# Northwest Ductless Heat Pump Pilot Project – a Holistic Approach to Market Transformation and Evaluation

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## Abstract

There are approximately one million existing electrically heated homes in the Northwest. The Northwest region of the United States as defined for this project includes the states of Washington, Oregon, Idaho, and western Montana. Within this area, there are a range of climate zones. The region also includes a wide range of electric markets, from rural to large urban areas. Ductless heat pumps (DHPs) have the potential to save several hundred average megawatts in this market and reduce the carbon intensity of target homes by more than 30%. To leverage this large potential resource for the region, the Northwest Energy Efficiency Alliance (NEEA) used a holistic approach to design, implement, and evaluate the Northwest DHP Pilot Project. NEEA worked with contractors, manufacturers, distributors, and utilities to, generate demand for DHPs, build a thriving and sustainable network to meet that demand, and ultimately transform the DHP market.

NEEA designed the DHP Pilot Project evaluation to conduct an integrated assessment of DHP technical performance and market acceptance. The evaluation included five "tiers" of DHP research: 1) market acceptance, including interviews with manufacturers, distributors, utilities, program implementation staff, and nearly 300 participants; 2) lab testing of two DHPs; 3) field monitoring of 95 participating homes; 4) billing analysis of the pilot population (3,899 sites); and 5) cost-effectiveness analysis of the DHP measure. By taking a "360 degree" perspective, the evaluators were able to make granular distinctions between performance-based and behavior-based determinants of energy savings.

This paper discusses the tools used to influence DHP market perception and to overcome skeptics of this technology. The paper also assesses the evaluation approach, including the pros and cons of assessing a technology and program design from multiple angles in order to identify reliable savings and the potential for future programs.

## Introduction

For more than 30 years, the Northwest has relied heavily on increased efficiency to reduce demand for energy. This effort has resulted in a substantial reduction in the growth of electricity demand and obviated the need to expand or build additional power plants across the region. As carbon reduction targets solidify and regional capacity becomes increasingly constrained, the need to dramatically reduce energy use in the Northwest has intensified. In response to this challenge, regional organizations and utilities collaborated to design and evaluate a large-scale ductless heat pump (DHP) Pilot Project.

There are approximately one million existing electrically heated homes in the Northwest. DHPs have the potential to save several hundred average megawatts[1] in this market and reduce the carbon intensity of target homes by more than 30%. To leverage this large potential resource for the region, the Northwest Energy Efficiency Alliance (NEEA) used a holistic approach to design, implement, and evaluate the Northwest DHP Pilot Project. NEEA worked with contractors, manufacturers, distributors, and utilities to create a unique business case, generate demand for DHPs,

1 An average megawatt is the amount of electricity produced by the continuous production of one megawatt over a period of one year. The term, sometimes also called average annual megawatt, defines power production in megawatt increments over time. Because there are 8,760 hours in a year, an average megawatt is equal to 8,760 megawatt-hours.

build a thriving and sustainable network to meet that demand, and ultimately transform the DHP market.

NEEA plays a unique role in the Northwest working to accelerate the innovation and adoption of energy-efficient products, services and practices across the region. Market transformation is the strategic process of intervening in a market to create lasting change in market behavior by removing identified barriers or utilizing opportunities to accelerate the adoption of all cost-effective energy efficiency as a matter of standard practice. NEEA seeks to find emerging opportunities and to create a path to make these opportunities a reality across the region. DHPs are one such example.

NEEA also utilized a holistic approach to design a companion evaluation of the DHP Pilot Project. The DHP evaluation spanned five years and was designed to conduct a sequenced and integrated assessment of the technical performance and market acceptance of the technology. The evaluation included five tiers of DHP research and analysis: 1) market progress evaluation, including interviews with manufacturers, distributors, utilities, program implementation staff, and 200 to 300 participants; 2) lab testing and analysis of two DHP units; 3) field monitoring and analysis of 95 participating homes; 4) billing analysis of the pilot population (3,899 sites); and 5) cost analysis, including non-energy benefits.

NEEA designed the multi-tiered evaluation to enable evaluators to understand the technical performance of the DHP as distinct determinants of savings. Since the DHP Pilot Project was built on a displacement model in which the DHP equipment was designed to supplement an existing zonal electric heating system, it was important to develop an understanding of the behavioral determinants of savings. This model for the DHP measure leaves more of the occupant interaction to chance; i.e., the occupant is able to reset the equipment, adjust the thermostat remotely, and change the load on the equipment through the use of the electric resistance heating or a supplemental heating system. The ability to differentiate between equipment performance and behavioral effects is critical in order to identify reliable savings estimates and programmatic impacts on savings potential.

The costs and benefits generated as part of the DHP evaluation were used to implement a cost/benefit analysis and final recommendations for a DHP energy savings estimate. This paper discusses the most effective tools used to influence DHP customer and market perception and to overcome skeptics of this technology. The paper also assesses the holistic evaluation approach, including the pros and cons of taking the time to look at a technology and program design from multiple angles in order to identify reliable and defensible impacts as well as the actual potential of DHPs for future programs.

