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Focus on Energy

Environmental and Economic Research and Development Program

Ductless Mini-Split Heat Pump Market Assessment and Savings Review Report

December 30, 2016

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1. EXECUTIVE SUMMARY

This report summarizes the findings from Tetra Tech's research into the ductless mini-split heat pump (DMSHP) market. The research project was funded under the Focus on Energy Environmental and Economic Research and Development Program. The goal of the research project was to inform Focus on Energy regarding the current market for DMSHP technologies in Wisconsin, how a program might be most effective at reaching customers who may purchase DMSHPs, and to provide information and guidance on issues and approaches to energy savings.

The report is structured to provide an Executive Summary with high level findings and conclusions, followed by sections that describe DMSHP technology, the DMSHP market, how programs similar to Focus on Energy are addressing DMSHP markets and technology, and lastly a workpaper that Focus on Energy can use or adapt for its Technical Reference Manual should DMSHP measures be offered incentives through Focus on Energy.

Below, we summarize the methods and data sources, followed by key findings and recommendations for Focus on Energy's consideration.

1.1 METHODS AND DATA SOURCES

The research was conducted using variety of secondary and primary information sources, including:

- A secondary literature review of general industry literature related to DMSHP, Technical Reference Manuals (TRMs), and peer energy efficiency programs offering DMSHP rebates
- Interviews with trade professionals, including DMSHP manufacturers and local installation contractors operating in Wisconsin
- Interviews with administrators of peer energy efficiency programs offering DMSHP rebates.

In addition to these research activities, Tetra Tech sought input from Focus on Energy implementation and evaluation contractor staff throughout the course of the project to support study objectives.

1.1.1 Secondary Research

Tetra Tech conducted secondary literature review of existing industry literature on DMSHP technologies, including market assessment studies, TRMs, and publically-available EM&V reports. These sources were used support the study market assessment, engineering review, and primary research activities.

Working with Focus on Energy staff, Tetra Tech also identified DMSHP programs throughout the United States and conducted internet research of publically-available rebate applications, energy efficiency plans, and evaluation reports. The secondary peer-program research focused on the following topic areas:

- Measure criteria and specifications, including efficiency ratings, size, quantity limits, measure life, and incentives
- Baseline and savings assumptions, including equipment type and efficiency rating
- Net-to-gross (NTG) research, including evaluated estimates of freeridership and spillover effects.

A bibliography of secondary data sources reviewed is included in Appendix C.

1.1.2 Trade Professional Interviews

In collaboration with Focus on Energy implementation staff, Tetra Tech identified DMSHP trade professionals to target for in-depth interviews to better understand the national and Wisconsin markets.

The sample frame for the trade professional interviews consisted manufacturers of DMSHP technologies and local installation contractors. Tetra Tech compiled a list of manufacturers to target for approximately three interviews. In addition, Focus on Energy implementation staff provided Tetra Tech with a list of 37 known DMSHP installation contractors throughout the state. From this list, we prioritized contractors based on location (climate zone) and numbers of DMSHP installations to target a mix of different types of installation contractors for interviews.

Tetra Tech completed in-depth interviews with three DMSHP manufacturers and 11 installation contractors operating in Wisconsin. Interviews were semi-structured following a topic guide, which can be found in Appendix A. The interviews focused on the following topics:

- Contractor and manufacturer company profiles including products and services offered, markets served (e.g., residential, commercial), and experience installing DMSHP systems
- Installations of DMSHP technologies including common applications, baseline and other key savings assumptions, existing equipment replaced by DMSHP systems, consumer usage (e.g., heating versus cooling, primary versus supplemental), types of backup heating/cooling systems used, and incremental costs
- Customer characteristics and applications that present the greatest savings potential from installing DMSHP systems
- Market trends including consumer awareness, market penetration, key market barriers, and changes in consumer preferences and attitudes.

1.1.3 Program Staff Interviews

Tetra Tech and Focus on Energy staff prioritized programs included in the secondary research, with emphasis on programs in cold-climates similar to Wisconsin, to target interviews with three to five program managers. Tetra Tech completed in-depth interviews with four program managers of DMSHP programs across the country. Interviews were semi-structured following a topic guide, which can be found in Appendix B. The interviews focused on the following topics:

- Confirm key elements of program design, including the structure, amount and type of incentive, eligibility requirements, approaches to fuel switching
- Marketing and recruitment of customers including how programs market and recruit customers, target markets, and key barriers to participation
- Approach to calculating program impacts including how programs determine baseline and technical assumptions, heating and cooling savings, and incremental costs.

1.2 KEY FINDINGS

The research revealed a number of insights on available DMSHP technologies and products, market and consumer trends, current energy efficiency programs, and approaches for calculating energy savings from DMSHP installations.

Below are key findings from the research:

- DMSHP technologies offer several benefits over alternative HVAC systems, including flexibility for zonal heating and cooling of individual spaces, general ease of installation, a variety of aesthetic options, and energy efficiency gains.
- The flexibility of DMSHP technologies, compared to traditional air-conditioners and heat pumps, also leads to variability in terms of occupant behavior and energy consumption. Baseline conditions also vary widely, which may be reflection of the relative “newness” and limited market share of DMSHP technology.
- While some field tests have found that actual Coefficient of Performance (COP) results suggest Seasonal Energy Efficiency Ratio (SEER), Energy Efficiency Ratio (EER), and Heating Seasonal Performance Factor (HSPF) results lower than rated results, the shortfall is not large and may be due to differences in rated conditions compared to in-field conditions, an issue that may also be present in traditional HVAC equipment.
- Feedback from manufacturers and local installation contractors suggests that the DMSHP market in Wisconsin and upper Midwest is still emerging and immature relative to some other regions such as the Northeast, West Coast, Southeast, and Northwest. Contractors generally reported that consumer and builder familiarity of DMSHP technologies is relatively low but is growing. Contractors are addressing consumer awareness issues via regular advertising on television, websites, display units, and home shows.

- Currently, DMSHP installations in Wisconsin are largely focused in the residential sector. Installation contractors identified a number of residential applications with high savings potential, including single family homes with electric, hydronic, oil, or propane heat, homes with wall or window AC units, additions and remodels, and spaces were zonal heating and cooling are common.
- The commercial sector currently makes up a relatively small portion of the DMSHP market in Wisconsin relative to residential. Installation contractors mentioned a number of specific commercial applications with high perceived savings potential, including, nursing facilities, gas stations, server rooms, modular offices, lodging, new car show rooms, dining halls, laundry facilities, and multifamily facilities.
- DMSHP units in Wisconsin are most commonly sold with space cooling as the primary end-use, with heating only being active during shoulder months. As space cooling is the primary focus of sales, contractors indicated that existing heating systems are still retained and used, with DMHSP only providing a portion of heating. In the commercial sector, there may be more variance in the usage of DMSHP for cooling and heating. In the particular, in the lodging industry, a higher proportion of space heating loads may be covered by DMHSP, especially when replacing guest room PTAC and PTHP.
- DMSHP systems in Wisconsin are most commonly sold as a solution to meeting a space conditioning need, not as a replacement for traditional space conditioning technology, with the value proposition based on the features of a DMHSP system.
- Seasonal Energy Efficiency Ratios (SEER) for DMSHP products currently installed in Wisconsin range widely from 13 to 30 SEER. Manufacturers and installation contractors generally view a SEER of 18 to 20 as the start of higher efficiency systems, with baseline SEER in the 13 or 14 range. The current minimum federal standard for heat pumps is SEER 14 and HSPF 8.2.
- DMSHP technologies are most commonly being installed in retrofit applications in Wisconsin, with minimal new construction. Eight of 11 contractors reported that 75-100 percent of DMSHP are installed in retrofit applications (average of 91 percent).
- Prescriptive DMSHP rebate levels are commonly based on estimated incremental costs. One program manager estimated an incremental cost between a baseline heat pump (the program's technical assumptions use a baseline of 14 SEER, 8.2 HSPF) and a qualifying heat pump (18.0, 12.0 HSPF) at approximately $600. Another program manager estimated the incremental cost between a baseline heat pump (the program's technical assumptions use a baseline of 14.5 SEER, 12.0 EER, 8.2 HSPF) and a qualifying heat pump (20.0 SEER, 12.0 EER, 10.3 HSPF) at $500-600.
- DMSHP programs most commonly assume a baseline condition of either a standard efficiency heat pump or electric resistance heating, both assuming electric-only savings and no fuel switching. Baseline SEER values range from 8.0 to 14.5 (most commonly 13.0 or higher), baseline EER values range from 8.5 to 12.0, and baseline HSPF values range from 3.2 to 8.2.

- Commercial programs generally do not target specific customer segments; however, interviewees report that DMSHP participants are most commonly smaller commercial customers.
- Among recommendations provided by DMSHP program administrators, interviewees suggested, 1) supporting a broader selection of qualifying high efficiency DMSHP products available on the market instead of targeting specific sizes or models can help to promote right sizing and market suitability, 2) developing and maintaining relationships with trade allies, and 3) keeping measure eligibility requirements simple and similar across sectors to minimize confusion in the market among contractors and participants.

1.3 RECOMMENDATIONS

Based on the research findings and conversations with Focus on Energy implementation and evaluation team members, Tetra Tech offers the following program recommendations for Focus on Energy's consideration:

- In the absence of primary market research with consumers, assume a baseline of a minimum federal standard heat pump, unless baseline conditions can be verified through customer eligibility criteria (e.g., must have electric resistance heating, displacement of natural gas, etc.). DMSHP fall under federal heat pump standards with a minimum SEER of 14 and HSPF of 8.2.
- Regardless of workpaper example calculations, evaluate individual project savings as a hybrid measure based on the actual specifications of installed DMSHP measures. Key criteria include capacities, SEER, EER (if available), and HSPF. With program history and market technology trends, a single deemed value may be possible to develop, but to do so now may undercount savings from the highest efficiency units or through program market shifts that emphasize higher efficiencies for program incented systems.
- If cold climate heat pumps receive a differentiated incentive, consider using approved measure lists to verify equipment qualifications and ease participation for customers and contractors.
- Engage installation contractor and manufacturers in program design and outreach efforts, as well as to ensure quality installation of rebated DMSHP products.
- Leverage program application material as a source of market research. Consider requesting more technical details of end-use applications, such a building square footage or approximate square footage of the area being served by the DMSHP. Consider requesting information to enhance insight into specific baseline conditions and whether the use can be considered a retrofit or new construction application.
- Periodically conduct supplier interviews to identify market trends and adjust the program as appropriate.
- Address uncertainties regarding baseline technology specifications via ongoing research and leveraging program and evaluation information. While this report recommends using the federal minimum heat pump standard as a baseline

assumption, there are some key uncertainties on actual market conditions which may impact baseline assumptions, including:

- AHRI data shows “active” DMSHP models starting at SEERs of 14.5, not SEER 14, the minimum federal standard
- Market sales data is likely to show that the average efficiency performance exceeds the federal minimum standards, potentially suggesting a higher baseline or addressing differences via net savings research.

With these considerations in mind, Focus on Energy should plan to make program refinements based on early experiences and information gathered by the program or evaluation teams. With an understanding of evolution in the Wisconsin DMSHP market, including market adoption and program influence, the program should expect to evolve as the market matures.

2. TECHNOLOGY DESCRIPTION

This section provides an overview of DMSHP technologies and current industry research on DMSHP applications and performance.

2.1 TECHNOLOGY OVERVIEW

Ductless minisplit heat pumps (DMSHP) represent a subset of variable refrigerant flow (VRF) heat pump technology. VRF technology is characterized by two major features that differentiate it from traditional direct-expansion heating and cooling technology.

- Variable refrigerant flow to the evaporator
- Inverter driven compressors that allow the compressor to operate continuously based on loads and reduces on/off cycling.

In general, DMSHP systems are able to connect to single phase power. They may have a single (single split) or multiple (multi split) indoor units to distribute heating or cooling, with individual controls for each of the indoor units. While the marketplace definitions of DMSHP vary, five tons of capacity is considered to be a ceiling for DMSHP technology, above which three phase power may be needed or more complex system design and installation creates a focus on the commercial market. In general, DMSHP are targeted to the residential and small commercial market.

