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Ductless Heat Pump Impact & Process Evaluation: Billing Analysis Report

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Glossary of Acronyms

AHRI	Air-Conditioning, Heating, and Refrigeration Institute
ASHRAE	American Society of Heating, Refrigeration, and Air-Conditioning Engineers
BPA	Bonneville Power Administration
CDA	conditional demand analysis
COP	coefficient of performance
DHP	ductless heat pump
DHW	domestic hot water
EB	error bound (.95 confidence interval)
HDD	heating degree days
HVAC	heating, ventilation, and air conditioning
IOU	investor-owned utility
ISO	International Organization for Standardization
kWh	kilowatt hours
kWh/yr	kilowatt hours per year
n	number of observations
NCDC	National Climatic Data Center
NEEA	Northwest Energy Efficiency Alliance
Council	Northwest Power and Conservation Council
PRISM	PRInceton Scorekeeping Method
R^2	coefficient of determination
RBSA	Residential Building Stock Assessment
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
VBDD	variable base degree day

Executive Summary

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-effectiveness.

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.

This report presents findings from the billing analysis tier of the DHP evaluation and focuses on the overall energy use of the pilot project population, based on an analysis of the billing records of a majority of the pilot project participants. This analysis used a variable base degree day (VBDD) methodology to estimate the heating energy use of each home and to compare that usage between the period prior to the installation of the DHP and the heating estimate for the year after the installation of the DHP. In this analysis, the VBDD used was a standard PRInceton Scorekeeping Method (PRISM) analysis.

In prior tiers of the DHP evaluation, the DHP equipment was evaluated in a lab to establish the performance characteristics of the equipment (Larson et al., 2011), and a detailed metering study was implemented on 95 homes to establish the details of the performance of the equipment in actual settings (Baylon et al., 2012a). These 95 metered homes were drawn from the pilot project and are included in the billing analysis presented in the current report. Out of the 3,899 pilot project participants, a total of 3,621 homes had a complete and useable billing record, and these homes were the basis of the billing analysis.

The objectives of the DHP billing analysis were to:

1. Estimate the aggregate space heating energy savings by comparing the pre-installation heating estimate and the post-installation heating estimate.
2. Establish the determinants of savings using information gathered at DHP installation including supplemental fuel use, climate, occupancy, and other factors.
3. Assess the impact of supplemental fuels and other takebacks on overall savings estimates.
4. Establish net electric savings from the DHP installations across the region.

To meet the first objective, Ecotope collected the billing records for the pilot project population, estimated the savings using PRISM, and evaluated the savings estimates by using climate and occupancy screens and by using a conditional demand analysis (CDA) to quantify the effects of supplemental fuel, climate, and other occupancy effects on the overall savings observed.

A billing analysis was conducted on all possible participants. Table ES-1 shows the initial results of that analysis. Table ES-1 is divided by the eight clusters used in this report. In

general, these clusters include reasonably homogeneous climates. The 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 ES-1. 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 ES-2 summarizes the results of this segmentation. 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 ES-2. 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
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[1] from the use of supplemental fuels and other occupancy effects. Table ES-3 summarizes the results from the CDA analysis.

Table ES-3. CDA Analysis Summary Results

	CDA Analysis Results			
	Predicted Heating Savings		Predicted Takeback	
Cluster	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

When the space heating savings is isolated as in Table ES-3, the savings predicted from the DHP installation is within 4% of the net savings developed in the previous metering analysis report. 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 ES-2).

The overall results of this analysis show a good agreement with the results of the previous 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.

[1] 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.

1. Introduction

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 (BPA), Energy Trust of Oregon, and more than 100 Northwest utilities on behalf of more than 12 million energy consumers.[2]

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 to December 2009. The DHP Pilot Project 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-effectiveness.

This report presents the results of an overall billing analysis conducted on the nearly 3,900 participants in the pilot project. This analysis built on the insights and findings of the previous phases of the analysis, especially the detailed metering conducted on 95 of the homes across the region (Baylon et al., 2012a). This report focuses on an evaluation of the bills collected for all the possible participants in the pilot project. Electric utility bills secured for 3,621 sites in the pilot project contained sufficient detail to conduct a normalized estimate of space heating use. This number of sites represented about 93% of all participants in the pilot project. The analysis used a variable base degree day (VBDD) methodology to estimate annual electric space heating use in the period prior to the installation of the DHP. The results were then compared using the same methodology for the period after the installation of the DHP to allow the savings to be calculated in each case. The results of this report will contribute to a more comprehensive understanding of DHP performance and applicability for energy savings in the Northwest.

1.1. The Ductless Heat Pump Efficiency Measure

In the summer of 2007, the Regional Technical Forum (RTF), at the behest of NEEA, began the process of assessing the use of a modernized mini-split heat pump technology. A new generation of equipment was introduced about this time, and 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.

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[2] See the website at www.neea.org.

The RTF approved a provisional measure that uses these new technologies. At that point, the measure was renamed ductless heat pump. The RTF used several assumptions to make preliminary 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. As a result, the DHP would provide a 30 to 40% reduction in annual 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 well in the coldest weather. The displacement model was thought to mitigate the risk associated with this scenario.

Homes with zonal electric resistance space heating systems have been the target of utility energy efficiency programs for most of the last 30 years. About half a million such homes are currently served by the region's electric utilities. These homes typically use a variety of zonal electric heat (including wall heaters, baseboards, or electric cable), do not use ducts, and are controlled in each room individually. The savings potential for these homes has typically been based on reducing the heat loss rate of the building through retrofit insulation and window upgrades. These efforts reduced the heating demands of the house and thus the electric heat bill.

1.2. The DHP Pilot Project

Beginning in the autumn of 2008, NEEA, BPA, and a number of cooperating utilities in the Northwest introduced a pilot project to market the DHP technology to customers who use zonal electric heat. 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. From the outset, the project targeted customers who were most likely to accept this technology and who were most likely to experience significant electric energy savings. Potential participants were asked about supplemental fuel use, and (within some utility service areas) certain customers were restricted from the project based on such usage or based on overall electric energy use patterns.

In the pilot project, NEEA and the regional utilities could install these systems and evaluate their performance over a significant number of installations. The DHP pilot project included several goals important to developing the DHP technology as viable efficiency measure:

- Develop an approach to marketing this technology based on introducing the product to residential heating, ventilation, and air conditioning (HVAC) contractors that could sell and install the product to the local markets throughout the region.

- Install at least 2,500 units (a total of 3,899 units were installed under this pilot by the end of 2009) across the region by using a combination of an integrated marketing strategy and substantial utility incentives sponsored by BPA and regional utilities.
- Use the installations from the pilot project to evaluate and assess the market acceptance of the DHP technology. This evaluation was designed to address the market and delivery process developed in the pilot project.
- Design an impact evaluation to mimic the approach to the central heat pump programs operating throughout the region. The impact evaluation includes both detailed assessment of field performance (including measurement of the field coefficient of performance [COP]) and the aggregate impact on billed consumption.
- Validate a simulation approach to predicting energy savings by using the regional residential analysis tool, Simple Energy and Enthalpy Model (SEEM).[3] This model would be used in the future to establish the electric savings associated with various DHP installation programs.

1.3. Integrated Evaluation of the DHP Pilot Project

To quantify the savings from increasing the efficiency of the zonal heating system, the pilot 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 project implementation staff and their opinions about the suitability of DHPs as an efficiency measure in markets other than those targeted by the pilot project. The evaluation explored responses to the technology and pilot project, and intentions to install DHPs among participating and nonparticipating installers (McRae et al., 2011).
- **Laboratory 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 et al., 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. This effort was meant to establish the results of occupant approaches to using the DHP in the context of the existing heating system (Baylon et al., 2012a).

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[3]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.

- **Billing Analysis.** An impact analysis using the results of the billing changes for the customers who use 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.
- **Cost-Effectiveness Analysis.** An analysis that integrates the impact evaluation with costs and benefits collected from the process interviews, the project reviews, and the impact evaluation.

1.4. Billing Analysis Objectives

This report focuses on the evaluation of bills assembled from all possible participants in the DHP pilot project. A total of 3,621 useable bills (approximately 93% of the sites) were collected from the participating utilities throughout the region. Using the VBDD analysis approach, two space heating estimates were made for all cases: heating use before the installation of the DHP and heating use after installation.

The objectives of the DHP billing analysis were to:

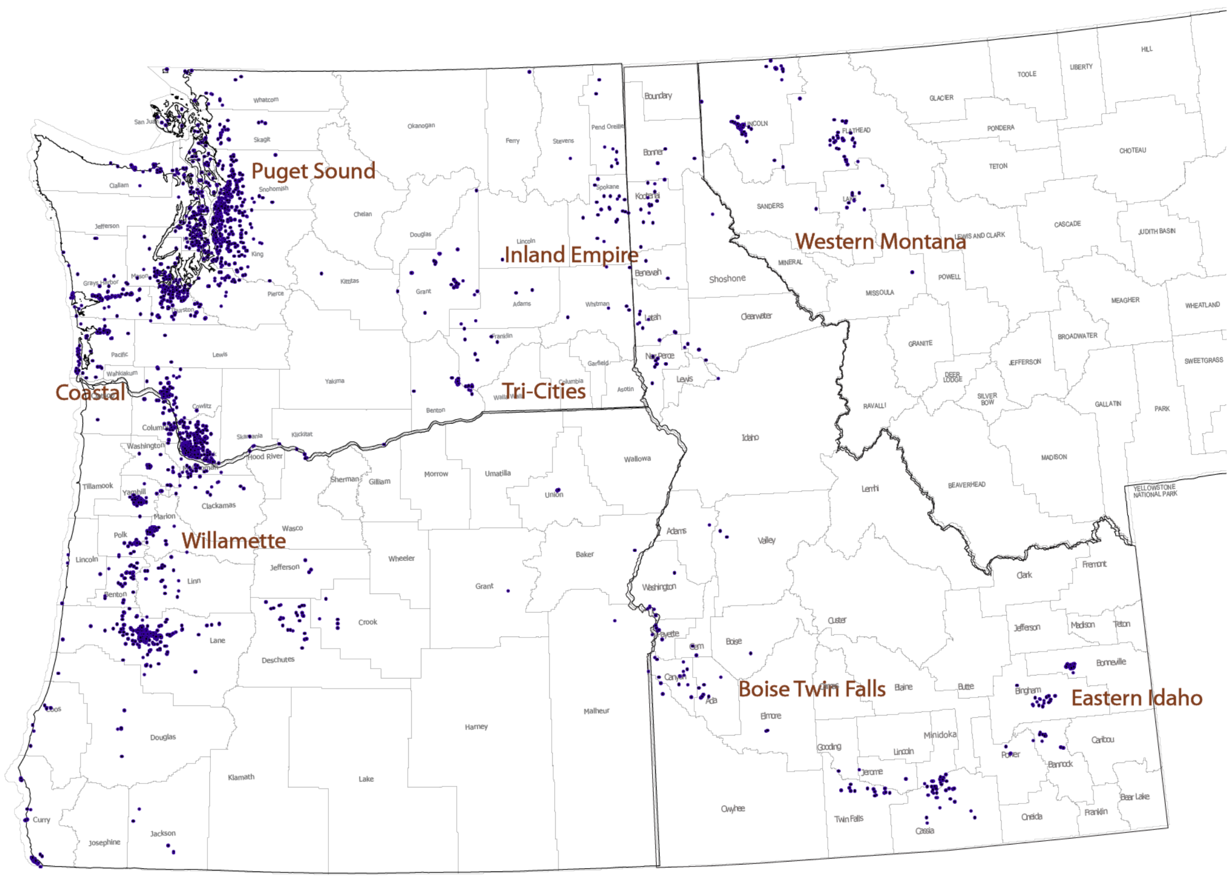
- Describe the energy use (controlling for local climate variations) for all valid bills collected under the pilot project.
- Use the results of the billing analysis to estimate space heating change (electric energy savings) that resulted from the installation of the DHP.
- Develop the climate and occupancy parameters needed to explain the savings observed.
- Use the results of the metering analysis (Baylon et al., 2012a) and other demographic variables to develop a conditional demand analysis (CDA) to explain the observed savings across the pilot population. The CDA would summarize both the impacts of various occupant takeback behaviors observed in the more detailed metering analysis and quantify these impacts on net electric savings observed in the billing analysis.

