STATE TECHNOLOGY ADVANCEMENT COLLABORATIVE

Residential Heat Pump and Air Conditioner Research, Demonstration, and Deployment
Improving Pacific Northwest Utility and State HVAC Programs

Submitted by:

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Acknowledgements

This report is dedicated to Larry Palmiter. Mr. Palmiter, a researcher at Ecotope who is well known in the field of building simulation, developed his SEEM model into a highly sophisticated tool for heat pump and air conditioner simulation through this project. He was instrumental in both the business and technical management of the project's lab testing that significantly increased knowledge about refrigerants. He assisted in other aspects of the project whenever needed, and was invaluable to its success.

Bob Davis at Ecotope was key to success of the long-term field monitoring. He is the main trainer in the commissioning video developed through this project. He authored the field study report and assisted in development other sections. David Baylon at Ecotope kept the technical research on track and did the analysis on commissioning cost-effectiveness. Thanks also to Ecotope's Erin Kruse (now with Xantrex) and Ben Larson for supporting SEEM and lab test research, and to Poppy Storm for rescuing documents including this report and its attachments.

Dave Robison, principal of Stellar Processes, developed software and performed data analysis. Dennis Landwehr, Landwehr Engineering, monitoring expert, assisted in the long term and short term monitoring (STM) system projects and trained the state energy office staff to use the STM.

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Thanks to Tom Eckman, Northwest Power and Conservation Council for providing a forum for discussion of heat pump issues, participating in the project advisory group and hosting the project task force on numerous occasions. Thanks also to the Energy Trust of Oregon for providing magnanimous support in matching funds, to Diane Ferrington of ETO for providing those match reports plus a site for short term monitoring training and to her and ETO's Fred Gordon for participation and guidance in advisory group meetings. Adam Hadley at Bonneville Power Administration (now an independent consulting engineer) shared generously of his technical expertise in the project technical advisory group and arranged for BPA's generous match. And thanks to Tom Hewes, Oregon Department of Energy, for supporting the project during the proposal stage when ODOE's last minute match commitment added so much to the project's capability.

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NOTE: Attachments 1-6 are available at
http://www.energywa.org/powerpoint/STAC_Heat_Pump_and_AC_Final_Report.zip

Executive Summary

In March 2006 the STAC Residential Heat Pump and Air Conditioner Research and Commissioning Training Development Project launched under a contract with the National Association of State Energy Officials. The Idaho Office of Energy Resources managed the project. State collaborators were the Oregon Department of Energy and the Washington State University Energy Program. The main technical contractor was Ecotope, Inc. of Seattle and Portland, Oregon. Subcontracting to Ecotope was Purdue University's Herrick Laboratory for bench testing of heat pumps and Stellar Processes for monitoring assistance and development of short term testing equipment and software. The project continued through June 30, 2008.

The project consisted of five major areas:

- Laboratory Tests
- Advanced Software Model Development
- Long-Term Field Monitoring Study
- Diagnostic Software and Equipment Development
- Advanced HVAC Technician Training Development
- HVAC Equipment and Commissioning Cost Study

The project resulted in new knowledge or significant developments in each area.

Laboratory tests at Purdue Universities Herrick Laboratory demonstrated that performance of heat pumps is impacted by deviations from the correct charge and airflow relative to the manufacturers' specifications. These impacts are not uniform between cooling and heating, and may enhance or harm performance. Machines charged with R22 were more tolerant of the variety of test conditions used in this study. In cooling mode, there is a bigger impact and a more consistent benefit from correct charge and airflow. This is particularly true of the R410a refrigerant where moderate overcharging resulted in complete compressor shut down at high temperatures.

Advanced Software Model Development was undertaken by Larry Palmiter at Ecotope, Inc. He expanded the SEEM software to model any heat pump using its performance curves; added a sophisticated simulation for latent loads; programmed the ability to vary system airflow; and developed a sophisticated ground contact model. The performance curves from the Purdue research were added to the SEEM model.

Long-Term Field Monitoring Study was a collaboration between the state partners and Bob Davis at Ecotope, Dave Robison at Stellar Processing and Dennis Landwehr, Landwehr Engineering. Two houses equipped with heat pumps in both mild and cold climates in each state of Idaho, Oregon and Washington were to be recruited and monitored for one year. In all seven participated, because one dropped out and was replaced. Partial year results were obtained on these two systems. The unintended discoveries were 1) that two thirds of these systems had major technical issues that had to be solved before they could perform as designed, and 2) that commissioning could be improved by analyzing split temperature for possible thermal expansion valve (TXV) malfunction and limiting defrost to 5 kW. The monitoring showed that if systems were sized, installed, and controlled properly, that air source heat pumps are capable of average annual heating COP of 2.5 in climates ranging from 4,000 up to 5,400 heating degree days.

Diagnostic Software and Equipment Development. The project developed laptop based monitoring equipment with software that managed and analyzed data and diagnosed heat pump or air conditioner system problems. The state partner field staff were trained in operation and use of this equipment and deployed it for training and technical assistance. Development was done by Stellar Processes and Landwehr Engineering.

Advanced HVAC Technician Training Development. The Pacific Northwest already has a highly developed system for training and certifying technicians with standards for system sizing, installation and commissioning called Performance Tested Comfort Systems. The major accomplishments of the training phase of this project are:

- Integration of the lessons learned in the laboratory and field study into the Pacific Northwest Regional duct and heat pump certification system.
- Provided project experience as input to development of ACCA standards.
- Development of a commissioning form that incorporates the lessons learned in the lab, field study, and use of the short term monitoring capability.
- Development of a heat pump and air conditioning field-commissioning booklet that incorporates the major findings on system performance.
- Development of an advanced training video that incorporates the lessons learned using the region's best commissioning trainers.
- Training and equipping the region's energy office staff with advanced heat pump and air conditioner diagnostic tools.

HVAC Equipment and Commissioning Cost Study. In this section the incremental system cost and surveyed cost of commissioning is reported. Collaborating in this study were the Oregon Department of Energy and the Washington State University Energy Program. Following this report is an analysis on the cost-effectiveness of commissioning by David Baylon, Ecotope. Both of these components are having an impact in the Pacific Northwest . They provided a basis for reexamining the cost-effectiveness of heat pumps by the Regional Technical Forum of the Northwest Power and Conservation Council, and for consideration of providing stand-alone incentives for heat pump commissioning.

Conclusion

A great opportunity exists in optimizing the performance of air-source heat pumps and air conditioners using standard duct delivery systems. Simple commissioning processes, training and diagnostic tools using laptop computers can significantly improve installed system performance and comfort.

Sophisticated research and simulation software provides the basis for these developments. This report shows how laboratory and long-term field research identified improvements to the commissioning process and provided the test bed for the short term monitoring systems. It also shows how SEEM can be used to assist decision makers in shaping incentives to achieve efficiency savings targets and the magnitude of what those targets should be.

Supporting detailed reports and documentation are contained in the attachments.