Figure 2-1 illustrates the potential blending of a DMSHP unit into serving single zones, split into multiple zones or integrated with a duct system. For a single-split system, only one air handler would be used, with a multi-split system potentially using all combinations in the illustration.

Figure 2-1 Potential Configurations of Ductless Mini-split Heat Pumps[1]

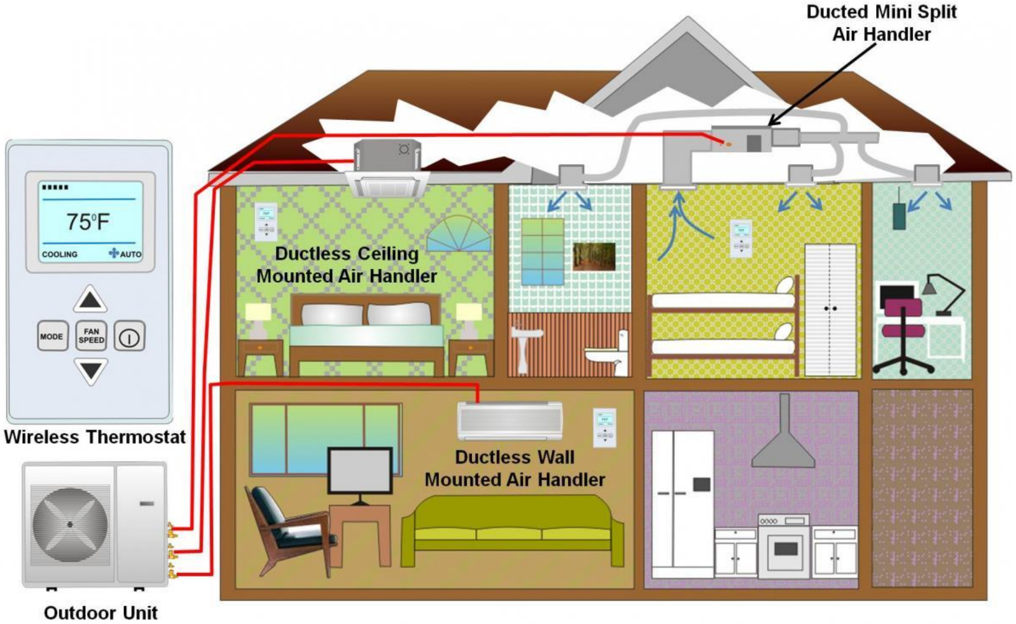

*Image courtesy of Pacific Northwest National Laboratories

DMSHPs are exhibiting market growth for a number of reasons, including the following:

- Small size and flexibility for heating and cooling individual spaces
- General ease of installation, with a relatively small wall penetration allowing for connecting the outdoor and indoor units
- Flexible locating of the outdoor unit, allowing for meeting aesthetic values
- Avoiding duct energy losses, particularly for ducts located in attics
- Security benefits over window air conditioners
- Flexibility for retrofits for buildings with hydronic heat and for placement of the indoor units
- Generally higher SEER ratings than standard ducted air-source heat pumps.

[1] https://basc.pnnl.gov/sites/default/files/HVAC%20132minisplit-5_DS2014.jpg.

2.2 ENERGY PERFORMANCE

As a form of air-source heat pumps, DMSHP are subject to minimum federal energy efficiency standards for air-source heat pumps. As split heat pumps, DMSHP minimum standards, are:[2]

- SEER = 14.0
- HSPF = 8.2.

In general, the capacities of a residential DMSHP are 65,000 BTU/hour or less (5 tons or less). These are often units able to run from single phase power. Larger systems, though with more complex system design and implementation, are available for larger commercial spaces, and often require three phase power. At 5 tons or less, the size range allows for heating and cooling many homes or small commercial spaces with a single outdoor unit. Actual efficiencies of DMSHP are generally higher than equivalent ducted heat pumps due to the lack of duct losses, but many (not all) models also use variable speed compressors able to maintain efficiencies at part-load. Rated efficiencies of DMSHP are typically higher than traditional heat pumps due to the variable refrigerant flow and use of variable speed compressors.

2.2.1 Cold-climate ductless heat pumps

The SEER and HSPF ratings test are conducted at standard test condition. The Airconditioning, Heating, and Refrigeration Institute (AHRI) publishes test standards used by the HVAC industry to develop consistent HVAC equipment energy performance and capacity ratings.[3] For the SEER, several test temperatures meant to capture cooling load performance across a season and with various loads (minimum, intermediate, and maximum) and outdoor temperatures are used. For heat pump ratings in cooling mode (SEER and EER), a constant indoor temperature of 80° F is maintained. The EER rating, reflecting maximum cooling loads with an outdoor temperature of 95° F, is used to capture a maximum load condition, but is not reflected in minimum federal standards for systems 65,000 BTU or less. The HSPF rating uses a constant indoor temperature of 70° F and range of temperatures from 17° F to 47° F. The heating system capacity is based on output at 47° F outdoor temperature. There are no AHRI test criteria to determine operational efficiencies at temperatures below 17° F.

As standard test conditions may not reflect heating performance in cold weather, the HVAC industry and energy efficiency programs have begun to offer and promote “cold-climate” ductless heat pumps. While not an official industry standard, heat pump systems meeting a cold-climate specification would be expected to maintain heating capacities and minimum performance at much colder temperatures than those in the AHRI test standard. One such specification has been developed by the Northeast Energy Efficiency Partnership (NEEP), set to go into effect January 1, 2017. The specification requires the following key performance parameters:[4]

[2] http://www.appliance-standards.org/sites/default/files/1009hvac_fact.pdf.

[3] http://www.ahrinet.org/App_Content/ahri/files/STANDARDS/ANSI/ANSI_AHRI_Standard_1230_2010_with_Add_2.pdf.

[4] http://www.neep.org/sites/default/files/Cold%20Climate%20Air-source%20Heat%20Pump%20Specification-Version%202.0Jan2017.pdf.

- Compressor must be variable capacity
- Indoor and outdoor units must be part of an AHRI matched system
- COP @5° F >1.75 (at maximum capacity operation).

NEEP additionally requires that the systems be ENERGY STAR® Certified and that the HSPF exceeds 10.

A cold-climate heat pump that meets these specifications will be able to output its rated heating capacity at 5° F with a minimum coefficient of performance. The requirement of a minimum COP at 5° F, ENERGY STAR certification, and minimum HSPF reflect the qualification goals of an energy efficiency program, not a reflection of standards that define “cold-climate” operations.

The DMSHP industry has responded to the growing interest of DMSHP for cold-climate operations by offering a variety of models. Efficiency Vermont, as part of its DMSHP incentives, publishes a list of qualifying cold-climate ductless heat pumps that meet the NEEP specifications. Six manufacturers are included on the current list, with approximately 70 models having capacities ranging from 9,000 BTU/hour to 48,000 BTU/hour and including both single-zone and multi-zone models.[5]

2.2.2 Actual energy performance

Although AHRI equipment ratings and NEEP’s cold climate specifications allow for consistent energy performance standards across the industry, the question of actual energy performance remains. Energy efficiency programs have been studying DMSHP over the last 10 years or so. The technology has changed over time and increased efficiency rating. In recent years, a number of studies have found that actual performance, particularly in colder climates, has not met with the expectations set by efficiency ratings. While this research does not conclusively describe performance relative to efficiency standards due to individual study design limitations, there is a general observation that field tests show a reduction in energy efficiency performance compared to laboratory testing. Most of the research relevant to Wisconsin has been conducted in the Northeast. Other studies in warmer climates are less relevant. Due to climatic differences, rapidly evolving nature of the technology and relatively short-term nature of many studies, this research is generally informative regarding DMSHP performance, but may not always apply directly to Wisconsin due to occupant behavior, residential home design, or the prevalence of non-utility heating fuels (e.g., fuel oil).

Below we summarize the results from several studies, only one of which provides a perspective on long term operations.

[5] https://www.efficiencyvermont.com/Media/Default/docs/rebates/qpls/efficiency-vermont-cold-climate-heat-pumps-qualifying-products.pdf.

A. Massachusetts and Rhode Island, 2015 and 2016

In 2014 and 2015 Cadmus conducted an in-field metering study of over 150 DMSHP units installed in Massachusetts and Rhode Island. In 2015, a memo was released that described initial findings for the heating season, while in 2016, a companion memo described their findings relative to the cooling season. A full report is forthcoming.

The heating season memo (2015)[6] identified that there are several space conditioning motivations for customers to purchase DMSHP. In their sample, about 30 percent indicated that they purchased a DMSHP for cooling-only purposes, while about 65 percent indicated their purchase was for heating and cooling. A small percentage indicated their purchase was motivated by heating only needs. Fuel oil was often the displaced heating source. Cadmus monitored the hours of use and adjusted the usage to derive average Equivalent Full Load Hours (EFLH) for heating. Calculated EFLH showed that cooling-only purchasers used their system the least for heating, while heating only purchasers used their system the most. A key observation is that those who purchased their system for cooling-only also used their system for some heating, though less than the other groups.

The cooling season memo (2016)[7] presented results on two research topics – the EFLH for cooling as well as a comparison of published SEER compared to in-field estimates of SEER. Cadmus found that EFLH for cooling was less than the existing TRM assumed EFLH for cooling, while SEER values tended to be two to three points below the published SEER for both single-split and multi-split systems. However, SEER performance calculations did not necessarily reflect those of AHRI test conditions, pointing to savings that may differ if test condition SEER values are applied to a savings equation. An additional observation provides perspective on the derived EFLH for cooling—“many users were observed to turn the units on and off for ‘on-demand’ cooling, rather than using them to consistently maintain a cooler space temperature.” This latter observation implies that had the systems been operating to maintain a set temperature point, the hours of use would have been higher. The Tetra Tech team speculates that as such, DMSHP users may adopt behaviors that lead to additional savings not found for conventional air-conditioning systems.

B. NEEP Ductless Heat Pump Meta Study, 2014

In 2014, the Northeast Energy Efficiency Partnership published a meta study that reviewed 40 other studies and manufacturer information. The results showed that cold weather performance offered substantial savings over oil heat in the Northeast and that some DMSHP systems could provide useful heat at very cold temperatures. However, NEEP also reported that defrost cycles added to parasitic loads (<10 percent) that reduced overall energy performance at these cold temperatures. Average heating COPs ranged from 3.5 at 40° F and higher, down to 1.4 at -10° F to -20° F. The data being cited came from reports spanning 2010 to 2014 and may not reflect current system performance for emerging higher efficiency or cold-climate systems and noted that all studies attempting to calculate a COP had challenges with their field studies. NEEP also

[6] http://ma-eeac.org/wordpress/wp-content/uploads/MA-Cool-Smart-DMSHP-Heating-Results-Memo_FINAL.pdf.

[7] http://ma-eeac.org/wordpress/wp-content/uploads/Ductless-Mini-Split-Heat-Pump-Draft-Cooling-Season-Results-Memorandum.pdf.

notes that all the studies showed lower SEER and HSPF than rated, though being derived from COP measurements, also shared the challenge of in-field measure consistency and results.

The NEEP study showed that most systems being installed and studied ranged from 0.75 to 1.5 tons. NEEP noted that the systems tended to be oversized for the specific spaces being heated, though not for the entire home being studied. The NEEP study also found that systems tended to be oversized for cooling loads (in order to meet heating loads), though with good part-load operations, little efficiency penalty was noted for cooling, despite the oversizing.

The NEEP study found that energy consumption was highly variable due to differences in climate and the weather being observed during the studies, but also by how occupants used their DMSHP systems. For example, kWh consumption per ton of capacity ranged from 90 kWh to 500 kWh per ton. For heating, the systems ranged from 1,800 kWh to 4,000 kWh per ton.

The NEEP study also found that energy savings were highly variable, partly driven by occupant uses of their DMSHP systems, the size and use of the zones being served by the DMSHP system, and the type of heating system being displaced by the DMSHP. Of note is the observation that customers had little understanding of how their DMSHP interacted with their primary heating system and how to control the DMSHP for optimal performance. Modeled savings for systems displacing electric resistance heat ranged from 1,200 kWh to 4,500 kWh per ton of heating capacity.

