A Ductless Heat Pump in Every Pot… or Home?

Justin Spencer, Navigant, Boulder, CO
Terese Decker, Navigant, Boulder, CO
Danielle Vitoff, Navigant, Boulder, CO

ABSTRACT

Ductless heat pumps (DHPs) offer high efficiency, winter and summer peak demand reductions, and increased comfort with very little noise. The authors have worked with energy efficiency program designers, policy makers, and evaluators in the Northwest and Northeast and present their findings about current DHP technology, in situ performance, and markets in this paper.

Policy makers and program designers should focus on cold-climate DHPs. Winter peak loads have become more important in power planning. The decisions homeowners make about their heating equipment could affect the utility's load for decades. States and utilities should incent the transition away from oil and propane heat and towards cold climate heat pumps.

Program designers should include participant education to maximize their energy savings behavior when they incent a DHP. Results of a metering study showed that DHPs experience higher usage (and savings) for cooling than might be expected, with lower than expected heating usage and savings. In some cases, homeowners are missing out on the opportunity for large cost savings because they are unaware of the heating savings that can be obtained by correctly setting up their DHPs.

The DHP market is evolving rapidly and programs need to regularly reassess their incentives and marketing to keep up. Cold climate heat pumps arrived on the market only recently and up until now have only been available with single indoor heads. New multi-head cold-climate systems will be available starting in 2015. Customer and contractor awareness of new technologies has been lagging.

Introduction

The energy efficiency and demand side management industry is undergoing two significant changes that will drive heat pumps (and specifically ductless heat pumps) to become more important to overall energy efficiency program designs. First, the recent pace of upgrades in codes and standards and success of utility programs has consumed a large amount of the proverbial *low-hanging fruit*.[1] Second, there has been an increasing emphasis on winter demand savings on the part of power planning institutions (PJM 2014; ISO-NE 2013; PNUCC 2014). As a result of all these changes, energy efficiency programs will be looking for opportunities to save heating energy and reduce winter peak demand. DHPs offer a solution to this problem. In addition, there are two significant market forces driving homeowners to consider heat pumps. First, prices for oil, propane, and electricity are driving people to switch to heating systems with lower operating costs. Second, homeowners are looking for solutions that provide increased comfort and are adding heating and/or cooling to spaces with currently inadequate heating or cooling. In cases where these homeowners are displacing fossil fuel use with electricity-consuming DHPs or adding a new electricity-consuming cooling amenity, utilities will see increased electricity consumption and demand.

Programs have an opportunity to send clear signals to the residential HVAC market, incenting homeowners, installers, distributors and manufacturers to build, install, and optimally use DHPs to minimize electricity consumption and peak demand impacts. This paper will lay out the key issues facing program designers and evaluators considering ductless heat pumps, including basics of operation, results from an

[1] EISA by itself has reduced savings from CFL-dominated EE portfolios by upwards of 20%.

early metering study for Con Edison, results of recent market studies for NEEA, and opportunities for further savings for DHPs and especially cold climate DHPs.

Heat Pump Space Conditioning Background

This section explains the terminology and savings mechanisms associated with DHPs and specifically cold climate DHPs.

Key terms

A **heat pump** generically refers to a device that uses electrically-driven compression and expansion of a working fluid in a thermodynamic cycle to *pump* heat from a relatively cold place to a relatively hot place. A heat pump is so-called because it *pumps* heat in the opposite direction that it naturally flows, in the same way that a water pump pumps water up a hill. While the generic, engineer's definition of a heat pump includes all devices using this kind of cycle, such as refrigerators, air conditioners, and heat pumps that heat air or water, the HVAC industry traditionally reserves the word heat pump when used alone to mean a thermodynamic device used for space heating.

A **ducted air source heat pump** is the most common heat pump used for space heating. When people in the HVAC industry use the term *heat pump*, this is generally what they mean. An air source heat pump moves heat between an outdoor air heat exchanger an indoor heat exchanger in a duct. A ducted air source heat pump pumps heat between an outdoor heat exchanger and indoor air handler and uses ducts to move heated or cooled air around a home.

