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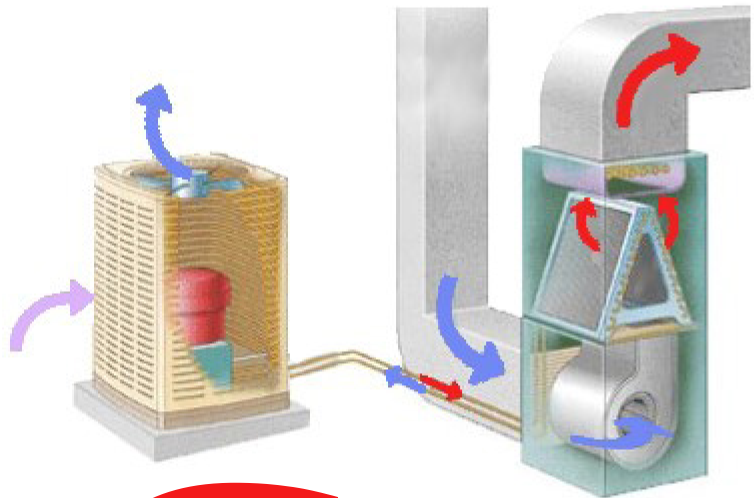

ASHP

Air Source Heat Pump Commissioning, Controls & Sizing Baseline Field Study Report

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Executive Summary

This field study gathered primary data to inform the current practice baseline model for residential air source heat pump, or ASHP, commissioning, controls, and sizing, or CC&S, in the Pacific Northwest region and to inform the BPA market model on installation context. The research team identified and examined residential ASHPs installed between 2015 and 2018, with a focus on CC&S practices. The team used permit data for the four-state region to identify homes with recently installed heat pumps and a mailer campaign to recruit study participants via web or phone survey. The team aimed for an equal study representation of homes east and west of the Cascades due to climate differences, and the expected experience level of heat pump contractors. Included in the study were all utility service territories, BPA's customer utilities, and investor-owned utilities.

The team completed 95 site visits almost evenly split between the regions east and west of the Cascades. Approximately half of the survey respondents indicated they participated in a rebate program to help with their heat pump installation; 37 of the homes visited participated in BPA's Performance Tested Comfort System®, or PTCS, program [1]. PTCS is intended to ensure CC&S specifications are met for every BPA-incented ASHP conversion and upgrade. Effective program penetration should be taken into consideration when determining the current practice baseline using data collected from this study.

A large majority of homes in the study are single-family detached homes that measure 1,000–3,000 square feet. More than half the homes in the study were built prior to 1980, and about a one third were built between 1980 and 2000. Approximately 5% of homes in the study are manufactured homes.

The research team originally designed the sample to achieve 10% relative precision at 90% confidence based on three assumptions:

- 70% probability that the heat pump contractor set the auxiliary heat lockout properly.
- A coefficient of variation, or CV, on heat pump sizing of 0.5.
- A sample size of 168 homes, specifically Interstate 84 east and west of the Cascades.

Based on the number of site visits completed, the observed rate of correct auxiliary heat lockout setting, and heat pump sizing CV, the team estimates achieved relative precision, or RP, at 90% confidence as shown in Table ES 1.

Table ES 1: Achieved Relative Precision

Domain	Site Visits	Auxiliary Heat Lockout		Heat Pump Sizing	
		Probability	RP	CV	RP
East	48	0.5	12%	0.24	6%
West	47	0.3	11%	0.23	8%

[1] This includes a variety of energy-efficiency programs in the region operated by BPA, its customer utilities and investor-owned utilities.

This report presents results summarized by domain, i.e., location relative to the Cascades, and other categories including PTCS or other utility program participation. The readers should note that only the findings summarized to the domain are statistically significant, while other summarized findings should be considered anecdotal because the study did not seek to represent the other categories with any statistical precision.

Overall, the field team found mixed results for heat pump installation practices meeting specifications. Table ES 2 presents a summary of the findings. Notably, only the controls practices were significantly more efficient for PTCS participants than the average regional practices. The commissioning and sizing practices found in the homes of PTCS participants were about the same as, or worse, than the general population.

Table ES 2: Percent of Installations that Meet PTCS Specifications

	Airflow	External Static Pressure	Refrigerant Charge	Auxiliary Heat Lockout	Compressor Lock Out	Sizing	HSPF
PTCS	67%	89%	68%	65%	84%	41%	95%
Other Utility Program	70%	91%	73%	14%	50%	44%	86%
No Program	67%	97%	75%	25%	72%	45%	56%
All Sites	67%	93%	72%	43%	72%	42%	78%

* 45% of homes had external static pressure readings below 100 Pascals which the research team considers to be too low but there is not a lower bound on the PTCS specifications.

† Sizing results presented here are based on the Ecotope heating load calculator. The team also used the PTCS sizing calculator and those results are presented in the report.

Overall Efficiency and Specifications

The research team found that 78% of observed heat pumps met or exceeded the PTCS program efficiency criteria of Heating Season Performance Factor, or HSPF, and Seasonal Energy Efficiency Ratio, or SEER. Given that only half of the field-study homes were program participants, it is encouraging that contractors and homeowners are selecting efficient heat pumps nearly 80% of the time.

Introduction & Background

This document reports on the findings from current practice baseline field study of recent ASHP CC&S practices in the region.

Research Objectives

This study has two objectives:

- Gather primary data to inform the current practice baseline model for residential ASHP CC&S in the Pacific Northwest region.
- Gather primary data to inform the BPA market model on installation context for new sales of residential ASHPs, as part of a larger model of all residential HVAC equipment.

This study gathered the data and the above-mentioned models will be run at a later date by another team. This document provides summaries of the data collected with a focus on providing the PTCS program team with insight into how the program may have changed the baseline over time and what the program should focus on going forward.

Background

The two research objectives listed above extend from efforts to update the Momentum Savings model and ASHP CC&S current practice baseline.

Momentum Savings Model

In 2015, BPA completed a study that delivered draft residential HVAC momentum savings from ASHPs. The 2015 study identified two major data gaps, which are discussed below. This report describes the findings of the field study undertaken to address Data Gap #2.

Data Gap #1: Installation Context. The 2015 study revealed that installation context is a main driver of the Momentum Savings results. The study team found that when an ASHP replaces an electric forced air furnace (a conversion), it yields much greater savings than when an ASHP replaces another ASHP (an upgrade). The study team did not have actual data on the split between conversions and upgrades in the market, and had to make assumptions in the model. Additionally, more data on the prevalence of fuel switching, installation quality, whether units are going into new construction or retrofit settings, and the mix of dwelling types (e.g., single family, manufactured homes, multifamily, and small-commercial establishments) would help reduce the uncertainty in the model and yield more robust results.

Data Gap #2: Representativeness of Sales Data. The Momentum Savings study team used sales data, which represented only a portion of the total market, in the 2015 model. BPA preferred additional corroborating data to ensure the results are robust and representative.

Since 2015, BPA has continued its research and developed a new residential HVAC model. Despite reflecting a major methodological overhaul and leveraging more recently available data to improve robustness, BPA's more recent modeling efforts, which concluded in 2019, would also benefit from additional data in both areas.

Commissioning, Controls and Sizing Current Practice Baseline

BPA's PTCS program requires every BPA-incented ASHP conversion and upgrade measure meet program CC&S specifications. The PTCS ASHP installation specifications can be found in *Appendix B: PTCS Specification*. The Regional Technical Forum, or RTF, develops savings values for residential HVAC measures, including those applied in the PTCS program. The measures include:

- ASHP Conversions Manufactured Homes, or MH
- ASHP Conversions Single Family, or SF
- ASHP Upgrades MH
- ASHP Upgrades SF (new and existing construction)
- CC&S SF (new and existing)
- CC&S MH
- New Construction Montana House 2 – ASHP
- Weatherization MH (heat pumps)
- Weatherization Single Family (heat pumps)

The reader can find the RTF specifications for the ASHP CC&S measures in *Appendix C: RTF ASHP CC&S Specifications*.

The RTF considers any measure that interacts with heat pumps in homes (e.g., weatherization) to be in "planning" status because the baseline needs to be updated. The RTF developed a draft research strategy[2] for determining the ASHP CC&S baseline to improve the reliability of the savings estimates.[3] The information collected through the current study will help the RTF update the provisional Unit Energy Savings, or UES, for the ASHP CC&S measure. The current study updates knowledge about installation practices, providing improved input assumptions for the CC&S baseline.

PTCS Program History

The Northwest has had an HVAC quality-install program since 1997. The first program was called Energy Efficient Air Distribution Systems, or ADS, which was a joint venture between the Northwest Energy Efficiency Alliance, or NEEA, and the Electric Power Research Institute, or EPRI. The goal of the program was to assess if "testing, retrofitting, and certifying of residential air distribution systems (ducts) for heating and cooling systems could be established as a viable, ongoing business in the Pacific Northwest," (NEEA, 2000). The program eventually decided to expand the scope of services to include all HVAC system improvements regardless of fuel type and also included weatherization services. In 1999, the expanded program was renamed Performance Tested Comfort Systems, and was set up to function as an independently run organization. The core functions of the program included performance testing, independent third-party certification of systems and contractors, and quality assurance and control. The program was meant to be a market-based program that generated revenue through contractor training and program certification fees. The program sought to be the premier source of information for residential HVAC and weatherization services.

[2] RTF CC&S research strategy: https://nwcouncil.app.box.com/s/dheg41o46n3beb43ztd6dxzscpmkikkq

[3] Background on the RTF research strategy presented at the December 2014 and March 2015 RTF meetings can be found on the RTF website: http://rtf.nwcouncil.org/archive.asp

In 2006, Bonneville Power Administration, which is a wholesaler of electricity from federally owned hydropower resources in the Northwest, assumed control and funding of the PTCS program. Due to BPA's role as an electricity wholesaler, they changed the scope of the program. PTCS became a heat pump quality-install program and also offered duct sealing services to electrically heated homes. The program no longer included weatherization services in its scope. The current program is funded and managed by BPA and serves ratepayers of 140 publicly owned customer utilities of BPA. The program continues to train and certify contractors to install air and ground source heat pumps, conduct duct sealing of distribution systems, and perform quality assurance and control of completed projects. PTCS-certified contractors serve customers across the region regardless of utility; therefore the effects of contractor training should extend to utility customers across the region.

Other Utility Programs

There are other utility programs in the region that provide incentives for heat pump equipment-efficiency standards and quality installation practices. Most of these programs are not as involved as PTCS in their installation specifications and quality control oversight; these programs effect the efficiency of heat pump installs throughout the region. The study reports many results by "PTCS", "Other Utility Program", or "No Program" to see the effect of programs. However, it should be noted that sites denoted as "Other Utility Program" used self-reported information provided by the homeowner. Program participation could not be independently verified. Details of the other utility programs are in *Appendix B*.

Previous Baseline Study

The only baseline study with onsite measurement of air source heat pump installation practices prior to this study was conducted in 2005 for NEEA and the regional Heat Pump Working Group (NEEA, 2005).[4] The 2005 study established the current RTF provisional baseline input assumptions for the unit of energy savings, or UES, calculations. The study included a billing analysis, field review of about 130 sites, laboratory testing, and interviews with installers and distributors. The field study gathered data on the heat pump size, the house heat-loss rate, heat pump controls (auxiliary heat lockout setting, compressor lockout setting) and evaporator airflow. The lockout settings bear directly on how much heating energy the refrigeration cycle produced in all heating bins. Heat pump output capacities came directly from the manufacturer-supplied curves (Carrier); process described in some detail (including impact of duct losses) in Francisco, et al. (2004). The 2005 study team grouped and applied control inputs frequencies to the various house prototypes to produce final estimates of house energy usage. The 2005 team re-ran the models with the assumption that PTCS cases would have a more efficient mix of control strategies and use properly sized heat pumps. The difference in usage between base and efficient case by prototype was then weighted by prototype occurrence and UES values resulted (by heating climate zone). Comparisons of this study to the 2005 study are presented in the results section of this report.

[4] Ecotope & Stellar Processes, "Heat Pump Installation Practices and Performance". NEEA. 2005.

Methodology

The research team sought to identify and examine residential ASHPs installed in the last three years, with a focus on CC&S practices. This section describes how the team determined the statistically significant number of homes to study, and recruitment and data-collection methods.

Sample Design

The team considered many factors when outlining the sample design, including the frame from which to recruit site visits; the variance of critical parameters such as location, dwelling type, and installation practices; and the desired confidence and precision.

ASHP Sample Frame

Locating the ASHPs represents the biggest challenge to conducting an ASHP field study. Neither the research team nor its predecessors were able to track down a comprehensive listing of ASHP installations in the region. Permit records capture a substantial portion of ASHP installation activity because jurisdictions typically require an electrical, and sometimes mechanical, permit application when an installer runs a new circuit or refrigeration line, and for all new construction. However, collecting permit records from all jurisdictions in the region was an undertaking of insurmountable complexity and unjustifiable expense. Fortunately, the team learned that data vendors compiled residential electrical and mechanical permit application records into a purchasable database, which covers ASHP installations across most jurisdictions in the region. One vendor, BuildFax, stood out for coverage of jurisdictions, count of heat pump records, customer service and low cost. The research team purchased more than 600,000 permit records from BuildFax to form the basis of the sample frame.

Table 1 presents the jurisdictional coverage, counts of permit records, and counts of unique heat pump homes by state from January 2015 to July 2018.

Table 1: Summary of BuildFax Permit Data, January 2015 – July 2018

State	Jurisdiction Coverage Rate*	Count of Permit Records	Count of Heat Pump Homes†
Washington	83%	278,237	14,012
Oregon	80%	278,929	11,943
Idaho	60%	41,730	2,418
Montana	40%	12,613	57
Total		**611,509**	**28,430**

* As provided by BuildFax in February 2018.

† Count after collapsing to unique property and eliminating inapplicable records. The permit data contained multiple permits per property, many non-residential properties, and many other records not relevant to residential HVAC installations.

The research team recognized this sample frame did not cover the heat pumps installed without a permit. The team was concerned about whether differences existed in practices between permitted and unpermitted installations; if so, a study of permitted installations would yield biased results. Fortunately, the team learned of a 2017 study for the California Public Utilities Commission, or CPUC, that concluded “permitting does not lead to increased energy efficiency of HVAC change outs.” (CPUC, 2017).

ASHP Sample Size

Sample designs primarily specify sample size by selecting confidence and precision targets, and identifying the expected variance in the population or probabilities of significant parameters. The research team considered variance in installation practices for these critical domains:

- Location.
- Dwelling types.
- New construction versus retrofit.
- Sizing decisions relative to site-specific conditions such as house heating load, system airflow, and duct losses.
- The discrete nature of controls set-up and commissioning (e.g., the installer either did it correctly or incorrectly).

The research team included Bob Davis of Ecotope, who played a significant role in the 2005 NEEA study. Drawing on his experience, the team determined installation practices likely do not vary significantly by dwelling type or between existing or newly constructed dwellings. The team also asserts that practices are unlikely to vary significantly between urban versus rural settings, reasoning that rural installers are likely from the same contractor pool as serves the nearest population center. Nonetheless, the field sample included enough rural installations to test this assertion. Installation practices could, however, vary significantly by location relative to the Cascades mountain range due to these considerations:

1. Uptake of ASHPs in the moderate climate of the more populated area west of the Cascades occurred earlier and faster than it did in the eastern area. The team thus expects the current base of installers in the west to be larger, more experienced and more competitive than the east.
2. ASHP installers in areas east of the Cascades have typically viewed heat pumps as central air conditioners with electric resistance heat, while in the west, installers recognize ASHPs are primarily used for heating.

To address this regional variance, the research team proposed two domains for the sample design, one for the area west of the Cascades and one for the area to the east. Within these domains, the team drew a simple random sample of homes, with an overall goal to provide enough diversity for the overall sample in terms of a rural/urban split.

The CC&S requirement for sizing (i.e., tonnage of heat pump) and various installer-set control settings —to reduce electric resistance heat usage and ensure compressor operation in temperature bins below 35°F — made it challenging to design a sample to obtain data on these items. Sample sizes were driven by the statistical criteria the research team sets and the team’s prior understanding of the probability of key metrics, in this case, the probability of controls being set up properly. The formula for such a discrete variable as proper/improper settings yields a sample size necessary to meet the statistical criteria that is largest when the probability is 0.5 (in this case, when half of the assessed systems are set properly and half are not). The team referred to the 2005 NEEA study data and noted that 30% of the sites had the outdoor thermostat (auxiliary heat lockout control) set up properly. Given that the outdoor thermostat is now part of residential code in Washington and Oregon, the team assumed a probability of 70%. This assumption yielded a sample size of 84 per domain when targeting ±10% precision at 90% confidence.[5]

To estimate the variance of the sizing value, the team also referenced the 2005 NEEA study and found its coefficient of variation for sizing was less than 0.5. The team applied a CV of 0.5 and calculated a sample size of 68 per domain to target ±10% precision at 90% confidence.

The team selected the larger sample size of 84 per domain to ensure a large enough sample to sufficiently cover the probability of the control settings. BPA subsequently concluded it did not have enough funds to conduct 168 site visits and set the study limit at 100, or 50 per domain.

Table 2 presents the final sample design. The researchers recruited site visits by sending letters directing people to a web survey, which assessed the presence of qualifying equipment and the householder's willingness to be visited. The team anticipated 10% of letter recipients would respond to the letters and take the survey and 40% of survey respondents would agree to a site visit. The research team planned to send approximately 2,500 initial letters and reminder letters to recruit survey respondents until the team successfully completed 100 site visits.[6]

Table 2: ASHP CC&S Sample Design

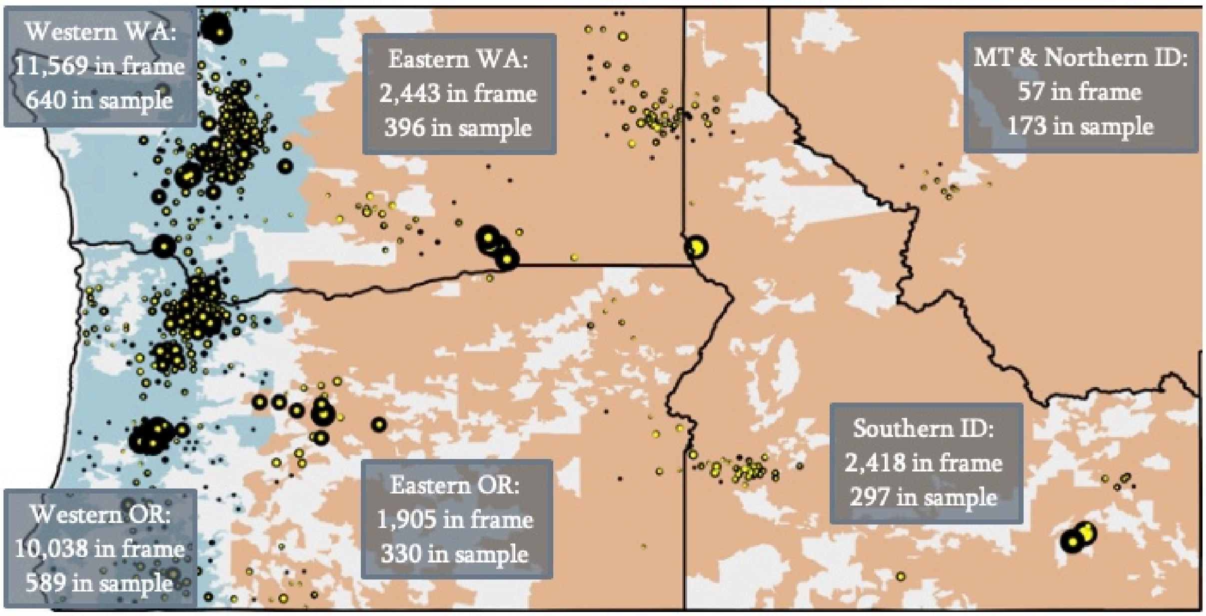
Domain	Target Confidence/ Precision	Probability	Site Visit Sample Size	Rate of Agreeing to Site Visit	Required Survey Responses	Eligible Response Rate	Initial Letters	Population
East	90% / 13%	0.7	50	40%	125	10%	1,250	6,823
West	90% / 13%	0.7	50	40%	125	10%	1,250	21,607
Total			**100**		**250**		**2,500**	**28,430**

The team observed some addresses in the sample frame that appeared to be a central office to a large complex of homes such as mobile home parks. The drawn sample selected only a few of these and the team replaced them with addresses to individual homes.

Figure 1 presents the distribution of heat pump homes (black circles) and sampled homes (yellow circles) in the region. The circle sizes represent the count of properties in the zip code. The blue background is the west sample domain and orange background is the east sample domain.[7]

[5] The team set the t-statistic to 2 instead of 1.645 based on the guidance of Scheaffer et al in *Elementary Survey Sampling* (Sheaffer. 1986).
[6] As discussed in Survey Disposition, below, the study team ultimately sent letters to 2,883 households, obtaining a 15% survey completion rate, with 43% of respondents agreeing to be contacted about a site visit. Conversion from agreement to be contacted to completion of a site visit was, in the end, lower than expected and the team completed 95 site visits.
[7] The unshaded areas reflect areas unmapped by the GIS. The map excludes central and eastern Montana because the sample frame included no heat pump properties in those areas.

Figure 1: Map of Sample Distribution



Recruitment and Data Collection

Survey of Households in the Heat Pump Permit Records

The research team conducted a short mail-to-web survey of a sample of households in the heat pump permit dataset. The survey verified heat pump installation in the respondent's home in the past three years, recruited households for onsite visits, and collected data about other important home and HVAC characteristics. The team achieved a 15% survey response rate using the survey methods discussed in the sections below.

Survey Recruitment

The team mailed 2,883 households an invitation letter asking them to complete the survey online or call the research firm to complete the survey by phone.[8] The team sent out 1,667 reminder letters to nonresponding households in western Oregon, eastern Oregon, and western Washington.[9] Both survey letters included a URL to the survey website, a unique passcode, and a phone number to call if the respondent preferred to complete the survey by phone.

The invitation letter introduced the research study, and the follow-up letter reminded those who had not responded to do so before the data-collection period ended. Both letters also explained the study's purpose, why households should respond, which member of the household should respond, who to contact for questions and how respondents could receive their incentive for completing the survey.

[8] The team also considered recruiting study households via a phone survey but permit data do not include households' phone numbers and vendor-supplied phone numbers can be costly and yield matches typically between 50% and 80%.
[9] The team observed the response rate was lower for the reminder letters so chose to send letters to different addresses in eastern Washington, Idaho, and Montana instead of reminder letters to the previous addresses.

The team printed invitation, reminder letters and envelopes featuring BPA's logo.[10] The team offered sampled households an incentive to complete the survey to help improve response rates and reduce the costs per completed survey.[11] The invitation and reminder letter envelopes included a box that read "Complete our survey, get a $25 gift card" to motivate households to take the survey. The team provided survey respondents with a $25 Tango e-gift card immediately after they submitted their survey online. Tango gift cards provide recipients a variety of retailer options to choose from, such as Amazon, Starbucks and Target. The team offered households completing the survey by phone the option of a Tango e-gift card or a physical Visa gift card sent via mail. Most callers chose the card sent by mail.

Study Pilot

The team piloted the survey and field recruitment prior to full-scale launch to estimate the likelihood an invitation letter recipient would qualify for, agree to, and participate in the field research. The analyses and onsite visits included households that responded to the survey pilot as well as the full-scale survey.

