Air Source Heat Pump Potential in Alaska

An Emerging Energy Technology Fund Report
For the Alaska Energy Authority

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Disclaimer

The products in this report were evaluated using the described methodologies. The authors caution that different results might be obtained using different test methodologies and suggest care in drawing inferences regarding the products beyond the circumstances described herein.

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Executive summary

The cost of heating buildings in Alaska provides ample motivation for identifying affordable, efficient, and reliable heating methods. When new heating technology becomes available it is crucial to evaluate whether it will perform as advertised, especially for technology that has equipment exposed to the ambient climate. Air source heat pumps (ASHPs) designed for cold climate operation are such a technology. These heat pumps include both ductless heat pumps (DHPs) that serve as room-specific heaters as well as central heating systems with ducted or hydronic heat delivery. Cold climate ASHPs are important to evaluate because they have the potential to reduce heating costs relative to oil and electric resistance heating appliances, they remove the complications of combustion safety and fuel handling, and they require little maintenance. The technology is also attractive to electric utilities that have a significant power demand from electric heating, as it creates a potential demand side management option.

This study monitored cold climate ASHPs installed in a diverse range of Alaskan communities to determine how well they perform and whether they can be an effective tool for reducing peak electric power demand for the case study community of Wrangell, Alaska by two megawatts. Three heat pumps were monitored in detail to characterize their operational characteristics and efficiency, and an additional 30 heat pumps were evaluated by a utility billing analysis and by interviewing building occupants about their satisfaction with the technology.

The direct monitoring of three cold climate ASHPs revealed that the installed performance can differ significantly from the manufacturer specifications for efficiency. The efficiency could be greater or less than the manufacturer specifications. Furthermore, our results and those from prior studies have shown that the efficiency differences between brands can differ enough that they should not be viewed as interchangeable products. Despite these distinctions, the vast majority of the heat pump users interviewed were satisfied with them irrespective of brand, with 29 out of 30 interviewees stating that they met or exceeded expectations. This finding agrees well with those from studies conducted in the Northwest and Northeastern U.S. states. While no evidence was found during this study of a cold climate ASHP failing to deliver heat within its operational limits, we recommend that homeowners and building managers include backup heating systems due to the potential for outside temperatures in Alaska to dip below a heat pump's operational limits, and the higher risk presented by failure of a heating system with mechanical components that operate outdoors.

Cold climate ASHPs should reduce electricity use by displacing electric heat, and should increase electricity use when displacing oil heat. However, this study found variability of the actual changes in energy use across the small sample of monitored retrofit installations. This makes it difficult to state a firm conclusion about the effect that retrofitted heat pumps in Alaska have on electricity use in a building. Factors such as the presence of wood heat and changes in occupant behavior influence the effects of retrofitting a DHP for any specific building. Furthermore, the community of Wrangell also includes residences heating with fuel oil, who may convert to heat pumps and raise the potential for an increase in electricity demand. Considering these findings, and those from prior research, it is unlikely

that ASHPs replacing electric resistance heat in Wrangell will be sufficient to meet the energy conservation goal. We recommend that Wrangell consider other demand side management strategies in addition to heat pump retrofits and that the strategies be based on energy goals shaped by broad community engagement so that the outcomes of a demand side management program can benefit residents with different heating appliances as well as the electric utility.

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Acronyms

ACEP	Alaska Center for Energy and Power
AEL&P	Alaska Electric Light & Power
ASHP	Air Source Heat Pump
BTU	British Thermal Unit
°C	Degree Celsius
CCHRC	Cold Climate Housing Research Center
CDD	Cooling Degree Day
cfm	Cubic Feet per Minute
COP	Coefficient of Performance
DHP	Ductless Heat Pump; also known as a Mini-Split Ductless Heat Pump
DHW	Domestic Hot Water
°F	Degree Fahrenheit
fpm	Feet per minute
gpm	Gallon per minute
HDD	Heating Degree Day
Hr	Hour
HSPF	Heating Season Performance Factor
HVAC	Heating, Ventilation, and Air-Conditioning
IRP	Integrated Resource Plan
kW	Kilowatt
kWh	Kilowatt-hour
Lb	Pound
MBTU	One Thousand BTUs

ML&P	Municipal Light & Power
MW	Megawatt
PEV	Plug-in Electric Vehicle
RH	Relative Humidity
s	Second
V	Voltage
W	Watt

Motivation

Cold climate air source heat pumps (ASHPs) have the potential to provide heating cost savings to consumers in many areas of Alaska. Because they do not use combustion to make heat, they present other benefits such as safety and ease of maintenance. Some models also provide the ability to both heat and cool a building with the same appliance. Additionally, using ASHPs as a demand side management tool for electric utilities for replacing electric resistance heat is a potential benefit of installing the devices on a community-wide scale.

Currently, several manufacturers produce ASHPs that can work in Alaska, including Mitsubishi, Fujitsu, LG, Daikin, and Panasonic. Building and home owners are installing ASHPs throughout Alaska, especially in the Southeast panhandle, where the mild climate and inexpensive hydropower makes them an attractive heating option. However, questions remain about the installed performance of the latest cold climate ASHP technology in the harsh climate of Alaska as well as the circumstances that allow the devices to reduce the net electric usage in a community.

This report documents a research project conducted by the Cold Climate Housing Research Center (CCHRC), the University of Alaska Fairbanks Bristol Bay Campus, and Wrangell Municipal Light and Power (ML&P). The study addressed two facets of ASHPs in Alaska: the performance characteristics of monitored heat pump installations, and the potential for the technology to be used as an energy conservation strategy for the community of Wrangell, AK. Specifically, the study sought to answer the following questions about ASHPs in Alaska:

> How do ASHPs perform in Alaska's cold climates? Do they meet manufacturer's specifications for efficiency, cutoff temperature, and heat output? Are building and homeowners satisfied with their performance?
>
> How much power and energy demand can ASHPs offset by displacing electric resistance heat as an energy conservation measure in Wrangell, AK?

This document describes the research performed in the winter of 2014 to 2015 by project partners to answer these questions. The study consisted of three separate parts to address the different aspects of the research questions. First, researchers installed monitoring equipment to measure electrical input and heat output of three heat pumps in Alaska. This detailed monitoring allowed researchers to assess the efficiency and defrost behavior of these specific installations to determine if they conformed to manufacturer specifications. Second, researchers evaluated 30 additional ASHP installations over the course of the winter to understand how homeowners felt about their performance and how retrofit installations affected whole building electrical load. The results from these two project components, along with literature from studies outside of Alaska, allowed for analysis of the potential of ASHPs to offset electric resistance heat in the Southeast community of Wrangell, Alaska.

The first section of this report, *Cold climate heat pumps*, provides a brief background on ASHPs in Alaska and other cold climates. The next three sections document the objectives, methodology, and results from the three parts of the research project: *Detailed monitoring*, *General monitoring*, and *ASHPs as an energy conservation measure in Wrangell, AK.* Finally, the document concludes by synthesizing information from the research on the performance and potential of current ASHP technology for use in Alaska.

Cold climate heat pumps

ASHPs have traditionally been used in mixed climates, where occupants can take advantage of their ability to provide both space heating and cooling in a single system. However, new cold climate systems are capable of providing heat at temperatures below freezing, and as a result more homeowners have been installing heat pumps in Alaska and other cold climates over the past several years.

Heat pump technology primer

Heat pumps are space-conditioning appliances capable of providing both heating and cooling. In heating mode, shown in Figure 1, the ASHP uses electricity to run a refrigeration cycle to extract heat from the outside air, step it up to a temperature suitable for space heating, and transfer it to the home's interior. In cooling mode, the heat pump acts like a kitchen refrigerator, removing heat from the inside of the home and rejecting it outside.

