# Advanced Heat Pump White Paper

*Opportunity for real world performance data to accelerate market adoption of heat pumps*
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**Abstract**

This white paper explores how improved metrics and post installation equipment data could increase the market adoption of advanced air source heat pumps. Utility and government support for market is limited by uncertainty of metrics, and inability to verify benefits to the utility grid and HVAC professional. This paper describes how more accurate metrics and total system performance focus would roughly double utility energy efficiency program support; plus provide opportunities for demand response value and decarbonization value to be added. In addition, the data from installed systems could be leveraged by manufacturers, distributors and dealers as training and HVAC services thus providing increased revenue streams and improved product differentiation resulting in enhanced profit and benefit for all parties.

Our vision is a future where accurate, consumer understandable performance differentiation information is readily available and post installation data that is used both by manufacturers to support their distributor/dealer networks and by utilities to ensure energy savings, grid stability and meet policy driven decarbonization objectives. If realized, this can enable heat pumps to be full valued as a clean energy resource and reasonably achieve a tenfold increase in market share by 2030, with a combined US and Canada technical potential source energy savings of 10 quadrillion Btus per year by the middle of the century.[1]

This white paper provides both context, potential benefits, and a conceptual framework for “roadmap specification”[2]. The intended audience includes energy efficiency organizations, utilities, and equipment manufacturers. The ideas expressed in this whitepaper are to spur discussion. Collaboration does **not** imply the authors’ or the contributors’ respective organizations are fully in agreement.


*“Begin with the end in mind” – Stephen Covey*

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[1] Estimate based 2019 “Market Transformation Potential of ASHPs”, 2018 ACEEE Summer Study, C Dymond, S Nadel, D Lis, R Weber
[2] A collaborative document that defines incremental levels that manufacturers and utilities can use as a guide for future products and incentives

**Contributors and Reviewers**

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# INTRODUCTION

This white paper is structured into three key parts. The first presents our current understanding of real-world performance. The second presents the potential benefits to industry, utilities, and policy makers that could be gained. The second presents a framework concept for a roadmap specification that could be used to guide mid to long term product and program direction. This builds to support the **core vision** of the whitepaper that:

*By 2030 all[3] new residential and small commercial HVAC systems use advanced heat pumps.*

## What is an Advanced Heat Pump

An "advanced heat pump" is used here to describe a future **variable capacity** heat pump (VCHP) with the following **wide operational range** and microprocessor driven **connected controls** capable of optimizing their performance and provide data to manufacturers that **verify real-world operation**.

Advanced heat pumps could be driven by natural gas, electricity or a hybrid of the two. Advanced heat pumps would be optimized for different climates or have control algorithms that adapt to situation. While some of these features have already appeared in current variable capacity heat pumps (VCHPs), their potential has not been fully realized. Our hypothesis is that if these features were fully realized, advanced heat pumps would provide substantial benefits for the installing and servicing contractors, manufactures, distributors, end use customers, and their serving utilities.

# CURRENT UNDERSTANDING

## Current Context

Inverter driven VCHPs were not readily available in the US and Canadian market until about 15 years ago. Those initially introduced were mini-split configurations with capacities less than 24,000 Btuh and with simple single indoor head configurations. Today VCHPs are available in a broad range of configurations including but not limited to: small packaged terminal systems, ducted and ductless mini split systems to large variable refrigerant flow (VRF) systems with multiple expansion value circuits capable of providing simultaneous heating and cooling from the same compressor/condenser located outside. Manufacturers are offering newer models each year that create challenges for contractors and building owners/operators alike to evaluate which system will best serve their needs. Many new designs are currently available outside of North America that have not yet been introduced.

Globally, there are now more than 20 million VCHPs sold each year representing roughly $40 billion/year in sales. Most of these are built for Asian markets to serve cooling loads in single zone configurations. The current North American market for VCHPs (under 65kBtuh) is less than 250,000 systems per year with an annual market growth rate of 15+% per year. This is a tiny fraction of the roughly 6 million small HVAC systems sold each year in North America. Most of these small HVAC sales will need to shift to some form of VCHPs (gas or electric driven) over the next 30 years to reach greenhouse gas reduction targets and move toward a low-carbon economy. Such a major market shift would require a continuous annual growth rate in excess of 15% per year for the next 20+ years, along with expanded operating ranges, features and economies of scale.

[3] All systems with refrigerant based cooling

HVAC markets of North America and Europe are beginning to see VCHP systems that are tailored to operate most efficiently in heating mode and to either serve whole house or multi-zone applications. Some variants of cold climate heat pumps (ccHP) are now capable of providing heat without back-up when outdoor temperatures drop below -20 °F and have 100% of rated capacity at 5°F. These products, while more expensive, offer a greatly increased potential for reducing peak utility loads in North America compared with conventional heat pumps. In much of the West and Southeastern US, it is now technically possible to eliminate the need for backup heating for conventional buildings, as well as highly efficient buildings in virtually every US climate. Reduction or elimination of backup heating would reduce the peak demand on utilities and result in lower operating costs and consequently lower electricity rates for consumers.

VCHPS offer the largest combined energy efficiency and demand benefit from an electric utility perspective[4]. Heat pumps can supply both heating and cooling with one system, replacing the more commonly used ducted gas furnaces coupled with split-AC cooling systems. VCHPs can alter their compressor speed, fan speed, and metering rate to respond to different operating conditions. VCHP systems have the potential to manage both power draw and heating/cooling delivery relative to specific outdoor temperature and indoor heating or cooling loads. When properly selected and sized for the space's conditioning load and climate, VCHPs have the potential to be optimized to deliver comfort at high efficiencies, with associated kWh savings compared to other space conditioning system options.

In new construction, with improved building envelopes and heat recovery ventilation, VCHPs can be better suited than traditional HVAC options—in both energy performance and installed cost—to supply the low- and part-load heating and cooling needs of homes, apartments, and small businesses. Heat pumps can also cost-effectively replace or displace low-efficiency heating systems in retrofit applications, particularly when displacing delivered fuels such as oil, propane, wood, or when displacing electric resistance heating systems such as zonal electric heaters or electric forced air furnaces.

The HVAC industry is very mature, with well-established manufacturing, distribution, sales, installation, technical service, and governing standards. Therefore, changes in the market are slow to occur with considerable entrenched inertia around existing practices. Four emerging technologies and a pair of market trend will driving change in the next decade. The technology changes are: inverter driven compressors, intelligent controls, low-GWP[5] refrigerants, and advanced heat exchangers. The first market trend is the proliferation of internet-connected products and online information that has swept other industries like automotive, consumer products, insurance, and real estate. The second market trend is utilities shift to lower greenhouse gas emission systems using supply side (e.g. solar, wind) and demand side resources (e.g. heat pumps, electric vehicles, LED lighting, controls).