The pilot study occurred in September 2018. The team mailed initial and reminder letters to 910 households across Inland Power's and Puget Sound Energy's service territories. The pilot letters and envelopes included BPA, Inland Power and Puget Sound Energy logos. Responses to the mail-to-web survey began one day after the invitation letter was mailed. Within the first week, 128 households completed the survey (a 14% response rate). The team mailed a reminder letter one week after the first letter was sent out. An additional 160 households completed the survey after the second mailing for a total recruitment survey completion of 288 households (32%).

Following the pilot, the research team launched the full-scale study in late 2018. In the full-scale survey effort, the recruitment letters and envelopes only featured BPA logos due to the large number of utility service territories spanned by the sample. Perhaps as a consequence, the full-scale study response rate was about half that of the pilot (15%; see Survey Disposition, below).

Survey Design

The survey verified whether the households installed a heat pump in the home or in an additional dwelling unit(s) on their property in the past three years. A series of questions assisted respondents in correctly identifying and reporting the type(s) of residential HVAC equipment in their home to help reduce the potential for self-reporting errors. The survey first used a list to ask respondents what type of HVAC equipment is in the home. The survey included a follow-up question to reduce uncertainty and narrow the list of heat pump systems that could be in homes. This question on the web version included images of each heat pump system type, while the phone survey included verbal descriptions of each type.

The survey then asked respondents who reported having a heat pump in their home to verify whether they installed the heat pump during the previous three years. The research team designed the survey to capture heat pumps installed in newly-built and existing homes.

Questions in the survey about respondents' HVAC and home characteristics helped the field team select households to contact for onsite visits and/or inform the market model. Important details included the

[1010] Response rates to mail-based surveys are often significantly higher when the outreach materials are sponsored by an organization with which respondents have a relationship (e.g., their utility) or an established institution (e.g., federal/state agencies, colleges/universities, etc.), compared to providing no sponsorships or sponsorships by private research or marketing firms (Dillman, Smyth, & Christian, 2014; Edwards, Dillman, & Smyth 2014).

[11] Singer & Ye, 2013; Dillman, Smyth, & Christian, 2014.

respondent's dwelling type, number of heat pumps serving the home, if the respondent is a homeowner or renter and what type of equipment the heat pump replaced. Other important characteristics included if the respondent received a rebate or discount to install or purchase their heat pump, if the home has a basement or crawlspace, the home's square footage (size categories), number of floors and year the home was built. The survey also asked respondents to report some demographic characteristics, such as their education level and household income.

The survey concluded with asking respondents who reported having a recently installed ASHP whether they were willing to participate in an onsite visit from a field engineer and, if so, how and when to best reach them for scheduling. The survey included an introduction that explained the purpose and benefits of the onsite visit, including the $50 incentive participants would receive, and what to expect regarding scheduling and visit details. The research team used the answers to contact respondents to schedule and confirm onsite visits.

Survey Disposition

Tables 3–5 provide the dispositions for the pilot survey, the full-scale survey and the total study (pilot and full-scale combined).

Table 3 provides the recruitment survey's disposition during the pilot phase. The team sent the mailings to heat pump permit households in two utility-service territories. The mailings used the logos of BPA and the two utilities. Almost one-third (32%) of those who received survey recruitment letters responded to the survey. A bit fewer than half of those respondents (44%) were both eligible for the site visit and willing to be contacted for scheduling.

Table 3: ASHP CC&S Pilot Survey Disposition

Domain	Sample (Mailing Sent)	Responded to Survey	Survey Response Rate	Eligible for and Agreed to Site Visit	Rate of Agreeing to Site Visit	Visited During Pilot	Visited During Full Study
East	410	113	28%	55	49%	2	6
West	500	175	35%	71	41%	2	9
Total	**910**	**288**	**32%**	**126**	**44%**	**4**	**15**

Table 4 provides the recruitment survey's disposition during the full-scale study period. The team sent the mailings to heat pump permit households across BPA territory. The mailings featured only the BPA logo. Fifteen percent of those who received survey recruitment letters responded to the survey. Fewer than half of those respondents (43%) were eligible for the site visit and willing to be contacted for scheduling.

Table 4: ASHP CC&S Full-Scale Survey Disposition

Domain	Sample (Mailing Sent)	Responded to Survey	Survey Response Rate	Eligible for and Agreed to Site Visit	Rate of Agreeing to Site Visit	Visited
East	1,518	194	13%	97	50%	40
West	1,365	244	18%	93	38%	36
Total	**2,883**	**438**	**15%**	**190**	**43%**	**76**

Table 5 provides the total ASHP CC&S study disposition, combining the pilot and full-scale recruitment survey results. Across the pilot and full-scale survey, the team sent nearly 3,000 letters. Approximately one-third of the letters featured logos of BPA and two utilities, and two-thirds featured only BPA's logo. Across the pilot and full-scale survey, 19% of households responded to the survey and 44% of these were eligible for and agreed to be contacted for a site visit.

Table 5: ASHP CC&S Study Recruitment Survey Disposition - Combined

Domain	Population	Sample (Mailing Sent)	Responded to Survey	Survey Response Rate	Eligible for and Agreed to Site Visit	Rate of Agreeing to Site Visit	Goal Site Visit Sample Size	Visited
East	6,823	1,928	307	16%	152	50%	50	48
West	21,607	1,865	419	22%	164	39%	50	47
Total	**28,430**	**3,793**	**726**	**19%**	**316**	**44%**	**100**	**95**

Site-Visit Recruitment

The team used survey responses to identify households with recent heat pump installations that were willing to participate in the onsite visits (qualified households). The field team began scheduling onsite visits with qualified households upon receipt of web survey responses (delivered daily by the surveying team), contacting qualified households via their preferred method (phone or email), as indicated in their survey response. When scheduling the onsite visits, the field team explained the purpose and details of the visit and the incentive provided to participants, as well as answered the household's questions.

Site-Visit Data Collection

The field team administered a brief survey of participants during the onsite visits. The onsite survey confirmed answers from the web survey, including questions about any problems participants experienced with their heat pump since it was installed, how they use their heat pump, their satisfaction, utility program participation and what equipment the heat pump replaced.

The research team developed and applied a site data collection protocol that took the field engineers up to six hours to complete.[12] This protocol is in *Appendix E: Data Collection Protocol.* The field engineers assessed:

- Heat pump control settings.
- Information needed to establish a house heat loss rate.
  - Area and insulation of heat exchanging surfaces.
  - Ducting system performance.
  - House airtightness.
- Indoor and outdoor unit nameplates.

[12] Unlike the 2005 NEEA study, the current study did not include a detailed heat pump refrigerant charge assessment or duct leakage test. The team determined that data from these tests were less relevant to study objectives than the other data the lengthy field visit focused on collecting.

- Heat pump lockout control settings.
- Fan-flow rate.
- External static pressure.
- Temperature change across coil.

Overall, heat pump performance depends on the combination of these elements, especially the nominal capacity of the heat pump (compared to house heat loss rate) and the heat pump control settings. Properly set, the controls should keep the compressor operating during almost all heating hours and keep electric resistance heat off during milder outdoor conditions.

The field engineer gave each study participant a $50 gift card upon onsite visit completion.

Training

The research team employed experienced engineers to conduct the field work and the field team underwent training before conducting onsite visits. The research team held a two-day classroom session, followed by work at two sites with significantly different characteristics and ample time for a debrief. The training ensured engineers were well-versed in items such as assessing system controls (thermostats, zoning controls), using airflow measurement tools and assessing the residence (house and ducts). The training also addressed subjects such as interacting with householders, moving efficiently when in the field and prioritizing efforts.

Bob Davis of Ecotope, the field director of the 2005 NEEA onsite survey, organized and conducted the training and provided primary input for field protocols and the accompanying documents form and content (e.g., thermostat technical guides). Mr. Davis also provided technical consultation to the field team as needed during site visits.

Analysis

The field team conducted a brief survey and inspected and documented various aspects of the home including but not limited to: number of occupants, number of appliances, HVAC operating habits, locations of major HVAC components, house thermal-shell types and dimensions. The team collected thermostat schedules, and compressor and auxiliary heat lockout temperatures. In some cases, the team could not find the relevant thermostat settings or the settings were disabled.

The team measured static supply and return pressures, and airflow at the indoor unit either by using a dedicated test mode or by calling for a 10 degree Fahreneit temperature change at the thermostat. Field engineers measured Normal Supply Operating Pressure, or NSOP, with the system filter in place and with TrueFlow, or TFSOP, replacing the filter. The square root of the ratio between NSOP and TFSOP created a correction factor the team used to account for the difference in measured flow and actual flow conditions. The difference between NSOP and return plenum pressure — taken downstream of the system filter and upstream of the indoor unit coil — yields the external static pressure.

The team measured the sensible temperature split across the indoor unit, in either heating mode or cooling mode depending on outdoor air temperature. In heating mode, the team measured the entering dry bulb temperature, or EDB, in the return ductwork just before the indoor unit filter and the leaving dry bulb temperature, or LDB, in the supply ductwork just after the indoor coil. In cooling mode, the team measured the entering wet bulb temperature in the return ductwork. Field engineers compared the resulting estimated sensible split to data in American Society of Heating, Refrigeration, and Air-Conditioning Engineers (ASHRAE) R-

410a lookup tables to determine whether the split met expected targets. Low temperature splits often indicate insufficient refrigerant charge. There is a more accurate way to assess refrigerant charge which involves connecting gauges to refrigerant lines; however, that process is invasive and requires someone with a certification to handle refrigerant to conduct the test. For these reasons, the study used air temperature split to assess refrigerant charge.

Field engineers ran a Blower Door test at 50 and 25 pascals (Pa) with respect to outdoor air pressure to determine rates of indoor air leakage in cubic feet per minute. The test was run in pressurization mode to reduce the chance of back-drafting and other problems. During these tests, engineers verified that all fenestration was closed, and that the air handler and all ventilation fans were turned off. The team combined the leak volume flowrate with an estimate of house volume to determine the air changes per hour at the test pressure.

The team also ran supply duct leak tests at 50Pa and 25Pa with respect to outdoor air pressure on supply ducting outside the conditioned space. The team ran Blower Door fans concurrently with these tests to reduce the pressure difference between the ducting and the house. This had the added benefit of eliminating from the leak measurement duct leaks into the house, which in fact contribute to meeting space conditioning demands. During this test the field engineers blocked off flow returning to the air handler and sealed all supply registers in the house. The ratio between supply duct leakage at 25Pa and the maximum flow rate through the air handler yields an approximation of useful heat lost through supply ducts under normal operation.[13]

The team identified house materials and insulation levels through visual inspection and discussions with the householder. Documented envelope characteristics included areas and orientations of windows, doors, walls, ceilings, floors, and the construction type and insulation levels.[14] The combined dimensions and observed characteristics yielded nominal values for envelope inputs in the PTCS[15] and Ecotope heat pump sizing calculators.

The Ecotope and PTCS calculators differed in some key aspects:

- The Ecotope calculator used detailed surface area types and their orientations, insulation, window constructions and orientations, number of inhabitants and number of appliances. The calculator allowed detailed numerical inputs for house and duct leakage rates, and cooling design temperature. The team used ASHRAE climatic design conditions for 2017 as cooling design temperatures.[16] The outputs included a heating design load and a cooling design load. The heating design output was calculated at 30 degrees Fahrenheit. The team recalculated heating output at 47 degrees Fahrenheit using the heat pump temperature performance curves from PTCS tool.
- The PTCS tool used simplified entries to calculate the minimum required heating capacity for the home with the goal of achieving a 30 degrees Fahrenheit or lower balance point. It required inputs of heat pump type (single speed, two speed or variable speed), heated floor area, total window area, foundation type, number of stories above grade, nominal insulation levels for walls, attic, floor, basement, and slab, nominal window type, selection of approximate whole house air leakages and selection of approximate duct leakage.

[13] Only supply leakage was measured since it is a much more significant aspect of duct loss than return leakage in the Pacific Northwest. Using a one-sided test also saved time in an already lengthy field protocol. Other methods may yield more accurate results in sizing calculations. Many of ducting parameters collected are estimated based on the ducting observed. These methods are discussed in the Issues for Future Research section.
[14] The team also visually estimated duct diameters, duct lengths, and R values. These estimated values, combined, yield an estimated conduction loss at an assumed design temperature at the ducting location, and an assumed return leakage. While the team recorded these values, it did not speculate on their contribution to heat losses.
[15] The team used the most recent, generally available version of the PTCS sizing calculator, which was released in December 2015.
[16] The team used 1% DB conditions in cooling load calculations. More cooling oriented design conditions would result in higher cooling loads.

The team determined installed heating capacity for each house using the indoor and outdoor unit model numbers in the Air Conditioning, Heating, and Refrigeration Institute (AHRI) directory of certified product performance and taking the heating capacity measured at 47 degrees Fahrenheit. This heating capacity was compared to the minimum required heating capacity calculated using the Ecotope calculator allowing for ±½ a heating-ton variance to determine if the unit was sized appropriately for the home.

Results

This section summarizes the survey responses and site-visit data.

Survey Responses

Of the 726 responses to the pilot and full-scale survey —288 and 438, respectively — 709 households indicated they have a centrally ducted heat pump for heating and cooling their home. Fifty-seven of those were installed before 2015, which the study excluded. Additionally, four respondents indicated their house type is multifamily with five or more attached units, which the study also excluded. These exclusions left the study with 648 eligible responses. Fourteen respondents rented their home, eight of whom expressed interest in a site visit though only one was able to gain permission from the owner. Of the 648 eligible households, 316 initially indicated interest in a site visit. Ultimately, the team was able to recruit and complete site visits at 95 of these households.

The recruitment survey included questions about the home, its heating and cooling equipment, and household demographics. The team confirmed, and in some cases corrected, these responses during site visits. The following tables summarize the data collected about the homes and demographics.

Home Characteristics

Program participation was split fairly evenly overall and by domain, as seen in Table 6.

Table 6: Respondent Indication of Program Participation

Domain	Survey Respondents		Visited		
	Any Program*	None†	PTCS	Other Utility Program	No Program†
East	131	176	23	6	19
West	172	247	14	16	17
Total	**303**	**423**	**37**	**22**	**36**

*The survey asked if the household received any incentive for installing the heat pump. BPA provided the study team which visited homes had been participants in the PTCS program specifically. The team could not determine if the homes had also participated in other programs.

† Includes "don't know" and blank responses.

Table 7 shows the existing heating and cooling equipment in the home the new heat pump replaced or supplemented, according to the survey respondents.[17] Approximately half of the respondents did not know or did not provide a response. Among those who did, the responses indicate that in the east, heat pumps comprise majority of supplemented or replaced equipment. In the west, furnaces were the majority of supplemented or replaced equipment, both electric and gas. Also west of the Cascades, the field team encountered 20 hybrid

[17] The survey did not distinguish electric or gas furnace, nor whether the new heat pump replaced or supplemented existing equipment.

systems of a heat pump plus gas furnace. Notably, there are a not insignificant number of “Other” equipment types reported, including central air conditioners (34) and baseboard heat (11).

Table 7: Type of Equipment Replaced or Supplemented

Domain	Survey Respondents				Visited			
	Furnace	Heat Pump	Other	No Response	Furnace	Heat Pump	Other	Unknown
East	38	93	26	150	16	26	5	1
West	85	72	41	221	20	21	6	0
Total	**123**	**165**	**67**	**371**	**35**	**47**	**11**	**1**

Among the 621 respondents who reported house type, 94% reported single-family homes, 4% reported manufactured homes, and the remaining reported small multifamily with four or fewer attached units, as shown in Table 8. The distribution of home types was fairly consistent on both sides of the Cascades, though there were proportionately more manufactured homes reported in the east.

Table 8: House Type

Domain	Survey Respondents				Visited	
	Single Family	Manufactured Home	Small Multifamily	No Response	Single Family	Manufactured Home
East	246	15	4	42	44	4
West	337	10	9	63	46	1
Total	**583**	**25**	**13**	**105**	**90**	**5**

As shown in Table 9, approximately 14% of respondents did not indicate home size. Among those who did, 80% reported home sizes 3,000 square feet or less with 96% of those between 1,000 and 3,000 square feet (per respondent self-report). This is fairly consistent among households on both sides of the Cascades.

Table 9: House Size

Domain	Survey Respondents			Visited	
	3,000 SF or less	Over 3,000 SF	No response	3,000 SF or less	Over 3,000 SF
East	214	51	42	45	3
West	289	71	59	40	7
Total	**503**	**122**	**101**	**85**	**10**

Table 10 shows home vintages. Again 14% of respondents did not report home age. Of those who did, 54% indicated their homes were built before 1980, 30% were built 1980 to 2000, and the remainder were built in the

2000s. According to the survey responses homes to the east of the Cascades tend to be newer than those to the west.

Table 10: House Vintage

Domain	Survey Respondents				Visited			
	Prior to 1980	1980 to 2000	After 2000	Don't know	Prior to 1980	1980 to 2000	After 2000	Don't know
East	121	92	53	41	24	16	8	0
West	217	98	43	61	28	16	3	0
Total	**338**	**190**	**96**	**102**	**52**	**32**	**11**	**0**

Table 11 shows house foundation type distribution. Fifty percent of respondents indicated other or did not respond. Of those that did provide an answer, 72% indicated crawl space and 28% reported basement.[18]

Table 11: House Foundation Type

Domain	Survey Respondents			Visited		
	Crawl Space	Basement	Other/ Don't Know	Crawl Space	Basement	Other/ Don't Know
East	119	46	142	31	11	6
West	142	57	220	25	12	10
Total	**261**	**103**	**362**	**56**	**23**	**16**

Household Demographics

Among respondents who answered the demographic questions, 60% are in the middle-income range of $50,000 to $150,000; this income range comprised 72% of the homes visited (Table 12). This distribution was consistent among respondents and field-study participants on both sides of the Cascades. Note: nearly 40% of respondents did not indicate income level.

[18] The survey did not distinguish between conditioned and unconditioned basements.

Table 12: Household Income

Domain	Survey Respondents				Visited			
	Less than $50k	$50k to $150k	More than $150k	No Response	Less than $50k	$50k to $150k	More than $150k	No Response
East	32	132	30	113	4	27	7	10
West	31	134	86	168	3	21	5	18
Total	**63**	**266**	**116**	**281**	**7**	**48**	**12**	**28**

As shown in Table 13, about 25% of respondents did not indicate level of education. Of those who did, nearly 50% reported to have an occupant with a graduate or professional degree, while the remainder has some college education, or completed an associates or bachelor's degree.

Table 13: Level of Education

Domain	Survey Respondents				Visited			
	High School	College	Graduate/ Professional	No Response	High School	College	Graduate/ Professional	No Response
East	11	125	92	79	0	19	21	8
West	13	150	160	96	0	15	21	11
Total	**24**	**275**	**252**	**175**	**0**	**34**	**42**	**19**

Anecdotally, the field team observed that many of the participants recruited for site visits were retirees, presumably because they could be home for the six-hour site visit during the week.[19] However, the team does not believe this employment status biases the study findings. Heat pump installation practices are more likely to vary based on home energy use or heat pump performance than on the age of home occupants.

Site-Visit Results

Based on the number of site visits completed, the observed rate of correct auxiliary heat lockout setting and heat pump sizing CV, the team estimates achieved relative precision at 90% confidence as shown in Table 14.

Table 14: Achieved Precision

Domain	Site Visits	Auxiliary Heat Lockout		Heat Pump Sizing	
		Probability	RP	CV	RP
East	48	0.5	12%	0.24	6%
West	47	0.3	11%	0.23	8%

[19] The field team did conduct a few site visits on weekends to accommodate recruited participants who could not be home on a week day.

This report contains results summarized by 1) PTCS Program 2) Other Utility Program 3) No Program. Other utility programs that provide incentives for air source heat pumps are shown in Table 15, including program requirements. In general, the other utility programs are not as stringent as PTCS regarding installation practices — apart from Idaho Power, which has very similar requirements to PTCS. Energy Trust of Oregon and Puget Sound Energy have quality installation requirements that are part of a separate rebate and do not have as many requirements and specifications as PTCS.

Of the 95 homes visited, 37 participated in the PTCS program; 23 homes in the east and 14 in the west. While not statistically significant, this is enough to consider results by PTCS program participation and provide insight on how the program may affect the current practice baseline, and suggest areas where the program should focus improvements.

The PTCS program requires heat pumps to meet the U.S. Department of Energy, or DOE, minimum HSPF and SEER. Fifty-five percent of heat pumps had an HSPF equal to or greater than nine, while 23% had an HSPF equal to or greater than 10. Therefore, 78% observed heat pumps met or exceeded the PTCS program efficiency criteria. About one-third of the homes visited had variable speed heat pumps; 13 homes in the east and 22 in the west.

Heat Pump Equipment Efficiency

The PTCS program requires a minimum HSPF of 9.0 to qualify for heat pump upgrade or conversion incentives. Seventy-eight percent of all sites had an HSPF greater than 9.0 while 95% of PTCS sites had an HSPF greater than 9.0. Sixty-seven percent of Other or No Utility Programs had an HSPF greater than 9.0. Figure 2 shows HSPF by program participation and Figure 3 shows the distribution of HSPF for all sites.

