February 19, 2014
REPORT #E14-274

Final Summary Report for the Ductless Heat Pump Impact and Process Evaluation

Prepared by:
Ecotope Inc.
4056 9th Avenue NE
Seattle, WA 98105

Northwest Energy Efficiency Alliance
PHONE
503-688-5400
FAX
503-688-5447
EMAIL
info@neea.org

Table of Contents

List of Tables

List of Figures

Glossary of Terms and Acronyms

6th Plan	Sixth Northwest Conservation and Electric Power Plan
ACH	air changes per hour
AHRI	Air-Conditioning, Heating, and Refrigeration Institute
ASHRAE	American Society of Heating, Refrigeration, and Air-Conditioning Engineers
BPA	Bonneville Power Administration
Btu/hr	British thermal units per hour
CDA	conditional demand analysis
CFM	cubic feet per minute
CI	confidence interval
COP	coefficient of performance
Council	Northwest Power and Conservation Council
CT	current transducer
DD	degree days
DHP	ductless heat pump
DHP Evaluation	Ductless Heat Pump Impact and Process Evaluation
DHW	domestic hot water
DOE	Department of Energy
EB	error bound
EPA	Environmental Protection Agency
ER	electric resistance
HDD	heating degree days
HSPF	heating seasonal performance factor
HVAC	heating, ventilation, and air conditioning
ISO	International Organization for Standardization
kWh	kilowatt hours
kWh/yr	kilowatt hours per year
MEL	miscellaneous electric load
MPER	market progress and evaluation report

N	number of observations
NCDC	National Climatic Data Center
NEEA	Northwest Energy Efficiency Alliance
NWS	National Weather Service
Pilot Project	Northwest Ductless Heat Pump Pilot Project
PRISM	PRInceton Scorekeeping Method
R^2	coefficient of determination
RAC	room air conditioning
RBSA	Residential Building Stock Assessment
RMS	root mean squared
RTF	Regional Technical Forum
SD	standard deviation of the population
SEEM	Simple Energy and Enthalpy Model
SEER	Seasonal Energy Efficiency Ratio
TMY	Typical Meteorological Year
UA	The sum of the thermal transfer coefficient (U) times the area (A) of the components of the building. Also includes convective losses from infiltration
UES	unit energy savings
VBDD	variable base degree day
VLT	vapor line temperature

Executive Summary

The Northwest Energy Efficiency Alliance (NEEA)[1] hired Ecotope, Inc., supported by Research Into Action, Inc., and Stellar Processes to evaluate the Northwest Ductless Heat Pump (DHP) Pilot Project (Pilot Project). The Pilot Project ran from October 2008 through December 2009. A total of 3,899 installations were included in the Pilot project. The DHP Impact and Process Evaluation (DHP Evaluation) includes a tiered analysis of five components of technical performance and market acceptance: market progress evaluation, laboratory testing, field monitoring, billing analysis, and cost analysis and non-energy benefits. This report summarizes the primary goals, objectives, activities, and evaluation results of the Pilot Project.

The Pilot Project was built on a displacement model in which the DHP equipment was designed to supplement an existing zonal electric heating system. This model for the DHP Pilot Project 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.

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” in recognition of their differences from conventional ducted counterparts, 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, the 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 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. 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[2].

[1] The Northwest Energy Efficiency Alliance (NEEA) is a non-profit organization working to maximize energy efficiency to meet future energy needs in the Northwest. NEEA is supported by, and works in collaboration with, the Bonneville Power Administration, Energy Trust of Oregon and more than 100 Northwest utilities on behalf of more than 12 million energy consumers. For more information see www.neea.org.

[2] The metering protocol developed for the BPA pilot was later adapted for the DHP impact evaluation discussed in this summary report. The results of the BPA pilot can be found at http://www.bpa.gov/energy/n/emerging_technology/pdf/BPA-Report_DHP-Retrofit-Monitoring-June2009.pdf.

In fall 2007, the Regional Technical Forum (RTF)[3] modeled DHP energy savings and began to discuss the evaluation requirements necessary to validate DHP savings estimates. At that point, 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 October 2008, NEEA, BPA, and regional utilities launched a large-scale, regional project 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. The Pilot Project included marketing and implementation activities to coordinate installations of DHPs with manufacturers, distributors, contractors, and Northwest utility programs that provided incentives to the end consumer.

The primary objectives of the Pilot Project included:

- Demonstrating the use of this new generation 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.

The DHP Evaluation was designed to conduct a sequenced and integrated assessment of the technical performance and market acceptance of the technology. The included five "tiers" of DHP research and analysis:

- **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).
- **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.

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[3] 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

- **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).
- **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).
- **Cost Analysis and Non-Energy Benefits**. Development of DHP capital cost estimates and non-energy benefits using DHP Evaluation results and program tracking information.

The DHP Evaluation established the market acceptance and technical viability of the DHP technology as a retrofit resource for electrically heated customers in Northwest climate zones. Moreover, the approach used in this Pilot Project focusing on displacement of heating load, rather than replacement of heating systems, offers many customers an option for including high-efficiency equipment without completely abandoning their existing heating system (at substantial expense).

DHPs have a strong consumer acceptance, a workable integration with existing market actors and supply chains, a reasonable level of agreement between manufacturers' claims and actual performance and, finally, a performance that integrates well with the space conditioning needs of the utility customer. While occupants should have the option of installing larger systems, the smaller more targeted system produced desirable savings numbers and is likely to be among the most cost-effective efficiency measures available to utility customers across the Northwest. This approach was used to develop the regional program proposed to the RTF in 2013.

The emphasis in the Pilot Project on installers as a delivery mechanism has been successful. The DHP Pilot Project provides a useful model for the implementation and marketing of an emerging efficiency technology in this specific market of the residential sector.

Lab testing of two different manufacturer DHPs compared well with actual field measured coefficients of performance (COPs) across a range of temperature conditions and largely validates that manufacturer ratings of this equipment are accurate. 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 average savings across the metered sample exceeded 3,800 kWh per year. Even when comparing heating energy use after DHP installation to heating energy use before, the evaluation measured a "net" energy usage that was still significant though less than measured directly from COP measurements.

The difference between the savings observed in the metered sample and the billing analysis sample illustrates the fact that roughly 20% of the heat produced by the DHP was used to provide other benefits (beyond energy savings) to the occupant. 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.

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, showed approximately 1,900 kWh/yr in energy savings.

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 reasonably 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. However, when error bounds are taken into account, there is not a statistically significant difference between the billing analysis savings estimates for the overall pilot population and for the subsample of metered sites.

The billing analysis for the overall Pilot Project is fairly 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. It is likely that a failure to screen for supplemental fuels will reduce the overall savings effect of the DHP technology.
2. At least in Heating Zone 2 and 3 in the eastern part of the Northwest, 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.

The overall results of this billing analysis show a good agreement with the results of the DHP metered study. 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.

In the final tier of the DHP Evaluation, the installation costs of the DHP units were summarized. It is apparent that local market conditions play a major role in the total costs observed. Given the disparity across the region's market areas and the large differences between the urban markets of the Puget Sound area and the more rural markets of Idaho and Montana, it seems likely that over time the competitive pressure to bring down the installation costs will result in some reductions. Nevertheless, at these costs the measure is cost-effective in most markets, and with careful screening can likely be cost-effective in virtually all Northwest market areas.

The overall program implications suggest that this is 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 regardless of the nameplate capacity or efficiency ratings 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. Average savings of 33% were observed across the Northwest climates. Higher savings were observed in the milder, western climates, while lower savings 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, as described in Section 4 and Section 5 of this report, 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. 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) 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).[4] 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.[5]

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[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

1. Introduction

The Northwest Energy Efficiency Alliance (NEEA) hired Ecotope, Inc., supported by Research Into Action, Inc., and Stellar Processes to evaluate the Northwest Ductless Heat Pump (DHP) Pilot Project (Pilot Project). The Pilot Project ran from October 2008 through December 2009. A total of 3,899 installations were included in the Pilot project. The DHP Impact and Process Evaluation (DHP Evaluation) includes a tiered analysis of five components of technical performance and market acceptance: market progress evaluation, laboratory testing, field monitoring, billing analysis, and cost analysis and non-energy benefits. This report summarizes the primary goals, objectives, activities, and evaluation results of the Pilot Project.

1.1. Background

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). These features combined with high efficiency presented an opportunity to use the DHP units to serve as a primary heating 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 this 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 heat pump to provide this heat, rather than the electric resistance heaters, energy savings would occur.

Beginning in 2006, a number of Asian manufacturers began to introduce the new generation of inverter-driven mini-split heat pumps into the North American market. Dubbed "ductless heat pumps" in recognition of their differences from conventional ducted counterparts, these new systems promised high levels of energy efficiency as well as increased comfort, low-noise, and ease of installation. The upgrades were largely the result of increases in federal standards established in early 2006 for heat pumps and air conditioning. Like the previous generation of mini-splits, the DHP systems used small wall-mounted air handlers with direct refrigerant supply from a compressor located outside.

As the new generation of equipment was introduced, it was apparent that this equipment would be substantially more efficient than conventional split-system heat pumps with central air handlers and a central ducting system. Moreover, such systems were low enough in cost and were flexible enough to be considered as a measure to offset electric resistance zonal heating systems, which are not easily retrofitted with ducting systems.

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 this new technology. Bonneville Power Administration (BPA) donated metering equipment to examine energy performance in two of the homes. An internal report was produced in early 2007 indicating that installation was quite simple and homeowner satisfaction was high, exceeding expectations in both areas. Simple comparison of electric bills implied significant energy savings. This small 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, BPA began a small metering pilot project in the summer of 2007. 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[6]. In fall 2007, the Regional Technical Forum (RTF)[7] modeled DHP energy savings and began to discuss the evaluation requirements necessary to validate DHP savings estimates. At that point, 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 determination of reliable “deemed savings” values across the region’s climate zones. This objective would require a small enough error bound on the estimate of the mean to be credible to the RTF.

[6] The metering protocol developed for the BPA pilot was later adapted for the DHP impact evaluation discussed in this summary report. The results of the BPA pilot can be found at http://www.bpa.gov/energy/n/emerging_technology/pdf/BPA-Report_DHP-Retrofit-Monitoring-June2009.pdf

[7] 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

The RTF provisional deemed savings value was estimated at 3,500 kWh per year with an incremental cost of $3,407 (RTF 2010). The RTF used the following assumptions to model and establish the provisional savings estimates:

- The equipment would be installed in main living zones without actually replacing the existing electric heating. This approach became known as the "displacement" heating model.
- Occupants would usually select this heating source over their existing system because of its efficiency and convenience.
- The DHP would provide up to 60% of the space heat and result in a 30–40% reduction in space heating energy requirements.
- Interaction with wood and other supplemental heating would be minimized by restricting the measure to homes that do not use substantial amounts of wood heat.
- Mechanical cooling usage, especially in the region's western climates, would not be large enough to offset the heating benefits in these climates and may provide added cooling benefits in the eastern climates with larger cooling loads.
- The systems could be delivered in any climate in the Northwest, although there was some concern that the DHP technology might not perform in the coldest weather. The displacement model was thought to mitigate the risk associated with this scenario.

In spring 2008, BPA added DHPs to the list of eligible measures for regional utilities and NEEA established a proposal for a regional pilot program and solicited funding support. In October 2008, NEEA, BPA and regional utilities launched a large-scale regional project intended to validate the RTF provisional savings estimate and simultaneously demonstrate market acceptance and delivery of DHPs in existing residential homes that currently use electric resistance zonal heating systems. The Pilot Project included marketing and implementation activities to coordinate installations of DHPs with manufacturers, distributors, contractors, and Northwest utility programs that provided incentives to the end consumer.

NEEA hired Ecotope, Inc., supported by Research Into Action, Inc., and Stellar Processes to evaluate the Pilot Project. The Pilot Project ran from October 2008 to December 2009. Ecotope is conducting the DHP Pilot Project Impact and Process Evaluation from October 2008 to December 2012. The DHP Evaluation includes a tiered analysis of five components of technical performance and market acceptance: market progress and evaluation, lab testing, field monitoring, billing analysis, cost estimates and non-energy benefits.

1.2. Pilot Project Goals and Objectives

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.

1.2.1. Target Market Description

The primary target market for the Pilot Project consisted of single-family, site-built homes using electric resistance zonal heating systems as the primary source of heat. To address this market with a cost-effective DHP measure, the systems were thought to be optimized with a single outdoor compressor and one or two indoor air handlers. This configuration represents a relatively low-cost way to supply the needs of a major portion of the heating load. The general approach for the Pilot Project was to market the system as a "displacement" technology—that is, a technology that would offset the existing space heating without replacing the existing electric-resistance space heaters. The other attractive aspect of the "displacement" approach is that it leaves in place the existing zonal electric heat, thereby not risking adverse home comfort.

1.2.2. 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 – and roughly coincident with the efficiency improvements in DHP technology undertaken by the manufacturers – 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.

1.3. Pilot Project Implementation and Marketing

1.3.1. 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.

1.3.2. 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.

1.3.3. 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.

1.4. Integrated Evaluation of the DHP Pilot Project

To quantify the savings from increasing the efficiency of the zonal heating system, the Pilot Project included an integrated project evaluation. This evaluation includes five components:

- **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).
- **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.
- **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).
- **Billing Analysis.** An impact analysis using the results of the billing changes in the homes using the DHP. This was designed around a large sample of participants across the region and was meant to capture the overall impacts of DHP use (Baylon, Robison, and Storm 2013).
- **Cost Analysis and Non-Energy Benefits**. Development of DHP capital cost estimates and non-energy benefits using DHP Evaluation results and program tracking information.

1.5. Pilot Project Timeline

The Pilot Project launched on October 1, 2008. The implementation phase of the Pilot Project ended on December 31, 2009 with the Pilot Project evaluation activities continuing through 2013. Table 1 presents major project milestones with timeframes for evaluation milestones.

Table 1. Evaluation Milestones

Evaluation Milestones	Timeframe
DHP Pilot Project Launch	Q4 2008
DHP Evaluation Launch	Q1 2009
Meter Installations	May 2009–January 2010
Meter Data Logging	May 2009–March 2011
Market Progress and Evaluation Report #1 (Wave 1)	Q1 2010
Market Progress and Evaluation Report #2 (Wave 2)	Q3 2011
Lab Testing Report	Q3 2011
Metering Report	Q2 2012
Billing Analysis Report	Q3 2013
Cost Analysis and Non-Energy Benefits	Q3 2013
Final Summary Report	Q1 2014

1.6. Pilot Project Organization, Roles and Responsibilities

- **Project Administration.** NEEA provided overall project conceptualization, design, direction, and administration of the Pilot Project on behalf of funding utility sponsors.
- **Project Execution.** Fluid Market Strategies, Inc. provided implementation services including Pilot Project design, development, marketing, installation verification, market and stakeholder coordination, and Pilot Project reporting.
- **Project Impact and Process Evaluation.** Ecotope, Inc., supported by Research Into Action, Inc. and Stellar Processes, is conducting the Pilot Project evaluation components.