## Real World Performance

For utilities and consumers, the real-world performance of the total HVAC system (post-installation) is what matters. Lab based test ratings, contractor training, qualified product lists, dealer certifications and other metrics are merely proxy indicators of the potential of what we want to know, which is:

"How does the total system actually perform in real world?"

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[4] Gas utility benefits are similar, but not the focus of this white paper.

[5] Global Warming Potential – The Kigali amendment to the Montreal Protocol will require reduction in GWP values of vapor compression refrigerants in 2024 and 2029.

Maximizing the energy savings potential of HVAC systems requires more than simply selecting equipment with higher rated performance. It also requires good design, installation, and operation. The pie chart to the right illustrates the sources of savings potential for an upgrade of a single-family home with a heat pump to a cold climate variable capacity heat pump with advanced controls. Substantial evidence exists[6] that well-designed, application-appropriate system choices that are installed using best practices can produce 30% more energy savings compared to standard practice. These savings are larger than the savings achieved through higher performance equipment alone. While the potential for increase savings is real, be noted that it is unlikely that all potential savings can be achieved cost-effectively.

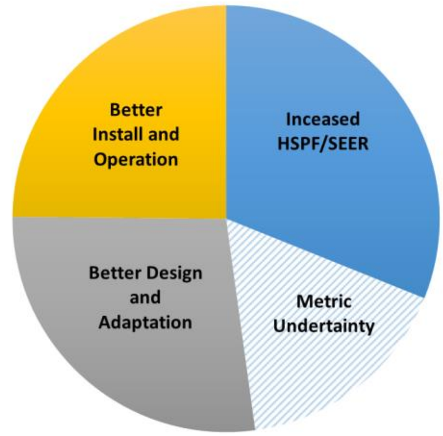


*Figure 1 - Source of Typical Residential VCHP Savings*

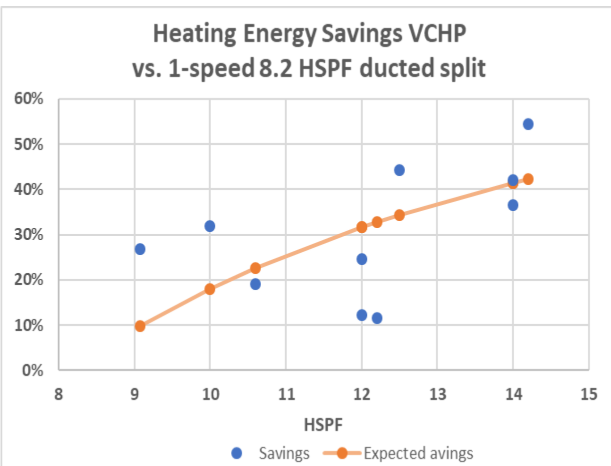


*Figure 2 - Real-World Savings Comparison*

Further, the current industry-standard heat pump efficiency metrics—SEER, EER, and HSPF, based on AHRI testing, are inadequate proxies for predicting real world performance, especially for VCHPs. There is considerable evidence of this fact from multiple utility field evaluations and lab home tests. Some data from such an evaluation is shown in Figure 2 to the Right[7]. The dynamic operating ranges of VCHPs mean that they can be manipulated to achieve higher maximum capacity output under the AHRI 210/240 test procedures that may never be matched when operating under as-shipped operating firmware. This can result in inaccurate relative ranking of products, and present misleading information to buyers.

***HSPF and SEER limitations result in diminished justification for heat pumps, and therefore reduced consumer and dealer support by utilities and policy makers.***

There are two basic approaches to estimate real world performance. The first approach (and most common), is to use a rating procedure that uses data from lab-based test procedures conducted under defined test conditions. The second approach is to conduct monitoring of the system once it is in use to measure performance after the equipment has been installed. Both approaches require some form of building energy modeling to predict future energy use based on standard operating conditions and weather. The lab-based approach provides data prior to the purchase decision and helps manufacturers refine their products but requires assumptions about design and installation make performance estimates less accurate. The post-installation data approach offers the advantage of estimating total system performance that includes the real-time effects of controls, system adaptation, operational

[6] NEEA Next Step Home Pilot homes, NW an NE HVAC evaluation studies, CEC funded research, etc
[7] California Central Valley Research Homes studies

settings, ducting, etc. The disadvantage of this approach is that installing monitoring systems and collecting data has, until recently, been prohibitively expensive.

New HVAC models increasingly feature internet connections and advanced microprocessor-based controls. Future versions will be capable of auto-commissioning, and more flexible operational settings which could potentially simplify design, application adaptation, installation and operation. This bodes very well for HVAC system professionals and consumers alike but could pose a problem for lab based testing and metrics that can only test an "as shipped" condition or a particular test mode. The ability (or inability) of equipment to adjust system operation to site conditions is already evident in recent lab testing using CSA EXP-07 test procedure. New connected systems have the potential to quickly auto-adjust to changing conditions and will be able to download new algorithms to improve performance over time.

The combination of these features could therefore make post installation, real world performance metrics a more accurate way of estimating performance, and thus savings relative to a default baseline. In addition, these features provide an opportunity for HVAC technicians to ensure optimal performance and reduce the cost of operation and maintenance. This already exists in some systems for which the service technician can remotely check in on the operation of VRF systems to troubleshoot individual system issues and determine if a site visit is warranted, and if one is warranted, what equipment and parts may be needed to resolve any problems.

## Why Now

Utility efficiency programs have focused primarily on acquiring low-cost energy savings through various incentives, training and marketing programs. This provides new energy resources comparable to adding generation assets, but at a lower cost to the utility and without the permitting and pollution abatement challenges of adding new generation assets. During the past 15 years, policymakers have been adding renewable portfolio requirements[8] to spur renewable energy technology maturation and reduce greenhouse gas (GHG) emissions from fossil carbon sources and refrigerant gas leakage. This, combined with the emergence of electric vehicles, has increased the need for energy efficiency programs to provide not only least-cost new energy resources, but also low carbon solutions and systems that support utility grid stability. Advanced heat pumps are potentially unique in that they can provide value in all three areas, if we can establish a framework that supports tracking these benefits, while at the same time benefitting the HVAC industry and end users.