2. Methodology

The approach to evaluating the pilot project in this report is to use a VBDD analysis to review all the sites. To implement this approach, the utilities that participated in the first phase of the pilot project were approached to secure billing records from pilot participants. The DHP installations in the pilot project were performed by HVAC contractors active in the local areas. These contractors interviewed each participant and provided basic demographic information as well as a signed billing release for each installation.

The DHP pilot project included 3,899 homes scattered throughout the Northwest region. A total of 59 utilities participated in the pilot and provided bills for their participating customers. Figure 1 shows the distribution of participants across the entire region. The pilot population was divided into eight clusters designed to maintain a somewhat homogeneous climate for homes assigned to each cluster (see Section 3.1 for a more detailed description of the clusters).

Figure 1. Distribution of DHP Pilot Project Participants



2.1. Analytical Approach

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.
- Develop a picture of the determinants of those savings by using secondary data that the installation contractor collected from the occupants.
- Use insights developed from the detailed analysis made possible by the metering sample to inform calculation of overall savings.
- 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.

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 exact same method can be used to calculate consumption in both periods. Known biases in consumption estimates will likely cancel because the same bias 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 (such as wood) 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.

2.1.1. Space Heating Estimation and Savings Calculation

The billing analysis estimates 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., domestic hot water [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 report.

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 report: 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.

2.1.2. 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.

2.1.3. Conditional Demand Regression Analysis

The VBDD savings estimates were combined into a CDA. This analysis was formulated regardless of the statistical veracity of the space heating estimates. 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 later 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 (see Section 3.5). 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.

2.2. Billing Data and Weather Normalization

Utility billing data from all the valid 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)[4] 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 degree day 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.

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

3. Site Characteristics

The site characteristics of the pilot population are significant in that the geographic distribution of the pilot project was dominated by the western climate clusters. These clusters together make up about 85% of the participants in the pilot. Consequently, the aggregate billing analysis results are heavily influenced by these clusters. In addition, due to the small number of participants in the eastern climate clusters, the savings estimates developed for these clusters are less reliable.

3.1. Geographic Distribution

As shown in Table 1, the participants in the pilot study were divided into eight clusters. Table 1 also provides the distribution of homes *metered* for the DHP evaluation. The results for this group are summarized in the previous metering report (Baylon et al., 2012a) and compared to the results of the overall pilot project billing analysis described in Section 4 of this report.

Table 1. Sample Distribution of Total Pilot Population and Metered Sites

	Sites	
Cluster	**Total**	**Metered**
Willamette	2,219	27
Puget Sound	797	25
Coastal	308	0
Inland Empire	167	17
Boise/Twin	128	16
Eastern Idaho	92	10
Tri-Cities	60	0
Western Montana	128	0
Total	3,899	95

The geographic clusters presented in Table 1 are defined as:

1. **Willamette**: This cluster is composed of sites between Eugene, Oregon, and Longview, Washington. The cluster is characterized by Portland or Willamette weather data. This cluster accounted for far more participants in the pilot than in any other cluster.
2. **Puget Sound**: This cluster is essentially the five counties that surround Puget Sound, from Olympia to the Canadian border, and it includes the largest investor-owned utility (IOU), Puget Sound Energy, as well as three large public utilities all actively involved in the DHP pilot project.
3. **Coastal**: This cluster is a large expanse including the entire Pacific coast of the region, from Port Angeles, Washington, to Brookings, Oregon.
4. **Inland Empire**: This cluster includes much of eastern Washington and northern Idaho. The population center is Spokane, Washington. The cluster includes the high plateau and mountainous regions of Idaho and Washington and is generally thought of as Heating Climate Zone 2 by the Northwest Power and Conservation Council (Council) climate definitions. A

few sites were located in the Bend area of central Oregon. Those sites were also assigned to this Inland Empire cluster.

5. **Boise/Twin Falls**: This is a southern Idaho cluster, and includes the lower Snake River Plain between Ontario, Oregon, and Pocatello, Idaho. The dominant utility in this cluster is Idaho Power, and the cluster is centered on the Boise/Twin Falls corridor.
6. **Eastern Idaho**: This cluster is composed of the upper Snake River Plain and the Rocky Mountains. This cluster is noticeably colder than the lower Snake River Plain and is generally characterized as Heating Climate Zone 3 by the Council.
7. **Tri-Cities**: This cluster is located along the Columbia River at the confluence of the Yakima and Snake rivers. It is an area immediately around Richland, Kennewick, and Pasco, Washington. The cluster includes southeast Washington, northeast Oregon, and a portion of central Idaho.
8. **Western Montana**: This cluster includes all the installations performed in Montana, which are centered on Flathead County, with some scattering in other utility service areas. As with the Eastern Idaho cluster, these areas are characterized as Heating Climate Zone 3.

The western Washington and western Oregon climates of the Willamette, Puget Sound, and Coastal zones include approximately 85% of the homes that participated in the pilot project. The remaining 15% is equally scattered among the eastern clusters, with approximately 10% of the total pilot population in the Inland Empire, Boise/Twin, and Tri-Cities clusters, all areas that are typically Heating Climate Zone 2 and have at least some cooling season, either as Cooling Zone 2 or 3. The last 5% are in Climate Zone 3 in far-eastern Idaho and western Montana.

3.2. House Size

Table 2 summarizes the overall house size in each of the eight clusters, providing the mean, the standard deviation of the population (SD), and the total number of observations (n). On average, these homes are about 1,600 square feet with some significant deviations in the Eastern Idaho and Western Montana clusters. This variance is largely due to the presence of conditioned basements in these samples. The overall house sizes compare reasonably well with the metered sample, although in the case of the metered samples the housing area was actually measured during the installation of the meters. For the overall pilot population, the house sizes were self-reported, either by the contractor or by the homeowner.

Table 2. Household Conditioned Area by Cluster

Cluster	Pilot			Metered Sample*		
	Mean	SD	n	Mean	SD	n
Willamette	1,531	576	2,218	1,503	432	27
Puget Sound	1,596	591	796	1,395	340	25
Coastal	1,600	612	309	—	—	—
Inland Empire	1,734	847	167	1,393	448	17
Boise/Twin	1,711	649	128	1,966	389	16
Eastern Idaho	2,156	873	92	2,316	912	10
Tri-Cities	1,355	619	60	—	—	—
W. Montana	2,103	809	128	—	—	—
Total	1,595	632	3,898	1,618	500	95

*Conditioned area based on audits conducted during the meter installations.

3.3. Occupancy

House size and occupancy in the pilot project were typically characterized by older adult couples with relatively few children. The overall occupancy of each home was slightly over 2.2 occupants, which is significantly lower than the average occupancy (2.72 occupants) observed in the Residential Building Stock Assessment (RBSA), which is a random sample of *all* single-family homes in the Northwest (Baylon et al., 2012b). In contrast, the age range in this pilot project is slightly lower than the RBSA sample, but the difference is not statistically significant.

When the pilot project is compared to the *metered* homes in the DHP metering report, the occupancy patterns are almost identical. For the pilot participants, only 18% of all households were families with children, and almost one-third were families that included one or more seniors or retired people. The remaining 50% of the households were adult households with no children.

Table 3 shows the distribution of age in the pilot project. Table 4 shows the contrast between the pilot and the metered homes.

Table 3. Household Occupancy Characteristics, Pilot Project Homes

Cluster	Under 18	18–65	Over 65	Average Occ.	Average Age
Willamette	0.32	1.38	0.52	2.22	46.2
Puget Sound	0.32	1.42	0.49	2.24	45.1
Coastal	0.29	1.34	0.55	2.17	47.1
Inland Empire	0.28	1.19	0.70	2.18	49.3
Boise/Twin	0.27	1.28	0.67	2.23	48.8
Eastern Idaho	0.31	1.57	0.41	2.29	43.8
Tri-Cities	0.33	1.23	0.58	2.13	47.7
W. Montana	0.32	1.45	0.51	2.28	46.3
Total	0.31	1.38	0.53	2.22	46.3

Table 4. Household Occupancy Characteristics, Metered Homes

Cluster	Average Age	Average Occ.	n
Willamette	46.3	2.35	26
Puget Sound	45.1	2.20	25
Inland Empire	48.5	2.00	17
Boise/Twin	48.1	2.38	16
Eastern Idaho	43.6	2.50	10
Total	46.2	2.27	94

3.4. DHP Installation Details

The pilot project involved a fairly rigorous implementation of the displacement model that was used to design the project. The implementation in all clusters focused on one or two indoor units and about 1.5 tons of heat pump capacity. The size of the compressor was typically the size needed to handle the one or two air handlers and partially offset to the heating requirements of the home. This approach tended to ensure that the potential impact of the DHP was reasonably similar from one installation to the next.

Table 5 summarizes the individual compressor capacity across the clusters. As shown in Table 5, the design of the DHP installations suggests that larger compressors were installed when multiple indoor units were included. This approach is consistent with the manufacturers' recommendations for sizing of systems with larger numbers of indoor heads. About 5% of all households had multiple compressors. Most of these sites were located in southern Idaho, where occasionally contractors installed what appeared to be systems large enough to completely supplant the existing heating system in those homes.

Larger compressors tended to appear in some of the colder climates, especially the Eastern Idaho and Inland Empire clusters. The pattern is not consistent with western Montana, however, where relatively small, single compressors were the rule.

Table 5. DHP Installed Capacity by Cluster

Cluster	Capacity (tons)		
	One Indoor Unit	Two or More Indoor Units	All
Willamette	1.39	2.12	1.66
Puget Sound	1.34	2.13	1.61
Coastal	1.22	2.19	1.38
Inland Empire	1.67	2.50	1.87
Boise/Twin	1.27	2.26	1.83
Eastern Idaho	1.30	2.40	1.55
Tri-Cities	1.28	2.20	1.56
W. Montana	1.25	2.77	1.47
Total	1.37	2.16	1.64

Table 6 shows the distribution of indoor units in each cluster. The pattern is relatively similar across all clusters with the exception of the Boise/Twin cluster. Only in that region did more than half of the installations include multiple indoor heads, and that factor is reflected by larger compressor sizes in that cluster. In other clusters, the number of installations that had only a single head constituted about 75% of all installations. In general, this pattern seemed to be independent of climate or house size.

Table 6. DHP Installed Indoor Units by Cluster

Cluster	1	2	3 or More	All
Willamette	1,397	632	190	2,219
Puget Sound	508	182	86	776
Coastal	255	38	15	308
Inland Empire	127	24	16	167
Boise/Twin	52	44	32	128
Eastern Idaho	70	16	6	92
Tri-Cities	41	10	9	60
W. Montana	109	12	7	128
Total	2,559	958	361	3,878

3.5. Supplemental Fuel Use

For purposes of this analysis, the determination of supplemental fuel use was based on the intake interview by the contractor as part of the installation of the DHP. Many participants mentioned fireplaces and other supplemental heat sources but also asserted that they were not in use. In those cases, the general rule was to assume that there was no supplemental heating effect. Those participants were coded as not having supplemental fuels. Although this was an estimate based on the intake questions, the responses were ambiguous in some cases. In most of those cases, the use of supplemental fuels was assumed if the space heating estimate was much lower than other cases in that cluster. It may be that in some cases the contractors had an incentive to avoid this question because some utility incentives depended on no significant supplemental heat. We made no attempt to account for this effect. Although some respondents mentioned the amount of supplemental fuel used, this factor was very inconsistent. For the most part, the amount of fuel used was taken into account only when the occupant responded that the supplemental fuels usage was very small or nonexistent. In most cases, the amount of heating used was taken as the indication of supplemental use. This approach mimicked the detailed screening done to select sites for detailed metering.