C. U.S. Department of Energy Long Term Monitoring, 2014[8]

The U.S. Department of Energy (USDOE) conducted a three year monitoring study of eight ductless mini-split heat pumps located in the Northeast. The report offered several key findings:

- Both laboratory and field experiments showed agreement with manufacturer equipment ratings of capacity and efficiency. The study found that in some cases, heating capacity at low temperatures exceeded the rated capacity.
- Temperature setbacks are not an optimal control strategy as the period of temperature recovery caused the systems to operate at full capacity, an operating point at which efficiencies are lower.
- COPs varied as expected in relation to outdoor temperatures, with heating COPs of 4 during warmer weather and 2 in the coldest weather. [note: COPs are reflective of installed systems' efficiency and not a general statement about DMSHP]
- Normalized uses across the eight homes averaged 0.00030 kWh/sqft-HDD65. The range was +/- 0.00010 kWh/sqft-HDD65.
- Standby energy use was found to be low in the monitored homes, with range of 4 to 5 watts on average.

In addition to the energy performance results, the study found that thermal buoyancy had a significant effect on occupant comfort and heat (or cooling) distribution. For systems with first

8 https://buildingscience.com/sites/default/files/migrate/pdf/BA-1407_Long-Term_Monitoring_Mini-Splits_Northeast_v2.pdf.

floor-installed DMSHP, the second floors tended to not receive adequate cooling, though conversely, did benefit from rising heat during the heating season. Additionally, the study found that occupants who chose to operate their DMSHP in an on/off manner and not use a standard set point tended to be less comfortable, with the systems tending to operate more often at full load as the systems were more often running in a temperature recovery mode. Finally, the study found that on average, the simulation results using REM/Rate were reasonably close to actual performance (though with wide variation between individual years and homes), suggesting that rated performance aligned with actual performance.

2.3 SUMMARY

DMSHP technology offers adopters benefits over alternative HVAC systems. Studies conducted in the Northeast show that flexibility of the technology, compared to traditional air-conditioners and heat pumps, also leads to variability in terms of occupant behavior and energy consumption. Baseline conditions also vary widely, which may be a reflection of the relative "newness" and limited market share of DMSHP technology. While some field tests have found that actual COP results suggest SEER, EER, and HSPF results lower than rated results, the shortfall is not large and may be due to differences in rated conditions compared to in-field conditions, an issue that may also be present in traditional HVAC equipment.

3. MARKET CHARACTERIZATION

This section summarizes research findings on the state of the DMSHP market nationally and specific to Wisconsin based on secondary research, interviews with national DMSHP manufacturers, and local DMSHP installation contractors. Interviews with manufacturers and installation contractors focused on customer markets, applications and usage, product availability and specifications, incremental costs, and market trends.

The Tetra Tech team investigated regional and national-level market trends through interviews with three major DMSHP manufacturers: Daikin, Mitsubishi, and Panasonic. The Tetra Tech team also interviewed 11 local DMSHP installation contractors throughout the state to gain market perspectives specific to Wisconsin. Home cities of contractors interviewed include Brookfield, Eau Claire, Evansville, Green Bay, Hudson, Marathon, Minocqua, Oostburg, Rhinelander, Schofield, and Sheboygan. Activity in the DMSHP market varied by contractor, with ductless products representing from 5 to 30 percent of sales.

3.1 CUSTOMER MARKETS

All three manufacturers serve both residential and commercial markets, though DMSHP technologies are most commonly associated with residential applications, while larger VRF systems are more commonly associated with commercial applications. A maximum capacity of 5-6 tons appears to be a cut-off for both contractors and manufacturers for defining DMSHP before more complex system design comes into play for larger commercial applications.

Daikin typically defines commercial products as those using 3-phase electric power. Typically residential products range up to 48,000 BTUs. Similarly, Mitsubishi's residential products are typically under 65,000 BTU/hr., while those over 5 tons are typically considered VRFs. Mitsubishi has a separate series of ductless mini-splits that are typically installed in commercial applications, but for their purposes they are grouped with residential products. Panasonic roughly defines VRFs as those at 6 refrigeration tons or more.

Table 3-1. Manufacturer Sector Definitions

Manufacturer	Residential	Commercial
Daikin	≤ 48,000 BTU/hr.	> 48,000 BTU/hr. (typically 3-phase)
Mitsubishi	< 65,000 BTU/hr.	≥ 65,000 BTU/hr.
Panasonic	< 6 tons	≥ 6 tons

All 11 Wisconsin installation contractors interviewed serve both commercial and residential customers, though DMSHP installations are largely focused in the residential sector. Nine of the contractors mostly served the residential market, while two mostly serve the commercial market. Two contractors work with school or government clients and only one mentioned multifamily units as a current market.

Installations contractors were asked about customer characteristics and applications that present the greatest savings potential from installing DMSHP systems. Contractors identified a number of residential applications with high savings potential, including:

- Single family homes with electric, hydronic, oil, or propane heat[9]
- Homes with wall or window AC units
- Additions and remodels
- Spaces where zonal heating and cooling are common, such as sunrooms, basements, seasonal rooms, and second floor rooms with higher cooling loads.

While the commercial market for DMSHPs makes up a relatively small portion of the market for almost all of the contractors interviewed, contractors did mention a number of specific commercial applications with high perceived savings potential, including:

- Nursing facilities
- Gas stations
- Server rooms
- Modular offices
- Lodging
- New car show rooms
- Dining halls
- Laundry facilities
- Multifamily units.

3.2 DMSHP APPLICATIONS AND USAGE

All installation contractors reported installing DMSHP technologies most commonly in retrofit applications, with minimal new construction. Eight contractors reported that 75-100 percent of DMSHP are installed in retrofit applications with the average being 91 percent. One contractor reported generally that "most" of the DMSHP are retrofits, while the other two could not provide an estimate.

Most contractors reported that DMSHP technology is being used for both heating and cooling by their customers, although most units are sold with space cooling as the primary end-use, with heating only being active during shoulder months. DMSHP systems are most commonly sold as a solution to meeting a space conditioning need, not as a replacement for traditional space conditioning technology, with the value proposition based on the features of a DMHSP system. Alternative technologies include window air-conditioners, PTACs, or expanding ductwork and central air-conditioning or heat pump systems. As space cooling is the primary focus of sales,

[9] Focus on Energy only supports energy saving projects for participating utility natural gas and electricity savings. Fuel oil and propane savings would not be eligible for program incentives.

contractors indicated that existing heating systems are still retained and used, with DMHSP only providing a portion of heating.

To a degree, contractors are targeting residential markets that have electric resistance space heat or non-utility fuels as the heating system, but generally do not attempt to sell DMHSP as an alternative to the underlying heating system due to heating capacity limits. With systems being sized for cooling loads, the majority of contractors do not feel the DMSHP technology can adequately serve as a heating system that displaces the main sources of heat in the homes. Contractors reported that customers with hydronic or forced air heat are more likely to maintain those systems as their primary heating source after installation of the DMSHP. In addition homes heated with electricity, LP, or oil are more likely to have DMSHPs installed as a primary heating source, while natural gas-heated homes use DMSHPs as a secondary heating source. This is due in part to the relatively high comparative cost of LP, oil, and electricity.

In the commercial sector, there may be more variance in the usage of DMSHP for cooling and heating. In the particular, in the lodging industry, a higher proportion of space heating loads may be covered by DMHSP, especially when replacing guest room PTAC and PTHP.

3.3 PRODUCT AVAILABILITY AND SPECIFICATIONS

3.3.1 Efficiency ratings

Efficiency ratings range from as low as 15 SEER to as high as 33 SEER among currently available DMSHP products from the three manufacturers interviewed. Daikin’s minimum efficiency levels are 14.5 to 15 SEER, with the standard being 16 to 17 SEER. Mitsubishi makes products from 16.5 SEER way up to 33.1 SEER and up to 16 HSPF. Close to 40 percent of Mitsubishi’s products meet a 20 SEER efficiency standard. Panasonic currently offers products in the 16 to 30 SEER range.

Table 3-2. Manufacturer Efficiency Ranges

Manufacturer	SEER (Low)	SEER (High)
Daikin	14.5	26.1
Mitsubishi	16.5	33.1
Panasonic	16.0	30.0

Installation contractors reported a wide range of efficiency ratings for DMSHP products they install, ranging from 13 to 30 SEER. Two contractors reported sales of high efficiency products only, with the least efficient units starting at 20 SEER. Contractor interviewees generally did not consider HSPF to be a significant factor for overall efficiency due to the use of DMSHP technology as a secondary and seasonal heat source in their region. Two contractors reported HSPF ratings between 11.0 and 13.5 for their equipment.

Manufacturers and installation contractors generally view a SEER of 18 to 20 as the start of higher efficiency systems, with baseline SEER in the 13 or 14 range. Two contractors also recommended using ENERGY STAR requirements to reduce complexity and confusion.

3.3.2 Cold-climate specifications

Efficiency Daikin and Mitsubishi's products claim to operate at 100 percent capacity down to 13 below zero. Panasonic manufactures products that operate at close to 100 percent down to zero degrees and will continue cycling down to 20 below zero. Panasonic also mentioned that some of their ductless product offerings include an auxiliary heat connection that will switch on if the heat pump is unable to keep up with low temperatures.

Most installation contractors we interviewed reported selling some cold-climate heat pumps with the ability to provide heating capacity to temperatures as low as to -15° F, though cold-climate heat pumps are currently not widely marketed due to the limited use of DMSHPs for heating applications. However, some contractors suggested that the market for cold climate heat pumps has increased in the last several years. One contractor noted that, "A lot of that is the product that has come up to the market that is filing a need that wasn't there three to four years ago in that we can do the low ambient heat now with some of these ducted systems." The contractor suggested that increased marketing on the part of manufacturers has increased awareness of cold climate products.

3.4 INCREMENTAL COSTS

A 2014 NEEP Regional EM&V Forum study compiled DMSHP incremental cost information from a variety recent evaluation studies[10]. Reported full installed costs for single-head cold-climate models averaged $3,500-$4,000 for one ton (12,000 Btu) units. The study found the lowest installation costs in Maine, attributing to high program participation and contractor competition driving down pricing. Using a baseline of a standard 8.2 HSPF model, the study found incremental costs of high efficiency 11.0 HSPF models generally ranging between $400 and $600, and cold climate 12.0+ HSPF models ranging between $700 and $900. Another 2013 NEEP study estimated DMSHP incremental costs from secondary sources and contractor interviews in Massachusetts[11]. Using a baseline of one ton SEER 13 unit, the study estimated an incremental cost of $335 for a SEER 18 and $603 for a SEER 21 unit.

Reported incremental installed costs of high efficiency DMSHP products compared to standard efficiency DMSHP product varies by application (cooling and/or heating), type (multi versus mini-split), size, and brand of equipment being installed. One contractor estimated that a low ambient temperature DMSHP would cost $200-$300 more than a standard DMSHP. Another contractor estimated the price difference from an entry-level model of 13-14 SEER to a high efficiency model can range from $600 to $1000. A third interviewee put a 20 percent premium on high efficiency DMSHP technology and another up to 30 percent.

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[10] Northeast Energy Efficiency Partnerships. Ductless Heat Pump Meta Study. Prepared by Energy Futures Group and Energy and Resource Solutions. 2014.

[11] Northeast Energy Efficiency Partnerships. Incremental Cost Study Phase Two: Final Report. Technical Report. Prepared by Navigant. 2013.

3.5 CONSUMER AWARENESS AND MARKET TRENDS

Manufacturer representatives reported varying levels of DMSHP market maturity by region. Interviewees reported that the Midwest market for ductless products is still emerging and relatively immature when compared to the Northeast, West Coast, Southeast, and Northwest. One manufacturer representative added that ductless products are the top trend in HVAC nationally, with multi-splits growing faster than 1-to-1 products.