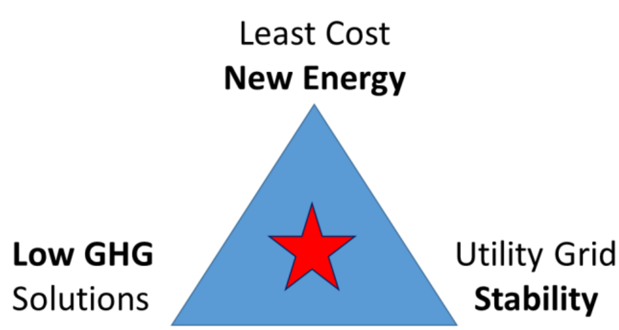


*Figure 3 - Three Sources of Value*

The confluence of extended operational ranges and web-connected microprocessor controls opens up the possibility to optimize and capture all three values of VCHPs. Over the next several years all major VCHP manufacturers will be upgrading their systems with these features, if they have not already done so. This time frame coincides with the continued proliferation of smart home devices and the emergence of 5G cellular technologies that will profoundly reduce the cost of reliably establishing two-way communication with HVAC equipment. Concurrently, manufactures are looking for ways to increase

[8] 29 states have renewable portfolio standards http://www.ncsl.org/research/energy/renewable-portfolio-standards.aspx

their value proposition to HVAC dealers by providing data and training that enable better design and operational decisions, reduced service call costs, improved customer relations, and increased use of "HVAC as a service" or "performance guarantee" based business models.

At a macro scale, air source heat pumps are technically capable of providing the same source-energy savings by 2050 as electric vehicles or photovoltaics[9]. The combination of these three technologies comprise the lion's share of demand side potential for decarbonization and reduced operating costs. The technology shifts emerging today could redefine residential and small commercial air source heat pumps (gas or electric driven) and enable greater integration of renewable energy resources. How this unfolds will be strongly influenced by the metrics and data structures available to maximize the potential value streams that advanced heat pumps can capture.

Utility, State, and NGOs are interested in establishing improved justification for investments in heat pumps. An important step is to determine how best to quantify all three utility values (energy, carbon, and grid stability) from advanced heat pumps. In December of 2018, NEEA, NEEP, MEEA and SMUD convened a coalition of U.S. and Canadian stakeholders to review current understanding of ASHP metrics and begin defining what heat pump features are important to utilities. More than 25 organizations participated and expressed interest in continued collaboration on test metrics and performance specifications. A working coalition of utilities formed and participated in meetings with several VCHP manufacturers to explore opportunities to increase market leverage of systems that deliver real world performance. These conversations focused on two themes:

1. Improving the alignment of expected and real-world performance.
2. Using post-installation data acquired from connected VCHPs.

The key learnings from these meetings are described later in this whitepaper.

## CSA EXP07 Voluntary Test Procedure and Rating Metrics

The challenges of accurately assessing real world performance for VCHPs has been recognized by many in the utility and HVAC industry since the early 2000's. A solution to address this was proposed, but not incorporated into the 2014 DOE rulemaking on HVAC test and rating procedures. In 2015, NEEP developed a cold-climate ASHP Specification to more effectively differentiation ASHPs able to operate efficiently at low temperatures. In 2015 the Canadian Standards Association (CSA) formed a standards development work group charged with developing draft test and rating procedures. This work was co-chaired by Charlie Stephens of NEEA and Gary Hamer of BC Hydro. Lab research was led by Dr. Jim Braun and his team at Herrick Labs at Purdue University and funded by NEEA, NRCan, and PG&E. After several years of lab and committee work, CSA published a technical review version of the EXP07 test and rating procedure[10] on March 29th, 2019.

EXP07 documents a voluntary test procedure and rating method for heat pump and air conditioning systems with capacities under 65,000 Btu/h[11]. In contrast to the AHRI 210/240 standard, EXP07 uses a dynamic load-based approach that measures a system's performance across a wide range of outdoor ambient conditions, meeting loads representative of typical residential applications, under its own controls. The test procedure applies a dynamic load that changes across 11 different outdoor heating conditions and 10 different cooling conditions. The tests are run at each condition until the system

[9] 2019 "Market Transformation Potential of ASHPs", 2018 ACEEE Summer Study, C Dymond, S Nadel, D Lis, R Weber

[10] EXP07 is Load-based and climate-specific testing and rating procedures for heat pumps and air conditioners

[11] EXP07 is currently limited to single zone ducted and ductless products

achieves a stable COP value or reaches the end of the test period. The COP values are then used to generate a climate-weighted seasonal coefficient of performance (SCOP) value for both heating and cooling (SCOPh and SCOPc), for 8 heating and 7 cooling climates. These SCOP values represent a much improved proxy for how the tested system will perform in real applications in a range of different climates.

Both Natural Resources Canada (NRCan) and NEEA have contracted an ANSI certified laboratory to conduct initial testing of various cold climate heat pumps to the CSA EXP07 procedure. PG&E has begun conducting EXP07 tests at their ATS lab in San Ramon CA, and at least two manufacturers have begun evaluation of their equipment with this test procedure at their own labs.

The use of EXP07 as a metric for utility programs, code compliance, or minimum requirements in Canada or other jurisdictions depends on how well it serves as a predictor of real-world performance. Work is underway to determine how to minimize testing burden through automation, and how representative, repeatable and reproducible the resulting ratings are. The tests conducted so far provide what appears to be very representative results, with considerably better product performance differentiation. Also revealed are the performance impacts of differences in: control strategies, defrost approaches, equipment design and standby energy. Additional testing is needed to evaluate how repeatable (run-to-run), and reproducible (lab-to-lab) the results of the test procedure are.

The two main objectives of the new test procedure are to:

1) Provide an improved, more accurate product differentiation metric that better represents how heat pump equipment will perform under a range of real-world operating conditions.
2) Reduce the chance that proprietary control modes and lab test setup can be used to distort the test procedure results.

One of the challenges with the current AHRI 210/240 test procedure is that a system with advanced controls can be tested with compressor and fan speeds that are unlikely to occur under normal operating conditions. This can exaggerate ratings compared with real world performance and increase the risk of false performance ranking among different products. This was clearly found in the initial testing of "cold climate" systems using CSA EXP07. Figure 1 (below) shows the seasonal coefficient of performance ($SCOP_h$) values of 10 systems with similar HSPF values (12-13.5) in the 8 different climate types defined by EXP07.