Residential Heat Pump and Air Conditioner Research, Demonstration, and Deployment: Improving Pacific Northwest Utility and State HVAC Programs

In March 2006 the STAC Residential Heat Pump and Air Conditioner Research and Commissioning Training Development Project launched under a contract with the National Association of State Energy Officials. The Idaho Office of Energy Resources managed the project. State collaborators were the Oregon Department of Energy and the Washington State University Energy Program. The main technical contractor was Ecotope, Inc. of Seattle, Washington and Portland, Oregon. Subcontracting to Ecotope was Purdue University's Herrick Laboratory for bench testing of heat pumps and Stellar Processes for monitoring assistance and development of short term testing equipment and software. The project continued through June 30, 2008.

The project was assisted by organizations that support high efficiency heat pump deployment in the Pacific Northwest and promote commissioning to improve installed performance. These organizations together provided $1,563,985 in matching funds. They were the Bonneville Power Administration, Energy Trust of Oregon, Oregon Department of Energy and the Northwest Power and Conservation Council.

Project Description

The project focused on discovering the simplest means to diagnose and optimize the new generation of high performance heat pumps and air conditioners and to integrate these diagnostic and optimization tools into the energy efficiency programs operated by the state energy offices and utilities of the Pacific Northwest. To achieve this required a number of interlocking steps that comprised the project goals.

- Conduct bench testing of heat pumps in both heating and air conditioning modes, at a variety of refrigerant charge levels, airflow rates and over a wide range of outdoor temperatures to determine critical parameters for optimizing system performance in both heating and cooling. The heat pumps studied included two systems charged with R22 of different efficiencies and one system charged with R410a. The analysis of the bench testing are contained in Attachment 1, Laboratory Test Report.
- Refine and improve the region's heat pump modeling tool developed by Ecotope. The SEEM model is a significant advance in modeling that simulates radiant and convective heat transfer effects as well as conductive. This project added a sophisticated duct mode, latent loads, ground contact and ability to modify air flow—all of which allowed it to simulate heat pump operation. The curves from the lab test informed the model about heat pump operation. The new SEEM is already being used by the Northwest Power and Conservation Council in analyzing recommended heat pump incentives for BPA and in developing residential supply curves for the Council's 6th Regional Power Plan. A detailed description of SEEM and its inputs is contained in Attachment 2.
- Conduct long term field monitoring in both heating and cooling modes of heat pumps that met the new Federal Standards and are charged with R410a on new and existing homes in Idaho, Oregon and Washington. Seven homes were recruited—two in Idaho, three in Oregon (one system dropped out) and two in Washington. Each original set included a mild climate (4,000 to 5,000 heating degree days) and a more severe climate (6,000 to 8,000 heating degree days). Only the system in Boise, Idaho faced a severely hot, dry

summer climate. The results of the long term monitoring are reported in Attachment 3, Long Term Field Monitoring Report.

- Develop, implement and evaluate a short term monitoring capability and field test protocol for diagnosing system performance. The short term monitoring equipment and software was developed and field tested in conjunction with the long-term field monitoring at one site in each state. The systems collected data on system temperatures, energy and power. The final software performs diagnostic based on short term performance data, making it useful in field training and system trouble shooting. The system documentation is found in Attachment 4.
- The experiences and insights from project lab, field and modeling efforts were incorporated into the HVAC commissioning protocol and training. The field handbook, DVD video and commissioning form developed for heat pump and air conditioner technicians implements the lessons learned from the research results. The commissioning handbook and form are in Attachment 5.
- Heat pump system and commissioning cost data were collected by the Oregon Department of Energy and Washington State University. The cost effectiveness of heat pump commissioning was analyzed using the collected cost data by David Baylon at Ecotope. The data and analysis are in this report. Survey instruments and raw data are in Attachment 6.

Project Context

After a five-year hiatus, Pacific Northwest utilities began promoting heat pumps as a conservation measure in 2001. Analysis of program evaluation information by Ecotope, Inc. of Seattle, Washington showed that most of the systems were not performing to specified output levels. Based on this information, the Regional Technical Forum (RTF), a standing committee established by the Northwest Power and Conservation Council, advised Bonneville Power Administration to reduce incentives on heat pumps 20 to 30%.

The main causes of the performance degradation proved to be duct leakage, premature compressor shutoff, and running of auxiliary electric heat at outside temperatures that could be handled by the compressor at reasonable coefficients of performance. As a result in 2001 the RTF adopted a prescriptive standard that required specified heat pump efficiency and duct sealing but only recommended performance testing and control changes. At the same time a venture funded by the Northwest Energy Efficiency Alliance called Climate Crafters issued the Performance Tested Comfort Systems® (PTCS) standards for heat pumps. These called for sealed and tested ducts plus mandated lockout of auxiliary heat to 40 ^{o}F outside air temperature, and no compressor lockout down to 0 ^{o}F. BPA adopted both standards as a two-tier system.

The table below shows the incentives and number of heat pumps involved in the BPA system for the years 2001 to 2006. The two standards (RTF prescriptive and PTCS test and commission) are shown in parallel columns for two different measures: “conversion” means a switch from an electric furnace to a heat pump, and “upgrade” means a heat pump replacement upgraded to either the RTF or the PTCS standards.

Heat Pump Data from the C&RD Data Base

	Heat Pump Conversions to RTF Specification		Heat Pump Conversions* to PTCS Specification		Heat Pump Upgrades** to RTF Specification		Heat Pump Upgrades to PTCS Specification		ETO Heat Pump Upgrades to PTCS Specification***		
	#	Average Credit	#	Average Credit	#	Average Credit	#	Average Credit	#	Average Credit	Total Heat Pumps by Year
FY2001	188	$2,180	19	$ 2,860	22	$ 345	9	$ 675			238
FY2002	1553	$2,000	232	$ 2,700	128	$ 302	25	$ 780			1938
FY2003	1173	$2,075	402	$ 2,575	125	$ 354	41	$ 695			1741
FY2004	736	$1,400	27	$ 1,384	260	$ 642	17	$ 800	409	$ 125	1449
FY2005	485	$1,325	25	$ 1,783	236	$ 602	16	$ 992	430	$ 248	1192
FY2006	272	$1,375	15	$ 1,354	244	$ 534	4	$ 807	678	$ 288	1213
									Grand Total §		7771

*means the base case included an electric forced-air furnace
**means the base case has a heat pump; the "upgrade" is to a higher efficiency heat pump
***Energy Trust of Oregon (ETO) offers two tiers of incentives for heat pumps: premium efficiency is HSPF 8.5; high efficiency is 8.2.
§The State of Oregon also gives tax credits for efficient heat pumps and air conditioners installed by an installer certified in performance checking that are not shown in this table.

Note that the prescriptive RTF standard was much more popular than the performance tested approach. When the Energy Trust of Oregon (ETO) began giving heat pump incentives in 2004, it initiated a PTCS only approach with two tiers based on differing efficiency standards of the equipment.

In 2004-2005 Ecotope and Stellar Processes conducted detailed monitoring of high-efficiency residential heat pumps for the regional agencies. This work was sponsored by the Oregon Department of Energy as part of its Building America funding and supported by the Northwest Power and Conservation Council and other entities. It included testing in heating only of a system at Purdue University and a field study of four homes.

In 2005 an evaluation (Baylon et al. 2005) raised concerns about whether the heat pumps across the region were operating well, or saving enough energy to be cost-effective. Consequently, in 2006 the RTF revised the heat pump PTCS specifications to require proper sizing, auxiliary lock out to 35 ^{o}F, airflow test using a True Flow® or duct blower, a refrigerant charge check and a number of other requirements.