2. Market Progress and Evaluation

The market progress and evaluation of the Pilot Project was implemented by Research Into Action, Inc. The evaluation consisted of two market progress and evaluation reports (MPER) broken up into two "waves" of interviews. This section summarizes the Pilot Project's accomplishments both during and one year after the Pilot Project implementation period.

The Wave 1 interviews were conducted for the first-year MPER (McCrae, Armstrong, and Harris 2010)[8] and reported on participants' reasons for installing a DHP, satisfaction with the DHP and program processes, use of heating and cooling equipment prior to installation of the DHP, and intended use of the DHP. It also reported on: the activities of manufacturers in support of the pilot; DHP installers' experiences with the Pilot Project and the technology; and activities and experiences of utilities participating in the pilot, as well as those of NEEA and program implementation staffs.

The Wave 2 interviews were conducted for second-year MPER (McCrae, Armstrong, and Harris 2011)[9] and reported on participants' use of DHPs over the prior year, use of other heating and cooling equipment, and their longer-term satisfaction with the DHP. It reports 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 MPER also explores responses to the technology and the pilot, and intentions to install DHPs among nonparticipating installers.

For the second-year MPER, Research Into Action conducted follow-up surveys with 223 consumers who had installed DHPs during the pilot, 192 of whom were surveyed for the first MPER. They also surveyed 15 nonparticipating installers, and follow-up with in-depth interviews of three NEEA staff, three staff of the Pilot Project implementation contractor, and 20 staff of utilities and energy agencies that offered their customers incentives for DHPs through the Pilot Project.

2.1. Sample Design

Table 2 illustrates the Wave 1 (first year) and Wave 2 (second year) MPER activities. In both waves of research, Research Into Action interviewed program stakeholders (including NEEA program staff, implementation contractor staff, and utility and energy agency stakeholders), manufacturer contacts, and installers. Research Into Action contacted Wave 2 participant respondents roughly one year after the initial Wave 1 interviews (between August and October 2010). The Wave 1 and Wave 2 consumer surveys each included approximately 230 participants.

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[8] See http://neea.org/research/reports/E10-215_Final.pdf.

[9] See http://neea.org/research/reports/E11-224_DHP_Pilot_MPER-2_062411_Combined.pdf.

Table 2. MPER Activities

Activities		Wave 1 2009	Wave 2 2010
Interviews and Surveys	NEEA Staff	X	X
	Implementation Contractor Staff	X	X
	Manufacturers / Distributors	X	X
	Utility Project Managers	X	X
	Participating Installers	X	
	Nonparticipating Installers		X
	Participating DHP Consumers	X	X
Document Review	Logic Model	X	X
	Project Tracking Data	X	X
	NAHB Research Center, *Ductless Heat Pump Market Research and Analysis*, June 2008	X	X

2.2. Key Findings

NEEA, program implementers, and utilities in the region continued in 2010 to support DHPs through customer incentives, installation tracking and quality assurance activities, contractor training, and interactions with manufacturers. 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 appeared to continue to overcome participants' first-cost hurdle in 2010. 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 8th and 9th respectively in 2010 national data in terms of the total number of DHP units sold, as compared with 2008, when they ranked 19th and 20th 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.

During both MPER #1 and #2 interviews, most participants reported receiving non-energy benefits from their DHPs, including increased comfort, ease of control, and air filtration. MPER #1 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; MPER #2 findings suggest the cost of DHPs installed with a single interior head may be falling.

During MPER #2 interviews, 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.

2.3. Conclusions

The Pilot Project has made substantial progress in attaining its goals and objectives. By directly intervening with market actors, the pilot appears to be effective in strengthening DHP marketing, training, and distribution networks, and in increasing consumer awareness of DHPs. By offering an incentive on DHP installations, utilities overcame many participants’ first-cost hurdle for DHP installation – persuading them to participate in the Pilot Project.

The Pilot Project has been successful creating consumer interest in and demand for the previously unknown technology. Consumer satisfaction is high. Throughout all stages of the Pilot Project, participants have embraced the DHP technology. Participants reported high levels of satisfaction with the performance, effectiveness, and operating costs of the DHP. Participants spoke enthusiastically about the increased comfort that the DHP has brought to their homes. While most of the participants had never heard of DHPs before the onset of the pilot, they have since become strong advocates for DHP technology. Word-of-mouth has proven to be a powerful method of disseminating information and promoting the DHP (98% of respondents said they would recommend a DHP to friends or colleagues). The performance of the technology speaks for itself and participants continue to recommend the technology to others.

By directly interacting with the supply-side of the market, the Pilot Project appears to have strengthened DHP training, marketing, and distribution networks, and increased consumer awareness of DHPs. By offering incentives for qualifying DHP installations, utilities overcame many participants' first-cost hurdle for DHP installation.

3. Lab Testing and Analysis

As an integral part of the DHP Evaluation, Ecotope, and Purdue University carried out an extensive laboratory analysis of DHP performance. The lab evaluation was designed to develop a detailed understanding of DHP performance for use in simulation tools and to support the field monitoring and subsequent data analysis of DHPs installed in homes. This section summarizes the Lab Testing and Analysis Report (Larson, Baylon, and Storm 2011)[10] and describes the equipment selected for detailed lab investigation, the methods used in the evaluation, the performance mapping results, and the performance model developed from the data for use in energy prediction tools. The work reported here was used to inform metering results from the field installations.

3.1. Lab Testing and Analysis Goals

Like all heat pumps, single point ratings of performance are published following guidelines specified by the Department of Energy (DOE) and Air-Conditioning Heating and Refrigeration Institute (AHRI). The rating points, such as the heating seasonal performance factor (HSPF) and seasonal energy efficiency ratio (SEER), depend on a single curve describing the performance of the equipment over a temperature range which is essentially continuous and predictable. For conventional split system heat pumps the single rating point is marginal, at best, for determining energy use (Francisco et al. 2004). Likewise, although the AHRI standard (AHRI 210/240-2008) has specific tests for variable speed equipment, early observations indicated that the standard ratings do not represent the typical performance of this equipment as it responds to the range of parameters that drive variable speed operation of the system components (Davis 2009). Moreover, existing field tests indicate DHP technologies often perform better than the ratings suggest by optimizing the outputs and inputs to the current environmental conditions (Geraghty, Baylon, and Davis 2009).

The efficiency and flexibility of the DHP systems stem from their ability to change thermal outputs and indoor fan flow in response to control signals from changing ambient conditions or the occupant. Therefore, a single rating point for variable speed DHPs can only represent a small fraction of the capable operational range. The lab testing and performance modeling of this project seeks to better understand DHP operation and energy use with an eye towards characterizing its energy saving potential.

In conjunction with NEEA, Ecotope established the following goals for the lab evaluation:

- Develop a performance map of the equipment at all temperature bins and operating modes while providing special focus to low temperature heating performance.
- Review standard ratings (AHRI 210/240) published by the manufactures and establish the relationship between the ratings at controlled test conditions and other tests at conditions more likely in the Pacific Northwest applications.
- Assess performance variation with various control strategies and operating modes.

[10] See http://neea.org/research/reports/E11-225-DHP-Lab-Testing.pdf.

- Conduct measurements to review and verify the data collected in the field metering, especially in situ coefficient of performance (COP) measurements. Ecotope installed a detailed metering package in over 30 houses to directly measure equipment output capacity and input power to observe COP.
- Establish empirical performance curves to predict the efficiency and output of the equipment in energy simulations and other engineering calculations. The modeling capability will directly support regional energy planning efforts and conservation program design.

3.2. Methodology

To expand on the published rating values and to gather enough information for energy modeling, the lab evaluation was designed to measure the performance impacts on the equipment over the range of operating conditions that would be encountered in real installations. In practice, as the equipment is installed in climates that encounter both -5°F and +105°F temperatures, this creates the need for a performance map over a wide temperature range. The lab setting provides a stable, controlled situation to accurately and precisely measure equipment output as a function of environmental conditions.

Due to the continuously variable compressor design, the equipment capacity and efficiency is also variable. Generally, higher capacity output results in a lower system efficiency while the converse is true for lower capacity output. With this in mind, the lab performance mapping was designed to explore high, medium, and low capacities and also included high, medium, and low indoor fan speeds.

The equipment for testing was selected in conjunction with NEEA and other regional stakeholders. The priorities in selecting the equipment models included: frequency of occurrence of the specific model in the field, number of similar models installed in the field, range of HSPF/SEER ratings, age of model, and the number of field sites installed with the detailed instrumentation (in situ COP testing) package[11]. By selecting equipment that is frequently used in the field (or similar models) we gained a better, direct understanding over that segment of houses. By covering a range of HSPF/SEER scenarios we can simulate a wider range of equipment. Next, by selecting newer, rather than older models, the lab data will be relevant farther into the future. The DHP equipment models are evolving and changing rapidly so selecting an older model might only represent many units installed in the early part of the Pilot Project while a newer model represent thousands of units installed in the Pilot Program.

Based on these criteria, we selected a Fujitsu 12RLS and Mitsubishi FE12NA. For the time period of the Pilot Project evaluation where the total number of units installed was 3,899, 7% of all units were the 12RLS. A total of 32% were Fujitsu units that behave in a similar way to the 12RLS. For the same period, 6% of installs used the FE12NA while we determined roughly 25% of all installations had comparable Mitsubishi units. Both units were recent models from the

[11] The field installed COP measurement package consists of supply and return air temperature sensors, airflow anemometers, and power meters. Using these measurements, the output capacity and input power are directly calculated.

manufacturers representing the most mature equipment designs. The rated HSPF values were 12.0 for the 12RLS and 10.6 for the FE12NA. This range of performance is reasonably representative, if slightly skewed towards the high end, across most of the DHP installation in the Pilot Project.

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 Pacific Northwest installations, including outside temperature ranges from -5°F to +105°F. 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.

Herrick Labs installed all necessary instrumentation to accurately and precisely measure the DHP operating parameters for all the data points in the testing plan. In particular, the lab measured both an air-side and refrigerant-side equipment output capacity. These measurements are two independent measurements of the same quantities. The agreement achieved between the two measurements was 6% or less for both equipment models in both heating and cooling modes. The agreement confirms the veracity of the data.

Using the data on the equipment performance map collected in the lab tests, both Ecotope and Herrick Labs developed predictive energy use models of the equipment. The model is now being used inside the Simple Energy and Enthalpy Model (SEEM)[12] residential energy use simulation to predict annual energy consumption and savings from DHP installations. The field data collected from installations across the region has been integrated with the laboratory test data and results to refine, calibrate, and validate the model.

3.3. Key Findings and Conclusions

The detailed performance mapping and subsequent analysis produced significant findings including:

- **The lab data demonstrates the high performance of both models.** The highly efficient operation will enable significant energy savings opportunities in both retrofit and new applications. Both equipment models have the potential to deliver on the promise of generous energy savings. Had the lab data revealed poor efficiency results, the ultimate energy savings estimates would be compromised. In the end, the savings achieved in a particular house will depend on a number of factors including the installation location within the building or the interaction with the existing heating system. Compressor and

[12] 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.

distribution efficiency of the DHP, however, will provide a strong foundation on which to build energy savings.

- **Lab and field COP measurements show good agreement.** The early analysis of the field data compares well to the lab measurements. Both measurements provide a useful cross reference for each other. The lab data is collected in a stable, repeatable, and highly controllable situation which provides a "reference set" for the field measurements of similar DHPs. Likewise, the field metering of COP shows which equipment operating modes are most common and therefore the most important parameters to measure in the lab. At the outset of the evaluation, Ecotope did not anticipate the amount of synergy between the two data sets. It yields more confidence in both, while simultaneously demonstrating the benefits of an integrated evaluation approach to ductless heat pumps.

  The steady state heating COP for the 12RLS is shown in Figure 1. Figure 1 shows high levels of performance at low temperatures; for temperatures from -10°F to 10°F, the steady state COPs are still shown to be 1.5 to almost 2.5. Actual performance is less because the equipment undergoes defrost cycles which are, by definition, not in steady state. The box plots from the field data are more representative of actual performance because they include both defrost events at low temperatures and cycling effects at warmer temperatures. The range of efficiencies for a given temperature also can be seen in Figure 1. For example, tests of varying compressor and fan speed at 47°F show a COP of 3.2 at maximum load to a COP of greater than 5.5 at a low load.

- **Both equipment models perform well at low outdoor temperatures.** Both models continue to operate well in cold temperatures with the 12RLS showing slightly higher capacity and efficiency. Figure 2 shows the comparative performance of the two units tested. It is clear that both units maintain COPs near 2.0 even as temperature go below 0°F. Installers and home-owners should be made aware that the equipment will continue to run and provide benefits at cold temperatures so that energy savings can be maximized.

Figure 1. 12RLS COP Plot

(Field data given as box plots. Steady state lab data plotted as points.)