## Background

Beginning in 2006, a number of Asian manufacturers began to introduce a new generation of inverter-driven mini-split heat pumps into the North American market. Dubbed ductless heat pumps to distinguish them from conventional ducted heat pumps, these new systems promised high levels of energy efficiency as well as increased comfort, low-noise, and ease of installation.

The Northwest began to study the DHP technology and its potential as a cost-effective efficiency measure with a high degree of energy savings. One of the first steps involved a small DHP demonstration project. In fall 2006, NEEA and Grant County Public Utility District co-funded a five-home DHP demonstration project in central Washington to assess the performance, contractor experiences, and homeowner interaction and satisfaction with DHPs. This work was an exploratory effort that helped inform future studies that eventually led to the regional pilot. This small demonstration project indicated high consumer satisfaction and significant energy savings and launched the concept of using these new systems as “supplemental” heat in homes with electric zonal heating systems.

Following the success of the Grant County demonstration, Bonneville Power Administration (BPA) began a small metering pilot project in the summer of 2007 (Geraghty et al., 2009). The small DHP pilot included two homes from the Grant County demonstration project, eleven homes in Monmouth, Oregon, and one home in Tacoma, Washington. The BPA pilot included metering of the DHP, electric resistance heat, water heat, and total energy consumption for the 14 homes. One of the main goals of the BPA pilot was to provide a proof of concept for this “quad-metering” protocol using real time monitoring of kWh energy use and temperature. This approach was meant to expand on the “triple-meter” protocol used in BPA residential programs throughout the 1980s and early 1990s. Like these programs, space conditioning was measured separately from domestic water heating (DHW) and total consumption. Unlike that protocol, the measurements were logged in real time and were designed to separate the consumption of the DHP systems from the remaining electric resistance zonal heating system. The quad-metering protocol developed for the BPA pilot was later adapted for the DHP impact evaluation discussed in this summary report.

In fall 2007, the Regional Technical Forum (RTF)[2] modeled DHP energy savings and began to discuss the evaluation requirements necessary to validate DHP savings estimates. At that time, the RTF established a “provisional deemed” savings estimate in order to allow large utility program participation in a pilot project that would generate a large enough population to support statistical analysis of savings. The DHP Evaluation was designed to provide the research necessary to convert the provisional savings estimate to a proven savings estimate for continued use as an efficiency measure across the Northwest.

In the fall of 2008, NEEA embarked on an implementation initiative─the Northwest Ductless Heat Pump Pilot Project─on behalf of funding sponsors to market and evaluate inverter-driven ductless mini-split systems to displace electric resistance heat in existing Northwest homes. The Pilot Project was intended to enable and inform future ductless heat pump programs by testing program designs and marketing messages, identifying market barriers such as low awareness, cost, maintenance and aesthetics, and by building an effective infrastructure to sustain and accelerate market growth.

The Pilot Project partnered with more than 60 utilities for a year, to install up to 2,500 inverter-driven ductless heat pumps throughout Oregon, Washington, Montana, and Idaho. The regional project was intended to validate the provisional savings estimate and simultaneously demonstrate market acceptance and delivery of DHPs in existing residential homes that currently use electric resistance zonal heating systems.

## Pilot Project Design

A key driver for this technology demonstration and pilot was the introduction of variable speed technology with advanced individual controls into the United States market. While prior versions of “mini-split heat pumps” had been available for years, both their efficiency, noise, and air distribution reputation did not make them particularly attractive for Northwest homeowners. Market acceptance of the technology was quite low. On the other hand, the new inverter-driven systems came with stated efficiencies that exceeded anything available from conventional ducted air-source heat pumps. From a comfort standpoint, these new inverter-driven systems had many attractive features, including variable output strategies that allowed for high starting temperatures such that consumers felt “instant heat” when the systems came on; both indoor and outdoor units that were virtually silent under normal operation; and a range of operation that delivered significant heating capacity even down to low outdoor temperatures (below 10°F or-12°C). These features combined with high efficiency presented an opportunity to use the DHP units to serve as a primary heating

2 The Regional Technical Forum (RTF) is a chartered scientific committee of the Northwest Power and Conservation Council. The RTF is charged with establishing criteria for and review of standardized energy savings measures and practices. For more information see [www.nwcouncil.org/RTF](www.nwcouncil.org/RTF)

system with minimal if any backup use of electric resistant heat. Indeed, these new systems appeared to have addressed all of the shortcomings of traditional air-source heat pumps.

The focus of the Pilot Project was to understand the impact of this technology when applied as a retrofit in single-family residences that currently use electric resistance zonal heaters as their primary heat source. The vision for the Pilot Project included electric resistance heaters remaining in place for the occupant to use as needed. The DHP was also to be installed in the main living areas of the home and would "displace" the need for heat from the existing electric resistance heat. The energy savings theory assumed that, on average, occupants keep the main living area warmer than bedrooms, so the main living area requires the most heating energy throughout the season. On mild winter days, bedrooms and other cooler rooms are likely to receive most or all of their heating needs via heat transferred from the warmer main living area. As a result, the heating system in the main living area acts as the primary heat source throughout most of the heating season. The Pilot Project estimated that if the occupants used the more efficient DHP to provide this heat, rather than the electric resistance heaters, energy savings would occur.