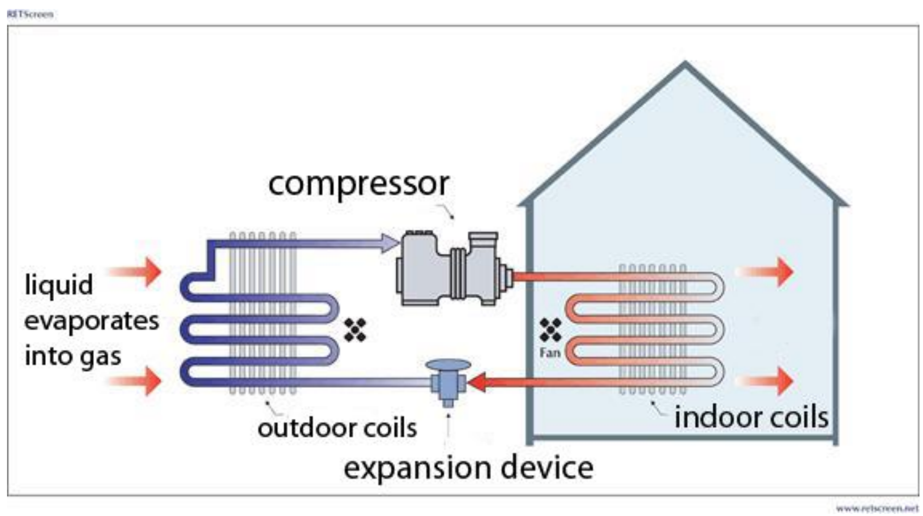


Figure 1: An ASHP in heating mode. Image courtesy of (RETScreen, 2012).

There are several different types of ASHPs. Traditional ducted systems use a forced air distribution system to distribute heat throughout a home. In these systems, the ASHP is a central heating appliance. Mini-split ductless heat pumps (DHP) have one set of outdoor coils with piping to one or more indoor heat exchanger coils, which distribute heat to different rooms. Figure 2 shows an example of the indoor heat exchangers for a DHP in North Pole, Alaska. In the picture, each room has an indoor unit that contains a fan to blow air over the coils containing the heated refrigerant and into the room.

Figure 2: Two indoor units for a ductless heat pump system.

Air-to-water heat pumps provide heated water rather than heated air. The water can provide space heating via a hydronic distribution system, such as a radiant floor or low-temperature baseboards. Most air-to-water heat pumps can also provide domestic hot water (DHW). Finally, ventilation-combination systems gather heat from exhausted ventilation air to boost the efficiency of the heat pump.

Because ASHPs only use electricity to transfer existing heat from the outside atmosphere instead of burning fuels like a combustion appliance, the efficiency of the appliance can be over 100%. There are several metrics to indicate their efficiency; in this report we use the Coefficient of Performance (COP), which is a ratio of the space heating provided by the appliance to the electricity required to run it. The COP can be measured over an entire heating season, or it can be calculated over shorter periods of time.

$$COP = \frac{Space\ heating\ in\ British\ Thermal\ Units\ (BTU)}{Electrical\ energy\ used\ in\ BTU}$$

As with any heating appliance, there are advantages and disadvantages to ASHPs. Potential assets include their capability to provide both heating and cooling through one appliance, minimal maintenance requirements, and their potential for inexpensive, environmentally-friendly operation depending on the cost and source of electricity. However, their heat output and efficiency decrease with falling outdoor temperatures. These factors, combined with high-cost electricity in rural Alaska (typically produced from diesel generators), have historically limited their use in the state and in other cold climates.

However, in recent years the installations of ASHPs in Alaska have increased substantially, especially in the Southeast panhandle. New cold climate ASHP models are designed for below-freezing temperatures, and many Southeast homes have access to inexpensive hydropower, making ASHPs a viable heating alternative. Now we estimate that there are well over 500 ASHPs in Alaska, consisting of traditional ducted systems, DHPs, and air-to-water appliances.

ASHP research in cold climates

ASHPs have been used for space heating in Alaska for decades, and have been the subject of prior research studies in the area. The first documented ASHP research in Alaska was performed by the Alaska Electric, Light, and Power Company (AEL&P) in Juneau. The utility commissioned a field study of ASHPs in 1979 to examine their efficiency and found that ASHPs were feasible in the region, but noted anecdotal evidence of problems with the defrost cycle (AEL&P and Ketchikan Public Utilities, 1982). This study played a major role in the creation of Juneau's heat pump rate in 1982, which at the time was intended as an alternative to mandatory demand billing for electric resistance customers (A. Mesdag, Juneau AEL&P, personal communication, December 17, 2015). A few decades later, AEL&P initiated a field test of the Hallowell Acadia heat pump in Juneau. This model was unique in that it used four strategies to provide heat: a two-stage primary compressor, a booster compressor, an economizer heat exchanger to put refrigerant back into the circuit between the primary and booster compressors, and finally electric resistance backup heat. The study measured a seasonal COP of 2.30 for the Hallowell in the study, which operated without utilizing the electric resistance backup heat down to -18°F, the coldest day during the study (Johnson Research, LLC, 2008). While initial results were promising, Hallowell heat pumps began to experience mechanical problems such as compressor failures and the Hallowell Company went out of business in May 2011 (Russell, 2011).

More recent ASHP studies in cold climates have not monitored field data but instead relied on interviews and modeling to establish their current use and performance. The Energy Solutions Centre has conducted two studies reviewing ASHPs in the Yukon, which border Alaska to the East. The first study, published in 2010, aimed to help people considering installing an ASHP to make an informed decision. It contained a review of recent developments in cold climate ASHP technology, and economic estimates of the cost of heating with an ASHP compared to other appliances in similar climates. It also included recommendations for the use of ASHPs in a cold climate, some of which are included below (Caneta Research Inc., 2010):

- A reasonably-sized heat pump for a cold climate is one with a heating capacity at 0°F of 25-35% of the house design heating load. Such a heat pump would supply 60-75% of the annual heating load and be considered economical.
- The heat pump should have a COP of 2 or better at 0°F.
- There are multiple types of heat pumps, including DHPs, air-to-water, and conventional models, each with different advantages and disadvantages. The user should consider the options and purchase the type that meets the user's needs.

The second report, published in 2013, evaluated the economic and technical feasibility of ASHPs in the Yukon with the goal of determining whether or not the Yukon government should promote the appliances. The report addressed the concerns that ASHP efficiency would decrease too much with colder outside temperatures and that the appliances could lead to increased diesel consumption if operated in a manner that caused the available hydropower capacity to be exceeded. This latter effect might occur if the ASHPs were used inefficiently in the winter, or used as air conditioners in the summer. The authors used modeling of their potential performance and a survey of current residential and commercial use of ASHPs to conclude that, subject to additional research, cold climate ASHPs should be included in the Government of Yukon's suite of energy efficient product promotion initiatives. They followed this conclusion with recommendations to implement contractor training, provide educational materials to people interested in the technology, and to support the promotion of ASHPs with further evaluation and monitoring (Energy Solutions Centre, 2013).

Two other reports were conducted in Alaska. In 2013, CCHRC published a technology assessment on ASHPs to document their current use in Alaska and their potential as a space heating option in warmer regions of the state. The authors noted that new cold climate ASHPs were becoming increasingly common in Southeast Alaska, where a combination of relatively mild temperatures and inexpensive hydropower in many communities make them an attractive heating appliance, both economically and environmentally. They also found that utilities had varying policies on their use, ranging from support in the form of a financial rebate to uncertainty on how they would affect the use of diesel-powered generators as backup electricity when hydropower resources were low, a potential challenge also identified in the Yukon by the Energy Solutions Centre. CCHRC's report also concluded that further investigation into the energy use of ASHPs and the results of heat pump deployment programs was necessary (Stevens, Craven, & Garber-Slaght, 2013). Finally, the City and Borough of Sitka, AK published a report on a rebate program implemented in 2012. The goal of the rebate program, discussed in more detail later in this report, was to reduce electrical demand by providing residents with a rebate for replacing inefficient electrical appliances with Energy Star rated appliances. This could include replacing electric baseboard heat with an ASHP (Agne, 2013).

Alaska ASHP market

People are currently using ASHPs throughout Alaska for heating and cooling. The majority of ASHPs in Alaska are installed in the Southeast panhandle, but homeowners and businesses also use ASHPs in Southcentral Alaska, as far west as Dillingham in Southwest Alaska, and as far north as Fairbanks in the central Interior.