Figure 2: HSPF of Heat Pump Equipment

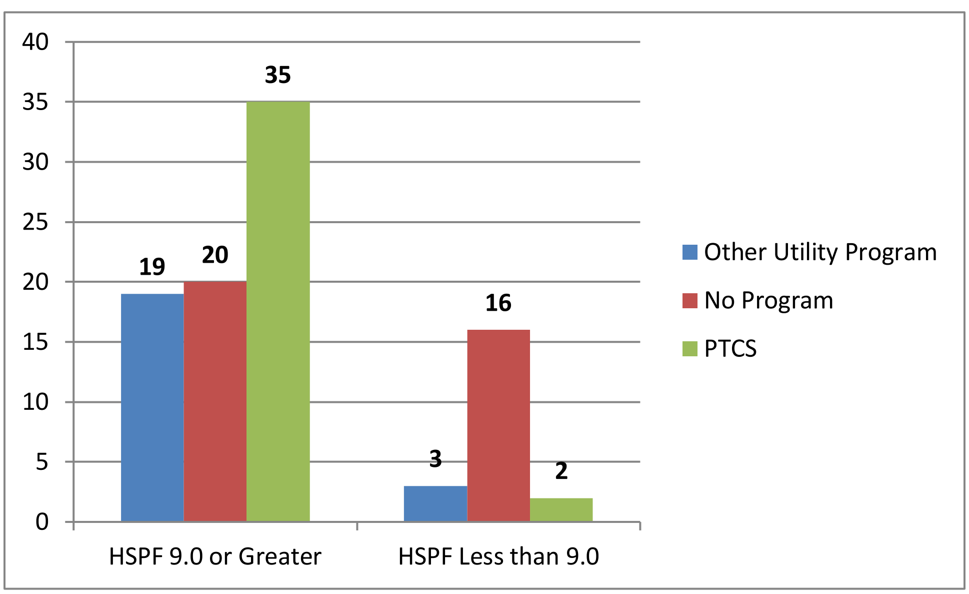
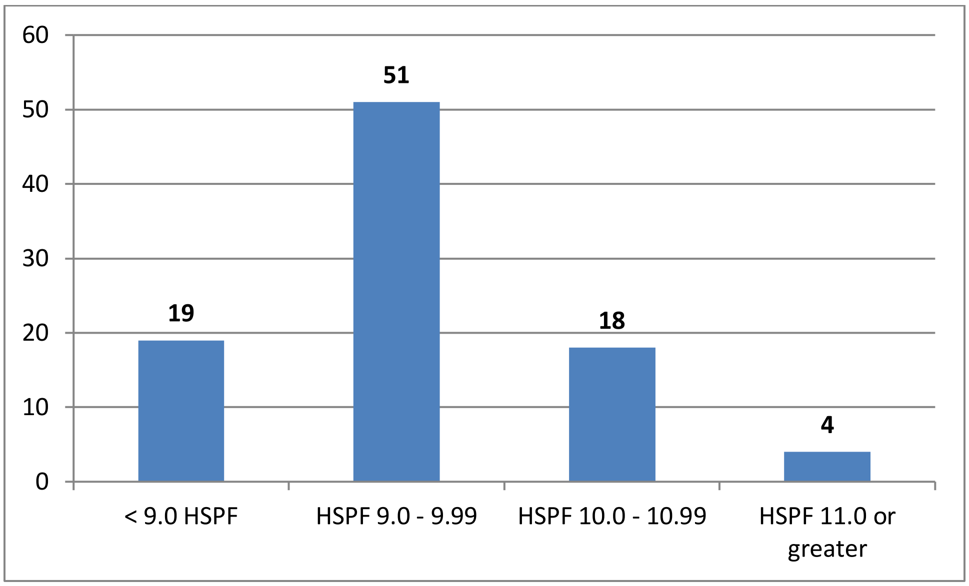


Figure 3: Distribution of HSPF of Heat Pump Equipment

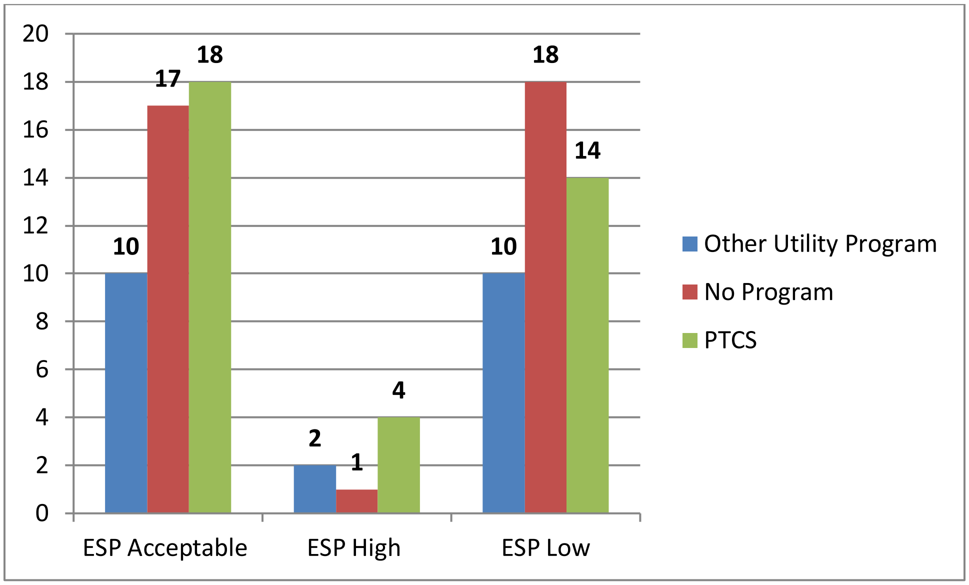


Commissioning

External static pressure measures the pressure exerted on the interior surface of the ducts and the resistance that air encounters as it moves through the ducts. High static pressures indicate improperly sized or designed duct systems. Figure 4 shows the number of homes with static pressures in acceptable, low or high ranges according to PTCS program participation and locations relative to the Cascades. The PTCS program requires pressure does not exceed 200 Pa or 0.8 inches of water. There is no minimum requirement in the program because duct sealing or duct redesign is not required for heat pump installation. However, the team flagged static pressures below 100 Pa as Low. Low static pressure often indicates leaky ducts or low fan speed. Excessive static pressure could be reduced by adjusting air flow in the air handler.

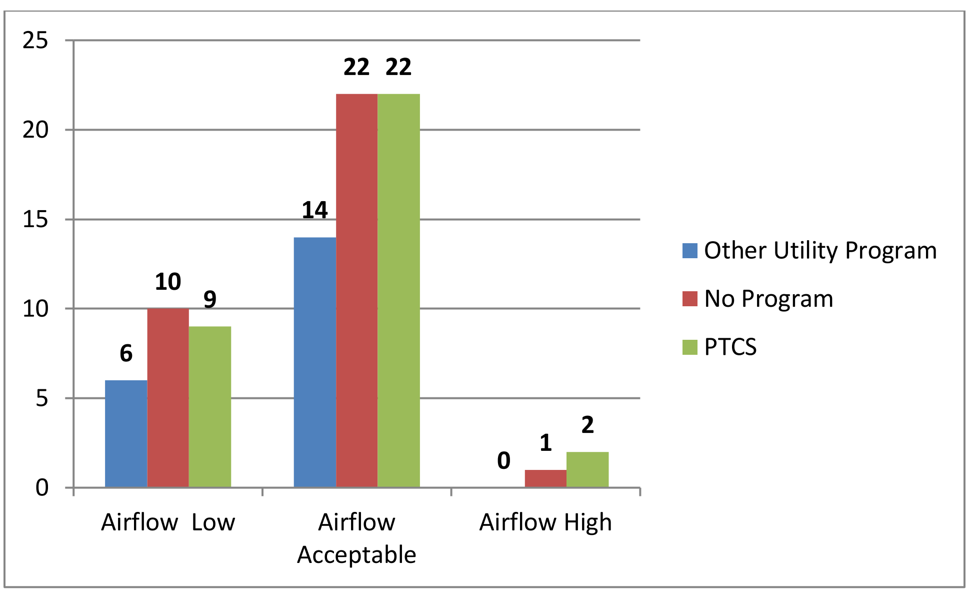
As Figure 4 shows, 48% of homes had static pressure in the acceptable range of 100 Pa – 200 Pa, and 45% had readings under 100 Pa. This proportion is stable across other utility programs, PTCS and No Utility Program. However, results varied by location with acceptable static pressure readings in 58% of homes in the east, 36% in the West and low readings in most of the remaining homes on both sides of the Cascades. There were seven homes with static pressures exceeding the acceptable range, of which four were program participants. Generally, the pressure readings among the PTCS participant homes closely matched the overall population.

Figure 4: Assessment of External Static Pressure on Duct Systems (Pascals)



The team measured airflow across the indoor coil to determine if it was sufficient enough to carry useful heat from the heat pump evaporator coil. Low flow affects the capacity of the heat pump to deliver heating and cooling efficiently. The team assessed if the airflow was acceptable based on the PTCS criteria of 325 – 500 Cubic Feet per Minute (CFM) per heating ton. Figure 5 shows the number of homes with airflow in the acceptable, low and high ranges according to program participation. Thirty percent of sites were found to have low airflow; this proportion is stable across Other Utility Programs, PTCS, and No Program.

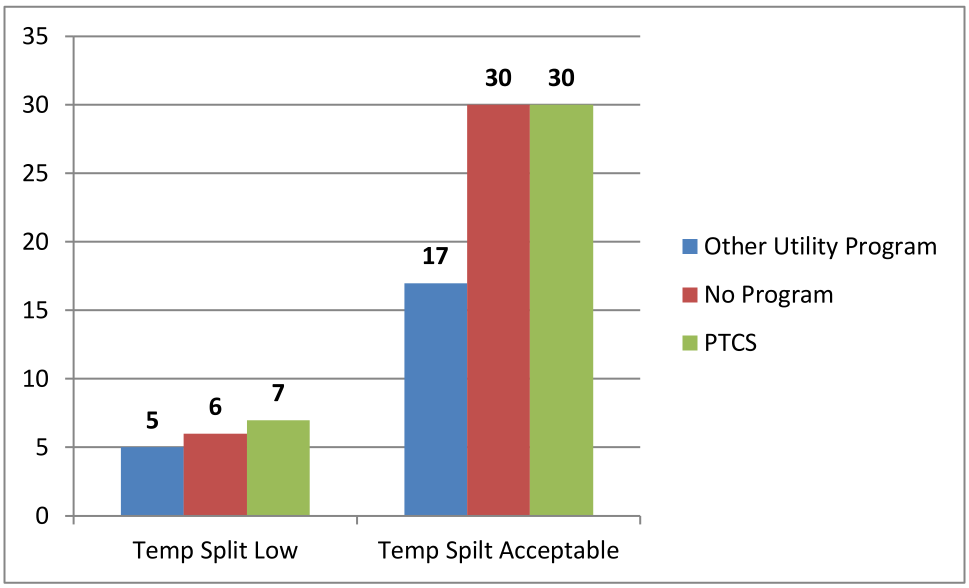
Figure 5: Assessment of Airflow Across the Indoor Coil (CFM per Ton)



The team measured temperature change across the air handler indoor coil to indirectly determine if the heat pumps had enough of a refrigerant charge. A low temperature split could indicate the heat pump had a less than ideal[20] refrigerant charge, low flow on the exterior fan, or problems with the compressor. The team calculated the required temperature split in heating mode for each home then compared it to the observed temperature split.

Figure 6 shows the number of homes by temperature split result according to program participation. The method used to assess refrigerant charge was air temperature split across the indoor coil, This method is not as accurate as using refrigerant gauges, so to account for measurement error, sites whose temperature split were more than 15% less than the required split are considered to have a low reading and likely have low refrigerant charge. Twenty-one percent of sites were found to have low refrigerant charge and 79% of sites were found to have an acceptable refrigerant charge. Other Utility Programs have the largest proportion of sites with low refrigerant charge, while PTCS and No Program Sites have a similar rate of low refrigerant charge.

Figure 6: Assessment of Temperature Split Across the Indoor Coil (Degrees Fahrenheit)



Controls

The auxiliary heat and compressor lockout controls are one of the most critical elements for energy efficiency of air source heat pumps in heating mode. The compressor should be operated as much as possible to produce heat instead of the auxiliary electric resistance heating elements. The team documented these control settings from the thermostat HVAC contractor setup menus. The contractors chose most of the settings during the installation, but the homeowners may have changed them.

Figure 7 shows the number of homes by whether the auxiliary heat lockout controls were set correctly according to program participation. Overall, 47% of homes had auxiliary heat locked out above 35 degrees Fahrenheit, indicating that the region still has a lot of savings potential in heat pump controls. The PTCS program is effective at ensuring efficient auxiliary heat lockout controls with 75% of PTCS sites having the correct lockout setting. Sites that were in Other or No Utility Programs largely did not have efficient auxiliary lockout settings as only 27% of these sites had settings PTCS considers efficient. Figure 8 shows the most common inefficient auxiliary

[20] The system airflow is within the manufacturer's recommended range and no other problem (such as a blocked refrigerant metering device) is known or suspected.

heat setting was to have the lockout disabled, which allows the manufacturers default settings to take over. Sites where the thermostat did not have a setting for auxiliary lockout controls were counted as disabled.

Figure 7: Assessment of Auxiliary Heat Lockout Setting

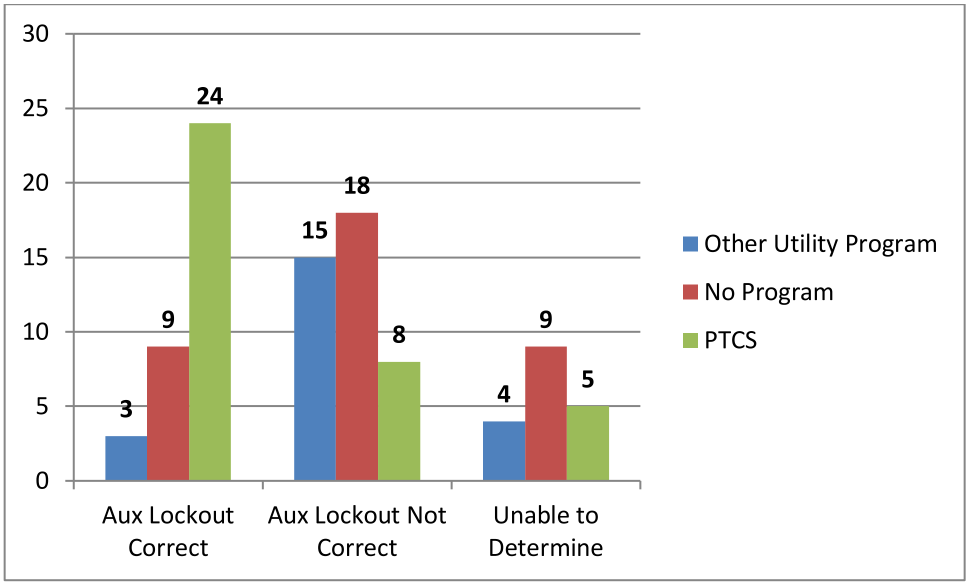


Figure 8: Assessment of Inefficient Auxiliary Heat Lockout Settings

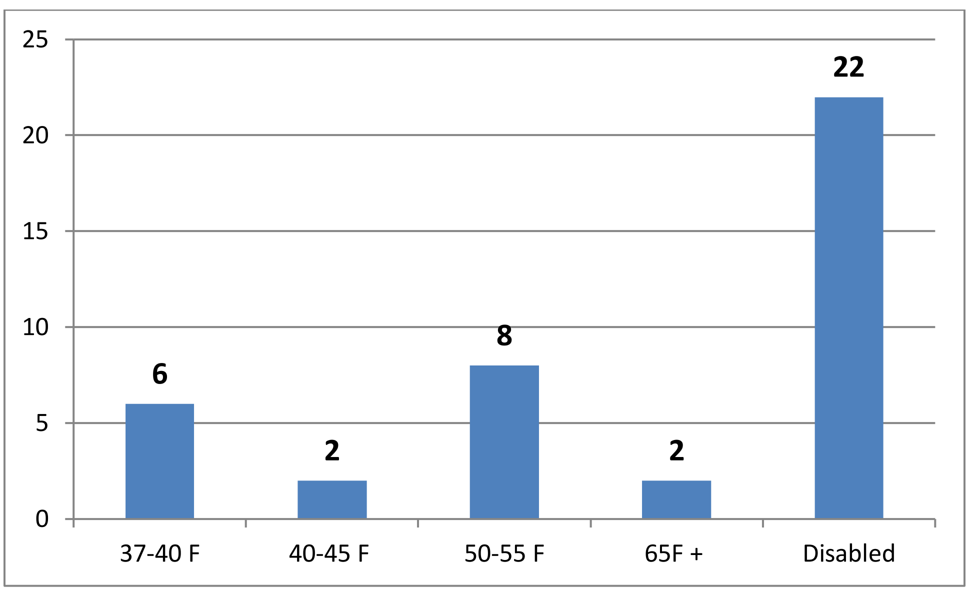


Figure 9 presents the results of the compressor lockout assessment. Most sites (72%) had the compressor lockout set correctly according to PTCS specifications of disabled or above 5 degree Fahrenheit or lower. Most PTCS sites (84%) had an efficient compressor lockout settings, while 64% of sites that did not participate in a utility program and 50% of sites that did participate in a non-PTCS utility program had the compressor locked out above 5 degrees Fahrenheit. Figure 10 shows the inefficient compressor lockout settings varied from 10–45 degrees Fahrenheit.

Figure 9: Assessment of Compressor Lockout Settings

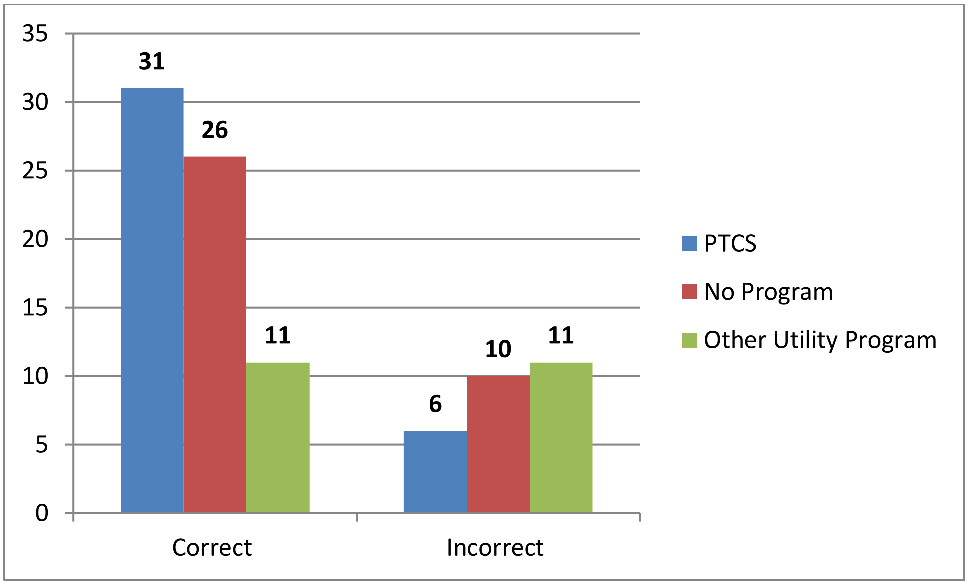
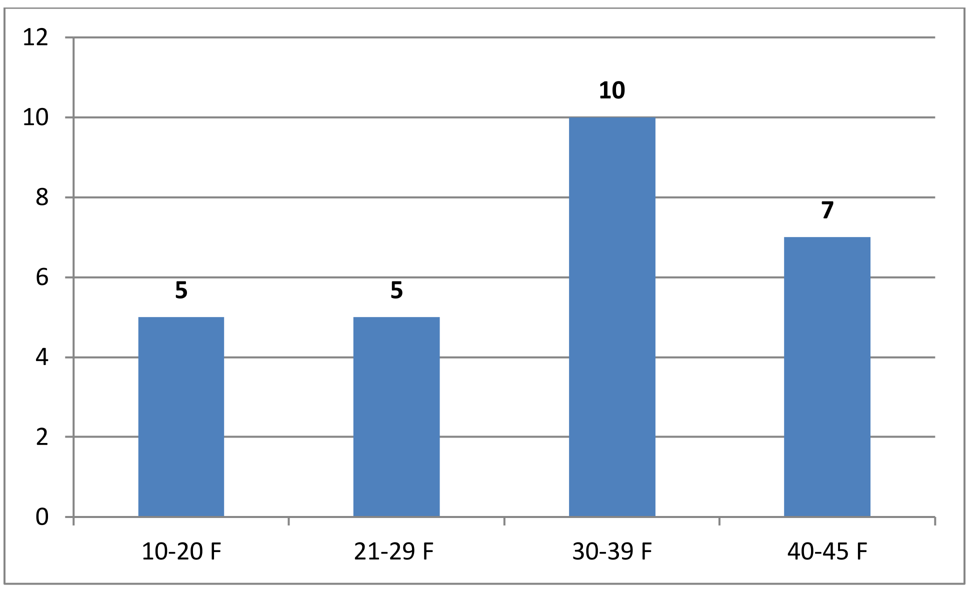


Figure 10: Assessment of Inefficient Compressor Lockout Settings



Sizing

Many factors contribute to the capacity needed to meet the home's heating and cooling loads. Important factors include the shell characteristics, air leakage rate, and distribution ducts condition and size. In this study, the team used two sizing calculators to assess the required heating and cooling needs in kBtu/hr: a PTCS sizing calculator developed by the Regional Technical Forum, or RTF, the program uses, and a sizing tool developed by Ecotope for a utility heat pump program in Idaho. The Ecotope calculator should be considered more accurate than the PTCS calculator due to having a greater number of inputs for a more accurate sizing estimate. An undersized heat pump is the most problematic for energy efficiency because the compressor will be unable to meet the home's heating needs by itself during the majority of the season's conditions. For PTCS, systems are supposed to be sized to meet the heating load with compressor only at a 30 degree Fahrenheit outdoor temperature. Undersized heat pumps must use more auxiliary heat, which drags down the seasonal heating efficiency. Grossly oversized heat pumps are also problematic because they cycle more than properly sized units during milder winter conditions, which can shorten the equipment's life and also reduce overall efficiency.

To determine whether the installed heat pump was appropriately sized, the team looked for the installed capacity per the AHRI reference number (AHRI, 2019) to be no greater than one-half ton (6,000 BTU) smaller or larger than the required capacity. Heat pumps are typically sized in half-ton increments so if the installed capacity was within a half-ton of the required capacity, the system is considered to be properly sized. Figure 11 shows the sizing result based on the PTCS calculator and figure 12 is based on the Ecotope calculator.

Figure 11: Heat Pump Sizing Based on PTCS Calculator

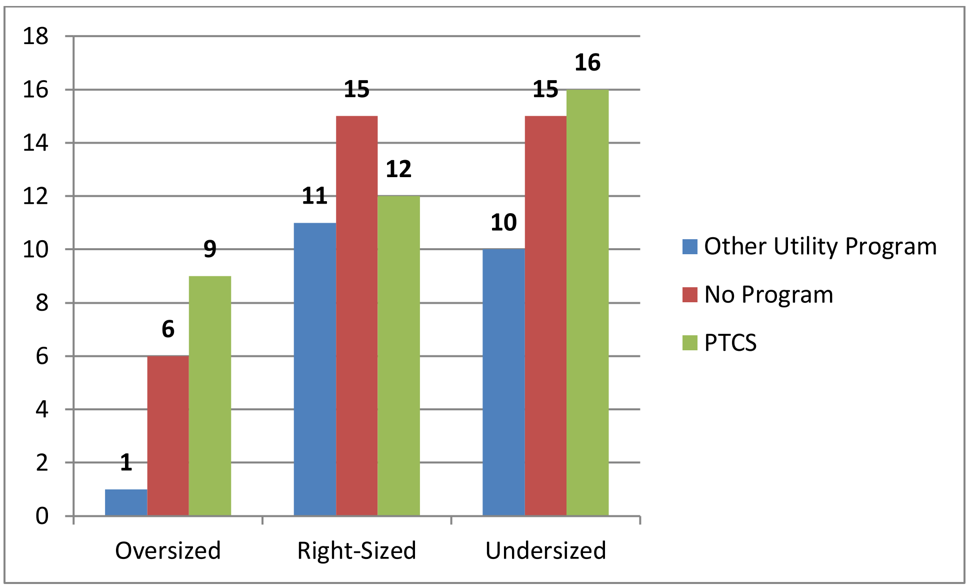
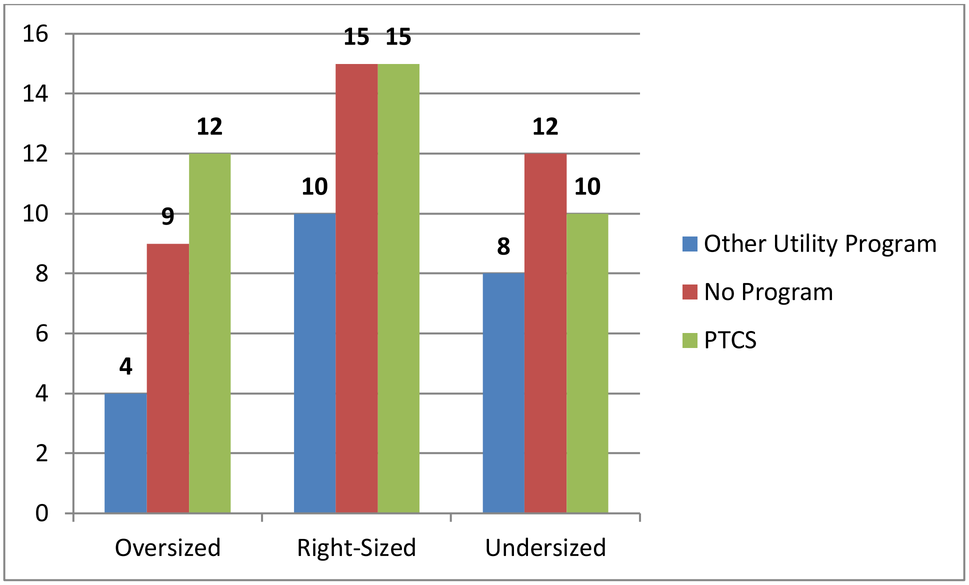


Figure 12: Heat Pump Sizing Based on the Ecotope Calculator

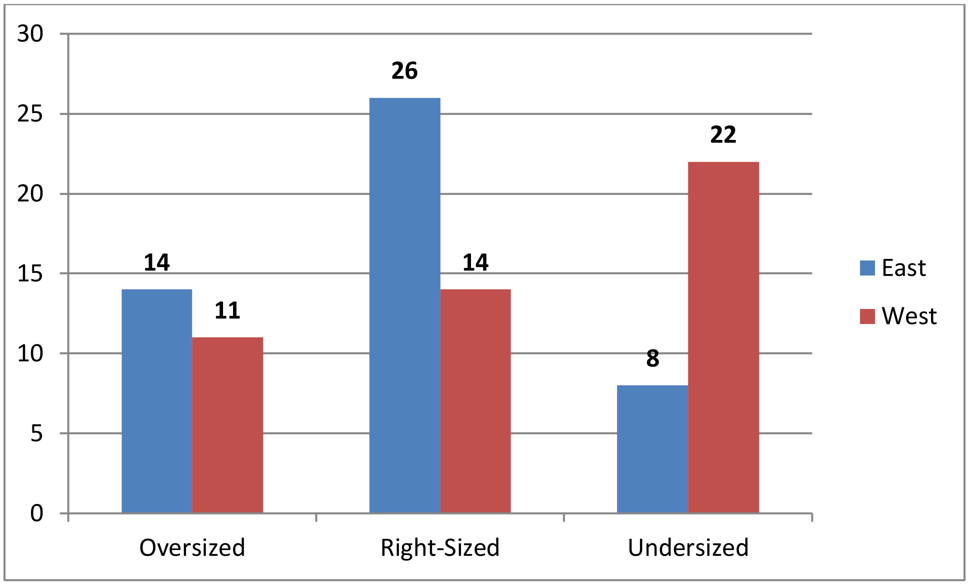


Overall, according to the Ecotope calculator results in Figure 12, 42% of the time contractors sized the heat pumps appropriately,[21] compared to 40% based on the PTCS sizing calculator in Figure 11. The Ecotope calculator revealed heat pumps were undersized 32% of the time, while the PTCS calculator indicated undersizing 43% of the time. Correspondingly, the Ecotope calculator results indicated significantly more oversized heat pumps (26%) than the PTCS calculator (17%). The rest of the sizing discussion is based on the Ecotope calculator.