Feedback from local installation contractors also suggests the DMSHP market in Wisconsin and upper Midwest is relatively immature and still emerging. Contractors generally reported that consumer and builder familiarity of DMSHP technologies is relatively low but is growing. About half of the contractors noted that a sizeable subsection of the public remains unaware of DMSHP technologies. Contractors are addressing consumer awareness issues via regular advertising on television, websites, display units, and home shows, although one contractor reported not actively promoting the technology. Word of mouth advertising is strong with many customers learning about DMSHP through a neighbor, friend, or family member.

Contractors were asked to note how consumer preference has affected sales of DMSHPs and whether it had changed over the years. Cost, appearance, comfort and performance ranked highly as major drivers in choosing DMSHP technology, with availability, reliability, versatility, features, size, noise, efficiency, and financing options also driving sales, although efficiency seems to be a small part of the decision-making process.

Key market barriers mentioned by contractors include unpredictability in the market, contractor training, aesthetics, consumer awareness, installation complexity and costs, backup heating requirements, maintenance requirements. Additionally, lower cooling loads may make the incremental costs of efficient units more difficult to overcome, especially in northern Wisconsin.

4. PROGRAMS PROMOTING DUCTLESS MINI-SPLIT HEAT PUMPS

This section summarizes findings from the secondary review of peer utility programs offering DMSHP incentives as well as in-depth interviews with managers of four DMSHP programs.

4.1 PROGRAM PROFILES

Tetra Tech and Focus on Energy staff identified 13 programs offering DMSHP rebates in the United States. Of these 13 programs, the Tetra Tech team interviewed four program managers from the following program administrators: Bonneville Power Administration, Efficiency Maine, Efficiency Vermont, and National Grid.

These programs represent a variety of geographic regions including the Midwest, Northeast, and Northwest. DMSHP rebates are typically housed within larger residential programs such as general HVAC or existing homes programs. All 13 program administrators offer residential DMSHP rebates, and seven also offer commercial DMSHP rebates. All utilities researched offer downstream rebates; three also have upstream rebate programs (Efficiency Vermont, Massachusetts Program Administrators, and National Grid).

Table 4-1. DMSHP Program Profiles

Program Administrator	Program Name	Upstream/ Downstream	Sector	Territory	Interviewed
AEP	In-Home Energy Program	Downstream	Residential	Ohio	No
Bonneville Power Administration (BPA)	Residential Program	Downstream	Residential	Northwest	Yes
	Commercial HVAC Program	Downstream	Commercial		
Commonwealth Edison (ComEd)	HVAC and Weatherization Rebates	Downstream	Residential	Illinois	No
Consolidated Edison (ConEd)	Residential HVAC Electric Program	Downstream	Residential	New York	No
Efficiency Maine	Home Energy Savings Program	Downstream	Residential	Maine	Yes
	C&I Prescriptive Incentive Program	Downstream	Commercial		
Efficiency Vermont	Residential Emerging Markets Program	Upstream	Residential	Vermont	Yes
	Business Energy Services	Upstream	Commercial		
Energize Connecticut	HVAC and Domestic Water Heating Program	Downstream	Residential	Connecticut	No
	Cool Choice	Downstream	Commercial		
Energy Trust of Oregon	Existing Homes Program	Downstream	Residential	Oregon	No
FirstEnergy	Residential HVAC and Water Heating Program	Downstream	Residential	Pennsylvania	No
	C&I HVAC and Appliances	Downstream	Commercial		
Idaho Power	Ductless Mini Spit Heat Pump Pilot Program	Downstream	Residential	Idaho	No
Massachusetts Program Administrators	Heating and Cooling Electric (Cool Smart)	Downstream	Residential	Massachusetts	No
	Nonresidential Upstream HVAC	Upstream	Commercial		
National Grid	ENERGY STAR HVAC Program	Downstream	Residential	Massachusetts, Rhode Island	Yes
	Large Commercial Retrofit Program	Upstream	Commercial		
Vectren	Residential Rebate Program	Downstream	Residential	Indiana	No

4.2 MEASURE CRITERIA AND INCENTIVES

Table 4-2 provides the detailed efficiency criteria and rebate amounts for each of the 13 programs. Key findings relating to DMSHP measure eligibility criteria and incentives include:

- The majority of programs (10 of the 13) have SEER requirements for cooling, ranging from 15 to 23 SEER, with three of the programs having two tiers with different rebate amounts
- Nearly all programs (12 of 13) have HSPF requirements for heating, ranging from 9.0 to 12.0
- Four programs have EER rating requirements, ranging from 12.0 to 12.5.
- Rebate amounts range from $150 to $1,200, with some programs offering multiple tiers based on unit efficiency or replaced unit
- Two program managers reported setting rebate levels based on estimated incremental costs between qualifying and baseline efficiency DMSHPs. One program manager estimated an incremental cost between a baseline heat pump (the program's technical assumptions use a baseline of 14 SEER, 8.2 HSPF) and a qualifying heat pump (18.0, 12.0 HSPF) at approximately $600. Another program manager estimated the incremental cost between a baseline heat pump (the program's technical assumptions use a baseline of 14.5 SEER, 12.0 EER, 8.2 HSPF) and a qualifying heat pump (20.0 SEER, 12.0 EER, 10.3 HSPF) at $500-600.

Table 4-2. DMSHP Efficiency Criteria

Program Administrator	RES/C&I	SEER	EER	HSPF	Rebate
AEP	RES	15.0	12.5	8.5	$200
BPA	Both	N/A	N/A	9.0	$800/$1200*
ComEd	RES	17.0	N/A	9.5	$300/$500†
ConEd	RES	18.0/20.0	12.5	9.0	$150/$380‡
Efficiency Maine	Both	18.0	N/A	12.0	$500
Efficiency Vermont	Both	20.0	12.0	10.3	$600
Energize Connecticut	RES	20.0	N/A	10.0	$300/$1000§
	C&I	14.0/15.0	N/A	N/A	$50/$85 per ton
Energy Trust of Oregon	RES	N/A	N/A	9.0	$800
FirstEnergy	RES	20.0	12.0	12.0	$200
	C&I	N/A	12.0	10.0	$150 per ton
Idaho Power	RES	N/A	N/A	N/A	$750
Massachusetts Program Administrators	Both	18.0/20.0	N/A	9.0	$250/$500‡
National Grid	Both	18.0/20.0	N/A	9.0/11.0	$250/$500‡
Vectren	RES	17.0/19.0/ 21.0/23.0	N/A	9.5/10.0	$500/$700 $850/$1,000‡

* BPA offers $800 for homes heated with zonal electric and $1,000 for homes heated with electric forced air furnaces. BPA's program manager suggested the electric forced air furnace incentives was raised to $1200 recently. BPA also offers a rebate of $800/ton to C&I customers.

† ComEd offers $300 for homes heated with conventional ASHP and $500 for homes heated with electric resistance.

‡ ConEd, Massachusetts Program Administrators, and National Grid offer two rebate tiers with higher incentives levels for more efficient DMSHPs. Vectren offers four rebate tiers.

§ Energize Connecticut offers $300 rebates except for homes with electric resistance heat, which are offered $1,000.

Other program-specific measure criteria include the following:

- Quantity limit of one DMSHP unit per household (Idaho Power and ComEd)
- Size requirements such as 0.75 tons or greater (BPA)
- AHRI certification of outdoor and indoor units (First Energy, ComEd, Massachusetts Program Administrators)
- Unit must be inverter driven (Efficiency Vermont, Energy Trust, Idaho Power)

- Indoor unit must be labelled and permanently affixed, condensate must be removed from the system, line set must be insulated and protected with UV-resistant covering (Energy Trust)
- Greater than or equal to 1.75 COP at 5° Fahrenheit and capable of providing heat down to -5° Fahrenheit (Efficiency Vermont)
- Must use R410a refrigerant (Idaho Power)
- No ductwork allowed (Idaho Power)
- Must be ENERGY STAR certified and sized within ½ ton of load calculation based on design temperatures for area (National Grid).

4.3 APPROACHES TO ESTIMATING SAVINGS

Programs researched use a mix of either deemed or hybrid savings values for DMSHP heating and/or cooling. Table 4-3 shows the useful life, size specifications, and savings values for each program.

Table 4-3. DMSHP Deemed Savings Values

Program Administrator	Measure Life	Size	Cooling Savings	Heating Savings
BPA	15 yrs.	≥ 0.75 tons	1634-3009 kWh*	
ComEd	18 yrs.	N/A	N/A	N/A
ConEd	15 yrs.[‡]	All	271 kWh/ton	51 kWh/ton
Efficiency Maine	18 yrs.	All	1,902 kWh	
Efficiency Vermont[†]	18 yrs.	9,000 BTU/hr	1,705 kWh	0.37 MMBtu
		12,000 BTU/hr	1,542 kWh	0.39 MMBtu
		15,000 BTU/hr	1,404 kWh	0.40 MMBtu
		18,000 BTU/hr	1,525 kWh	0.39 MMBtu
		24,000 BTU/hr	1,642 kWh	0.46 MMBtu
Energize Connecticut	15 yrs.	N/A	N/A	N/A
Energy Trust of Oregon	15 yrs.	≥ 0.75 tons	1634-3009 kWh*	
FirstEnergy	15 yrs.	N/A	N/A	N/A
Idaho Power	15 yrs.	≥ 0.75 tons	1634-3009 kWh*	
Massachusetts Program Administrators	18 yrs.	1.25 tons	648 kWh	
National Grid	18 yrs.	1.25 tons	330 kWh	

*BPA deemed savings depend on climate zone. BPA, Energy Trust and Idaho Power appear to use the same savings tables.

† Efficiency Vermont has deemed savings values for five DMSHP sizes.

‡ The New York TRM does not list DMSHPs. The measure life listed here is for conventional heat pumps.

Baseline assumptions for DMSHP installations vary by program Baseline assumptions and efficiency ratings used by each program are listed in Table 4-4. Key findings include the following:

- Programs most commonly assume a baseline condition of either a standard efficiency heat pump or electric resistance heating, both assuming electric-only savings and no fuel switching
- Baseline SEER values range from 8.0 to 14.5, most commonly 13.0 or higher
- Baseline EER values range from 8.5 to 12.0
- Baseline HSPF values range from 3.2 to 8.2
- Generally, programs that assume a baseline of electric resistance heat have lower HSPF values, while those that assume a baseline of low efficiency DMSHPs have higher HSPF values. Several programs (ComEd, Energize Connecticut, and First Energy) use multiple baseline conditions depending on the equipment being replaced.

Table 4-4. Baseline Efficiency Ratings

Program Administrator	Baseline Description	SEER	EER	HSPF
BPA*	Electric zonal heat or forced air furnace	N/A	N/A	N/A
ComEd†	Permanent electric resistance or ducted air source heat pump	8.0-9.1	N/A	3.4-5.4
ConEd	Standard efficiency DMSHP	13.0	11.1	N/A
Efficiency Maine	Standard efficiency DMSHP with supplemental heat	14.0	N/A	8.2
Efficiency Vermont	Standard efficiency heat pump	14.5	12.0	8.2
Energize Connecticut†	Electric resistance or fossil fuel	10.1-13.0	N/A	3.4-7.7
Energy Trust of Oregon*	Electric resistance heat	N/A	N/A	N/A
FirstEnergy†	DMSHP, central AC, room AC, electric resistance heat or electric furnace	11.3-14.0	9.8	3.2-8.2
Idaho Power*	Zonal electric heat	N/A	N/A	N/A
Massachusetts Program Administrators	Standard efficiency DMSHP	14.0	8.5	8.2
National Grid	Standard efficiency DMSHP	14.0	8.5	8.2

* BPA, Energy Trust, and Idaho Power use deemed baseline figures.

† ComEd, Energize Connecticut, and First Energy have multiple baseline figures depending on the replaced unit.

Three of the programs interviewed (Efficiency Maine, Efficiency Vermont, and National Grid) assume a baseline of standard efficiency heat pump, claiming electric savings for the installation of a high efficiency DMSHP. Under this condition, savings are claimed for only the efficiency gains of a qualifying DMSHP unit. One program manager noted, “The fundamental assumption is that heat pumps are being installed without our influence. We offer a small rebate to encourage installation of high performance cold-climate systems.”