BPA decided in 2006 to fund the infrastructure to support the new PTCS duct sealing and heat pump requirements. Through an RFP, they hired ECOS Consulting to train technicians, review paperwork submitted by technicians, keep a database of installed heat pumps, and do on-site quality assurance inspections.

The BPA Conservation Rate Credit (CRC) rules for Oct 2005-Sept 2009 (FY 2006-2009) established a much lower credit with higher standards than the past heat pump measures. In Heating Zone1/Cooling Zone1 (which corresponds to the I-5 corridor), a credit of $915 was available for HSPF 8.5/SEER 14 heat pumps installed with PTCS Commissioning & Controls and PTCS Duct Sealing. A credit of $470 was available for the same heat pump if duct sealing was not needed (i.e. basement homes). BPA estimated that approximately 600 heat pumps would be installed under the program in the first year (2006), 1,800 the second, and 3,400 the third.

Heat pump installations reported to BPA through their CRC program to date (March 2006 thru May 2008) suggest that approximately 2,100 PTCS heat pumps were installed that received incentives (579 in 2006, 1,574 in 2007). In this same time, 1,443 heat pump technicians were certified (597 in 2006, 846 in 2007, and 401 through May of 2008).

Feedback from utilities and contractors during this period identified the following barriers:

- Complicated rules about what systems qualified
- High incremental cost to reach HSPF and SEER requirements
- Difficulty accomplishing duct sealing/testing due to equipment/skills

Inspections have been completed on approximately 100 heat pump and 100 duct seal jobs since fall of 2006. Findings include:

- Control settings & airflow are the biggest reasons why jobs failed. Controls of interest are settings/sensors that keep auxiliary (electric resistance) heat off until the outdoor temperature drops below 35º F and also any control that can limit compressor operation above 0º F outside temperature. Airflow usually refers to the fan setting on the system. PTCS standards require that there be at least 350 cubic feet of air per minute per ton of cooling (CFM/Ton) moving across the coil. Installers are also required to measure external static pressure in the system to identify cases where the duct system is creating a problem.
- Several of the jobs that failed were due to simple things that can, and usually are, quickly addressed by the contractor. These include things like thermostat settings, fan settings, and CO alarm installation.

Projects of this complexity inevitably have issues. Complexities include:

- Convincing contractors to invest in new equipment and techniques
- Ensuring energy efficiency dollars are only spent on cost effective resources
- The challenge of administering and selling equipment and services that are not well understood
- The effect of taking the HVAC contractor out of the position of the final expert

BPA and the utilities have worked hard to define program parameters that work for BPA, utilities and contractors. A lot of value has resulted from these efforts, including:

- Many trained technicians
- New insights about the quirks of the new generation of heat pumps and controls equipment

- Companies that see value in the new testing equipment beyond just meeting program requirements
- Partnerships between HVAC and niche duct sealing companies have been very successful, resulting in high market share and very satisfied customers (with better systems installed)

BPA is in the process (summer 2008) of modifying their CRC measures and credits (based on analysis done by the RTF) in the following ways:

- Define commissioning and controls as a stand-alone eligible measure on any new heat pump installed in any existing home (regardless of home vintage or climate zone). This gives the option for HVAC contractors to focus on commissioning alone, not requiring at the same time duct sealing and higher HSPF/SEER machines.
- Utilities have the option to offer this measure to their customers and contractors. Some utilities that have well established duct sealing companies in their territory are expected to maintain the standard that duct sealing is required so that they can get the maximum savings per home.
- Define duct sealing in manufactured homes as an eligible measure (with a credit) for any vintage and any zone.
- Establish the Master Technician status developed by the RTF to enable experienced heat pump and duct sealing technicians to train and certify new technicians. This enables highly skilled HVAC companies to expand their capability in house without having to attend outside training. It also allows highly skilled utilities to better build and support their contractor networks.

In the future, BPA and the utilities are planning the following initiatives to continue to increase the number of heat pumps that are installed in the region:

- Provide additional technical training requested (e.g. heat pump sizing and duct design)
- Provide support to companies to help them understand the value of PTCS, and how to structure their sales and service to maximize benefits to customers and profit to the business
- Coordinate with state initiatives that require PTCS (Washington and Oregon codes, tax credits, and legislation).
- Reduce the administrative burdens related to eligibility, reporting and incentive processing.
- Increase the levels of QA inspections so that contractors are realize that simply filling out the forms is not sufficient, and that in order to uphold their certification they need to master the testing techniques and control strategies.
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The collaborative that conducted this STAC project plan to integrate the commissioning lessons learned in STAC into the PTCS standards. Collaborative members are active in the RTF and have already had an impact by participating in efforts like developing the Master Technician program.

Project Results

The project was a multi-pronged effort to lift the work on heat pumps and air conditioning to a new level from that described in the Project Context. This required gaining more knowledge about the new generation of heat pumps and the new refrigerant; to study the new, complex systems in the field; to develop more sophisticated modeling software that could analyze latent as well as sensible loads; to develop and demonstrate a field diagnostic tool for use by state energy offices, utilities and HVAC companies to troubleshoot systems, and to import the lessons learned into a set of training and model commissioning tools for the next generation of certified technicians.

Laboratory Tests

As proposed, Ecotope, Inc., the project's main technical contractor, entered into contract with Purdue University to conduct tests on three heat pumps at its Herrick Lab under the direction of Dr. James Braun on August 15, 2006. One of the three units had already been tested in heating mode under a previous research contract—cooling tests were performed on it. The other two were tested in both heating and cooling.

After contract signing, Larry Palmiter began working with Dr. Eckhard Groll who is in charge of the lab and testing regarding the actual lab set up. During the last week of September 2006, Palmiter visited the Purdue lab for detailed discussions with Dr. Groll and his staff on testing set up and procedures. From that point the testing proceeded with stops and starts with issues ranging from staff to equipment to scheduling issues throughout 2007 and into 2008.

Testing reached a dramatic finale in May 2008 when cooling tests on the third machine showed collapse in performance at high temperatures. The results had implications for the performance of R410a, and Ecotope requested that Purdue rerun the tests. Purdue agreed and in early June the tests were completed.

Tests were conducted on the following heat pumps: an "economy model" with a SEER of 10 and HSPF of 7.2 using R-22 refrigerant (with suction-line accumulator), a "high-performance model" with a SEER of 14.5 and HSPF of 9.0 using R-22, and a "medium-performance model" with a SEER of 13.0 and HSPF of 7.9 using R-410a. In each mode all of the tests described in American Refrigeration Institute Standard 210/240 (2006) and U.S. Department of Energy Test Standard presented in CFR430 October 2005 were done. The tests were sufficient to calculate the Seasonal Energy Efficiency Ratio (SEER) and Heating Seasonal Performance Factor (HSPF) for each heat pump at each combination of airflow and charge.

The results are summarized in a complete set of reports located in Attachment 1. The most interesting or dramatic are:

- Performance of heat pumps is impacted by deviations from the correct charge and airflow relative to the manufacturers' specifications. These impacts are not uniform between cooling and heating, and may enhance or harm performance.
- Small variations from manufacturer's specified charge and airflow resulted in little impact in any of the tested heat pumps.