Study results indicate that heat pump sizing continues to be an issue in the region. Fifty-eight percent of sites were under or oversized by one-half ton or more. Heat pumps were significantly undersized by one ton or more at 18 (19%) sites and significantly oversized by one ton or more at nine (9%) sites. The team found significantly more undersized heat pumps west of the Cascades (47%) than east (17%). There was a similar proportion of homes with oversized heat pumps west (23%) and east (29%) of the Cascades. The team observed that neither PTCS nor Other Utility Program participation improved heat pump sizing.

[21] The Ecotope calculator computes home heating load at 30˚F which the team converted to nameplate capacity at 47 ˚F.

Figure 13: Heat Pump Sizing Based on the Ecotope Calculator by Domain



Comparison to 2005 Baseline Study

One of the goals of this study is to benchmark regional progress made in heat pump installation practices resulting from utility program intervention. Table 16 shows the proportion of sites that met current PTCS specifications in the 2005 study compared to the current study. Overall, the only areas where significant progress was made is around heat pump sizing and equipment efficiency. In 2005, units tended to be undersized by about 30% across all sites, where today at least 43% of the sites appeared to have appropriate sizing. The mean equipment efficiency in 2005 was 7.69, which has been increased to 9.36, due in part to federal standards, but more likely the results of utility program minimum HSPF specifications. The proportion of sites with low airflow or excessive static pressure remained stable over time. Most sites in the 2005 study lacked outdoor temperature sensors and thermostats that allowed auxiliary or compressor lockout controls based on outdoor temperature. Therefore, we cannot make comparisons regarding changes in controls from the 2005 study to the present study. The fact that most thermostats installed with heat pumps today know the outdoor temperature through a weather-station service — and use this information to enable lockout controls — is significant progress in heat pump efficiency.

Table 16: Comparison of Field-Visit Findings to 2005 Study

	Airflow	External Static Pressure	Refrigerant Charge	Sizing	Mean HSPF
2005 Study	62%	93%	92%	Most units undersized by 30%	7.69
Current Study	67%	94%	72%	43%	9.36

Conclusions and Recommendations

Ultimately, the team completed 95 site visits, 13% of eligible survey respondents evenly split between east and west of the Cascades. Forty percent of the survey respondents and 62% of homes visited indicated participation in a program for their heat pump installation. Particularly, the team identified 39% of homes visited as PTCS program participants. An additional 23% of homes visited received incentives for their heat pump install from their local utility outside of the PTCS program. This speaks to effective program penetration and should be taken into consideration when determining the current practice baseline with the data collected from this study.

Overall, the field team found mixed results for meeting PTCS specifications. Table 16 presents a summary of the findings. Notably, only the controls practices were significantly improved for PTCS participants. The commissioning and sizing practices found in the homes of PTCS participants were about the same as or worse than the general population.

Table 16: Percent of Installations Meeting PTCS Specifications

	Airflow	External Static Pressure	Refrigerant Charge	Auxiliary Heat Lockout	Compressor Lock Out	Sizing	HSPF
PTCS	67%	89%	68%	65%	84%	41%	95%
Other Utility Program	70%	91%	73%	14%	50%	44%	86%
No Program	67%	97%	75%	25%	72%	45%	56%
All Sites	67%	93%	72%	43%	72%	42%	78%

The following summarizes conclusions from the assessment of the most critical and measurable commissioning, controls and sizing tests.

Heat Pump Equipment Efficiency

A majority of air source ducted heat pumps installed in the region would meet the PTCS program's equipment efficiency specification of 9.0 HSPF. Both PTCS and Other Utility Programs are effective at getting efficient equipment installed; however, approximately 56% of heat pumps installed outside of utility programs would meet PTCS specifications.

Commissioning

The team measured airflow across the indoor coil to determine if there was sufficient airflow to carry useful heat from the heat pump evaporator coil. Low flow affects the heat pump's capacity to deliver heating and cooling efficiently. The field team found that airflows met the PTCS specifications 67% of the time with little variation by program participation.

The team measured temperature change across the air handler indoor coil to indirectly determine if the heat pumps had enough of a refrigerant charge. A low temperature split could indicate the heat pump had a less than ideal refrigerant charge, low flow on the exterior fan or problems with the compressor. Overall, the team found that the temperature split across the indoor coil was within an acceptable range at 72% of the sites visited. The distribution of low temperature split versus meets requirement remained consistent by location and program participation.

The PTCS program requires that external static pressure does not exceed 200 Pa. Excessive static pressure could be compensated for by adjusting the air flow in the air handler. Overall, 93% of households met the PTCS specifications for static pressure. The team considered readings below 100 Pa to be low and an acceptable range to be 100–200 Pa. As such, 48% of households had static pressure readings in the acceptable range. The proportion of households with acceptable static pressure readings were similar, regardless of program participation.

Controls

Heat pumps provide heat more efficiently at higher outdoor temperatures and are supported by auxiliary heat at very low temperatures. The most efficient control configurations leverage more operation out of the heat pump. A fully electric heat pump heating system should continue to operate to the minimum compressor design setting before auxiliary heat becomes the primary heat source. Most sites (72%) had the compressor lockout set correctly or left to manufacturer default. The auxiliary heat lockout settings were mixed, with 43% of homes preventing the auxiliary heat from operating above 35 degrees Fahrenheit —as is optimal. The remaining homes either allowed the auxiliary heat to come on above 35 degrees Fahrenheit or did not have a lockout set at all. In some cases, the householder may have changed these settings, though often a trained technician would be needed to successfully navigate through heat pump controls set up in the thermostat.

The PTCS program is significantly more effective at ensuring efficient heat pump controls. Sixty-five percent of PTCS sites had the auxiliary heat lock out set at 35 degrees Fahrenheit, while only 21% of sites in Other or No Utility Program sites had a similar setting. Eighty-four percent of PTCS sites had a compressor lockout set at or below 5 degrees Fahrenheit, while only 64% of Other or No Utility Program sites had a similar setting.

Sizing

Many factors contribute to the capacity needed to meet the home's heating and cooling loads. Important factors include the shell characteristics, air leakage rate, and the condition and size of the distribution ducts. An undersized heat pump is the most problematic for energy efficiency because the compressor is unable to meet the home's heating needs by itself during the majority of the heating season's conditions, relying more on auxiliary heat. The team found that contractors sized the heat pumps correctly at 42% of the sites, undersized 32% and oversized at 26% of sites. These proportions remained fairly consistent regardless of program participation. There was a difference by location; homes east of the Cascades tended to have more oversized heat pumps, while homes to the west had a relatively higher proportion of undersized heat pumps. This may be a reflection of heat pumps in the east being sized for cooling, while heat pumps in the west more frequently being paired with gas furnaces. Further analysis beyond the scope of this study would be needed to confirm this analysis.

Recommendation: There is room for improvement in the application of PTCS specifications for the critical parameters the field team was able to measure in the general population of heat pump installers and for PTCS practitioners.

Lessons Learned

The survey's full study response rate was 15% (438 responses out of 2,883 letters sent) compared to a 32% response rate (288 responses out of 910 letters sent) in the pilot study. The research team believes the primary driver in the response rate difference was the pilot recruitment letters featured utility branding in addition to BPA branding, while the full study only featured BPA branding. The lower response rate meant that many more recruitment letters were sent to attract enough homes for the study. It also caused less efficient travel because typically only one or two sites could be scheduled in an area consecutively, thus extending the duration of the field work from an anticipated four months to more than five months. Many pilot study survey respondents were still engaged and eager to participate in a site visit when the team contacted them again in spring 2019,[22] which was necessary because the full study response and recruitment rates were so low. The research team concludes that the utility branding in the initial outreach made a significant difference in the response and recruitment rate.

Recommendation: BPA should consider collaborating with its customer utilities and other regional utilities when conducting field work to use utility branding for end-user outreach. To facilitate this collaboration, all addresses should be mapped to their respective utility service territories. While conducting the field study, the team made the following observations about potential improvements for future similar field studies:

1. Familiar utility branding is a critical factor in achieving higher response rates in mailed study recruitment campaigns.

2. Homeowners were very interested in our opinions on which energy improvements they could make. The field team could have had a prepared generic list of recommendations to leave behind at each visit. Also, many participants requested a copy of their home's results. Offering this from the start could be an additional incentive to participate in the study.

3. Many survey respondents were not interested in a six-hour home visit and indicated the visit was too long for them to accommodate. Some portions of the data-collection process could be performed in less time. Useful data such as thermostat settings, nameplates and basic house characteristics could have been collected in a phone call and an email. The team believes an equally effective approach would have been to do only the interview, thermostat settings, and static pressure test and temperature split at 75% of sites, and perform the full protocol sites at the other 25%.

4. Due to time constraints, the field team did a qualitative — rather than quantitative — assessment of duct condition. The state of the duct work, particularly in unconditioned spaces, can have a significant impact on the calculation of the heating load of the home. After some sensitivity testing, the team realized many of the other parameters they collected and calculated data for, particularly to inform the heating load, could have fairly large tolerances compared to qualitative assessment (good, fair, bad) of duct condition.

5. Some unanticipated issues challenged the field team including:

    - **Measuring the airflow of variable speed blowers.** The heating test mode did not necessarily put the airflow at 100% even if the compressor was at 100%. The reduced airflow also may have affected the measured static pressure.

[22] The pilot study only sought four site visits but 126 eligible respondents indicated interest in a site visit.

- **Measuring return static pressure away from the air handler.** Another option would be to place the tap upstream of the filter and make an adjustment based on the filter type. Measuring in between the filter and coil is impractical and prone to error.
- **Time-consuming duct blaster tests.** Having two manometers — especially the digital ones — would simplify the duct leakage test, especially in situations where the air handler is located in an inconvenient location, such as an attic or crawlspace.

6. **The team suggests manufacturer support** would help improve understanding of how different controls affect the performance of different units.

Issues for Future Research

In addition to lessons learned, the research team also suggests the following areas of analysis and study:

- The region should make an effort to create and maintain a single GIS database of utility service territory boundaries. This would facilitate assigning utilities to addresses.
- Compare mix of various household characteristics in this study to Regional Building Stock Assessment (RBSA) to better understand representativeness of homes in this study to the region as represented in the RBSA.
- In addition to the summaries reported here, the RTF current practice baseline models, and BPA's market model, there is more potential for the data collected in this study. For example, the Ecotope heating load calculator and the PTCS sizing calculator result comparisons could lead to PTCS calculator improvements that would not require more expensive and time-consuming sizing assessments by the PTCS contractor. Also, analysts could further examine reasons for disparity in sizing practices between contractors east and west of the Cascades.

Appendix A: References

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Appendix B: PTCS Specification and Other Utility Program Specifications

PERFORMANCE TESTED COMFORT SYSTEMS®

Last Updated April 1, 2017

PTCS Air Source Heat Pump Installation Specification

1. **Equipment Selection and Sizing**

   The new Air-Conditioning, Heating, and Refrigeration Institute (AHRI) rated air source heat pump system must be sized using a balance point of 30°F or less. To determine the balance point, the following specification must be used:

   a. A 70°F indoor design temperature for heating and 75°F for cooling load calculations using ASHRAE winter design temperature and cooling design temperature for the nearest weather station representative of the installation.

   b. U-values and F-values consistent with those found in Air Conditioning Contractors of America (ACCA) Manual J 8th Edition, or later.

   c. An infiltration rate of 0.8 air changes per hour for homes built before 1980 and 0.5 for homes built 1980 or later, unless a house (de)pressurization test has been performed and an estimate is made using the result. If a duct pressurization test has not been performed on the house, a default duct system loss of 25% shall be used. *Exception:* If the air handler and all ductwork are within the thermal envelope of the house, 0% shall be used as the duct system loss in sizing calculations.

   The recommended method and form for calculations is available in the ACCA Manual J. Alternate computer or manual methods of calculating heating and cooling loads may be used if approved in advance by the utility.

2. **External Static Pressure**

   The total external static pressure acting on the system air handler must not exceed 0.8 inches of water (200 Pa).

3. **Air Flow**

   Air flow across the indoor coil must be as specified in the heat pump manufacturer's documentation, or at least 325 to no more than 500 cubic feet per minute (CFM) per 12,000 Btu/hr output at AHRI rating conditions if the manufacturer's documentation is not specific. Approved measurement methods are using a TrueFlow plate or using the duct pressurization fan matching method per plate.

4. **Refrigerant Charge**

   a. **Heating.** If the outdoor temperature is 65°F or less, test in heating mode after operating the heat pump for a recommended 15 minutes, if not specified by manufacturer, with auxiliary back-up heat off. Temperature change across the air handler indoor coil must be at or above the minimum temperature split shown in the R-410A Temperature Split Table (https://www.bpa.gov/EE/Sectors/Residential/Documents/HP_Temp_Split_Table.pdf).

b. **Cooling.** If the outdoor temperature is greater than 65°F, test in cooling mode after operating the heat pump for a recommended 15 minutes if not specified by manufacturer. The sub cooling (discharge temp. – liquid line temp.) must meet manufacturer's documented requirements. See R-410A Pressure-temperature chart (https://www.bpa.gov/EE/Sectors/Residential/Documents/R-410A_Pressure_Temperature_Chart.pdf) for discharge pressures and corresponding temperatures.

Other alternative refrigerant measuring methods approved and documented by the manufacturer are also acceptable.

5. **Controls**

a. **Compressor Control.** If a low ambient temperature compressor cutout option is installed, it must not cut out the compressor at temperatures above 5°F.

b. **Auxiliary Heat Control.** Auxiliary heat must be controlled in such a manner that it does not engage when the outdoor air temperature is above 35°F, except when supplemental heating is required during a defrost cycle or when emergency heating is required during a refrigeration cycle failure.

For constant speed systems with multiple stages of compression and supply air temperature sensor control, auxiliary heat shall be controlled in such a manner that it does not engage when the supply air temperature is above 85°F.

PTCS ASHP Installation Best Practices

The program recommends but does not require the following as Air Source Heat Pump installation best practices:

- Check with the local utility about any requirements they may have about sizing auxiliary heat.
- Make sure openings in the unit cabinet or building structure are properly sealed.

Other Utility Program Specifications

Utility	Measure Offerings	ASHP Incentive Levels	CC&S Practices and/ or Measures
Idaho Power	ASHP, GSHPs, Duct Sealing	$250 8.5 minimum HSPF; Conversion (Forced Air or Zonal) $800 8.5 minimum HSPF; Propane or Oil Conversion $400. $50 incentive for ECM. $150 incentive for installing tech.	Detailed installation worksheet that is very similar to PTCS with also identical requirements.
Puget Sound Energy	ASHP and ASHP Controls	10 HSPF/ 16 SEER - $800. $1500 for conversion from electric forced air. 8.5/ 14 SEER or better. Both can be combined with $300 sizing and lock out	Rebate for verifying sizing and installing a lockout control (40F) on new or existing HPs.
Energy Trust of Oregon	ASHP and ASHP Controls	> 8.5 HSPF- $700, Heat Pump Controls - $250 (settings for the heat pump)	Separate rebate for heat pump control. Controls must either have an outdoor temperature sensor and be configured with a 35°F furnace lockout, or be a qualified web-enabled model that is connected to the internet
Snohomish PUD	ASHP, GSHP, Duct Sealing	Conversion minimum 9 HSPF, 14 SEER $1000. Inverter Driven Minimum 10 HSPF, 14 SEER - $1,500. Commissioning Controls and Sizing - $200. Less than 9.0 HSPF and 14 SEER.	Utilize the CC&S Measure, robust contractor network.

Appendix C: RTF ASHP CC&S Specifications

Adopted: May 12, 2015; Revised July 21

Measure Specification

This document details the measure specification for the RTF Heat Pump Commissioning, Controls, and Sizing measure for single family and manufactured homes. When installing a new single-speed or two-speed central air source heat pump, heat pump should be installed in accordance with this specification.

Component	Specification	Additional Notes	Delivery Verification Checklist
Measure Identifiers	Heating zones		□ Check for correct heating zone.
Baseline	Current practice		n/a
Implementation and Product Standards	Heat pumps must be new and rated by Air-Conditioning, Heating and Refrigeration Institute.		□ Check heat pump is new and rated by AHRI.
	The heat pump shall be sized with a heating balance point of 30 degrees Fahrenheit or lower.	The recommended method and form for calculations and selection are available in the ACCA Manuals J and S. Component U-values and F-values used in the heat loss and heat gain coefficients shall reflect the actual construction of the building and be generally consistent with those found in ACCA Manual J 8th Edition, or later. A natural infiltration rate of 0.5 or 0.8 air changes per hour shall be used for houses built after 1980 or before 1980, respectively, in sizing calculations unless a house	□ Check heat pump balance point is at 30 degrees Fahrenheit or lower.

Component	Specification	Additional Notes	Delivery Verification Checklist
		(de)pressurization test has been performed and an estimate is made using the result. Where available, the results of duct pressurization testing shall be used to estimate the duct system efficiency used in sizing calculations. If a duct pressurization test has not been performed on the house, a default duct system loss of 25% shall be used. Exception: If the air handler and all ductwork are within the thermal envelope of the house, 0% shall be used as the duct system loss in sizing calculations. Sizing for cooling load is outside the scope of this specification. If the cooling loads justify a larger unit, than the minimum size required based on the heating sizing process, the larger unit should be installed.	
Implementation and Product Standards (cont.)	Auxiliary heat shall be controlled in the following manner depending on system type: Single stage OR multistage without air temperature sensor control: Auxiliary heat shall be controlled in		☐ Check auxiliary heat is controlled to one of the following: Single stage OR multistage without air temperature sensor control: auxiliary heat is controlled so that it does not engage when the outdoor temperature is

Component	Specification	Additional Notes	Delivery Verification Checklist
	such a manner that it does not engage when the outdoor air temperature is above 35 degrees Fahrenheit, except when supplemental heating is required during a defrost cycle or when emergency heating is required during a refrigeration cycle failure. Multistage with air temperature sensor control: Auxiliary heat shall be controlled in such a manner that it does not engage when the supply air temperature is above 85 degrees Fahrenheit.		above 35 degrees Fahrenheit, except when supplemental heating is required during a defrost cycle or when emergency heating is required during a refrigeration cycle failure. Multistage with air temperature sensor control: auxiliary heat is controlled so that it does not engage when the supply air temperature is above 85 degrees Fahrenheit.
	Thermostats for both heating and cooling shall have a manual changeover feature or heating/cooling lockout.		☐ Check thermostat has manual changeover feature or heating/cooling lockout (if applicable).
	Temperature change across indoor coil after 10 minutes of heating operation shall be at or above the temperature split in Table 1 below.		☐ Check temperature change across indoor coil is at or above temperature in Table 1 below.
	If a low ambient temperature compressor cutout option is installed, it shall not cutout the compressor at temperatures above 5 degrees Fahrenheit.		☐ Check that compressor is not cutout at temperatures above 5 degrees Fahrenheit (if applicable).

Component	Specification	Additional Notes	Delivery Verification Checklist
	Air flow across the indoor coil shall be either: As specified in the heat pump manufacturer's literature. If not specified in the literature, ≥ 325 CFM per ton of nominal heating capacity.	Approved measurement methods include using a TrueFlow plate or using the duct pressurization fan matching method per plate or fan manufacturer's instructions.	☐ Check airflow across indoor coil is either: As specified in manufacturer's literature. ≥ 325 CFM per ton of nominal heating capacity.
Implementation and Product Standards (cont.)	The total external static pressure acting on the system air handler shall not exceed 0.8 in of water (200 Pa) after the new heat pump is installed.		☐ Check that external static pressure does not exceed 0.8 in of water (200 Pa).
Sunset Date	March 31, 2016		n/a

Minimum Temperature Split (°F)				
Outdoor Temperature (°F)	**CFM per Ton**			
	300	**350**	**400**	**450**
5	13	11	10	9
10	15	13	11	10
15	17	15	13	11
20	19	17	15	13
25	20	18	16	14
30	21	19	17	15
35	23	21	18	16
40	25	23	20	18
45	28	25	22	20
50	31	27	24	22
55	34	29	26	23
60	36	31	28	25
65	38	33	29	26

Recommendations for Commissioning Controls and Sizing Programs

The following sections provide additional guidance to support commissioning, controls and sizing programs. These additional recommendations are not included in the RTF measure specification. However, the RTF recognizes these as best practices for commissioning, controls and sizing.

1. **Auxiliary Heat Sizing.** Installed auxiliary heat capacity shall not exceed 125% of the heating design load.
    a. The recommended ASHRAE winter design temperature and cooling design temperature for the nearest weather station representative of the installation shall be used. Exception: If state or local code specifies a design temperature, the state or local code design temperature value shall be used.
2. **Penetrations.** Refrigerant piping passing through openings in the unit cabinet or the building structure shall be properly sealed.