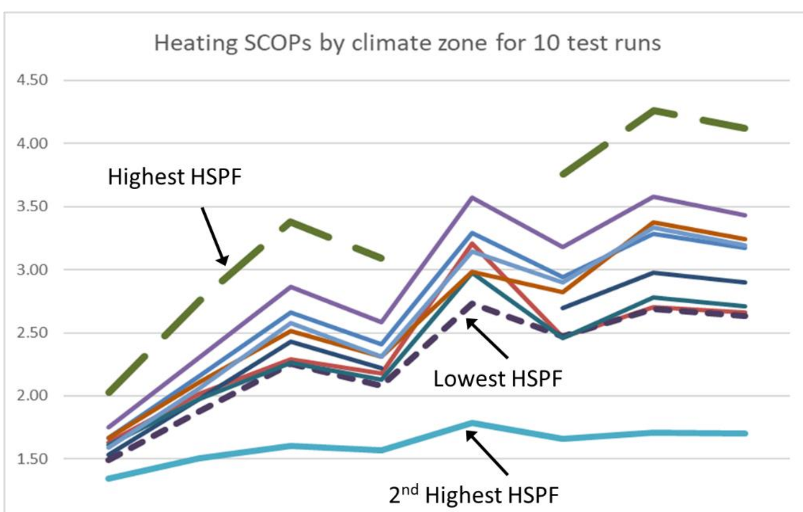

*Figure 4 - Preliminary Results of EXP07 Testing*

Figure 1 provides ***preliminary*** results with a small sample size of similar products (1-1.5 ton cold climate DHPs). No definitive conclusions can be drawn due to the small sample, but it is clear that climate variations yield a wide range of SCOP values, and that some systems clearly perform better in cold climates than others. The results certainly show some heating performance rankings that do not match the rankings by HSPF.  Other test results from this initial sample set indicated that low temperature capacity and ability to operate very efficiently under low load conditions are vary significantly among similarly rated systems.  This is important because in many cases, utilities are interested in capacity at more extreme temperatures, as much or more than in moderate differences in seasonal efficiency ratings, as the capacity at in extreme conditions affects the need for additional heating or cooling and the consequent effect on peak utility loads and grid stability.

## Post-Installation Performance Data

While improved lab test and rating procedures are critical for equipment selection, the value of VCHPs is based on many factors: total HVAC system energy savings, demand savings, demand responsiveness, reliability, and persistence of performance. Most of these factors cannot be measured by a lab test or represented by a rating metric. If a high efficiency system is installed poorly, operated poorly, applied to the wrong situation or develops trouble such as refrigerant leaks, the benefits of the system may be far smaller than the lab test results would suggest.

For example, the graph (right) illustrates how sizing can have a profound impact on even variable capacity cold climate heat pumps. The load and capacity graph shows that the system was oversized for the range of measured loads. Because of this, the system rarely operated in modulating mode, during which variable speed compressors and fans are optimally efficient. The impact on performance was significant: the system had an effective seasonal COP of 1.3, using 2.5 times more energy than the HSPF value suggested. No lab test or rating can provide the feedback to help designers and installers monitor, verify, and improve system performance.

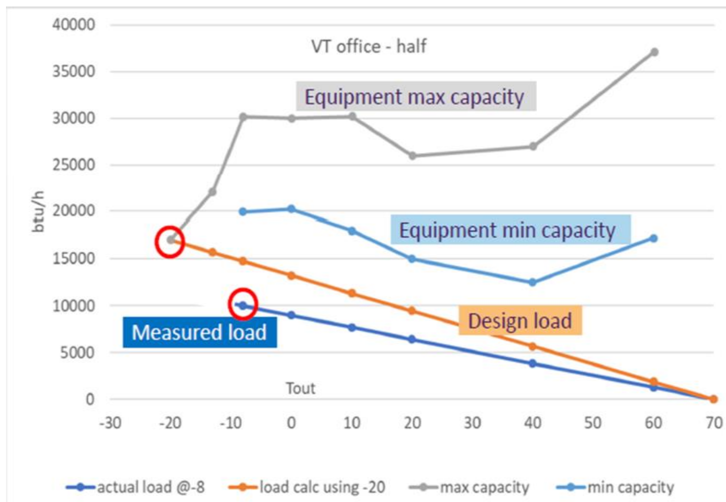


*Figure 5 - Example of oversizing VCHP*

A key feature of advanced heat pumps is that they will provide data to manufacturers via connected communications. While the nature of these communications systems continues to evolve, most VCHPs sold in 2019 either have built-in or low-cost options for Wi-Fi connection. Future systems will likely have 5G cellular, robust Wi-Fi connections, integration with connected thermostats, and possibly CTA 2045 connectivity, all of which provide greater data-gathering opportunities. This data could be used to inform designers, installers, and utility programs, and improve customer experience. This brings us to our core hypothesis about what heat pumps in the future can do.

***Hypothesis****: HVAC system post-installation data will enhance the value of VCHPs*

### Value Proposition

Properly refined and analyzed, post-installation data from connected VCHPs can provide multiple values for each market actor. The non-efficiency benefits to the manufacturer are large enough that many have already begun adding connectivity and data gathering capabilities to their products. The following is a partial list of potential benefits:

**Manufacturers**

1. Inform product engineers how to improve their products to increase reliability and longevity.
2. Inform product engineers how their products operate in the field to revise control algorithms that improve occupant comfort, efficiency, and product satisfaction
3. Provide information that can be used reduce warranty risk that is extended to top dealers. Many manufacturers provide their top dealers warrantees that are several years longer
4. Increase brand loyalty of dealers who become familiar with the products that make use of data to provide additional customer services and improve customer satisfaction
5. Provide information that can be used to improved design, sizing, and product selection methods and training – improving the relationship between manufacturers and contractors and customer product satisfaction

**Distributors**

1. Increase loyalty of dealers by providing them with actionable data that increase opportunities for selling additional customer services or improve customer satisfaction
2. Help dealers diagnose operational problems of systems sales without requiring a site visit
3. Improve training offered to dealers on how to optimize comfort and performance
4. Attract new dealers and expand market share over competitors

**Dealers**

1. Offer additional services to customers that make use of post install data:
    a. Service warranties
    b. Post installation commissioning reports
    c. System warnings/alerts of faults
2. Tell a more compelling sales story about why a customer should choose the dealer and model
3. Maintain and support customer relationship, build “word of mouth” referrals for future work
4. Reduce time to diagnose system problems, potentially pre-diagnosing and eliminating on-site time, improving cost competitiveness in the market
5. Feedback to installation crews on what is working, what is not, and track general operational improvements of the company
6. Reduce risk from customers who claim system is not meeting expectations. In many cases, the system is in fact operating as it intended and the source of dissatisfaction comes from user behavior, system settings or a user interface (e.g. NEST, Ecobee) that interferes with optimal operation of the system