- Most of these machines were tolerant of moderately reduced airflow, although the performance penalty is generally accepted in the manufacturers' literature as part of the "Comfort" settings for both heating and cooling.
- The machines charged with R22 were more tolerant of the variety of test conditions used in this study. This is consistent with manufacturer installation guidelines that emphasize more attention and more careful installation procedures when using the R410a refrigerant.
- In the cooling mode, there is a bigger impact and a more consistent benefit from correct charge and airflow. This is particularly true of the R410a refrigerant where moderate overcharging resulted in complete compressor shut down at temperatures well below levels seen in typical cooling climates.

Advanced Software Model Development

Beginning in 2003 the RTF began a project to update the performance evaluation tools used to validate and evaluate residential energy initiatives. The principle goal of this effort was to provide a residential energy model that could accurately analyze the effects of duct leakage, heat pumps efficiency, and heat pump commissioning. It was the finding of the RTF that none of the then currently available software met the region's need in this area. Larry Palmiter of Ecotope was contracted to develop a new model that would be able to analyze the impacts of variables such as duct sealing, system efficiency and commissioning on heating and cooling loads. The resulting model is known by the acronym SEEM.

Because the resources to develop this model were extremely limited, certain simplifications were made that sped the development. This decision resulted in less flexibility. The goal of this project was to add capabilities to this program. Specifically the proposed enhancements included adding latent loads in the calculation of heat pump performance and the flexibility to add performance curves from manufacturer's performance tables or ARI test results to allow analysis of a variety of heat pumps.

Mr. Palmiter succeeded in achieving the proposed enhancements and went beyond these goals. The new model can simulate the impact of various air handler flows on system efficiency. It has a sophisticated ground contact capability. And it uses the new TMY3 weather data. Mr. Palmiter included a weather file viewer that provides great insight into the differences in climates and their impacts on heat pump and air conditioner performance.

The new model was put to use during the project to test results coming from the lab. It was also used to perform the analysis on the cost effectiveness of commissioning that is submitted as an additional deliverable under this study.

The program documentation and detailed points list are included in Attachment 2.

Long-Term Field Monitoring Study

This phase of the project studied installed heat pump efficiency. The original field monitoring design was to select six high performance systems using R410a refrigerant installed in energy efficient new homes and monitor them for a complete heating and cooling season. Two homes were to be located in each state of Idaho, Oregon and Washington with one of these to be located in a relatively mild climate and the other in a colder climate. Monitoring started during the 2006 cooling season and continued through summer of 2007. For the most part we were fortunate that all but one of the systems used R410a and had been commissioned, and that the homes they served were quite efficient.

We had hoped to find homes ready to monitor and certainly did not select systems with significant issues. It turned out that many of the systems had performance problems, and we were able to study them and use the experience to refine and test installation protocols and to develop training curriculum and materials for installers and other interested parties.

The sites are located in diverse climate zones in the Pacific Northwest, including central Oregon (Bend), the greater Portland metro area (Deer Island), the Olympic Peninsula (Shelton), Boise, north central Washington (Moses Lake), and at higher elevation in far-eastern Idaho (Ashton). The Bend site was withdrawn in November 2006 due to a death in the family. A replacement site at Roseburg, OR was set up in early March 2007, and primarily cooling data were collected at this site.

The Pacific Northwest is a heating-dominated climate, ranging from about 4250 Heating Degree Days (HDD; base 65º F) at the Shelton site to about 8611 HDD at the Ashton site. Most sites had thermal shells that were sufficiently efficient that base 65º F heating degree days are perhaps not the most accurate estimators of annual heating energy usage (that is, base 50 or 55º F degree days would be more descriptive). The Boise, Moses Lake, and Roseburg sites had the most cooling demand (but it amounts to no more than 1500 kWh/year at these sites given the combination of relatively mild climate, efficient building shell, and minimal latent cooling load). The Shelton site, located about 100 feet from the Puget Sound, used no mechanical cooling during the monitoring period. The Deer Island site, located near Portland, OR, also used no mechanical cooling.

The monitoring system used multiple temperature sensors, current transducers, and measurement of system airflow (from an averaging velocity pressure grid. Data were stored on a laptop computer that served as the interface between sensors and the Internet for data retrieval.

It is important to note that proper monitoring required the ability to bin performance according to system operation. That is, the mode of system operation was determined in real time during data collection and results were aggregated by mode. The modes include compressor heating, cooling, backup heating, defrost, ventilation and thermal scavenging at the end of a cycle. Thus, it is possible to determine overall system performance during a cycle, including the effects of duty cycling, defrost, and backup heating.

Four of the heat pump systems needed major repair when found—another had a blocked duct system. The performance measurements are the results of long-term monitoring after the systems or ducts were repaired in 3 of the 6 cases. The Bend case was among the repair group, but was dropped prior to repair, and Roseburg was substituted. Boise was not repaired until late in the study—its system performance would probably be comparable to Moses Lake if defrost had been limited to 5 kW at the outset. Note that Ashton operated primarily as an electric furnace due to over sizing, but may have used more energy than an electric furnace if it had not been repaired. Moses Lake would have had no effective cooling system without a TXV replacement. Thus, of 7 houses chosen by chance, 6 had been commissioned, and 5 still had problems that significantly affected performance when we arrived to install equipment. Many of the problems were found only through monitoring. The lessons learned are discussed in detail in the project report.

Since only seven sites were studied, performance generalizations to all new heat pump installations in the Pacific Northwest are not recommended, except to note that such a high percentage of random sites with fundamental problems indicates major room for improvement. This perception is enhanced by similar findings in earlier studies. The detailed monitoring and site review were helpful to inform ongoing efforts to improve heat pump performance.

The primary findings from the study are:

- Heating season efficiency, expressed in units equivalent to the Heating Seasonal Performance Factor (HSPF) used to rate efficiency, ranged from very poor to slightly better than expected.
- Even in cases where HSPF did not meet expectations, heating season usage (when normalized by house size), was not out of line with recent regional billing analysis that informs the amount of installation incentives offered by some Northwest electric utilities.
- Cooling energy was only a very small part of annual HVAC energy at all sites (as expected). At two sites near the coast, there was little or no cooling. Southwest Idaho, on the other hand, has a summer peak driven by air conditioning, and even modest efficiency improvements that enhance the performance of a large number of systems are important.
- Repairs were needed at most sites. In some cases, repairs required more than one day of work to complete. This and previous studies indicate that in the Pacific Northwest there is a good chance that the current commissioning program on a regional basis fails to bring a significant percentage of systems to full performance potential.
- Current heat pump installation and field check out procedures used by Northwest utilities would benefit from revisions concerning the defrost system and also measurement of temperature split across the indoor unit coil in both heating and cooling.
- Equipment should be properly sized to load. Gross over sizing can lead to severely hampered heat pump performance.

The extensive report by Bob Davis and David Robison may be found in Attachment 3. And as of the time of this writing, the study data summaries may be found at: http://www.ezsim.com/STAC/.