Compliance with Applicable Codes and Manufacturer Requirements. Installation must comply with all applicable codes and be installed according to the manufacturer’s specifications, including but not limited to, those for sizing, airflow, protective devices, equipment placement, refrigerant piping, refrigerant charge, condensate management and fossil fuel backup systems.

Appendix D: Research Plan

Sample Design

The team considered many factors when outlining the sample design. These included: the frame from which to recruit site visits; the variance of critical parameters such as location, dwelling type, and installation practices; and the desired confidence and precision.

ASHP Sample Frame

Locating the ASHPs represents the biggest challenge to conducting an ASHP Field Study. Neither the research team nor its predecessors have been able to track down a comprehensive listing of ASHP installations in the region. Permit records capture a substantial portion of ASHP installation activity because jurisdictions typically require an electrical, and sometimes mechanical, permit application when an installer runs a new circuit or refrigeration line, as well as for all new construction. However, collecting permit records from all jurisdictions in the region would be an undertaking of insurmountable complexity and unjustifiable expense. Fortunately, the team learned that data vendors compile residential electrical and mechanical permit application records into a purchasable database, which covers ASHP installations across most jurisdictions in the region. One vendor, BuildFax, stood out for coverage of jurisdictions, count of heat pump records, customer service, and low cost. The research team purchased over 600,000 permit records from BuildFax to form the basis of the sample frame.

Table 1 presents the jurisdictional coverage, counts of permit records and counts of unique heat pump households by state since January 2015.

The research team recognizes that this sample frame does not cover the heat pumps installed without a permit. The team was concerned about whether bias may exist in practices between permitted and unpermitted installations. Fortunately, the team recently learned of a study completed in September 2017 for the California Public Utilities Commission which found that "permitting does not lead to increased energy efficiency of HVAC changeouts." (CPUC, 2017)

Appendix D1: Permit Data Processing describes in detail the process of cleaning and preparing the permit data into the sample frame.

ASHP Sample Size

A sample design primarily controls for sample size with selection of confidence and precision targets and controlling for variance in the population or probabilities of significant parameters. The research team considered variance in installation practices for the following critical domains:

- Location.
- Dwelling types.
- New construction versus retrofit.
- Sizing decisions relative to site-specific conditions like house heating load, system airflow and duct losses.
- The discrete nature of controls set-up and commissioning (i.e., the installer either did it correctly or incorrectly).

The research team includes a member who played a significant role in the 2005 baseline study, Bob Davis of Ecotope. Drawing on his experience, the team determined that installation practices likely do not vary significantly by dwelling type or between existing or newly-constructed dwellings. The team also asserts that practices are unlikely to vary significantly between urban versus rural settings because the installers are likely from the same contractor pool as the nearest population center. Including sufficient rural installations in the field sample will test this assertion. Installation practices could, however, vary significantly by location relative to the Cascades mountain range. The reason is two-fold:

1. Uptake of ASHPs in the moderate climate of the more populated area west of the Cascades occurred earlier and faster than it did in the eastern area. This likely led to a larger, more experienced and more competitive base of installers.
2. Installers of ASHPs in areas east of the Cascades have typically viewed heat pumps as central air conditioners with electric resistance heat, while in the west, installers recognize ASHPs are primarily used for heating.

To address this variance, the research team proposes two domains in the sample design, one for the area west of Cascades and one for the area to the east. Within these domains, the team will draw a simple random sample of households, with an overall goal to provide sufficient diversity for the overall sample (in terms of a rural/urban split).

The CC&S requirement for both a sizing value (i.e., 'tons' of heat pump) and various installer-set control settings (to reduce electric resistance heat usage and ensure compressor operation in temperature bins below 35 degrees Fahrenheit) creates a sampling challenge. Principle issues in establishing sample size are the statistical criteria and the team's prior understanding of the probability of controls being set up properly. The formula for such a discrete variable maximizes target sample size for a given control setting when half (probability=0.5) of the systems being assessed are set properly and half are not. Looking back at the 2005 study data, the research team noted that 30% of the sites set up the outdoor thermostat (auxiliary heat lockout control) properly. Given that the outdoor thermostat is now part of residential code in Washington and Oregon, the team believes the probability should be adjusted to 0.7. This yields a sample size of 84 per domain when targeting ±10% precision at 90% confidence.[23]

The team also referenced the 2005 study to estimate the variance of the sizing value and found it to be relatively low (coefficient of variation less than 0.5). The team applied a CV of 0.5 and calculated a sample size of 68 per domain to target ±10% precision at 90% confidence.

The team selected the larger sample size to ensure a large enough sample to sufficiently cover the probability of the control settings. BPA indicated that there were not enough funds to conduct 168 site visits and set the limit to 100, or 50 per domain. The team expects this reduced sample size would achieve ±13% precision at 90% confidence.

Table 2 presents the resulting sample design. The researchers will recruit site visits by sending letters that direct people to a web survey. The team anticipates 10% of letter recipients will respond to the letters and 40% of survey respondents will agree to a site visit. The research team plans to send 2,500 initial letters plus reminder letters to recruit survey respondents until the team has successfully completed 100 site visits.

The team observed in the sample frame some addresses, which appear to be a central office to a large complex of homes such as mobile home parks. The drawn sample selects only a few of these and the team plans to replace them in the sample with addresses to individual homes.

[23] The team set the t-statistic to 2 instead of 1.645 based on the guidance of Scheaffer et al in *Elementary Survey Sampling* (Sheaffer. 1986).

Figure 1 presents the distribution of heat pump households (black circles) and sampled households (yellow circles) in the region. The size of the circles represents the count of properties in the zip code. The blue-shaded background is the west sample domain and orange-shaded background is the east sample domain[24].

Utility Assignment

To facilitate coordination with impacted utilities, the research team attempted to assign the appropriate utility to each record in the sample frame. The team has been collaborating with other Market Research contract team members and NEEA to identify the best source for assigning utilities. That effort is ongoing. For the purposes of this memo, the team used a dataset provided by NEEA originally developed for the 2011 RBSA to assign utilities by zip code with subsequent updates and refinements.

- Out of the 2,154 zip codes in the NEEA utility assignment dataset:
    - There were 821 zip codes assigned to BPA or Energy Trust of Oregon. We did not assign utilities as either group in the sample frame.
    - There were 152 zip codes assigned to more than one utility (excluding BPA and Energy Trust). The team selected one utility for each zip code such that 1,150 zip codes have utility assignments.[25]
- The frame has 47 records with no zip code so the team assigned utility by city for these records.
- There are 7,229 records in the frame with no utility assignment because they would have been assigned to BPA or Energy Trust. Of these:
    - 1,994 are in Portland, OR which had zip codes assigned to Energy Trust in the NEEA dataset. We assigned them to Portland General Electric, though many may be in Pacific Power service territory.[26]
    - This leaves 5,235 records in the frame with no utility assignment; 5,122 of which are in Oregon and are likely in Portland General Electric, Pacific Power or Avista territory.[27]
- There are 305 records in the sample drawn to receive recruitment letters with no utility assignment.
- The frame has 63 records which may have incorrect utility assignments because more than one utility serves the zip code for these records. Five of these records are in the drawn sample.[28]

[24] The census GIS layer did not map to every zip code in the region, explaining the unshaded areas. Central and eastern Montana are excluded because there were no heat pump properties in the frame in those areas.
[25] This was a somewhat arbitrary selection in which we sorted alphabetically and picked the one on top.
[26] We elected to assign to Portland General Electric to the Portland, OR records because Pacific Power is assigned to other zip codes, so it will come up as a utility to coordinate with. Otherwise, Portland General Electric would not show up in the frame.
[27] These three utilities are assigned to other records so will be part of the engagement efforts.
[28] The recruitment letters will list all possibly utilities in near proximity to the address.

The following table presents the count of recruitment letters mailed in each phase by utility.

Table 15 Count of Initial Letters Sent by Phase and Utility

Phase	Utility	Letters
NE	Avista Utilities	256
	Benton County PUD	115
	PacifiCorp	114
	Benton Rural Electric Association	107
	City of Cheney	8
	Missoula Electric Cooperative	8
	Big Bend Electric Cooperative	4
	Columbia Rural Electric Association	4
	NorthWestern Energy	3
	City of Chewelah	2
	Kootenai Electric Cooperative	1
	Vera Water & Power	1
NW	Puget Sound Energy	374
	Clark Public Utilities	68
	Seattle City Light	59
	Snohomish County PUD	49
	Cowlitz County PUD	31
	Tacoma Power	29
	Lewis County PUD	10
	Clallam County PUD	10
	Peninsula Light Company	6
	Unknown IOU	5
	Parkland Light and Water Company	5
	City of Fircrest	5
	Elmhurst Mutual Power & Light Company	4
	Eatonville Power	2
	Mason County PUD No. 1	2
	City of Port Angeles	2
SE	Idaho Power Company	313
	Unknown IOU	106
	Midstate Electric Cooperative	99
	Central Electric Cooperative	93
	Hermiston Energy Services	8
	Idaho Falls Power	5

Phase	Utility	Letters
	Oregon Trail Electric Cooperative	3
SW	*Unknown IOU*	269
	Portland General Electric	111
	Eugene Water and Electric Board	102
	Salem Electric	59
	Canby Utility Board	13
	Tillamook PUD	11
	City of Monmouth	9
	Consumers Power	6
	City of Forest Grove	3
	Emerald PUD	2
	City of Ashland	1
	Douglas Electric Cooperative	1
	City of Drain Light and Power	1
	Lane Electric Cooperative	1

Figure 3 shows the utility assignments. Blue shading indicates only one utility assigned to the zip code. Yellow shading indicates multiple utilities assigned to the zip code. Red census blocks have unknown or no utilities assigned.[29]

[29] Much of Oregon *should* be red because the one "utility" assigned was Energy Trust of Oregon.

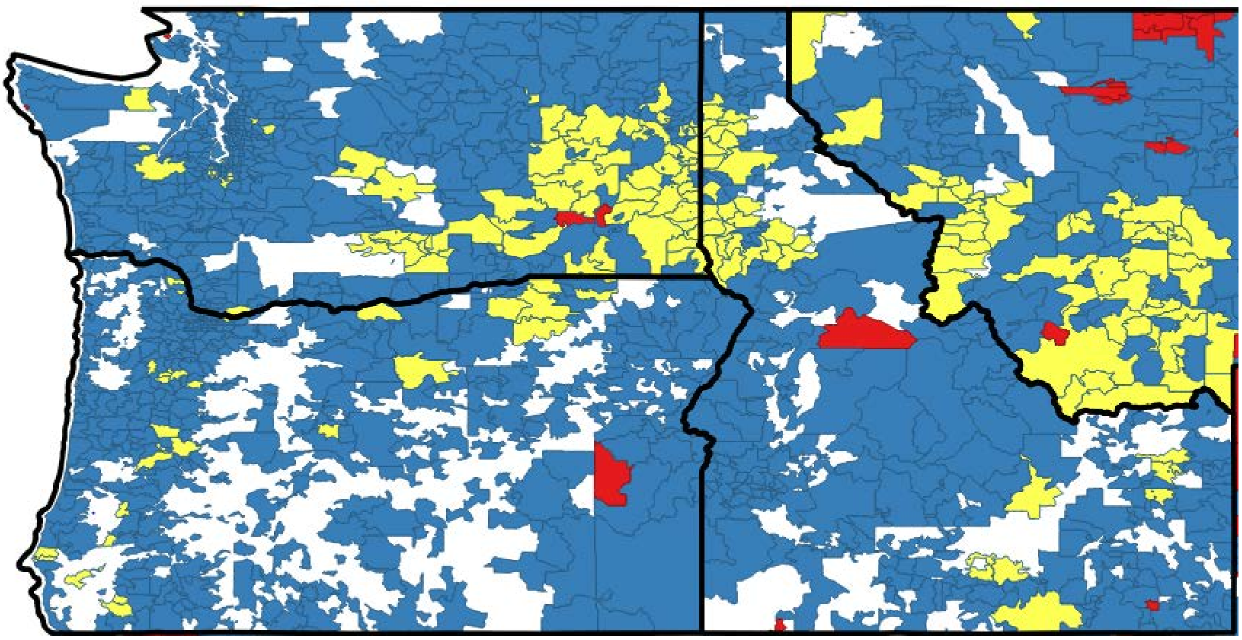

Figure 3 Utility Assignment

Pilot Study

The team recruited two utilities for the pilot: Inland Power service territory and Puget Sound Energy, or PSE, service territory. Inland Power represents a medium-sized public utility and a territory east of the Cascades while PSE represents an Investor Owned Utility, or IOU, and a territory west of the Cascades. The team included enough records to send approximately 500 letters to households in each of the two service territories with the goal of completing two site visits in each territory for the pilot.

The Inland Power list included properties in Spokane, Spokane County, and several more that were marked as being in Inland Power's service territory by zip code, census block, or service map. Fewer than 500 addresses were identified. Some of these properties may be within Avista's service territory.

The PSE list included properties in Bellevue, Redmond and Kirkland. The team observed many addresses on the PSE list were not single-family or small multifamily properties. To further eliminate irrelevant records, the team obtained shapefiles with zoning information from city websites to select only addresses in single-family residential zones. This attention to detail for further eliminating multifamily properties will not be possible with given resources to expand to the full frame.

For the full study, we will compare the drawn sample to the pilot sample. If there are addresses selected in the full sample that correspond to households which already responded to the pilot survey, we will remove them from the full study sample. For those households, we will apply the responses from the pilot survey in the full study. If they indicated interest in a site visit but did not receive one during the pilot, we will include them as site visit recruits for the full study. If any of the four homes which received site visits during the pilot are selected as part of the full study, we will include them in the full study as a site visit completion. We will accordingly reduce the target site visit quota for the full study by the number of site visit recruits we are able to apply from the pilot.

Recruitment and Data Collection

This section describes the strategy for recruiting households with recently-installed ASHPs and discusses the types of data that will be important to collect during site visits. This section also presents an approach to filling the installation context gap for the Residential HVAC market model.

ASHP CC&S Survey and Site Recruitment

Survey of Households in the Heat Pump Permit Records

The research team will conduct a short mail-to-web survey of a sample of households in the heat pump permit dataset to verify whether a heat pump was installed in the home in the past three years, to recruit households for onsite visits, and to collect data about other important household and HVAC characteristics. The team estimates a 10% survey response rate, using the following survey methods.

The team will mail all sampled households two letters asking them to complete the survey online or call the research firm to complete the survey on the phone: an invitation letter and a reminder letter.[30] Both survey letters will include a URL to the survey website, a unique passcode and a phone number for households that are unable to or do not want to complete the web survey.

The invitation will introduce the research study to households, whereas the follow-up letter will thank those who already responded and remind those who have not responded to do so before the data collection end date. Both letters will also explain the purpose of the study, why households should respond to the survey, which member of the household should respond, who to contact for questions, and how respondents can receive their incentive for completing the survey. The team recommends including slightly different reasons for households to participate in the study in each letter. Research has found that changing the reasons to participate and the order of the information in each survey letter increases readership, broadens the appeal to more households, and improves response rates (Dillman, Smyth, & Christian, 2014).

The team also recommends printing letters on a utility's letterhead and mailing the letters in an envelope with its logo, along with first-class postage, to maximize response rates. If it is not possible to use utilities' letterheads and logos, the team recommends using BPA's letterhead and logo, even though households will likely be less familiar with BPA than their utility.[31] Response rates to mail-based surveys are often significantly higher when the outreach materials are sponsored by an organization with which respondents have a relationship (e.g., their utility) or an established institution (e.g., federal/state agencies, colleges/universities, etc.), compared to providing no sponsorships or sponsorships by private research or marketing firms (Dillman, Smyth, & Christian, 2014; Edwards, Dillman, & Smyth 2014).

Offering sampled households an incentive to complete the survey will help improve response rates and will likely reduce the costs per completed survey (Singer & Ye, 2013; Dillman, Smyth, & Christian, 2014). The team recommends providing survey respondents with a $25 gift card they can use for nearly any purchase (e.g., Visa

[30] The team also considered a phone survey but permit data do not include households' phone numbers. Vendors like Marketing Systems Group can match phone numbers to residential addresses, but address-to-phone match rates vary between 50% and 80% and can be costly. Overall, this approach is less cost-effective than the mail-to-web approach, and reduces coverage of the population by excluding from the permit data all households without a matched phone number.

[31] Another alternative is to use the Washington State University's (WSU) Social and Economic Science Research Center (SESRC) to field the mail-to-web survey and WSU's letterhead and logos in the survey letters and website. WSU is likely a known academic institution for many households in BPA's service territory.

card instead of an Amazon, Starbucks, or other vendor-specific card).[32] The respondent can claim the gift card electronically on the web ("e-gift cards"); the end of the survey will provide them with a unique code and direct them to a website to claim the gift card. If any of the sampled households call to complete the survey over the phone, they can claim the gift card electronically with information the interviewer provides or, if households do not have web access, they can receive a gift card via mail.

The team recommends pre-testing the survey with a small sample of households from the permit data to achieve up to three survey completes per sample cluster. This will help the team to determine if the survey approach is sufficient to meet its objectives, particularly in recruiting households for onsite visits, and to identify any changes necessary to improve the survey letters or questions prior to launch of the full survey. The analyses and onsite visits can still include households that respond to the survey pre-test.

The team plans to field both the survey pre-test and the full survey during a one- to two-month period. For mail-to-web surveys, responses tend to begin two to three days after mailing the letter to households and tend to stop after another four to five days. Thus, the team recommends sending the survey letters about six or seven days apart. For example, the survey schedule could resemble the following:

- Week 1, Monday: Send the survey invitation letter to the pre-test sample.
- Week 1, Friday: Analyze pre-test results and make any necessary revisions to the survey questions or invitation letter; start calling qualified pre-test respondents to schedule onsite visits; and send the survey follow-up letter to the pre-test sample.
- Week 2, Monday: Send the survey invitation letter to the full sample, and start site visits with qualified pre-test survey respondents.
- Week 2, Thursday: Analyze pre-test results, make any revisions to the follow-up letter, call more qualified pre-test respondents to schedule onsite visits.
- Week 2, Saturday: Send the follow-up letter to the full sample.
- Week 3, Monday: Start scheduling onsite visits with full survey respondents and continue until the end of data collection.

The survey of permitted households will attempt to verify whether they installed a heat pump in the home or in an additional dwelling unit(s) on their property in the past three years. As such, the team recommends including a request in the letters and on the survey website that the household member most knowledgeable about their home's heating and cooling equipment complete the survey.

The team will design a series of questions to include in the survey to assist respondents in correctly identifying and reporting the type(s) of residential HVAC equipment in their home and to help reduce the potential for self-reporting errors about their HVAC equipment. For example, the survey will first ask respondents a question about what type of HVAC equipment is in the home, using a list of equipment types, and a follow-up question about how certain they are about the type of equipment they selected.

[32] Incentives greater than $25 will likely be only slightly more effective at increasing response rates but likely will not be very cost-effective; BPA can consider a larger incentive if budget is available. An alternative incentive strategy that often results in the higher response rates but may not be as cost-effective as the gift cards is to include a $1 or $2 bill in the survey invitation letter mailed to all sampled households (Singer & Ye, 2013; Dillman, Smyth, & Christian, 2014). The team recommends against using a lottery, drawing, or sweepstakes, or not including an incentive as part of the survey approach, since research shows these strategies result in lower response rates and can be less cost-effective (Singer & Ye, 2013; Dillman, Smyth, & Christian 2014).

The survey will then ask the respondents who are uncertain of what kind of HVAC equipment they have additional questions to help reduce their uncertainty and narrow the list of the types of equipment that could be in their home. Examples include: a question that provides descriptions and images of each type of HVAC equipment, as well as questions about their HVAC equipment fuel type (e.g., electricity, gas, etc.); whether their heating/cooling comes through vents in the floor, wall, or ceiling or from a small unit mounted inside their home; and/or how they adjust the temperature settings (e.g., via thermostat, controls on the unit, etc.).[33, 34]

The team recommends also asking respondents if there is an additional dwelling unit or building with conditioned space on their property. Respondents who report they do have a conditioned unit or building on their property will be asked the same HVAC equipment questions as they were asked about their home.

The survey will then ask respondents who reported having a heat pump in their home to verify whether they installed the heat pump during the previous three years. The research team will design the survey to capture heat pumps installed in newly-built and existing homes.

The survey will ask respondents who report having a recently-installed heat pump whether they are willing to participate in an onsite visit from a professional contractor and, if so, how and when to best reach them to schedule the visit. The survey will include an introduction that explains the purpose and benefits of the onsite visit, including the incentive participants will receive, and what to expect regarding the scheduling and details of the visit. The research team will use answers to these survey questions to contact respondents to confirm and schedule the onsite visits.

The team also recommends including some questions in the survey about respondents' HVAC and household characteristics that could help select households to contact to schedule onsite visits and/or inform the market model. For example, important details might include respondents' dwelling type whether the respondent is a homeowner or renter, and what type of equipment the heat pump replaced.[35] Other important characteristics include whether respondents participated in a utility program to install or purchase their heat pump, respondents' satisfaction with the installation and performance of their heat pump, their thermostat settings, and whether they have experienced any problems with their heat pump. The team recommends asking these questions during the onsite visits to confirm web survey responses.

The team identified three potential risks associated with the proposed survey approach that could lead to some bias in the results, as follows:

- First, the study may not be able to estimate exact response rates to the web-to-mail survey approach proposed above and/or meet the targeted number of completes for one or more of the sampled clusters. The team plans to draw large enough samples of households from the permit data to avoid these risks but recommends including one of three follow-up approaches in the data collection plan to be safe. One potential follow-up approach would involve sending survey non-respondents in the sample a third contact letter to boost response rates enough to meet the targeted number of completes. A second follow-up approach to consider is to match non-respondents' addresses to phone numbers, and

[33] The team considered asking respondents to upload a picture of their HVAC equipment, or entering information from the HVAC equipment's name plate, such as the brand and model/serial numbers. However, this approach will likely be too burdensome for most respondents, particularly renters and seniors, and risks significantly reducing survey response rates and possibly increasing bias in survey responses.

[34] Respondents who complete the survey on the phone will be unable to see images but can be read detailed descriptions of HVAC equipment types.

[35] Since there is a low incidence of heat pump installations in the region, it is unlikely that many contractors will have recently installed a heat pump, which will likely limit the amount of heat pump stock turnover data collected in the HVAC contractor interviews (see section below). Asking households what equipment they replaced with their heat pump can thus help inform the BPA market model and heat pump stock turnover estimates in the region.

to then call them to complete the survey on the phone, until achieving the targeted number of completes. A third approach involves using the permit data to draw a separate, additional sample of households not included in the original sample, send them the survey invitation letter and possibly the survey follow-up letter, to achieve the targeted number of completes.

- A second risk with the proposed survey approach is that survey research shows response rates to surveys are often lower for renters and low-income households (Dillman, Smyth, & Christian, 2014). Therefore, results from the survey may include a lower proportion of these types of households than exist in the general population. Providing a survey incentive, as the team recommends, can help reduce the potential for nonresponse bias, but does not mitigate it completely.[36] However, if heat pump installation practices do not vary by homeownership or income, then risks of bias will likely be minimal.
- Third, certain types of respondents, including renters, seniors, people with disabilities, and residents of manufactured homes or low-rise buildings are likely to be less knowledgeable about their HVAC equipment. Thus, they may be unsure about the type of HVAC equipment they have and/or when it was installed. Including the team's proposed series of HVAC questions in the survey may help minimize respondents' uncertainty.[37] If heat pump installation practices do not vary by homeownership, dwelling type, and/or age or disability status of the household members, then risks of bias will likely be minimal.