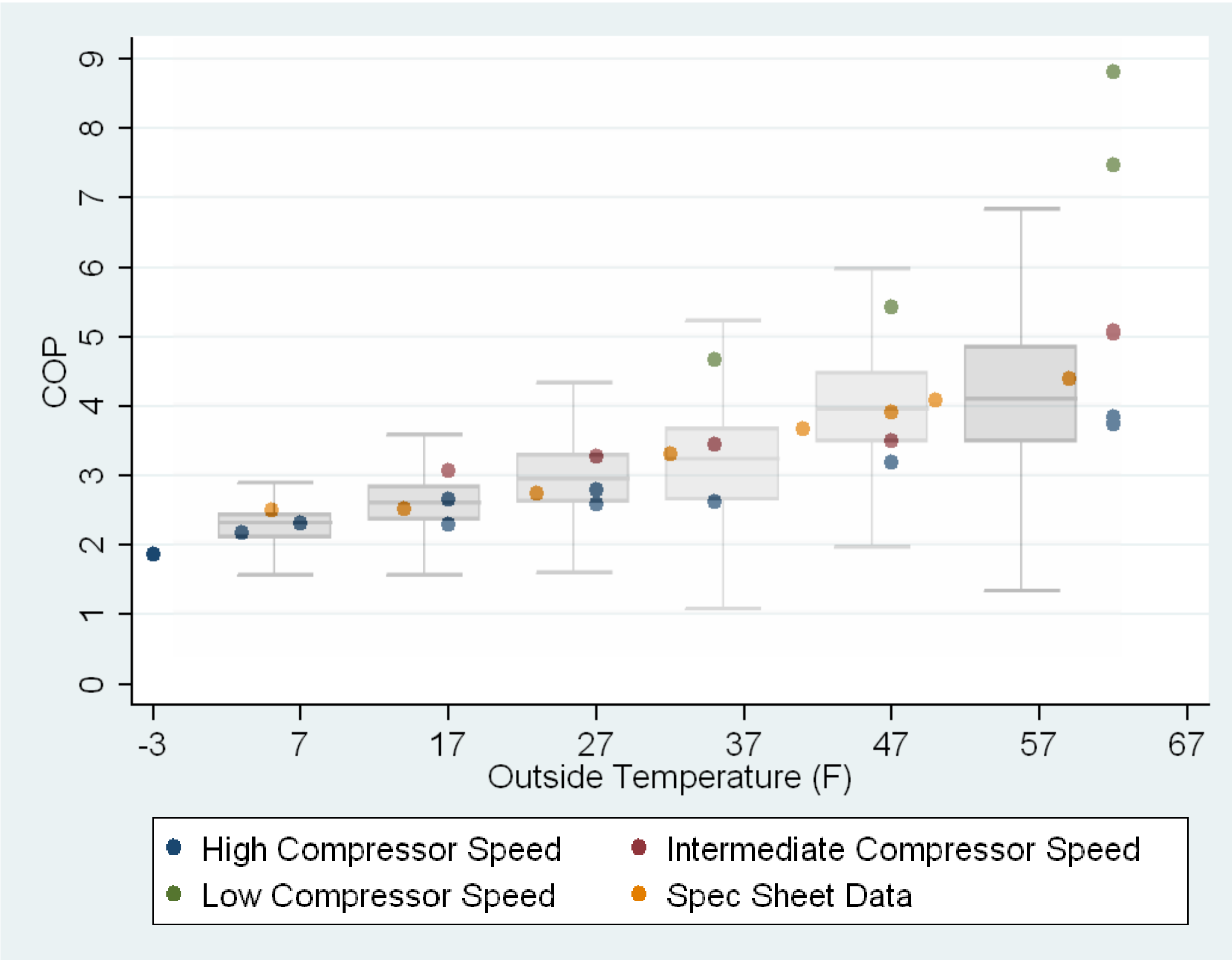
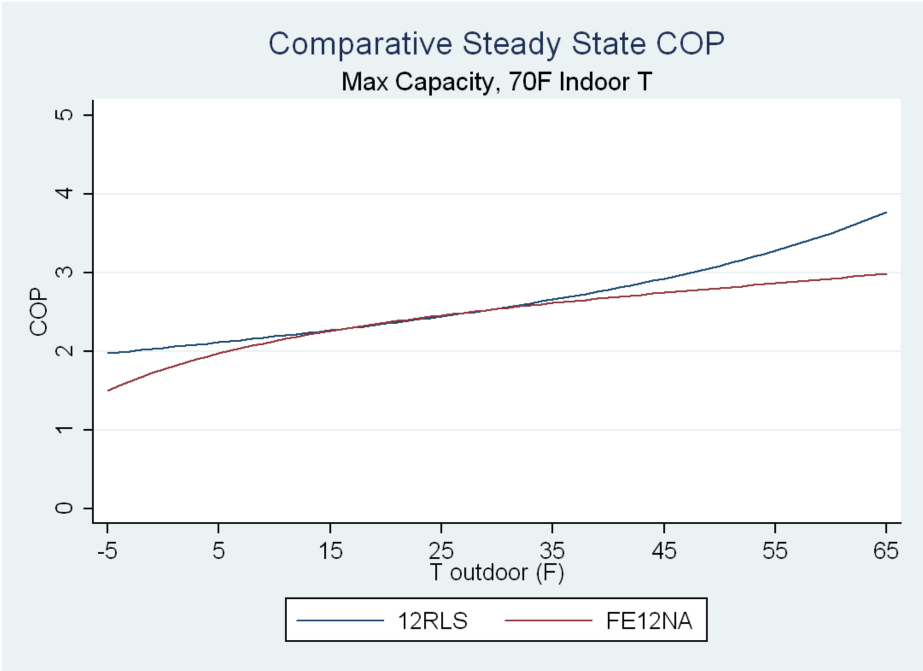


Figure 2. Comparative Efficiency and Maximum Capacity



- **The current HSPF and SEER ratings are not well suited to DHPs.** The testing standard and calculation procedure do not always produce ratings which characterize the performance of the equipment well or allow one to determine how the equipment might operate in a controlled lab environment, let alone a field installation. In lieu of the ratings, more data is needed to assess both the relative performance between models and the likely energy use of a single model. Performance curves (including capacity and input power over a range of compressor loadings) and descriptions of operational strategies will be useful in this regard. An updated testing procedure should include changes to the testing conditions, compressor speeds in particular, that make them more applicable to the way the DHPs perform in actual operation.
- **The equipment can be modeled in SEEM.** The performance model developed with the data collected in the lab will be implemented within SEEM. The models will be carefully calibrated with field data to provide accurate predictive capacity. The simulation will be appropriate to determine energy savings in both retrofit applications and new construction scenarios. This will allow the results of the lab testing and field data to be generalized to future evaluation of DHPs as a regional energy efficiency resource.

The lab testing demonstrates the value of an integrated approach to program evaluation. The simultaneous lab and field measurements reinforce one another. For example, the carefully measured indoor airflows in the lab were useful for calibrating the field measurements of output capacity and the subsequent equipment efficiency. Further, the field data showed which operating conditions were important to investigate in the lab. Finally, both can be combined to produce energy modeling tools.

4. Field Monitoring and Analysis

4.1. Field Monitoring and Analysis Goals

This section summarizes the DHP metering report (Baylon et al. 2012a). The Pilot Project was built on a "displacement" model in which the DHP equipment was designed to supplement an existing zonal electric heating system. This model for the Pilot Project 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. Detailed field monitoring was necessary to distinguish performance impacts related to occupant actions (e.g., thermostat adjustments) from those resulting from the efficiency and performance of the DHP equipment as installed by contractors under the pilot program.

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. 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" CO. These COP sites allowed for comparison with laboratory measurements as well as direct measurement of energy savings delivered by the DHP.

The objectives of the DHP field metering were:

- Describe the total energy use of the heat pump as it operates in each home, including the effective heat output and the total heating energy required.
- Determine the total equipment cooling use across cooling climates throughout the region.
- Establish the offset to space heating brought on by this equipment and the cost-savings impact of the incremental cooling from the equipment.
- Develop the climate and occupancy parameters needed to explain the observed savings.
- Summarize the non-space heating energy uses across the monitored houses.

4.2. Sample Design

The DHP field monitoring sample design required that a sufficient number of homes be metered in most Northwest climates to allow for a reliable assessment of the performance of the DHP equipment. Pilot participants were divided into eight climate clusters. These clusters reflected marketing clusters that were part of the contractor marketing program developed in the pilot program and provided some geographic continuity.

To minimize the extent to which the analysis would be compromised by supplemental (non-electric) heating fuels that could not be directly measured, all potential metered sites were screened. The screening took the form of a variable base degree day (VBDD) assessment of the bills collected for the period before the installation of the DHP. This methodology allowed an assessment of the electric heating use of the home based on month-to-month changes in consumption predicted by outdoor temperature. The screening process had the effect of increasing the potential electric savings from the sample. The results from the metering should be generalized with care given the potential bias in the metering sample.

The sampling process included:

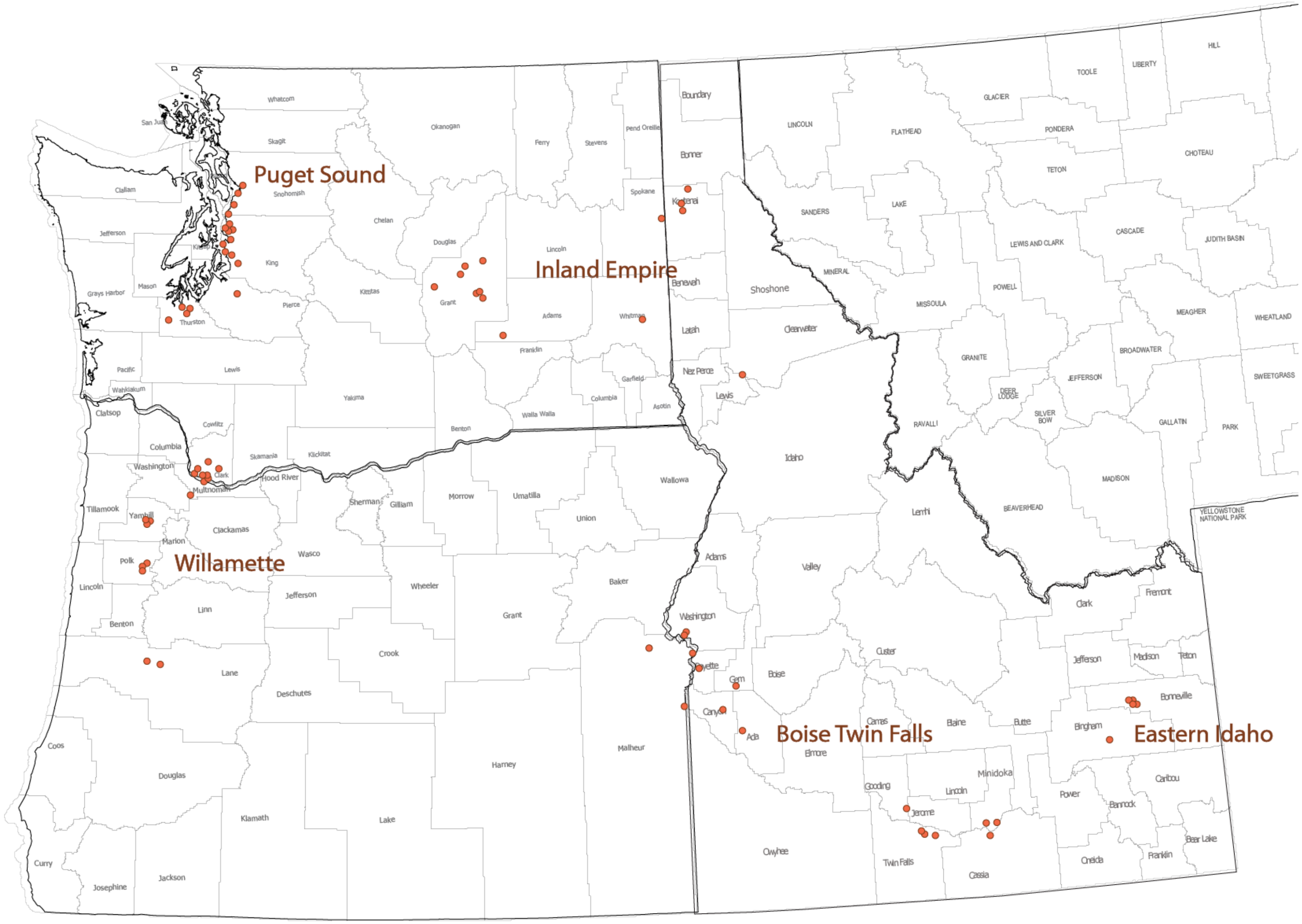
- A review of the bills collected from the pre-installation billing records.
- A VBDD-type screening to establish that the homes used electric heating (not wood or some other supplemental heating).
- A random sample of the available homes that passed the screening. The number of homes to be metered in each of two of the clusters was set at 25. The screening resulted in about 25% attrition in the sample frame.
- The remaining three clusters in the eastern parts of the region were selected from a very limited pool to be those homes with an acceptable heating signature even if there was evidence of supplemental space heating from wood or other fuels.
- Recruitment of the samples, with potential sites offered an incentive to allow meters to be placed in the home over the course of 14 to 18 months.

The eight geographic clusters are summarized in Table 3, including the total number of sites ultimately used in each cluster. Figure 3 shows the geographic distribution of the final metered sample.

Table 3. Sample Distribution of DHP Metered Sites

	Sites		
Cluster	Pilot Project Total	Quad Metered	COP Metered
Willamette	2,219	27	9
Puget Sound	797	25	11
Coastal	308	0	0
Inland Empire	167	17	5
Boise/Twin	128	16	4
Eastern Idaho	92	10	6
Tri-Cities	60	0	0
Western Montana	128	0	0
Total	3,899	95	35

Figure 3. Mapped Distribution of DHP Metered Sites



4.3. Methodology

4.3.1. Metering Specifications

To achieve the DHP metering goals, Ecotope customized a "quad-metering" system to measure four key categories of energy usage:

1. **DHP channel** measured with a combination of split-core current transducer (CT), true root mean square (RMS) watt transducer, and pulse counter.
2. **House electric service drop** measured with the same combination of equipment.
3. **Electric Resistance (ER) heaters** measured with a simple CT.
4. **Domestic Hot Water (DHW) tank** measured with a current transformer and true-RMS conversion module.

In addition to the energy use of the home, several other auxiliary data streams were measured:

- **Outdoor (ambient) temperature.** A stand-alone, weatherproof temperature sensor/datalogger was placed in a shaded location near the metered home and recorded hourly average temperature. These data were compared with National Weather Service (NWS) weather site data and also used in COP analysis.
- **Indoor central zone temperature where the DHP was installed.** This logger collected the average hourly temperature for the entire metering period. Indoor temperature data were downloaded at the end of the metering period and synchronized to the time/date stamps in the metered data set. The purpose of this measurement was to give the analyst an idea of the comfort in the main area of the home during the heating season.
- **Vapor line temperature (VLT) of the refrigerant line from the DHP to the indoor air handler.** The VLT was used in conjunction with the recorded outside temperature to determine whether the DHP was in heating or cooling mode. The DHP energy was then separated into those two categories based on this determination in each five-minute data collection interval.

The decision to measure VLT was based on preliminary metering in another small DHP pilot in the Northwest (Geraghty, Baylon, and Davis 2009). This previous research suggested that the cooling signal determination using only indoor temperature was very problematic, and the analyst was left to guess when cooling was occurring in the swing seasons of late spring and early autumn. The controls for the DHP equipment are very interactive, and it is possible for simultaneous cooling and heating to occur. Measuring the VLT allows the analyst to know when the unit is cooling and allows a direct accumulation of the total cooling load and the conditions where cooling is supplied while ER heat is also used.

The data collected in the metering process were recorded at either five-minute or one-minute intervals. After six months, a review of the data resulted in a decision that this extra precision was not helpful, and the metering interval was reset to five minutes. These data were available from Ecotope's automated download process and included all the energy use and most of the temperature information collected.

4.3.2. Coefficient of Performance (COP) Measurements

Thirty-five of the sites were metered with additional points that would allow the estimate of an *in-situ* system efficiency, the COP. The COP is the ratio of heating (or cooling) output from the DHP to the power needed to run the compressor and indoor and outdoor fan. Output is converted from British thermal units per hour (Btu/hr) to kilowatts (kW) so that the numerator and denominator are in the same units. Another way of expressing the COP is in efficiency percentage, with a COP of 1 meaning 100% efficiency. The COP measurement is very useful for comparison to AHRI-rated performance, and to inform the development of inputs for simulation assessment of the DHP (also used to determine savings from application of the ductless technology).