Diagnostic Software and Equipment Development

It was observed in the long-term monitoring of 2004 and 2005 that actual field performance of premium efficiency heat pump systems was much lower than the specified seasonal ratings or anticipated performance based on manufacturer specifications. The reason often was due to errors in the installation and controls. It appeared that as the sophistication of the equipment increased, the units became more sensitive to installation and manufacturing errors. Through detailed monitoring of the equipment, the exact control errors and installation faults that lead to this reduced performance were identified and repaired. In general, these problems were not apparent without performance data – all the units had passed a thorough installation inspection. Since the project only monitored a small sample of cases, one expects that there are additional failure modes that have not yet been observed.

The project proposed to create a simplified instrumentation set utilizing new technology, including wireless sensors, to minimize installation complexity. It also proposed to develop software to perform analysis in real-time and streamline the output data to avoid overwhelming the user with the amount of data and the task of analyzing it.

Stellar Processes and Landwehr Engineering began work on what was called Short Term Monitoring (STM) equipment and software at the beginning of the project. By the time the long-term field study was launched, Stellar was ready to install a STM system to operate in parallel with the standard data acquisition system in order to test the data collection, sensor function and data analysis capability. The system documentation may be found in Attachment 4.

The system is designed to use a standard laptop computer with wireless temperature sensors and current transformers connected through to the computer through a USB hub. It connects through the Internet to a site where it places data results and can be accessed remotely via standard software to check its function, modify its processes and download data.

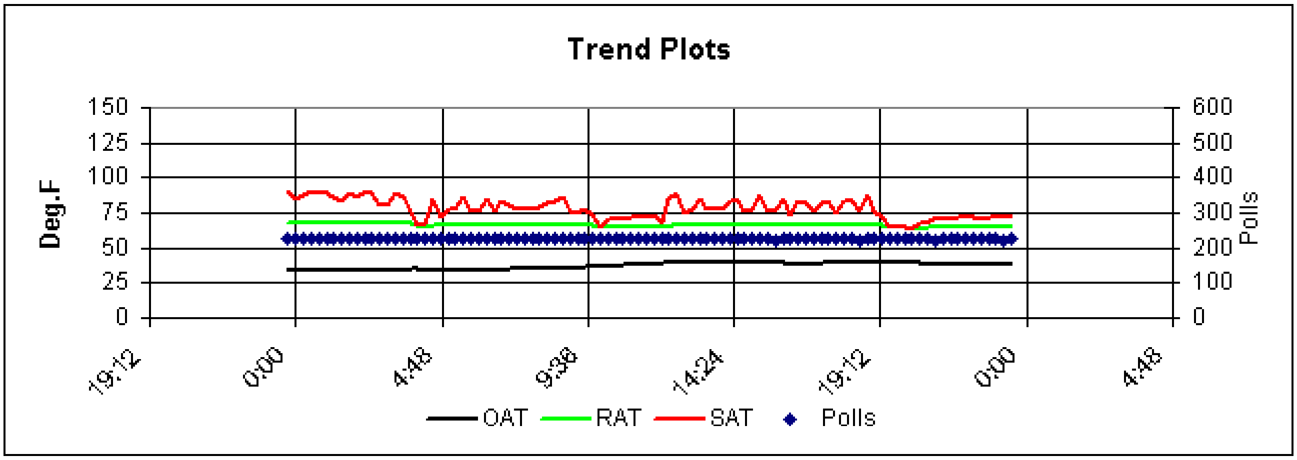
One of the features added by Stellar to the software was a diagnostic capability. In doing so, they accomplished a deliverable from the original Statement of Work's Task 4—"Documentation including decision tree, background performance curves, and trial results". Now with the STM, most of the really tough installation issues can be identified with a few days monitored operation.

Here is an example from STM data analysis performed by its diagnostic software on one day worth of data. Note the list labeled "Error Checks". It is telling us that on this December day in Moses Lake the system had none of the following malfunctions:

- High number of incidents of cycling on and off (HiCycling)
- High amount of defrost energy (HiDefrost)
- High use of fan energy (HiFan)
- Auxiliary heat on above 35 ^{o}F (WarmR.Heat)
- Split temperatures too small in heating (LowHDT)
- Split temperatures too small in cooling (LowCDT)
- Split temperatures too big in heating (HiHDT)
- Split temperatures too big in cooling (HiCDT)
- Coefficient of performance too low (LowCOP)

This is from the charts section output of the STM data analysis. This first chart shows the temperature data collected.

Site: TB4346 12/23/2007



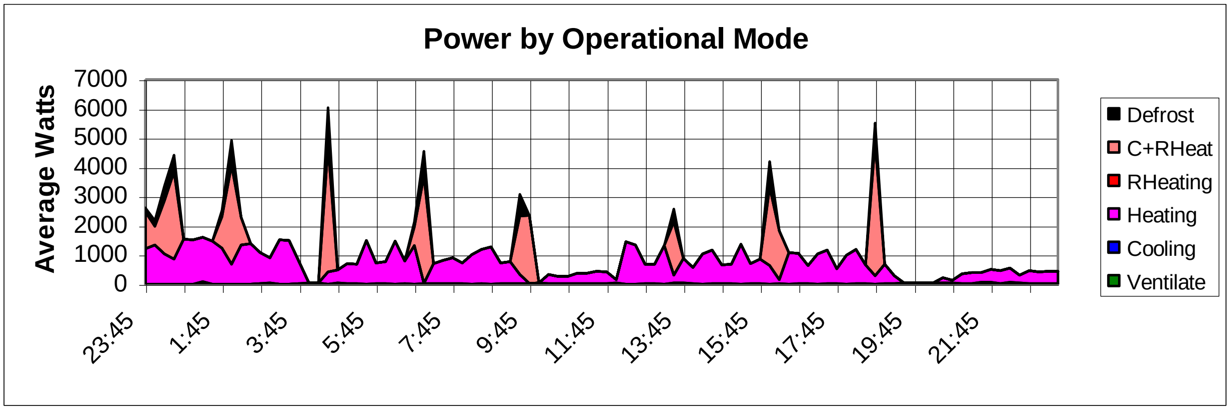
Shows % of time, energy and other calculations from the data. Note high compressor and low backup use.

	Duty Fraction	kWH	Cycles /Day	COP	Average Cycle, Minutes
Ventilation	36%	2	1882		
Fan:Scav	7%	1			
Cooling	0%	0	0	NA	NA
C.Heating	48%	68	60	3.4	11.5
R.Heating	0%	0			
C+R.Heat	6%	36			
Defrost	6%	8	19		
Gas Heat	0%	0			
Outdoor Temp, Ave		37			
Indoor Temp, Ave		66			
Data Capture / Total:	96 / 96 : 100 %				