A **ductless heat pump (DHP)** works exactly the same as a ducted air source heat pump, except that it moves heat between an outdoor heat exchanger and one or more indoor heat exchanger *heads* located in individual rooms without any significant ductwork. A **minisplit** ductless heat pump refers to a ductless heat pump with one indoor *head* connected to the outdoor heat exchanger and compressor. A **multisplit** ductless heat pump refers to a ductless heat pump with multiple indoor *heads* connected to the outdoor heat exchanger and compressor.

A **cold climate heat pump** refers to a heat pump designed to operate in cold temperatures. While ducted cold climate systems nominally exist, cold climate ductless heat pumps are much more common in the market today. A cold climate heat pump uses a special compressor capable of running at a higher compression ratio and higher corresponding temperature differential. A normal heat pump has significant degradation of capacity at cold temperatures (below 20 degrees F), while a cold climate heat pump maintains significant capacity at low temperatures, between -10 and +10 degrees F. Backup electric resistance heating is used by conventional ducted air source heat pumps to maintain system capacity at cold temperatures, but the effective coefficient of performance (COP) drops to 1.0 when the electric resistance backup is used.

Ductless Heat Pump Baselines, Motivations, and Savings Opportunities

Baseline varies depending on program design and desired outcomes for participants. The key questions when considering the baselines are: Are participants trying to improve cooling comfort? Improve heating comfort? Or save money? What would they have installed if the program was not available? (Vitoff et al. 2014)

People who are looking to improve comfort are installing a new amenity through the installation of a DHP. For homeowners looking to add heating or cooling to an existing space where ducts are not present, ductless heat pumps are often the only cost-effective option available that offers a comparable set of amenities to traditional central heating and cooling. In these cases, the proper baseline for gross impacts is a code-minimum DHP. Programs can influence these homeowners to purchase an improved DHP with better peak heating, peak cooling, seasonal cooling, or seasonal heating efficiency, depending on their desired program outcomes. In addition, programs can educate the customer in how to get the most savings out of their DHP, but these individuals were going to install some level of DHP regardless of the program's actions. People who are looking to save money on heating bills are generally using a DHP to displace the use of an existing, more expensive fuel. These system installations frequently leave the existing equipment in place, so the appropriate baseline is the existing equipment under a retrofit. Programs can influence homeowners using oil, propane, and electric resistance heat to install DHPs. The potential savings opportunities are quite large, but they may come in oil or propane savings instead of electricity savings. Programs can influence these homeowners to install DHPs in replacement of their current system. Programs can also educate these homeowners in how to maximize savings.

Con Edison Metering Study

In partnership with ERS, Navigant led a study metering DHPs installed in 2011 and 2012 through Con Edison's Residential HVAC Electricity program (ERS 2014). The study was based on relatively small sample sizes, but utilized a double ratio estimation method to leverage multiple evaluation methods to increase precision within the small sample. The methods and results from this study are presented in the following sections.

Methods

Program impacts were determined through a nested sample which included 25 metering sites randomly selected from a sample of 79 participants who completed telephone surveys. The participants who completed the phone survey were asked about how they use their DHP systems, while the 25 participants selected for metering had their DHPs metered for nine months.

The evaluation team calculated gross impacts by leveraging the program tracking database, program participants' billing data, phone survey responses, and on-site metered data as well as other data collected on-site. The use of double-ratio estimation reduces uncertainty at a reasonable cost by leveraging the results of the low-cost, medium-accuracy phone surveys with the results from the high-rigor, higher-cost, on-site metering (Spencer, Greenberg & Decker 2013). By nesting the on-site sample within the phone survey sample, the evaluators were able to achieve a more accurate estimate of the frequency of some outliers, which may include extremely high air conditioning or heating usage participants or extremely low air conditioning and heating usage participants, while still utilizing on-site metering to provide rigorous results. A schematic of the sampling plan is shown in Figure 1.

