Evaluation of a Large-Scale Ductless Heat Pump Program

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ABSTRACT

Over 2 million single and multifamily homes in the Pacific Northwest use electric resistance heat as their primary heating system (NWPCC 2010). A large scale utility incentive pilot program underwritten by the Bonneville Power Administration and operated by the Northwest Energy Efficiency alliance (NEEA) has resulted in the installation of over 5,000 ductless minisplit heat pumps, and the region's utilities and policy makers are eager to know the conservation impacts. Heating loads in the Pacific Northwest range from about 5,000 to 15,000 kWh/year for electric resistance-heated homes, and cooling loads are typically less than 500 kWh/year in most parts of the region. The pilot program was designed to encourage installation of a single ductless heat pump indoor unit and the evaluation focuses on how much of the home's electric resistance heating can be offset with the ductless heat pump. The evaluation also reports on results of minisplit heat pump lab testing and field testing in very cold weather conditions.

Introduction

The Northwest Energy Efficiency Alliance has supported a comprehensive evaluation of a residential ductless minisplit heat pump program, including both impact and process elements, since October, 2008. The evaluation includes field instrumentation (95 sites), utility bill analysis (about 3,500 records; these results will be available in summer, 2011), laboratory bench testing of minisplits from two manufacturers, and progressive interviews with homeowners, installers, and manufacturers. This paper will, present results from fieldwork, and bench testing, discuss the importance of checking data streams, describe notable findings about the pilot program's demographics, and summarize homeowner, installer, and manufacturer responses to the incentive programs.
Of particular importance in each element of the evaluation:

- Lessons learned from field instrumentation, including how to check multiple data streams in an automated fashion
- Presentation of preliminary savings results, including discussion of the variable-base degree day approach used for evaluating pre-ductless heat pump heating usage
- Brief comparison of field and bench-testing data and summary of system performance in very cold weather
- Discussion of homeowner acceptance of the technology
- Discussion of the installer's perspective, including challenges in marketing the product

Technology Description

Beginning in the late 1970s, Mitsubishi and other manufacturers introduced into the Asian market a single zone, ductless minisplit heat pump designed mostly for cooling needs and developed for the high density housing developments. This technology has been further developed using variable speed technologies and advanced individual controls. These products have been available to the American market but have been used in limited applications with a small overall market niche.

Until recently, the efficiency and effectiveness of the product was based on its ability to provide zonal cooling and, where appropriate, zonal heating and as a result it was used mostly in commercial applications where space conditioning requirements could not easily be served by a central AC system. Small equipment rooms and media display rooms often use this technology.

In 2006, federal standards for heat pump and air conditioners required minimum performance of HSPF 7.7 and SEER 13. No ARI-approved testing procedure had been developed for minisplit systems so their reported HSPF and SEER values were a subject of controversy. There was a brief exemption for this product until an ARI process could be developed; some manufacturers are now listing approved HSPF and SEER values.

The current technology is based on a set of relatively small compressors that range in size from approximately ¾ - 3 tons nominal capacity (1 ton = 12, 000 Btu/hr heating or cooling capacity at a specified ambient temperature). The smaller capacity units (1 or 1.5 tons, which make up the bulk of systems in this evaluation, utilize a single air handler that is wall-mounted and delivers heating and cooling into a single heating zone. In the larger sizes the compressor can handle up to three separate air handlers in three separate heating zones. In general the ¾ - 1 ton units can only handle a single air handler and a single zone while the larger sizes of 1 ½ - 3 tons can manage two or more air handlers.

The installation of this equipment requires a main electrical hookup for the main outdoor unit that typically provides a variable speed compressor that is connected to the indoor unit by a cable of control wire and refrigerant piping. The installation is fairly standardized within twenty to thirty feet of the compressor and there is direct interactive control between the compressor and the air handler. The air handler is, in most cases, connected to a 220 volt circuit in the house and controlled using the same control setting sequence that runs the compressor. The controls are designed around a remote control sensor that signals the compressor. These controllers use pre-programmed algorithms that then select the compressor and air handler speeds to deliver the requested temperatures. This process provides the occupant with a more interactive control than is typical in a standard residential thermostat. It also provides a wider variety of options for combinations of air handler speed and compressor speed to deliver on a particular temperature request.

Field Measurement Objectives and Results

The measurement design had four goals:

1. Measure heating system energy use once the minisplit is installed. This was accomplished by metering the minisplit and separately metering all the resistance loads in the zone electric heating system that was displaced (but not removed).
2. Meter the domestic hot water (DHW) electricity usage to help establish regional planning assumption based on sub metering done in the early 1990s but not repeated. About 55% of homes in the Pacific Northwest use electricity to heat domestic hot water.
3. Meter the total electric energy usage of the home by metering the service drop for the whole house. This has the effect of giving a sum check on the other meters and (with subtraction) characterizes the combined miscellaneous electric loads (refrigeration, lighting, plug loads) in the home. Like the DHW, this load was sub-metered in the early 1990s and no similar data set had been accumulated since.
4. Measure *in situ* Coefficient of Performance for about one-third of sites. This goal was difficult to achieve given the ductless design, but a method was devised to determine real-time airflow (so that thermal output could be determined). Thermal output divided by electricity input (in equivalent units) equals COP. Direct COP evaluation allows a direct calculation of offset in

electric resistance heating and also facilitates comparison with manufacturer-supplied ratings and controlled laboratory test data (also collected as part of this evaluation).