The principal goal of the Pilot Project was to show that DHPs could interact with the homes of individual owners and provide savings that justify the relatively significant cost of adding a split system to an individual zonal electrically heated house.

The primary objectives of the Pilot Project included:

- Demonstrating the use of inverter-driven DHPs to displace electric resistance space heat in existing Northwest homes.
- Supporting evaluation efforts to document Pilot Project implementation and determine the costs and potential energy savings of DHPs in this application.
- Examining non-energy benefits and potential barriers to large scale implementation of DHPs.
- Building a regional infrastructure to sustain and accelerate market growth.

## Market Barriers and Opportunities

The Pilot Project sought to identify barriers to market acceptance of residential DHPs and to explore methods to overcome those barriers. Pilot Project staff reported that prior to the project, consumer barriers to DHP uptake included lack of familiarity with DHP technology, aesthetic concerns, and cost; additionally, distribution networks for residential DHPs were weak.

Prior research reported that as of 2008, DHPs represented only 1% of the $15 billion U.S. commercial and residential market for heating, ventilation, and air conditioning (HVAC) equipment and found that only 5% of the American public was aware of the existence of DHPs (NAHB 2008). The source does not provide residential saturations. However, installer respondents who had installed DHPs prior to the Pilot Project had installed twice as many commercial units as residential units.

To address these issues program stakeholders engaged utilities, manufacturers, distributors, and installers in a cooperative relationship to leverage their resources in support of the project. These relationships were vital for building awareness about the project. By offering an incentive for DHP installations, utilities across the region sought to motivate their customers to participate.

## Pilot Project Implementation and Marketing

**Utilities.** Utility buy-in was critical to the overall success of the Pilot Project. Early in the Pilot Project, efforts were focused on reaching out to utilities across the region and developing an infrastructure of utility participants. As the Pilot Project ramped up, the team created numerous resources and tools for utilities, established channels of communication to provide participants with Pilot Project updates and findings, and developed mechanisms for obtaining feedback from utilities.

Since DHPs were virtually unknown to the Northwest market, the Pilot Project aimed to create a marketing platform that would inform customers about this new product through clear and consistent messaging. The marketing plan placed a heavy emphasis on working through utilities to leverage their communication channels and credibility, and a number of customizable marketing templates were developed for utility use.

**Manufacturers and Distributors.** Supply chain actors reacted favorably to the prospect of utility support for ductless systems, but the team still had to build consensus regarding the target market and the opportunity for DHPs as an efficiency measure. The Pilot Project leveraged existing relationships between distributors and contractors to educate the market about displacement theory and to develop a regional installer base. The Pilot Project provided distributors with marketing support by coordinating display units for internal trainings, utility use, and home shows, as well as attending distributor-hosted contractor barbeques and open houses to provide an overview of the Pilot Project and encourage contractor participation.

**Contractors.** Contractors in the Northwest perceived ductless heat pumps as an application specific technology with limited market potential before the Pilot Project. The Pilot Project's early efforts and outreach were focused on educating contractors about displacement theory and communicating the market opportunity presented by electrically heated homes across the region. Contractors that adopted the displacement theory and DHPs as an energy saving technology for their customers were able to identify appropriate target homes and generally found, as the Pilot Project had hypothesized, that the technology has a positive impact on their businesses and on the satisfaction of their customers.

## Evaluation Design

The DHP Evaluation was designed to conduct a sequenced and integrated assessment of the technical performance and market acceptance of the technology. The purpose of this paper is to present an evaluation that integrated the results from five research tiers instead of basing the ultimate savings estimate on one or two typical analyses. These five tiers basically roll up into three main categories: market acceptance, savings, and costs. A measure cannot be built without an understanding of these factors. Unlike a typical program evaluation, this pilot evaluation used lab tests, a field study, billing analysis, and a calibrated engineering model to determine the savings estimate. This is a unique approach and recognizes the depth of analysis that is required to build a reliable measure as opposed to the task of developing realization rates for an existing program. The point was not to estimate the savings of the whole program as implemented, but rather reveal a reliable savings estimate of a typical installation.

The five "tiers" of DHP research and analysis included in the evaluation were as follows:

- **Tier 1 – Market Progress Evaluation.** Assessment of Pilot Project participants' use of DHPs, their use of other heating and cooling equipment, and their satisfaction with the DHPs. The market progress evaluation also reported on the evolving experiences and perspectives of manufacturers, utilities, and NEEA, as well as those of program implementation staff and their opinions about the suitability of DHPs as an efficiency measure in markets other than those targeted by the pilot. The evaluation explored responses to the technology and pilot, and intentions to install DHPs among participating and nonparticipating installers (McRae, Armstrong, and Harris 2011).
- **Tier 2 – Lab Testing and Analysis.** Detailed laboratory testing that established the efficiency of the DHP technology. The lab testing sought to establish the efficiency and performance of the equipment at various outside temperatures (Larson, Baylon, and Storm 2011). DHP lab performance was compared to *in-situ* metered performance.