**System Owners**

1. Provide additional system controls and security (also possible with connected thermostats).
2. Provide remote access using mobile devices, directly with equipment (avoiding third-party products that may compromise system operation)
3. Information about how a system is performing and confirmation that it is working correctly and meeting intended comfort, operating cost and system life expectations.
4. Improve information about products when making the purchase decision

**Utilities**

1. Reduce costs for evaluation studies
2. Improve forecast of savings and demand benefits

3. Increase cost effectiveness of programs by capturing actual system level energy savings (not just savings estimated from equipment specifications), and demand savings
4. Improve information for assisting customers with major energy choice decisions
5. Ability to work with dealers to identify what level of savings can be achieved and improving the sales opportunities for top-tier dealers that consistently provide better services

**Policy Makers, Cities, Other Efficiency Stakeholders**

1. Increased justification for support (incentives) of VCHPs as a key part of clean energy and decarbonization objectives
2. Increased awareness of the carbon and grid-stability benefits of VCHPs
3. Accurate prioritization of public resources that produce the biggest benefits

## Manufacturer Feedback

Authors of and contributors to this paper met with VCHP manufactures at the 2019 AHR Expo in at Atlanta to determine if there were manufacturers interested in collaboration on improved equipment performance metrics and data collection.  This was followed up by several meetings with manufacturers that expressed strong interest collaboration.

The objective was to identify those companies with current business and product development plans that substantially parallel the goals expressed in this paper. This in turn, would form the basis of collaboration for mutual benefit.  The desired outcome of this collaboration is to define 2-, 5-, and 10-year visions for how products, testing, data and market communication can expand the value proposition for VCHPs to end users, distributors and dealers. These visions are based on market opportunities and are not based US DOE's mandated testing and rating of products.

During Q2 of 2019 the authors traveled to meet with the product development teams of five major VCHP manufacturers. Specific collaboration with individual manufacturers were held under non-disclosure agreements. The 4-5-hour meetings covered general context, HVAC market perspectives, current product roadmaps, test metrics, the CSA EXP07 preliminary test results and how post-installation performance data might be used to leverage and expand market opportunities.

### Learnings

The following is a list of common themes and discoveries

- Some manufacturers do not fully understand how their equipment performs in different climates relative to each other and were surprised and/or interested in the differences between models discovered in real world and lab test conditions
- Manufacturers generally believe their products will continue to gradually increase in performance over time, without any major technological changes that will dramatically impact product performance
- Major product revisions are likely to begin in 2021-2023 in preparation for updated federal standards and refrigerant requirement changes
- Manufacturers are adding connected data systems into their lower cost products. While most products sold in 2019 have remote data option that can be easily added or activated, there did not appear to be any that have reached a level of product sophistication that can be easily adopted by distributors, and none have considered how this data could useful to utilities in a way to enhance company profitability

- Although many larger VCHP systems (e.g. medium to large VRF systems) have on-board sensors and diagnostic capabilities that could support the as-installed data collection discussed above, most smaller models would need modest additions to support a range of functions that would maximize value to all relevant stakeholders
- Manufacturers are already pressed for meeting AHRI testing changes to AHRI 210/240. Lab space is limited so they need to know more about CSA EXP07's value to them before wanting expending resources to testing to EXP07
- Manufacturers agreed that the current metrics (HSPF, and SEER) do not adequately highlight what they believe is the value proposition of VCHPs, especially for those with good low temperature efficiency and capacity

### Opportunities

The following are general opportunities that were identified:

- Conduct several pilot projects with specific manufacturers to test and evaluate how post installation performance data can be reduced to essential, actionable metrics that utilities are willing to pay for
- Provide machines that have been tested using CSA EXP07 to interested manufacturers so they can conduct the same testing in their labs. The general data will be shared anonymously, but specific results will remain under NDA restrictions to prevent competition
- Collaboration on developing a set of post-installation metrics that can be used to maximum value by utilities, while balancing the cost of data management, customer privacy, and proprietary manufacturer information

## Advanced HP Strategy

The following proposes a strategy for expanding the value proposition to utilities, manufactures, dealers and consumers for advanced heat pumps through improved metrics and post-installation data. It is intended to spur discussion about the direction for future products, how utilities and decarbonization efforts can both expand and consolidate their support for the technology, and consequent manufacturer go-to-market strategies.

The strategy contains the following components:

1. Vision statement
2. Objectives
3. Roles and responsibilities of each market actor
4. Draft "roadmap specification"

### Vision Statement

By 2030 all[12] new residential and small commercial HVAC systems use advanced heat pumps.

These HVAC systems provide low-carbon solutions that are grid supportive (alonetic[13]), maximize customer comfort and minimize total cost of ownership. Advanced heat pumps are easily identifiable with clear metrics that provide users, dealers, and manufacturers with data that that justify their premium value though:

[12] All systems with refrigerant based cooling

[13] Alonetic is a term coined by Conrad Eustice which in simplicity means beneficial to utility grid operation http://aceee.org/sites/default/files/files/pdf/conferences/hwf/2016/Eustis_Session3A_HWF16_2.22.16.pdf

- Utility demand reduction and demand response (DR) capabilities
- Quantified green house gas (GHG) reductions
- Climate-optimized energy efficiency (lower operating cost)
- Improved customer comfort
- Reduced dealer/installer risk via equipment auto commissioning and remote diagnostics
- Enabling distributors to provide their customers (dealers) with solutions that expand service contract and financing options

Market demand for such products will enable heat pumps to be fully valued as a *clean energy resource* and help them achieve a tenfold increase in the market share by 2030 with a combined US and Canada technical potential source energy savings of 10 quadrillion Btus per year by the middle of the century.[14]

## Objectives

**2-year Objectives**

- Form a heat pump coalition of interested parties that share knowledge and coordinate collective investments and present a collective request to the heat pump manufacturing industry
- Develop a "roadmap specification" that clarifies what is needed and provides reason for market actor support for advanced heat pumps
- Establish the design, training and resources that can be used by all parties to optimize real-world performance of variable capacity heat pumps
- Quantify support for advanced heat pumps to help manufactures justify investments in manufacturing capacity and product changes
- Complete field trials that demonstrate how operational data improves the product value proposition to dealers, distributors, utilities, and policy makers
- Evaluate and improve CSA EXP07 test procedure so that the SCOP ratings provide accurate product performance differentiation that increases incentives offered by city, state and utility programs that support variable capacity heat pumps
- At least one major manufacturer has begun integrating post install performance in their go-to-market strategy and hardware features