Field Instrumentation and Error Checking

To reliably measure whole-house electricity usage, hot water usage, and heating usage (including minsplit) over a year's time, the metering equipment needed to be well-designed, durable, and weather-resistant. The hardware selected included industry-standard current transformers, wired thermistors, watt transducers, and pulse counters. Details for two of the instruments used in the project are found in the references (Continental Control Systems 2008, Onset Computer Corporation 2008). The equipment was designed to be installed outdoors, if needed. Data were sampled every five seconds and compiled into five-minute averages. Storage was made into a solid-state data logger equipped with internal Global System for Mobile communications (GSM) type communication technology. Data were uploaded automatically every six hours to a web-based server. From this point, data were screened for anomalous readings through a custom automated process. More details can be found in Davis and Geraghty (2010).

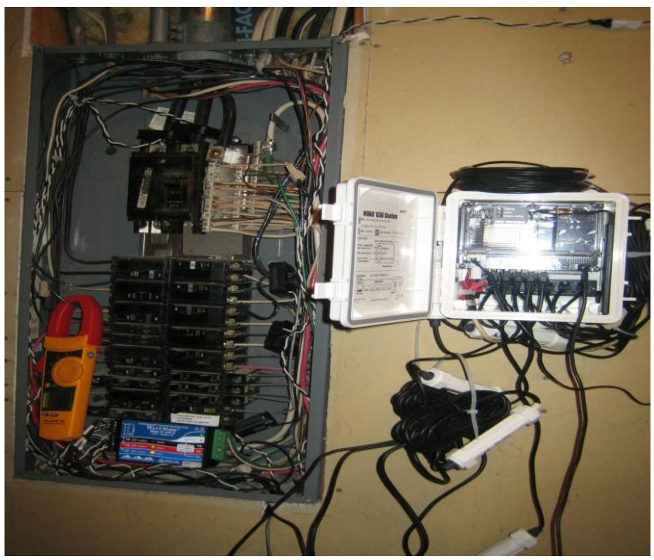

Figure 1: Site Metering Installation

From the perspective of a year-to-several-years-long data gathering effort such as the one discussed in this paper, the principal advantage of near real-time data retrieval – as opposed to long-term accumulation onsite and one-time retrieval – is to provide an early-warning system for data production or quality problems, so that timely corrections or repairs can be made. With nearly 100 sites in the field producing data at a rate of roughly 300,000 data points/day, this early warning system needed to be highly automated in order not to overwhelm human monitors. As of early March, 2011, our estimate of the percentage of unrecoverable data in this study is about 2%.

The data logging vendor offered two interfaces for clients to gather and interact with site data remotely once it had been delivered to the web-served data warehouse: first, a website interface, and, second, a "web services" interface where Ecotope's computers could directly retrieve data from the data warehouse using the Simple Object Access Protocol (SOAP) internet web services protocol (Onset Computer Corporation 2009).

Ecotope invested in the latter method – automatic SOAP calls using in-house client routines – because it was the most automated method of delivering site data to our local repository. For timely data-monitoring purposes we did not, and do not, believe that the website point-and-click interface scales adequately beyond more than a handful of sites.

The system we established automatically retrieved all new site data from the warehouse once a day via command-driven batch files, and subjects it to range and sum checks. Because one of our site monitoring channels is total service power consumption, we were able to compare service consumption against the sum of sub metered power consumption channels (usually electric resistance, domestic hot water, and ductless heat pump). The difference between the service load and the sum of these sub metered loads, constituting lighting, kitchen appliances, and plug loads, should of course never be negative. In practice this summing constraint proved to be one of the most useful ways of detecting data quality problems. Temperature readings (also five-minute averages) were also checked for reasonableness, and the heat pump vapor line temperature used to determine the operational mode of the equipment (heating or cooling).

We check each batch of new data for the expected time gap between successive observations (five minutes or one minute, depending on the site). We also take the opportunity to check the timeliness of the most recent data obtained in our retrieval request. Given that the site loggers call to transfer accumulated data to the warehouse every six hours, a "most recent time" significantly in excess of six hours indicates trouble. The daily retrieval and data-checking process currently takes about two hours to run each night.

In its current tuned state, the system works well as an early-warning system which alerts us only to problems important enough to pay attention to (such as faulty energy usage measurements, disconnected/damaged temperature sensors, or minisplit operation problems), but stays silent on negligible data problems. The key to the daily and detailed error checking is the use of custom programming that is part of exploratory data-analysis software. This approach allows construction of targeted programs which can quickly comb through hundreds of thousands of data points per day and produce automated, compact text files which are e-mailed to the field monitoring program manager each morning. The contents of the text files indicate the condition of each of the 95 sites and flag problems.