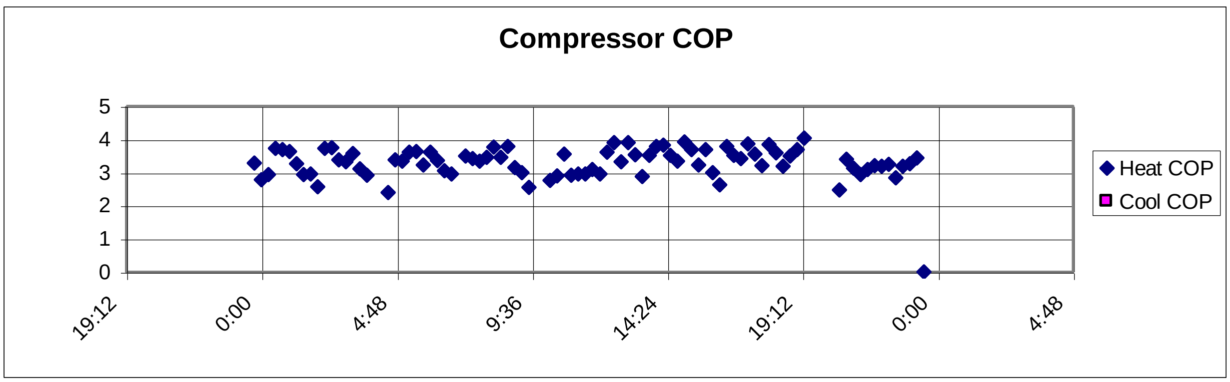
Error Checks

HiCycles	No cases
HiDefrost	No cases
HiFan	No cases
WarmR.Heat	No cases
LowHDT	No cases
LowCDT	No cases
HiHDT	No cases
HiCDT	No cases
LowCOP	No cases

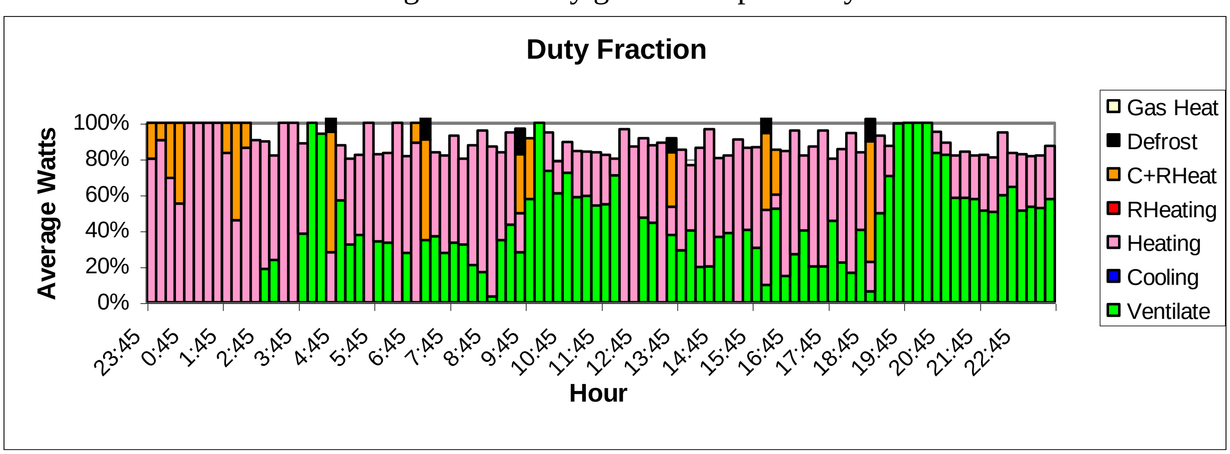
This chart shows the compressor heating in purple, the compressor plus resistance heat in orange, and defrost energy in black. Note the resistance is never on by itself even though the temperatures were around freezing in the lower temperature bins. The ventilation is pretty constant, but power use is so low that it barely shows on the chart.



Here is the system coefficient of performance. Although the chart title says "Compressor COP" the calculation includes air handler energy, thus including both the evaporator and condenser.



This chart shows the % of wattage used at any given time period by various uses.



Advanced HVAC Technician Training Development

The concept was to develop enhanced commissioning protocols and build training around those. The enhanced components would then be taught to technicians who were already trained and certified by the existing system. We would use the short term monitoring equipment on some of their projects they did prior to advanced training, have them update the commissioning in light of the training and retest.

Unfortunately a two-year timeline proved too short to accomplish this in its original form. The enhanced protocols depended on lessons learned from the Purdue Lab testing and the long-term field-testing. Some of the key lessons from the field test came only in the latter part of 2007, and the most important result of the lab test came during the project extension in May 2008. The short term monitoring equipment training was done in the fall of 2007, and the training video was shot in April 2008 and was edited during the reporting phase of the project.

The major accomplishments of the training phase of the project are:

- Integration of the lessons learned into the Pacific Northwest Regional duct and heat pump certification system.
- Provided project experience as input to development of ACCA standards.
- Development of a commissioning form that incorporates the lessons learned in the lab, field study, and use of the short term monitoring capability.
- Development of a heat pump and air conditioning field-commissioning booklet that incorporates the major findings on system performance.
- Development of an advanced training video that incorporates the lessons learned using the region’s best commissioning trainers.
- Training and equipping the region’s energy office staff with advanced heat pump and air conditioner diagnostic tools.

Integration into the Regional System

The system standards are governed by the Regional Technical Forum, which owns and governs the Performance Tested Comfort Systems® trademark and standards. In 2007 the project collaborators participated in a regional meeting to create a path for industry technicians to become qualified instructors within the PTCS system in the duct testing and sealing certification process. The manager of this STAC project lobbied to extend the concept to heat pump commissioning, and volunteered to draft an amendment to the regional PTCS Service Provider Standards. This amendment was adopted by the RTF at its February 5,2008 meeting. The approved standards include in the curriculum for the instructional path the two major commissioning findings of the project. They are highlighted in the specification language below. The curriculum recommended by the project collaborators is the complete list of topics including the highlighted discoveries of the project. The complete standard is contained in Attachment 5.

Regional Technical Forum Performance Tested Comfort Systems® Service Provider Standards January 8, 2008

3.2.4.1.4. Utility program staff and technical staff for HVAC efficiency contractors may qualify as a Master Heat Pump Technicians by either:

3.2.4.1.4.1. Following the work experience path:

a. Co-commissioning at least 30 certified systems;
b. Achieving a 90% or higher score on the PTCS test for Certified Heat Pump Technician;
c. Applying to and receiving approval from Provider as required in 3.2.5.1.3.d and e.

3.2.4.1.4.2. Following the instructional path by attending a class of least two days by instructors approved directly by the RTF for this purpose that includes the hands on testing of heat pumps. In addition, the path includes compliance with 3.2.4.1.4.1. subsections b and c. The class must include the following topics:

a. PTCS Heat Pump Commissioning process and requirements
b. PTCS Quality Assurance process and requirements
c. Airflow measurement using acceptable PTCS methods
d. Fan performance curves including ECM
e. Function of outdoor thermostat/sensor (including placement and measurement of sensor output
f. Basics of refrigeration cycle including role of reversing valve and function of TXV and accumulator
g. Affect of substandard airflow (indoor and outdoor) on coil performance
h. Diagnosis of malfunctioning TXV
i. Compressor function, suction and discharge pressures expected amp draw
j. Refrigerant handling, charging, manifold gauge handling/calibration
k. Electrical components (contactors, capacitors, control boards)
l. Defrost kW check method, actual kW defrost requirements and impacts of excessive kW on system performance
m. Troubleshooting defrost boards
n. Attendees must have a valid EPA refrigerant card (or the card may be included as part of the class)

<u>Input into the ACCA Standards</u>

The project collaborators, led by Michael Lubliner of the WSU Energy Program, was given the opportunity to review the draft technical installation standards during **2007. Much of the PTCS and STAC HP & AC recommended practice was integrated into the standards or the technical appendices.