Two temperature sensors were added (to measure change in temperature across the indoor unit), and a small vane anemometer was installed to provide a proxy measurement for airflow. This device accumulated pulses in a manner similar to that for the electric energy current transformers/watt transducers. Different pulse rates could be compared with a one-time calibration to determine cubic feet per minute (CFM) of airflow. The product of temperature split and airflow is thermal output in heating or cooling. Because energy usage/power of the DHP and outdoor temperature are also unknown, system COP can be calculated as a function of outdoor temperature bins. With this level of on-site data, considerable insight was available both on system performance and as a check in real time of laboratory measurements (Larson, Baylon, and Storm 2011).

4.3.3. On-Site Audits and Interviews

Each site received a detailed physical energy audit (including a measurement of house air-tightness). The audit’s primary purpose was to generate a heat loss rate for the home.

The primary site occupant was interviewed twice during the study. The first interview occurred when metering equipment was installed, and focused on satisfaction with the DHP equipment as well as occupancy patterns in the period before DHP installation.

The second interview was conducted during the decommissioning. This interview again focused on satisfaction with the DHP equipment and also upon what changes in the occupancy and house thermal shell occurred during the metering period. Finally, several specific questions were asked about supplemental heating from wood or other fuels. Unlike the previous interview, the occupant was also asked about the household’s use of low-voltage (110-volt [110V]) space heaters.

Wherever possible, these audits and interviews became explanatory variables that could be used in the analysis of the observed metered data.

4.3.4. Data Collection and Assembly

Depending on the meter installation schedule for various clusters, one to two years of metered data were collected for the DHP sites. The metered installations were complete by January 2010, and data were collected for nearly the full suite of sites through March 2011. As a result, a full common year of data was gathered for each site in the sample. Except for small data gaps in the manual download sites and two sites where the occupants insisted on removing the meters, all sites in the analysis data had at least 14 months of data; the median number of data-days per site for the entire sample was 569.

The “annualized” dataset was used throughout the analysis. In addition to variables representing the four directly measured energy use channels (total service, DHP, 240V ER heat, and DHW), a “residual” variable was calculated representing the energy use left over after all metered channels (DHW, ER, DHP) were subtracted from the total service energy. This residual was summarized on the same time scale as the remaining metered channels.

The bulk of these data were downloaded to the Ecotope file server on a nightly basis using a 3G connection (cell phone). Because the instruments had substantial data storage capacity, short-term interruptions in cell phone service were easily remedied in a subsequent download period. When this failed, a site visit could be arranged to reset the datalogger. In most cases, such an intervention ensured a continuous data record.

4.3.5. Error Checking and Data Quality Control

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.

4.3.6. Billing and Weather Data Assembly

Utility billing data from the metered sites were analyzed to establish the baseline (pre-DHP) heating energy consumption. Utility bills were evaluated using VBDD methods to establish an estimate of seasonal heating loads. Although such an estimate is only approximate, the metering protocol did not allow monitoring before the DHP was installed. Even with detailed metering, there is some uncertainty in the base space heating energy use.

In general, the billing record extended (at least) from the beginning of 2007 (about two years before the beginning of the monitoring year and at least 12 months before any installations) to the end of the monitoring period, March 2011. The pre-installation billing record was assembled from approximately 14 to 24 months of bills collected before the installation of the DHP. The post-installation period included a minimum of approximately 15 months of bills.

In addition to billing data, the record for each home included daily minimum and maximum outdoor temperatures recorded at a nearby weather station. The weather stations used were selected individually for each site from those available through the National Climatic Data Center (NCDC). All were either NWS stations or members of the NWS's Cooperative Station Network. The daily minimum and maximum temperatures were used to construct daily heating-degree and cooling-degree estimates to various bases at each site.

4.4. Analysis Approaches

The primary goal of this analysis was to develop a savings estimate to assess the use of the DHP technology. Several strategies were used to meet this objective:

- Assess heating energy savings from actual energy use, both before and after the installation of the DHP. The detailed metered data from the DHP was compared to the ER heating.
- Develop a picture of the determinants of those savings using secondary data collected from the occupants and from the metered data.
- Construct a simulation model that is calibrated against the results of the billing and metered analyses that can be used to predict the savings from a more widespread application of the DHP program throughout the region.
- Provide insights that can be used in future billing analysis to inform the overall savings from a more general evaluation of the DHP Pilot Project.
- Provide implications that can be used to inform the development of a utility program to support the installation of DHPs as an energy-efficiency resource.

To support these strategies, the following data sets were developed over the course of the Pilot Project:

- Electric bills collected from the utilities servicing these homes. The billing data included an average of two years of consumption before the installation of the DHP and up to 30 months of data after the installation. For the analysis, we averaged about 18 months of post-installation billing.
- Metered data for four power channels and three temperature channels at five-minute intervals and a pendent temperature logger at one-hour intervals.
- Full energy audit data detailing the heat loss rate of the home, including a blower door test to inform the air infiltration component.
- Three separate surveys taken of the occupants: the first by the installation contractor at the time of the installation of the DHP; the second by the instrumentation team when the

meters were installed and the energy audit was conducted; the third at the time of decommissioning the metering system after at least 15 months of data collection.

The rich datasets assembled for this project enabled a variety of methodological approaches to measuring changes in space-conditioning energy consumption. These approaches fall into three main categories:

1. Those that rely only on billing data and weather station data. The great advantage of billing-data-only methods is that the exact same method can be used to calculate consumption in both periods. Known biases in consumption estimates can have little consequence on savings estimates because the biases are present both before and after installation.
2. Those that rely on short-interval metered data and site temperature data for the post-installation period. This method depends on detailed metering of the DHP and a direct assessment of its output without reference to the previous conditions in the house.
3. Mixed methods using short-interval metered consumption data, site temperature data for the post-installation period, and billing and weather station data for the pre-installation period. This method provides detailed insight into the operation of the DHP and the overall heating and cooling energy of the home but requires careful consideration and estimation of potential biases both before and after installation.

There were several sources of known bias that influenced our analysis. Notable sources were:

- The use of supplemental fuels (such as wood) to offset some of the space heating requirement.
- Changes in operating approaches to the heating system, especially the increase in thermostat settings.
- Changes in occupancy, especially changes in the number of occupants or the period of occupancy during the year.
- The presence of large (and seasonal) loads that are not part of the heating system of the home but would appear as part of the space heating estimate in a conventional billing analysis.
- An unexpected complication in the metered space heating, which appeared during the metering phase of the project. We noted the issue of unsuspected apparent space heat hidden in the residual load (the non-metered portion of domestic electric consumption) in a previous report (Ecotope, 2010).

All of the 220V circuits used to power resistance zonal heaters were separately metered as the "ER" channel, but any use of plug-in 110V heaters in convenience outlets throughout the home was not separately measured. The approach to this problem was to apply the VBDD regression machinery to all *residual* loads in determining heating signatures. This approach allowed an estimate of "space heat" otherwise hidden in the residual loads. However, this approach also captured other seasonal loads correlated to heating degree days (HDDs) such as partially heated outbuildings, spas, and hot tubs. These uses introduce added biases, but those biases probably appear in the pre-installation period so it is important to account for them when calculating savings using only pre-installation billing analysis as the basis of the savings estimate.

Specific measurement approaches for residual heat could be any of the following, depending on the site:

- Ignore any degree day (DD) response in residual load and set residual heat to "0" (in cases where we could confidently ascribe the apparent heat to some other end use not present in the pre-installation period).
- Employ the VBDD technique used in Geraghty, Baylon, and Davis (2009).
- Sort residual energy use by month, take the fourth-largest month as a "base," and assume that usage over this base amount in the three largest months is space heat. This approach applies in cases where space heat is suspected but, because of irregular usage, the VBDD technique fails to produce plausible estimates.
- Use DD regressions but fix the balance point exogenously (e.g., DD rather than VBDD).

In practice, Ecotope used approach No. 3 for most sites.

4.4.1. Weather Normalization vs. Weather Adjustment

"Weather normalization" entails casting weather-sensitive consumption or savings results in terms of a long-term average or "normal" weather. If space heat energy is assumed to be linear in HDDs, and if this linear response coefficient can be estimated, weather normalization is a straightforward matter of multiplying this response coefficient by long-term average annual HDDs. VBDD regression provides an established method of estimating the degree day (DD) response coefficient. In the context of this report, "long-term average" means all the data available from NCDC for a site's chosen weather station. This varies from station to station, but averages about 15 years (ending in mid-2011) for the stations used here.

"Weather-adjustment," as we define it, means casting consumption or savings results in terms of some specific reference weather period. In this report, the specific reference weather period is the post-installation period for which we have detailed metered data. Post-installation metered data were gathered during the chosen reference weather period and hence need no alteration. Pre-installation temperature-sensitive consumption can be expressed in terms of reference period weather using the same procedure as the normalization discussed above.

We present some results here in weather-normalized form, but in general we prefer to present weather-adjusted results (expressed in terms of recorded post-installation weather). We adopt this approach partly because DD response coefficients for metered data can be estimated only by aggregating it to at least daily aggregation intervals. Much of the fine detail of the data is lost in the process. In addition, weather normalization via VBDD assumes linearity in DD response, and heat pumps, because of temperature-dependent COPs, do not satisfy this linearity requirement. Finally, other elements of our analysis data set such as the questionnaire data used in cross-sectional analysis cannot be readily time-shifted.

4.4.2. Metered Savings Calculations

There were separate heating savings estimates for each baseline method (normalized and adjusted). Ecotope combined metered channels and residuals to calculate savings estimates that accounted for the biases observed in each metering record. Several separate savings estimates were developed:

- In general, the method selected in about 85% of the cases was based on the on-site temperature data (the post-installation weather period). The billing analysis was adjusted to that temperature record. This approach allowed more flexibility in deriving the savings by using the appropriate combination of estimations from the metering period. In these cases, the residual calculated from the residual analysis was used to modify the metered space heat and actually reduce the apparent savings.
- In a few cases (4%), the metered data included large loads that were metered. This was rare because the instrumentation often was fully used in the quad-metered specification. In those cases, however, the seasonal biases from the extra loads were removed from the base, and the savings were calculated using the adjusted results.
- In about 10% of cases, the space heating was erratic or had missing data. In those cases, the billing analysis for the post-installation period was used if an adequate billing record could be assembled. The billing data were adjusted to the weather for the post-metering period in those cases.

The metered results allow the assessment of the runtime of each DHP in each metering period (generally five minutes). As a result, the COP monitoring data and the laboratory testing could be applied to the observed runtime, and an estimate of the heat output of the DHP was made.

4.5. Audit Characteristics of Metered Sites

4.5.1. House Envelope and Size Characteristics

The average size of the homes in the metered sample is reasonably comparable to the average size of homes in the larger pilot of 3,899 sites. Table 4 shows a comparison of the metered sample to all pilot participants.

Table 4. Comparison, Metered Sample to All Participants

	Pilot Participants		Metered Participants	
Cluster	Sq. Ft.	N	Sq. Ft.	N
Willamette	1531	2219	1503	27
Puget Sound	1594	797	1395	25
Inland Empire	1734	167	1393	17
Boise/Twin Falls	1711	128	1966	16
Eastern Idaho	2156	92	2316	10
Average/Total	1595	3899	1618	95

Table 5 shows the distribution of house area across the different clusters for the floor area estimated by the homeowner or contractor at intake and the measured area taken from the detailed audit. A lot of variation exists between these two groups. Despite the variance, the average floor area across clusters is consistent. This variance was largely due to several cases where basements, although conditioned, were not counted in the square-footage area in the original assessment.

Table 5. Conditioned Floor Area

	Reported by Intake Form		Computed from Audit Measurements	
Cluster	Sq. Ft.	N	Sq. Ft.	N
Willamette	1524	27	1503	27
Puget Sound	1335	25	1395	25
Inland Empire	1386	17	1393	17
Boise/Twin Falls	1599	16	1966	16
Eastern Idaho	1926	10	2316	10
Average/Total	1504	95	1618	95

A blower door test of the envelope tightness was conducted on all metered homes. Table 6 summarizes the results of these tests. The table also translates the blower door results into an effective natural infiltration rate in four different ways. The first uses an old rule of thumb that an effective infiltration rate is the air changes per hour (ACH) at 50 pascals of pressure (ACH50) blower door test divided by 20. The last three estimates are made using the SEEM simulation program with individual models for each house. The simulation calculates infiltration on an hourly basis by using house height, the blower door results, and weather data including outdoor temperature and wind speed, and then outputs an annual, heating season, and heating design day averages. The overall average heating season ACH of this sample agrees well with findings from comprehensive Northwest region infiltration studies from the 1980s on electric resistance heated houses (Palmiter 1991).

Table 6. Blower Door results

Cluster	Blower Door Results		Natural Infiltration Estimates				N
	ACH50	SD	ACH50 / 20	ACH Annual Average (SEEM)	ACH Heating Season Average (SEEM)	ACH Heating Design Day Average (SEEM)	
Willamette	9.5	2.5	0.48	0.24	0.28	0.35	27
Puget Sound	10.7	5.4	0.54	0.28	0.32	0.41	25
Inland Empire	8.8	3.6	0.44	0.22	0.26	0.35	17
Boise/Twin	7.9	4.0	0.39	0.20	0.24	0.31	16
Eastern Idaho	4.8	1.1	0.24	0.15	0.17	0.22	10
Average / Total	8.9	4.1	0.45	0.23	0.27	0.35	95

Table 7 shows the distribution of heat loss rate across the homes measured by the sum of the heat loss rate of the homes envelope components (UA). When the overall heat loss rate is normalized by house size, the heat loss from one cluster to the next is quite consistent. It is likely that the overall size and insulation level is typical of small electrically heated homes throughout the region. Only in the coldest climate, eastern Idaho, was there a deviation from this norm, with appreciably lower heat loss rates per square foot.

Table 7. Heat Loss Rates by Cluster

Cluster	UA Total		UA/Sq. Ft.		N
	Mean	SD	Mean	SD	
Willamette	503	165	0.336	0.055	27
Puget Sound	500	172	0.366	0.115	25
Inland Empire	459	200	0.332	0.083	17
Boise/Twin Falls	580	198	0.331	0.135	16
Eastern Idaho	532	131	0.236	0.050	10
Average/Total	511	177	0.332	0.099	95

4.5.2. DHP Installation

Most of the sites in the study have only one DHP outdoor unit and one DHP indoor unit. This factor results from the prevailing installation type in the DHP pilot and the limitations of the meter equipment (which can accommodate a single outdoor unit and up to two indoor units). Systems with more than two indoor units or one outdoor unit were not metered. In the entire pilot study, about 34% of the DHP installations had more than a single indoor air handler (head). In this sample, only 18% had two indoor heads. Table 8 shows the average size (measured by capacity) of the installed DHP equipment by cluster as well as the number of homes with two indoor heads.

Table 8. DHP Installations, Metered sites

Cluster	Tons	2 Indoor Heads	Total Metered
Willamette	1.76	3	27
Puget Sound	1.20	1	25
Inland Empire	1.79	4	17
Boise/Twin	1.51	8	16
Eastern Idaho	1.33	1	10
Total	1.53	17	95

4.6. Key Findings and Conclusions

To describe the total energy use of the heat pump as it operates in each home, Ecotope installed a detailed instrumentation package to measure DHP electricity input and thermal output. Table 9 shows the DHPs performed extremely well generating heat with an annual COP of 3 across all metered sites.