4.4 NET-TO-GROSS ASSUMPTIONS

The secondary peer-program research also investigated freeridership, spillover, and net-to-gross (NTG) values for the various DMSHP programs in order to provide context for attributing savings. Eight of the 11 programs publish NTG values, with the remaining either not conducting NTG research or not publishing their findings. NTG estimates based on evaluation research range from 0.40 to 0.80. Three program administrators have stipulated or deemed NTG ratios ranging from 0.75 to 1.10. Table 4-5 shows the NTG findings for each of the researched programs.

Table 4-5. DMSHP Program NTG Estimates

Program Administrator	Net-to-Gross	Free-riderhsip	Spillover	Source
BPA	None	None	None	N/A
ComEd	Unknown	Unknown	Unknown	N/A
ConEd*	0.53	0.47	0.00	Evaluated
Efficiency Maine*	0.75	0.25	0.00	Stipulated
Efficiency Vermont*	0.88	0.19	0.07	Stipulated
Energize Connecticut	Unknown	Unknown	Unknown	N/A
Energy Trust of Oregon†	0.80	0.28	0.08	Evaluated
FirstEnergy	0.40	0.62	0.02	Evaluated
Idaho Power‡	1.00	N/A	N/A	Stipulated
Massachusetts Program Administrators	0.62	0.45	0.07	Evaluated
National Grid	0.62	0.45	0.07	Evaluated

* ConEd, Efficiency Maine, Efficiency Vermont, FirstEnergy, Massachusetts, and National Grid figures are measure-specific for DMSHP.

† Energy Trust of Oregon evaluates NTG at the program level.

‡ Idaho Power uses a deemed NTG of 1.00 for all programs and measures.

4.5 MARKETING, RECRUITMENT, AND BARRIERS TO PARTICIPATION

Interviews with program managers investigated marketing and recruitment strategies for DMSHP measures. Direct marketing for the residential programs interviewed is largely focused on digital media and social networking, with little conventional advertising. One interviewee noted that marketing is generally done seasonally, with a focus on summer cooling and winter heating. Efficiency Vermont and National Grid, both of which operate midstream programs, also report strong relationships with contractors and distributors and that these relationships have been essential to promoting high efficiency DMSHP technology. Commercial programs generally do not target specific customer segments; however, interviewees report that DMSHP participants are generally smaller commercial customers.

Program managers also spoke about barriers to participation and program success. Interviewees identified the following key adoption barriers for DMSHP measures specifically:

- High incremental costs associated with high efficiency equipment over baseline.
- Slow residential contractor adoption rate of DMSHP technology; commercial DMSHP installers tend not to cross over into residential applications.
- Less contractor engagement in midstream and upstream programs than with downstream model.

4.6 KEY LESSONS LEARNED

Program managers also noted a number of lessons learned from their experiences designing and implementing DMSHP programs, including the following:

- There is an adjustment period where customers change their usage patterns in the first couple of years as they become accustomed to the new technology. This results in increased load displacement as customers learn how to use the system.
- Successful DMSHP programs require a number of moving parts including marketing, trade ally engagement, financing, adequate rebate structures, and high efficiency standards.
- Supporting a broader selection of qualifying high efficiency DMSHP products available on the market instead of targeting specific sizes or models can help to promote right sizing and market suitability.
- Midstream programs can be challenging as distributors may be reluctant to share customer information which is crucial for program tracking purposes. Developing and maintaining relationships with distributors is key to the success of midstream programs.
- Keep measure eligibility requirements simple and similar across sectors. Complexity causes confusion in the market with contractors and participants.
- Manufacturers are working in global markets, typically a two-to-three year development cycle for new specs, so programs have to keep up with this cycle.

5. TECHNOLOGY WORKPAPERS

This section of the report presents the workpapers that the Tetra Tech team has developed for consideration by Focus on Energy as a possible addition to the Focus on Energy Technical Reference Manual (TRM). Three workpapers are provided to describe calculations and considerations for DMSHP technology. They are meant to complement an existing residential workpaper already developed by Focus on Energy covering a DMSHP retrofit to homes with electric resistance space heating in 2016. In contrast to the existing Focus on Energy workpaper, the baseline conditions of the Tetra Tech workpapers are assumed to be less efficient DMSHP systems.

The workpapers are structured around savings associated with recommended minimum SEER and HSPF efficiency ratings in order to qualify for the program. These are presented in Table 5-1, below.

Table 5-1. Recommended Minimum Efficiency Factors

Efficiency Factor	Single-split	Multi-split
SEER	20	18
HSPF	10	10

Due to the savings potential for units with energy efficiency criteria exceeding these minimum requirements, the Tetra Tech team recommends that Focus on Energy claim savings as a hybrid measure and based on the actual specifications of incentivized equipment. Doing so serves two purposes:

1) Allows the Focus on Energy program to claim higher savings and greater cost effectiveness, and
2) Provides an incentive for programs to gather market data and track the efficiency ratings of equipment incentivized by the program.

The workpapers have as their underpinnings several resources that were referenced during the course of the project. These include:

- TRMs from other programs that offer DMSHP as a measure
- The workpaper developed by Focus on Energy used to support the current pilot program supporting DMSHP technology
- Interviews with Wisconsin contractors currently selling DMSHP and several manufactures who make DMSHP for their markets
- Interviews with program managers whose programs offer DMSHP.

The logic of the workpapers is based on the following key market findings:

- The DMSHP market is dominated by residential sales, by a ratio of about 3:1.
- DMSHP is still a relatively immature technology to the Wisconsin market.

- Most units are sold with space cooling as the primary end-use, with heating only being active during shoulder months.
- Trade allies view a SEER of 18 to 20 as the start of higher efficiency systems, with baseline SEER in the 13 or 14 range.
- DMHSP systems are sold as a solution to meeting a space conditioning need, not as a replacement for traditional space conditioning technology, with the value proposition based on the features of a DMHSP system. Alternative technologies include window air-conditions, PTACs, or expanding ductwork and central air-conditioning or heat pump systems.
- As space cooling is the primary focus of sales, contractors indicated that existing heating systems are still retained and used, with DMHSP only providing a portion of heating.
- In the commercial market, the lodging industry may be the exception of the general opinion around space heating use, with higher space heating loads being covered by the DMHSP.
- To a degree, contractors are targeting residential markets that have electric resistance space heat or non-utility fuels as the heating system, but generally do not attempt to sell DMHSP as an alternative to the underlying heating system due to heating capacity limits. With systems being sized for cooling loads, the majority of contractors do not feel the DMSHP technology can adequately serve as a heating system that displaces the main sources of heat in the homes.

As a result, the structure of the workpapers is also based on the following program assumptions and recommendations:

- Actual baseline conditions will be difficult to verify absent onsite verification. While a blended baseline may be one solution, it is not clear that the market data is available to develop a blended baseline across the fuels that reflects the current Wisconsin market.
- In most applications, consider the baseline technology as a less efficient DMSHP. This recommendation is based on DMSHPs being sold as a solution (a DMHSP would have been sold, regardless) and avoids the cross-fuel or potential for negative kWh savings that might happen if other heating fuels are considered the baseline (i.e., fuel switching). The one exception we recommend is for the lodging industry, due to the presence of PTAC or PTHP technology.
- For the residential and most commercial markets, cooling should be the primary focus of savings, with heating impacts based on adjusting the heating loads to reflect shoulder month heating or heating during less-cold weather. The exception is for the lodging industry, with either a PTAC or PTHP serving as a baseline, and for server closets, for which less heat load should be assumed.
- Since DMSHP technology is a relatively new measure to Wisconsin and contractors have a relatively limited perspective on potential efficiency levels or cold-climate packages supporting greater heating use, the program should direct the market toward greater efficiency. In contrast to markets in which DMSHPs have been

operating for a longer time and for which higher efficiency requirements may be appropriate, Focus should approach DMSHP efficiency requirements incrementally. A laddered approach in which program efficiency eligibility requirements are periodically reviewed and potentially increased will enable to market to develop greater understanding of the technology and efficiency options. Savings calculations may also need to be adjusted in response to program eligibility requirements. Doing so may also allow Focus on Energy to demonstrate market effects and avoid either curtailing a growing market by moving too fast on efficiency requirements or risk lower efficiency technology market growth.

The workpapers utilize a number of assumptions that stem from a variety of sources. These include the Focus on Energy TRM for heating and cooling measures, the Illinois TRM to inform full load hour estimates, and technical research described earlier in this report. Tetra Tech notes that there are still substantial uncertainties and variability in how DMSHP systems are used even in more mature markets. For Wisconsin, these uncertainties should be researched over time and workpapers updated to reflect current market knowledge.

A major point of uncertainty relates to the equivalent full load hours for heating. The Tetra Tech team worked with Focus on Energy and its evaluator to discuss a number of approaches to address equivalent full load hours for heating. In the end, while it appears that assuming standard residential full load hours are appropriate due to systems not being used during the coldest weather, a temperature bin approach in which full load hours are scaled based on the number of heating hours above a threshold (e.g., 30 F) misses the mark as well. With systems being sized for cooling loads and with Wisconsin being a heating-dominated climate, undersized systems would operate more hours closer to full load at warmer temperatures than a system sized to meet all heating loads would be. This issue is a point for further research and Tetra Tech's proposed solution simply discounts the TRM's heating full load hours to account for this uncertainty to create a more conservative assumption than the TRM would otherwise suggest.

Next we present potential DMSHP workpapers for three sectors – Residential, General Commercial, and Lodging.

5.1 RESIDENTIAL DUCTLESS MINI-SPLIT HEAT PUMPS

5.1.1 Measure description

A residential-sized ductless mini-split heat pump (DMSHP) with an output capacity of ≤ 65,000 Btu/hr. This work paper documents the energy savings for ductless mini-split heat pumps with energy efficiency performance of 20 SEER (single-split), 18 SEER (multi-split) and 10.0 HSPF or greater with inverter technology.

5.1.2 Description of baseline condition

The DMSHP systems could be installed as the primary cooling system for the house or as a secondary heating or cooling system.

Qualifying baseline scenarios involve a less efficient ductless mini-split heat pump as the alternative technology to provide space cooling and a portion of annual heating.

Measure characteristics assume a DMSHP baseline technology installed without connection to ductwork.

5.1.3 Description of efficient condition

The efficient condition for ductless single-split heat pumps is 20 SEER and 10.0 HSPF or greater with inverter technology. For ductless multi-split heat pumps the assumption is a SEER of 18 and HSPF of 10.0.

Savings are dependent on a less efficient DMSHP unit meeting minimum federal requirements for HSPF and SEER as well as SEER, and HSPF of efficient unit from nameplate information. DMSHP EFLH for heating are assumed to be 75 percent of the Focus on Energy TRM residential heating EFLH (1,909 hours).[12] Although a system sized for cooling may only be used for heating for a portion of the heating season, the undersized nature of the equipment would lead to higher EFLH than for a system sized for heating and heating in the same ambient temperature conditions due to operating more often close to its full output capacity.

EER for efficient equipment should be taken from manufacturer data if available, but otherwise use the following formulae, provided by Cadmus, the Focus on Energy EM&V contractor, using product information from the NEEP database.[13]

Single-split: $EER = 0.0178 \times SEER^2 - 0.5731 \times SEER + 17.344$

Multi-split: $EER = 0.0831 \times SEER + 11.382$

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[12] Focus on Energy Technical Reference Manual. October 22, 2015. Statewide EFLH heating, p. 527. https://focusonenergy.com/sites/default/files/TRM%20Fall%202015%20_10-22-15.compressed2.pdf.

[13] http://www.neep.org/initiatives/high-efficiency-products/emerging-technologies/ashp/cold-climate-air-source-heat-pump.