- **Tier 3 – Field Monitoring and Analysis.** Detailed metering of the equipment installed in a sample of single-family homes throughout the Northwest (Baylon et al. 2012a). This effort was meant to establish the results of occupant approaches to using the DHP in the context of the existing heating system (which remained intact in most cases).
- **Tier 4 – Billing Analysis.** An impact analysis using the results of the billing changes in the homes using the DHP. This analysis was designed around a large sample of participants across the region (Baylon, Robison, and Storm 2013).
- **Tier 5 – Cost Analysis and Non-Energy Benefits**. Development of DHP capital cost estimates and non-energy benefits using DHP Evaluation results and program tracking information.

## Evaluation Findings

This section presents the salient findings from all five evaluation tiers, with particular emphasis on the savings analysis. Ecotope used findings from the lab tests, field monitoring, and billing analysis to compare and contrast energy savings from multiple perspectives. This process of cross checking and integrating findings contributed to the development of a calibrated engineering model informed by an in-depth and vetted understanding of the determinants of savings for the DHP measure.

### Tier 1: Market Progress Evaluation

Manufacturer contacts frequently cited the activities of the Pilot Project as a primary driver of growth in the residential DHP market and reported they view the Northwest as an important market for DHPs. Program staff reported that they aim to establish retail sales of DHPs as a milestone for 2011.

Utility incentive programs helped to overcome participants' first-cost hurdle. In 2010, DHP installations meeting parameters outlined by the Pilot Project continued at the same pace as they had during the Pilot Project implementation period. As of November 15, 2010, 7,116 DHP installations met parameters outlined by the Pilot Project (estimated to be 5% market penetration), 86 utilities offered DHP programs, and 76 utilities had at least one installed DHP. Multiple utility contacts reported that despite reduced DHP marketing efforts in 2010, consumer demand for DHPs continued to grow. Most of the utility contacts attributed the increased consumer demand for DHPs to substantial word-of-mouth advertising resulting from the high level of consumer satisfaction with DHPs.

Quality assurance efforts and continuing contractor education as the project progressed appears to have addressed many of the problems identified with some of the early DHP installations. Program contacts reported that because of an increase in the overall quality of installations, the project has been able to reduce the proportion of quality assurance inspections and still observe a high proportion of high quality installations.

In 2010, project and implementation staff continued to provide installer orientations that described the basis of the Pilot Project. To further develop the installer infrastructure and thereby sustain and accelerate growth in the market, project staff reported development of a *Master Installer Program* to increase the degree to which installers understand and promote displacement of zonal electric heat.

Comments from installer respondents indicate that the activities of the Pilot Project have strengthened DHP supply chains, resulting in increased availability of DHPs. Nearly all of the installer respondents reported that obtaining DHPs is "easier" or "the same degree of difficulty" as obtaining other types of space-conditioning equipment.

The majority of both participant and installer respondents reported that DHP installations were quick, minimally invasive, and did not require installer follow-up. The majority of manufacturers estimated that 90% to 100% of residential DHPs installed in the Northwest are installed properly and function optimally. However, several interviewed utility staff, installers, and participants reported issues with the installation of DHP line sets.

Manufacturer contacts reported that they increasingly view the Northwest as an important market for DHPs. One reported that Oregon and Washington ranked 8$^{th}$ and 9$^{th}$ respectively in 2010 national data in terms of the total number of DHP units sold, as compared with 2008, when they ranked 19$^{th}$ and 20$^{th}$ respectively. Manufacturers also reported that the availability of DHPs had increased in the Northwest, including the most up-to-date cold-temperature products, which manufacturers had previously offered almost exclusively in Scandinavia.

Participants reported high levels of satisfaction with DHPs (92%) and with Pilot Project implementation processes (85%), including: ease of understanding incentive qualification requirements; ease of finding an installer; ease of locating program information; and the speed with which they received their incentive checks.

Most participants reported receiving non-energy benefits from their DHPs, including increased comfort, ease of control, and air filtration. The market progress evaluation identified that potential barriers to large-scale implementation of DHPs include concerns about their ability to provide adequate heat in colder temperatures and the cost of DHPs. In addition, findings suggest the cost of DHPs installed with a single interior head may be falling.