Table 9. 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	1876	962	6048	2872	3.40	0.32	20
Puget Sound	1823	708	5549	2570	3.05	0.56	20
Inland Empire	2492	1097	5637	2126	2.41	0.59	12
Boise/Twin	2256	1274	6440	3040	2.96	0.30	8
Eastern Idaho	2188	978	6112	2675	2.84	0.30	9
Average / Total	2052	969	5886	2602	3.00	0.55	69

Figure 4 shows the metered data Ecotope collected over one full year for a DHP installation in Idaho Falls. The DHP on site has a single indoor heat exchange, a nominal output capacity of 16,000 Btu/hr and is rated at HSPF 12. The yearly data, displayed as daily averages provides an overall view of DHP behavior. The graph shows the DHP was nearly in continuous over the entire year. When the home owner turns the DHP off, the graph shows no energy usage over that day. The daily average outside temperature varies from 0F to 80F over the period and the occupant uses the DHP for both heating and cooling. The equipment coefficient of performance (COP) shows positive for heating and negative for cooling.

Figure 4. DHP Performances Over One Year

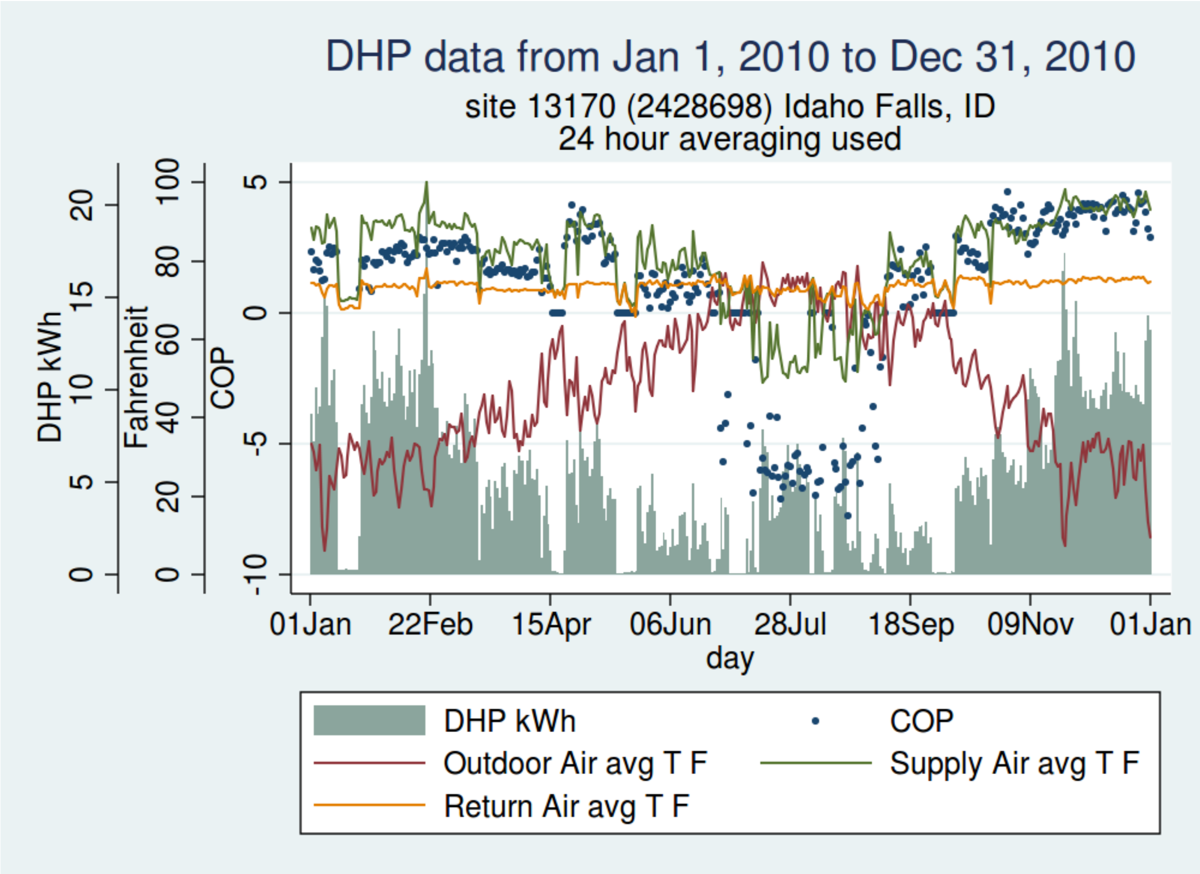


Figure 5 shows a monthly snapshot of the same metered data used in Figure 4. The one month snapshot, plotting data at hourly intervals gives a detailed look at DHP behavior. The occupant used the DHP extensively throughout the month of November. In early November, the graph shows diurnal temperature swings from 35°F to 60°F. The DHP responds accordingly providing more heat at the colder times of day. Further, the Figure 5 shows the COP changing as outside temperature changes. When the outside temperature is 50°F and above, COPs of 5 are common. When the outside temperature is 30F-40°F, the COP settles in to ~3. The graph shows that the period in late November is characterized by operation with a number of defrost cycles. The defrost cycles are evident in the rapid variation of supply air temperature and concurrent drop in COP over that interval.

Figure 5. DHP Performance at Low Temperatures Over One Month

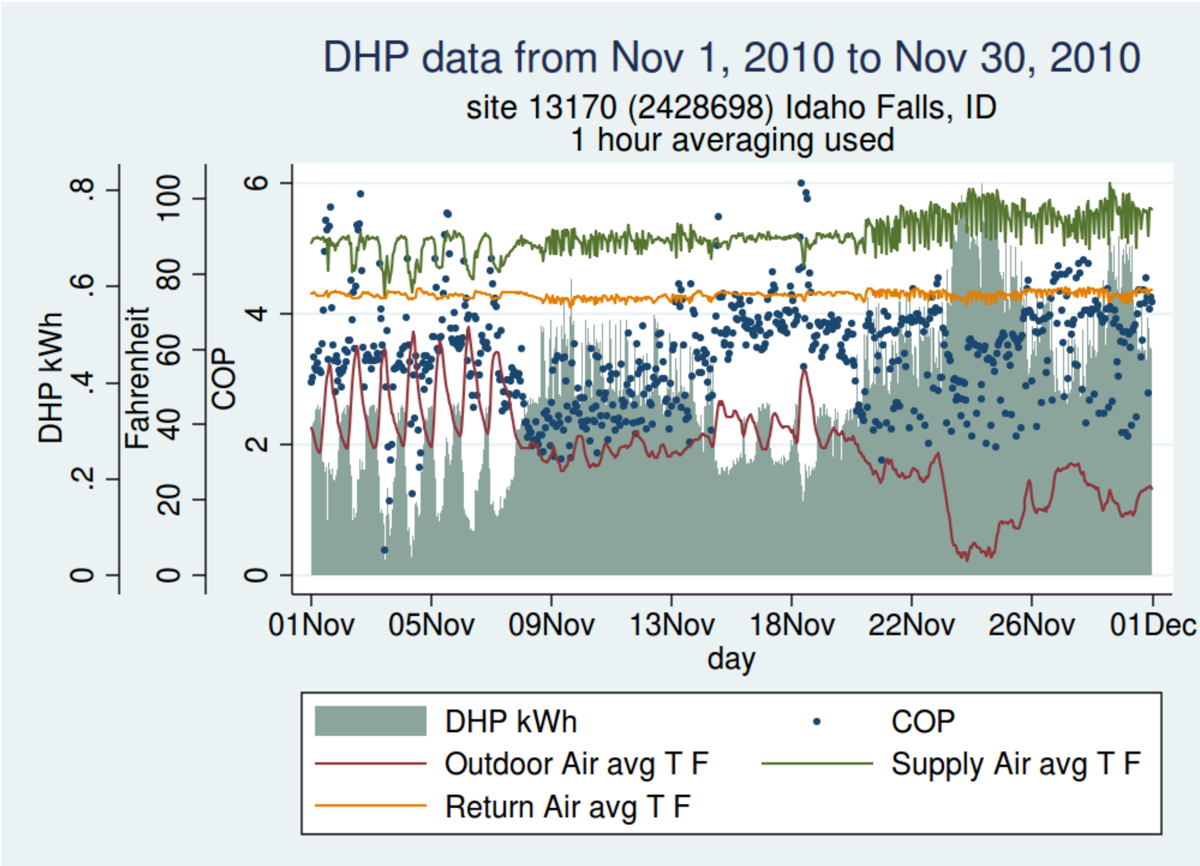
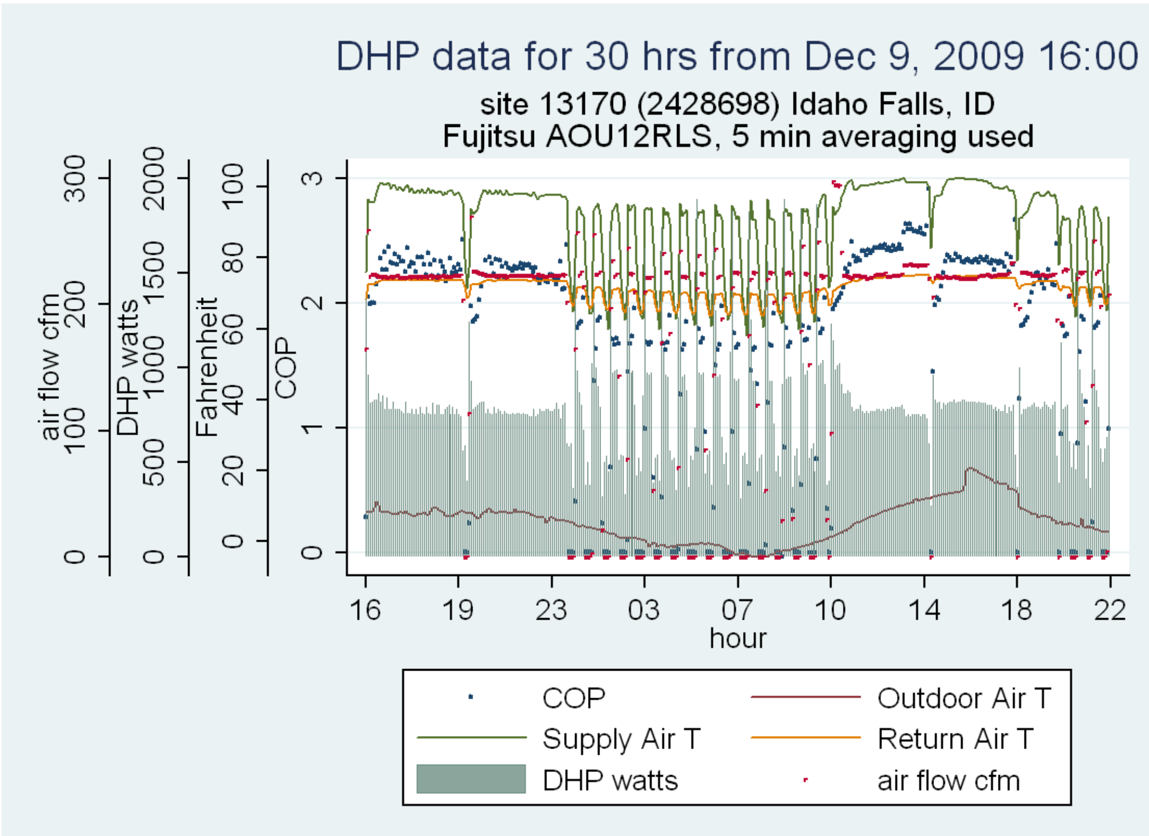


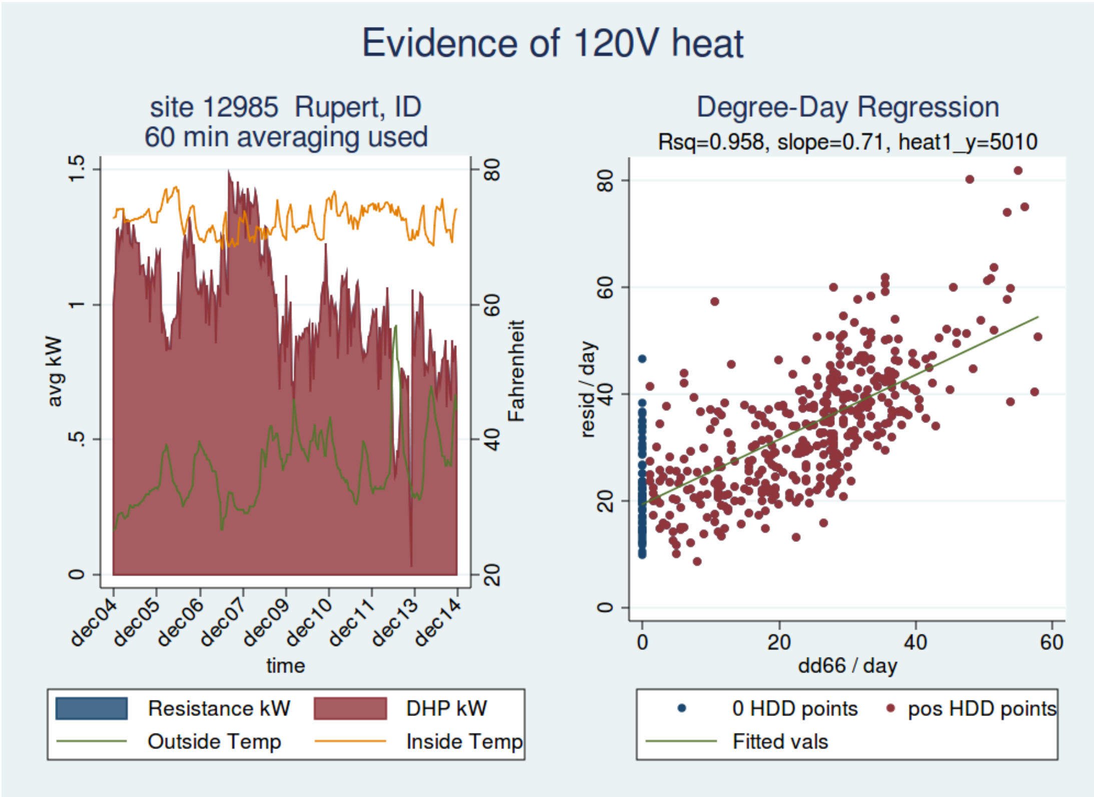
Figure 6 shows 30 hours of metered data at the same site used in Figure 4. This graph illustrates the DHP behavior at a finer level of detail.