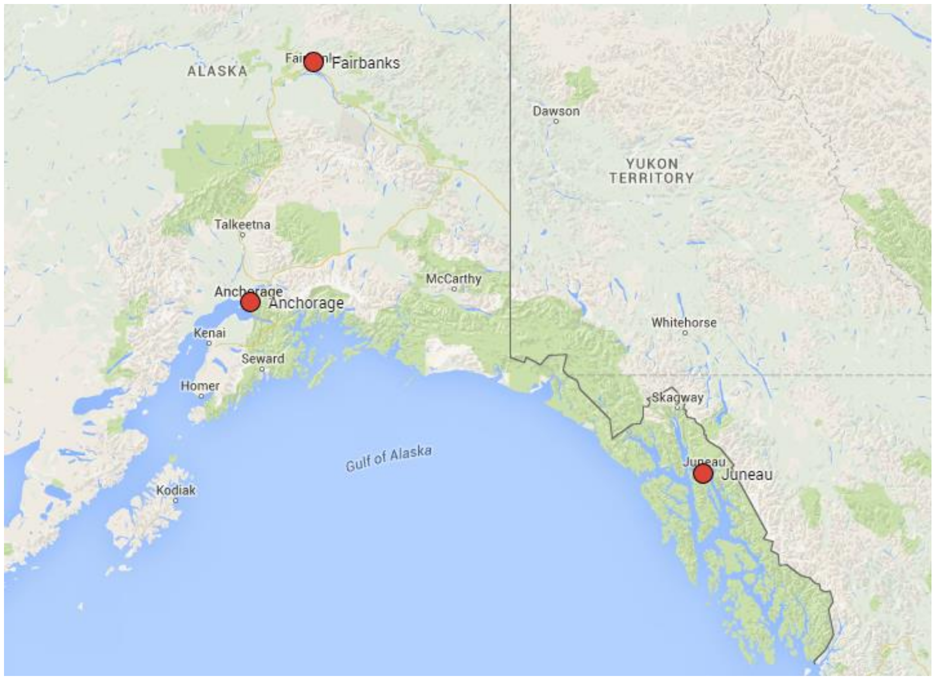


Figure 3: ASHPs are being used for heating and cooling in the southern half of Alaska.

Manufacturers

Currently, there are at least five manufacturers distributing ASHPs in the state. Mitsubishi and Fujitsu both sell cold climate DHP models. Homeowners who participated in the general monitoring for this project reported having a DHP from one of these two companies. These manufacturers account for approximately half of the residential DHP sales in the U.S. (Steven Winter Associates, Inc., 2014), while several homeowners in Sitka purchased DHPs manufactured by LG (Agne, 2013). Recently, Panasonic has begun to market DHPs in Alaska, with a focus on the Southeastern region, according to its Northwest Region Sales Manager (K. Nelson, personal communication, April 2015). Another company, Daikin Altherma, dominated the air-to-water heat pump market in the state, including the installations in the general monitoring in this project. However, Daikin has since discontinued the sale of its air-to-water units in the United States, choosing instead to focus on selling their DHPs, which are now available in Alaska. The air-to-water model may be sold again in the future, but at this time it is uncertain, according to Stinebaugh & Company, the Daikin distributer in Alaska (M. Lloyd, personal communication, November 18, 2015).

Conditions for success

Stevens, Craven, & Garber-Slaght (2013) outlined three reasons that cold climate ASHPs are finding success in parts of Alaska, especially in the Southeast panhandle. Homeowners are continuing to install ASHPs in 2015, as the first two of these conditions, the mild climate and low cost electricity, still apply.

First, the climate in Southeast and Southcentral Alaska is milder than the northern parts of the state, and climatic conditions remain within the operating capacity of cold climate heat pump models for most of the year, if not all year.

Second, many Southeastern communities produce electricity using hydropower. In fact, in 2011, hydropower accounted for over 95% of the electricity produced in the region (Fay, Mendelez, & West, 2012). These communities have among the lowest electric rates in the state, in part because the construction of several of the hydropower plants was paid for with public funds and financing (Mendelez & Fay, 2012). Electricity prices in these hydropower communities range between 9 and 15 cents per kilowatt-hour (kWh). These lower prices, combined with the potential of an ASHP to have efficiencies over 100%, or COPs greater than 1, can result in ASHPs being economically attractive in a community, especially when the price of fuel oil is high.

Finally, there have been incentives for homeowners to install ASHPs in the past, and there is the potential that more incentives might apply in the future. In 2012, the City and Borough of Sitka, AK ran a rebate program that offered a $1,500 incentive to homeowners heating solely with electricity if they switched to an ASHP (Agne, 2013). Other incentives are available to homeowners outside of reduced utility costs. The Home Energy Rebate Program, operated by the Alaska Housing Finance Corporation, requires homeowners to obtain an “as-is” energy rating on their home, make energy efficiency improvements, and then obtain a “post” energy rating. Depending on the energy efficiency improvements shown by the ratings, homeowners may qualify for up to $10,000 in rebate funds. If the retrofit included replacing an inefficient heating appliance with an ASHP, these rebate funds could go toward the installation cost. Due to budget constraints, the rebate program did not receive additional funds in fiscal year 2016. Remaining funds currently allow the program to continue, but its future remains uncertain.

Electric utility policies

Depending on the original heating appliance, utility customers switching to ASHPs may have a positive or negative effect on overall electricity consumption. For instance, if a homeowner was previously relying on electric baseboards, an electric furnace, or an electric boiler, a switch to an ASHP for heating will likely result in a net decrease in electrical use, even if the ASHP is also used for air conditioning in the summer. On the other hand, homeowners switching from a combustion device, such as an oil-fired or natural gas-fired furnace or boiler, or a biomass appliance, will likely see an increase in their electric energy consumption while their fuel usage decreases.

As the Southeast region has many communities that have to balance hydropower resources with more expensive backup power generation, they undertake regional planning to manage their resources. Many communities with lower electricity prices due to hydropower have seen homeowners switch to using electricity for space heating, and in 2011 the Southeast region had the highest levels of consumption, with residential customers consuming an average of 860 kilowatt-hours per month (Fay, Mendelez, & West, 2012). This issue was noted in the 2012 Southeast Integrated Resource Plan (IRP), which said, “There is clear evidence that widespread conversions of energy supply for heating has eaten into reserve hydroelectric power capacity and energy supplies, such that nearly all of the hydro rich subregions need to supplant hydro power production with diesel-fired generation…” (Black and Veatch, 2012). The IRP recommended that the Southeast region would need to pursue the implementation of demand side management and energy efficiency programs. It also recommended biomass space heating conversion programs, noting that while ASHPs reduce electrical demand if the homeowner converts from an electric heating appliance, homeowners converting from oil-fired appliances to an ASHP would put an additional strain on the electric grids (Black and Veatch, 2012). Regional energy planners continue to stand by such recommendations, as the region requires multiple energy options to find the right solutions for each community, not a singular solution applied uniformly across the region (R. Venables, personal communication, Dec. 18, 2015).

Electric utilities and regions throughout the state have differing views and policies on ASHPs because of how they affect energy consumption. This is especially true for communities who use hydropower, because they have to effectively plan how to allocate their energy resources throughout the course of the year. Some organizations with ASHPs in their jurisdictions have shared their policies through interviews for this research project.

Juneau

AEL&P continues to offer a heat pump service rate for its residential customers. This heat pump rate includes a demand charge. However, both the energy and demand rates for heat pumps are slightly lower than the non-incentivized residential rate that includes a demand charge. Customers should consider carefully if this heat pump rate would provide a net benefit for them considering that AEL&P's standard residential rate does not include a charge based on power demand. According to their director of energy services, AEL&P is interested in reevaluating their policy in regards to heat pumps, but currently has no specific plans (A. Mesdag, personal communication, Oct. 1, 2015).

Wrangell

Wrangell ML&P maintains their discounted heat rate service for customers that use electric resistance heating. While this heat rate increased in 2013 to 8.56 cents per kWh, it remains substantially lower than the base residential rate of 13.48 cents per kWh. Because of the substantial growth in their power demand over the past several years, Wrangell ML&P is considering a cap to limit further customers from signing up for the heat rate service (C. Hammer, personal communication, Sept. 22, 2015). Wrangell ML&P is a project partner for this study, and is interested in exploring a heat pump incentive as part of a demand side management strategy.

Petersburg

Petersburg Municipal Power & Light formerly had an incentive program limited to ground source heat pumps. However, due to a lack of installations for ground source systems and an increase in the use of electric resistance heat, the utility has shifted to an incentive program for all heat pumps in residential buildings (J. Nelson, personal communication, Nov. 13, 2015). The program is open for retrofits or new construction, and provides a rebate, ranging from $450 to $1,500, depending on the capacity of the heat pump. Mr. Nelson reported that almost all of the heat pump installations are Mitsubishi DHPs and that local demand for the systems is sufficiently strong that the incentive may no longer be necessary. When asked about the utility's capacity to cover electric resistance and DHP heating, Mr. Nelson stated that he wasn't concerned, but felt that heat pumps were a more responsible use of the hydropower resources since they reduce waste compared to electric resistance heat.