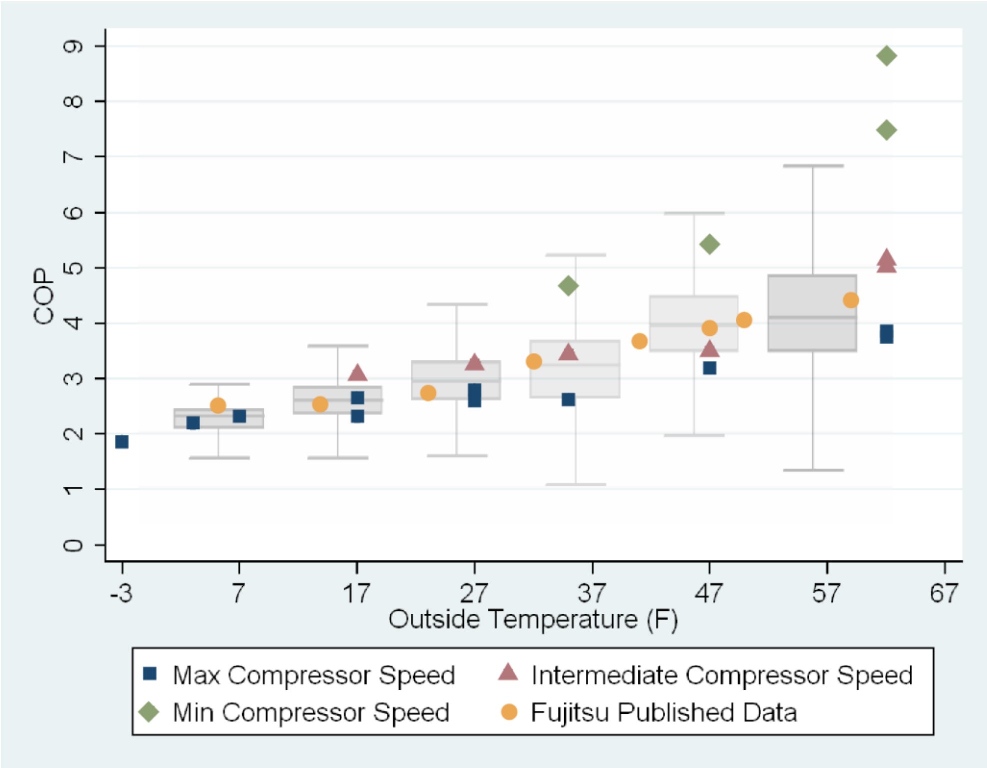
The majority (96%) of respondents reported having used the DHP on the coldest days of the year and slightly over three-quarters (77%) indicated that the DHP was able to keep their space at a comfortable temperature despite the cold. Respondents described the heat from the DHP as “more even,” “more consistent,” and “more efficient” than their previous heat.

## Tier 2: Lab Testing

Working with NEEA, Ecotope selected two DHP models to evaluate which are representative of those found in the field installations: the Fujitsu 12RLS and Mitsubishi FE12NA. Ecotope developed a testing strategy and contracted with Herrick Labs of Purdue University to conduct the measurements. The lab measured performance impacts on the two equipment models over a wide range of operating conditions that would be encountered in Northwest installations, including outside temperature ranges from -5°F to +105°F (approximately -20°C to 40°C). Additionally, because the efficiency and flexibility of the DHP systems stem from their ability to vary compressor thermal outputs and indoor fan flow in response to changing ambient conditions or occupant intervention, the testing plan also called for measuring high, medium, and low capacity outputs and also included high, medium, and low indoor fan speeds.

Lab testing of the two different DHPs compared well with actual field measured coefficients of performance (COP) across a range of temperature conditions and largely validates that manufacturer ratings of this equipment are accurate. Figure 1 below shows lab measurements, manufacturer’s published performance data, and field measurements for one manufacturer. The performance ranges from the field data at various temperatures are shown as box plots. The steady state lab data from the manufacturer and from the Ecotope lab tests are plotted as points. The graphic illustrates that, except for some outliers, the lab data and the manufacturer’s published data fall closely or within the field data box plots, demonstrating good agreement between rated and measured performance in DHP field installations. This agreement was critical to determine in order to use the field and lab data to construct a model for extending observed savings to the residential sector targeted by the Pilot Project.

**Figure 1. 12RLS COP Plot**




## Tier 3: Field Monitoring

Ecotope installed metering equipment on a total of 95 homes selected from the participants in the Pilot Project. The metered sites were analyzed to develop the determinants of energy savings of the DHP systems as they operated across a variety of climates and occupants. The sites were metered for between 14 and 18 months. Energy end-use metering included measurement of whole house energy use, both electric resistance and DHP energy use, and domestic water heater energy usage. A subset of the metered homes included direct measurement of DHP heating contribution to the home by measuring air flow and temperature rise across the indoor head of the DHP facilitating calculation of an "in-situ" COP. These COP sites allowed for comparison with laboratory measurements as well as direct measurement of energy savings delivered by the DHP.

The data handling and data quality were developed to ensure a high-quality data stream throughout the project. Each stage of the installation was addressed:

- A field installation guide was developed in the early stages of field installation. Site installation managers were required to fill out a detailed site protocol, including types of sensors and individual sensor serial numbers (because these are the primary identifiers of sensors after data returns from the datalogging vendor).
- The datalogging vendor offered a "web services" interface by which Ecotope's computers could directly retrieve data from the data warehouse. Ecotope used the automatic calling functions to deliver site data to the local Ecotope repository.
- Ecotope's datalogging system automatically retrieved all new site data from the warehouse once a day via command-driven batch files, and subjected the data to range and sum checks. Because one of the site-monitoring channels was total service power consumption, Ecotope analysts were able to compare service consumption against the sum of metered power consumption channels.