Figure 6. DHP Performance at Low Temperatures



An important finding from the metering is the use of low-voltage space heaters as a significant heating source. The metering did not monitor these low-voltage portable heaters so the analysis was designed to quantify this effect. Figure 7 illustrates this analysis. The occupant in this home uses only the DHP and low-voltage space heating. The meters captured only the DHP space heat, and the later analysis of the residual revealed the space heat from the low-voltage plug-in heaters.

Figure 7. Example of 120V Heat



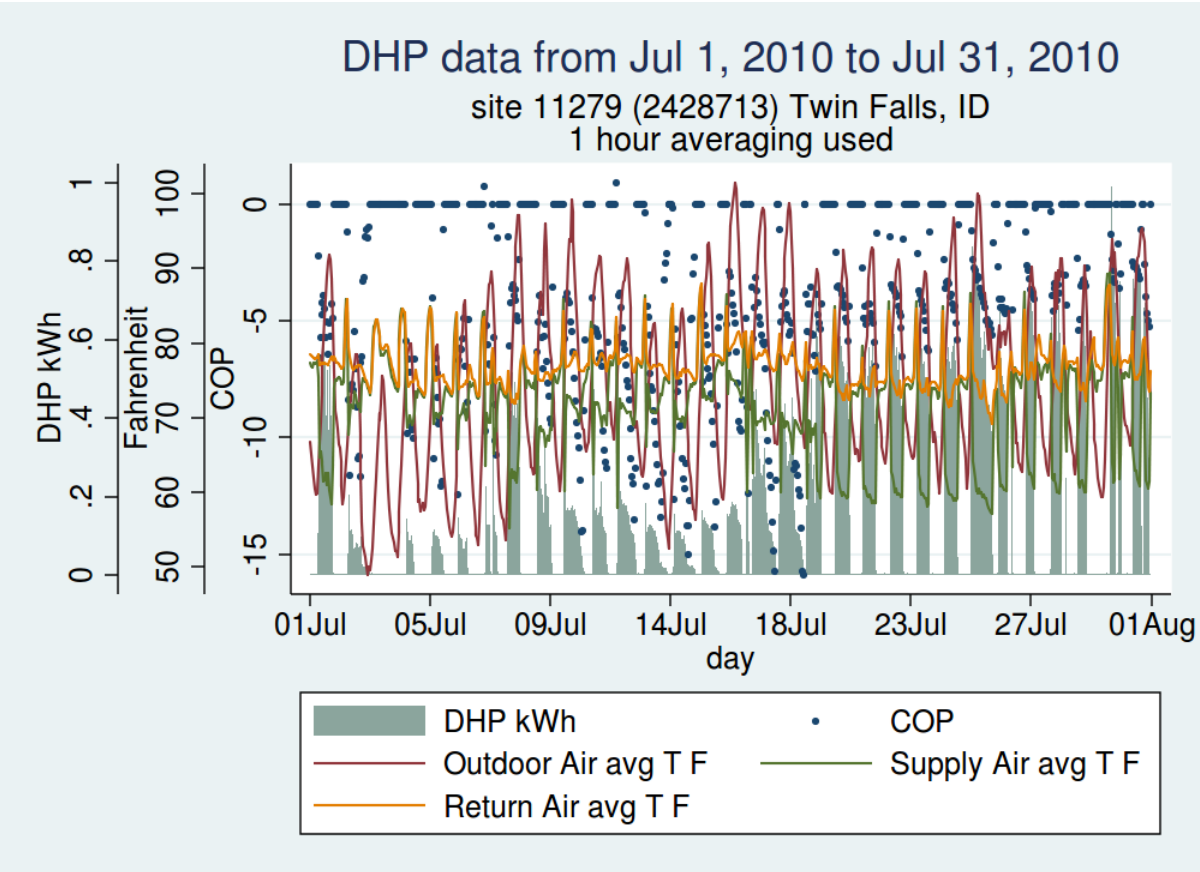
The metering equipment also recorded the energy each DHP used for space cooling. Table 10 demonstrates that little energy was used. In fact, in the more significant cooling climates of the Inland Empire and Boise/Twin, house audits showed the DHP cooling often replaced far less efficient window air-conditioning units likely resulting in net cooling energy savings.

Table 10. DHP Cooling Energy Use

Cluster	DHP Cooling Use (kWh/yr) Mean	SD	N
Willamette	156	134	26
Puget Sound	72	76	25
Inland Empire	408	260	16
Boise/Twin	306	184	15
Eastern Idaho	211	208	10
Average/Total	208	204	92

Figure 8 shows metered data over one month for a DHP providing significant cooling. The DHP on site has a single indoor heat exchange, a nominal cooling output capacity of 12,000 Btu/hr and is rated at SEER 22. The outside temperature in Twin Falls, ID in July is characterized by large diurnal temperature swings from 55°F all the way to 100°F. The DHP responds by providing cooling at the hottest times of day and turning off at night. The graph shows measured supply air temperatures of 60F in cooling while the occupant is keeping the space at a 70-75°F set point. The COP varies throughout the day as the outside conditions change. COP is plotted as zero when the equipment is off.

Figure 8: DHP Metered Data, Cooling Month



Ecotope implemented two approaches develop final savings estimates for the DHP metered sample. The approaches are divided into a total savings estimate and a net savings estimate:

- **Total savings** indicated by overall net heat output of the DHP as measured by the metering (Table 11). This approach relies on the metered heating output of the DHP regardless of the other heating systems in the house. We used a coefficient of performance (COP) estimate as well as the runtime and power draw of the equipment throughout the year to generate these savings estimates.

Table 11. Total Savings, Metered

Cluster	Savings from COP (kWh/yr) Mean	SD	N
Willamette	4148	2061	18
Puget Sound	3812	1981	19
Inland Empire	3264	1470	11
Boise/Twin	4184	1871	8
Eastern Idaho	3924	1767	9
Total	3887	1844	65

- **Net savings** are calculated from the change in space heat consumption between the pre-installation period and the metered space heat after the DHP is installed (Table 12). This approach is complicated by the uncertainty in the base case but includes occupant "take-backs" such as increased indoor temperature and reduced supplemental fuel use.

Table 12. Net Heating Savings, Metered

Cluster	DHP Savings (kWh/yr) Mean	SD	N
Willamette	3316	2121	26
Puget Sound	3043	2357	25
Inland Empire	1882	1580	16
Boise/Twin	3628	2985	16
Eastern Idaho	3307	3230	10
Average/Total	3049	2424	93

The ratio between the two saving calculations is about 80%. This suggests that almost 20% of the heat produced by the DHP is used to provide other benefits (beyond energy savings) to the occupant. 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.

The metered results and billing records were used to calibrate the SEEM simulation. This proved successful once the performance curves for the DHP equipment were integrated into the program. The results were within 5% of metered performance measurements.

The last metering objective was to collect information on non-space conditioning energy use in the houses. Table 13 summarizes the metered water heating energy use by number of occupants per house.

Table 13. Domestic Hot Water Energy Use, Metered

Occupants	Metered DHW Use (kWh/yr)		N
	Mean	SD	
1	1824	831	17
2	3049	1005	51
3	3201	1688	14
4	4436	1067	8
5+	6538	1375	3
Average/Total	3080	1430	93

Table 14 summarizes the net residual load derived from the difference between the heating, cooling, and DHW uses and the total metered space heating load. The total of the "other" electric loads sources is expressed as the total of the miscellaneous electric loads (MELs). The low voltage and other heating derived from the metering analysis is included here as a separate column. This use represents about 7% of the MELs in this sample.

Table 14. Miscellaneous Electric Loads

	Total MELs			
Cluster	**Total**	**Heat**	**Other**	**N**
Willamette	13729	787	12942	26
Puget Sound	10103	565	9538	25
Inland Empire	13382	842	12540	16
Boise/Twin	13631	1171	12460	16
Eastern Idaho	13488	1209	12279	10
Total	12652	849	11803	93

To ascertain how the components of the system, the characteristics of the house, and the behavior of the occupants interact, a multivariate conditional demand analysis (CDA) was developed using regression estimating procedures. The goal was to establish the variables that explained the final net savings and the degree to which those variables were predictive of the DHP performance. This analysis added insights that were used to assess the DHP pilot program, develop conclusions, and provide recommendations:

The metering results provide insights into the DHP/electric resistance system operation, including:

- Supplemental heat from other fuels has less overall impact on savings than was originally expected. Overall supplemental heat has little or no impact on DHP savings if the initial electric heat signature is strong.
- The analysis strongly indicates that increased temperature results in lower savings. The effect is small (less than 10% of measured savings) but, throughout the sample, evidence

indicates that the occupants, on average, are opting for slightly higher temperatures once the DHP is installed.

- The use of the displacement model is far less sensitive to the characteristics of the home than would be expected in a conventional heating system. The DHP offsets a fairly uniform amount of electric resistance heat while that source makes up any shortfall.
- The second indoor air handler (head) allows another zone to be conditioned. In colder regions, the effect is to offset the load more effectively and reduce the time that the electric resistance operates. The effect is much smaller in warmer regions.

Secondary evaluation findings include:

- The occupant acceptance of this equipment is quite good. There is almost uniform satisfaction with the DHP within the metered sample.
- The impact of DHP efficiency ratings on overall performance or overall savings appears somewhat minimal. The study encompassed a wide variation in efficiency ratings but the savings were more correlated to the system operation and occupant control.
- In no climate did the cooling from the DHP exceed or even approach the levels of heating savings.

Overall, the impact of the metering on this sample suggests a successful technology when applied to buildings heated with zonal electric systems. The impact of the DHP displacement model appears to deliver significant savings for the minimum amount of capital equipment.

It is important to note that the houses selected for this study were all screened to ensure that the pre-DHP installation electricity usage indicated a strong correlation with outdoor temperature. This screening for an “electric heat signature” was conducted to ensure the best possible calculation of “baseline” electricity usage for comparison of post-installation whole-house energy bills and comparison of pre-bills against the metering results. This screening, however, was not generally conducted on the rest of the Pilot Project population of 3,899 houses. This limits the direct comparability of the “net savings” results with the rest of the sample since this metric relies on pre-installation electricity bill screening.

Houses without a strong relationship between pre-installation electricity usage and outdoor temperature are far more likely to have supplemental heating sources such as wood stoves that make it difficult to ascertain net savings. The lack of a strong electric heat signature, however, does not necessarily imply that “total savings,” i.e., heat delivered to the house by the DHP would be reduced compared to the results of the direct metering observed in the sample. From this study, total savings appears to be primarily a function the existing electric resistance heat and a number of factors including climate electric resistance and DHP heating setpoints; and number of indoor heat exchangers.

5. Billing Analysis

This section summarizes findings from the billing analysis tier (Baylon, Robison, and Storm 2013) of the DHP Evaluation. This tier focused on the energy use and savings of the Pilot Project population as a whole and builds on the insights and findings of the previous phases of the analysis tiers, especially the detailed metering conducted on 95 of the pilot homes across the region (Baylon et al., 2012a).

5.1. Billing Analysis Goals

The main goals of the DHP billing analysis were to:

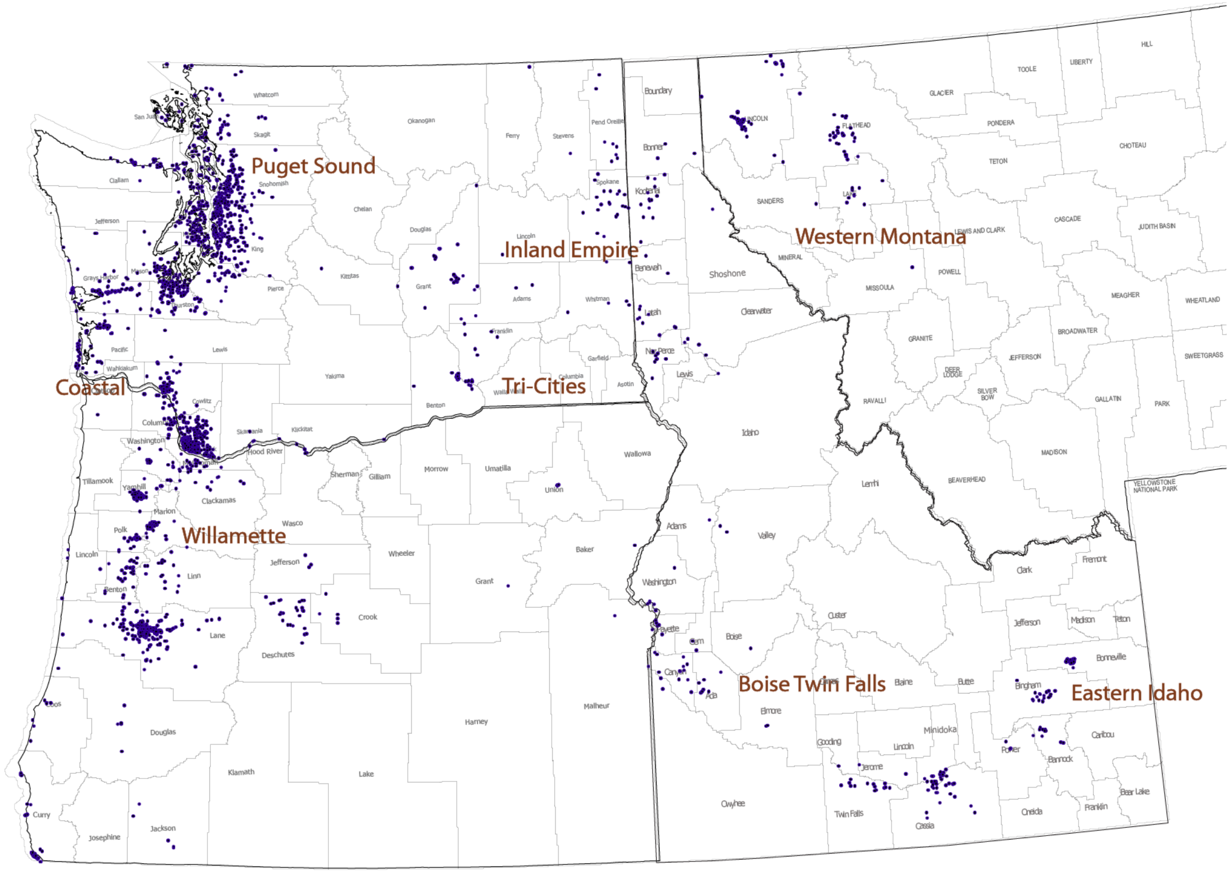
- Estimate the aggregate space heating energy savings by comparing the pre-installation heating estimate and the post-installation heating estimate.
- Establish the determinants of savings using information gathered at DHP installation including supplemental fuel use, climate, occupancy, and other factors.
- Assess the impact of supplemental fuels and other takebacks on overall savings estimates.
- Establish net electric savings from the DHP installations across the region.
- Provide implications that can be used to inform the development of a utility program to support the installation of DHPs as an energy-efficiency resource.