The only compelling reason for frequent automated data retrieval is timely data-quality monitoring. It is therefore ironic that the selected vendor's data-retrieval system has proven to be the source of some data quality problems. We cannot say how many of these problems would be remedied by a different implementation of this technology – to date we have only used one data logging system – but there is an inherent complexity to the process which may make the data-retrieval system more fragile and failure-prone than a simpler alternative of long-term onsite accumulation. Although an occasional failed upload call is not a problem given the loggers´ data storage capacity, site loggers intermittently unable to call in may deteriorate into states in which they neither respond to remote commands nor record data; in such a situation a site visit offers the only hope of putting the logger back to work. In addition there has been at least one episode of widespread synchronous call-in failure in which the GSM vendor was apparently the source of the problem.

Far more of our data problems originate with the data loggers themselves rather than the data transfer mechanism. Data loggers are temperamental and not straightforward to install and configure correctly. Timely data retrieval and scrutiny is essential in detecting and attending to subtle configuration problems, and logger-originated data quality issues, such as data corrupted by electromagnetic interference, cannot be mitigated in all cases.

Empirically, a fairly high percentage of critical problems at a typical site surface, and are resolved, within the first week or so. This occurs despite the care taken onsite to check that sensors are configured and recording properly. A site can have problematic GSM phone communication despite an apparently strong signal onsite; sensor serial numbers (typically nine digits) can be recorded incorrectly so that incoming data streams cannot be automatically matched to known characteristics data. Data-averaging intervals can be set incorrectly so that what is supposedly an average amperage value over five minutes is in fact the last recorded instantaneous value in a five-minute period. The data loggers have a web-based remote management interface which permits the resolution of some problems without repeated site visits, e.g., mistaken data averaging intervals. At regularly scheduled data upload intervals there is a window of opportunity to send configuration instructions to the data logger, and with reasonable luck these are in fact executed. In addition, problems which are essentially ones of interpretation (incorrect sensor serial number, incorrect pulse count multiplier applied to power consumption data) can also be corrected remotely. But there remain certain problems that can only be addressed with site visits. The following table summarizes important site interventions.

Table 1. Site Interventions

Total sites	95
Data logger replaced	8
Other critical interventions requiring a site visit	3
Important configuration issues resolved using remote interface	7
Other critical first-week data quality issues cleared up without site visit	6
Site visits to fix signal interference problems (desirable, not essential (in most cases))	23

Savings Analysis

For the post–installation period, the submetered data are used directly to assess the effect of the minisplit on heating (and cooling) energy usage (although cooling loads are so modest at most sites that there is a limited influence on annual electricity usage in most cases). No submetering was installed for the pre-minisplit period, so utility billing analysis was used to disaggregate space conditioning usage from the total bill.

We regressed billing period consumption on billing period degree-days using a slight modification of the standard variable-base degree day method pioneered by Fels (1986). Under the Fels PRISM method, also known as variable-based degree-day (VBDD) regression, the heating degree-day base and the regression response coefficient of energy consumption to degree-days are jointly estimated by finding the heating degree-day base which maximizes R^2, the regression coefficient of determination. Using R^2 as a criterion effectively maximizes the proportion of total variation in consumption explained by a linear response to heating degree-days. In a single zone structure (like a manufactured house) heated with an electric resistance furnace and a seasonally unvarying baseload, the linear coefficient has the interpretation of house heat loss rate and the regression intercept has the interpretation as a seasonally constant average baseload.

The degree-day base estimated by this procedure has an interpretation as the house balance point. Balance point is not thermostat set point, but rather is the lowest outside temperature at which the set point temperature can be maintained without space heating—where house internal and solar gains precisely match heat loss. Except in the special and implausible case where house internal and solar gains are zero, balance point is lower than thermostat set point. Although 65º F is a plausible thermostat set point, it is not a reasonable balance point for the vast majority of houses. Varying solar gains and thermostat set point changes have the effect of changing the balance point, so that the actual heating input data (the bills) in fact reflect some random mix of effects of heating degree days to different bases.

The “Ecotope modification” to the Fels PRISM procedure involves excluding data points from a regression estimation where the billing interval’s heating degree-days (HDD) to that base are zero (Geraghty et al. 2009). Empirically, this serves to insulate the estimated HDD slope coefficient and constant from the influence of summertime cooling loads, which certainly exist for some of our sites.