- The above processes were supplemented with field visits when data quality or downloads failed. This happened rarely except for the sites where no cell phone coverage resulted in a failure of the automated systems. In these cases, the data were downloaded manually approximately every three months. In some cases, sensor or logger failure was observed in the data downloads, and a technician was dispatched to download or repair the site.

Table 1 below illustrates the performance of the DHP systems from the field-metered subsample of the Pilot Project. These findings were corroborated by the laboratory testing indicating that the manufacturers' rated performance was very close to the measured field performance. With seasonal COPs ranging from 2.4 to 3.4 and an average of 3, the inverter driven technology delivered high performance across the Northwest. The COP estimates were derived from the onsite meters, the lab testing, and the manufacture's specifications. A total of 69 sites had sufficient data to allow the combination of these data sources to be applied.

**Table 1. Ductless Heat Pump Performance**

| | **DHP Heating Input Energy (kWh/yr)** | | **DHP Heating Output Energy (kWh/yr)** | | **DHP Heating Seasonal COP** | | |
|---|---|---|---|---|---|---|---|
| **Cluster*** | Mean | SD | Mean | SD | Mean | SD | **n** |
| Willamette | 1,876 | 962 | 6,048 | 2,872 | 3.40 | 0.32 | 20 |
| Puget Sound | 1,823 | 708 | 5,549 | 2,570 | 3.05 | 0.56 | 20 |
| Inland Empire | 2,492 | 1097 | 5,637 | 2,126 | 2.41 | 0.59 | 12 |
| Boise/Twin | 2,256 | 1274 | 6,440 | 3,040 | 2.96 | 0.30 | 8 |
| Eastern Idaho | 2,188 | 978 | 6,112 | 2,675 | 2.84 | 0.30 | 9 |
| Average / Total | 2,052 | 969 | 5,886 | 2,602 | 3.00 | 0.55 | 69 |

* Willamette = NE Oregon (around Portland); Puget Sound = NE Washington (around Seattle); Inland Empire = Eastern Washington; Boise/Twin = Southern Idaho.

The average weather normalized savings across the metered sample in Table 1 exceeded 3,800 kWh per year (the difference between average/total heating input energy and heating output energy). Even when comparing annual heating energy use after DHP installation to heating energy use before (at least a year for both pre and post-installation time periods), the evaluation measured a "net" energy usage that was still significant though less than measured directly from the COP measurements in Table 1. Table 2 illustrates savings compared to a "pre-DHP" baseline.

**Table 2. Net Heating Savings, Metered**

| | **DHP Savings (kWh/yr)** | | |
|---|---|---|---|
| **Cluster** | Mean | SD | **N** |
| Willamette | 3,316 | 2,121 | 26 |
| Puget Sound | 3,043 | 2,357 | 25 |
| Inland Empire | 1,882 | 1,580 | 16 |
| Boise/Twin | 3,628 | 2,985 | 16 |
| Eastern Idaho | 3,307 | 3,230 | 10 |
| Average/Total | 3,049 | 2,424 | 93 |

The difference between the savings observed in Table 1and Table 2 illustrates the fact that roughly 20% of the heat produced by the DHP was used to provide other benefits (beyond electrical energy savings) to the occupant. While the difference between the savings shown in Table 1 and the savings derived from the measured data shown in Table 2 have many potential causes, occupant surveys and temperature observations suggest that much of the difference is the result of improved comfort and reduced use of supplemental fuels not metered in the electric system (e.g., non-utility provided fuels such as wood pellets and propane). These benefits included increased temperature setpoints in the main living space, reduced supplemental fuel consumption, increased temperatures in adjacent secondary living zones, and increased occupancy during the heating season.

**Tier 4: Billing Analysis**

Ecotope requested electric utility bills for the 3,899 Pilot Project participants. A total of 59 participating provided bills for their participating customers. Ecotope obtained billing data for nearly 100% of the participating sites; billing data for 93% of the sites (3,621) were complete and clean enough to conduct a variable degree day (VBDD) analysis to estimate annual electric space heating use. Even with fairly rigorous statistical screening criteria, more than 3,300 sites had reliable heating estimates for at least one year prior to DHP installation and the year after the DHP installation.

The overall savings from the simple billing analysis of the Pilot Project population can be divided into two categories. First, the unscreened version of the billing analysis averaged across all climates and all space heating types, approximately 1,900 kWh/yr. When this same group is screened for supplemental fuels, as identified in the customer intake interview conducted at the installation of the DHP, the savings estimates increase to about 2,700 kWh/yr, a better than 30% increase in savings. This result compares well to the billing analysis conducted in the metered sample, where more careful screening of supplemental fuels was done. In that sample, the billing analysis suggested that space heating savings or the energy savings from the DHP installation were approximately 3,100 kWh/yr, or about 12% higher than the savings observed here. This finding is within the error bounds of these estimates and confirms substantial agreement between the two samples.