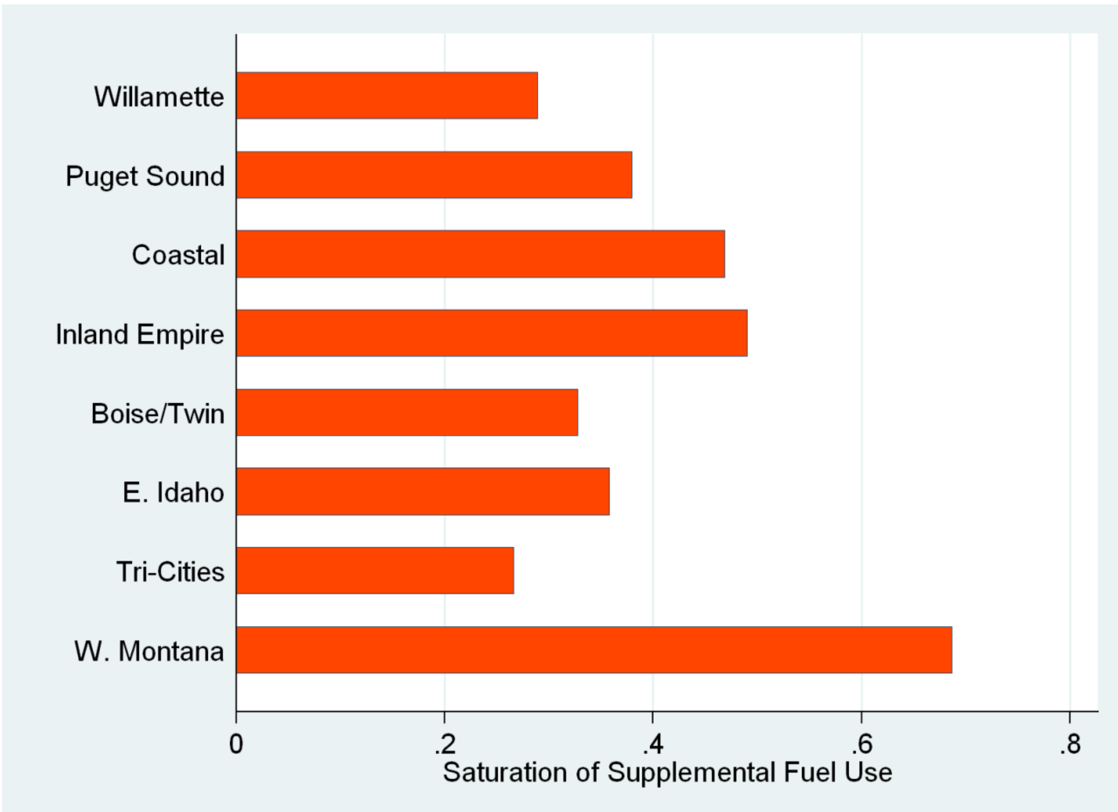
Table 7 shows the saturation of various supplemental fuels across the population. During the installation interview, the pilot project participants were asked about their use of such systems. In the more rural clusters such as in the Coastal cluster and the western Montana cluster, supplemental fuels are common. In the other clusters, approximately 25% of all homes had supplemental fuel of some sort.

Table 7. Saturation of Supplemental Fuel Use by Type and Cluster

Cluster	Percent of Households			
	Wood/Pellets	Propane/Gas	Other	All
Willamette	26.9%	1.9%	0.2%	29.0%
Puget Sound	31.4%	6.6%	0.3%	38.0%
Coastal	39.5%	7.1%	0.3%	46.9%
Inland Empire	38.9%	9.6%	0.6%	49.1%
Boise/Twin	29.7%	2.3%	0.8%	32.8%
Eastern Idaho	23.9%	12.0%	1.1%	35.9%
Tri-Cities	20.0%	6.7%	0.0%	26.7%
W. Montana	46.9%	20.3%	1.6%	68.8%
Total	29.9%	4.5%	0.3%	34.6%

The principal difference between the population for the metered sample and the overall pilot project population used as the basis for the billing analysis is that prior to site selection, the bills for the metered sites were screened for supplemental fuel use. Thus, although some supplemental fuels existed in the metered sample as well, for the most part, the fuel use in these homes had very little effect on the space heating requirements. Figure 2 shows the saturation of self-reported supplemental fuel use across the clusters.

Figure 2. Saturation of Self-Reported Supplemental Fuels by Cluster



3.6. Air Conditioning

Table 8 shows the saturation of air conditioning in the pilot population. However, the impact of cooling on the total savings in the pilot project is not included in this billing analysis due to the extreme variance in cooling signatures. In most climate zones in the Northwest, a consistent relationship between outdoor temperature and cooling use does not typically characterize the operation of the cooling system. Moreover, only a small fraction of homes in the pilot population, especially in the western climates, actually include a cooling system of any significance.

Table 8. Saturation of Air Conditioning

Cluster	%	n
Willamette	25.4%	2,218
Puget Sound	8.1%	777
Coastal	4.5%	308
Inland Empire	38.3%	167
Boise/Twin	55.5%	128
Eastern Idaho	25.0%	92
Tri-Cities	88.3%	60
W. Montana	24.2%	128
Total	22.7%	3,878

Nevertheless, in some climates, notably the Boise/Twin Falls climate and the Tri-Cities climate, the saturation of cooling equipment is high, and it would be reasonable to expect that the use of the DHP probably increased savings by virtue of the fact that it offset existing cooling systems with substantially lower Seasonal Energy Efficiency Ratio (SEER) ratings than the DHP equipment. Overall, however, only 22.7% of the entire pilot population and less than 20% of the participants in the western climates had any cooling equipment at all at the outset of the pilot project.

4. Analysis

Participating utilities provided electric bills for all homes participating in the pilot project. The general approach to the billing analysis used a VBDD analysis (PRISM) to assess the outdoor temperature sensitive portion of the utility bills.[5] This approach resulted in a space heating estimate both before and after the installation of the DHP. These estimates were used to calculate electric savings. These savings and the overall electric energy use were normalized to long-term weather at the site.

A significant goal of this analysis was to assess the impact of occupant heating behavior on DHP savings. This section focuses on both the overall savings and the impact of supplemental fuels on the overall savings estimates.

4.1. Billing Analysis

The analysis below includes the entire pilot population for which useable bills could be assembled. Approximately 93% of all participants were included in the final billing analysis. Table 9 shows the distribution of overall electric energy consumption and space heating estimates in kilowatt hours (kWh) across the entire population.

Table 9. Pre-Installation Normalized Energy Use (kWh)

Cluster	Total (normalized)		Space Heat		n
	Mean	SD	Mean	SD	
Willamette	17,528	7,458	7,053	4,220	2,087
Puget Sound	16,585	6,205	6,792	3,661	752
Coastal	17,049	7,849	6,144	4,263	284
Inland Empire	20,365	9,721	8,175	5,540	140
Boise/Twin	23,096	7,862	9,486	4,247	96
Eastern Idaho	22,050	7,365	9,364	4,191	84
Tri-Cities	16,662	7,896	5,670	4,204	55
W. Montana	20,945	9,500	9,130	6,042	123
Total	17,759	7,582	7,139	4,311	3,621

Some of the sites were not used due to an inadequate number of bills (especially in the heating season). This problem can occur in either the pre-installation bills or the post-installation bills. In addition, there were cases where multiple meters were reported without any guidance as to the correct meter that covered the site of the DHP installation. After anomalous billing records were removed, a total of 3,621 sites were used in the balance of the billing analysis. Table 9 was not screened for the quality of the fit in the VBDD.

In general, the more frequent the fuel use from supplemental sources, the lower the quality of the space heating prediction. This relationship is indicated by R^2 of the predicted space heating.

[5] The mechanics of the VBDD/PRISM analysis are discussed in Section 2.1and described in detail in Fels, 1986.

Because a lower R^2 can also be the result of intermittent occupancy or erratic thermostat operation, the analysis used virtually all the available data to summarize the overall savings estimates. Nevertheless, the effect of the quality of the space heating prediction is discussed in Section 4.2.

For comparison, Table 10 shows the billing analysis results for the subset of homes that received metering in the previous phase of the DHP evaluation. This table provides a useful contrast that helps assess the distinction between the overall pilot project and the sub-metered sample. In general, the metering participants had consistently higher annual consumption and space heating demand than the overall project. The metered sample was screened using a VBDD analysis to avoid the homes with observable supplemental heating. Although this screening did not completely preclude those participants, the effect was to screen for homes with larger space heating usage.

Table 10. Pre-Installation Normalized Energy Use (kWh), Metered Sample

Cluster	Total (normalized)		Space Heat		n
	Mean	SD	Mean	SD	
Willamette	18,773	6,209	7,621	2,937	27
Puget Sound	15,795	4,511	7,125	2,535	25
Inland Empire	23,527	7,403	8,883	4,473	16
Boise/Twin	22,659	5,558	10,299	2,913	13
Eastern Idaho	23,254	6,144	12,783	3,802	10
Total	19,838	6,583	8,656	3,658	91

Ecotope conducted an assessment of potential bias in VBDD billing analysis techniques using 95 sites sub-metered for heating in NEEA's DHP pilot project evaluation. For purposes of this work, a bias is defined as systematic over- or under-prediction of house heating energy. Data loggers in 95 houses directly recorded the heating, and that record is taken to be the truth set. Utility bills provide the information source for VBDD analysis, which results are compared to the metered record. The analysis shows that, although VBDD analysis provides a highly variable estimate of heating energy in the population, we found, on average, no significant bias in this set homes.

4.2. Screened VBDD Results

All billing analysis is impacted by scatter in the billing data over the course of the heating season. This scatter can be the result of many anomalies, including meter reading errors, intermittent vacancy (such as vacations), or unusual extra loads. For this analysis, the quality of the space heating fit was critical to assessing the space heating savings associated with the DHP installation. The billing analysis included adjustments for many types of vacancy and occupancy shifts and some types of meter reading errors using a PRISM weighting strategy. After these corrections were made, however, some of the estimates were not well determined by the PRISM analysis itself. As a result, the final estimates were screened to ensure that a minimum statistical standard could be achieved. Table 11 shows the comparison between the entire billing analysis sample and two possible screening criteria based on R^2. The R^2>.45 criteria provides a reasonable screen on values that were significantly scattered in spite of the precautions and adjustments. The R^2>.65 is a more typical screen but, as shown in Table 11, provides relatively little additional adjustment. The use of supplemental fuels tends to reduce the R^2, so it is desirable to use as much of the sample as possible if the impact of supplemental fuels is to be assessed.