Given a variable-base heating degree day (VBDD) fitted regression coefficient and estimated balance point, a straightforward estimate of heating load for a given month is the product of the regression coefficient with HDD to that balance point base for that month. An accompanying estimate of annual non-heating related base load is simply the fitted regression constant times 12 months. A problem with this simplest of approaches is that it is well established from sub-metered data that non-space-heat load components do have seasonal variation, notably electric light (with length of day) and hot water heat (with seasonally varying intake water temperature), and without adjustment these seasonally varying base load components are imputed to heating load. An adjustment method first proposed by Fels et al (1986) is to fit a cosine function using the regression constant. Following the Fels approach, we adjust our heating estimate using a trigonometric function of the estimated regression "base load" constant α as follows:

$$\text{Heat for month } m = Max(\beta \cdot HDD - \alpha \cdot (.1 + .1 \cdot \cos(2\pi m / 12)), 0)$$

Where β is the estimated regression slope coefficient, *HDD* is calculated heating degree days for month *m* to the chosen base, and α is the estimated regression constant. In effect, some of the seasonally varying load is taken away from the heating estimate $\beta \cdot HDD$ and given to the base load estimate α.

Given estimated coefficients, the above formula can be used to predict heat consumption given a new set of HDD data—not the HDD data which were used in the actual coefficient estimation. This is how we derive our estimates of the heating consumption which would have occurred in the "post" period had the old heating system not been replaced by a minisplit. The parameters estimated in the "pre" period are applied to the "post" period's HDD in the above formula. Although external temperature is one of our post-installation submetered data streams, and could optionally be used as a basis for post-installation period HDD calculation, we chose to continue with the same cooperative weather station temperature data stream that was used to estimate the "pre" billing data regressions. Figure 2 shows the process applied to a well-behaved site (note "DHP" means "ductless heat pump" in figure title/legend):

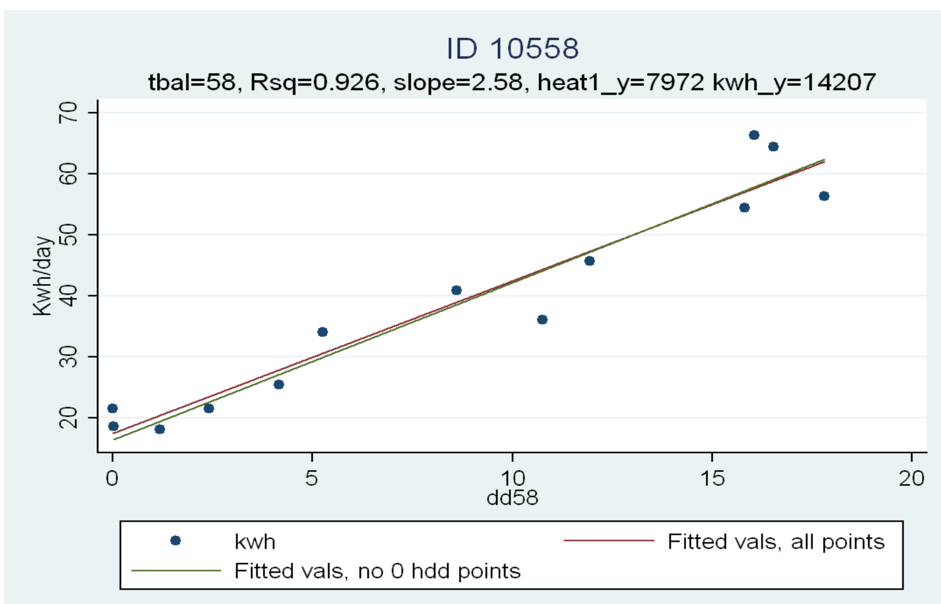

Figure 2. Typical Pre-DHP Installation VBDD Regression

The VBDD method was also used to screen potential sites for inclusion in the study. Because of the widespread use of wood for space heating, especially in rural areas, it was desirable to <u>exclude</u> these sites from this study. (Otherwise, a true estimate of actual electric resistance heat offset would not be obtained.) Once bills were obtained for prospective sites, they could be screened relatively quickly using a batch-run version of the VBDD procedure.

Graphical display of results shows considerable range. For many sites, the weather-adjusted reduction in electric resistance heating usage is significant. Figure 3 shows a site located in the Puget Sound where reduction in heating usage is almost 50%. This level of savings was not unusual in this region, or in the Willamette Region, where average savings were between 40 and 50% (Table 2).