<u>Development of Field Commissioning Form</u>

The form embodies the specification. The Heat Pump and AC Commissioning Form is based on the PTCS form used in the Pacific Northwest. It uses the same format. More importantly, if the technician uses the STAC form, he or she will also meet all the PTCS standards. The main differences between the STAC form and the PTCS form are:

- The STAC form is for heat pumps and air conditioners—PTCS is only for heat pumps. This is critical for utilities like Idaho Power where residential air conditioning in Southwest Idaho is driving its annual peak. By expanding the scope of the form, all the resources behind improving the performance of heat pumps are made available for air conditioning.
- The STAC form is set up to facilitate a subcooling test, because it is a more precise test for systems with TXV installed.
- The STAC form requires the taking of split temperature and contains a warning that if the split temperature is too low, the TXV may be malfunctioning.
- The STAC form includes calculation of heat or cooling output and comparing it to the manufacturer's stated output for the test temperature.
- The STAC form requires checking the amount of auxiliary heat staged to come on with the defrost and limiting it to 5 kW. As discussed in the field study report, the auxiliary heat is only activated for comfort, but studies show that the heat stored in the ductwork and air is sufficient to maintain temperature during defrost cycles. In most cases, particularly where the ducts are inside conditioned space, the auxiliary heat could be eliminated altogether.

The STAC form can be found in Attachment 5.

<u>Development of Field Commissioning Booklet</u>

One of the most popular and widely used technical resources in the Pacific Northwest is the Northwest Duct System Diagnostic Field Guide by David Hales at WSU Energy Program. As part of his work in this program, David created a Field Commissioning Booklet for Heat Pumps and Air Conditioners. It is expected to be as widely used as its predecessor. A copy of it can be found in Attachment 5.

<u>Training Video Development</u>

To make the training video required a distinct clarity about the integration of the collaboration's discoveries with the regional curriculum. There is a great deal of pressure to simplify the PTCS standard and not to add anything to it. At the same time the project was proving that in many cases commissioning, as it was currently practiced, did not ensure that systems would reach their full performance potential. The video engages two of the best and most experienced heat pump commissioning instructors in the region who are also well known nationally through ACI—Bob Davis of Ecotope, Inc. and Bruce Manclark, Delta T.

While Mr. Davis is the primary instructor in the video, Mr. Manclark created the heat pump ala'carte and hosted the shoot at his home. Both provided technical assistance to the production. A member of the project collaboration shot the video, wrote the script and engaged John Glenn Hall of Boise to produce the video. It is intentionally not a smooth production, in order to enhance its effectiveness with its intended audience. A copy is included in the submittal of this report.

The video is focused on the Heat Pump and AC Commissioning Form. The form provides the structure for the video, and the training leads to successful completion of the form. The net effect is to enhance the value of the form as a device to help the technician remember what needs to be done and how to do it.

Because the video follows the form, the form includes the PTCS standards, and the instructor is PTCS certified, it can be used for PTCS heat pump commissioning training. When it is, the findings of the STAC project will also be passed on. The video combined with the STAC form and the field-commissioning booklet will be made available as a package with the intent that the level of commissioning will be raised in the Pacific Northwest.
With the addition of cooling and discussion on the impacts of latent load on cooling split temperature, the potential value of the package goes beyond the Pacific Northwest.

The video outline is:

- Technician, Site and System Information
- Site Information
- Certification Certificate
- Project Information
- Static Pressure and Airflow
- Charge and System Performance
- Controls Set Up
- Defrost Heat and System Efficiency
- Inside the Outside Unit

The video also warns the technician about the sensitivity of R410a to overcharge, particularly in hot, dry climates and the impact it has on cooling performance at high temperatures. This information came directly from the lab tests at Purdue University.

<u>Advanced Heat Pump Diagnostics</u>

The short term monitoring system has already been used by WSU Energy Program to troubleshoot installations and provide advanced technical assistance and training to installers. The file used as an example in the STM section of this report came from that work. Regional technical experts and resident experts at HVAC contractors who become Master Heat Pump Technicians may be the next to acquire and use this capability. It is the kind of transforming technology that could lift installation and commissioning to a new level.

HVAC Equipment and Commissioning Cost Study

The cost effectiveness of heat pumps and commissioning depends on performance and on incremental cost above the baseline. The Regional Technical Forum recommends allowable measures and incentives to Bonneville Power Administration. During the period of this project the RTF revisited the cost effectiveness of both residential and commercial heat pumps.

The Oregon Department of Energy and the Washington State University Energy Program collaborated in the cost data collection. ODOE operates a tax credit program that includes ducts and residential heat pumps. It has independent requirements for obtaining these credits that correspond with PTCS standards for duct sealing and testing and heat pump commissioning. It provided current cost information from its detailed tax credit data base on participating Oregon systems. The WSU Energy Program spearheaded a survey of HVAC companies throughout the Pacific Northwest on the cost they charge for heat pumps with efficiencies above the base case and for commissioning.

The cost data produced by this project was key to the RTF analysis. In this section of the report the incremental system cost and surveyed cost of commissioning is included. Following this report is an analysis on the cost-effectiveness of commissioning by David Baylon, Ecotope.

Regional Cost Analysis for Heat Pump Efficiency Upgrade and Commissioning

Two sources were used to collect data on costs of heat pump equipment and required commissioning procedures in the Pacific Northwest. A survey questionnaire was developed and mailed to over 400 HVAC contractors in Washington, Oregon, Idaho and Montana with follow-up phone contact when possible to encourage participation. A survey was also performed on the database of tax credit incentives maintained by the state of Oregon to track incentive payments. Records for 435 tax incentive payments for heat pumps and commissioning made between 1//1/06 and 6/21/07 were examined. A copy of the mail survey with cover letter, and the collected data from both sources are included in Attachment 6.

The intent of the process was to establish the incremental cost to consumers for the purchase of higher efficiency equipment and required commissioning procedures used to assure system performance.

The baseline system in the mail survey was defined as a 7.7 HSPF, 13 SEER single stage split system air source heat pump. The first tier of improved efficiency was defined as an Energy Star Homes Northwest qualified heat pump with a minimum 8.5 HSPF and 13 SEER and the top tier of efficiency was defined as 9.0 HSPF, 14 SEER or greater. All ratings were required to be ARI certified.

Commissioning costs in the mail survey were to be reported as total added cost beyond the installer's standard practice to commission a heat pump to the Performance Tested Comfort System (PTCS) standards. PTCS requires verified control settings; airflow measurement across the indoor coil; and verification of proper charge. The mail survey also asked for heat pump equipment costs only for 2, 3 and 5 ton systems not to include ductwork or installation labor. Twenty seven contractors responded who reported installing over 1800 heat pump systems..

The Oregon Tax credit database provided information on 435 heat pump systems that received tax credit incentive payments for improved efficiency and included itemized costs for commissioning. Most of the Oregon systems used the CheckMe$_{TM}$ system for commissioning, which, as used in the Pacific Northwest, has been deemed equivalent to the PTCS standard. The Tax Credit Database did not track the capacity of the heat pump equipment.

The table below summarizes the findings.