Ketchikan

Ketchikan Public Utilities does not currently offer incentives for the installation or use of heat pumps (C. Shaffer, personal communication, Dec. 8, 2015). There has been some concern within the utility about the impact of electric heating appliances, however, KPU does not currently undertake demand side management strategies.

Sitka

The Sitka Electric Department formerly offered an Energy Star appliance rebate program that included air source heat pumps, however, funding for this program was exhausted in early 2013 (Agne, 2013). Currently, they offer a plug-in electric vehicle credit for their customers that provides $120 of account credit for residential customers, and $200 for general service customers (City & Borough of Sitka, 2015).

Kodiak

The Kodiak Electric Association does not currently have any policies in regards to heat pumps, nor any concerns about the impact of electric heating methods (D. Scott, personal communication, Dec. 7, 2015). Heat pump implementation in Kodiak is still relatively slow, which the CEO of the utility, Darron Scott, partially attributes to the recent slump in heating oil prices.

Anchorage

Chugach Electric Association currently offers no incentives for heat pumps and does not have any policies on electric heating appliances (K. Ayers, personal communication, Dec. 18, 2015).

Detailed monitoring

Researchers tracked the performance of three air source heat pumps during the winter of 2014-2015, including two DHPs and one air-to-water heat pump.

Objectives

The purpose of the detailed monitoring of these three heat pumps was to determine their instantaneous efficiency and heat output at various ambient temperatures, cutoff temperature, seasonal efficiency, and the effect of the defrost cycle on these operational characteristics.

Methodology

Researchers installed monitoring equipment on the three ASHPs in fall of 2014. This section describes the heat pumps and the test set-up and methods used to:

- Measure electrical consumption by the heat pump units;
- Measure heat energy delivered to the indoor environment;
- Measure outdoor temperature;
- Identify defrosting status; and
- Analyze the collected data.

Heat pump and site details

Researchers monitored the following three heat pumps in detail:

1. Mitsubishi DHP in a residence in Dillingham, AK;
2. Fujitsu DHP in a commercial building in Wrangell, AK; and a
3. Daikin Altherma air-to-water heat pump in a residence in Juneau, AK.

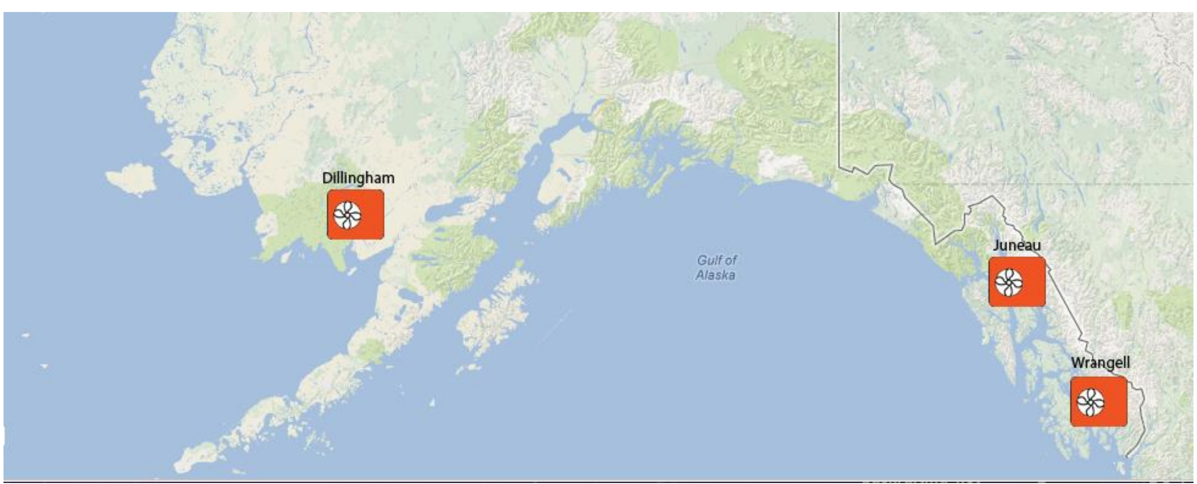


Figure 4: Locations for the three heat pumps in the detailed monitoring study.

Because the heat pumps had been installed prior to the study beginning, each unit had a different capacity and specifications. Table 1 provides the manufacturer specifications for each unit.

Table 1: Specifications for the three heat pumps in the detailed monitoring study.

Location	Dillingham	Wrangell	Juneau
Manufacturer	Mitsubishi	Fujitsu	Daikin Altherma
Heat pump type	Ductless mini-split	Ductless mini-split	Air-to-water
Outdoor unit	MUZ-FE09NA-1	AOU12RLS2	ERLQ030BAVJU (2 units)
Indoor unit	MSZ-FE09NA - 8	ASU12RLS2	EKHBH030BA6VJU (2 units)
Seasonal COP	2.93	3.52	Not stated in specs
Rated heating capacity	10,900 BTU/hour	16,000 BTU/hour	28,760 BTU/hour
Lowest temperature for maximum heat output	5°F	19°F	Not stated in specs
Operating range	Down to -18°F	Down to -5°F	Down to -4°F

These three heat pumps are all located in coastal towns in different climate zones in southern Alaska. The coldest area is Dillingham, located in Southwest Alaska, with a larger number of heating degree days (HDD) and colder average temperatures than Wrangell or Juneau, in Southeastern Alaska. Each of the three locations are similar in that they experience very few cooling degree days (CDD), with a majority of the year considered to be the heating season.

Table 2: Climate averages for the monitoring locations. Data from (Alaska Climate Research Center, 2014).

Location	Dillingham	Wrangell	Juneau
Average HDD (65°F base)	11,216	7,458	8,351
Average CDD (65°F base)	1	4	3
Average annual temperature	34.3°F	44.6°F	42.1°F
Average annual precipitation	25.32 inches	91.21 inches	62.27 inches
Average annual snowfall	90.9 inches	NA	86.7 inches

The heat pumps in Dillingham and Juneau are located in residences, while the heat pump in Wrangell is located in the office building of the Wrangell ML&P utility. Both residential heat pumps are the sole heating appliance in the homes, with the heat pump in Juneau also providing DHW to the residence. In Wrangell, the heat pump provides space heating to a portion of one floor of the office building. All three heat pumps are retrofit heating systems that were installed to replace less efficient systems.

Table 3: Building characteristics for the detailed monitoring heat pumps.

Location	Dillingham	Wrangell	Juneau
Building	Residence	Office	Residence
Area (footprint)	600 ft^2	1,800 ft^2	1,850 ft^2
Stories	1.5	2	1
Occupancy	3	3 (work week only)	4
Backup appliance	Electric wall heater	Electric baseboard	Indoor units contain backup electric resistance heat
Domestic hot water	Separate GE heat pump utilizing heat from interior environment	Electric 40-gallon tank	Daikin EKHWS; contains backup electric resistance heat
Installation date	Installed in 2012 and first used January 1, 2013	November 2013	August 2013

In Dillingham, the heat pump replaced an electric wall heater that remains in the home as a backup appliance. The DHP provides space heating, and also generates the heat taken from the indoor environment by a separate heat pump water heater during the approximately six months of the year when internal heat gains are not sufficient. The DHP is controlled by a Mitsubishi MHK1 external programmable thermostat. The thermostat was programmed to keep the heat pump off at night – the energy efficient building envelope prevents the house from cooling too much at night so supplemental heat is not needed. The settings of the heat pump during the day were varied to capture data for a wide range of operating conditions. This sometimes involved the maximum possible set point, 88°F, at the beginning of the day to force the heat pump into its maximum output power. The indoor temperature during the day was typically maintained around 68°F, which typically meant running the heat pump at a high output for a few hours in the morning for the house to recover from the night-time setback and then the heat pump shutting off for the rest of the day, or running the heat pump at a lower output for a proportionally longer period. The fan speed was typically set to high or auto.

Figure 5. Outdoor unit of the Mitsubishi heat pump in Dillingham.

In Wrangell, the heat pump replaced electric baseboard heaters, which remain as the backup system. The DHP was installed in the front of the office building near the front door, and thus provides heat to the entrance, front office, hallway, and further down the hallway to the kitchen and conference room. The outside unit is visible in Figure 6, just to the left of the front door. Electric baseboards still heat the remaining parts of the building, which includes additional offices and the downstairs level. The fan speed on the heat pump is set to auto at all times. The indoor temperature was typically maintained at 72°F at all times.