5.1.4 Annual energy-savings algorithm (example)

$kWh = kWh_{heating} + kWh_{cooling}$

$kWh_{heating} = (CAP_{EE} * HOU_{heating-} * (1 / HSPF_{base} – 1 / HSPF_{EE}) / 1000$

$kWh_{cooling} = (CAP_{EE} * HOU_{cooling-} * (1 / SEER_{base} – 1 / SEER_{EE}) / 1000$

Where:

CAP_{EE} = Capacity of efficient equipment (Btu/hour)

$HSPF_{BASE}$ = Baseline heating seasonal performance factor (=8.2 for DMSHP)[14]

$HSPF_{EE}$ = Efficient measure heating seasonal performance factor

$HOU_{heating-EE}$ = Hours of Use for efficient equipment heating (=1,432)[15]

$SEER_{base}$ = Baseline seasonal energy efficiency ratio (=14.0 for air conditioning provided by heat pumps).[1]

$SEER_{EE}$ = Efficient measure seasonal energy efficiency ratio

$HOU_{cooling-EE}$ = Hours of Use for efficient equipment cooling (= 321)[16]

[14] Code of Federal Regulations. Starting January 1, 2017, the minimum HSPF for split heat pump systems is 8.2. Federal minimum SEER = 13.0. Federal minimum EER = 11.2.

[15] This value is the result of multiplying the Focus TRM assumed statewide average effective full load hours for heating (1,909 hours) by 0.75. See: https://focusonenergy.com/sites/default/files/TRM%20Fall%202015%20_10-22-15.compressed2.pdf p. 527.

[16] Focus on Energy Technical Reference Manual. October 22, 2015. Statewide EFLH cooling, pp. 614-615. https://focusonenergy.com/sites/default/files/TRM%20Fall%202015%20_10-22-15.compressed2.pdf.

5.1.5 Summer coincident peak savings algorithm

$$kW = CAP * (1 / EER_{base} – 1 / EER_{EE}) * CF / 1000$$

Where:

CAP_{EE} = Capacity of efficient equipment (= 18,000 Btu/hour)

EER_{base} = Energy Efficiency Ratio of baseline unit (=12.8 single-split, 12.5 multi-split)

EER_{EE} = Energy Efficiency Ratio of efficient unit (using relevant formula below))

Single-split: $EER = 0.0178 \times SEER^2 - 0.5731 \times SEER + 17.344$

Multi-split: $EER = 0.0831 \times SEER + 11.382$

CF = Coincidence factor (=0.68)[17]

5.1.6 Lifecycle energy-savings algorithm

$$kWh_{lifecycle} = kWh_{saved} * EUL$$

Where:

EUL = Effective useful life (=18 years)[18]

5.1.7 Example savings

The following savings are presented for illustration purposes only, showing an outcome of the hybrid calculation. Input values that could vary include capacity, SEER, EER, and HSPF. This example uses the following input assumptions:

Capacity = 18,000 BTU/hr

Efficient SEER = 20 for single-split and 18 for multi-split

Efficient EER = 13.0 for single-split and 12.9 for multi-split

Efficient HSPF = 10.0

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[17] Focus on Energy Technical Reference Manual. October 22, 2015. Residential coincidence factor., p. 454. https://focusonenergy.com/sites/default/files/TRM%20Fall%202015%20_10-22-15.compressed2.pdf.

[18] Assumed based on similar measures and other programs' TRMs.

Type of Savings (kWh)	Measure	
	Efficient Ductless Single-split, Replacing Less Efficient Ductless Mini-split	Efficient Ductless Multi-split, Replacing Less Efficient Ductless Mini-split
Annual	690	566
Lifecycle	12,413	92

Type of Savings (kW)	Measure	
	Efficient Ductless Single-split, Replacing Less Efficient Ductless Mini-split	Efficient Ductless Multi-split, Replacing Less Efficient Ductless Mini-split
Annual	0.014	0.025
Lifecycle	0.014	0.025

5.1.8 Assumptions

For the example calculation, the capacity of residential heat pump is assumed to be 1.5 tons for equipment installed in the Wisconsin market. At 12,000 Btu/hour per ton, the assumed average capacity is therefore 18,000 Btu/hr.

Based on market research conducted by Tetra Tech, the current Wisconsin DMSHP market is focused on providing cooling solutions to residential spaces where no ducts currently exist. The potential spaces are diverse and include residential additions, areas with no current air-conditioning and existing zonal heating, or areas that may otherwise use a room air-conditioner. Ductless heat pumps are being sold as a solution to cooling and partially heating these spaces. The marketing emphasizes cooling loads and the existing heating systems are retained to provide heating, but not to provide all heating. As such the heating hours of use across end-users are likely highly variable and may offset electric resistance heating or hydronic heating with natural gas or non-utility fuels. However, as the DMSHP technology is being sold as the solution to meeting customer needs and with cooling as the core value proposition, fuel switching is not being shown for displacing the current heating system – only the less efficient DMSHP system.

The efficient criteria of SEER = 20 and SEER = 18 for multi-split was selected based on interviews with Wisconsin contractors currently selling DMSHP systems and a review of cold-climate DMSHP equipment specifications. HSPF of 10 was selected based on a brief review of technical specifications of equipment that met the SEER= 20 criteria. These factors provide a significant gain from federal minimum standards for heat pump performance.[19] Tetra Tech recommends that the actual installed performance factors be used to calculate savings for each project, allowing for the mix of diverse products and capacities to be accounted for in program savings. As a hybrid measure, the key performance factors that would vary include SEER, EER (if available), HSPF, and BTU/hr capacity. Hours of use and baseline energy performance factors would remain constant.

5.2 GENERAL COMMERCIAL

5.2.1 Measure description

A small capacity ductless mini-split heat pump (DMSHP) with an output capacity of ≤ 65,000 Btu/hr.[3] This workpaper documents the energy savings for ductless mini-split heat pumps with energy efficiency performance of 20 SEER (single split), 18 SEER (multi-split) and 10.0 HSPF or greater with inverter technology.

5.2.2 Description of baseline condition

The DMSHP systems could be installed as the primary cooling system for the account or as a secondary heating or cooling system for a single room.

Qualifying baseline scenarios involve a less efficient ductless mini-split heat pump as the alternative technology to provide space cooling and a portion of annual heating.

Measure characteristics assume a DMSHP baseline technology installed as a single zone system and without connection to ductwork.

5.2.3 Description of efficient condition

The efficient condition for ductless mini-split heat pumps is 20 SEER (single split), 18 SEER (multi-split) and 10.0 HSPF or greater with inverter technology.

Savings are dependent on a less efficient DMSHP unit meeting minimum federal requirements for HSPF and SEER as well as SEER, and HSPF of efficient unit from nameplate information.

EER for efficient equipment should be taken from manufacturer data if available, but otherwise use the following formulae, provided by Cadmus, the Focus on Energy EM&V contractor.

Single-split: $EER = 0.0178 \times SEER^2 - 0.5731 \times SEER + 17.344$

Multi-split: $EER = 0.0831 \times SEER + 11.382$

[19] The Code of Federal Regulations specifies heat pump performance criteria for systems manufactured on or after Jan 1, 2015. https://www.gpo.gov/fdsys/pkg/CFR-2012-title10-vol3/pdf/CFR-2012-title10-vol3-sec430-32.pdf.

5.2.4 Annual energy-savings algorithm (example)

$$kWh = kWh_{heating} + kWh_{cooling}$$

$$kWh_{heating} = (CAP_{EE} * HOU_{heating-} * (1 / HSPF_{base} – 1 / HSPF_{EE}) / 1000$$

$$kWh_{cooling} = (CAP_{EE} * HOU_{cooling-} * (1 / SEER_{base} – 1 / SEER_{EE}) / 1000$$

Where:

CAP_{EE} = Capacity of efficient equipment (Btu/hour)

$HSPF_{BASE}$ = Baseline heating seasonal performance factor (=8.2 for DMSHP)[20]

$HSPF_{EE}$ = Efficient measure heating seasonal performance factor

$HOU_{heating-EE}$ = Hours of Use for efficient equipment heating (=1,466)[21]

$SEER_{base}$ = Baseline seasonal energy efficiency ratio (=14.0 for air conditioning provided by heat pumps).[20]

$SEER_{EE}$ = Efficient measure seasonal energy efficiency ratio

$HOU_{cooling-EE}$ = Hours of Use for efficient equipment cooling (= 380)[22]

5.2.5 Summer coincident peak savings algorithm

$$kW = CAP * (1 / EER_{base} – 1 / EER_{EE}) * CF / 1000$$

Where:

EER_{base} = Energy Efficiency Ratio of baseline unit (=12.8 single-split, 12.5 multi-split)

EER_{EE} = Energy Efficiency Ratio of efficient unit ((using relevant formula below)

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[20] The Code of Federal Regulations specifies heat pump performance criteria for systems manufactured on or after Jan 1, 2015. https://www.gpo.gov/fdsys/pkg/CFR-2012-title10-vol3/pdf/CFR-2012-title10-vol3-sec430-32.pdf

[21] Focus on Energy Technical Reference Manual. October 22, 2015, p. 452. EFLH for heating for ground source heat pumps. https://focusonenergy.com/sites/default/files/TRM%20Fall%202015%20_10-22-15.compressed2.pdf, p. 452.

[22] Focus on Energy Technical Reference Manual. October 22, 2015. Statewide EFLH cooling and coincidence factors, p. 136 for commercial split system A/C units. https://focusonenergy.com/sites/default/files/TRM%20Fall%202015%20_10-22-15.compressed2.pdf.

Single-split: EER = 0.0178 x SEER² - 0.5731 x SEER + 17.344

Multi-split: EER = 0.0831 x SEER + 11.382

CF = Coincidence factor (=0.66)[23]

5.2.6 Lifecycle energy-savings algorithm

$kWh_{lifecycle}$ = kWh_{saved} * EUL

Where:

EUL = Effective useful life (=18 years)[24]

5.2.7 Example savings

The following savings are presented for illustration purposes only, showing an outcome of the hybrid calculation. Input values that could vary include capacity, SEER, EER, and HSPF. This example uses the following input assumptions:

Capacity = 18,000 BTU/hr

Efficient SEER = 20 for single-split and 18 for multi-split

Efficient EER = 13.0 for single-split and 12.9 for multi-split

Efficient HSPF = 10.0

Type of Savings (kWh)	Measure	
	Efficient Ductless Single-split, replacing less efficient Ductless Mini-split	Efficient Ductless Multi-split, replacing less efficient Ductless Mini-split
Annual	726	688
Lifecycle	13,065	12,381

[23] Focus on Energy Technical Reference Manual. October 22, 2015, p136. https://focusonenergy.com/sites/default/files/TRM%20Fall%202015%20_10-22-15.compressed2.pdf.
[24] Assumed based on similar measures and other programs' TRMs.

Type of Savings (kW)	Measure	
	Efficient Ductless Single-split, replacing less efficient Ductless Mini-split	Efficient Ductless Multi-split, replacing less efficient Ductless Mini-split
Annual	0.014	0.024
Lifecycle	0.014	0.024

5.2.8 Assumptions

For the example calculation, the capacity of a small DMSHP is assumed to be 1.5 tons for equipment installed in the Wisconsin general commercial market. At 12,000 Btu/hour per ton, the assumed average capacity is therefore 18,000 Btu/hr.

Based on market research conducted by Tetra Tech, the current Wisconsin DMSHP market is focused on providing cooling solutions to residential spaces where no ducts currently exist. Contractors, in general, have less experience with the commercial market, but are selling to commercial end-users. The potential spaces are diverse. Ductless heat pumps are being sold as a solution to cooling and partially heating these spaces. The marketing emphasizes cooling loads and the existing heating systems are retained to provide heating, but not to provide all heating. As such the heating hours of use are likely highly variable across end-users and may offset a variety of potential heating system types and fuels. However, as the DMSHP technology is being sold as the solution to meeting customer needs and with cooling as the core value proposition, fuel switching is not being shown for displacing the current heating system – only the less efficient DMSHP system and the heat it would supply.

The efficient criteria of SEER = 20 for single-split and SEER = 18 for multi-split was selected based on interviews with Wisconsin contractors currently selling DMSHP systems and a review of cold-climate DMSHP equipment specifications. HSPF of 10 was selected based on a brief review of technical specifications of equipment that met the SEER= 20 criteria. These factors provide a significant gain from federal minimum standards for heat pump performance.[25] Tetra Tech recommends that the actual installed performance factors be used to calculate savings for each project, allowing for the mix of diverse products and capacities to be accounted for in program savings. As a hybrid measure, the key performance factors that would vary include SEER, EER (if available), HSPF, and BTU/hr capacity. Hours of use and baseline energy performance factors would remain constant.