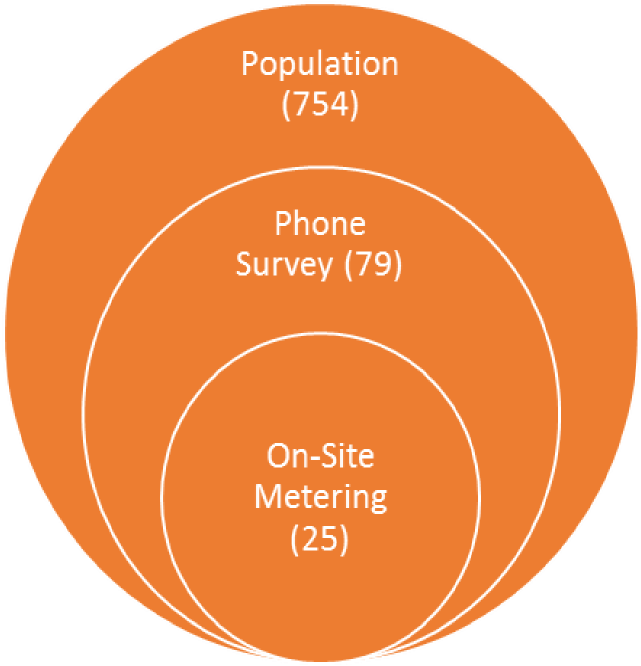


Figure 1. Nested Sampling Schematic for Con Edison Evaluation

The team metered true power and energy at two-minute intervals over a nine-month period. The team then used manufacturers' performance curves to estimate the delivered capacity and equivalent performance of a baseline piece of equipment operating at the same point. While this method was ultimately successful, it introduced another opportunity for error that could be eliminated by metering actual capacity delivered as well as power. The manufacturers' curves for DHPs were not as well developed or necessarily as believable as those that are available for Central Air Conditioners. Some participants' DHPs were rated at an operating point significantly below their full capacity.

Results

DHP operation was highly variable across the sampled sites. Metered results frequently contradicted homeowner answers. The team suggests that this may be because homeowners didn't really know how to use the systems properly.

Heating-season energy savings (51 kWh/ton) were much lower than expected and cooling-season energy savings (271 kWh/ton) were much higher than expected for this program,[2] primarily due to a shift in runtime hours from the perceived norms. DHP heating usage as metered was lower than expected for this climate. This low heating usage is likely a result of DHPs being purchased primarily for the central cooling amenity and being used for zonal heat.

The effective coincidence factor was much lower (0.47) than predicted for DHPs. The verified peak demand savings of DHPs were lower than the deemed values due to the systems running less during peak hours than predicted. Some of this difference in expectations can be explained by the fact that DHPs provide zonal heating and cooling for a single space or portion of a home, and thus are used much more erratically than central systems, which are typically used to meet a certain thermostat setpoint for most or all hours of the day.

[2] These savings assume a code-minimum ductless heat pump with the same amount of heating and cooling supplied as the baseline.

Savings could not be correlated well to rated equipment efficiency and capacity. Some manufacturers rated their equipment at a lower capacity, higher efficiency part load condition. With the small sample size, separate savings algorithms as a function of rated size and efficiency could not be developed for the different manufacturers.

Northwest Ductless Heat Pump Market

Navigant, along with Research Into Action, conducted a study for NEEA to determine the potential DHP installations and savings over the next 20 years in the Northwest (Navigant 2015). The study included conducting surveys and a Delphi Panel with market actors and market experts to determine the main factors driving the market and the remaining opportunities for displacing electric resistance heating loads with this DHP technology.

Methods

The DHP-driven displacement of electric resistance heat is a fundamentally different application than most HVAC equipment retrofit applications, in that the DHP is typically not a full replacement of existing equipment because these systems are not necessarily designed to meet loads at low ambient temperatures. Additionally, DHPs are typically used to condition part of a home rather than a whole home. Navigant's previous work has shown that customers purchase DHPs for two main reasons: they want to save money on heating; they want a new central cooling amenity in a home without ducts; or they want to do both (Vitoff et al. 2015). The diversity of combinations in a customer's desired results, existing equipment, and home characteristics mean that a wide variety of products may be installed. The Navigant team's discussions with manufacturers and distributors indicate that the DHP market is changing rapidly, with new varieties of products entering the market to meet specific niche applications. With this in mind, the team undertook the study based on the methodology shown in Figure 2.

The team split the project task into two main parts: market characterization of DHPs in the Northwest (shown in Figure 2 with light blue boxes) and potential load displacement of DHPs in the Northwest (shown in Figure 2 with green boxes).