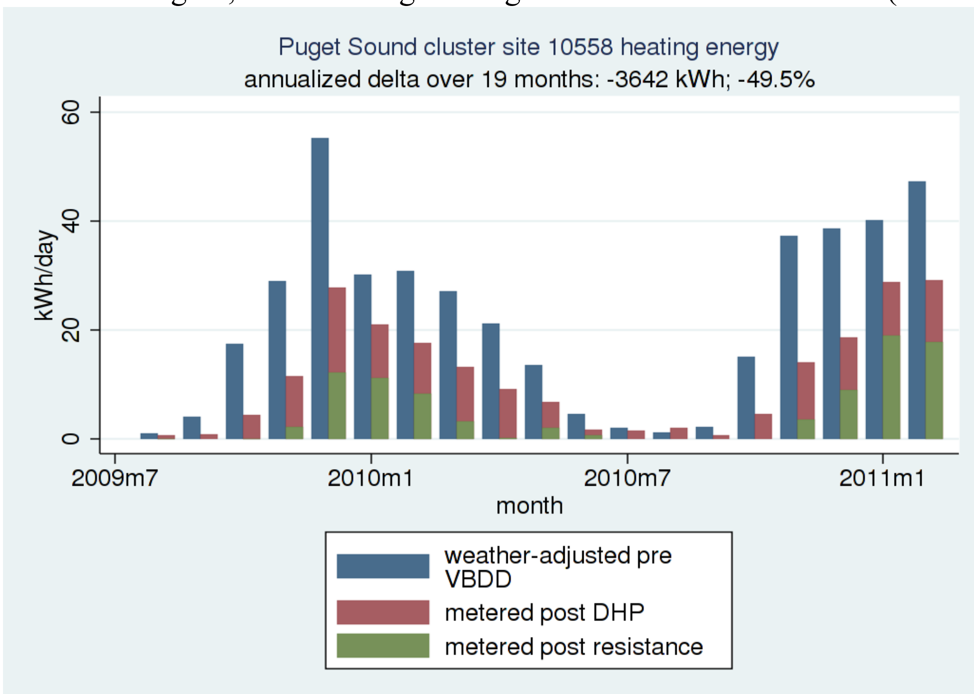

Figure 3. Typical Savings Graphic

Other sites showed very little reduction in usage. In the next example, also located in Puget Sound, there was very little change in heating usage. Further investigation revealed the homeowner used the minisplit very little, turning it on and off manually only on occasion.

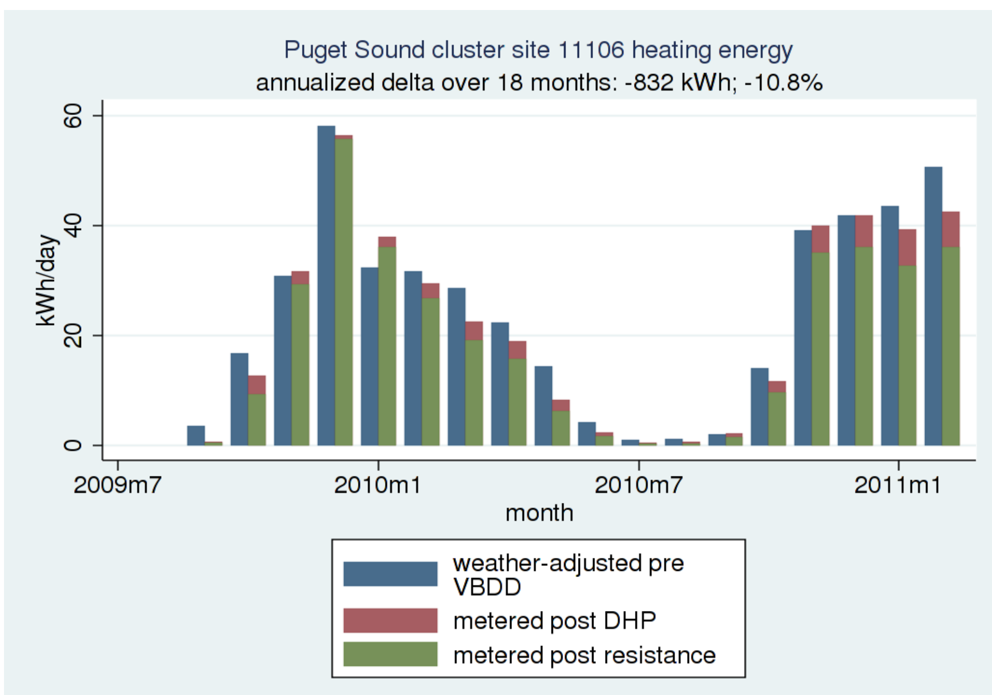

Figure 4. Minimal Heating Offset

The current savings estimates for all sites are shown in Table 2. Results are reported for 84 sites; other sites do not have sufficiently complete records (given when metering was installed) to be included in the analysis at this point. These figures include any added cooling usage for sites that did not have cooling prior to minisplit installation and also do not include any adjustments for added 120V heating sources such as space heaters (which can appear as simple base load usage). In prior evaluation, these influences have proven to have some effect on overall savings but tend to cancel out.