Summary of Average Costs

System or Measure	Cost in Mail Survey	Incremental Cost Above Baseline	Oregon Tax Credit Cost	OR #Systems
Base line system (3Ton)	$5,024			
8.5 HSPF/SEER !3	$5,851	$827	$3,418	134
9.0HSPF/SEER 14	$7,054	$2,030	$3,722	203
9.5 HSPF			$3,868	62
10.0 HSPF			$3,645	6
PTCS Commissioning	$345			
CheckMe®			$228	

The costs reported in the mail survey are significantly higher than those in the Oregon database as are commissioning costs. CheckMe, as used in the Pacific Northwest, complies with requirements of the PTCS standards.

<u>Commissioning Cost Effectiveness</u>

David Baylon of Ecotope, Inc wrote the following analysis. It the basis for the RTF to consider recommending to Bonneville Power Administration that it offers a stand-alone incentive for commissioning heat pumps. This analysis does not include the cost/benefits of the commissioning improvements recommended in this report.

Note that Mr. Baylon differentiates "commissioning" from "set-up" in this report. "Commissioning" is used to identify the benefits of PTCS airflow and charge tests, and "set-up" identifies the PTCS control setting requirements. Throughout the rest of this report, commissioning means the entire process covered by the Heat Pump and AC Commissioning Form including airflow and charge tests and control setting requirements.

Heat Pump Commissioning and Controls

Using information gathered from field work done on this STAC Heat Pump and AC project and previous projects, the Regional Technical Forum of the Northwest Power and Conservation Council (NPCC) has developed a procedure for generating electric energy savings from implementation of the recommendations of this report. The assumptions integrated into this calculation are meant to substitute for the performance deficiencies we observed from the various observed controls and components in "typical" heat pump installations. The results of this calculation procedure are summarized in Table 1 for the weather sites that would represent the sites used in this heat pump review.

Table 1: Energy Saving and Cost Benefit for Heat Pump Commissioning

Climate	Base Use	Commissioning Savings	Set-up Savings	Total Savings	Improved Use	$/kWh Saved	Payback (yrs)
Seattle	7,381	290	1,244	1,534	5,883	0.051	2.7
Moses Lake	11,559	399	1,608	2,007	9,630	0.039	2.1
Boise	11,194	368	1,511	1,879	9,379	0.042	2.2
Portland	6,792	277	1,138	1,414	5,423	0.056	2.9
Roseburg	5,821	255	1,030	1,285	4,591	0.061	3.2
Jackson Hole	25,116	519	2,599	3,118	22,024	0.025	1.3

Modeling Assumptions

The savings calculations summarized in Table 1 were generated using the SEEM thermal simulation model as modified in this STAC project. These savings were generated using a prototype home with insulation and window performance consistent with the Northwest Energy Star® program. The home itself is modeled as a 2,200 square foot split level home. The duct systems were modeled as a well sealed ducts located in the unheated crawlspace and attic buffer zones.

The heat pump modeled is a Carrier HCA series (R410a) used in the STAC laboratory testing at Purdue University. In this case the assumptions were based on a target airflow consistent with the manufactures specification. In the base case configuration there were several control options modeled and weighted in accordance with the procedures used in describing the typical heat pump performance:

- Standard ARI control configuration with 3 degree temperature dead band between heating stages: weighting 40%;
- Comfort "Plus" control using 5 kW of resistance heat at temperatures below 30F: weighting 15%;
- First stage resistance element heating using 5 kW in all compressor heating cycles: weighting 25%;
- Compressor cutout at 30F used to eliminate staging at low temperatures (especially in colder climates): weighting 10%;
- Standard ARI controller with outdoor temperature lockout of resistance elements at temperatures above 35F: weighting 5%.

These control strategies are combined to characterize the base case operation as observed in regional field studies conducted in 2005 (Baylon et al. 2005). The base case for this calculation assumes a weighted average of these five control packages. This weighting is meant to reflect the combination of the controls used in various heat pump surveys and the use of first stage resistance heat for about 20 percent of the heating duty cycle as part of the comfort control typically used by many installers.

In developing the commissioning and set-up specifications for the Pacific Northwest region's installation standards the weighting system was changed to remove all first stage heating and compressor cut-outs and to reflect the requirement for outdoor temperature control and element lockout reflected by control strategy five in the above list. In addition, a commissioning credit amounting to 5% of the compressor energy was taken to reflect the repairs needed when detailed review of many installations is undertaken. This is consistent with billing analysis done in the regional heat pump review and the impact of adjustment made to several of the field reviewed heat pumps monitored in this STAC study.

Table 1 shows a cost benefit ratio calculated in levelized cost per kWh saved. This is a standard ratio used in energy planning in the Pacific Northwest. In addition, a simple payback (in years) is calculated based on the regional average of electric energy costs ($0.085/kWh). In both cases, the cost of the commissioning and alternative controls set up was assumed to be $350 that would include the cost of some quality control mandated by the regional utilities for heat pump support.

As shown in Table 1, the savings from these two effects is about 15% of the overall energy use of the heat pump in heating mode. When heat pumps with somewhat higher rated efficiency are used in this analysis the savings are very similar. Generally, overall these savings offer cost effective savings to any supporting utility and a consumer payback of less than three years.

Conclusions

A great opportunity exists in optimizing the performance of air-source heat pumps and air conditioners using standard duct delivery systems. Simple commissioning processes, training and diagnostic tools using laptop computers can significantly improve installed system performance and comfort.

Sophisticated research and simulation software provides the basis for these developments. This report shows how laboratory and long-term field research identified improvements to the commissioning process and provided the test bed for the short term monitoring systems. It also shows how SEEM can be used to assist decision makers in shaping incentives to achieve efficiency savings targets and the magnitude of what those targets should be.

This was made possible through an investment by US Department of Energy through an innovative process created and managed by the National Association of State Energy Officials that brings states together to collaborate to solve regional and national problems in energy efficiency and to explore and implement creative solutions together. In the case of this project, the model succeeded very well. The progress reflected in this report could not have been achieved through any other means.

In an era where climate change is of increasing concern, bringing the level of efficiency of any disperse technology to its full potential is paramount. The field study shows that just because the heat pump or air conditioner has an efficient rating does not mean it will be installed to work efficiently. A lot of factors over which the manufacturer has no control will determine the actual performance, including ductwork, technical knowledge, and field quality control systems.

In an future where temperatures are predicted to rise it is disconcerting to find that the refrigerant chosen because it has no impact on the ozone layer exceeds system pressure at modestly high temperature if it is moderately overcharged. The technical contractor and laboratory were shocked when the fragility of the system to R410a with modest overcharge was revealed during the final series of tests—so shocked they redid the test—and got the same result. As we have seen from the field study, it is not easy to get charge exactly right. Perhaps as we go forward we will find a technical solution.

The researchers have already submitted a great deal of this research in peer reviewed forums including ASHRAE and ACEEE, and we can look for more in the future. Some of the papers are attached to this report. Much more remains to be done, including development of diagnostics and commissioning processes for optimized heat pumps for cold climates and air conditioners for hot, dry climates. Field performance research, commissioning and diagnostic tools for ductless mini-split heat pumps and air conditioners is a new area that due diligence requires we explore.