Site Visit Recruitment and Survey

The team will use survey responses to identify households with recent heat pump installations that are willing to participate in the onsite visits (qualified households). The team recommends an experienced, knowledgeable research team member who can answer any questions and schedule the visits.

The team will select qualified households in each of the sample clusters and will contact them via the mode they provided in the survey (e.g., phone or email) to schedule the most convenient time to conduct the onsite visit. The team will begin scheduling onsite visits with qualified households upon receipt of web survey responses. When scheduling the onsite visits, the team will explain the purpose and details of the visit, the incentive provided to participants, and answer any questions participants might have about the visit.

The team recommends providing qualified households a large incentive to complete the onsite visit to maximize the number of households who agree to participate in the visit. The incentive amount will be a minimum of $50, but may be more, depending on how much time and effort is required of the household member who agrees to be available during the visit. The field technician will give the study participants the incentive upon completion of the onsite visit or mail it to respondents after the onsite visit — depending on BPA's policies for providing incentives.

[36] Two other options to consider to increase the proportion of renters and low-income households who respond to the survey is to: 1) draw a larger sample of households from the permit data to increase the number of renters and low-income households in the sample, or 2) use a vendor to match sampled household addresses with auxiliary data such as homeownership status and annual income, and the target the identified renters and low-income households with additional survey letters or phone calls.

[37] The team considered a couple of strategies to reduce the risk of potential bias from the types of residents who are most likely to not know much about their HVAC equipment. A strategy for reducing potential bias from renters is to purchase property parcel data that lists the property owner's name and mailing address. Parcel data can be matched to the permit data to identify permitted addresses that are owned by a resident with address that is different from the property's address. The team would then include the owner instead of the renter in the sample frame. This strategy, however, will require expensive parcel data that does not cover all of BPA's service territory, and a substantial amount of time and additional survey management. Another strategy is to include language in the survey letters that instructs residents who do not know much about their HVAC equipment to forward the letter to the person who does know about their equipment (e.g. landlord, property management company, caretaker, etc.). Survey research shows that this type of language can be intimidating in that it signals the survey will include some difficult questions, which is a disincentive to respond, and often is not successful in achieving responses from the desired contact due to the extra effort required by the recipient of the survey letter to make sure the desired contact gets the letter.

The team also recommends that experienced contractors administer a brief survey of participants during the onsite visits. The field technician may conduct the survey via a tablet or a paper questionnaire. The onsite survey could include questions about any problems participants experienced with their heat pump since it was installed, how they use their heat pump, and other questions about their satisfaction, participation in a utility program, and what equipment the heat pump replaced (if these questions are not included in the web survey of permitted households).

The team also recommends conducting a pre-test of up to 10 onsite visits to coincide with the pre-test of the web-to-mail survey of households in the permit data (see above). This will enable the team to identify and make any revisions to improve the recruitment strategy, scheduling process, and onsite visit data collection protocols. The results will include households that participate in the onsite visits pretest.

Site Visit Data Collection

The field technician will assess heat pump control settings, as well as establish a house heat-loss rate, and qualitatively determine duct system condition. Overall, heat pump performance depends on the combination of these elements, especially the nominal capacity of the heat pump — compared to house heat-loss rate — and the interaction of the system size with the controls settings. The controls should keep electric resistance heat off during milder outdoor conditions and, for variable speed units, keep the compressor operating during almost all heating hours.

The research team will design a site data collection protocol that will take an experienced field technician about three hours to complete.[38]

At the heat pump, the field technician will evaluate:

1. Heat pump size (nominal tons), determined from system make/model.
2. Thermostat/zoning control make/model.
3. Electric resistance (backup) heat lockout setting.
4. Compressor lockout setting (low ambient cutout).
5. System airflow.
6. Refrigerant charge (indirectly).

The field surveyor will catalogue the heat pump make and model of outdoor and indoor units, then assess system controls. At the thermostat, the field surveyor will check the system setting for backup heat and compressor control. Most modern thermostats allow direct programming of these settings. In some cases, the surveyor will have to check settings at the indoor or outdoor unit, or perhaps examine the zoning control. Research staff will provide field surveyors with programming instructions for most modern thermostats and zoning controls, so they can retrieve settings quickly and reliably. The research team assumes these tests will take 20–40 minutes at most sites.

At the indoor unit, the surveyor will run the system long enough to measure evaporator airflow since this is a primary contributor to system performance and required for CC&S incentives, additionally the surveyor will

[38] Unlike the 2005 study, the current study will not include a detailed heat pump refrigerant charge assessment or duct leakage test. These changes reflect a fuller understanding of the most important aspects of heat pumps to assess in the field and the typical installer method of accounting for duct effects during heat pump sizing.

measure the sensible temperature split across the evaporator to identify the percentage of systems that might have refrigerant charge problems. The product of system airflow and sensible temperature split is sensible capacity. The combination of these tests should take about 20 minutes.

The field technician will evaluate the following whole-house elements:

1. House heat loss rate (UA).
2. Duct review (largely qualitative).

The house's heat-loss rate represents a combination of opaque component (i.e., ceiling, wall, floor and door) heat loss, window heat loss/gain and air leakage. The field surveyor will perform the following steps:

- Measure opaque components and windows and use a provided set of heat loss/gain factors to calculate the house heat loss rate at a set design condition (30 degree Fahrenheit outside temperature for heating[39] and 1% design temperature for cooling).
- Sketch each site that will assist in calculation and aid any later data interpretation.
- Conduct a one-point blower door test to allow estimation of the air leakage contribution.
- Describe the location and insulation characteristics of the supply and return ducts, including any notes on observed leakage sites.
- Interview the study participant as described in the survey approach above and take several pictures of the duct system.

The research team will review duct notations and assign a duct loss factor to the base (static plus air leakage) heat loss and compare this to the nominal heat pump size. This part of the field protocol should take 40–70 minutes.

Training

The research team will employ experienced technicians to conduct the field work and the field team will undergo training before heading out to "live" sites. These personnel will have several years' experience conducting residential surveys and installing HVAC equipment. Field surveyors will have to examine a variety of equipment and assess the house and ducts, so the training will ensure that technicians are well-versed in the evaluation of items such as system controls (thermostats, zoning controls), airflow measurement tools and residential physical assessment (house and duct). The training will also address subjects such as interacting with homeowners, moving efficiently when in the field, and prioritizing efforts. The research team expects to hold a half-day classroom session, followed by work at two sites with significantly different characteristics and ample time for adebrief.

The field director of the 2005 onsite survey, Bob Davis of Ecotope, will organize and conduct the training, and provide primary input into the form and content of the field protocol and accompanying documents (e.g., thermostat technical guides, etc.). He will also be available for technical consultation during site visits.

[39] Design balance point required by CC&S specifications.

Analysis Plan

This section describes how the research team will use the collected data to address the following field study objectives:

1. Determine the current practice baseline for residential ASHP commissioning, controls, and sizing in the Pacific Northwest region.

Analysts for the RTF established the current practice baseline and UESs for several measures associated with ASHP CC&S using the Simplified Energy Enthalpy Model, or SEEM.[40] SEEM allows latitude in describing how the analyst uses various house prototypes, which incorporate different house sizes, heat loss rates, and heat pump-related inputs to build up underlying energy usage estimates.[41]

The team must extrapolate the site visit and web survey results to the region to prepare the results for input into SEEM. Processing and analyzing the results will require the team to compile the following sources of data and information:

- Data collected onsite.
- Data collected from the recruitment survey.
- Data collected from most recent RBSA.
- Permit data jurisdictional coverage.
- Regional distributor sales data due to BPA in spring 2018.

The research team will summarize and organize the following results from the site visits by SEEM input variable:

- Commissioning
    - System airflow across indoor coil.
    - Refrigerant charge.[42]
- Controls
    - Auxiliary heating high-temperature lockout setting.
    - Compressor low-temperature lockout setting.
    - Sequencing of compressor and auxiliary heat backup.
- Sizing
    - House heat load, as determined from insulation levels of the home, air infiltration rate and duct leakage test.
    - Heat pump capacity as determined from nameplate.

[40] https://rtf.nwcouncil.org/simplified-energy-enthalpy-model-seem

[41] The original PTCS savings estimates relied on a field review of the base case condition of heat pumps (used to condition various house prototypes). The analysts producing the original estimate specified prototype homes, as used for other RTF measures, in different climates. These prototypes incorporate different house sizes, heat loss rates, and duct characteristics. Both crawl and half-crawl cases were used to get a melded duct effect. The duct part of the model was the original impetus for SEEM's development and was informed by field research conducted by Ecotope in the early 1990s.

[42] Refrigerant charge is not currently an input to SEEM. However, it will be useful and relatively simple while conducting the other tests to collect information on whether there are a significant number of systems with undercharged refrigerant in the region. If this is found to be the case, refrigerant charge may be recommended to become a SEEM input.

The team will QC the summarized values to ensure they fall within reasonable ranges that are representative of the data collected in the field. The team will then apply the appropriate sample fraction to the results for each site to extrapolate the results to the sample frame.

Since the sample frame only covers the households in the permit data, the research team will use the jurisdictional coverage rates to extrapolate the results to all jurisdictions. The research team will attempt to estimate the likely size of missing permit activity based on the jurisdictions missing from the permit data, then establish the jurisdictional coverage rates by sample domain (east and west of the Cascades). Further, the team will estimate the fraction of ASHPs installed without a permit by comparing the count of heat pumps in the permit data to sales data. The team will then extrapolate the results from the permit data sample frame to the full region.

The research team will provide all assistance necessary to ensure the information transfer to the RTF Contract Analyst Team, or CAT, is smooth and timely. The research team's long-term experience with handling the field data, familiarity with SEEM, and relationship with CAT staff on this group of measures will facilitate this process.

In addition to preparing the results for SEEM, the team will also apply the site visit data to the PTCS program installation specifications, including the heat pump sizing calculator, for each home visited to assess whether installation followed program required practices. The team will record which criteria were met and which were not for each home then summarize those findings across the homes in the sample to the study level. BPA may use these results to compare to PTCS evaluation findings and to improve the program.

Appendix D1: Permit Data Processing

The team found that inconsistencies in how data was recorded between jurisdictions (what information was recorded and in which data fields), missing data, and spelling errors introduced challenges in processing and searching the data to prepare the sample frame. A balance was struck between trying to include all relevant records while excluding non-relevant records. The permit data came with the following fields:

Table 16 Permit Data fields

PropertyID	PermitProposedUse
PermitID	PermitClass
PermitNumber	Category
PermitDate	PropertyAddress
PermitStatus	PropertyCity
PermitType	PropertyState
DetailedDescription	PropertyZipcode
PermitWorkClass	PermitJobCost

The research team took the following steps to prepare the sample frame. First, the team searched all fields for evidence of non-residential properties included in the permit records. The following search terms and patterns identified non-residential properties:[43]

[43] Capitalization is ignored in all searches

- Commercial, Industrial, Mutifam, Multi(|-)?fam, government, church, School, Public, Non(|-)?res, Office, retail, Institut, Apartment, Condo, (Apt|unit|#) [a-z]*[0-9].[44]

The team eliminated 98,061 records matching these terms from the permit data, leaving 513,448 records in the frame.

Second, the team searched all fields for terms related to heat pump. The following search terms and patterns identified possible heat pump records that are not for *air source* heat pumps:

- Duct(|-)?less, Dhp, Wshp, Water(|-)?(source|heat|pump), (multi|mini)(|-)?Split, Geo(|-)?(therm|heat|spring|unit), [a-z]hp.

The team eliminated 47,264 records matching these terms from the permit data, leaving 466,184 records in the frame.

Third, the team isolated the records in the frame with empty DetailedDescription. This was the primary field for describing the work being done under the permit application. The team does not know what the jurisdiction designation is for reporting permit records to BuildFax. Assuming the jurisdiction is city, the team found 41 jurisdictions that always had empty DetailedDescription. To avoid entirely excluding these jurisdictions, the team instead eliminated records it determined were not associated with heat pump installation. The following search terms identified these records:

- Plumb, Window, Alternative, Cell, Circuit, Conditioner, Fire, Pool, Deck, Solar, sign, Repair, Foundation, Demolition, a/c, Vent, Water, Garage, Siding, Roof, Mobile, Demo, addition, Remodel, Gas, Accessory, Stove, Heater, Hood, Alteration, Damage, Temp.

There are 2,739 possibly relevant records with empty DetailedDescription.

Fourth, the team isolated records with non-empty DetailedDescription containing words related to air source heat pumps. The following search terms and patterns identified air source heat pumps:

- heat(|-)?pump, ashp, air(|-)?source, hp.

To ensure that "hp" does not refer to horsepower rather than heat pump, the team excluded records containing the following pattern: ([0-9]{1,4}( )?hp). This left 35,086 records with non-empty DetailedDescription which relate to air source heat pump installations.

Fifth, the team combined the blank DetailedDescription records with the non-blank DetailedDescription, heat pump related records and collapsed by unique PermitID in case there were overlapping records between the two datasets, for a total of 37,758 records in the frame. Then the team explored PermitNumber, PermitStatus, and related fields to understand reasons for multiple permit records at individual property addresses. From this exploration, the team determined that the following fields contained superfluous information causing multiple instances of permit records for the same jobs:

- PermitID, PermitStatus, PermitDate, PermitType, Category, PermitJobCost, DetailedDescription.

The team sorted records by PropertyID, PermitNumber, and PermitDate then collapsed records across these fields, keeping the last record (most recent PermitDate) by PropertyID and PermitNumber. This eliminated 341 records, leaving 37,417 records in the frame.

[44] In PropertyAddress field only

Sixth, the team examined PermitStatus to identify records in the frame associated with abandoned permit applications. There were 151 unique permit status descriptions of which the team determined 39 indicated the permit application had been abandoned or otherwise did not represent a completed heat pump installation.[45] Eliminating records with abandoned permits left 32,067 records in the frame. The team observed among the remaining records that there were often unique PermitNumbers for the same job, e.g., one for Mechanical, one for Electrical, etc. Additionally, the team noticed that the same property address occurred multiple times with different jobs in the same time frame. Investigating further, the team looked up some of the addresses and found that they belonged to a central office of a large complex, such as a mobile home park. There are 44 property addresses which have more than four records[46] and seven of these properties are in the drawn sample. The team then further collapsed the frame across PermitNumber to unique PropertyID. This formed the final record set for the frame of 28,430 records.

Seventh, the team assigned utilities as described in the main body of the memo above.

Finally, the team assigned records to sample domain east or west based on location relative to the Cascade Mountain range. All records in Idaho and Montana received the East domain assignment. Eastern/western Washington and, Oregon do not have consistent definitions. Western and eastern Washington appear to be best/most frequently defined based on counties. Therefore, the team used counties for domain assignments in Washington and Oregon.

The team assigned counties as follows based on information in the referenced web links:

- Washington counties[47]
  - East: Adams, Asotin, Benton, Chelan, Columbia, Douglas, Ferry, Franklin, Garfield, Grant, Kittitas, Klickitat, Lincoln, Okanogan, Pend Oreille, Spokane, Stevens, Walla Walla, Whitman and Yakima.
  - West: Clallam, Clark, Cowlitz, Grays Harbor, Island, Jefferson, King, Kitsap, Lewis, Mason, Pacific, Pierce, San Juan, Skagit, Skamania, Snohomish, Thurston, Wahkiakum and Whatcom.
- Oregon counties[48]
  - East: Hood River, Wasco, Jefferson, Deschutes, Klamath, Lake, Crook, Wheeler, Gilliam, Morrow, Grant, Umatilla, Harney, Union, Wallowa, Baker, Malheur.
  - West: Clatsop, Columbia, Tillamook, Washington, Yamhill, Polk, Lincoln, Benton, Linn, Lane, Douglas, Coos, Curry, Josephine, Jackson, Linn, Marion, Clackamas, Multnomah.

The team used a spatial join in QGIS to assign each zip code a county and side of the Cascades. The team manually changed the assignments of several zip codes after the join. Some zip codes cross county boundaries near the Cascades, so the team assigned them to the side that the majority of the zip code was in.

[45] The team left incomplete permits in the frame to include jobs which may have completed but did not complete the permitting process.
[46] The team defined having more than four records for the same property as being a large complex.
[47] https://www.usmarshals.gov/district/wa-e/general/area.htm
[48] https://geology.com/topographic-physical-map/oregon.shtml, https://geology.com/county-map/oregon.shtml

Appendix E: Data Collection Protocol

The research team will employ three data collection methods for the field study:

- Acquire existing data sets.
- Remotely survey ASHP households via web or telephone.
- Visit ASHP households.

Acquisition of Existing Data

The research team will first need to develop sample frames from which to recruit participants into the Field Study. The ASHP CC&S baseline study will rely on regional permit data to locate households with recent heat pump installations.

The research team will purchase permit records from BuildFax, which is one of three permit data vendors the team identified as having the most records for BPA's service territory and the highest quality data. BuildFax will provide the records in a .csv file via a secure file transfer protocol, such as Sharefile. The records will comprise all residential permits from the previous three years, which BuildFax estimates will be more than one million records. The records will include fields for the type of permit (e.g., mechanical, electrical, etc.), the permit date, description, status, and proposed use. The records will also include the contractor's and inspector's notes, the address of the residence associated with the permit (e.g., street, city, state, and zip), the year the residence was built, and any other available fields that will be useful for developing the sample frame and extrapolating results. The team will then analyze the permit records to screen out any permits that do not mention "heat pump" or any variation of the spelling (e.g., heat pump, heatpump, HP, etc.). The remaining heat pump permits will comprise the sample frame for sending sampled households a letter to complete a survey and recruit them for a site visit.

Surveys

The research team will conduct surveys remotely to recruit participants into the field study. This section describes how the research team will conduct these surveys.

The following sections present the protocols for collecting information from households in the permit sample frame that likely installed a heat pump in the past three years. The sections also describe how the research team will recruit ASHP households for a site visit by a field surveyor to verify CC&S. The team will contract with a survey center that will print and mail the letters, host the web survey, and provide a toll-free number that respondents can call to complete the survey via telephone. The team will pre-test the survey with a small sub-sample to ensure the survey implementation, design, and questions perform as expected and to make any necessary improvements.

The team will design and mail two invitations to complete the online survey to sampled households. The survey will include questions that satisfy the following objectives:

- Confirm the respondent installed an ASHP in their home or another building on their property (e.g., additional dwelling unit, conditioned garage, or storage building, etc.) during the past three years.
- Determine the type of heating/cooling equipment the newly installed ASHP replaced.

- Collect key demographic and household characteristics.
- Recruit households to participate in a site visit by a field surveyor.

Contacting Households

The survey center will mail two letters to sampled households by post, inviting them to complete the web survey. The center will print letters single-sided, on standard 8.5” X 11” utility-, BPA-, or survey center-branded letterhead. They will mail it in a business-class envelope featuring the logo for the respondent’s utility, BPA, or the survey center in the upper left-hand corner of the envelope.[49]

The first letter will introduce the study to households and invite them to take the survey. The second letter will thank those who already responded to the survey and remind those who have not yet responded to complete the survey.

Both letters will include:

- Compelling reasons for why it is important for respondents to participate in the study, information about how long it should take to complete the survey, and assurances that their responses will remain confidential.
- Details about the $25 gift card incentive, including what it is and how they will receive it.
- The survey website address and unique passcode respondents will use to access the survey, including brief instructions for entering the address into their web browser (not a search engine).[50]
- Two phone numbers and email addresses: one number and email for the survey center, which respondents can use if they have questions or wish to complete the survey via telephone, and another number and email for the study sponsor, in case respondents have questions about the actual study.

Survey Landing Page and Survey Design

The survey landing page is the first webpage respondents will see when they enter the URL address into their web browser. The top of the landing page will prominently display a banner with the respondent’s utility logo, BPA logo, the survey center logo, and the study’s title.[51]

The middle of the page will include instructions for accessing and completing the survey, a few details about the study, and a field for the respondent to enter their unique passcode. The bottom of the page will display contact information for the survey center and study sponsor.

Each subsequent survey page will include the banner with the logos and study title, one survey question, and ‘Back’ and ‘Next’ buttons below the survey question, which the respondent will use to navigate through the survey. Responses to most survey questions will be voluntary (e.g., respondents can skip questions without

[49] The team recommends using the respondent’s utility logo and letterhead, because respondents have a preexisting relationship with their utility and would be more likely to open and read the letter. If this is not possible, the team recommends using BPA’s logo and letterhead or, if the team uses a locally known institution to conduct the survey (e.g., Washington State University’s Social and Economic Sciences Research Center), using the institution’s logo and letterhead.
[50] The website address should be as simple as possible so that it is easy for respondents to type it into their web browser
[51] The team recommends using the respondents’ utilities’ logos in the banner since they have a preexisting relationship with their utility. If this is not possible, the team recommends using BPA’s logo and/or, if the team uses a locally known institution to conduct the survey (e.g., Washington State University’s Social and Economic Sciences Research Center), using the institution’s logo in the banner.

providing a response). However, as noted below, a few questions will be mandatory or require a response before the respondent can move to the next question.

Screening Questions

The research team will design the first series of questions to screen respondents by confirming that a heat pump was installed in their home or building on their property in the past three years. This is important because the sample frame includes ambiguous notes for some records (e.g., installed furnace/heat pump) that indicate households could have installed a heat pump or some other type of equipment. The screening questions will confirm the permit records and the date of installation.

The survey team recommends these questions include language that explains the heat pump could have been installed in the respondent's home or in another building on their property, such as an additional dwelling unit, conditioned garage or storage building, barn, etc. The permit data does not specify the location of the equipment on the property, and the team does not want to exclude households that installed the heat pump in a building other than their home.

If respondents have trouble recalling details about the installation, the survey team recommends asking a series of follow-up questions to help them determine whether and when they had a heat pump or other type of equipment installed, and if the heat pump is located in their home or another building on their property.

- The survey will screen out respondents who report that they did not have a heat pump (Option 2) or any heating/cooling system (Option 4) installed.
- The survey will ask a follow-up question (S3) of respondents who report having a heat pump installed on a different date than that the permit records provide (Option 1) to confirm the installation occurred in the past three years. The survey will screen out those who report their system was installed more than three years ago.
- The survey will ask a follow-up question (S4) of respondents who report having heating/cooling equipment installed but are unsure of the type of equipment (Option 3). The question will list the most common types of heating/cooling equipment and provide images of each type of equipment to help respondents determine which equipment they have. For the phone version, the interviewer will read detailed descriptions of each type of equipment to help the respondent determine which system they installed. The survey will screen out those who select any equipment type other than a heat pump.
- The survey will automatically direct respondents who do not know whether a heating/cooling system was installed during the past three years to the Housing and Demographic Characteristics questions. This will help the team determine whether these respondents are renters or owners, what type of home they live in, etc.

Following are examples of how the research team will design the questions.

S1. [ASK ALL; REQUIRED RESPONSE] Permit records indicate that a heat pump system for heating and cooling your home was installed in your home or another building on your property around [MONTH/YEAR FROM PERMIT DATA]. Is that correct?

1. Yes → SKIP TO S5.
2. No → SKIP TO S2.

S2. [ASK IF S1 = NO (2); REQUIRED RESPONSE] Which of the following best describes the heating/cooling system installation that occurred in your home or another building on your property?

1. The heat pump was installed, but the date provided is incorrect → SKIP TO S3.

2. A heat pump was not installed in my home or another building on my property, but another type of heating/cooling system was installed → THANK & TERMINATE.
3. A heating/cooling system was installed in my home or another building on my property, but I'm not sure what type of system → SKIP TO S4.
4. A heating/cooling system was **not** installed in my home or any other building on my property → THANK & TERMINATE.
5. I don't know if a heating/cooling system was installed in my home or another building on my property → SKIP TO 'Housing & Demographic Characteristics.'