[25] The Code of Federal Regulations specifies heat pump performance criteria for systems manufactured on or after Jan 1, 2015. https://www.gpo.gov/fdsys/pkg/CFR-2012-title10-vol3/pdf/CFR-2012-title10-vol3-sec430-32.pdf.

5.3 LODGING INDUSTRY

5.3.1 Measure description

A small capacity ductless mini-split heat pump (DMSHP) with an output capacity of ≤ 65,000 Btu/hr.[3] This work paper documents the energy savings for ductless mini-split heat pumps with energy efficiency performance of 20 SEER (single-split), 18 SEER (multi-split) and 10.0 HSPF or greater with inverter technology.

5.3.2 Description of baseline condition

The DMSHP systems could be installed as the primary cooling system for the account or as a secondary heating or cooling system for a single room.

Qualifying baseline scenarios involve either a PTAC with electric resistance heating or a PTHP at the end of useful life or major renovation serving guest rooms and without central heating. For true new construction assume PTHP as the baseline.

Measure characteristics assume a DMSHP baseline technology installed as a single zone system and without connection to ductwork.

5.3.3 Description of efficient condition

The efficient condition for ductless mini-split heat pumps is 20 SEER (single split), 18 SEER (multi-split) and 10.0 HSPF or greater with inverter technology.

Savings are dependent on PTAC or PTHP units meeting minimum federal requirements for HSPF and SEER as well as SEER, and HSPF of the efficient DMSHP unit taken from nameplate information.

EER for efficient equipment should be taken from manufacturer data if available, but otherwise use the following formulae, provided by Cadmus, the Focus on Energy EM&V contractor.

Single-split: $EER = 0.0178 \times SEER^2 - 0.5731 \times SEER + 17.344$

Multi-split: $EER = 0.0831 \times SEER + 11.382$

5.3.4 Annual energy-savings algorithm (example)

$$kWh = kWh_{heating} + kWh_{cooling}$$

$$kWh_{heating} = (CAP_{EE} * HOU_{heating-} * (1 / HSPF_{base} – 1 / HSPF_{EE}) / 1000$$

$$kWh_{cooling} = (CAP_{EE} * HOU_{cooling-} * (1 / SEER_{base} – 1 / SEER_{EE}) / 1000$$

Where:

CAP_{EE} = Capacity of efficient equipment (Btu/hour)

$HSPF_{BASE}$ = Baseline heating seasonal performance factor (=8.2 for PTHP; 3.4 for PTAC with electric resistance heat)[26]

$HSPF_{EE}$ = Efficient measure heating seasonal performance factor

$HOU_{heating-EE}$ = Hours of Use for efficient equipment heating (=2,038)[27]

$SEER_{base}$ = Baseline seasonal energy efficiency ratio (=13.0 for air conditioning provided by PTAC, 14.0 for PTHP).[28]

$SEER_{EE}$ = Efficient measure seasonal energy efficiency ratio

$HOU_{cooling-EE}$ = Hours of Use for efficient equipment cooling (=718)[29]

5.3.5 Summer coincident peak savings algorithm

$$kW = CAP * (1 / EER_{base} – 1 / EER_{EE}) * CF / 1000$$

Where:

EER_{base} = Energy Efficiency Ratio of baseline unit (=10.2 for PTAC, 11.0 for PTHP)[30]

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26 The Code of Federal Regulations specifies heat pump performance criteria for systems manufactured on or after Jan 1, 2015. https://www.gpo.gov/fdsys/pkg/CFR-2012-title10-vol3/pdf/CFR-2012-title10-vol3-sec430-32.pdf.

27 Based on the ratio of EFLH (heating) to the normal HDD of Rockford IL multiplied by the Wisconsin average HDD per the Focus on Energy TRM.

28 The Code of Federal Regulations specifies heat pump and packaged air-conditioner system performance criteria for systems manufactured on or after Jan 1, 2015. https://www.gpo.gov/fdsys/pkg/CFR-2012-title10-vol3/pdf/CFR-2012-title10-vol3-sec430-32.pdf

29 Based on the ratio of EFLH (cooling) to the normal CDD of Rockford IL multiplied by the Wisconsin average CDD per the Focus on Energy TRM.

30 EER is assumed based on current ratio of EER to SEER requirements by the Code of Federal Regulations for single packaged air-conditioners. An EER of 11 and SEER of 14 are required for specific states, with this performance ratio assumed as a general indicator of PTAC and PTHP EER.

EER_{EE} = Energy Efficiency Ratio of efficient unit (using relevant formula below)

Single-split: $EER = 0.0178 \times SEER^2 - 0.5731 \times SEER + 17.344$

Multi-split: $EER = 0.0831 \times SEER + 11.382$

CF = Coincidence factor (=0.66)[31]

5.3.6 Lifecycle energy-savings algorithm

$kWh_{lifecycle} = kWh_{saved} * EUL$

Where:

EUL = Effective useful life (=18 years)[32]

5.3.7 Example savings

The following savings are presented for illustration purposes only, showing an outcome of the hybrid calculation. Input values that could vary include capacity, SEER, EER, and HSPF. This example uses the following input assumptions:

Capacity = 18,000 BTU/hr

Efficient SEER = 20 for single-split and 18 for multi-split

Efficient EER = 13.0 for single-split and 12.9 for multi-split

Efficient HSPF = 10.0

performance. See: https://www.gpo.gov/fdsys/pkg/CFR-2012-title10-vol3/pdf/CFR-2012-title10-vol3-sec430-32.pdf.

31 Focus on Energy Technical Reference Manual. October 22, 2015, p136. https://focusonenergy.com/sites/default/files/TRM%20Fall%202015%20_10-22-15.compressed2.pdf

32 Assumed based on similar measures and other programs' TRMs.

Type of Savings (kWh)	Measure			
	Efficient Ductless Single-split, Replacing PTAC With Electric Resistance Heat	Efficient Ductless Multi-split, Replacing PTAC With Electric Resistance Heat	Efficient Ductless Single-SPLIT, Replacing PTHP	Efficient Ductless Multi-split, Replacing PTHP
Annual	7,470	7,398	1,082	1,010
Lifecycle	134,454	133,161	19,481	18,188

Type of Savings (kW)	Measure			
	Efficient Ductless Single-split, replacing PTAC With Electric Resistance Heat	Efficient Ductless Multi-split, Replacing PTAC With Electric Resistance Heat	Efficient Ductless Single-split, Replacing PTHP	Efficient Ductless Multi-split, Replacing PTHP
Annual	0.25	0.24	0.17	0.16
Lifecycle	0.25	0.24	0.17	0.16

5.3.8 Assumptions

For the example calculation, the capacity of the heat pump or electric resistance heating system (for a PTAC) is assumed to be 1.5 tons for equipment installed in the Wisconsin market. At 12,000 Btu/hour per ton, the assumed average capacity is therefore 18,000 Btu/hr.

Based on market research conducted by Tetra Tech, the current commercial DMSHP market is small compared to the residential market, but the lodging industry may have potential for savings that differ from the residential or general commercial markets. The workpaper focuses on guest rooms for which a PTAC or PTHP are the alternative technology and central heating does not heat the guest rooms. In the case of a PTAC, electric resistance heat is the assumed baseline. For a PTHP, the baseline technology is assumed to be a federal minimum standard PTHP, not a less efficient DMSHP. The hours of use differ from the general commercial example based on the EFLH identified for guest rooms in the Illinois TRM. The EFLH are adjusted to the Wisconsin average climate by multiplying by the ratio of HDD and CDD to the respective EFLH (heating or cooling) from the Illinois TRM for Rockford.

The efficient criteria of SEER = 20 for single-split and SEER = 18 for multi-split was selected based on interviews with Wisconsin contractors currently selling DMSHP systems and a review of cold-climate DMSHP equipment specifications. HSPF of 10 was selected based on a brief review of technical specifications of equipment that met the SEER= 20 criteria. These factors provide a significant gain from federal minimum standards for heat pump performance.[33] Tetra Tech recommends that the actual installed performance factors be used to calculate savings for each project, allowing for the mix of diverse products and capacities to be accounted for in program savings. As a hybrid measure, the key performance factors that would vary include SEER, EER (if available), HSPF, and BTU/hr capacity. Hours of use and baseline energy performance factors would remain constant.

[33] The Code of Federal Regulations specifies heat pump performance criteria for systems manufactured on or after Jan 1, 2015. https://www.gpo.gov/fdsys/pkg/CFR-2012-title10-vol3/pdf/CFR-2012-title10-vol3-sec430-32.pdf

APPENDIX A: TRADE PROFESSIONAL INTERVIEW GUIDE

This topic guide was used for interviews with manufacturers and installation contractors of ductless mini-split heat pump (DMSHP) technologies in Wisconsin. Interviews with trade professionals were semi-structured. While this guide served to offer consistent direction, interviews were tailored based on the specific program designs and the roles and responsibilities of each interviewee. As a result, not all questions were asked of all interviewees and interviews may have explored other topics specific to each program.

The interviews focused on the following topic areas:

- Company profile—products and services offered, markets served (e.g., residential, commercial, schools and local government), service area, number of employees, involvement with Focus on Energy programs
- Installations of DMSHP technologies—proportion of new construction vs. retrofit, existing equipment replaced by DMSHP systems, consumer usage (e.g., heating vs. cooling; primary vs. supplemental), and types of heating/cooling systems used in conjunction with DMSHP, and incremental costs
- Customer interactions—consumer awareness of DMSHP, key market barriers, consumer preferences and motivations for purchasing DMSHP systems, marketing and outreach
- Market—future of DMSHP market, customer segments and applications that present the greatest market potential, perceptions on role for Focus on Energy.

Introduction

Hello, my name is _________________ with Tetra Tech. We are working with Wisconsin Focus on Energy (Focus) to assess the market for energy efficient ductless-mini split heat pump (DMSHP) technologies in effort continually improve their energy efficiency program offerings to customers. As part of this effort, Focus is interested in learning more about installations and usage of DMSHP systems in Wisconsin. Specifically, I would like to ask you a few questions about your experiences selling/installing DMSHP systems and interactions with your customers. Your feedback is greatly appreciated.

Before we begin, is it okay if I record our call to help with note-taking? Your individual responses will not be identified with you or your company.

Installation Contractor Questions

[If installation contractor, continue. If manufacturer/distributor, skip to “Manufacturer/Distributor Questions” section]

Company Profile

1. Please describe the types of services your company provides in the HVAC market?

2. Can you estimate what percentage of your HVAC business is for a) residential customers, b) commercial customers, and c) schools and local government?

a. Residential ______%

b. Commercial _____%

c. Schools and Local Government ______%

3. What areas within Wisconsin do your company primarily serve?

4. How many full-time staff are employed by your company?

5. Can you please describe your involvement with Focus on Energy's programs?

DMSHP Installations

1. How would you describe your company's level of activity in the DMSHP market? Would you say you are "very active", "somewhat active", or "not very active"? *(Probe for reasons why and any barriers to entry in the DMSHP market)*

2. What types of ductless mini-split heat pump (DMSHP) equipment you sell or install *(Probe on efficiency levels, cold climate vs. non-cold climate, etc.)*?

3. Approximately what percentage of your HVAC business is from DMSHP sales or installations?

4. Of your DMSHP sales or installations, approximately what percentage are for a) residential customers, b) commercial customers, and c) including schools and local government?

a. Residential ______%

b. Commercial _____%

c. Schools and Local Government ______%

5. Of your DMSHP sales or installations, approximately what percentage are in retrofits versus major renovations versus new additions applications:

a. Retrofit ______%

b. Major renovations _____% (Probe: What applications or locations are DMSHP being installed to serve?)

c. New additions (Probe: What applications or locations are DMSHP being installed to serve?)

6. How are DMSHP systems typically being used by customers?

a. Are they being used for heating, cooling, both and heating and cooling?

b. Are they being used as the primary heating/cooling source, or supplemental to other HVAC equipment?

c. Does consumer use vary by sector (residential, commercial, schools/local government)?