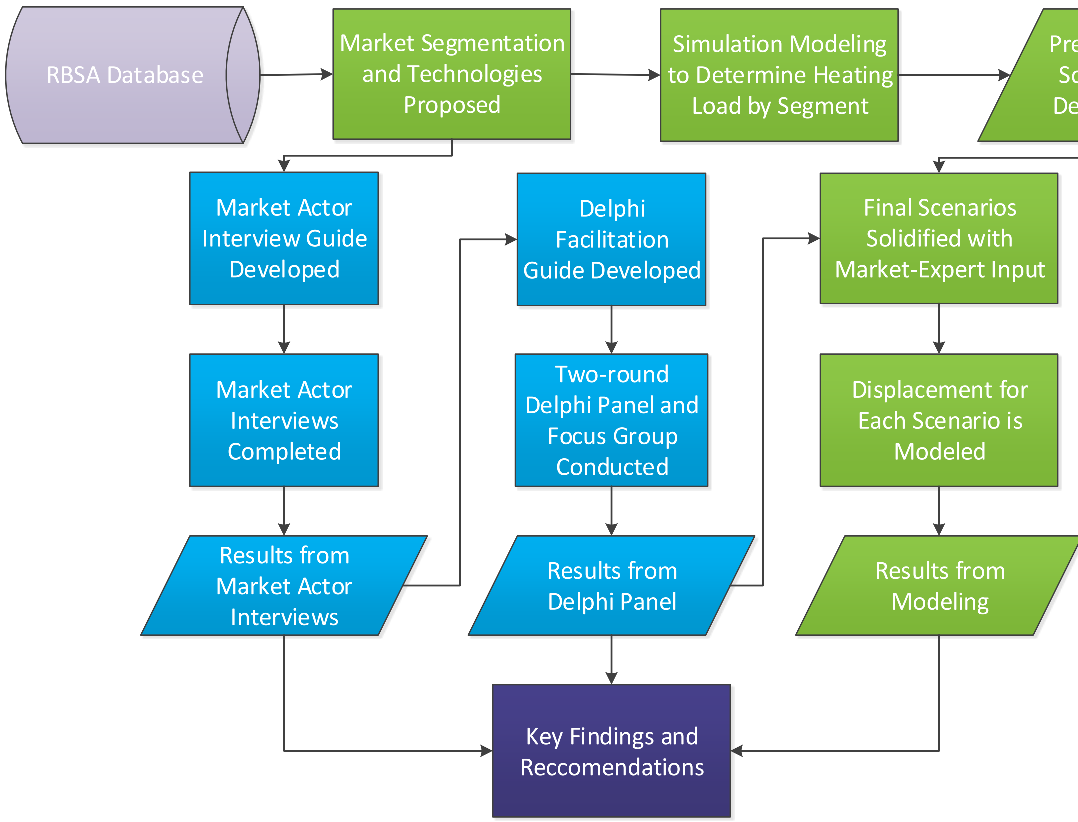
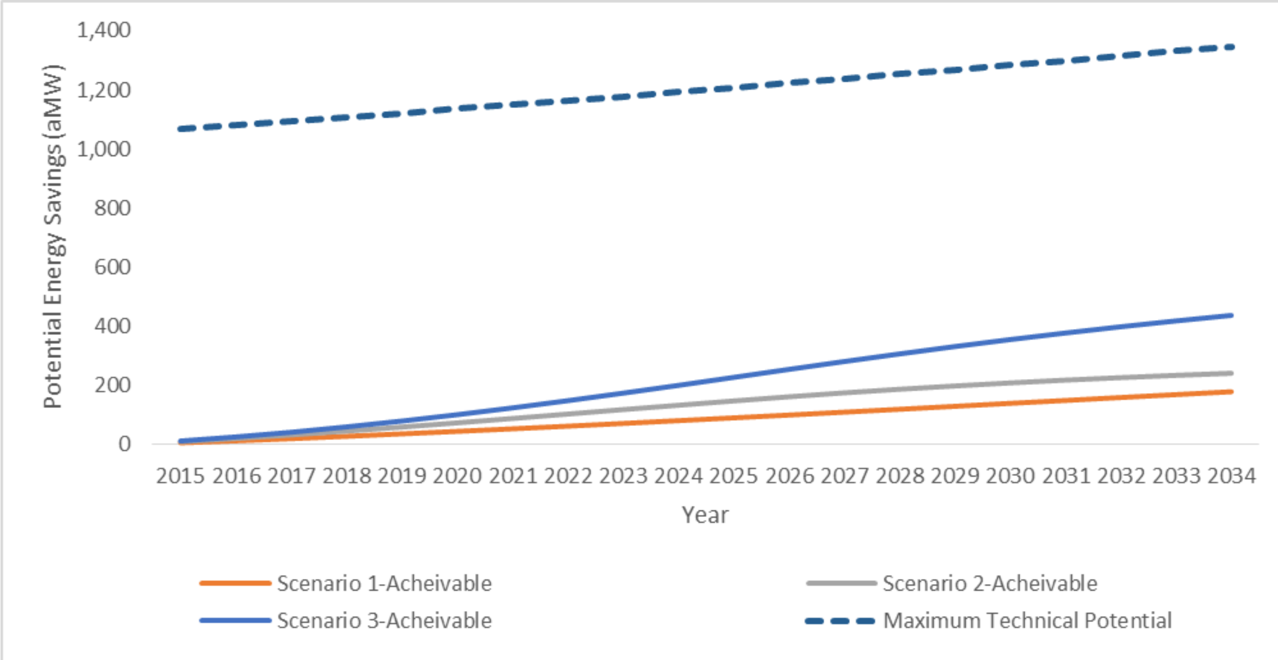