Figure 6: The Wrangell ML&P office; the heat pump outdoor unit is visible to the left of the door.

The Juneau heat pump system consists of two identical sets of outdoor and indoor units, referred to in this report as HP1 and HP2. HP1 provides DHW for the home, heating an 80-gallon tank to 115°F. The DHW tank contains an internal backup electric resistance heater. When the outside temperature drops below 30°F and there is no demand for hot water, HP1 operates with HP2 to provide space heating. HP2 is the primary heat pump for space heating. Heat is distributed throughout the building by in-floor radiant heat as well as air handling units. The system has an outdoor reset controller, which drops the supply temperature for the space heating when the outside air is warmer. The supply temperature is set to 120°F at the outside temperature of 0°F. The supply temperature linearly decreases with increasing outside temperature and is set to 80°F at the outside temperature of 60°F. The outdoor units are shown in Figure 7, located outside the mechanical room of the residence.

Figure 7: The outdoor units for the Juneau heat pump.

Test set-up for ductless systems

To a large extent, researchers followed the protocol for monitoring ductless heat pumps in the field described by Christensen et al. (2011), who provided a consistent methodology for measuring the performance of a DHP installed in a building (Christensen, Fang, Tomerlin, Winkler, & Hancock, 2011). However, there were a few exceptions:

- This ASHP study did not include measuring relative humidity - see Appendix A
- This ASHP study used a different method to measure airflow (a hot wire anemometer) though it was calibrated in a similar fashion with the use of a duct blaster to measure the volumetric flow.

To monitor the performance of the heat pumps, researchers installed temperature sensors on the inlet and outlet air streams, the outdoor coils, and in the outdoor atmosphere; a hot-wire anemometer that was used as a proxy to determine air flow; and a voltage transformer and current transformer to measure electrical energy consumption.

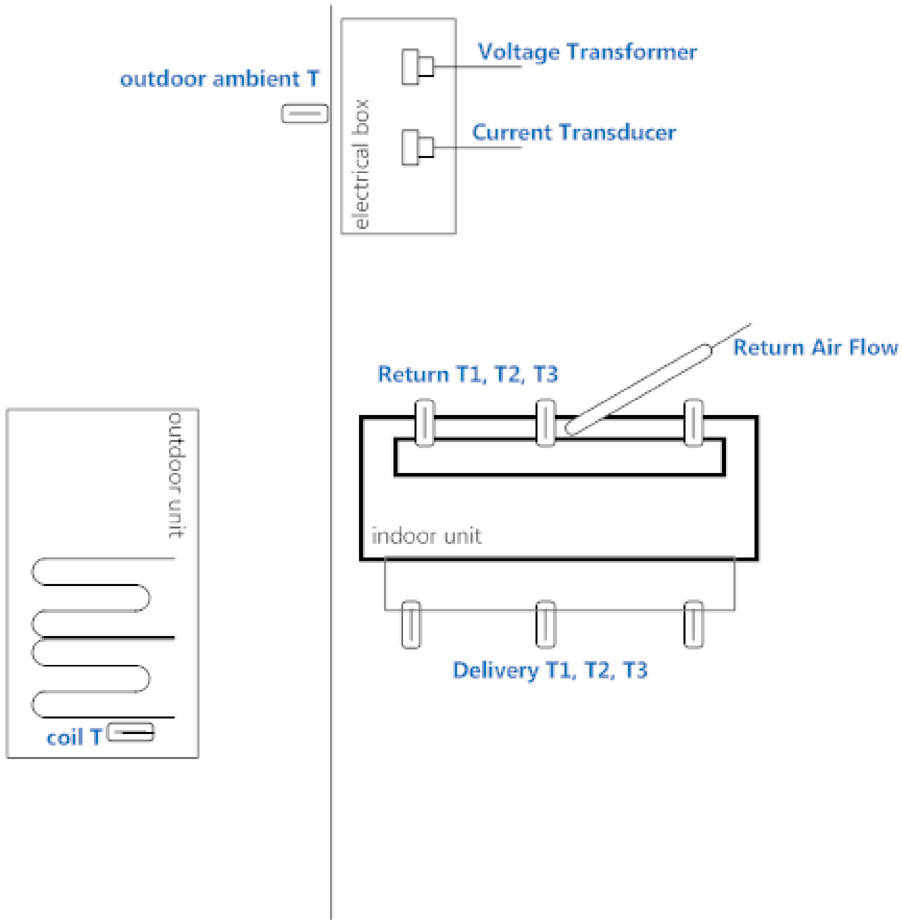


Figure 8: Location of the sensors placed on the ductless heat pump units.

Table 4 gives details on the sensors deployed to measure these quantities, including what they measured and why, model numbers and manufacturers, and accuracy.

Table 4: Measurements and sensors for the ductless heat pump monitoring systems.

Measurement	Purpose	Sensor	Manufacturer	Accuracy
Voltage	Measure the electricity consumption of the heat pump	Voltage transformer (SPT-0375-300)	Magnelab	±1%
Current	Measure the electricity consumption of the heat pump	Current transformer (SCT-0400-030)	Magnelab	±1%
Air flow	Proxy to determine air flow to measure delivered heat energy	Hot-wire anemometer (FMA901R-V1)	Omega	±15 fpm
Delivery temperature (3)	Determine delivered heat energy	Thermistor (PS103J2)	U.S. Sensor	±0.18°F
Return temperature (3)	Determine delivered heat energy	Thermistor (PS103J2)	U.S. Sensor	±0.18°F
Coil temperature	Monitor defrost status	Thermistor (PS103J2)	U.S. Sensor	±0.18°F
Outdoor temperature	Monitor local outside temperature	Thermistor (PS103J2)	U.S. Sensor	±0.18°F

The data loggers used for the project allowed researchers to convert the raw voltage output from the sensors into measured and/or calculated values. The loggers also allowed for variable sampling rates for the sensors and averaging intervals for the final recorded values. Table 5 lists the data that was recorded for the ductless heat pumps along with the sampling rates and averaging intervals.

Table 5: Data variables recorded by the data loggers for the ductless heat pumps.

Recorded value	Unit	Input sensor(s)	Sample interval	Averaging
Data logger temperature/battery voltage	°C/V	Data logger internal sensors	1 s	1 hour
Electrical power	Watt	Voltage transformer and current transformer	1 s	10 s 1 min 5 min
Air velocity	fpm	Hot wire anemometer	1 s	10 s 1 min 5 min
Delivery temperature (3)	°F	Thermistors	10 s	10 s 1 min 5 min
Return temperature (3)	°F	Thermistors	10 s	10 s 1 min 5 min
Coil temperature	°F	Thermistors	10 s	10 s 1 min 5 min
Outdoor temperature	°F	Thermistors	10 s	10 s 1 min 5 min

Air flow proxy calibration

To calculate the heat supplied by the indoor unit of the DHPs, researchers needed to know the air flow rate through the indoor unit. The air flow rate was calculated from the proxy of the air velocity, which was monitored by the hot wire anemometer attached in a fixed position on the inlet of the indoor unit. Researchers determined the relationship between the air flow rate through the indoor unit and the air velocity using a duct blaster.

Figure 9: Duct blaster set-up for calibration of the anemometer.

Researchers attached the duct blaster to the outlet of each indoor unit using a plenum made out of a trash bag with supporting elements inside that prevent the bag from collapsing. The indoor units of the heat pumps were manually set to available fan speeds, and for each fan speed researchers adjusted the duct blaster's fan to achieve a zero differential pressure between the inside of the plenum and the surrounding environment. This mimics the conditions of the indoor unit discharging into an open space. In Wrangell, the Fujitsu controller has a fan-only mode, which allowed researchers to measure the air flow without the outlet air being heated. This allowed the density of the outlet air stream to match as closely as possible the density of the inlet air. In Dillingham, the heat pump did not have a fan-only mode, so the researcher performing the test put the ASHP into cooling mode with the temperature set point at the maximum possible value, 88°F. This setting acts as a fan-only mode as the compressor is not running because the actual temperature is below the cooling set point. This indirect fan-only mode would not be possible in heating mode because the set fan speed can be overridden by the heat pump's cold air prevention control that is active during the heating mode.