Table 11. Comparative Energy Use, Alternative Screening Criteria

Screened Datasets	Normalized Total Consumption (kWh)		Space Heating Consumption (kWh)		Space Heating Saved (kWh)	n
	Pre Install	Post Install	Pre Install	Post Install		
All Sites with Valid Bills						
All	17,768	15,875	7,141	5,248	1,892	3,621
R^2>.45	17,978	15,931	7,425	5,343	2,081	3,390
R^2>.65	18,209	15,933	7,715	5,415	2,300	3,038
Sites with Valid Bills and No Reported Supplemental Fuel Use						
All	18,039	15,443	7,816	5,149	2,667	2,357
R^2>.45	18,075	15,459	7,905	5,187	2,718	2,295
R^2>.65	18,156	15,458	8,021	5,235	2,786	2,149
Sites with Valid Bills and Reported Supplemental Fuel Use						
All	17,263	16,679	5,882	5,434	448	1,264
R^2>.45	17,774	16,921	6,418	5,670	747	1,095
R^2>.65	18,336	17,081	6,976	5,850	1,126	889

The impact of supplemental heating has been assessed using both screens for the quality of the space heating fit and the self-reported use of supplemental fuels by the pilot participants. The amount of supplemental fuel generally was un-reported. For this analysis, an indication of a secondary heating system, regardless of the type of supplemental fuel mentioned, was generally coded as a supplemental user. In cases where the participant directly specified the fireplace was used for decorative purposes or if the participant asserted that no supplemental fuel was used, the case was coded as no supplemental fuel. Table 11 shows the results of screens on both R^2 and on the supplemental fuel indicator in the pilot population. Although rural clusters tend to have a higher incidence of supplemental heat (especially wood heat), the incidence of supplemental heat is comparable between the eastern and western portions of the region. Only Montana has a significantly larger saturation of supplemental fuels (66%) than any other region, rural or otherwise. Without Western Montana, the saturation of supplemental fuels in the pilot populations is similar in both the eastern clusters and the western clusters.

Figure 3 shows the results from the Table 11 segmentation spread over the clusters. The variation between the various clusters is apparent here, although several of the clusters include relatively small samples. The most significant finding that Figure 3 illustrates is the impact of supplemental fuels particularly in the colder eastern climate zones.

Figure 3. Savings Segmented by Cluster and Supplemental Fuel Use

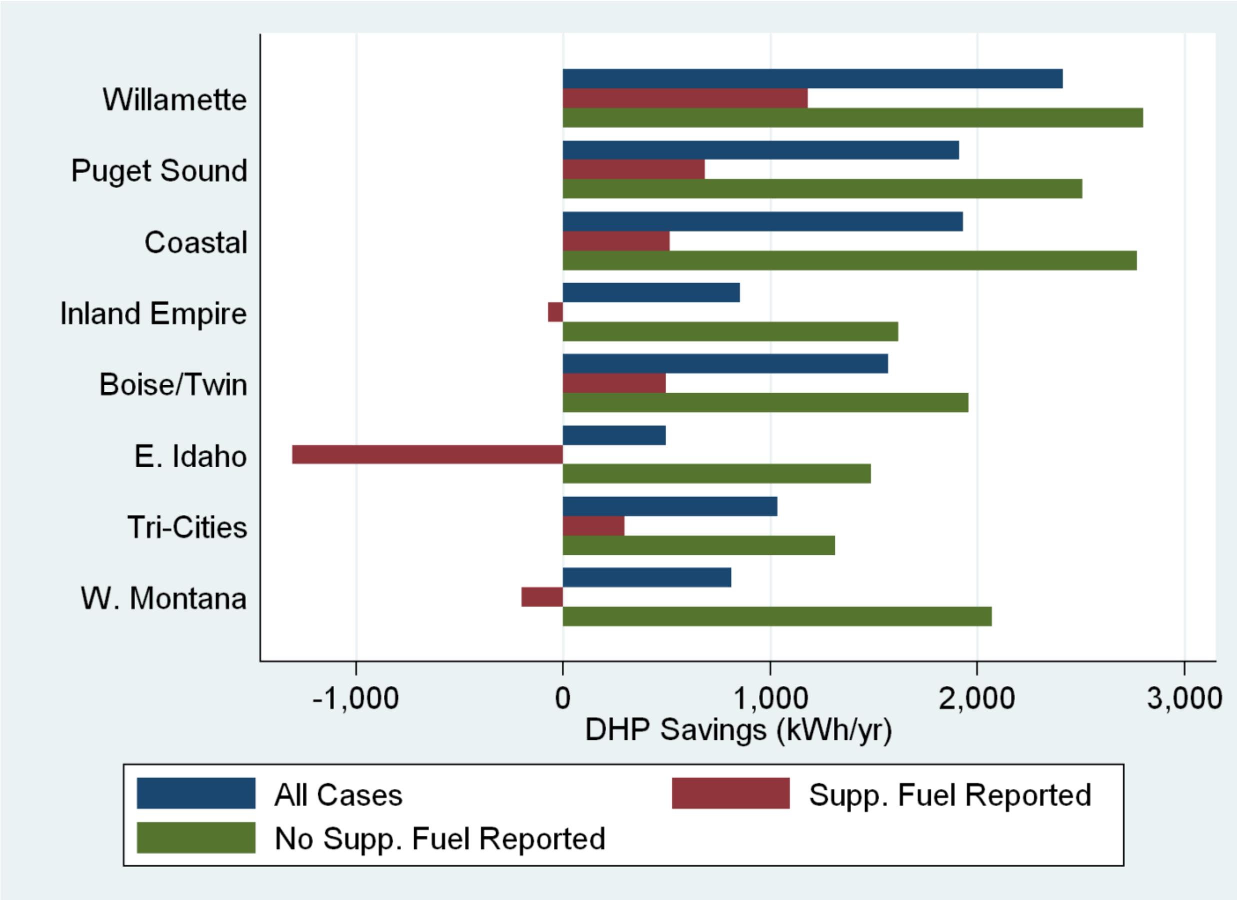


Table 12 shows the comparison between the characteristics of the various screened samples. The western climate column refers to sites that are located west of the Cascade Mountains. Eighty-five percent of the pilot population included sites in the more mild western climates. Except for the Western Montana participants, the use of supplemental fuels is comparable between the eastern climates and the western climates.

Table 12. Comparative Household Characteristics, Alternative Screening Criteria

Heating Signature	Area (Sq.Ft.)	Occupancy	Percentage in Western Climates	n
All Sites with Valid Bills				
All	1,605	2.19	86.2%	3,621
R^2>.45	1,603	2.19	86.6%	3,390
R^2>.65	1,595	2.18	87.5%	3,038
Sites with Valid Bills and No Reported Supplemental Fuel Use				
All	1,530	2.15	89.0%	2,357
R^2>.45	1,533	2.14	89.2%	2,295
R^2>.65	1,529	2.14	89.5%	2,149
Sites with Valid Bills and Reported Supplemental Fuel Use				
All	1,744	2.27	81.1%	1,264
R^2>.45	1,752	2.28	81.2%	1,095
R^2>.65	1,754	2.28	82.8%	889

4.3. Savings Evaluation

The primary goal of the statistical analysis in this section was to assess the determinants of the savings observed in the summary of the VBDD analysis in the previous sections. This process mirrors the review of the sites that received detailed metering (Baylon et al., 2012a).

In this analysis, the primary source of additional information was the intake questionnaire administered as part of the pilot project. This questionnaire provided basic demographic information and information on supplemental fuel use and supplemental heating systems. The number of variables available from this intake questionnaire was not as detailed as the detailed audit and multiple interviews conducted on the metered sample. As a result, the initial effort used a similar specification but proved unstable with multiple explanatory variables.

To assess the statistical impact of the supplemental fuel behavior, a regression-based analysis was specified using a CDA as the basis for the regression specifications. Several regression specifications were attempted in which the VBDD predicted savings were used as a dependent variable. The heating system characteristics and demographics were formulated as independent variables. The specifications were meant to approximate the variables thought to be useful in the metered analysis.

The results of most of these regression specifications showed virtually no statistical significance for a wide range of variables. These variables included house size, homeowner demographics (household size and age), DHP equipment size (heating capacity), and number of DHP zones. Overall, the only variables that showed a significant relationship with the savings estimates were the presence of supplemental fuels and a simplified climate variable that separated the population into two climate zones: east of the Cascades and west of the Cascades.

The supplemental fuel variable was formulated as an indicator variable, taking the value of "true" whenever the intake questionnaire identify a secondary heating system or when a secondary fuel type was identified. In cases where the occupant explicitly said that the secondary system was not used or was strictly decorative, the variable was set to "false." Cases where there was no mention of secondary fuels or heating systems were also set to "false."

4.3.1. Regression Specification

Given the differences between heating use in the homes in the pilot project, there is considerable scatter in the space heating predictions. The source of this scatter is, in part, a function of supplemental fuels that are used to offset the electric space heating system. Other occupancy patterns such as extensive absence during the heating season ("snow-birds") and intermittent use of outbuildings contribute to the uncertainty in space heating estimates but were not addressed in the intake questionnaire. As a result we have no basis for quantifying this effect separately. The impact of these patterns on the space heating prediction from the VBDD analysis is to reduce the quality of the fit and thus the robustness of the space heating estimate itself. Some of this impact is the result of supplemental fuels, but much of it is due to other factors.

Table 13 summarizes the savings estimates with a simple screen removing the most uncertain VBDD results. Unfortunately, many of the sites removed in this formulation also use supplemental fuel. As a result, the ability to formulate an analysis that quantifies the effect on DHP savings is compromised.

Table 13. Estimated Space Heating Savings, VBDD

Cluster	Space Heating Savings (kWh/yr)		n
	Mean*	SD	
Willamette	2,415	2,717	2,001
Puget Sound	1,913	2,821	701
Coastal	1,930	2,962	233
Inland Empire	856	3,241	126
Boise/Twin	1,572	2,402	92
Eastern Idaho	496	2,899	81
Tri-Cities	1,035	2,608	51
W. Montana	812	3,780	105
Total	2,081	2,853	3,390

*Screened on R^2>.45, negative space heating estimates.

In order to quantify the effects of supplemental fuels and climate, an additional specification was developed by using a robust regression approach. In this approach, the outliers in the regression fit were weighted to reduce their impact on the final results[6].

[6] Robust regression was used in this study to reduce the influence of outliers or high leverage data points. Since these data points are not data entry errors, we have no compelling reason to exclude them from the analysis. The robust regression weights the observations differently based on how well behaved these observations are. It is a form of weighted and reweighted least squares regression.

Two explanatory variables emerged from this specification: pre-installation space heating estimates and a dummy variable based on the presence of supplemental heat as indicated in the intake questionnaire results. A third variable (western and eastern climate zones) was used to segment the analysis.

The final regression equation took the form of:

$$SH_{Saved} = c_1 SH_{Pre} + c_2 Fuel + C$$

Where:

SH_{Saved} = VBDD predicted space heating savings in kilowatt hours per year (kWh/yr)

c_1,c_2 = Regression Coefficients (see Table 14)

SH_{Pre} = VBDD predicted space heating prior to DHP installation (kWh/yr)

Fuel = Indicator: "true" if supplemental fuel is indicated in the intake questionnaire

C = Regression constant (kWh/yr, see Table 14)

For this regression, the c_1 coefficient provides the multiplier that predicts the underlying fraction of the pre-installation space heating that is saved as a result of the DHP installation. This parameter is estimated in the robust regression controlling for the use of supplemental space heating. The c_2 coefficient shows the typical impact on these savings given the presence of supplemental space heating fuels. C is the regression constant and generally refers to variables not in the regression that further modify the space heating savings. Although these variables vary from one case to the next, they generally include house size, occupancy patterns, and particular DHP equipment installations.

4.3.2. Regression Results

Using the generalized regression equation (Section 4.3.1), the data were evaluated by using all the VBDD regression results, except a few cases where the savings could not be calculated because of problems with either the pre-installation or the post-installation estimates or where the VBDD procedure predicted negative or zero space heating in the pre-installation case.

The regression was calculated by using the entire pilot sample and subsequently segmented by climate. With the segmentation, four separate regressions were specified of the general form of the regression equation.

