenced more by thermostat controls and sizing than it is by the rated specification of the installed equipment. This work showed that HSPF ratings do not currently correlate with field-measured efficiency. Efficiency programs and market interventions should thus focus on improving the installation quality of VSHPs as AC replacements rather than promoting HSPF cut-off levels for program development. While ASHPs as AC replacements are remarkably similar to traditional AC replacements, some best practices have yet to be universally adopted. Important best practices worth highlighting for AC replacement applications include:

- **Consider sizing before the sale.** Don't assume existing systems are sized correctly for the home loads or existing duct work. Always reassess sizing calculations to avoid missing an opportunity to right-size a majorly oversized HVAC system.
- **Choose the right ASHP.** Match the ASHP type to each customers' priorities, supplemental heating fuel, and budget. If the incremental costs of a VSHP are too high, consider an SSHP for natural gas customers and emphasize the operational cost savings opportunities for propane customers. Customers keen for comfort, carbon emission improvements, or flexibility in their heating fuel should consider a VSHP.

- **Install a dual fuel thermostat**. Not all thermostats can operate ASHPs in dual fuel systems. Ensure a dual fuel thermostat is installed and programmed appropriately (refer to Table 3 and Table 4).
- **Implement good thermostat controls.** Again, refer to Table 3 and Table 4. Use the latest available cost-of-heat calculators to estimate the economic switchover and compare it to the capacity switchover for the given system specifications and home load. If the thermostat has staged heat controls, ensure the default settings prioritize the ASHP for heating or manually adjust them to maximize ASHP runtime above the switchover.
- **Select a winter-friendly site.** ASHPs operate year-round, unlike ACs. Ensure the ASHP is installed in a protected location away from snow and ice debris. Snow stands are recommended.
- **Double check the install work.** Test run the system with heating and cooling calls to catch easy-to-fix wiring or thermostat issues before the installation is deemed complete.
- **Educate homeowners on their thermostat.** Since occupants can inadvertently lockout their ASHP via thermostat controls, provide recommendations for efficient use while balancing customer comfort preferences for long-term satisfaction.

Programs should be developed to increase the adoption of these best practices by the industry. Eliminating high-efficiency AC rebates in favor of dual fuel VSHPs is also recommended. The development of dual fuel electric heat rates could further improve customer economics for efficient fuel switching. Otherwise, SSHP incremental costs are relatively low while still beneficial for shoulder season heating. A modest rebate for this product class could make SSHPs the least-cost option, significantly impacting low-income efficiency programs. Overall, this work further demonstrates that there is an ASHP available for almost any residential application and that ASHPs should increasingly be favored over ACs in all regions.

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