S3. [ASK IF S2 = WRONG DATE (1); REQUIRED RESPONSE] Was your heat pump installed in the last three years, after [MONTH/YEAR FOR THREE YEARS PRIOR]?

1. Yes.
2. No → THANK & TERMINATE.
3. Don't know → THANK & TERMINATE.

S4. [ASK IF S2 = DON'T KNOW TYPE OF EQUIPMENT (3); REQUIRED RESPONSE] Below is a list of common heating and cooling systems, along with images of each type of system. Which of these was installed in your home or another building on your property around [DATE]? [Images of equipment types would be thumbnails placed next to each option that respondents can click on to enlarge].

1. Heat pump → CONTINUE.
2. Gas or electric furnace → THANK & TERMINATE.
3. Baseboard heating → THANK & TERMINATE.
4. Radiant heating → THANK & TERMINATE.
5. Fireplace (gas or wood) → THANK & TERMINATE.
6. Central air-conditioner → THANK & TERMINATE.
7. Other → THANK & TERMINATE.
8. Don't know → THANK & TERMINATE.

S5. [ASK ALL] Was the heat pump system installed in your home or in another building on your property like a garage, workshop, barn, storage unit, guest house, or rental unit?

1. It was installed in my home.
2. It was installed in another building on my property (please specify):

HVAC Characteristic Questions

After confirming the respondent had a heat pump installed in the past three years, the survey will ask what type of equipment the heat pump replaced, how satisfied the respondent is with the equipment, and whether they received an incentive. These questions could help BPA's HVAC modeling efforts and will provide important background information to the field surveyor. Below are example questions:

Q1. [ASK ALL] Did you replace an older heating/cooling system with your heat pump?

1. Yes.
2. No → SKIP TO Q3.
3. Don't know → SKIP TO Q3.

Q2. [ASK IF Q1 = YES (1)] What type of heating/cooling system did the heat pump replace?

1. A different heat pump model.
2. Electric furnace.
3. Gas furnace.
4. Oil furnace.

5. Baseboard heating.
6. Radiant heating.
7. Fireplace (wood or gas).
8. Central air conditioner.
9. Room or window air-conditioning unit.
10. Other.
11. Don't know [If don't know, consider including this in the site visit. The respondent may be able to provide pictures during the site visit to identify what was replaced.]

Q3. [ASK ALL; OPTIONAL] How satisfied have you been with your heat pump system? Please use a scale from 0 to 10, where 0 means not at all satisfied and 10 means extremely satisfied.

0	1	2	3	4	5	6	7	8	9	10
(Not at all satisfied)										(Extremely satisfied)

Q4. [IF Q3 < 7] Why do you say that?

1. Response:

Q5. [ASK ALL] Did you receive an incentive, rebate, or discount on your heat pump system from your energy utility?
1. Yes.
2. No.
3. Don't know.

Housing & Demographic Characteristic Questions

The next series of questions will ask about the respondents' housing and demographic characteristics, which the team can use for selecting households to contact to schedule site visits. This data can also inform the market model. Important details include a respondent's dwelling type, whether the respondent is a homeowner or renter, the age of the home (to determine if it is new or existing), and how long the respondent has lived in the home (to determine how much the current resident may know about the home's history). Below are some example questions.

Q6. Which of the following best describes your residence? [CATEGORIES ARE DIRECTLY FROM RBSA]
1. Manufactured or mobile home.
2. Single-family detached home.
3. Single-family attached home such as a townhouse.
4. Duplex, triplex, or fourplex.
5. Apartment or condominium with five or more units.
6. Other (please specify).
7. Don't know.

Q7. Do you own or rent your home? [DIRECTLY FROM RBSA]
1. Own/buying.
2. Rent.
3. Occupy without rent.
99. Prefer not to say.

Q8. Approximately what year was your home built [CATEGORIES ARE COMPARABLE TO RBSA]?

1. Before 1970.
2. 1970 to 1979.
3. 1980 to 1986.
4. 1987 to 1992.
5. 1993 to 2000.
6. 2001 to 2014.
7. After 2014.
98. (Don't know).

Q9. How long have you lived in your current home? [NOT ASKED IN RBSA]

1. Under 1 year.
2. Between 1 and 3 years.
3. Between 3 and 5 years.
4. 5 or more years.

Q10. [OPTIONAL] What is the highest level of education you have completed so far? [CATEGORIES ARE COMPARABLE TO RBSA]

1. HIGH SCHOOL GRADUATE OR LESS (INCLUDES GED).
2. SOME COLLEGE, NO DEGREE.
3. COLLEGE DEGREE (ASSOCIATES DEGREE OR HIGHER).
98. DON'T KNOW.

Q11. Which of the following categories best describes your total annual household income for 2017, before taxes? [CATEGORIES ARE COMPARABLE TO RBSA]

1. UNDER $20,000.
2. $20,000 TO UNDER $30,000.
3. $30,000 TO UNDER $40,000.
4. $40,000 TO UNDER $50,000.
5. $50,000 TO UNDER $60,000.
6. $60,000 TO UNDER $75,000.
7. $75,000 TO UNDER $100,000.
8. $100,000 TO UNDER $150,000.
9. $150,000 TO UNDER $200,000.
10. $200,000 OR MORE.
98. Don't know.
99. Prefer not to say.

Recruitment for Site Visits

The survey will ask respondents who report having installed a heat pump in the past three years if they are willing to allow a field surveyor to conduct a site visit and, if so, how and when to reach them to schedule the visit. The research team recommends that this portion of the survey contain an introduction that explains the purpose and benefits of the site visit, including the $50 incentive participants will receive and what to expect regarding the scheduling and details of the visit. Below is an example of how the survey may present this information.

Q12. [REQUIRED RESPONSE] We are looking for households willing to allow a field surveyor to visit their home to take measurements and record details about their heat pump system. The surveyor will assess the sizing and set up of the heat pump relative to the home's characteristics. The field surveyor will not attempt to sell you anything during the visit. The visit will take between [TIME REQUIRED], depending on the size of your home, and will take place [DATE RANGE].

This is important for BPA's efforts to improve contractor training and update how they forecast energy usage in the region. If you are interested and selected for the home visit, you will receive a [ONSITE INCENTIVE] at the beginning of your home visit.

If you are interested, please provide your contact information on the next screen. If you are selected for this part of the study, we will contact you [TIME PERIOD].

Are you interested in participating in this study?

Yes.

No.

[IF YES] Thank you for your interest in participating. We just need to get some contact information from you, so we can contact you to schedule a visit. Please provide the following information:

First Name:

Last Name:

Phone Number:

Email Address:

Home Address:

Unit Number:

City:

State:

ZIP Code:

When is the best time to contact you?

Morning (9am-12pm).

Afternoon (12pm-5pm).

Evening (5pm-9pm).

Closing

The survey's closing will be different for those who agree to a site visit than for those who do not agree. For those who agree to a site visit, the closing will confirm that they will receive a call to schedule the visit. For those who do not agree to a site visit, the closing will include a statement about what to do if they change their mind. The closing will also include a question about how to send the $25 gift card incentive to the respondent and will thank them for their responses.

Here is an example of what the closing might look like:

[If yes, respondent agrees to site visit]

Great, we will try to call you at [pipe in their preferred time and their phone number]. If we are unable to reach you by phone, we will email you at [pipe in their email address].

Q13A. [REQUIRED RESPONSE] What is the best way to send you the [SURVEY INCENTIVE]?

1. Email (enter email address):
2. Mail (enter mailing address):

We will send you the [SURVEY INCENTIVE] via [RESPONSE: email or mail] within the next three business days. If you have any questions, you can reach us at [phone number] or [email address]. Thank you for your time and feedback. We'll be in touch [TIMEFRAME]

[If no, respondent does not agree to site visit]

Q13B. [REQUIRED RESPONSE] What is the best way to send you the [SURVEY INCENTIVE]?

1. Email (enter email address):
2. Mail (enter mailing address):

We will send you the [SURVEY INCENTIVE] via [RESPONSE: email or mail] within the next three business days. Thank you for your time and feedback. If you have any questions, or if you do become interested in participating in the site visit from a field surveyor, you can reach us at [phone number] or [email address].

Scheduling Site Visits

The survey center will send the research team the survey completes at the end of each day of data collection, or the following morning. The research team will review the responses and provide the field team with a list of respondents who agreed to participate in a site visit. The field team will use this list to contact households to schedule and conduct the visits.

Field Staff Training and Safety

The research team will use classroom and onsite training to familiarize the field staff with this protocol and ensure they collect consistent, reliable data in the field. The training will cover all aspects of the site visit protocol (see next section), with a particular emphasis on the data collection forms (see Appendix E1: Heat Pump Site Data Collection Form). Appendix E2: Sample Training Slides provides examples of training slides, which focus on key topics the team will cover.

The classroom and onsite training will pay considerable attention to heat pump system controls, including thermostats and related components. The research team plans to use existing PTCS technical documents as a reference point and will also direct field staff to use electronic resources if needed while on site to figure out how to access control settings. This information is now readily available online.

The team will visit at least one site where all field staff will be required to fill out the field data collection forms and practice using the various measurement instruments required by the protocol.

The training will also cover participant relations and site safety, as these are crucial to success in the field. The participant must receive clear information on what will happen during the site visit and feel confident that detailed information on the condition of the system (including needed repairs) will be confidential. The training will also cover site safety procedures, especially electrical safety (although it is unlikely field staff will encounter line voltage during the visit). Field staff will also receive training on the procedure for the blower door and duct leakage tests to ensure minimal or no disruption; this includes issues such as how to handle fireplaces, woodstoves, or gas water heaters so there are no safety or ash issues. The training will introduce all topics in the classroom training session then review and demonstrate each topic during the site visit.

Site Visits

The site visit portion of the field study begins following participant recruitment. The field surveyors will adhere to the following protocols for each site visit.

Pre-Visit Protocol

Field surveyors will receive lists of eligible sites from the recruiting team; the field surveyor will have already supplied their availability to the recruiters to populate the site visit calendar. The field surveyor will have final responsibility for confirming the site visit day and time and will contact the site occupant 24 to 48 hours in advance of the site visit.

During the confirmation call, the field surveyor will briefly discuss the steps in the site survey and how long the visit will take. The surveyor will remind occupants about the access needed to the house, including the heat pump and duct zones.

The field staff must keep the site visit schedule up to date, and, if a change is necessary, the surveyor will be responsible for rescheduling the visit and notifying the Recruiting Manager. The team will use scheduling software to keep track of the site visit schedule.

Field forms (see Appendix E1: Heat Pump Site Data Collection Form) will be available on the project website and retained on the field surveyors' local computers. Field surveyors will print blank forms in preparation for each site visit and manually fill them out while onsite.

The surveyor must ensure all onsite equipment (see Appendix E1: Heat Pump Site Data Collection Form) is ready to go before the site survey.

Onsite Protocol

The overall process will take at least four hours. Some sites could require up to six hours.. The length of the visit will depend on the size and complexity of the house, as well as how difficult it is to set up the house for the air leakage tests. The surveyor should plan to take at least 10 pictures per site, including heat pump nameplates, thermostat front and sub-base (if applicable), and other notable details, as described below.

Data collection will involve the following steps, presented in the order recommended for the site visit:

1. Participant Interview and Acknowledgment (see Appendix E1: Heat Pump Site Data Collection Form).

   The surveyor will ask the participant for basic information about the home's layout and occupancy, the location of the thermostat, the location and typical operation of the heat pump, what other heating sources are in the house, and how frequently the occupants use them. The surveyor will review the steps involved in the site survey with the occupant, answer any clarifying questions, and then have the occupant sign a form acknowledging that they understand the study's objectives and the field staff responsibilities. This step should take 10–15 minutes. At this point, the occupant will also receive their participation incentive.

2. Heat Pump System Nameplates and Control Settings (see Appendix E1: Heat Pump Site Data Collection Form).

The surveyor will record the model numbers of the outdoor and indoor heat pump units, the model of the thermostat, and t*he* system's control settings. (If a gas furnace is part of the system, its model number should also be recorded, since this can affect the nominal efficiency rating of the heat pump.) *Important control settings include the thermostat setpoints and schedules, the compressor low-temperature lockout temperature, and the auxiliary heating high-temperature lockout temperature. The surveyor will also take pictures of the equipment nameplates and the thermostat front and sub-base, if applicable. This step should take about 20 minutes.*

3. Heat Pump System Performance (see Appendix E1: Heat Pump Site Data Collection Form).

   The surveyor will test the performance of the heat pump system by measuring the airflow across the indoor coil, the temperatures at the inlet and outlet of the indoor coil, the static pressure in the supply and return plenums, and the temperature of the outside air entering the outdoor coil. The temperature and airflow measurements are necessary to calculate the actual output of the system for comparison against the rated capacity (an indirect assessment of refrigerant charge). The static pressure measurements help identify systems that might have undersized ducts, and they are also a factor in the external duct leakage test described below. Outdoor temperature will determine whether the test is done with the heat pump in heating mode (outdoor temperature < 60 degrees Fahrenheit) or cooling mode (outdoor temperature >= 60 degrees Fahrenheit). For staged and variable capacity heat pumps, or VCHP, the surveyor must note the stage or percentage of full capacity tested, since this will have bearing on the expected airflow rate and temperature split. The surveyor may have to consult manufacturer's installation guides to determine the best way to control the heat pump for this set of tests. This step should take about one hour.

4. House Envelope and Exterior Duct Insulation Audit (see Appendix E1: Heat Pump Site Data Collection Form).

   The surveyor will conduct an audit of the house envelope and the exterior ductwork to evaluate the level of insulation of the conditioned spaces and to determine how much of the ductwork is located outside the conditioned spaces. This is a necessary factor in estimating the overall house heat loss rate for comparison against the nominal heat pump size, which occurs in the final data preparation stage. For the envelope audit, the surveyor will sketch each conditioned floor of the house and label the sketch with component areas and insulation/window details. Window areas shall be gathered by window type (frame type, number of panes) and window elevation. It is likely a simple low-emissivity detector will be used to determine presence of a low-e window coating, which has leverage on the cooling load. For the duct audit the surveyor will estimate the percentage of the ductwork that is located outside the envelope and the insulating value of the material that wraps around or covers the ductwork. The surveyor will take pictures of each of the elevation views of the house, as well as notable envelope and ductwork details. This step should take about two hours, depending on the complexity of the house.

5. House Envelope and Exterior Duct Air Leakage Test (see Appendix E1: Heat Pump Site Data Collection Form).

   The surveyor will use a blower door to evaluate the air leakage rate of the house envelope and the exterior ducts. This is necessary to calculate the contribution of envelope and exterior duct air leakage to the overall house heat loss rate. The surveyor will take pictures of notable leakage details. These tests should take about one hour to complete, depending on the complexity of the house.

The surveyor will check the protocol sheets after completing these steps to look for omissions, gather testing equipment and take additional pictures.

Post-Visit Protocol

The post-visit process will have three steps. The first step is to scan the field forms and label and store the pictures by the unique site identifier so they are available electronically during quality control. The second step involves entering the site data and notes into an electronic form and calculating the overall heating and cooling load of the house. Heating load is of primary interest, but it is necessary to know the cooling load to determine if it should have been the dominant load in the context of system sizing. The field surveyor will then find the detailed output tables for the heat pump at the site and determine the correct heat pump. This is the coil combination that meets the dominant load, which is the heating load at 30 degrees Fahrenheit or the cooling load at 95 degrees Fahrenheit. The research team will provide an electronic tool for the field surveyor to enter relevant site information for this step. Appendix E3: Heat Pump Sizing Worksheet shows this form. It is possible an alternate sizing method will be employed during the project. The third step is to enter the site data into the PTCS sizing tool to compare the size of the actual system with the size of the system that PTCS would require. This tool does not allow as much flexibility as the Appendix E3: Heat Pump Sizing Worksheet tool but is the primary tool now used by contactors to size systems that receive CC&S incentives.

Quality Control

The field team will employ several procedures to ensure data quality. Some of these procedures will involve direct supervision by the Field Manager, especially at the outset of the project. Others will include internal QC at the site, ready access to technical resources and the Field Manager when on site, and a final acceptance procedure for the field data, before entering it into the project data set.

The Field Manager will accompany each field surveyor to the first two sites and be available to answer all technical questions while on site. The Field Manager will also receive the first three field report forms from each surveyor, perform a detailed review within one day of the site visit, and provide feedback to the surveyor. This will help each surveyor identify potential improvements that may be necessary and iron out any problems with the data acquisition process.

Each surveyor will have ready access to the Field Manager when questions arise onsite. The Field Manager will also make available a set of reference documents that describe many heat pump controls.

The field protocol forms include detailed instructions on how to conduct Blower Door and airflow measurement tests. The Blower Door Test includes built-in QC that will indicate if the field surveyor conducted the test correctly. The airflow measurement test includes a similar built-in QC element.

The surveyor will take pictures of the heat pump nameplates, the thermostat or other primary control, the supply and return ducts, and any other noteworthy details to help complete the site survey and support final QC review and acceptance. Field surveyors will submit the data they collected at each site for a final review within a week of completing the site visit.

The Field Manager, with assistance from senior field staff, will review the field data for completeness and accuracy. The reviewer will closely examine the site sketch and its relationship to measured component areas and volume, duct characterization (location/insulation amount), Blower Door Test results, and airflow measurement results. Note, the Blower Door and airflow tests require the surveyor to record intermediate data instead of using automated features of modern pressure gauges to facilitate corrections, if necessary. When the review and any follow-up activities are complete, the research team will accept the site and enter it into the project database.

Appendix E1: Heat Pump Site Data Collection Form

Name:	**Date:**
Address:	**Field Engineer(s):**
Phone:	**Organization:**
Utility:	

Homeowner Acknowledgment:

I acknowledge that I have given permission for SBW Consulting or its representative to test my heat pump system and house as part of a review of northwest heat pumps for Bonneville Power Administration. SBW and its subcontractors are covered by $1 million professional liability insurance. SBW will repair or cause to be repaired any damage caused as the result of the testing.

____ _______________

Homeowner signature Date

By signing below, I give permission to Bonneville Power Administration or its contract team to request access to my utility billing records. The billing records would be used anonymously to characterize heat pump energy usage.

____ _______________

Homeowner signature Date

<u>Equipment checklist</u>

____ Protocol form/pencil
____ Camera or phone (pictures)
____ Flashlight/headlamp & extra batteries
____ Tape measure or equivalent
____ 6-foot ladder/dropcloth
____ Respirator/gloves
____ Blower Door, controller, frame/panel, tubing, digital pressure gauge & extra batteries
____ Duct Blaster or equivalent (duct test)
____ Static pressure tap or Pitot tube
____ TrueFlow kit: 2 plates and all spacers
____ Blue masking tape/duct tape/metal tape
____ Digital thermometer and thermocouples
____ Cordless drill/step bit

Order of tests

1. Basic house info/homeowner questions/acknowledgment signature.
2. Heat pump controls review.
3. Heat pump functional review (air flow and temperature split tests).
4. House heat loss and duct assessment.
5. Blower Door and duct tests.

<table>
<tr>
<td rowspan="2">House Type (circle):
Rambler multi- story
Split level attached garage (y/n)
Manufactured home
Other (specify):

Heat Pump service area:
Main living space Whole house
Single room or rooms Basement only
(such as bedrooms)
Other (specify):</td>
<td>Location of heat pump indoor unit:
Conditioned space Garage Crawl Attic
Unfinished basement
Other:</td>
</tr>
<tr>
<td>Take picture of front of house and all other elevations. Label each picture with elevation direction and site ID.</td>
</tr>
</table>

Homeowner interview:

How many people live here full-time? Adults (age 12 or over):_____Children (under 12):______

At what temperature do you usually set your thermostat (for heating)?_____

Do you set back your thermostat? ___yes ___no. If yes, to what temperature ____?

During heating season, first thing in the morning, do you turn your thermostat up if you feel the house isn't heating up fast enough? ___yes ___no.

How much wood do you burn in a typical winter?_________

What is your water heat fuel? ____

Does the house have an LPG or natural gas fireplace ____ or stove/oven _______ or dryer _____?

Other auxiliary electric loads: well pump____ extra refrigerator/freezer ________

shop equipment ____ Spa/hot tub ______

Other_______________________________________

If you lived in the home when the heat pump was installed:

Did you install the heat pump system mainly for heating, cooling or both?

What equipment was replaced by the heat pump?

About how old was the equipment that was replaced?

Do you have any problems to report with your heat pump/ducts?

Is there anything else we should know about the equipment?

Heat Pump/Thermostat Data

Month and year heat pump installed (if known)	

	Make/Model #
Outdoor unit	
Indoor coil	
Gas furnace (if applicable)	
Is compressor staged/VCHP? (note type at right)	Staged VCHP
Heat pump heating efficiency (HSPF, *Look up later if necessary*)	

Take pictures of nameplates; Be sure the indoor unit M/N is for the coil, not for the backup electric element. M/N format should be similar to outdoor unit.

Thermostat make/model	
If zoned, record zone board make/model	

Thermostat setpoint schedule

Setpoint type	Wake	Away	Return	Sleep
Setpoint start time				
Heating setpoint				
Cooling setpoint				

Refer to thermostat installation guide material as needed to determine location of following settings:

Auxiliary (strip) heat lockout setting: ________________________________

(indicate if unable to determine or N/A)

Compressor cut-out setting: ________________________________

Record outdoor temperature_________________________

If outdoor temperature > 40 degrees Fahrenheit, turn up heat 3 degrees Fahrenheit, let system run five minutes, measure air temperature in a supply register and record: ______________ (For VCHP systems, instruct controller to run system at 60% capacity or greater (start with a call for 100%) Notes:

System Airflow & Static Pressure

This test measures supply static pressure with the system filter in place (Normal Supply Operating Pressure, or NSOP) then replaces the filter with the TrueFlow, re-measures the supply static (TrueFlow System Operating Pressure, or TFSOP), and also measures the pressure drop across the plate (Plate Pressure). Return plenum static pressure, between the filter and coil, is also measured. A correction factor can be applied if needed. Note: the TrueFlow should be placed so that the side with the label faces the house.

The test can be done in either heating or cooling mode. It is fine to run the system in TEST mode if desired to prevent staging. If staged/ VCHP system, note here and also note stage or % of full capacity. Use static pressure tap or Pitot tube and point sensing end into flow.

For all tests, specify units (inches of water or Pascals). Do not switch units within a test.

	Test 1	Test 2*
Mode tested (heating/cooling)		
Stage/% tested		
As-found filter condition (new, somewhat dirty, filthy, missing)		
Return static pressure		
Normal Supply Operating Pressure (NSOP)		
TrueFlow Supply Operating Pressure (TFSOP)		
Correction Factor (NSOP/TFSOP)^0.5		
Plate (14 or 20)		
Plate Pressure		
Raw Flow		
Corrected Flow		

*if needed

Notes:

Performance (Capacity) Test

Measure temperatures leaving/entering indoor coil after 15 minutes of system operation. Measure return temperature just upstream of the indoor coil; you may be able to do this without adding a test hole. For supply side, again measure as close to the outlet of the indoor coil as possible. If supply temperature is in excess of 105 degrees Fahrenheit, make sure strip heat is not on and retest.

Test system in heating mode if outside temp <60 degrees Fahrenheit; test in cooling mode if outside temp >=60 degrees Fahrenheit. If test is done in cooling mode, also record entering wet bulb, or EWB, temperature.