The four regression segments included:

1. The entire sample across all climates zones
2. The Western sample including all sites west of the Cascades
3. The Eastern sample including all sites east of the Cascades in Washington, Oregon, and Idaho
4. The Western Montana sites only[7]

The results of the four regressions are summarized in Table 14. For the most part these regression results were statistically significant.[8]

Table 14. Regression Results

Climate Zone Segment	Parameter						n
	c_1		c_2		C		
	Est.	EB	Est.	EB	Est.	EB	
Western	0.479	0.016	-1078	131	-676	140	3,122
Eastern*	0.219	0.046	-1220	456	-226	519	375
W. Montana*	0.241	0.096	-1761	1263	-275	1545	123
All	0.426	0.015	-1208	129	-466	139	3,620

*Constant term "C" not statistically significant

The results summarized in Table 14 show good agreement with the results of the metering study. When the effects of supplemental fuels and other occupancy effects are taken into account, the percentage impact on space heating in the CDA is nearly identical to the CDA in the metering study. For the western climates, space heating savings as a fraction of initial estimated space heating is a little less than half and very consistent with the regression analysis presented with the metered data (Baylon et al., 2012a). More striking is that this same analysis shows that the ratio of DHP savings to overall space heating in the eastern clusters is about half of this ratio in the western clusters. The fact that the size of the systems in the pilot project is very similar in all climates indicates that the colder eastern climates could benefit from more capacity. This effect was not apparent in any regression controlling for DHP system size, but only 4% of the pilot included a higher capacity system, and these sites were located in one of the colder eastern climates.

[7] Montana was segmented separately because the saturation of supplemental fuel use was much higher than any of the other climates and more than twice as large as the remaining sample as a whole.

[8] F-test value shows significant at $\alpha<.01$ for all four regressions.

4.4. CDA Savings Predictions

The regression tool allows the analysis to take into account the large amount of supplemental fuels across the pilot population. This approach has two advantages:

1. The impact of the DHP on actual electric space heating can be separated from other effects, including the impact of the DHP on supplemental fuels and the impact of the DHP on occupant comfort.
2. The impact of supplemental fuels on the overall project savings can be separated from the general installation of DHP systems in zonal electric homes.

The results of the robust regression analysis including the climate segmentation are shown in Table 15, Table 16, and Table 17. Table 15 shows the heating-only savings predicted by the regression from the c_1 coefficient on the original space heat estimate from the billing analysis. Table 16 shows the impact of the supplemental fuels and the constant on these estimates by market cluster. Table 17 shows the overall net savings that result from this analysis.

Table 15. Predicted CDA Savings, Space Heat Only

Cluster	Savings		n
	Mean	SD	
Willamette	3,380	2,021	2,086
Puget Sound	3,253	1,754	752
Coastal	2,948	2,040	285
Inland Empire	1,790	1,213	140
Boise/Twin	2,077	930	96
Eastern Idaho	2,051	918	84
Tri-Cities	1,242	921	55
Western Montana	2,200	1,456	123
Total	3,120	1,937	3,621

Table 16. Predicted Savings Reduction, All Sources

Cluster	Savings		n
	Mean	SD	
Willamette	-988	489	2,086
Puget Sound	-1,090	525	752
Coastal	-1,179	539	285
Inland Empire	-862	612	140
Boise/Twin	-645	582	96
Eastern Idaho	-691	596	84
Tri-Cities	-559	548	55
Western Montana	-1,507	811	123
Total	-1,014	546	3,621

Table 17. Net Heating Savings Predicted, CDA

Cluster	Savings		n
	Mean	SD	
Willamette	2,392	2,162	2,086
Puget Sound	2,163	1,980	752
Coastal	1,769	2,256	285
Inland Empire	928	1,531	140
Boise/Twin	1,432	1,302	96
Eastern Idaho	1,360	1,265	84
Tri-Cities	683	1,002	55
Western Montana	693	1,897	123
Total	2,106	2,109	3,621

Table 18 shows the comparison results (unweighted) for the simple summary of the savings estimated by the VBDD analysis. This summary was screened for the quality of the VBDD fit so as to be more comparable with the robust regression.[9]

Table 18. Screened Savings, VBDD Screened Results

Cluster	Savings		n
	Mean	SD	
Willamette	2,549	2,721	1,863
Puget Sound	2,149	2,686	626
Coastal	2,327	2,728	170
Inland Empire	1,247	2,916	108
Boise/Twin	1,626	2,172	83
Eastern Idaho	945	2,530	60
Tri-Cities	1,188	2,643	43
Western Montana	1,416	3,404	85
Total	2,300	2,753	3,038

[9] The robust regression downweights outliers in the regression. This has the effect of de-rating points that significantly deviate from the regression fit. The algorithm uses "Cook's distance (D)" to set the initial weights. Cook's distance measures influence of each observation on the OLS error of the regression. The weights are proportional to Cook's D. The case is given no weight if Cook's D exceeds 1.0. The screening of the VBDD results has a similar (but not identical) result. In this summary, the R^2 for the VBDD regression was restricted to .65 or greater.

The agreement between the regression results and the overall savings predicted from the VBDD analysis is about 9%. In some clusters, the agreement is much better. It is important to remember that the VBDD results shown here are adjusted for poor regression fit to the billing analysis. The eastern climates have more variation than the western climates, resulting in larger errors between the regression results and the VBDD results.

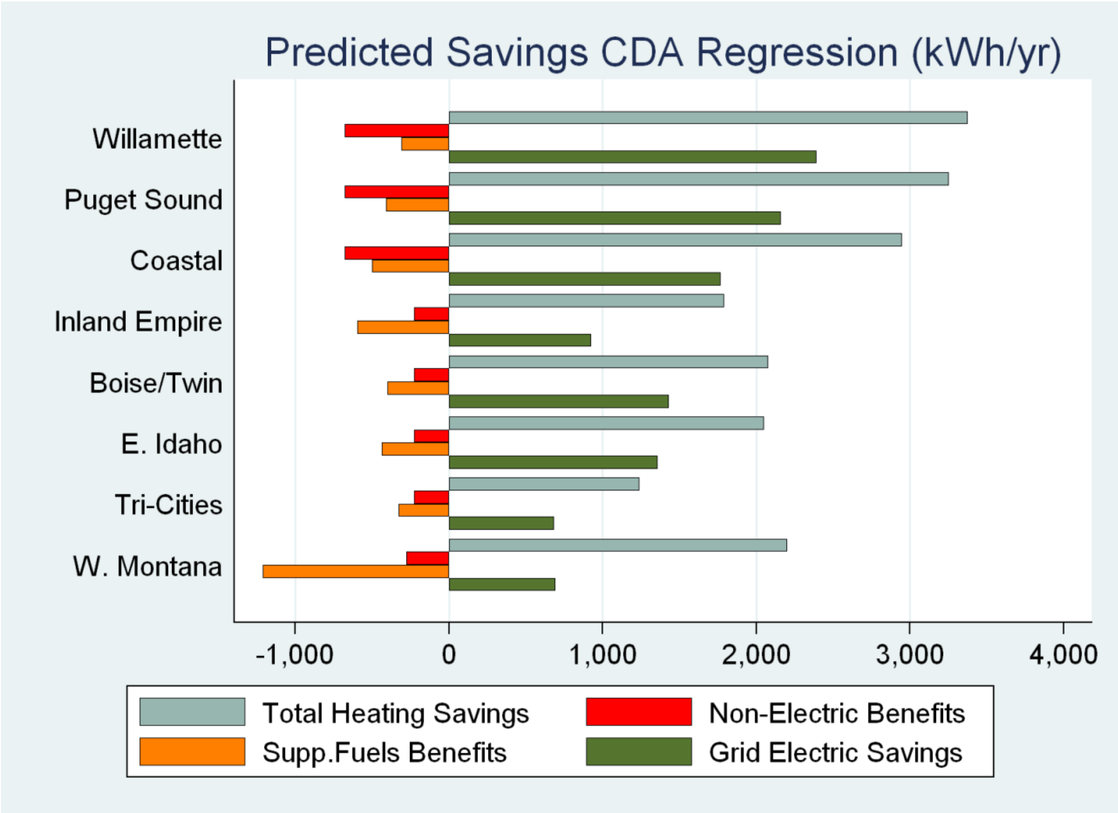
The regression predicts the space heating savings when the impact of supplemental fuels is controlled out. This is taken as the value of the c_1 coefficient in Table 14. When this coefficient is applied to pre-installation space heating, the results could be interpreted as the underlying impact on space heating without the effects of occupancy and supplemental fuels. Table 15 shows the results of the application of this coefficient across the various clusters.

When the effects of supplemental heat were removed, the overall billing analysis savings are comparable with the metered analysis. Net savings developed in the metering study were 3,049 kWh/yr. The heating-only savings in the billing analysis of the pilot population is 3,166 kWh/yr. Overall, there is less than 5% difference between the savings calculated here and the savings calculated in the metering analysis.

Figure 4 shows the relationship of the components of the regression results between predicted space heating savings and the savings reduction summarized in Table 16. In Figure 4, the two components of these reductions are shown separately: Supplemental Fuels, Non-Electric. For this summary, takeback is defined as the sum of the supplemental fuel coefficient. It is assumed in this calculation that the aggregate effect of occupancy, DHP placement, and supplemental fuel use on the overall savings is used to calculate the electric savings that accrue across the region. In general, these two effects are about equal, although in the eastern zones the impact of supplemental heat is generally much larger than the impact of the regression constant.

It is important to remember that these effects are the result of particular baseline conditions in the use of supplemental fuels to offset electric heating loads. Although the effect of this baseline is a large impact on the resulting savings estimates, it is also likely to be transient as particular occupants or the decisions of those occupants change over time. In areas with a large amount of supplemental fuel use, it would be reasonable to assume that these effects will be influenced by the cost and embedded labor in that fuel and the efficiency of the DHP that would displace some or all of these costs.

Figure 4. CDA Predicted Savings and Takeback (kWh)



5. Conclusions

The result of the billing analysis and savings analysis conducted on the DHP pilot project has two major implications:

1. When compared to the metered study, the estimated savings are reduced dramatically.
2. The cause of this reduction is the prevalence of wood heat and other supplemental fuels that reduce both the initial heat load of the homes in question and provide an opportunity for fuel switching away from these supplemental fuels.

5.1. Summary of Results

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 DHP pilot project evaluated in this billing analysis had approximately 3,900 participants, with installations that began in late 2008 and continued through 2009. This relatively large participant base was the basis for all the billing analysis. Approximately 93% of the homes in the pilot had bills provided by the participating utilities. A minimum of a two-year period was provided including at least a year prior to the DHP installation and a year after the installation. The total number of homes in the billing analysis exceeded 3,600, and even with fairly rigorous statistical screening criteria, more than 3,300 had reliable heating estimates for at least one year prior to DHP installation and the year after the DHP installation.

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 RBSA (Baylon et al., 2012b), which is based on a large sample from across the region. These were often wood-heated systems, but propane was 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, a 10% increase in those savings was observed when only homes with reasonable regression fit were included. When this same group is screened for supplemental fuels, as identified in the customer intake interview done at the installation of the DHP, the savings estimates increased 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 10% higher than the savings observed here. Given the accuracy of the VBDD process, that would appear to be substantial agreement between the two samples.

5.2. Determinants of Savings

The analysis presented in this report used a CDA regression specification to quantify the impacts of supplemental fuels and other effects on the observed savings. A CDA specification was developed for the entire pilot population. The regression sought to predict the impact of the supplemental fuels and the effects of other factors (taken as a constant in the regression equation) on the overall savings observed in the pilot project. The same CDA specification was used on both the overall pilot project and the individual climate sub-populations.

In this analysis, the effects of supplemental fuels on the overall space heating savings were about 1,200 kWh/yr on average per home with supplemental fuels. This amount represented more than one-third of all the savings observed in the remaining homes where no supplemental fuels were mentioned. Although the ability to understand occupant behavior, especially thermostat and occupancy patterns, is impossible compared to the detailed metering study, it is apparent that savings were reduced a certain amount by combinations of occupant takeback from thermostat setting and occupancy shifts that were coincident with the installation of the DHP. It is difficult to quantify those effects; however, the CDA regression equation suggested that on average about 500 kWh/yr of savings (across all participants) were the result of some combination of these effects.