**5-year Objectives**

- Advanced heat pumps can be clearly differentiated in the marketplace using the NEEP qualified product list[15] based on a load-based test procedure (i.e. CSA EXP07 or equivalent variant)
- Metrics and heat pump data systems have been established that enable energy efficiency, decarbonization and DR programs to reward choices that deliver real world performance
- Post installation data is available to programs. This data is sufficiently specific to reward dealer choices, but also includes controls to flexibly implement relevant customer, distributor and manufacturer anonymity and privacy needs

**10-year Objectives**

- There is widespread alignment of energy efficiency, decarbonization and grid stability programs with contractor training efforts that reward choices that deliver real world performance
- Leading distributors have embraced the use of data and real-world performance to support dealer profitability and brand loyalty. This is further enhanced by EE, decarbonization, and DR programs through incentives, recognition, marketing, training and other resources

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[14] Estimate based 2019 "Market Transformation Potential of ASHPs", 2018 ACEEE Summer Study, C Dymond, S Nadel, D Lis, R Weber

[15] NEEP cold climate heat pump specification and product list - https://neep.org/ASHP-Specification

- Manufacturer's dealer programs leverage the resources real world performance data to reduce warranty risk, improve brand loyalty and increase sales of additional HVAC services

## Roles and Responsibilities

Achieving a tenfold increase in advanced heat pumps by 2030 is far from certain. It is our premise that this will require engaging the forces of city and state policies, as well as utility efficiency and grid stability procurement objectives. Under this assumption, each party shares responsibility for the outcome. The following section outlines the type of actions needed by each party:

**Utilities**

- Formalize and lead a coalition of advanced heat pump interested parties
- Continue providing incentive support for top tier products using existing performance metrics
- Conduct field performance validation studies to identify best practices and identify cost effective consumer solutions
- Continue contractor training and use of Quality Installation (QI) standards in their programs
- Conduct pilot projects to test the use of post-installation performance bonuses for contractors based on real world outcomes
- Identify homes with good energy saving opportunities and sharing them with HVAC contractors – what homes and businesses have low efficiency systems
- Fund validation studies of CSA EXP07 lab testing and development of top-tier qualified products list and data that can be included as a 2nd tier of the NEEP cold climate heat pump list
- Work with energy policy advocates and regulators to revise program evaluation methods to capture full value of VCHPs using EXP07 equipment ratings

**Cities, States, Regional Groups and other Decarbonization-driven Organizations**

- Policy makers and staff assess greenhouse gas emission goals, evaluate local potential, best solutions and priorities for their policy driven efforts involving heat pumps
- Policy makers and staff develop actions that support adoption of decarbonization technologies. Likely examples of this include: energy codes, zoning ordinances, efficiency goals for publicly funded capital improvement projects, direct incentives, tax credits, etc
- Redefine the criteria for cost effectiveness used by utility program rate-base allowances beyond simple 20-year horizons, and update to include other public benefits such as decarbonization, and local economic investment. Work with energy policy advocates and utilities to promulgate program evaluation methods and criteria that optimize the use EXP07 equipment ratings for ex-ante savings estimates and the use of installed-base data collection for ex-post savings validation

**Manufacturers and Distributors of VCHPs**

- Assist the heat pump coalition members to develop and finalize the roadmap specification (see following section)
- Integration of onboard operation and performance sensors and demand response capabilities.
- Develop in-house experience with EXP07 to better understand product performance and development of algorithms that optimize efficiency while preserving comfort and longevity and optimize climate specific control
- Participate in utility and government funded field studies
- Promote data use case opportunities and support development of data driven market opportunities (financing, bonuses, warranty extension, etc)

- Contribute towards training and knowledge dissemination regarding advanced heat pump specific design, installation, operation, and verification nuances.

## Roadmap Specification

The purpose of this "roadmap specification" is to provide product development direction for energy efficiency, decarbonization and grid stability goals. It is a multi-tiered specification that outlines future targets, data, and criteria. It is based on an understanding of the technology capabilities, manufacturer direction and potential market yet to emerge. This is different from a "market specification" like ENERGYSTAR with criteria based on currently available products and market shares. The key benefit of a "roadmap specification" is to provide direction and align efforts of many market actors and provide clarity to manufactures for product development and improvement, with confidence that these developments will be valued and rewarded by incentive providers such as cities, states and utilities.

The presence of higher tiers enables additional benefits (efficiency, demand response, data reporting, etc.) to be assigned value. Manufacturers will build products to achieve these tiers if they believe the consumers will want these benefits, or in some cases if the benefits are valued adequately by third parties while being essentially invisible to consumers. The likelihood of increased incentives for higher tiers provides manufacturers information they can use to plan on which advanced features they wish to add to their products in an open competitive market, where price signals include both the consumer's needs and the value to utilities and decarbonization interests.

The following are four proposed criteria groups that comprise a draft roadmap specification, with examples of tier criteria. The intent is that products would not have to have same level of performance in each tier. They might meet top tier in one group, and a lower tier in another. The value of the different tiers and incentives paid by various programs will evolve over time as a function of the utility and policy maker goals, which do vary among different market regions. However, a structure to categorize and agree generally on all valued features is critical to aligning a range of stakeholder interests.

*This table has **example** criteria only – considerable discussion is needed to define*

| Criteria | | Easy | Moderate | Aspirational |
|---|---|---|---|---|
| **Performance Capabilities** | **COP** | ENERGY STAR level (based on HSPF and SEER) | Min rating and equipment capacity data using a dynamic load-based test procedure | Min rating TBD – higher than Tier 2 |
| | **Utility** | Meets AHRI 1380 standard for demand response capability | Integrated DR hardware and capability | DR hardware automatically connects to utility DR system |
| | | | | |
| **Design & Installation** | **Design** | ACCA manual J, D and S based system design | Training refinement provided by post install data via manufacturers | Post install data is integrated with design tools |
| | **Install** | Installation criteria ---- TBD | System intelligence provides diagnostic feedback for installer | Confirmation of proper install automatically reported to manufacturer |
| | **CX** | | Automatic commissioning | commissioning and operation improves over time with AI optimization |
| **Post Installation Data** | **Connect** | Wifi connected systems that confirm installation | Data (to mfr) confirms system basic operational performance | Data provides measurement of performance of system |
| | **Faults** | | Data provides HVAC technician with fault information | |
| | **Diagnose** | | Data provides HVAC technician with diagnostic recommendations | Data provides HVAC technician with predictive diagnostic warnings |
| **Customer Interface & Benefits** | **Connect** | Capable of remote operation via connected devices | ? | ? |
| | **IAQ** | Comfort and IAQ - TBD | Automatic ASHRAE 62.2 verification of system | CO and VOC sensors enable IAQ optimized performance |
| | **Utility** | System interface provides user with energy efficiency options | System interface provides user demand response options | Automatic optimization based on energy price signal |

**Performance Rating**

The current situation is that the performance metrics for VCHPs (HSPF and SEER) are inadequate to convey maximized value of advanced heat pumps. Current manufacturer published data such as capacity and COP at lower operating temperatures, part load operation and lowest operation temperature is available, but is not consistently reported, or does it reflect the impact of improved onboard controls logic, performance differences between different climates.