Table 2. Savings Estimates (Submetered Results vs Weather-Adjusted Pre-Minisplit Heating)

Cluster (DOE Heating Zone)	Sites	Savings (%)	Savings (kWh)
Willamette (4 Marine)	25	51.0	4605
Puget Sound (4 Marine)	25	41.9	3498
Inland Empire (5)	9	16.7	1783
Boise/Twin Falls (5)	15	22.3	3362
Eastern Idaho (6)	10	26.7	3655

Savings as a percentage of pre-minisplit heating usage are greater in milder climate zones such as the Puget Sound and Willamette Valley. Colder areas such as Eastern Idaho and Inland Empire show smaller percentage savings, but kWh savings across most zones are similar given overall heating loads are larger in colder climates. Note the kWh savings estimates for the colder sites are not fully complete given a full heating season's data is not yet included in the analysis. Percentage savings figures are more helpful for these areas at this point. More investigation is underway to explain the noticeably reduced savings in the Inland Empire (Spokane) cluster, but final results are not expected until after time of publication. One probable contributor to reduced savings in this cluster is that the screening process for wood and other non-electric heat had to be reduced somewhat to obtain test sites.

Given current utility rates (which average about 8 cents/kWh in the Pacific NW), average savings of about 3500 kWh, and average installation cost for a single-indoor unit minisplit of about $3500, the minisplit measure yields a favorable Total Resource Cost. Decreasing savings or increasing the system first cost (by adding a second indoor unit, for example), result in negative TRC.

Note the electric utility bills for prospective metering sites were pre-screened using the VBDD process. This screening turned up many sites that used large amounts of non-electric heat (especially wood). A broader utility billing analysis, scheduled for completion in November 2011 will almost certainly find overall savings from minisplit installation will be significantly less than shown in Table 2, especially in colder climate zones. This suggests regional utilities should consider using a screening mechanism if they are to deliver meaningful energy savings from this measure.

Cold Weather Detailed Performance

About 15% of the sites in the pilot study were located in the coldest parts of the region, near Idaho Falls. In early 2011, an additional six sites were instrumented in the western Rockies (near Helena, Montana). Most of the minisplits installed in these sites were marketed as performing well in colder climates, but the project sponsors were interested in seeing if this claim proved out during cold snaps. For the most part, the technology has indeed proven to work very effectively even in subzero conditions. The following graphic depicts supply air temperatures (green line) at or above 100 F with outdoor temperatures of 0° F or below with a Coefficient of Performance (COP) greater than 1.5 (blue dots). (About one-third of field sites were outfitted with instruments that could measure thermal output.) Adjacent sites showed similar performance, although there was some variation that could have to do with installation problems (under investigation).

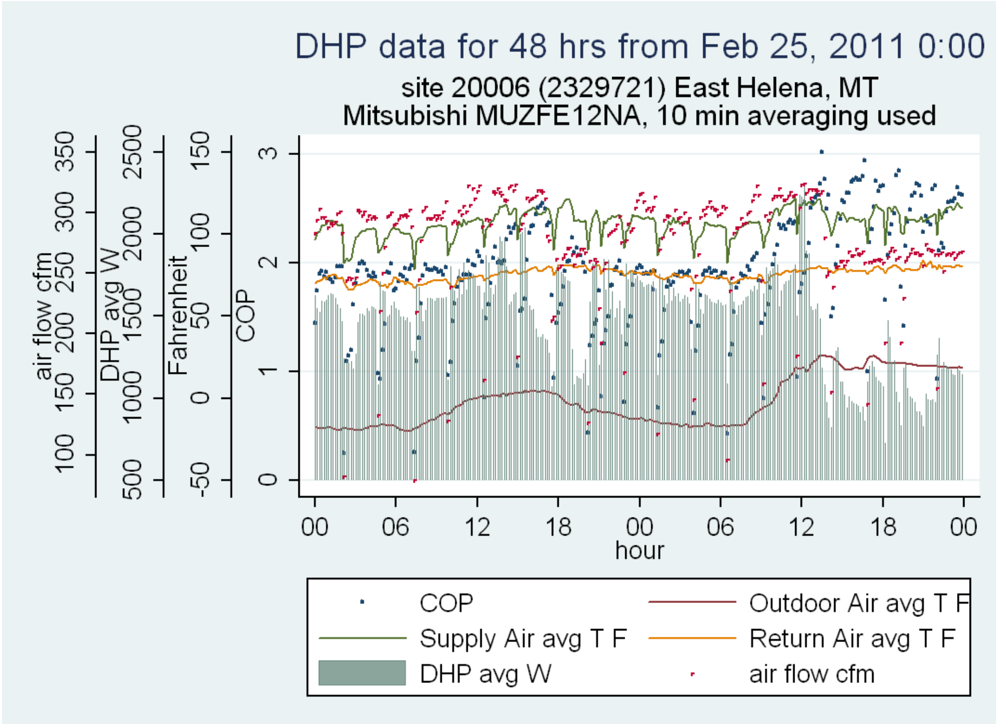

Figure 5. Cold Climate Detailed Performance

Lab (Bench Test) Results

The laboratory evaluation of ductless heat pumps was designed to measure the performance impacts on the equipment over the range of operating conditions that would be encountered in real installations. The value of this work is to directly indicate how much electric resistance heat would have been used at a particular site rather than impute that amount from billing analysis. Of course, the measurement of system performance allows evaluation of the nominal rating factors applied to the equipment. In practice, as the equipment is installed in climates that encounter both -5° F and +105° F temperatures, this results in creating a performance map over a wide temperature range. The lab setting provides a stable, controlled situation to accurately and precisely measure equipment output as a function of environmental conditions.