The effect of climate was important in the overall savings in the pilot project. To evaluate climate, the region was divided effectively into three categories:

1. The main group consisted of the participants located in the climates of western Washington and western Oregon, including the coastal zones.
2. The second group was located in the eastern climates of Washington and Idaho, including both Climate Zone 2 and 3 under the NPCC definition.
3. The final group consisted of the participants located in western Montana. This locality was analyzed as a separate climate because the saturation of supplemental fuels was almost double the saturation in the rest of the sample.

When these three climate zones are taken into account, the savings estimates on net of all the supplemental fuel and other occupant effects were almost double the savings of a fraction of electric space heating load in the western climates over the eastern climates. There are several reasons why this might have occurred. The primary reason was that there were relatively few, if any, distinctions in capacity and distribution systems between the relatively cold eastern climates and the relatively warmer western climates. Given the displacement strategy used in the DHP project design, the strategy had a higher savings fraction in the milder western climates than in the eastern climates. Nevertheless, the overall savings associated in these two climates differed by 25%, and when the individual units were metered, there was very little difference in overall heat production. With the impact of supplemental fuels, the climate effect in this analysis regarding similarity in overall heat production is partly masked by the interaction with supplemental fuels.

Using the results of the CDA regression fits, the net savings from the individual homes could be estimated, taking into account the impacts of supplemental fuels and other direct effects. When this is done, the savings estimates for the DHP pilot project overall was estimated at about 3,100 kWh/yr. The savings from the western climates taken alone were approximately 3,300 kWh/yr, and for the eastern climates approximately 2,000 kWh/yr.

5.3. Comparison to the Metering Sample

After accounting for the impact of supplemental fuels, the results of the pilot project and the metered study converge. The supplemental fuels reduce electric savings by at least 30%; however, once this factor is taken into account, the savings differ by approximately 10% between the metered analysis and the overall estimates for the full pilot project. Moreover, there is evidence that had parameters such as temperature and occupancy patterns (that were available in the metered sample) been available for the billing analysis, a better agreement between the two groups would have been observed.

When the underlying impact of the DHP on space heating only is taken into account, the difference between the billing analysis conducted in the metering evaluation and the billing analysis conducted in the overall pilot project, the two studies come to substantially the same conclusion: the impact of the DHP installation (using the constraints of the displacement model) resulted in approximately 48% savings in space heating use in the western climates and 23% savings in the eastern climates.

The principal difference between the billing analysis conducted for this report and the billing analysis conducted for the metering report is the difference between the apparent *net* savings from the billing analysis and the *total* savings observed when the detailed operation of the DHP can be taken into account. This was, of course, possible in the metered study and is impossible in this broader context with only a billing analysis. In the metered study, this factor resulted in an approximate 20% increase between the net savings observed from the billing analysis and the total savings observed from the operation of the DHP. It is likely that the conditions that warrant this increase in savings also exist in the larger pilot population, and a similar adjustment could be applied. Overall, it would appear that more detailed understanding of the distinction between the total savings observed in the metering study and the savings derived from the billing analysis should be more clearly understood. This is a topic for future research.

Finally, the billing analysis for the overall pilot project is fairly conclusive on two 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 to 40%. 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 region, 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.

6. References

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Technical Memo

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Ductless Heat Pump Billing Analysis Bias Assessment

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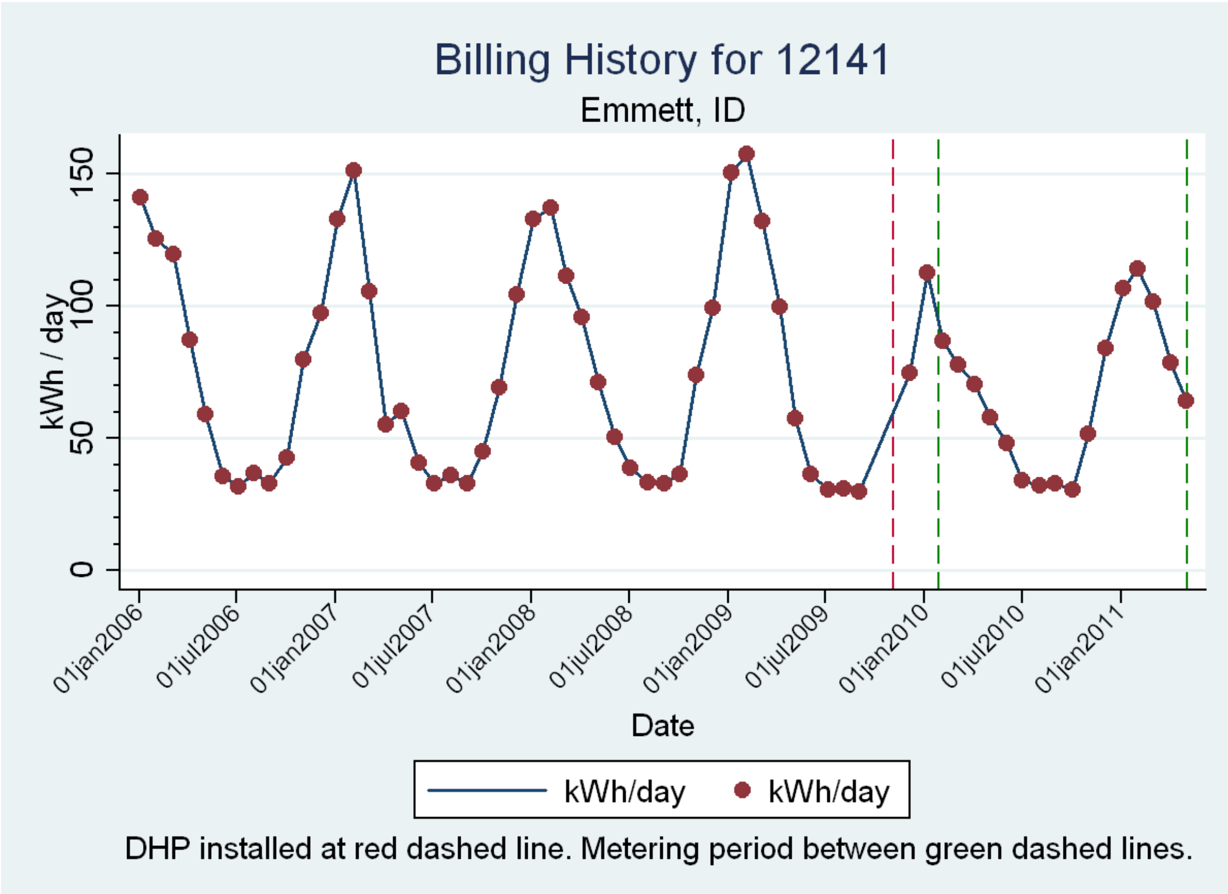
List of Figures

Ecotope conducted an assessment of potential bias in variable-base degree day (VBDD) billing analysis techniques using 95 sites submetered for heating in NEEA's ductless heat pump (DHP) pilot project evaluation. For purposes of this work, "bias" is defined as systematic over- or under-prediction of house heating energy. Data loggers in 95 houses directly recorded the heating and that record is taken to be the truth set. Utility bills provide the information source for VBDD analysis and consequently the heating energy estimates. These estimates are compared to the measured space heating from the metered record. The analysis results show that although VBDD analysis provides a highly variable estimate of heating energy in the population, we found, on average, no significant bias in this set of 95 houses.

Variable-base degree day methods are a means to predict space heating energy use from a house's utility bills and a nearby record of outdoor temperature. The method assumes heating energy increases linearly with decreasing outdoor temperature. The measure of outdoor temperature comes from a nearby weather station which has recorded daily temperature maximums and minimums over the billing period. The daily temperature is defined as the average of the maximum and minimum temperature for that day; the monthly temperature is defined as the average of the daily temperatures. Billing data generally reflects monthly time segments. For a given climate in the northwest, the number of months where heating is actually used could be as little as four and as much as nine. VBDD works best with more months in heating and more years over which bills are available.

This project compared bills and submetered data collected over a one to two year time frame. The submeters, installed at the electric panel, logged energy use at five minute intervals on all 240V electric resistance heat in the house and the DHP. The bills report the total electric use of the house over a month period. All houses were primarily heated with electricity. None of the houses used natural gas. Figure 1 shows an example billing history. The figure shows, with a red dashed line, the date of the DHP installation. In between the green dashed lines, is the submetered period. It is for the billing data and submetered data in this period that we performed the bias assessment. Note that not all sites clearly show such a distinct heating season peak and a lower peak post DHP installation.

Figure 1. Example Billing History



As a quality control check, the onsite data logging recorded the total house electric use, also known as the service drop. This is the same wire as the one the utility billing meter uses. Therefore, when aggregated over the same time interval, they should agree. Figure 2 shows good agreement. Figure 3 shows a discrepancy between the submeters and the utility reported use. This is not atypical. The utility bills have the correct shape but, in this case, show more usage than measured at the site. One possible explanation is "estimated" vs. "actual" meter reads followed by corrections. Still, it is not entirely clear why most of these discrepancies exist. The discrepancies have real consequences in the VBDD estimation. In the Figure 3 example, the bills indicate a higher peak than the actual usage which will lead VBDD estimates to over predict the heating dependence on decreasing outdoor temperature. Other bill patterns can demonstrate opposite effects. Despite potentially suspect billing data in some cases, this group of 95 sites generally had well-behaved bills because the participants were screened based on a clear heating signature in the VBDD analysis of the pre-installation bills.

Figure 2. Example Comparison of Whole House Meters to Bills – Good Agreement.