The use of EXP07 or a similar dynamic load-based test procedure can provide better product differentiation which would increase valuation of those machines that perform better. The following are elements that should be considered:

- Climate specific seasonal coefficient of performance
  - Heating – dry climates
  - Heating – marine climates
  - Cooling – dry climates
  - Cooling – humid climates
- Minimum and maximum capacity vs. ambient temperature data
- Dehumidification minimum requirements in humid cooling climates
- Maximum standby energy requirements
- Controls sophistication designation that defines what the equipment is capable of (e.g. does it have CTA 2045 or Open ADR capabilities, does it have adaptive learning algorithms, is it capable using occupancy sensors or VOC measurements to adjust operation, etc)

**Design and Installation**

Design – including equipment sizing, equipment selection, distribution system design – is significantly different for VCHP equipment than for fixed speed heat pumps. Residential HVAC industry norms, tools, rules of thumb, and expectations have all been built based on split air conditioning and gas furnaces design needs, then adapted for fixed speed heat pumps and adapted further for VCHPs. In contrast to design for fixed speed heat pumps or gas furnaces, which is singularly focused on providing capacity at the design load, ideal VCHP system design understands the nuances of VCHP modulating performance and applies a goldilocks design principle that simultaneously considers operation (both capacity and operating COP) at the design load, the lowest partial load, and high frequency conditions in between. The current suite of contractor training and education opportunities are insufficient.

The desired outcome is to enable utility and others to reward installers who do the sizing and installation correctly. This would be in comparison to a reference baseline of typical HVAC contractor design and operational practice (untrained). A validated system can help build a network of contractors and distributors who do this right.

The following are elements of design and installation best practices that should be considered:

- ACCA manual J, D and S design guidance
- Different design guidance that are unique to VCHP systems.
- Minimum owner training standards – we have seen many cases where the owners do not receive adequate information or training about the system and the result is poor or under-utilized performance
- How can systems be integrated with pre-existing systems that are not removed, but potentially operate in parallel

**Post Install Data**
Developing a set of key performance indicators (KPIs) of the total system is essential if we are to maximize the value proposition to utilizes, and decarbonization efforts. The data collected needs to automatically compiled and refined to a minimum set as neither manufacturers, installers nor utility programs have the capacity nor desire to sift through detailed data to determine if the installed system is performing well.

Our current thinking is that as few as possible metrics would be best. At the most basic level, the post installation KPIs could be reduced to three levels of performance.

1. Inadequate
2. Acceptable
3. Exceptional

How these performance levels are determined should be developed by the manufacturer, not the utilities or other entity. A method of verification of the metrics needs to be established that is clear and accurate. This is a non-trivial task, and it may require additional sensors or minor hardware changes to the VCHPs. Exceptional rated performance may need to include indication of actual energy performance from which savings can be calculated and attributed to the HVAC dealer that completed the project.

The data needed to generate good KPIs would likely need to include the following through either through direct or proxy measurement:

- Operation (run time, cycle time, faults etc)
- Indoor and ambient conditions
- Energy transferred to the space (heating or cooling)
- Utility energy consumed and demand (kWh and kW)
- Hours of operation (by mode – heating, cooling, fan only, defrost, other)
- Refrigerant charge is in range (based on subcooling and superheat)

**Human Interface & Comfort**
Human interface with the HVAC system does not provide the user with clear information about how the system is performing or how it is taking advantage of utility pricing or demand response signals. Minimum comfort standards also need to be established to prevent energy or demand savings to come at the expense of human comfort.

The following are should be considered:

- What defines a system that delivers good comfort?
- What information is needed to define bottom-line customer values
    - Operation
    - Comfort
    - Indoor air quality
    - Demand response
    - Carbon offset value

## Conclusion

There is enormous opportunity for advanced heat pumps to provide increased value of heat pumps, namely improved savings, decarbonization and grid stability. To do this they (the efficiency community) need to identify areas of common value enhancement with manufacturers of these products. This needs to be done in collaboration with the leading VCHP manufacturers that are already heading down a parallel path for their own reasons, to leverage common interests and help ensure success and high value for all.

The actions that need the most focus in the next two years are:

1. Development of a roadmap specification that both manufacturers and energy efficiency organizations can use as a guiding tool for product and program investments
2. Improvement and support of laboratory test and rating procedures
3. Development of post-installation data reporting and performance validation KPIs
4. Development of qualified products lists

Lastly, it is important to acknowledge that all this work begins by being able to accurately measure the outcomes we want and having trust in the metrics used. While the CSA EXP07 test procedure and rating shows considerable promise, it is currently in a technical evaluation period. During this time, it is hoped that many organizations try using it and provide recommendations that will help reduce testing cost and time, and improve it as a useful metric. A core element of this work needs to be evaluation of the test procedure's representativeness, repeatability, and reproducibility.

# Appendix A – Relevant Studies

The following are the studies, reports and other publications that while not specifically referenced in this document, provided context and insight used in our collective learning. These are organized by publishing year, with title shown first.


## 2019

*New Efficiency: New York. Analysis of Residential Heat Pump Potential and Economics.* New York State Energy Research and Development Authority (NYSERDA). (2019).

*The Total Value Test: A Framework for Evaluating the Cost-Effectiveness of Efficient Electrification.* Electric Power Research Institute (EPRI). (2019).

*Increased Savings with MicroChannel Heat Exchanger.* Danfoss. (2019).

## 2018

*Utility Billing Analysis of 2013-2014 - Multifamily Ductless Heat Pump Retrofit.* Energy Trust of Oregon. Rubado, Dan. (2018).

*PGE Central Valley Research Homes. Variable Capacity Heat Pumps: Evolution of Ducted and Ductless Configurations 2016-2017.* Pacific Gas and Electric Company. (2018).

*Utility Billing Analysis of 2013-2014 – Multifamily Ductless Heat Pump Retrofits.* Energy Trust of Oregon. Rubado, Dan. (2018).

*Low GWP Refrigerants – System Solutions and Components.* Heat Pump Technologies Magazine. Vol. 36 No. 3. (2018).

*Comparison of Ductless and Ducted Heat Pump Retrofits in Manufactured Homes.* Energy Trust of Oregon. (2018).