5.2. Methodology

Ecotope requested electric utility bills for the 3,899 Pilot Project participants. A total of 59 utilities participated in the pilot and provided bills for their participating customers. Figure 9 shows the distribution of all Pilot Project participants across the Northwest. The pilot population was divided into eight clusters designed to maintain a somewhat homogeneous climate for homes assigned to each cluster (see Section 4.2 for a more detailed description of the clusters).

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 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.

Figure 9. Distribution of DHP Pilot Project Participants



The analysis developed for this evaluation relies only on the billing data and weather station data at each participant site. The significant advantage of billing-data-only methods is that the same method can be used to calculate consumption in both periods. Known biases in consumption estimates likely cancel because the same biases would be present in both the pre-installation and post-installation billing analysis.

There were several sources of known bias that influenced the analysis. Notable sources were:

- The use of supplemental fuels (including wood, pellets, propane, and oil) to offset some of the space heating requirement (particularly when the use varies between the pre-installation period and the post-installation period) has the effect of reducing the size of the space heat offset available and could result in reduced supplemental fuel use when the DHP is present.
- Changes in operating approaches to the heating system, especially the increase in thermostat settings, would have the effect of reducing savings from the DHP while increasing occupant comfort.
- Changes in occupancy, especially changes in the number of occupants or the period of occupancy during the year would result in differences in heating and cooling needs unrelated to the presence or absence of a DHP.

- The presence of large and/or seasonal loads that are not part of the heating system of the home, but would appear as part of the space heating estimate in a conventional billing analysis, would represent loads unrelated to space heating and that would not be reduced by the DHP.

5.2.1. Space Heating Estimation and Savings Calculation

The billing analysis estimated the space heating used in terms of the degree-day temperature that was observed during each billing period. This process allows the VBDD analysis to develop a space heating estimate (based on the degree days) for the period before and the period after the installation of the DHP. Even though these estimates may have biases based on other seasonal loads (e.g., DHW), the savings calculations assume this bias is constant, so the difference between the pre- and post-installation heating estimates constitutes an estimate of the savings attributable to the DHP. This estimate is the basis for all the summaries used in this section.

The intake questionnaire filled out by the installation contractor and the homeowner was the source of additional information that could be used to explain the savings calculated in the billing analysis. Two approaches to this analysis were developed for this section: normalize billing analysis from the VBDD, and a CDA that allowed the savings to be computed when controlling for the conditions reported by the intake questionnaire.

5.2.2. VBDD Segmentation

In the initial analysis, the savings estimates from the VBDD were segmented based on variables derived from the questionnaire. The segmentation included the use of supplemental fuels and the particular climate in which the home was located.

Other variables, such as total occupants, house size, and overall DHP capacity, did not provide any significant explanatory power beyond these two main segmentation variables. The segmentation estimates were tabulated by each category to describe the changes in space heating estimates depending on climate and the use of supplemental fuels.

In compiling these summaries, VBDD results were screened based on the quality of the regression fit. The VBDD reports the coefficient of determination (R^2) as an indication of the quality of the billing data as a predictor of space heating use. This value varies depending on the amount of space heat provided by the supplemental (non-electric) heating system and by variations in occupancy such as extended vacancy or increase in home occupancy during the heating season. These effects reduce the ability of the VBDD regression to fit the billing data to the outdoor temperature assigned to the site.

The segmentation process screened sites for low R^2 (a poor overall regression fit) and developed summaries by using a subset of the overall billing results to summarize the DHP performance. Most of the sites screened in this way were reported as using supplemental fuels. Other issues of occupancy and anomalies in billing records also contributed.

5.2.3. Conditional Demand Regression Analysis

The VBDD savings estimates were combined into a CDA. The CDA used dummy variables to assess the influence of variables derived from the questionnaire to assess the contribution of these characteristics to the savings.

Several potential variables were explored in this process. In the final analysis, only two variables were shown to be consistently significant in the regression analysis—namely, the estimate of space heating in the pre-installation period and the self-reported use of supplemental fuels. The latter variable was a Boolean formulation based on the presence of a secondary space heating system and/or a reported secondary fuel source.

The analysis used these two variables in a robust regression analysis. It was conducted across three market areas selected to characterize principal differences in climates and supplemental fuel use. The three areas include the portion of the region west of the Cascade Mountains, the portion of the region east of the Cascades and the State of Montana. The Montana participants were separated since they had significantly more supplemental fuel use than the other regional market clusters. Final assessment included the impact of these two variables and a constant term that subsumed the variance associated with the wide variety of other variables that influenced the savings in particular homes. These results were computed separately for the three market divisions and for the population as a whole.

5.2.4. Billing Data and Weather Normalization

Utility billing data from all possible sites were analyzed to establish the baseline (defined as pre-installation) heating energy consumption. Utility bills were evaluated by using VBDD methods based on the PRInceton Scorekeeping Method (PRISM)[13] approach to establish an estimate of seasonal heating loads. The pre-installation billing record was assembled from approximately 18 to 30 months of billing data collected before the installation of the DHP. The post-installation period included a minimum of 18 months of billing data.

In addition to billing data, the record for each home included daily minimum and maximum outdoor temperatures recorded at a nearby weather station. Each case was assigned a nearby weather city (generally the site in closest proximity). The read dates were then used to compute the average daily temperature during the read interval. The weather city also provides long-term average weather data (based on Typical Meteorological Year [TMY]), used to normalize any climatic variations that may occur. Long-term normal weather is taken from TMY3 records. The actual weather data used for the billing analysis was collected from National Climatic Data Center (NCDC) for the period represented by the billing data.

Weather normalization entails casting weather-sensitive consumption or savings results in terms of a long-term average or normal weather. If space heating energy is assumed to be linear in heating degree days (HDD), and if this linear response coefficient can be estimated, weather normalization is a straightforward matter of multiplying this response coefficient by long-term average annual HDDs. VBDD regression provides an established method of estimating the

[13] For more information on the PRISM methodology, see Fels (1986).

degree day response coefficient. In the context of this section, long-term average means all the data available from NCDC for a site's chosen weather station. This varies from station to station, but averages about 15 years (ending in mid-2011) for the stations used here.

5.3. Key Findings and Conclusions

Table 15 is divided by the eight DHP clusters and shows the initial results of DHP billing analysis. In general, these clusters include reasonably homogeneous climates. This initial summary includes all cases where a full set of bills was available. The screened results do not include the VBDD results with poor statistical fits for the estimated space heating or cases where the electric space heating estimate was less than zero.

Table 15. Billing Analysis Savings Summary

	Space Heating Savings			
	All Cases		Screened Cases	
Cluster	kWh/yr	n	kWh/yr	n
Willamette	2,294	2,086	2,416	2,001
Puget Sound	1,677	752	1,913	701
Coastal	1,528	285	1,930	233
Inland Empire	792	140	856	126
Boise/Twin	1,407	96	1,572	92
Eastern Idaho	503	84	496	81
Tri-Cities	861	55	1,035	51
Western Montana	289	123	813	105
Total	1,892	3,621	2,081	3,390

The evaluation of savings was then segmented by separating the homes with supplemental fuel usage (self-reported) from the homes with no reported supplemental fuel usage (Table 16). In this summary only the screened cases were used. In several clusters the presence of supplemental fuels results in an *increase* in heating energy usage.

Table 16. 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	-1307	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

The final step in this evaluation was to specify a CDA to disaggregate and quantify the observed savings and the takeback effects[14] from the use of supplemental fuels and other occupancy effects (Table 17).

Table 17. CDA Analysis Summary Results

Cluster	CDA Analysis Results			
	Predicted Heating Savings		Predicted Takeback	
	kWh/yr	SD	kWh/yr	SD
Willamette	3,380	2,021	-988	489
Puget Sound	3,253	1,754	-1,090	525
Coastal	2,948	2,040	-1,179	539
Inland Empire	1,790	1,213	-862	612
Boise/Twin	2,077	930	-645	582
Eastern Idaho	2,051	918	-691	596
Tri-Cities	1,242	921	-559	548
Western Montana	2,200	1,456	-1,507	811
Total	3,120	1,937	-1,014	546

[14] Throughout this report the term "takeback" is used to refer to changes in occupant consumption patterns that result in decreased savings from the DHP installation. These effects include reduced use of supplemental fuels, increased temperature in the home, and increased occupancy (especially during the heating months). The analysis quantifies the impact of changes in supplemental fuels but other takeback effects are inferred from the data analysis.

When the space heating savings is isolated as in Table 17, the savings predicted from the DHP installation is within 4% of the net savings developed in the metering analysis (Baylon et al., 2012a). When takeback from all sources is taken into account, savings are reduced by about one-third as a result of the use and interaction with supplemental fuels (mostly wood). Even without an analysis of the takeback effects, the savings from the DHP are within 15% of the savings observed in the metering study when similar screens for supplemental fuels were applied (Table 16).

The result of this effect is to reduce the apparent savings from billing analysis from approximately 3,100 kWh/yr in the metered study where careful screening was done, largely to eliminate the impact of supplemental fuels, to about 2,000 kWh/yr in the overall savings predicted by the billing analysis. In the Pilot Project, some screening was done in some utilities, but, for the most part, large quantities of supplemental fuel are used throughout the geographic clusters. This reduction of about 1,100 kWh/yr (between the two groups) is only partly a function of the supplemental fuel behavior. Other behaviors observed in the metering sample also contribute. Given the nature of a large-scale billing analysis, most of the information about occupant behavior has to be inferred and cannot be directly measured by the intake interviews that were part of the initial participant intake in the Pilot Project

The results of the initial billing analysis suggested that the overall energy savings from the DHP was approximately 2,000 kWh/yr. This level of savings is only about half of the *total* savings observed in the metering sample, although there are several mitigating factors:

- About one-third of all participants used supplemental fuels as a self-reported component of their heating system. This level of non-utility supplemental fuel use is comparable to the findings of the Residential Building Stock Assessment (RBSA) (Baylon et al. 2012b), which is based on a large sample from across the Northwest. These supplemental fuels are often wood, but propane is also common. As a result, the heating impact of the DHP could not possibly have been as large as was observed in the metering sample where careful screening of the participants included homes where relatively little evidence of supplemental heat could be discerned.
- The use of supplemental heat, irregular occupancy, DHP placement, and other factors in the utility billing records themselves contributed to a low quality of the regression fit in estimating the space heating either before *or* after the installation of the DHP. In about 10% of cases, the homes had to be dropped because of the anomalies in the billing records received.
- The impact of climate is apparent in this analysis, but only about 15% of the Pilot Project participants were located in the colder eastern climates. This factor made the detailed assessment of climate zones somewhat problematic.
- In Montana, the coldest climate zone in the study, the saturation of wood heat exceeded two-thirds of the participant population. As a result, most summaries that include Montana have a fairly depressed heating savings estimate, even though the amount of heat used in the Montana climate is potentially much larger than the western parts of the region.

The overall savings from the simple billing analysis 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 reasonably 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. Given the accuracy of the VBDD process, that would appear to be substantial agreement between the two samples.

The billing analysis for the overall Pilot Project is fairly 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 of the order of 30% or more. It is likely that a failure to screen for supplemental fuels will reduce the overall savings effect of the DHP technology.
2. At least in Heating Zone 2 and 3 in the eastern part of the Northwest, 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.

The overall results of this analysis show a good agreement with the results of the DHP metered study. 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.

6. Cost Analysis and Non-Energy Benefits

The RTF guidelines (RTF 2013)[15] provide a format for evaluating the unit energy saving (UES)[16] 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 described in this section. The full cost benefit analysis conducted for the DHP UES development is available in the DHP UES measure workbook on the RTF Website.[17]

6.1. Capital Costs

The cost of the DHP installation varies depending on several factors. Like all residential HVAC systems costs, market conditions are important in the final cost determination. In the DHP Pilot Project, costs were collected on all installations by the participating utilities. These costs included labor equipment taxes and contractor mark-up. The total cost reported is consistent across all market areas, which formed the basis of the measure cost summary.

The Pilot Project operated from late 2008 until December 2009 and cost tracking continued through March 2012. During this period utility participants supplied information on their DHP installation to a regional program database. The database was the basis for the DHP Evaluation sampling and billing analysis conducted on nearly 4,000 installations through December 2009. A total of 15,425 homes received DHP installations by March 2012. These installations were not restricted as to size or number of units in each home.

To develop the cost assessment for the DHP, the cost information was screened so that the installations evaluated were commensurate with the regional program specifications as proposed in 2013. This set of specifications was presented to the RTF as part of the development of a proven UES for the DHP measure. The specifications used in this analysis are:

- A single outdoor compressor.
- Compressor capacity of ¾ to 2 tons (cooling capacity).
- A single indoor air handler.
- Installations in single-family residences only (four units or less).

The specification of the units evaluated in the detailed DHP field metering and the billing analysis closely follows these specifications. Thus, the costs summarized in this section were used to develop the cost/benefits estimates for the DHP measure applied across the region.

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[15] 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.

[16] 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)

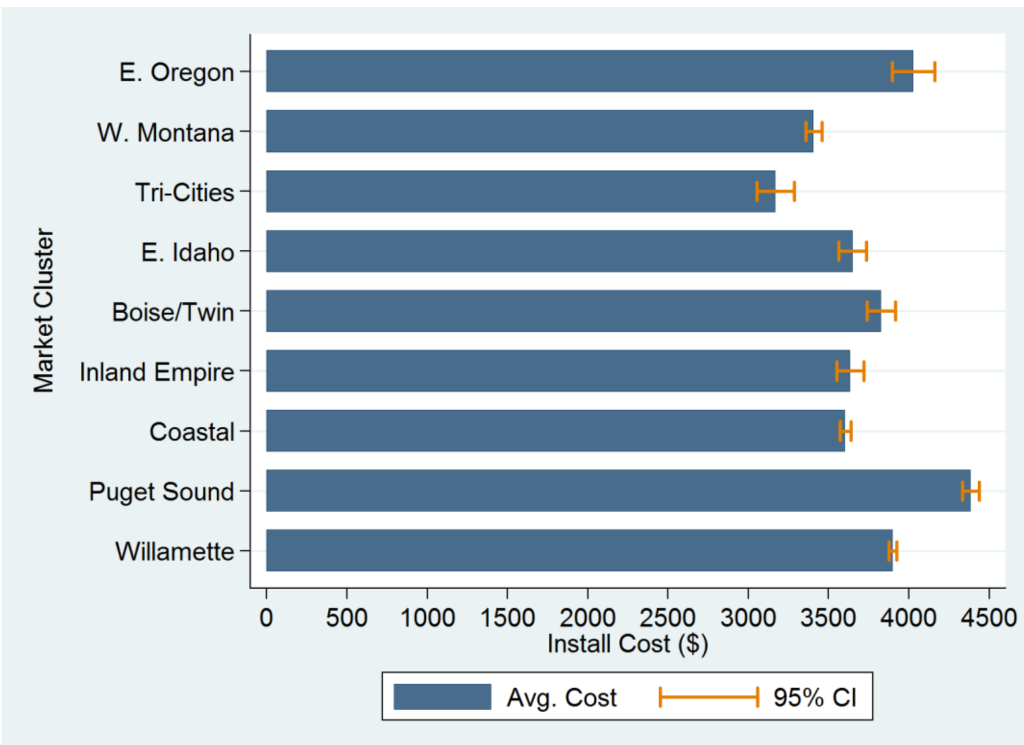
[17] For more information on the DHP UES see the full RTF DHP measure workbook at http://rtf.nwcouncil.org/meetings/2013/11/DHP_UES_2013-11-13%20PROPOSED.XLSM

When the overall DHP regional database was screened to focus on equipment that met these specifications, a total of 9,046 installations were identified. The installation became the basis of the cost estimates for DHP installations.