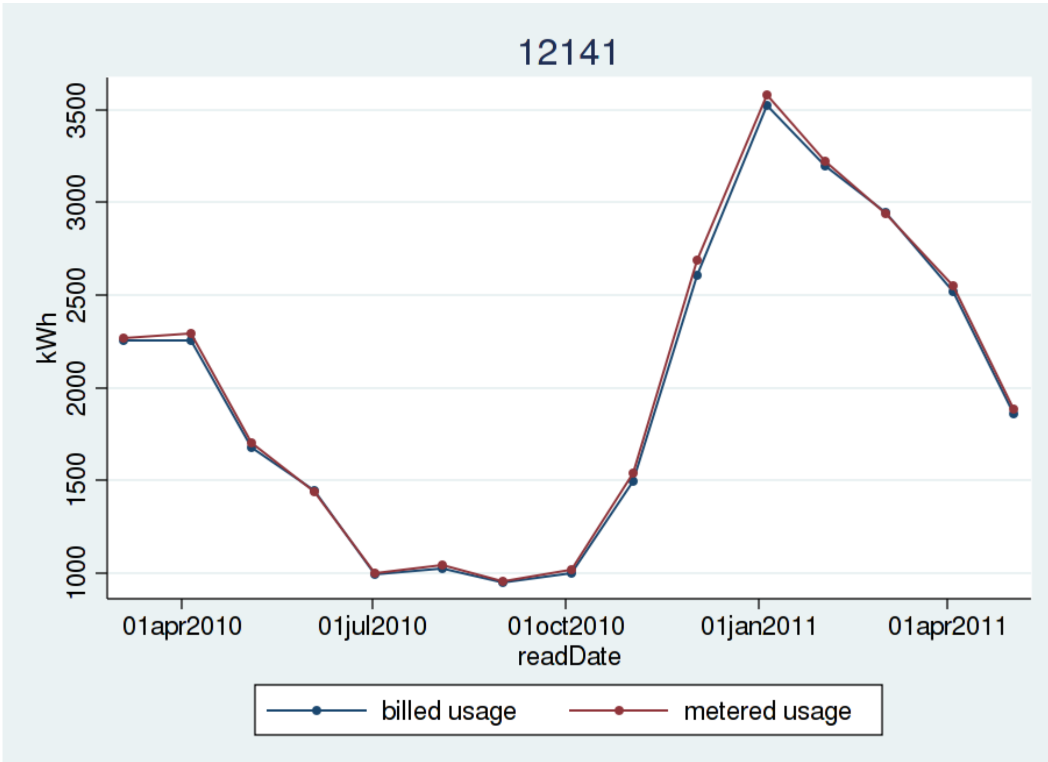
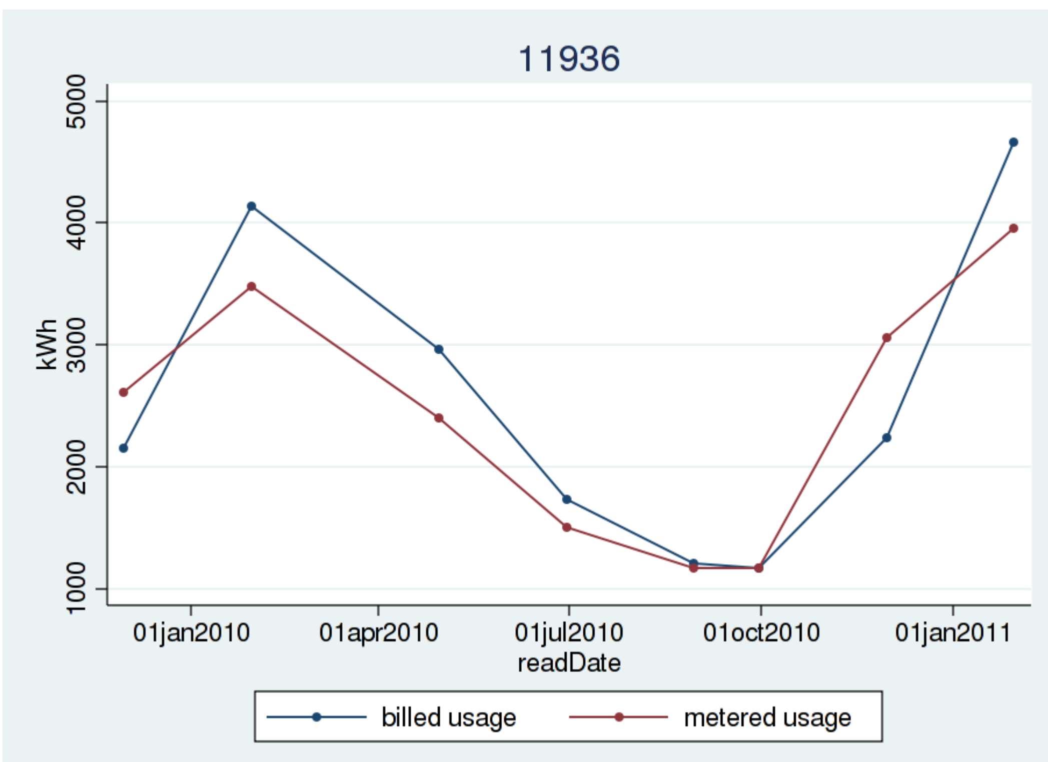


Figure 3. Example Comparison of Whole House Meters to Bills – Poor Agreement.



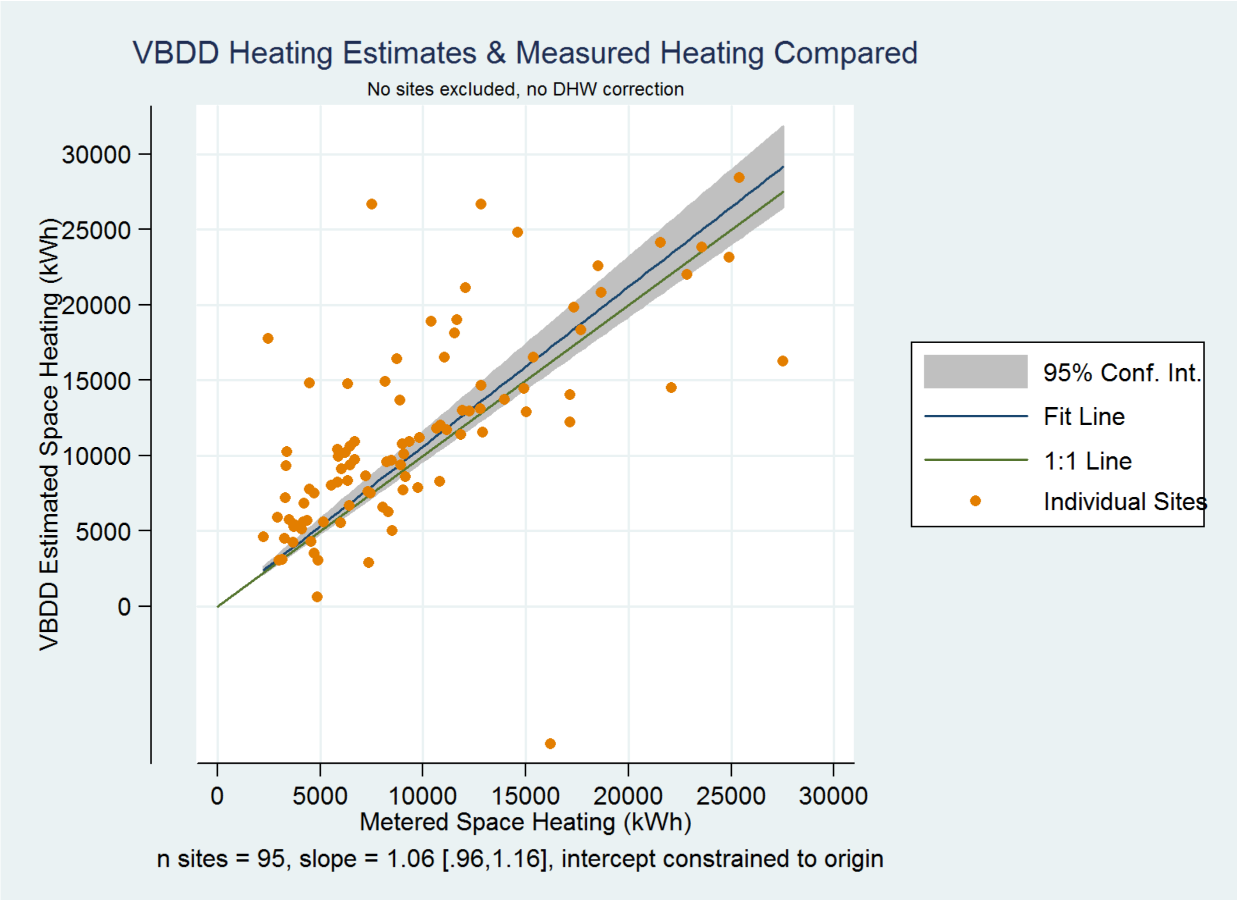
The philosophy used to guide the bias assessment was to conduct a VBDD analysis with as little data manipulation as possible and compare it to the best measurements of metered space heating. In doing so, we chose to exclude sites for several reasons as follows:

- In several cases the billing data went to zero or some implausibly low number during the period. Those four sites were excluded from the analysis.
- On the data logging side, occasionally the DHP or ER channels would not report data. Since we are comparing total metered heating, any missing data over the time period would under-report actual use. Therefore, we excluded six sites where the DHP or ER data was missing greater than 0.1% of the time.
- The last category for excluding sites was due to suspected, non-metered electric heat. Our data loggers monitored only the 240V loads at the circuit panel. Any use of plug-in 120V heaters was missed. This can lead to an under-count of electric heating use. To account for the possibility, we examined the residual metered load (total service - DHW - DHP - ER) for a dependence on outside temperature. We chose to exclude seven sites because the residual load showed a much stronger dependence (greater than one standard deviation above the mean) than most sites.

This next section presents the graphical results of comparing the VBDD estimated heating to the metered heating. All comparisons are done using the total metered heat and total estimated heat over the time period. The time periods ranged from 14 to 24 months depending on site. Consequently, the energy use totals are not in terms of annual heating use but rather total heating use over the number of months involved. We present the results this way, instead of annualizing, to avoid unnecessary manipulation of the data. Figure 4 shows the VBDD heating estimates versus metered heating for all 95 sites. The figure includes a number of suspect data points which make a true bias assessment problematic. For example, one site shows a negative VBDD heating estimate while several others show estimates near zero. We later exclude those sites from further analysis.

In Figure 4, and all subsequent comparison graphs, we can visually examine the ratio of VBDD estimated heating to measured (or metered) heating. The ratio is displayed on the bottom of the graph as the slope corresponding to the blue line; with the numbers in brackets "[#,#]" corresponding to the 95% confidence interval of the slope. The 1:1 line, indicating no bias in the ratio, is plotted as the green line. The gray area on the graph shows the 95% confidence interval around the blue line.

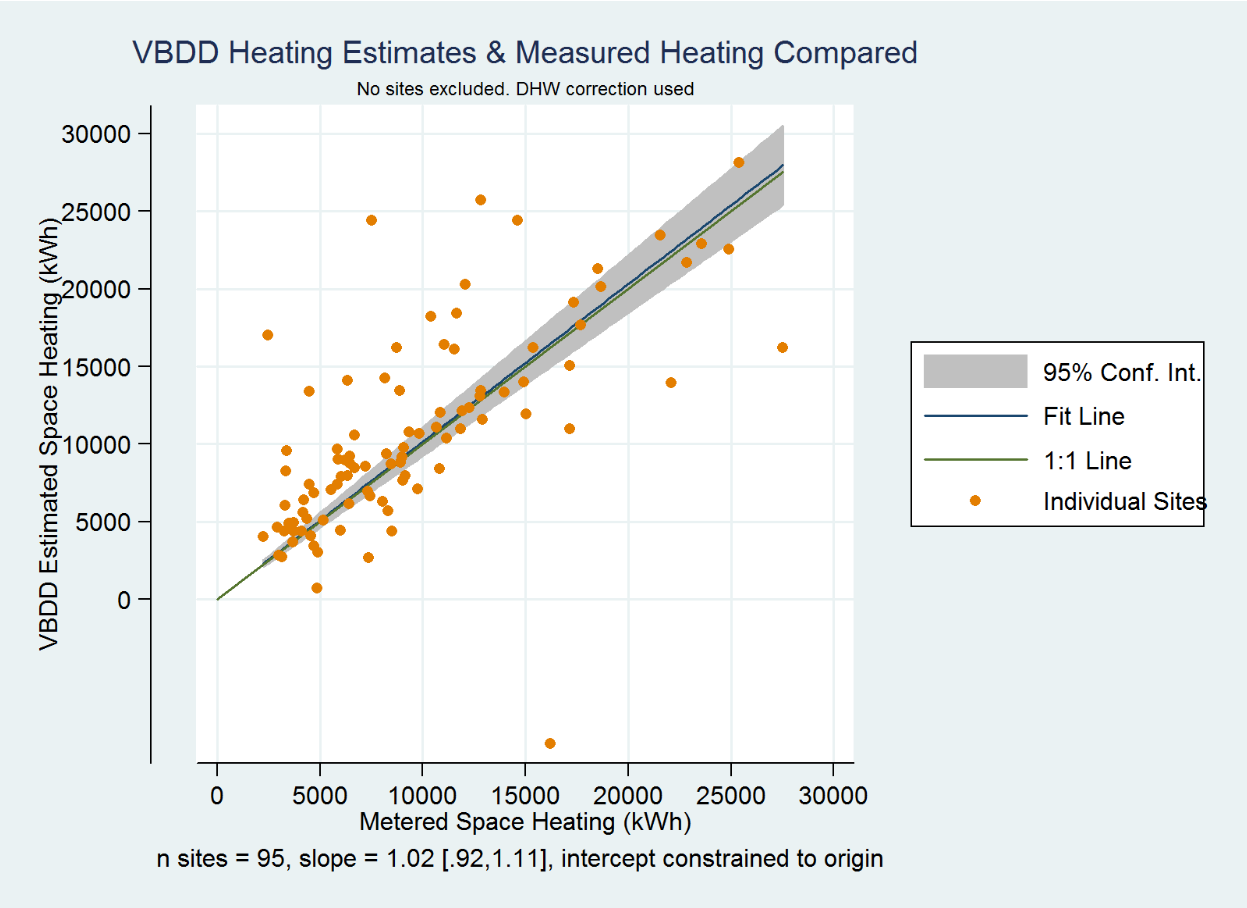
Figure 4. VBDD Heating Estimates vs Metered Heating – All Sites