*Are Ducted Mini-Splits Worth It?* ASHRAE Journal. Metzger, C.E., Zhang, J., Maguire, J., Winkler, J., February (2018).

*Radiation Defrosting Technique.* U.S. Department of Energy Office of Energy Efficiency and Renewable Energy. Nawaz, Kashif. (2018).

*Flexible, Sustainable and Clean System Solutions.* Heat Pump Technologies Magazine. Vol. 36 No. 1. (2018).

*Impact Evaluation of Residential Ductless Heat Pump and Prescriptive Duct Sealing Measures.* Bonneville Power Administration. Navigant. (2018)

*The Economics of Electrifying Buildings: How Electric Space and Water Heating Supports Decarbonization of Residential Buildings*. Rocky Mountain Institute. (2018).

*Heating, Ventilation, and Air Conditioning (HVAC) Technology Guide.* Bonneville Power Administration. (2018).

## 2017

*Cold Climate Air Source Heat Pump.* Minnesota Department of Commerce, Division of Energy Resources. Center for Energy and Environment. (2017).

*Documentation of Heat Pump Retrofits in Multi-Unit Residential Buildings.* City of Vancouver. The University of British Columbia. (2017).

*Performance Testing of Cold Climate Air Source Heat Pumps.* International Energy Agency Heat Pump Conference. (2017).

*Evaluation of Cold Climate Heat Pumps in Vermont.* Vermont Public Service Department. Cadmus. (2017).

*Heat Pumping Technologies: Annual Report.* Technology Collaboration Programme on Heat Pumping Technologies. International Energy Agency Heat Pump Conference. (2017).

*Cold Climate Air Source Heat Pump (ASHP) Evaluation: 2017 Regional Cold Climate ASHP Market – Transformation Workshop.* Cadmus Presentation. (2017).

*Annex 41: Cold Climate Heat Pumps: Improving Low Ambient Temperature Performance of Air-Source Heat Pumps.* Technology Collaboration Programme on Heat Pumping Technologies. International Energy Agency. (2017).

*Latest Heat Pump Technologies in Japan.* Saito, Kiyoshi. International Energy Agency Heat Pump Conference. (2017).

*An Examination of the Opportunity for Residential Heat Pumps in Ontario.* Ministry of Energy. Independent Electricity Systems Operator (IESO). (2017).

*Massachusetts and Rhode Island Ductless Mini-Split Heat Pump Evaluation*. Cadmus Presentation. (2017).

*CO2 Combination Space Conditioning and Water Heating Stress Tests in the Pacific Northwest National Laboratory (PNNL) Lab Homes.* Pacific Northwest National Laboratory. (2017).

*Northeast/Mid-Atlantic Air-Source Heat Pump Market Strategies Report 2016 Update.* Northeast Energy Efficiency Partnerships, Inc. (2017).

*Northeastern Regional Assessment of Strategic Electrification.* Northeast Energy Efficiency Partnerships, Inc. (2017).

*Electrification Futures Study: End-Use Electric Technology Cost and Performance Projections Through 2050.* National Renewable Energy Laboratory. (2017).

*Ductless Heat Pump Quick Connect Stage II Report.* CLEAResult. (2017).

*Renewable Heating and Cooling Policy Framework: Options to Advance Industry Growth and Markets in New York.* New York State Energy Research and Development Authority (NYSERDA). (2017).

## 2016

*Central Valley Research Homes: Variable Compressor Speed Heat Pumps.* Pacific Gas and Electric Company. (2016).

*Ductless Mini-Split Heat Pump Systems: The Answers to Questions about Efficiency You Didn't Know You Had.* ACEEE Summer Study on Energy Efficiency in Buildings. Cadmus. National Grid. (2016).

## 2015

*Air Source Heat Pump Potential in Alaska: An Emerging Energy Technology Fund Report for the Alaska Energy Authority.* Cold Climate Housing Research Center – University of Alaska Fairbanks Bristol Bay Campus. (2015).

*Heat Pumps: Community Workshop – Manchester Library, Manchester.* Presentation by Efficiency Vermont. (2015).

*HVAC Save: A Case Study in the Next Evolution of Residential Quality Installation Programs. A Midwest Energy Efficiency Alliance White Paper.* Midwest Energy Efficiency Alliance (MEEA). (2015).

*Heat Pumps in New Zealand: Study Report.* BRANZ from the Building Research Levy. (2015).

*Residential Inverter-Driven Heat Pump Technical and Market Assessment.* Northwest Energy Efficiency Alliance (NEEA). Navigant. (2015).

*Residential Ducted Mini-Splits vs. Ductless Heat Pumps. BPA E3T White Paper.* Washington State University. (2015).

*Combination Ductless Heat Pump and Heat Pump Water Heater Lab and Field Tests.* Northwest Efficiency Alliance. Energy 350. (2015).

*A Case Study of Residential New Construction Ductless Heat-Pump Performance and Cost Effectiveness.* Washington State University Energy Program – Building Technologies Program. Tacoma Power. (2015).

## 2014

*Performance Comparison of Round Tubes Finned Heat Exchangers and Macro Micro-Channel Heat Exchanges in a Low Capacity Heat Pump.* Purdue University. International Refrigeration and Air Conditioning Conference. (2014).

*Cooling and Heating Season Performance Assessment of a Mini-Split Cold Climate Air Source Heat Pump.* CanmetENERGY. (2014).

*Climate Impacts on Heating Seasonal Performance Factor (HSPF) and Seasonal Energy Efficiency Ratio (SEER) for Air Source Heat Pumps.* Florida Solar Energy Center. (2014).

*EM&V Forum: Primary Research – Ductless Heat Pumps.* Northeast Energy Efficiency Partnerships (NEEP). (2014).

Long-Term Monitoring of Mini-Split Ductless Heat Pumps in the Northeast. Building Science Corporation. U.S. Department of Energy. (2014).

## 2013

*Adoption of Ductless Heat Pumps in the Pacific Northwest.* Texas A&M University. Northwest Energy Efficiency Alliance (NEEA). (2013).

*Ductless Heat Pump Impact and Process Evaluation: Billing Analysis Report.* Northwest Energy Efficiency Alliance (NEEA). Ecotope. (2013).

## 2012 and earlier

*Ductless Heat Pump Impact and Process Evaluation: Field Metering Report.* Northwest Energy Efficiency Alliance (NEEA). Ecotope. (2012).

*Ductless Heat Pump Impact and Process Evaluation: Lab-Testing Report.* Northwest Energy Efficiency Alliance (NEEA). Ecotope. (2011).

*Energy Star® Water Heater Market Profile.* D&R International. Oak Ridge National Laboratory. (2010).