Researchers then recorded the air flow rate through the duct blaster along with the corresponding air velocity measured by the hot wire anemometer for all available fan speeds. These data were used to establish the relationship between the air flow rate and air velocity, which was then used in the calculations for heat output.

Test set-up for air-to-water system

To monitor the performance of the air-to-water heat pump, researchers installed in-line temperature sensors on the supply and return lines to the heat pumps, DHW tank, and inside the house; in-line flowmeters for the heat pumps, domestic hot water tank, and the house; temperature sensors on the outdoor coils and in the outdoor atmosphere; and a voltage transformer and current transformer to measure electrical consumption of each heat pump unit. The set-up for the sensors is shown in Figures 10 and 11.

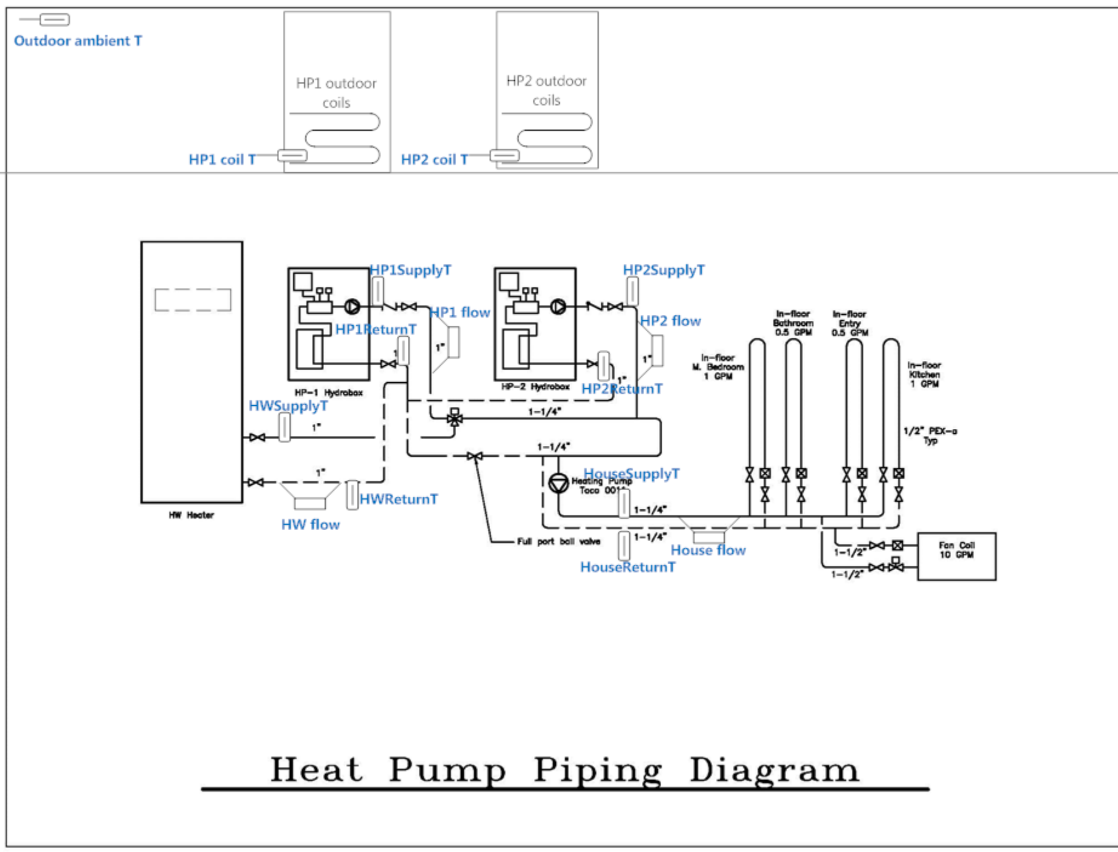


Figure 10: Sensors used to measure temperature and flow on the Juneau heat pump system.

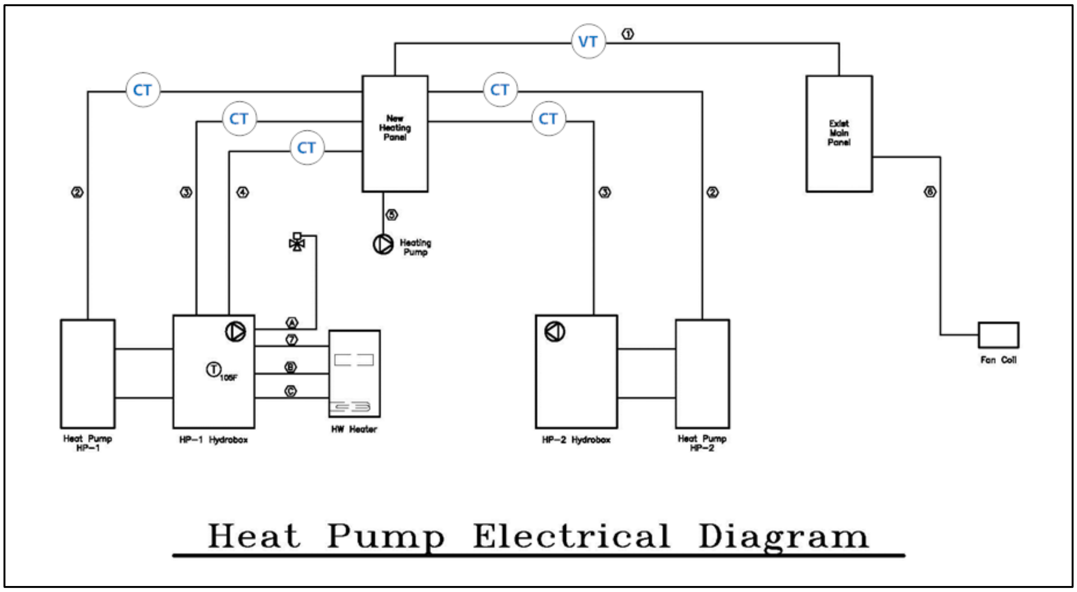


Figure 11: Electric set-up and corresponding sensors for the Juneau heat pump system.

Table 6 gives details on the sensors deployed to measure these quantities, including what they measured and why, model numbers and manufacturers, and accuracy.

Table 6: Measurements and sensors for the air-to-water heat pump system.

Measurement	Purpose	Sensor	Manufacturer	Accuracy
Voltage	Measure the electric consumption of the heat pump system components	Voltage transformer (SPT-0375-300)	Magnelab	±1%
Current (5)	Measure the electric consumption of the heat pump system components	Current transformer (SCT-0400-030)	Magnelab	±1%
Flow rate (4)	Measure the flow through the heat pumps, house, and DHW tank	Flow sensor (VFS 10-200)	Grundfos	±1.5%
Supply temperature (4)	Determine delivered heat energy from the heat pumps, to the house, and to the DHW tank	Thermistor (PS103J2)	U.S. Sensor	±0.18°F
Return temperature (4)	Determine delivered heat energy from the heat pumps, to the house, and to the DHW tank	Thermistor (PS103J2)	U.S. Sensor	±0.18°F
Coil temperature (2)	Monitor defrost status	Thermistor (PS103J2)	U.S. Sensor	±0.18°F
Outdoor temperature	Monitor local outside temperature	Thermistor (PS103J2)	U.S. Sensor	±0.18°F

As with the DHPs, the data logger used for the project allowed researchers to convert the raw voltage output from the sensors into measured and/or calculated values. The logger also allowed for variable sampling rates for the sensors and averaging intervals for the final recorded values. Table 7 lists the data that was recorded for the air-to-water heat pump along with the sampling rates and averaging intervals.

Table 7: Data variables recorded by the data loggers for the air-to-water heat pump system.

Recorded value	Unit	Input sensor(s)	Sample interval	Averaging
Data logger temperature/battery voltage	°C /V	Data logger internal sensors	2.5 s	1 hour
Electrical power (5)	Watt	Voltage transformer and current transformers	2.5 s	10 s 1 min 5 min
Flow rate (4)	gpm	Flow sensors	2.5 s	10 s 1 min 5 min
Supply temperature (4)	°F	Thermistors	10 s	10 s 1 min 5 min
Return temperature (4)	°F	Thermistors	10 s	10 s 1 min 5 min
Coil temperature (2)	°F	Thermistors	10 s	10 s 1 min 5 min
Outdoor temperature	°F	Thermistors	10 s	10 s 1 min 5 min

Data acquisition system

This project employed Campbell Scientific data acquisition equipment to record and transmit data. Each monitoring site had a CR1000 data logger to record sensor data, a multiplexor to accommodate the temperature sensors, a module to connect the data logger to the internet, and a power supply for the data logger. Each CR1000 was programmed to automatically upload data to a server located at the CCHRC office in Fairbanks. The data were then uploaded to the CCHRC web server for access by researchers located outside of Fairbanks, and to the Alaska Center for Energy and Power, which periodically checked data collection on behalf of the Emerging Energy Technology Fund program.