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

The performance mapping was conducted in Herrick Labs at Purdue University using two, side-by-side, psychrometric chambers. Each chamber provides an independently controllable temperature and humidity environment. The outdoor unit of the minisplit was installed in one chamber while the indoor unit was installed in the other. Refrigerant and control lines are connected through ports between the chambers. The indoor unit is attached to a discharge plenum which is used to measure air temperature and flow to determine the air-side capacity. A set of instrumentation is also installed on the refrigerant lines to measure mass flow, temperature, and pressure in order to calculate a refrigerant-side capacity. Throughout the performance mapping process, these capacities are compared. The good agreement between the two verifies the validity of the measurements.

The test design called for steady-state measurements of efficiency with variations in outdoor temperature (and RH), indoor temperature (and RH), indoor fan speed, and compressor power.

Additional tests with wet and dry indoor coils, outdoor defrost conditions, and equipment on/off cycling were also conducted. The methods and procedures used in the lab adhered to industry standards, including ASHRAE Standard 116 and AHRI Standard 210/240.

Figure 6 plots the steady-state coefficient of performance (COP) versus outside temperature for one, high-performance, DHP model in heating mode. The lab measurements are shown in blue, red, and green for maximum, intermediate, and low power settings. The manufacturer's catalog data is shown in yellow. The catalog data relates only to the intermediate power conditions used in part to generate the rated HSPF and SEER values and does not show the full performance range of the equipment. Our measured data shows good agreement with the catalog data. The box plots in Figure 6 show the observed field performance of this same model. The variation in the field data for a given temperature bin can largely be explained by the equipment operating at different capacity levels as it responds to the house load. Additionally, the field data includes the effects of degraded performance due to frosting and defrost cycles. The plotted lab data is for steady-state, non-frosting conditions only. Frosting occurs most prevalently in the 30-45° F outdoor temperature range. The field data show excellent agreement with the lab data.

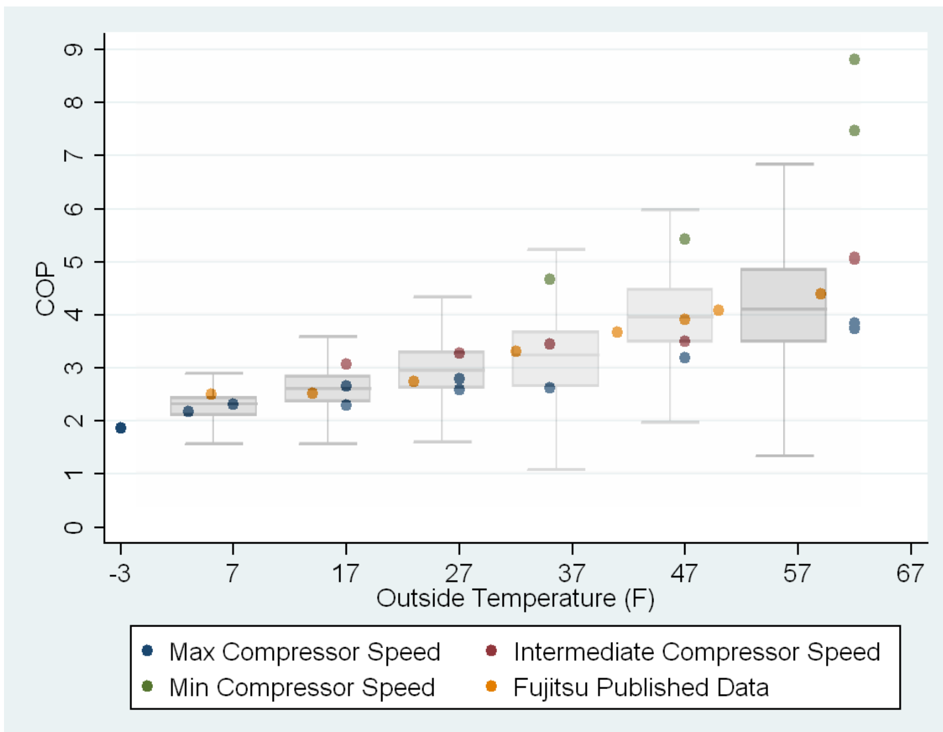

Figure 6. Bench Test vs. Field Data

Participant and Installer Experience

Parallel with the technical evaluation, a comprehensive process evaluation of the pilot was undertaken. This effort included extensive work with both participating homeowners and installation contractors. Because the product is quite new and unfamiliar to most of those involved, this part of the evaluation was designed to probe many questions surrounding the technology and its large scale introduction to the Pacific Northwest. The results reported below are from the first phase of the process evaluation, begun not long after the program began. This phase was designed to get immediate, top-of-mind thoughts and reactions to the technology from homeowners and installers. A second process evaluation was undertaken to assess acceptance of the minisplit after it had been in a home for at least a year.