Any energy end use which has a correlation with outdoor temperature will influence the VBDD heating estimate. The biggest, non-heating end use is water heating (DHW). Other such end uses include lighting and some appliances like refrigerators. All of those will tend to inflate the VBDD heating estimate, although the seasonal impacts of these uses are quite small by comparison to the heating and DHW uses. In the study, we metered DHW use onsite so we have a direct measure of its seasonal variation. Using this information, we can correct the VBDD estimate's over prediction of heating energy use. To do so, we collapse DHW use into billing months and run a VBDD estimate against that data. This produces a number which describes the temperature dependence of the hot water load in the same form as the heating estimates (kWh/HDD). The next step is to subtract the DHW slope from the initial estimate of VBDD heating slope. Although such a step can never be done in a billing analysis study alone, we need to do it here because Ecotope-installed meters specifically monitored heating only. Without such a correction, VBDD estimates would always appear to overestimate metered heating. While the correction could be applied to the metered data, we elected to apply it to the billing-based VBDD estimate and leave the metered data as the unaltered truth set.

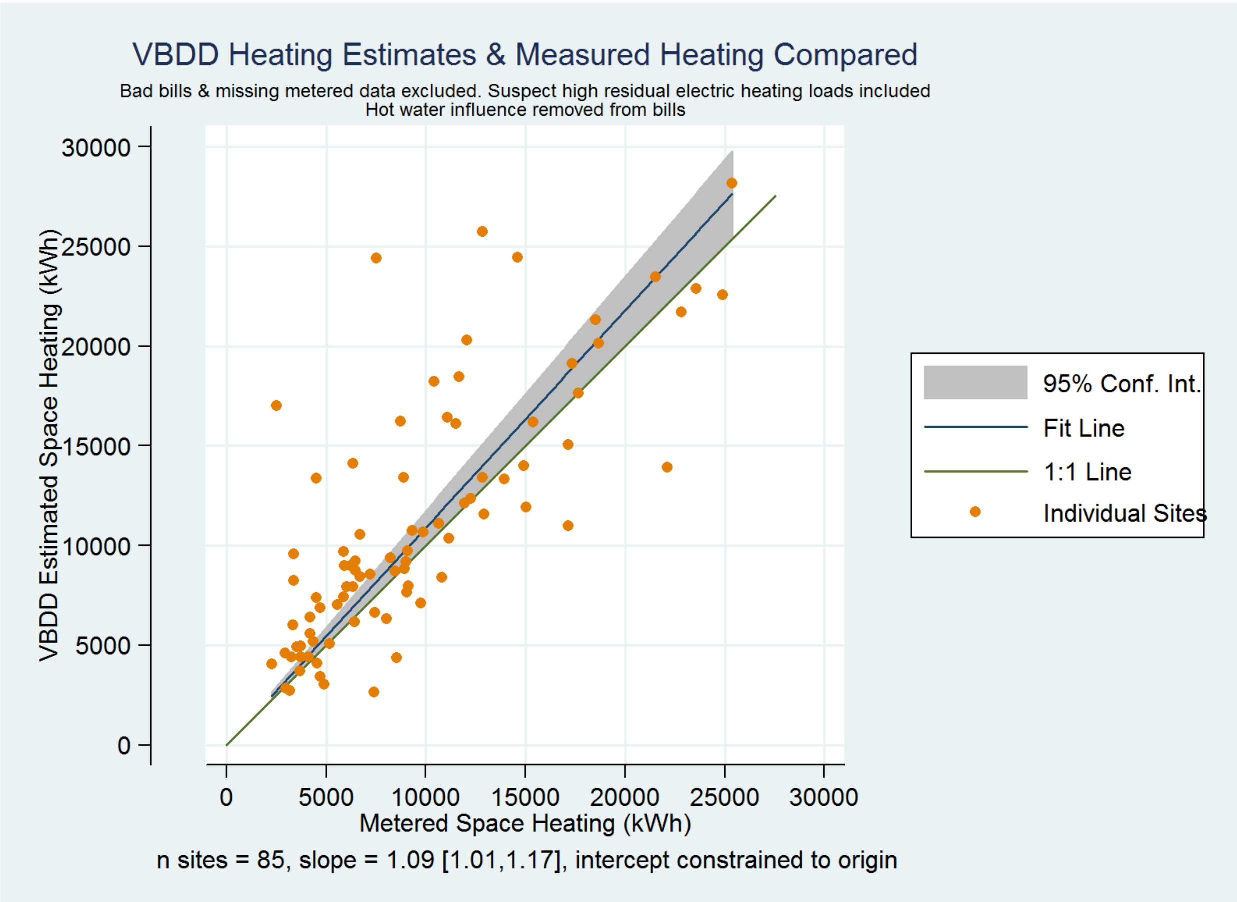
The DHW correction as applied to the data in Figure 5 reduces the slope.

Figure 5. VBDD Heat Estimates vs. Metered Heating – All Sites with DHW Correction



The next analytical step was to exclude the sites with suspect billing data and with significant amounts of missing metered data. As mentioned previously, in several cases the monthly billing data went to zero or some implausibly low number during the period (those four sites were excluded from the analysis). In all, missing metered data and suspect bills accounted for ten sites and the results are shown in Figure 6. The result is an improved data set but a larger discrepancy between the VBDD estimates and the metered space heat.

Figure 6. VBDD Heat Estimates vs. Metered Heating – Bad Bills and Missing Meters Excluded with DHW Correction



The last step taken to arrive at the best estimate comparison involved excluding metered sites due to suspect residual heating. The meters only monitored 240V heating circuits at the electrical panel. If the house occupants used plug-in 120V heating sources, the meters did not measure it and the resulting metered total electric use would be low. To account for the possibility, we performed a VBDD analysis on the residual metered load in the house looking for significant outdoor temperature dependence. In seven cases, we found the relationship to be large enough to indicate a space heat contribution that was not captured by our metering system. Those sites were flagged and excluded. Figure 7 presents the best estimate comparing VBDD estimated heating energy and metered heating energy.

Figure 7. VBDD Heat Estimates vs. Metered Heating – Bad Bills, Missing Meters, and Residual Heating Loads Excluded with DHW Correction

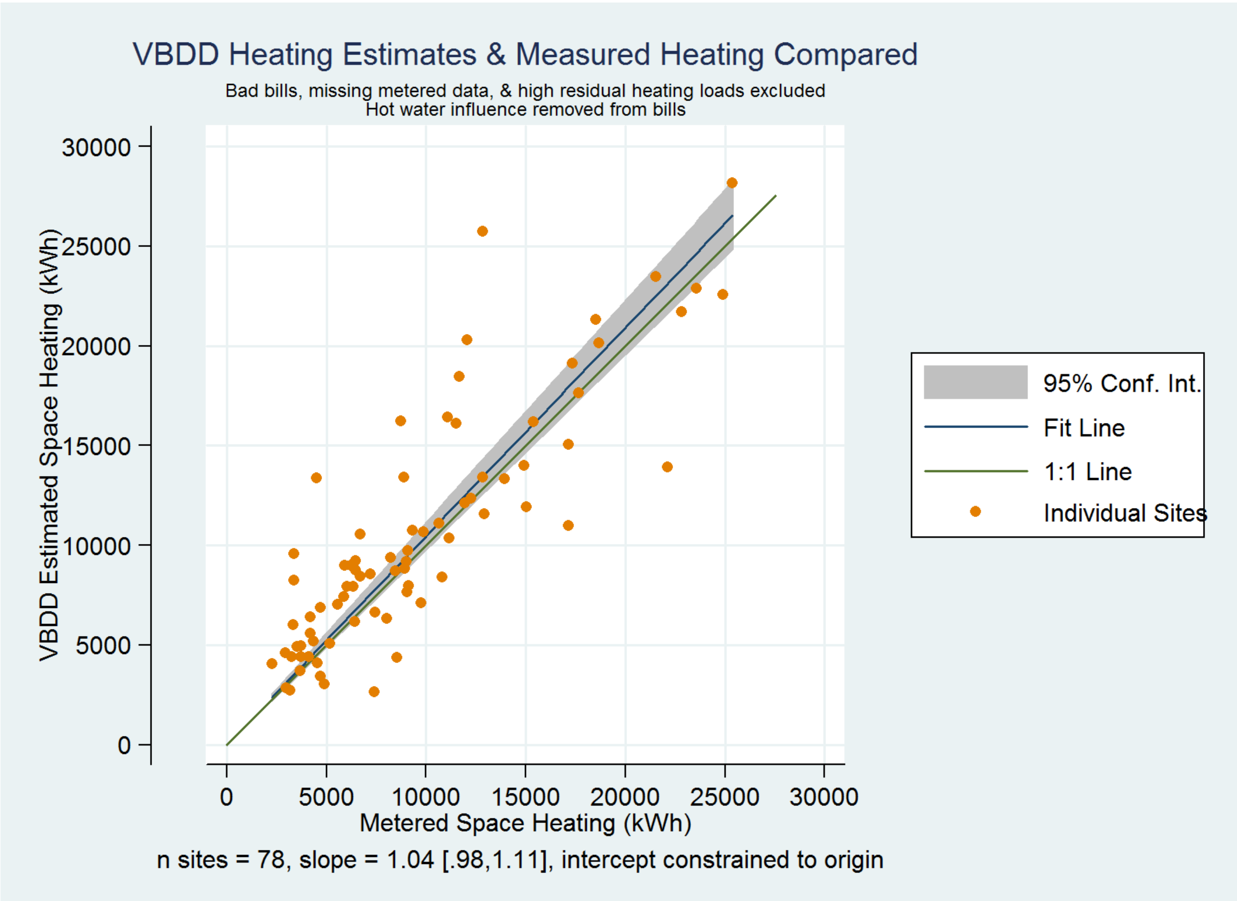


Figure 7 clearly shows there is no significant bias in the VBDD space heating estimates compared to the directly metered space heating. The ratio of VBDD to metered estimates is slightly higher than one but the 95% confidence interval spans the 1:1 line demonstrating there is no discernible difference in slope. That VBDD estimates are potentially somewhat high could be due to several reasons.

Some of the discrepancy between the metered space heat and the VBDD estimates could be the result of two known factors that were not measured:

1. The VBDD estimates are subject to all temperature correlated end uses. The hot water influence was removed but the remaining influences of lighting and/or appliances could force the VBDD estimate slightly high.
2. Although we metered the largest heating devices in the house and excluded those sites with suspect plug-in heaters, there still remains the chance of non-metered electric space heating. In our best estimate, taking all of these into account might reduce the slope more but it will not move the 95% confidence interval beyond the 1:1 line.

All of the graphs show that overall the VBDD estimate of space heat is generally highly variable and scattered. Although such an outcome is undesirable from any procedure, on average, the estimates appear to be unbiased. Consequently, the analysis shows that a VBDD assessment should be used with caution on a single house or a small group of houses. It works best on a large set of houses where the variations can be averaged to a more reasonable estimate. In the end, despite the fact that VBDD analysis provides a highly variable estimate of heating energy in the population, we found, on average, no significant bias in this set of houses.