Figure 2. Project Methodology Flow Diagram

Results

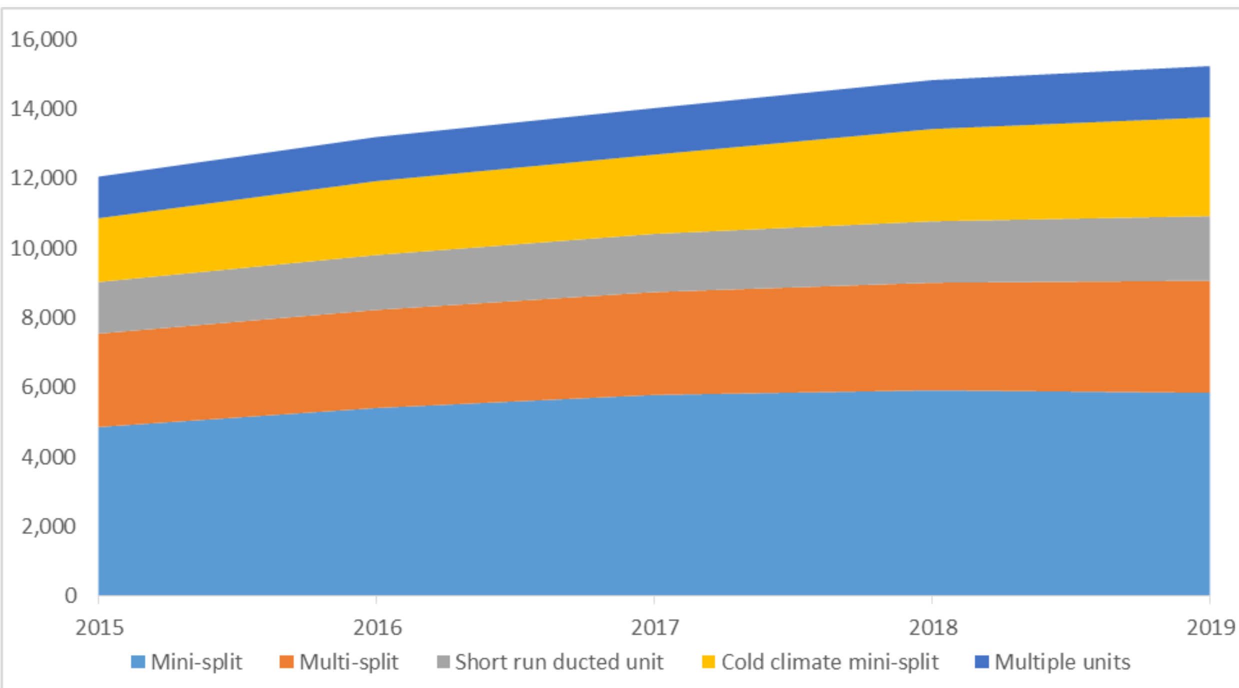
As part of this study, Navigant projected ductless heat pump sales to increase steadily over the next several years and for these increased sales to achieve a cumulative 440 aMW[3] of savings in the most aggressive, achievable scenario by 2034. The projected savings resulting from the least aggressive scenario over five years are shown in Figure 3. Navigant's projected ductless heat pump sales in the Northwest by equipment type are shown in Figure 4.