The billing analysis for the overall Pilot Project was conclusive on two main points:

1. The use of supplemental fuels in this particular population, namely customers with zonal electric resistance heat, leads to substantial reduction in savings on the order of 30% or more. Failure to screen for supplemental fuels will reduce the overall savings effect of the DHP technology.
2. At least in in the colder, eastern part of the Northwest (Heating Zone 2 and 3), a more careful engineering analysis might be appropriate to specify systems that are more likely to produce a similar level of savings as those observed in the western climates. This research would likely include the introduction of a second indoor air-handler unit and/or the introduction of a higher capacity compressor in these colder climates.

Table 3 shows the results of the billing analysis segmented between participants with supplemental fuels and participants without such systems.

The overall results of this billing analysis show a good agreement with the results of the DHP metered study when similar analytical screens were used to isolate determinants of savings in both datasets. Not only are the results comparable when the same screening is done on the billing analysis as was conducted in selecting the sites in the metering study, but when the regression controls for the effects of supplemental fuels and other occupancy effects, the results of the regression also show a comparable savings fraction. This result confirms the net electric savings analysis developed using the detailed metering.

**Table 1. DHP Savings by Supplemental Fuel Usage**

| Cluster | Space Heating Savings | | | |
|---|---|---|---|---|
| | Supp. Fuel | | No Supp. Fuel | |
| | kWh/yr | n | kWh/yr | n |
| Willamette | 1,167 | 547 | 2,886 | 1,454 |
| Puget Sound | 678 | 247 | 2,586 | 454 |
| Coastal | 514 | 95 | 2,905 | 138 |
| Inland Empire | -70 | 65 | 1,842 | 61 |
| Boise/Twin | 497 | 29 | 2,067 | 63 |
| Eastern Idaho | -1,307 | 30 | 1,557 | 51 |
| Tri-Cities | 299 | 14 | 1,314 | 37 |
| Western Montana | -168 | 68 | 2,615 | 37 |
| Total | 747 | 1,095 | 2,718 | 2,295 |

## Tier 5: Cost Analysis and Non-Energy Benefits

The RTF guidelines[3] provide a format for evaluating the unit energy saving (UES)[4] and cost benefit ratio for Northwest energy efficiency measures. The DHP measure as applied to zonal electric resistance heating was presented and approved in 2013 using the cost analysis and non-energy benefits assessed in the DHP Evaluation and described below in Table 4. The full cost benefit analysis conducted for the DHP UES development is available in the DHP UES measure workbook on the RTF Website.[5] The RTF uses a total resource cost (TRC) test to determine cost effectiveness. The TRC accounts for all the costs of a measure with all of its benefits, regardless of who pays those costs or who receives the benefits. The DHP capital costs were calculated as the average of the installed costs across the Pilot Project population. Foregone cooling investments were accounted for assuming new zonal cooling equipment would be purchased in the fraction of homes consistent with the projected saturation of zonal cooling. Supplemental fuel offsets were computed assuming that DHP savings were distributed between the electric heat usage and the supplemental fuel usage. The value of this offset was computed at the retail cost of electricity to these customers.

**Table 4. DHP Costs and Offsets**

| Regional DHP Costs and Offsets | $ |
|---|---|
| DHP Capital Costs | $3,572.00 |
| Cooling Capital Cost Offset | $84.00 |
| Supplemental Fuel Offset | $0.09/kWh |

3 For more information on the RTF guidelines see the *Roadmap for the Assessment of Energy Efficiency Measures*, at http://rtf.nwcouncil.org//subcommittees/guidelines/RTF_Guidelines_2013-04-16.pdf.
4 Unit Energy Savings (UES). is the RTF measure classification for measures "whose unitized savings, e.g., savings per lamp or motor, is stable (both the mean and variance) and can be reliably forecast through the period defined by the measure's sunset date."( http://rtf.nwcouncil.org/subcommittees/Guidelines/RTF_Guidelines_2013-04-16.pdf)
5 For more information on the DHP UES see the full RTF DHP measure workbook at http://rtf.nwcouncil.org/meetings/2013/11/DHP_UES_2013-11-13%20PROPOSED.XLSM

## Evaluation Conclusions and DHP Measure Development

The overall program implications of the DHP evaluation suggest that DHPs are an important and transformational technology which can appreciably offset electric space heating requirements in simple electric resistance systems without disrupting the existing heating system or underlying home structure. As installed in the Pilot Project, the manufacturer ratings for the DHP do not appear to have a significant impact on the savings; i.e., with few exceptions the savings were similar across manufacturers and models as long as the equipment met the criteria for inverter-driven operation. This finding indicates that the technology is adaptable to a utility program with the goal of providing improved heating efficiency and energy savings resources. One caveat is that the savings are strongly determined by the amount of pre-existing electric heating. Higher savings fractions were observed in the warmer milder climates; lower savings percentages were observed in the more severe heating climates.