During the first phase of the process evaluation, participants reported high levels of satisfaction with minisplits and with pilot project implementation processes, including: ease of understanding incentive qualification requirements; ease of finding an installer; ease of locating program information; and the speed with which they received their incentive checks (between 80% and 90% of respondents reported being "very" or "extremely satisfied" with each of these processes). The incentive (typically about $1500 although lower in some service territories) appeared to overcome participants' first-cost hurdle; 66% of participants reported that they "would not" or "might not" have purchased their minisplit without the utility incentive. Another indicator of the influence of the rebate on purchase decision comes from participants who received a substantially lower-than-average incentive; only 11% of these participants said their decision "may have" or "would have" changed were the incentive not available.

Prior to minisplit installation, most participant respondents experienced dissatisfaction with the compromised comfort and high cost of operation associated with their existing zonal electric heat source. During weather extremes, such participants are particularly dissatisfied. As the field evaluation shows, some homes, or at least the main living space of these homes can be kept comfortable during very cold weather with the minisplit technology.

Because the response to the technology was very positive, evaluators had to probe to learn of criticism of minisplits. The main complaints were the bland appearance of the unit (about 15% of respondents mentioned this) and confusion about operation (units use a remote control rather than a central thermostat). During installation of metering equipment, field staff generally found occupants had adapted to the presence of the minisplit (most said they "forgot it was there"), but there were questions about the remote control and also about filter cleaning (as these homes had previously been heated with wall heaters, baseboard, or ceiling radiant heat). A few minutes reviewing control and maintenance issues were generally all that was needed to re-explain the procedures to occupants.

The majority (about 90%) of both participant and installer respondents reported that minisplit installations were quick, minimally invasive, and did not require installer follow-up. However, several interviewed utility staff, installers, and participants reported issues with the installation of minisplit refrigerant line sets. The latter issue has now been largely resolved as the region has become more conversant with the specialized tools and fittings needed to install this product.

The majority (78%) of installer respondents provided high ratings regarding mandatory minisplit orientation sessions (which include some amount of installation training). Installers requested additional information on general project requirements, utility-specific project requirements, and the "displace, not replace" theory. Manufacturer contacts and project staff reported that the pilot's reliance on the Internet to communicate program information represented a barrier, as some installers did not want to access the Internet.

Contractors see more profit in installing multi-indoor unit systems and are concerned about supply chain reliability. Multi-indoor unit systems could heat/cool an entire house but the cost of these systems versus a single-head system would make minisplit economics unattractive using standard cost-effectiveness tests.

Conclusions

- The research's primary question was to answer the question of how much electric resistance heat could be offset by placing one ductless heat pump in the main living area of a home. The submetered data, in combination with a variable base heating degree-day billing analysis, estimate average regional savings of about 3,500 kWh per home. This represents an average offset of about 40% of pre-minisplit electric heat usage, with larger reductions coming in milder climate zones.

- Participants that previously used non-electric fuels for their primary heat source may undermine pilot cost-effectiveness. The region may choose to view the program as serving the house, and not the application, and thus decide that applicant behavior should not drive program eligibility. Yet the region would then need to reconcile such a design philosophy with the program's cost-effectiveness analysis.
- Frequent error checking is imperative for a field data collection project of this scope. Ecotope developed a daily error checking system that has kept overall data loss over 18 months to fewer than 2% of all data collected.
- Real-time efficiency proves out close to advertised efficiency and controlled lab testing.
- Very cold climate performance is impressive, with COPs well over 1 and delivery temperatures of near 100° F even at outdoor temperatures close to 0° F.
- Homeowners report high very high satisfaction with systems.
- Most HVAC companies report positive acceptance of the technology and the installation process.
- The most challenging occupant issues are use of the remote control and system maintenance.

References

Davis, B. and K. Geraghty. 2010. *Development and Implementation of a Ductless Heat Pump Metering Plan.* American Council for an Energy-Efficient Economy (ACEEE) Summer Study.

Fels, M., J. Rachlin, and R. Socolow. 1986. *Seasonality of Non-Heating Consumption and Its Effect on PRISM Results*. Energy and Buildings, Volume 9 (1986), pp. 139-148.

Fels, M. 1986. *PRISM: An Introduction*. Energy and Buildings, Volume 9 (1986), pp. 5-18.

Geraghty, K., D. Baylon, R. Davis. 2009. *Residential Ductless Mini-Split Heat Pump Retrofit Monitoring*. Prepared for Bonneville Power Administration.

Northwest Power and Conservation Council (NWPCC). 2010. *6th Northwest Power Plan* (supporting data spreadsheet). Pre-publication edition, February, 2010.

McRae, M., N. Harris and A. Armstrong. 2010. Northwest Ductless Heat Pump Pilot Project First Market Progress Evaluation Report. Prepared for Northwest Energy Efficiency Alliance.