[3] An aMW is an average megawatt, commonly used in the Northwest as a unit of energy equal to one megawatt-year or 8.76 million kWh.



Source: Navigant Analysis

Figure 3. Low, Medium, and High Penetration Scenarios and Maximum Technical Potential Over Time



Source: Navigant Analysis

Figure 4. Achievable Installations by Technology over Next Five Years

Based on the results of market actor interviews and the Delphi panel, evaluators came to the following conclusions about the Northwest DHP market:

- The overall DHP market is growing fast and the technology is improving steadily.

- Cold climate heat pumps increase savings potential, but contractors are not emphasizing these units in their sales[4].
- Prices for DHPs are unlikely to drop significantly in future years.
- Different motivations than we see in other regions of the country (primarily about saving money, converting from electric baseboards)
- When there are ducts, program really should be working on regular ducted heat pumps instead.

Applicability of Cold Climate Heat Pumps

Cold climate heat pumps can provide high heating capacity at much colder temperatures than standard heat pumps. A cold climate heat pump does a much better job of satisfying loads and customers at cold temperatures. While cold climate ducted heat pumps have occasionally made it onto the market, multiple cold climate DHPs are currently available on the market, with new models added annually. Most DHPs are installed with a backup heating source, frequently the existing heating system. Under extremely cold temperatures, this backup heating source will run to supplement the output of the DHP. If the supplemental heat source is electric resistance baseboards or electric resistance furnace, this non-cold climate system will consume a significant amount of energy at cold temperatures. If there is no supplemental heat or the supplemental heat is fossil-fueled, the non-cold climate system will consume no more electricity at cold temperatures; however the system may consume a significant amount of fossil fuel energy to supplement the DHP. Cold climate DHPs offer improvements in peak demand and/or customer satisfaction, depending on the application, as shown in Table 1 below.

Table 1. Qualitative Impacts of Cold Climate Heat Pumps

Cold Climate DHP?	**Supplemental Heating Fuel?**	**Electricity/Peak Demand Change from Typical Conditions**	**Customer Satisfaction Impact**
No	None	None	Low Satisfaction (Baseline Condition)
No	Electricity	Large Increase	High Satisfaction
No	Fossil Fuel	None	High Satisfaction
Yes	None	None	Medium Satisfaction
Yes	Electricity	Small Increase	High Satisfaction
Yes	Fossil Fuel	None	High Satisfaction

Somewhat counterintuitively, cold climate heat pumps have important savings impacts throughout the country. Anywhere winter energy or winter peak demand savings are desired, cold climate heat pumps have a role to play in energy efficiency and demand side management programs. While the authors of this study have direct knowledge of the markets in the Northeast and Northwest regions of the country, there are also significant savings to be realized in the South.

In the Northeast, a significant portion of the heating load occurs at temperatures below freezing. Cold climate heat pumps are an obvious solution there, with significant energy and demand savings available, but contractors are not currently telling most participants about the benefits of cold climate heat pumps in

[4] This finding was also prevalent in the research completed by Navigant and Cadmus in Massachusetts (Vitoff et al. 2015).

Massachusetts (Vitoff et al. 2015). This may be due to the fact that up until this year, multi-split cold climate units were not available on the market. Energy efficiency programs have a big opportunity to move the market to adopt cold climate heat pump technology. In the Northwest, the potential energy savings of cold climate heat pumps are lower than what is possible in the Northeast, but the high prevalence of electric resistance heating being used as the supplemental heat source and the resulting high winter demand savings make cold climate heat pumps an important opportunity for programs to consider. Likewise, in the Mid-Atlantic and Southeast, the winter peak demand savings of cold climate heat pumps may be very valuable in the future, as power planners look to solve winter peak capacity issues. The value of the winter peak demand reductions may ultimately dwarf the value of the cooling and heating energy savings.

Recommendations for Program Designers

1. **Promote cold climate heat pumps.** Anywhere that winter demand savings or heating energy savings are available, cold climate heat pumps can generate savings that may be cost-effective. This generally includes the Southeast, Northeast, and Northwest portions of the United States, as well as portions of the Southwest with a high heating load or heating peak.