The total cost of each installation was used to develop the cost summaries. It was necessary to use total costs because many installations did not detail the components of the cost and no entries specified contractor mark-up. This total cost included sales tax. The states of Washington and Idaho have a sales tax which varies slightly across the jurisdictions in each state. For these two states the sales tax was removed from the analysis in accordance with the cost analysis guidelines developed by the RTF for evaluating regional cost effectiveness. In Montana and Oregon, no adjustment was made for state or local taxes.

The analysis of costs was conducted using the same geographic market areas used in the field metering and billing analysis and was repeated using the heating climate zones as specified by the RTF and the Northwest Power and Conservation Council (Council) for regional analysis and planning. Figure 10 shows the distribution of costs across all nine market areas.[18] As shown in this graph there are differences across the various geographic regions. Installations costs are typically higher in the more urbanized Puget Sound area and lower in rural areas east of the Cascades and on the Washington and Oregon coasts.

Figure 10. DHP Capital Cost by Market Cluster



[18] Eastern Oregon was not included in the original billing analysis since no program addressed this geographic area before January 2010.

These market areas were collapsed into the three heating zones and the three cooling zones used by the RTF to summarize the savings findings and assumptions of essentially all measures addressing heating equipment and heating loads throughout the region. While both heating and cooling zones are considered by the RTF, the cost and benefit information presented here is summarized by heating climate except where the cooling impacts are presented. The costs are summarized by each heating zone. The differences between the more populous western markets (Heating Zone 1) and the more rural markets of the eastern climates (Heating Zone 2 and 3) are apparent even in this summary. Table 18 summarizes the capital cost distribution across the region.

Table 18. Capital Costs by Heating Zone

Heating Zone	Capital Cost	Std. Dev.	EB	n
1	3,915	893	20	7,913
2	3,699	632	51	579
3	3,472	575	48	554
Total	**3,874**	**870**	**18**	**9,046**

The error bound shown in Table 18 represents a 95% confidence interval (CI). The costs reported in the western climates (Heating Zone 1) are higher than the other heating zones and the regional average as a whole. This result is largely due to the higher costs observed in the Puget Sound cluster.

It should be noted that the DHP program is dominated by the western regions. In this summary 87% of the installations are in Heating Zone 1. As a result, the program costs and savings benefits are dominated by the markets in Heating Zone 1.

6.2. Capital Cost Credits

Using the guidelines from the RTF, capital costs that are foregone when an efficiency measure (such as the DHP) is installed are included in the final cost benefit analysis. In this case, the primary capital cost that would be offset by a DHP installation would be future purchases of room air conditioning (RAC) units. These are typically window-mounted units providing zone cooling. In homes with zonal electric heat there is no duct work available so cooling equipment is generally of this type. To evaluate the size of this benefit the estimated saturation of RAC equipment developed in the Sixth Northwest Conservation and Electric Power Plan (6th Plan)(Council 2010) was used. The 6th Plan developed an estimate of future saturations of RAC units across the region. Ecotope used this analysis to estimate the fraction of the DHP participants that would have been expected to buy a RAC had they not purchased the DHP equipment.

The estimate of the cost of the RAC equipment that is offset by the DHP is based on a survey of RACs available from major retailers in 2013. This inquiry was limited to RAC units of comparable cooling capacity to the DHP. The average cost of RACs from these retailers was about $447[19]. Combining this cost with the results of the estimated increased saturation from the

[19] http://rtf.nwcouncil.org/meetings/2013/08/DHP%20UES%20Costs-NEBs_2013-08-20_v3.pptx

6th Plan resulted in the summary shown in Table 19. These credits were used to develop a regional cost benefit estimate. For this analysis, a 15-year time horizon was used corresponding to the assumed useful life of the DHP installation. The RTF assumes that after that period the majority of units would be upgraded or no longer serviceable in their current form.

Table 19. Capital Cost Offset, Future RAC Purchases

Cooling Zone	RAC Capital Cost ($/RAC Unit)	RAC Saturation Increase	Capital Cost Reduction ($/DHP Installed)
1	447	11%	48
2	447	33%	146
3	447	18%	78
Total	**447**	**20%**	**90**

6.3. End-User Benefits

The RTF guidelines specify that other benefits that might be accrued to the DHP participants be taken into account. In this analysis, several potential benefit streams were identified:

- The evaluation of supplemental fuels quantified a reduced fuel requirement for participants that relied in whole or in part on non-utility fuels.
- Supplemental fuels were reviewed for pollution impacts based on Environmental Protection Agency (EPA) research. This was not quantified and not included in the final cost and benefit assessment.
- In cases where the DHP provided cooling that offset the energy used by existing RAC equipment, the overall energy savings were increased to account for the cooling efficiency improvements from this technology.
- In other cases where the DHP installation did not offset existing cooling the cooling energy use was taken as a reduction in the total energy savings from the DHP installation.

6.3.1. Supplemental Fuel Benefits

The analysis of DHP interaction with various supplemental fuels was based on the installation database that asked participants if they used wood or other supplemental fuels (e.g., propane, oil). These questions were designed to document fuel use that currently offsets some of the heating requirement and reduces the electric heat used. In the DHP measure the savings that resulted from the high-efficiency DHP technology would usually offset both the electric fuel used and the supplemental fuel used. The billing analysis was used to predict the amount of supplemental fuel benefit that occurred across the entire DHP pilot program. Table 20 summarizes the average non-electric fuel savings benefit calculated for each heating climate. In this table the benefit is summarized in kWh of heating equivalent per year. The overall value of the supplemental benefits is based on the retail cost of electricity which would have been offset by the wood burning. This consumer benefit is used to offset as an added benefit within the regional cost benefit requirements.

Table 20. Supplemental Fuel Benefits

Heating Zone	Supplemental Fuel Saturation	Energy Offset (kWh/yr)	Non-Electric Benefit ($/yr)
1	28%	590	48
2	20%	402	33
3	70%	2,580	212
Total	**28%**	**668**	**55**

6.3.2. Supplemental Fuels Environmental Benefits

Preliminary analysis suggested that environmental benefits would occur when DHP installations result in the reduction of wood use and thus the reduction of wood smoke particulates. The EPA has constructed a procedure to quantify these benefits. In this analysis the air quality impacts associated with reduced wood burning were not evaluated. The RTF has embarked on a study of these effects that may result in additional benefits for the DHP technology.

6.3.3. Cooling Benefits and Offsets

The DHP is often installed in homes with no pre-existing cooling equipment. This is particularly true of the cooler western climates. As shown above some existing cooling systems are present in participant homes. These systems are almost exclusively window mounted RAC units. This type of equipment is substantially less efficient than the DHP equipment as installed. The amount of cooling offset by the DHP was assumed to be the amount of cooling actually provided by the DHP when it was measured during the metering phase of this evaluation (see Section 4). Table 21 summarizes benefits of the cooling impacts of the DHP installation. These benefits can be converted to occupant savings to include in the cost/benefit analysis or can be used to offset the electric energy savings from heating. Table 21 summarizes both the incremental savings for homes with pre-existing cooling and the electric energy offsets for homes that do not have pre-existing cooling.

Table 21. Cooling Impacts of DHP Installations

Cooling Zone	Cooling Savings (kWh/yr)		
	With Existing Cooling	Without Existing Cooling	Average Cooling Impact (All Cases)
1	121	-63	-39
2	263	-176	-1
3	412	-272	292
Total	**301**	**-135**	**-28**

8. Conclusions

The DHP Evaluation established the market acceptance and technical viability of the DHP technology as a retrofit resource for electrically heated customers in Northwest climate zones. Moreover, the approach used in this Pilot Project focusing on displacement of heating load, rather than replacement of heating systems, offers many customers an option for including high-efficiency equipment without completely abandoning their existing heating system (at substantial expense).

DHPs have a strong consumer acceptance, a workable integration with existing market actors and supply chains, a reasonable level of agreement between manufacturers' claims and actual performance and, finally, a performance that integrates well with the space conditioning needs of the utility customer. While occupants should have the option of installing larger systems, the smaller more targeted system produced desirable savings numbers and is likely to be among the most cost-effective efficiency measures available to utility customers across the Northwest. This approach was used to develop the regional program proposed to the RTF in 2013.

The emphasis in the Pilot Project on installers as a delivery mechanism has been successful. The DHP Pilot Project provides a useful model for the implementation and marketing of an emerging efficiency technology in this specific market of the residential sector.

Lab testing of two different manufacturer DHPs compared well with actual field measured COPs across a range of temperature conditions and largely validates that manufacturer ratings of this equipment are accurate. Figure 11 below shows lab measurements, manufacturer ratings, and field measurements (in box and whisker plots) for one manufacturer illustrating the good agreement between ratings and measured performance in DHP field installations.

Figure 11. 12RLS COP Plot

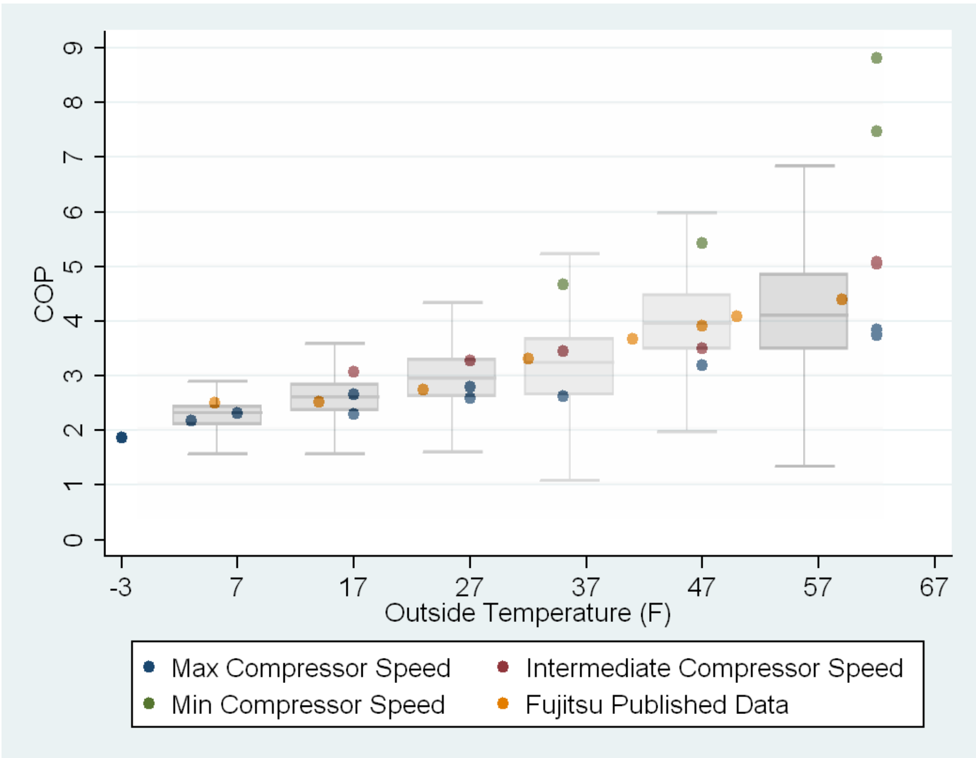


Table 22 below illustrates the performance of the DHP systems from the field-metered subsample of the Pilot Project. These findings were corroborated by the laboratory testing indicating that the manufacturers' rated performance was very close to the measured field performance. With seasonal COPs ranging 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 22. Ductless Heat Pump Performance

Cluster	DHP Heating Input Energy (kWh/yr)		DHP Heating Output Energy (kWh/yr)		DHP Heating Seasonal COP		N
	Mean	SD	Mean	SD	Mean	SD	
Willamette	1876	962	6048	2872	3.40	0.32	20
Puget Sound	1823	708	5549	2570	3.05	0.56	20
Inland Empire	2492	1097	5637	2126	2.41	0.59	12
Boise/Twin	2256	1274	6440	3040	2.96	0.30	8
Eastern Idaho	2188	978	6112	2675	2.84	0.30	9
Average / Total	2052	969	5886	2602	3.00	0.55	69

The average savings across the metered sample in Table 22 exceeded 3,800 kWh per year. Even when comparing heating energy use after DHP installation to heating energy use before, the evaluation measured a "net" energy usage that was still significant though less than measured directly from the COP measurements in Table 22. Table 23 illustrates savings compared to a "pre-DHP" baseline.

Table 23. Net Heating Savings, Metered

Cluster	DHP Savings (kWh/yr)		N
	Mean	SD	
Willamette	3316	2121	26
Puget Sound	3043	2357	25
Inland Empire	1882	1580	16
Boise/Twin	3628	2985	16
Eastern Idaho	3307	3230	10
Average/Total	3049	2424	93

The difference between the savings observed in Table 22 and Table 23 illustrates the fact that roughly 20% of the heat produced by the DHP was used to provide other benefits (beyond energy savings) to the occupant. 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.

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 reasonably 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. Given the accuracy of the VBDD process, that would appear to be substantial agreement between the two samples.

The billing analysis for the overall Pilot Project is fairly 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. It is likely that a failure to screen for supplemental fuels will reduce the overall savings effect of the DHP technology.
2. At least in Heating Zone 2 and 3 in the eastern part of the Northwest, 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 24 shows the results of the billing analysis segmented between participants with supplemental fuels and participants without such systems.

Table 24. DHP Savings by Supplemental Fuel Usage

	Space Heating Savings			
	Supp. Fuel		No Supp. Fuel	
Cluster	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
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Eastern Idaho	-1307	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

The overall results of this billing analysis show a good agreement with the results of the DHP metered study. 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.

In the final tier of the DHP Evaluation, the installation costs of the DHP units were summarized. It is apparent that local market conditions play a major role in the total costs observed. Given the disparity across the region's market areas and the large differences between the urban markets of the Puget Sound area and the more rural markets of Idaho and Montana, it seems likely that over time the competitive pressure to bring down the installation costs will result in some reductions. Nevertheless, at these costs the measure is cost-effective in most markets, and with careful screening can likely be cost-effective in virtually all Northwest market areas.

The overall program implications suggest that this is 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 regardless of the nameplate capacity or efficiency ratings as long as the equipment met the criteria for inverter driven operation. This 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. Average savings of 33% were observed across the Northwest climates. 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, as described in Section 4 and Section 5 of this report, 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. 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 SEEM 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 UES. 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.[20]

[20] 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

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