Heating test (perform if outside temp below 60 F)	Test 1	Test 2*
Outside temp		
Entering dry bulb (EDB)		
Leaving dry bulb (LDB)		
Sensible split (entering DB – leaving DB)		

Cooling test (perform if outside temp s above 60 degrees Fahrenheit)	Test 1	Test 2*
Outside temp		
Entering wet bulb		
Entering dry bulb		
Leaving dry bulb		
Sensible split		

*If needed

Re-measure supply static pressure after test done and compare to NSOP measured for TrueFlow test. If not within 5%, re-run test.

House Heat Loss/Gain Rate

We need to know enough about the house to estimate its heating and cooling load**.** The purpose of this is to compare the load with the heat pump size. Use accompanying grid paper for sketches; make sure all dimensions and associated R-values/window types are clearly shown/labeled. See last page of protocol for a U-value reference table. Indicate clearly on the sketch where insulation values are estimated.

- Areas of all components but windows can be reported to the nearest 20 ft^2. Windows/doors should be measured to the nearest 1 ft^2. Accuracy is more important in poorly insulated houses.
- Using out-to-out or in-to-in dimensions is fine. For vaulted ceilings, use best judgement on how to adjust attic area to account for vault slope.
- Slab-on-grade or slab-below-grade features are assigned F-values (vs U-values) and we need to know the running feet of these features (vs ft^2).
- Record ceiling heights (by floor); add 1 foot for upper stories to account for framing. Calculate house volume. Account for half-stories, etc. as best you can.
- For windows, the big break is between single- and double-glazed units; within double-glazed units with metal frames, older units have smaller air spaces and non-thermally improved frames. It is not necessary to draw elevations but make sure to double-check each elevation and to make sure all windows/doors are accounted for.

Additional notes:

Record heated floor area here: ______________ ft^2

Record house volume here: _________ft^3

Ducts

Estimate feet of supply and return ducts in <u>unheated buffer spaces</u> (attics, crawlspaces, most garages). You can use a tape measure but it's faster to refer to your house map and make reasonable estimates of the trunk and run-out lengths. For duct R-values, use nominal R-value on duct or best guess (or thickness). Average R-value is okay. If there is a lot of missing/damaged insulation, use Notes field.

Supply ducts

Duct type (metal/flex/other)	Duct location (garage, attic, crawl, other)	Cross-sectional area (sq inches)	Est. feet of duct	Duct Insulation (best guess on R-value)*	Notes

*R-value/inch is about 3 for fiberglass; derate if damaged or missing.

Return ducts

Duct type (metal/flex/other	Duct location (garage, attic, crawl, other)	Cross-sectional area (sq inches)	Est. feet of duct	Duct Insulation (best guess on R-value)*	Notes

Blower Door Test

<u>Pressurize</u> to near 50 and 25 Pa with respect to outside. Note: the house pressure WRT outside doesn't have to be exactly 50 or 25 Pa; the actual values will be corrected to 50 Pa during analysis. The test will be done in <u>*pressurization*</u> mode to reduce disruption and to save time for the duct test.

Make and model of Blower Door used ____

<u>Blower Door, or BD, Test Procedure:</u>

1. *Close all windows and doors to the outside. Open all interior doors and supply registers.*
2. *Turn off whole-house ventilation system. Leave intentional return leaks in their as-found condition. Make sure all exhaust fans and clothes dryer are off.*
3. ***Make sure doors to interior furnace cabinets are closed**. Also make sure crawlspace hatch is on, even if it is an outside access. Check attic hatch position. Put garage door in normal position.*
4. *Set fan to <u>pressurize</u> house. Run outside pressure tap out through door shroud.*
5. *Pressurize house to 50 Pa or thereabouts. Record house pressure, BD flow pressure, and BD ring (below, "Test 1" line). If you cannot reach 50 Pa, get as close as possible and record information. <u>Make sure that the BD fan pressure is measured WRT outside.</u>*
6. *Now take the house down to 25 Pa WRT outside and record information on "Test 1" row.*

Blower Door Tests	House P near 50 Pa (P_{50})	BD fan pressure	BD Ring	BD flow near 50 Pa (Q_{50})	House P near 25 Pa (P_{25})	BD fan pressure	Ring	BD flow near 25 Pa (Q_{25})
Test 1								
Test 2 (if needed)								

7. *To check test, calculate the flow exponent, n. Use the following formula, $n = \ln(Q_{50}/Q_{25})/\ln(P_{50}/P_{25})$. Note Q_{50} and Q_{25} are the flows through the blower door at the testing pressures (which are denoted P_{50} and P_{25}.) Depending on the test, you may not get the house to exactly 50 or 25 Pa WRT outside. Use the exact ΔP you measure when checking the flow exponent. For example, if the house gets to 48 Pa for the high ΔP, use this as the P_{50} in the equation. If the flow exponent is not between 0.50 and 0.75, repeat the test and record results on the "Test 2" line.*

Note testing conditions (if windy, inaccessible room(s), garage door open or closed, etc):

Exterior Duct Leakage Test

1. *Exterior house doors and garage doors should be closed for exterior duct leakage test.*
2. *Tape off TrueFlow so that the supply side of system is separated from return side.*
3. *Pressurize the house to about 50 Pascals WRT outside. You may have to turn the fan around for this. Use of the Cruise feature on the gauge is a good option.*
4. *Pressurize supply ducts to about 50 Pascals with smallest flow ring possible. Note below where pressure tap placed.*
5. *Measure pressure of ducts WRT house. Get as close to 0 as possible.*
6. *Re-check pressure of ducts WRT outside. Record below.*
7. *Measure duct tester fan pressure. Look up flow in table, use gauge* ***(make sure gauge is paired with the right duct tester and ring)*** *or use flow equation. Record duct pressure WRT out, DB fan pressure, DB fan ring.*
8. *Repeat steps 2-7 with house and ducts at about 25 Pa WRT outside.*
9. *Check flow exponent (as above).*

Supply Duct Leakage to Outside Data (Note: duct pressure WRT outside may not be exactly 50 or 25 Pa.)

	Duct P near 50 Pa (P_{50})	DB fan pressure	DB Ring	DB flow near 50 Pa (Q_{50})	Duct P near 25 Pa (P_{25})	DB fan pressure	Ring	DB flow near 25 Pa (Q_{25})
Test 1								
Test 2 (if needed)								

Note any unusual testing conditions:

Exit Protocol

____ *Remove split at air handler and replace filter.*

____ *Turn breakers on where applicable and confirm thermostat and heat pump operation.*

____ *Turn any gas appliances and whole house ventilation systems back* **ON** *and confirm operation.*

____ *Inspect home, garage, crawlspace, attic for any equipment, tools, garbage, etc.*

House Audit U-value Tables (for reference)

Above Grade Walls

Uninsulated	0.25
R-11	0.09
R-19	0.053

Doors

Hollow wood*	0.50
Panel or solid wood*	0.40
Insulated metal	0.20

*subtract 0.15 from U-value if storm door installed.
If more than half glass, use appropriate glass U-value.

Below Grade Walls (fully below grade; assumes uninsulated slab)

Uninsulated	0.2
R-11	0.06
R-19	0.04

Floor Over Crawlspace

Uninsulated	0.12
R-11	0.055
R-19	0.04
R-30	0.03

Slab Floors (use lineal feet, not ft^2)

Uninsulated on grade	0.75
Uninsulated below grade	0.50
Insulated on grade	0.55

Attics/Vaults

Uninsulated	0.3
R-11	0.06
R-19	0.05
R-30	0.04
R-38	0.03

Windows

Single glazing	1.1
Double glazing metal	0.75
Double glaze metal improved	0.65
Double with wood/vinyl frame	0.55
Dbl wood/vinyl low-e	0.40
High performance/ENERGY STAR®	0.30

ROUND DUCT SQ. IN. EQUIVALENCY

Size	SQ. IN.	Size	SQ. IN.
5	20	12	113
6	28	14	154
7	38	16	201
8	50	18	254
9	64	20	314
10	79	22	380

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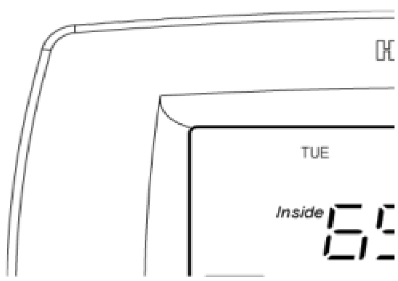
Installer Setup

ENTER INSTALLER SETUP

1. Press the SYSTEM key
2. PRESS and HOLD the two unmarked keys as shown until the display changes
   - approximately 5 seconds



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Balance Point Definition

- The lowest outdoor temperature for which the output of the heat pump can heat the house by using the compressor only.
- Below this temperature, the strip heat is needed to help heat the house.

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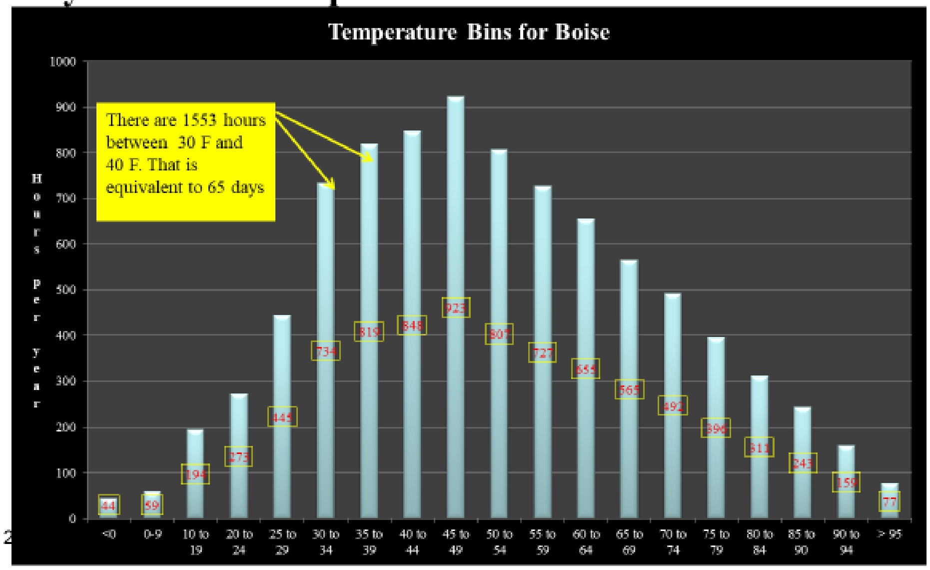
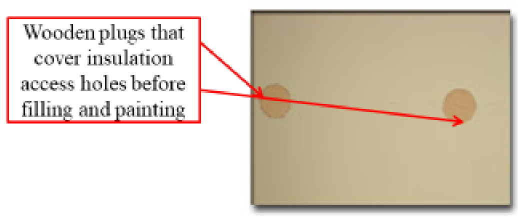
Temperature Bins:
Why a 30 F balance point makes sense



Checking For Wall Insulation



Removing the outlet cover and sliding a non-conductive probe such a plastic crochet hook or a chop stick between the sheetrock and the outlet base can help to determine if the walls are insulated

Walls that have been insulated post construction will have patched holes on the interior walls or exterior walls. Look for 2-1/2 inch holes that have been filled and painted over

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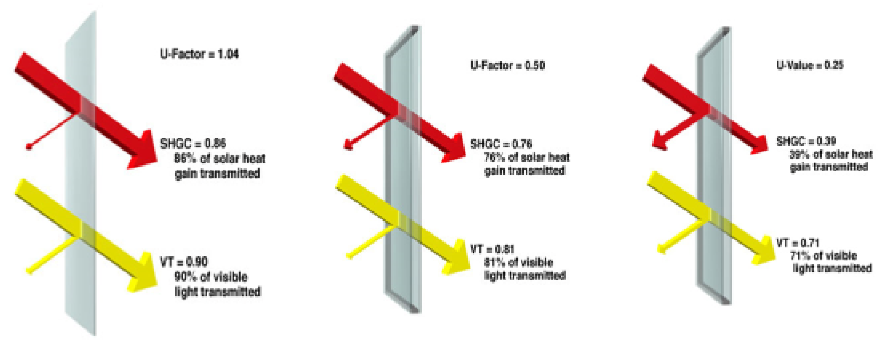
Low SHGC= Lower Heat Gain



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Finding the Correction Factor

Normal System Operating Pressure (NSOP) In. H_2O

TrueFlow System Operating Pressure (TF SOP) In. H_2O	0.20	0.22	0.24	0.26	0.28	0.30	0.32	0.34	0.36	0.38	0.40	0.42	0.44	0.46	0.48	0.50	0.52	0.54	0.56	0.58	0.60
0.20	1.00	1.05	1.10	1.14	1.18	1.22	1.26	1.30	1.34	1.38	1.41	1.45	1.48	1.52	1.55	1.58	1.61	1.64	1.67	1.70	1.73
0.22	0.95	1.00	1.04	1.09	1.13	1.17	1.21	1.24	1.28	1.31	1.35	1.38	1.41	1.45	1.48	1.51	1.54	1.57	1.60	1.62	1.65
0.24	0.91	0.96	1.00	1.04	1.08	1.12	1.15	1.19	1.22	1.26	1.29	1.32	1.35	1.38	1.41	1.44	1.47	1.50	1.53	1.55	1.58
0.26	0.88	0.92	0.96	1.00	1.04	1.07	1.11	1.14	1.18	1.21	1.24	1.27	1.30	1.33	1.36	1.39	1.41	1.44	1.47	1.49	1.52
0.28	0.85	0.89	0.93	0.96	1.00	1.04	1.07	1.10	1.13	1.16	1.20	1.22	1.25	1.28	1.31	1.34	1.36	1.39	1.41	1.44	1.46
0.30	0.82	0.86	0.89	0.93	0.97	1.00	1.03	1.06	1.10	1.13	1.15	1.18	1.21	1.24	1.26	1.29	1.32	1.34	1.37	1.39	1.41
0.32	0.79	0.83	0.87	0.90	0.94	0.97	1.00	1.03	1.06	1.09	1.12	1.15	1.17	1.20	1.22	1.25	1.27	1.30	1.32	1.35	1.37
0.34	0.77	0.80	0.84	0.87	0.91	0.94	0.97	1.00	1.03	1.06	1.08	1.11	1.14	1.16	1.19	1.21	1.24	1.26	1.28	1.31	1.33
0.36	0.75	0.78	0.82	0.85	0.88	0.91	0.94	0.97	1.00	1.03	1.05	1.08	1.11	1.13	1.15	1.18	1.20	1.22	1.25	1.27	1.29
0.38	0.73	0.76	0.79	0.83	0.86	0.89	0.92	0.95	0.97	1.00	1.03	1.05	1.08	1.10	1.12	1.15	1.17	1.19	1.21	1.24	1.26
0.40	0.71	0.74	0.77	0.81	0.84	0.87	0.89	0.92	0.95	0.97	1.00	1.02	1.05	1.07	1.10	1.12	1.14	1.16	1.18	1.20	1.22
0.42	0.69	0.72	0.76	0.79	0.82	0.85	0.87	0.90	0.93	0.95	0.98	1.00	1.02	1.05	1.07	1.09	1.11	1.13	1.15	1.18	1.20
0.44	0.67	0.71	0.74	0.77	0.80	0.83	0.85	0.88	0.90	0.93	0.95	0.98	1.00	1.02	1.04	1.07	1.09	1.11	1.13	1.15	1.17
0.46	0.66	0.69	0.72	0.75	0.78	0.81	0.83	0.86	0.88	0.91	0.93	0.96	0.98	1.00	1.02	1.04	1.06	1.08	1.10	1.12	1.14

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Appendix E3: Heat Pump Sizing Worksheet

Sample Heat Pump Sizing Worksheet (excerpt)

	SQ. Feet	R-0 Heat	R-0 Cool	R-7 Heat	R-7 Cool	R-11 Heat	R-11 Cool	R-19 Heat	R-19 Cool	R-27 Heat	R-27 Cool	R-30 Heat	R-30 Cool	R-38 Heat	R-38 Cool	Heat BTUs	Cool BTUs
Surface																	
Vented Attics	2,000	21.5	20.3	6.8	5.6	4.9	4.0	2.9	2.4	2.1	1.7	2.0	1.6	1.6	1.3	5,800	4,800
Unvented Attics		21.5	28.5	6.8	7.8	4.9	5.7	3.0	3.4	2.1	2.4	2.0	2.2	1.6	1.8		
Framed Walls	1,180	16.5	6.3			5.9	2.3	4.1	1.2							6,962	2,714
Attic Knee Walls		19.0	20.3			4.9	4.0	3.0	2.4								
Masonry Walls		18.5	5.2	7.9	2.0	5.4	1.1	3.8	0.7								
Basement Walls extends five feet or less		20.4		5.1		2.7		2.4									
Basement Walls extends five feet or more		12.6		4.1		3.0		2.2									
Vented Floors - Crawlspace or over Garage	2,000	9.2	3.8			3.1	0.8	3.1	0.5			2.1	0.3			6,200	1,000
Unvented floor Perimeter R0 walls		6.8	2.2			3.2	1.0	2.3	0.8			1.9	0.6				
Unvented floor Perimeter R7 walls		4.8	0.7			2.7	0.5	2.0	0.4			1.7	0.3				
Unvented floor Perimeter R11 walls		4.4	0.5			2.6	0.4	2.0	0.3			1.6	0.3				
Unvented floor Perimeter R19 walls		4.1	0.3			2.5	0.3	2.0	0.3			1.5	0.2				
Slab (**lineal feet**)		56.4		28.6		26.2											
Basement Slab (**lineal feet**)		30.6															

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	SQ. Feet	North Heat	North Cool	North Cool Shade 50%	NE/ NW Heat	NE/ NW Cool	NE/NW Cool Shade 50%	East/ West Heat	East/ West Cool	East/ West Cool Shade 50%	SE/SW Heat	SE/SW Cool	SE/SW Cool Shade 50%	South Heat	South Cool	South Cool Shade 50%	Heat BTUs	Cool BTUs
Window																		
Single Pane U=1.27 SHGC=.75		77.5	39.6	39.6	77.5	70.9	55.3	77.5	95.6	67.6	77.5	86.2	62.9	77.5	59.2	49.4		
Double Pane U=.60 SHGC=.60		36.6	23.4	23.4	36.6	48.4	35.9	36.6	68.1	45.8	36.6	60.6	42.0	36.6	39.0	31.2		
Double Pane Vinyl U=.5 SHGC=.5		30.5	19.5	19.5	30.5	40.4	29.9	30.5	56.8	38.1	30.5	50.5	35.0	30.5	32.5	26.0		
Double Pane U=.35 SHGC=.35		21.4	13.6	13.6	21.4	28.3	20.9	21.4	39.8	26.7	21.4	35.4	24.5	21.4	22.8	18.2		
Single Pane U=1.27 SHGC=.75		77.5	39.6	39.6	77.5	70.9	55.3	77.5	95.6	67.6	77.5	86.2	62.9	77.5	59.2	49.4		
Double Pane U=.60 SHGC=.60	110	36.6	23.4	23.4	36.6	48.4	35.9	36.6	68.1	45.8	36.6	60.6	42.0	36.6	39.0	31.2	4,026	7,491
Double Pane Vinyl U=.5 SHGC=.5		30.5	19.5	19.5	30.5	40.4	29.9	30.5	56.8	38.1	30.5	50.5	35.0	30.5	32.5	26.0		
Double Pane U=.35 SHGC=.35		21.4	13.6	13.6	21.4	28.3	20.9	21.4	39.8	26.7	21.4	35.4	24.5	21.4	22.8	18.2		
Single Pane U=1.27 SHGC=.75		77.5	39.6	39.6	77.5	70.9	55.3	77.5	95.6	67.6	77.5	86.2	62.9	77.5	59.2	49.4		
Double Pane U=.60 SHGC=.60	50	36.6	23.4	23.4	36.6	48.4	35.9	36.6	68.1	45.8	36.6	60.6	42.0	36.6	39.0	31.2	1,830	2,420
Double Pane Vinyl U=.5 SHGC=.5		30.5	19.5	19.5	30.5	40.4	29.9	30.5	56.8	38.1	30.5	50.5	35.0	30.5	32.5	26.0		
Double Pane U=.35 SHGC=.35		21.4	13.6	13.6	21.4	28.3	20.9	21.4	39.8	26.7	21.4	35.4	24.5	21.4	22.8	18.2		
Single Pane U=1.27 SHGC=.75		77.5	39.6	39.6	77.5	70.9	55.3	77.5	95.6	67.6	77.5	86.2	62.9	77.5	59.2	49.4		
Double Pane U=.60 SHGC=.60	75	36.6	23.4	23.4	36.6	48.4	35.9	36.6	68.1	45.8	36.6	60.6	42.0	36.6	39.0	31.2	2,745	1,755
Double Pane Vinyl U=.5 SHGC=.5		30.5	19.5	19.5	30.5	40.4	29.9	30.5	56.8	38.1	30.5	50.5	35.0	30.5	32.5	26.0		
Double Pane U=.35 SHGC=.35		21.4	13.6	13.6	21.4	28.3	20.9	21.4	39.8	26.7	21.4	35.4	24.5	21.4	22.8	18.2		

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	SQ. Feet	North Heat	North Cool	NE/NW Heat	NE/NW Cool	East/ West Heat	East/ West Cool	SE/SW Heat	SE/SW Cool	South Heat	South Cool	Heat BTUs	Cool BTUs
Sky Lights													
Single Pane		83.57	62.19	83.57	93.48	83.57	118	83.57	108.7	83.57	81.73		
Double Pane		45.14	38.43	45.14	65.96	45.14	87.65	45.14	79.36	45.14	55.63		

	SQ. Feet	Heat	Cool	Heat BTUs	Cool BTUs
Doors					
Wood Doors	40	20.67	11.11	827	444
Insulated Doors		15.37	8.265		

	SQ. Feet	Heat	Cool	Heat	Cool	Heat	Cool	Heat	Cool	Heat	Cool	Heat	Cool	Heat	Cool	Heat BTUs	Cool BTUs
Air Changes/hour (Select ACH based on vintage indicated in the sizing assumptions.)	2,000	0.2 1.6	0.2 0.5	0.3 2.4	0.3 0.8	0.4 3.2	0.4 1.1	0.5 4.0	0.5 1.3	0.6 4.8	0.6 1.6	0.7 5.6	0.7 1.8	0.8 6.4	0.8 2.1	6,400	1,600

		Cool	Cool BTUs
Number of appliances	2	Add 1,200 BTUs per appliance for cooling only	2,400
Number of people	4	Add 300 BTUs per person for cooling only	1,200

	Heat BTUs	Cool BTUs
Pre Duct Multiplier Sub Total	34,790	25,825

Duct Heat Loss/Heat Gain		Heat	Cool	Heat	Cool	Heat	Cool	Heat	Cool	Heat BTUs	Cool BTUs
Duct Multiplier (Select Duct Multiplier based on location of ductwork indicated in the sizing assumptions.)		0	0	10%	10%	20%	20%	30%	30%	6,958	5,165

		Heat	Cool	Heat	Cool	Heat	Cool	Heat	Cool	Heat	Cool	Heat	Heat	Heat	Heat BTUs	Cool BTUs
Design Temperature Offset °F (See instructions)		8°F 1.5%	96°F 1.5%	7°F 3.0%	97°F 3.0%	6°F 4.5%	98°F 4.5%	5°F 6.0%	99°F 6.0%	3°F 9.0%	100°F 7.5%	1°F 10.5%	0°F 12.0%	-6°F 21.0%		

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	Heat BTUs	Cool BTUs
Total	41,748	30,990

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