Although, the five research tiers in this study provided important insights into the technical performance and market acceptance of the DHP technology, the DHP Evaluation was not designed to single out any particular savings estimate as the final DHP savings estimate. Furthermore, the savings can vary widely depending on occupant behavior such as pre-installation supplemental fuel use, post-installation occupancy changes, and migrating thermostat settings. However, by taking a multi-tiered, “360 degree” perspective, the evaluation team and regional stakeholders were able to make fairly granular distinctions between performance-based and behavior-based determinants of energy savings. For example, savings relating directly to the performance of the equipment versus changes in thermostat setpoints, pre and post-installation supplemental fuel usage, and occupancy changes.

In 2013, these savings distinctions, along with the full suite of DHP Evaluation results, were used to develop a calibrated engineering model of DHP performance using the Simple Energy and Enthalpy Model (SEEM)[6] simulation tool. The costs and benefits generated as part of the DHP Evaluation were used to implement a cost/benefit analysis and final recommendations for the proven DHP unit energy savings (UES).[7] In November 2013, the RTF approved an unscreened version of the DHP UES as a cost-effective efficiency measure in most climates and converted the UES from provisional to proven status.[8]

## Reflections on Pilot and Evaluation Methodology

The DHP Pilot Project and the DHP evaluation were interdependent, holistic, long-term efforts aimed at achieving broad market transformation and an in-depth understanding of an emerging technology. Although, the Pilot Project itself only lasted for one year before converting to a regional program, the evaluation and measure development spanned nearly five years. It is critical that large regional efficiency investments are supported by in-depth, primary research tailored to the Northwest climates and market context. However, there are some limitations to this approach. For example, using billing analysis alone to assess the savings impact of a measure can be a relatively quick approach compared to the additional time necessary to do lab testing, one to two years of field

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6 SEEM consists of an hourly thermal, moisture, and air mass balance simulation that interacts with duct specifications, equipment, and weather parameters to calculate the annual energy requirements of the building. It employs algorithms consistent with current American Society of Heating, Refrigeration, and Air-Conditioning Engineers (ASHRAE), Air-Conditioning, Heating, and Refrigeration Institute (AHRI), and International Organization for Standardization (ISO) calculation standards. SEEM is used extensively in the Northwest to estimate conservation measure savings for regional energy utility policy planners.

7 Unit Energy Savings (UES). is the RTF measure classification for measures “whose unitized savings, e.g., savings per lamp or motor, is stable (both the mean and variance) and can be reliably forecast through the period defined by the measure’s sunset date.” http://rtf.nwcouncil.org/subcommittees/Guidelines/RTF_Guidelines_2013-04-16.pdf

8 For more information on the DHP UES see the full RTF DHP measure workbook at http://rtf.nwcouncil.org//measures/res/ResHeatingCoolingDuctlessHeatPumpsSF_v2_0.xlsm

monitoring, and synthesis of the results of all tiers in the study. However, this level of detail and insight provides more substantiated and nuanced program design feedback and the specific inputs required to develop efficiency measures in accordance with Northwest measure development guidelines. In addition, much of this primary research can be extended to other similar climates nationally and internationally.

Ultimately the holistic approach implemented for the DHP zonal technology has provided Northwest planners an unprecedented level of detail and insight into the technology, which supports NEEA's overall, goal of long-term market transformation as a key strategy for offsetting the need for additional power plants in the Northwest. In particular, information on supplemental fuel use collected as part of the DHP Pilot Project, combined with detailed metering and billing analysis, provided the region with the data required to determine cost-effectiveness at the climate zone level. These findings led to the development of a simplified screening approach that Northwest utilities can use to focus DHP incentives on homes with the highest savings potential. Further, the technical understanding of the fundamental DHP performance will be used to underpin savings estimates for a variety of additional DHP applications, such as forced air furnaces and manufactured homes.

Although, the Pilot Project was only operated for one year, NEEA has continued to apply the DHP evaluation results throughout subsequent years of the regional program. In addition, NEEA and Ecotope, as its technical evaluation contractor, have leveraged lessons learned from the DHP Pilot Project and evaluation to streamline the design and implementation of initiatives for other emerging technologies. For example, the pilot phase of NEEA's heat pump water heater (HPWH) initiative has been reframed as a "market test" and was designed to correspond with a smaller and much shorter technical validation and market assessment. Based on modeling requirements for the DHP evaluation, the field component of the HPWH study was more explicitly designed to provide key inputs to validate the engineering model and, therefore, required less sites and a shorter field monitoring timeframe.

In sum, the DHP Pilot Project and evaluation methodology were very effective in providing a sound basis for measure development. Lessons learned from the evaluation also contributed a foundation for fine tuning future studies. However, the appropriate level of effort for any technology evaluation will always depend on the nature of the technology, measure interactions, and occupancy factors. And as efficiency programs move toward deeper savings, more complex equipment, and net-zero loads, it will become increasingly important to design studies that holistically evaluate and synthesize both equipment and behavior-based determinants of savings.

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