2. **Provide contractor training and homeowner education to maximize the performance of DHP equipment.** Results from around the country show that most participants learn about DHPs from contractors. Contractors need better training both to sell customers the benefits of the right kind of DHP technology and also to inform customers how to use their systems to generate maximum savings. For example, the authors have encountered homeowners with expensive oil heat who did not use their DHP(s) for heating. In other cases, homeowners may use the heat pump erratically, like a switched device to bump up the temperature, rather than using thermostats to control operation. These systems are dramatically more efficient at part-load than full-load and much more cost-effective than using oil, propane, or electric resistance to heat a home. Homeowners installing these systems should be aware of these benefits.

3. **Target DHPs to displace existing oil, propane, and electric resistance heat, depending on the relative value of these impacts.** These applications offer the most cost-effective savings for this technology, which would enable higher rebate levels and a corresponding increase in program influence on the market.

4. **Promote a broad array of heat pump technologies.** With the range of technologies available on the market today, there is a heat pump application for almost every home in the United States. A variety of ductless heat pumps can be used for homes without ducts, while ducted heat pumps should still be promoted for homes with ducts.

5. **Consider promoting DHPs in high-end residential new construction.** In situations where the baseline heating system is two or more, separate ducted systems, a ductless heat pump may offer large cost-effective savings. The incremental cost of a DHP relative to a ducted system with zoning is lower than the incremental cost of a DHP relative to a single zone central system and additional savings can be realized by avoiding ducts in the first place.

6. **Consider changing codes to require a minimum efficiency higher than the federal minimum for DHPs.** Because DHPs have much lower rated indoor fan energy consumption than

ducted systems, the same outdoor unit hooked up to a ductless head will use ~15% less energy than it will when hooked up to a normal air handler and evaporator.

7. **Consider requiring manufacturers to publish additional design point system efficiencies and use those to determine program eligibility.** The current ratings of some DHPs state efficiency and capacity at a point below full output. This inflates the rated efficiency. If these systems run closer to their full capacity, they perform significantly worse than their rated efficiency.

Recommendations for Evaluators

1. **Design the metered sample to stratify based on surveyed usage**. Conduct a survey to determine predicted run time before the field study begins and post-stratify based on predicted savings for each DHP.
2. **Use a higher coefficient of variation (CV) when using a nested sample of onsites within phone surveys about residential HVAC usage.** In the Con Edison study, a coefficient of variation (CV) of 0.7 was used for the phone survey. The evaluation team incorrectly assumed that the phone survey would be indicative of relative metered run time and used a corresponding CV of 0.25. The CVs actually achieved for the DHP stratum for phone and onsite within phone were 0.57 and 0.80, respectively.

3. **Consider targeting 90/15 confidence and precision for future DHP metering studies.** Targeting 90/10 confidence and precision requires a large metering investment for DHP technologies. Ex Ante usage is much more uncertain than +/- 10%.

4. **Future metering studies should consider alternatives for quantifying the precise in-situ capacity and efficiency of DHPs.** Given the nature of DHP's inverter-driven technology, the evaluation team was unable to sufficiently correlate the metered data with rated capacities and efficiencies. Navigant and Cadmus are currently working on a larger metering study for the Massachusetts program administrators that strives to measure power and capacity delivered over a 9 month metering period.

5. **Pay attention to the program design and actual usage to get the baseline right.** The baseline for DHP technologies can vary significantly, depending on the region, program design, and participant motivation. Programs pushing displacement of heating equipment in climates with limited cooling usage will frequently find that a retrofit or existing equipment baseline is adequate. Meanwhile, programs offering rebates in areas with homes that do not currently have ducts and have a need for cooling will generally see a low efficiency DHP as an adequate baseline. Evaluators should consider the possibility that programs pushing high efficiency equipment are responsible for the market share of minimum efficiency DHPs being low, and that programs may induce a purchase decision, resulting in either fuel conversions or load building.

6. **Meter actual summer and winter peak conditions to determine true peak operations.** Heat pumps behave differently at very cold temperatures. Do not extrapolate from other heating operation. The share of the heating delivered by the heat pump will vary depending on how supplemental heat is being controlled.

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