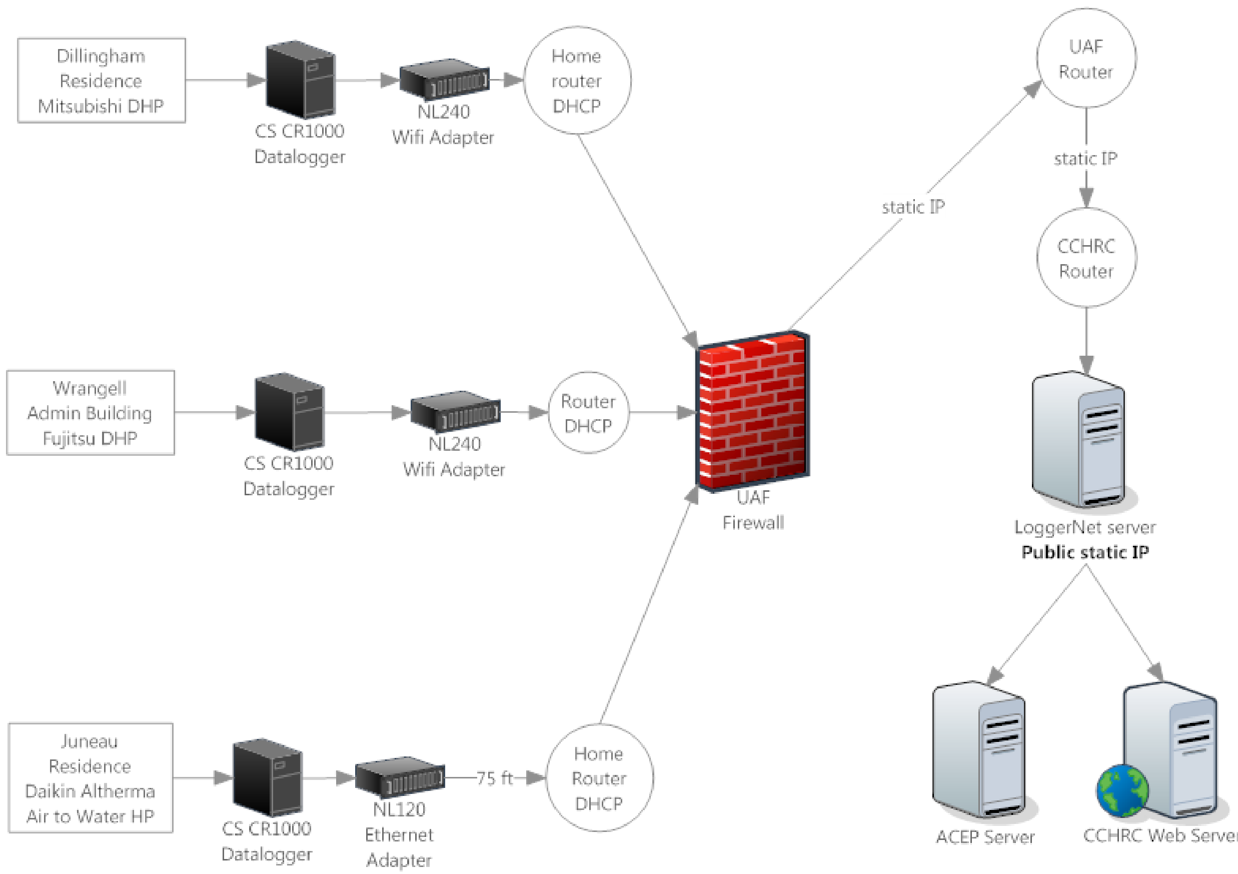


Figure 12: The network diagram for the detailed monitoring component.

Testing procedures

A CCHRC employee was responsible for checking that the monitoring systems remained online once a week. At that time, the most current data were uploaded to a web server so that other researchers would have access to it. A second researcher was responsible for monthly data checks to ensure that sensors were still collecting data as expected.

The Mitsubishi heat pump in Dillingham was enabled on 10/5/2014 after a short pre-test on 10/04/2014. The last day the heat pump was used was 4/18/2015, which is when the heating season for the house ended. Therefore, the data period for the Mitsubishi heat pump is 10/5/2014 – 4/18/2015. The filters and the hot wire anemometer were cleaned approximately once a month during the data recording period, except at the beginning they were not cleaned for about two months. No significant dust accumulation was observed during the cleaning after two months and the airflow data didn't show any significant change.

The Fujitsu heat pump in Wrangell was instrumented on 9/5/2014. Problems with data transfer occurred in October 2014 and a portion of the data were lost. Filters and the hot wire anemometer were cleaned on 12/2/2014 for the first time. An approximate 15% increase in measured air flow was observed. The increase is likely due to a combination of a clean hot wire anemometer, which doesn't change the actual flow, but does change the reading, and clean filters, which change the actual flow, but it wasn't possible to determine what portion of the increase was caused by the clean anemometer itself in order to apply correction to previously collected data. Because of some missing data and the issue with the flow measurement, all data up to 12/2/2014 were ignored. The first air conditioning (cooling) event using this heat pump occurred on 5/8/2015, the use of which would skew the data for calculating the overall COP because the COP during the cooling event is negative. Therefore, the data period for the Fujitsu heat pump for the analysis in this project spanned from 12/3/2014 to 5/7/2015. The filters and the hot wire anemometer were cleaned approximately once a month during the data period, except for one situation when they were not cleaned for about 2 months. No significant dust accumulation was observed during the cleaning after 2 months and the air flow data did not indicate any significant change.

The Daikin heat pump in Juneau was instrumented on 9/10/2014. However, the wells for the temperature sensors in the pipes were not completely insulated until 11/23/2014 and the data logger program required some additional troubleshooting. Therefore, all data recorded prior to 11/23/2014 were ignored. Data collection was disabled on 6/1/2015 so the data recording period for the Daikin heat pump spanned from 11/24/2014 to 5/31/2015, with data for March 12 and 13, 2015 missing due to data transmission issue.

Because the Daikin HP1 is used for both DHW and space heating, the data presented for space heating for this system is data from Dakin HP2, which was used solely for space heating. Samples for HP1 taken during space heating were compared with samples for HP2, and the corresponding samples were in reasonable agreement with respect to efficiency.

Comparison of space heating and DHW heating COPs for the Daikin heat pump was only done for temperatures above 30°F, because at temperatures below 30°F, HP1 alternates between space heating and water heating. While both operations contribute to the outdoor coil icing up, it is a matter of coincidence when the defrost cycle occurs, whether it is during space heating (most often) or water heating (shorter durations). Therefore, it is not possible to accurately analyze the penalty of the defrost cycles on the efficiency of water heating at outdoor temperatures below 30°F.

Data analysis

Data was analyzed using MATLAB modeling software. Steady-state COP analysis was done by having MATLAB identify steady-state situations, which means periods with minimal changes in variables.

Integrated COP represents the actual COP of the system and is affected by cycling, which can occur due to defrost or low-load conditions below the heat pump's minimum load. The Mitsubishi heat pump in Dillingham was mostly used in a way that prevented short-cycling due to low-load conditions; it was only run for a small portion of a day, which required a higher output to supply the needed amount of energy for the day. Defrosting can happen at outside temperatures up to around 40°F, as the coil temperature is lower than outside air temperature so frosting can still occur at outside temperatures around 40°F. However, due to the house's super-efficient building envelope, little to no heat was necessary at outside temperatures above 40°F. Therefore, when the heat pump is running, it is typically cycling due to defrost. An algorithm was implemented in MATLAB to recognize the beginning and end of these cycles - the cycle ends when defrost ends, so the defrost itself is counted as a part of the cycle, and the next cycle starts when defrost ends. Then the integrated COP was calculated for these cycles as the energy output divided by energy input which includes the energy used for the defrost.