7. For applications where DMSHP is being used as a supplemental heat source…

a. What types of heating equipment is typically used in conjunction with the DMSHP?

b. How does the system control how and when the DMSHP is used?

c. What actions, if any, are taken to reduce heating load of the primary heating system?

8. For retrofit applications…

a. Is the DMSHP equipment generally replacing existing equipment, or used in conjunction with the existing HVAC system? (If needed: for example, if customer had existing electric baseboard heat and then installs DMSHP, is the baseboard heat removed or left in place?)

b. What types of equipment are DMSHP systems most commonly replacing?

9. Based on your experience, how does the cost of installing a DMSHP generally differ…?

a. By efficiency level or rating

b. From a traditional air-source heat pump

10. What aspects of DMSHP installation…

- a. Cost the most?
- b. Take the most time?
- c. Presented the most challenges when you first began installations?
- d. Presented challenges at first, but you have since been able to overcome? Have installation costs come down as a result of working through these challenges? How so?

Customer Interactions

1. How would you characterize the level of customer awareness of DMSHP technologies? Have you seen any changes in customer awareness in past couple of years?

- a. What percentage of customers are aware of DMSHP technologies?
- b. What do they know DMSHP? What don't they know?

2. What are customer's perceptions of DMSHP technologies? Have you seen in shifts in consumer preferences in the past couple of years?

3. What are the primary reasons customers typically decide to install DMSHP systems?

4. What are the primary concerns/questions customers ask you about a project they are trying to address?

5. Do you actively promote or recommend DMSHP systems to your customers?

- a. How so? What information do you provide to them
- b. Does this vary by customer type or segment?

6. In what situations or applications would you recommend a DMSHP system to a customer?

a. What makes DMSHP the 'right' choice?

b. In what applications would you consider making the DMSHP the sole heating and cooling system for the home or building?

7. What types of marketing messages have seemed to resonate most with customers? What are your key selling points for DMSHP systems?

8. How does the efficiency of a DMSHP come into play for customer purchase decisions? Do you promote DMSHPs with higher SEERs or HSPFs than just the base federal standards? What have you seen driving customers to select higher efficiency DMSHPs when lower efficiency options exist?

9. When residential customers are making a choice to select a DMSHP, what are you seeing as the main alternatives they are choosing from? Traditional furnaces or boilers? Standard air-source heat pumps? Something else? Why are they selecting the DMSHP option?

10. When commercial customers are making a choice to select a DMSHP, what are you seeing as the main alternatives they are choosing from? Window air-conditioners? Packaged terminal air-conditioners or heat pumps? Furnaces or boilers? Something else? Why are they selecting the DMSHP option?

11. What do you see as the major barriers to participation for DMSHP technologies?

a. Do these vary by customer type or segment?

b. (If not mentioned) How much of a barrier in the sales process is the appearance of the interior unit? What have you found to be most effect in addressing this concern?

Manufacturer/Distributor Questions

[If manufacturer/distributor, continue. If installation contractor, skip to "Future Market and Role for Focus on Energy" section]

Company Profile

1. Can please describe the types of DMSHP equipment you manufacture or sell? *(Probe on efficiency levels, cold climate vs. non-cold climate, etc.)*

2. In what markets does you company operate specifically relating to DMSHP technologies?

a. Residential vs. Commercial vs. Schools and Local Government

b. Geographic regions (Wisconsin, regionally, nationally)

3. Who are your main competitors? How do the products they offer differ?

Market Trends

1. What trends are you seeing in the DMSHP market by sector? Are there any particular sectors where DMSHP installations are growing more rapidly than others?

a. Residential vs. Commercial vs. Schools and Local Government

b. Geographic regions (Wisconsin, regionally, nationally)

2. What trends are you seeing in terms of DMSHP efficiency levels? What you would you consider to be “standard efficiency” and “high efficiency” DMSHP equipment? What is the best way to differentiate standard efficiency and high efficiency for a program?

3. Based on your experience, how does the price of a DMSHP generally differ…?

a. By efficiency level or rating

b. From a traditional air-source heat pump

4. How would you characterize the level of customer awareness of DMSHP technologies? Have you seen any changes in customer awareness in past couple of years?

a. What percentage of customers are aware of DMSHP technologies?

b. What do they know DMSHP? What don’t they know?

5. What are customer’s perceptions of DMSHP technologies? Have you seen in shifts in consumer preferences in the past couple of years?

6. What are the primary reasons customers typically decide to install DMSHP systems?

7. What do you see as the major barriers to participation for DMSHP technologies? Do these vary by customer type or segment?

Cold-Climate Performance

1. How does the performance of DMSHP systems differ in cold-climates versus milder climates? How does this affect what applications are most suitable for different climates?

2. Do you have any information or research that you can share on actual performance and equipment settings for cold-climate regions like Wisconsin?

3. How can DSMSP technologies installed in Wisconsin be expected to perform in relation to nameplate specifications? *(Probe for reasons for any expected deviations)*

Future Market and Role for Focus on Energy

Lastly, I have just a few final questions on where you see the DMSHP market heading in the future and what role you see if any for Focus on Energy.

1. What direction do you see the DMSHP market taking in Wisconsin in the next 2 years?

2. Do you expect your sales/installations of energy efficient DMSHP systems to increase, decrease or stay the same in the next 12 months? Why?

3. From your perspective, what types of customer segments or applications present the highest market potential from installing DMSHP systems?

4. If Focus on Energy were to promote high efficiency DMSHP, what do you think is the right level of SEER or HSPF for them to promote? Do you have products available that can meet that level? How much more do these cost than lower efficiency DMSHPs (percentage, $/ton, absolute $)?

5. Do you see a specific role for Focus on Energy to promote the installation of energy efficient DMSHP systems? If yes, what role(s) do think would be most useful?

Wrap-Up

1. Do you have any other comments or feedback you would like to share with Focus on Energy?

2. Would it be alright if we were to follow-up with you if we have any additional questions?

Thank you for your feedback and your time. Have a great day!

APPENDIX B: DMSHP PROGRAM STAFF INTERVIEW GUIDE

This topic guide was used for interviews with program managers of peer-utility programs offering incentives for ductless mini-split heat pump (DMSHP) technologies. Interviews with program managers were semi-structured. While this guide served to offer consistent direction, interviews were tailored based on the specific program designs and the roles and responsibilities of each interviewee. As a result, not all questions were asked of all interviewees and interviews may have explored other topics specific to each program.

The interviews focused on the following topic areas:

- Confirm key elements of program design, including qualifying DMSHP measures, incentive structure, amount and type of incentive, and eligibility requirements.
- Identify customer market segmentation and marketing strategies used by program administrators to successfully identify and recruit prospective candidates.
- Identify standard approaches for estimating and verifying program impacts, including key baseline and technical assumptions.
- Understand how programs estimate and track penetration and standard practice in their markets.
- Gain insights from program administrators on key lessons learned and future opportunities/challenges for DMSHP programs.

Introduction

Hello, my name is _________________ with Tetra Tech. We are working with Wisconsin Focus on Energy (Focus) to assess the market for energy efficient ductless-mini split heat pump (DMSHP) technologies, in an effort to continually improve their energy efficiency program offerings to customers. As part of this effort, Focus is interested in learning more about current programs offering incentives for DMSHP technologies. Specifically, I would like to ask you a few questions about your DMSHP measure offerings, marketing and recruitment efforts, and key impact assumptions. Your feedback is greatly appreciated.

Before we begin, is it okay if I record our call?

Program Design

1) First, could you briefly describe your roles and responsibilities for the organization/program? How long have you been involved with this program?

2) Can you provide some background on why your organization began offering DMSHP offerings in your portfolio? What were your objectives?

3) Does your program have electric savings goals, natural gas savings goals, or both? Does your organization have any standards or policies for addressing fuel-switching?

4) What are your target market(s) for DMSHP offerings? (Probe on Res SF, Res MF, C&I sectors (esp. schools and gov't, and small business). If sectors are excluded ask why.)

    a) Do you have customer eligibility requirements relating to customer energy consumption or building size?

5) What types of ductless mini-split heat pump measures are offered by your program? What are your current measure eligibility requirements?

    a) Measure specifications

    b) Retrofit vs. New Construction vs. Additions?

    c) Have these measure offerings/requirements changed in the past few years? If yes, how so?

    d) What other applications did you consider outside of the eligible measure configurations? *(For example, if new construction is not eligible, why was it deemed not eligible?)*

    e) Are DMSHP equipment installed through your program generally used for cooling, heating, or both?

6) How are the incentive levels for your DMSHP measure offerings determined?

    a) Are they based on project costs, incremental costs, or some other factor(s)?

    b) Custom vs. prescriptive incentives?

7) What are your current incentive levels?

    a) Approximately what percentage of the project incremental costs do your incentives cover?

    b) Have your incentive levels changed over time? If yes, how so?

Measure Impacts

Next, I want to ask a few questions about how you estimate and verify the energy savings impacts of your DMSHP offerings:

1) Can you briefly describe your approach for estimating energy savings for your DMSHP measures?

    a) Custom vs. Prescriptive vs Hybrid (some variable inputs like conditioned sq. ft., # heads installed etc.)?

    b) What are the sources of baseline and technical assumptions (e.g., TRMs, prior evaluations, custom engineering calculations, etc.)?

    c) If new construction, what is the baseline assumption and how are savings calculated?

2) Are you able to briefly summarize your approach for the following savings calculation inputs and any concerns/uncertainties you may have with the input.

Inputs	**Summary of Approach**	**Concerns/Uncertainties (if any)**
Baseline equipment (for both new construction, retrofits, and additions)		
Minimum efficiency ratings (e.g., capacity, SEER rating)		
Operating hours and factors that differ from other HVAC technologies (e.g., ASHP)		
Useful measure life		

3) Have the inputs or technical assumptions used for calculating savings changed over the course of the program? If so, how have they changed and why?

4) Does your program incorporate estimates of net-to-gross, free-ridership or spillover effects for your DMSHP offerings?

    a) If yes, what are those estimates and how were those estimates derived?

5) How do you estimate and track penetration and standard practice in your market? Does this vary by customer segment?

6) Have you had a formal impact evaluation conducted on the program? If so…

    a) Where can we find the results of that evaluation?

    b) Any specific concerns raised during the evaluation?

Marketing and Recruitment

Next, I would like to ask a few questions about your target markets for your DMSHP incentives and your customer outreach and recruitment efforts:

1) What types of customers typically participate in your DMSHP offerings?

2) How do you identify potential candidates for your DMSHP offerings?

3) What is the process for recruiting customers for the program?

    a) What types of customer marketing and outreach efforts do you use?

    b) Do you perform any direct marketing efforts for your DMSHP offerings?

    c) What is the relative success of different marketing activities in recruiting customers for the program?

4) What types of marketing messages have seemed to resonate most with customers?

5) What do you see as the major barriers to participation for DMSHP technologies?

    a) Do these vary by customer types (or segments)?

    b) What strategies have you used to overcome these barriers?

6) How does the program leverage the trade ally market infrastructure?

    c) What role do trade allies play in the implementation of the program, particularly in relation to DMSHP measures?

    d) What types of trade allies typically participate in the program (e.g., study providers, installation contractors, distributors, manufacturers, etc.)?

7) Are you seeing your other HVAC measure uptake changing as the DMSHPs have come into the market?

Lessons Learned and Program Outlook

Lastly, I just want to ask a couple of final questions about your experiences administering your DMSHP offerings:

1) What are the key lessons you have learned from your experiences administering the program?

2) What do you see as future opportunities and/or challenges for the program?

3) If you were to redesign the program with a blank slate, what would you do differently? Why? Are there any pitfalls to avoid or considerations you'd recommend to programs just starting to offer DMSHP as a measure?

Wrap-Up

1) Are there any other topics that we have not covered in this interview that we should be aware of?

2) Do you have any program documentation (e.g., program filings/plans, status reports, FAQ sheets, evaluation results) that you would be willing to share with us?

Thank you for your feedback and your time. Have a great day!

APPENDIX C: BIBLIOGRAPHY OF SECONDARY LITERATURE

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