Unlike the Mitsubishi heat pump in Dillingham, which was programmed to be on only for a small portion of the day, the Fujitsu heat pump in Wrangell and the Daikin heat pump in Juneau were on continually. Therefore, it was possible to calculate the integrated COP from longer periods of data. For the Fujitsu and Daikin, the collected data was broken into 8-hour sections and the integrated COP was evaluated for each section.

Unexpected circumstances

One of the objectives of this study was to test the heat pumps at their cutoff temperatures. However, due to a warmer than average winter in Alaska during 2014-2015, this was not achieved. Despite that, the discussion section of this report elaborates on some behavior around cutoff temperatures using data gathered elsewhere.

Another unforeseen circumstance was that the outside temperature sensor in Wrangell was occasionally affected by the sun, which resulted in some temperature readings being higher than the air temperature. The temperature sensor was shaded from direct sun, but possible explanations for the higher readings include sun reflecting off other objects or a warming of objects close to the temperature sensor due to the sun. These situations were identified by quick increases or decreases in the measured outdoor temperature, so an algorithm was incorporated into MATLAB to eliminate these samples from the analysis.

Results

The steady-state and integrated COPs as a function of the outside temperature for all three heat pumps are shown in Figure 13. The Figure also includes manufacturers' specifications.

While Figure 13 allows comparisons among the heat pumps, some data cannot be seen because data of one model covers a portion of the data of another model. Therefore, Figures 14, 15, and 16 show the same data for the three heat pumps individually.

Figures 13 to 16 only represent space heating, despite the fact that the Daikin heat pump can be used for both space heating and DHW heating. Therefore, Figure 17 shows the integrated COP for the Daikin heat pump for both space heating and DHW heating.

Figure 18 shows an example of cycling due to defrost for the Fujitsu heat pump.

At building heat loads below the minimimum heat output for a heat pump, the only way to supply the desired heat load is through cycling. An example of such cycling for the Fujitsu heat pump is shown in Figure 19.

An interesting phenomenon was observed with the Mitsubishi heat pump, for which the COP is decreasing with decreasing heat load, potentially reaching a COP below 1 in some rare situations. Such a situation is shown in Figure 20.

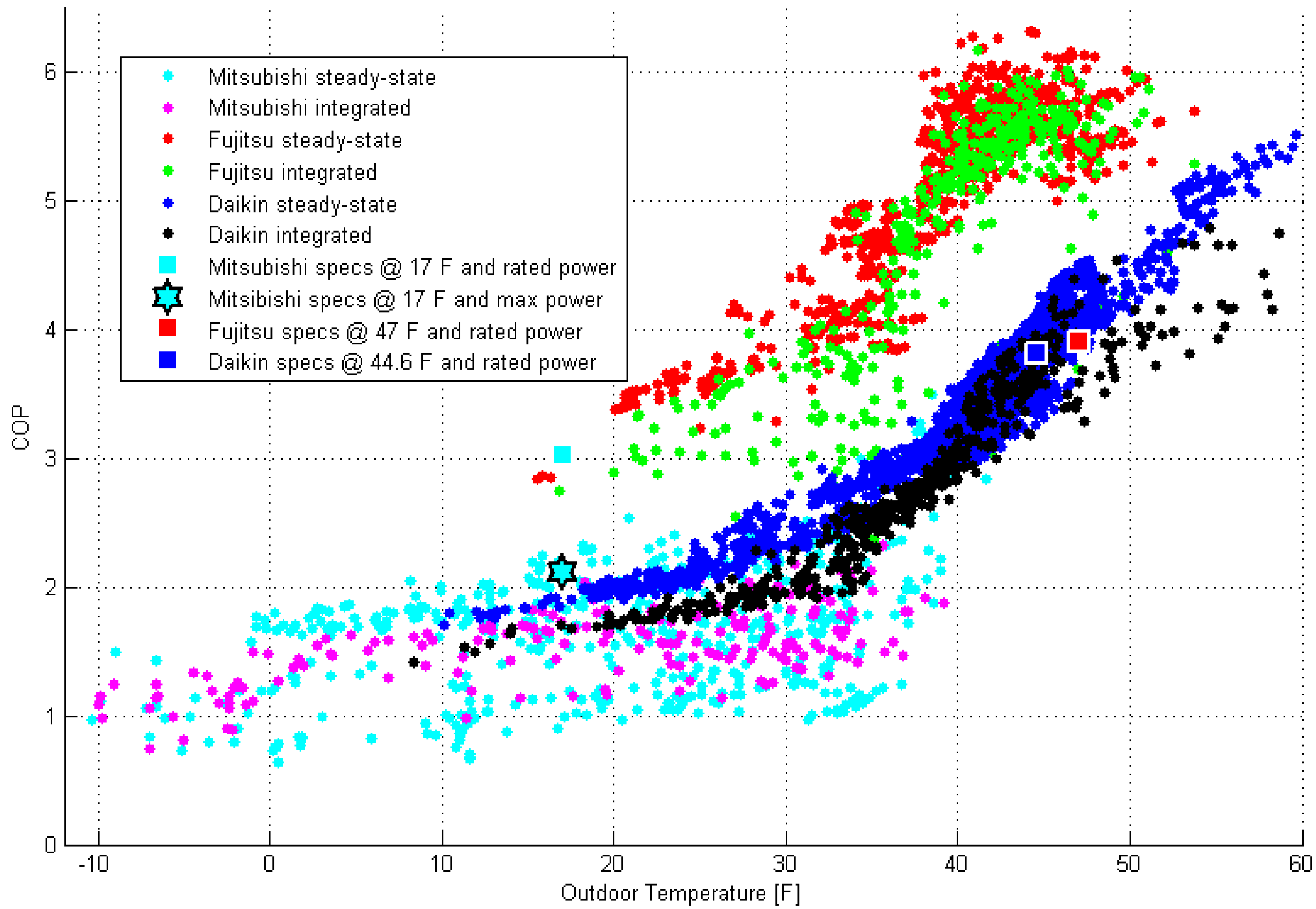


Figure 13: COP versus outdoor temperature for all three heat pumps.

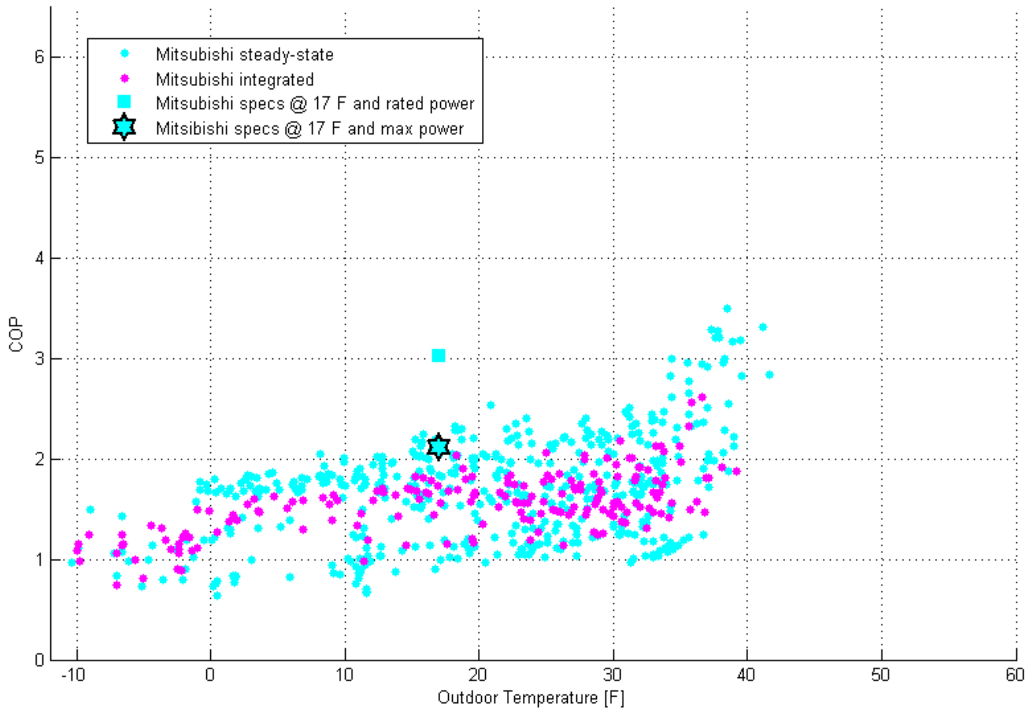


Figure 14: COP versus outside temperature for the Mitsubishi heat pump.

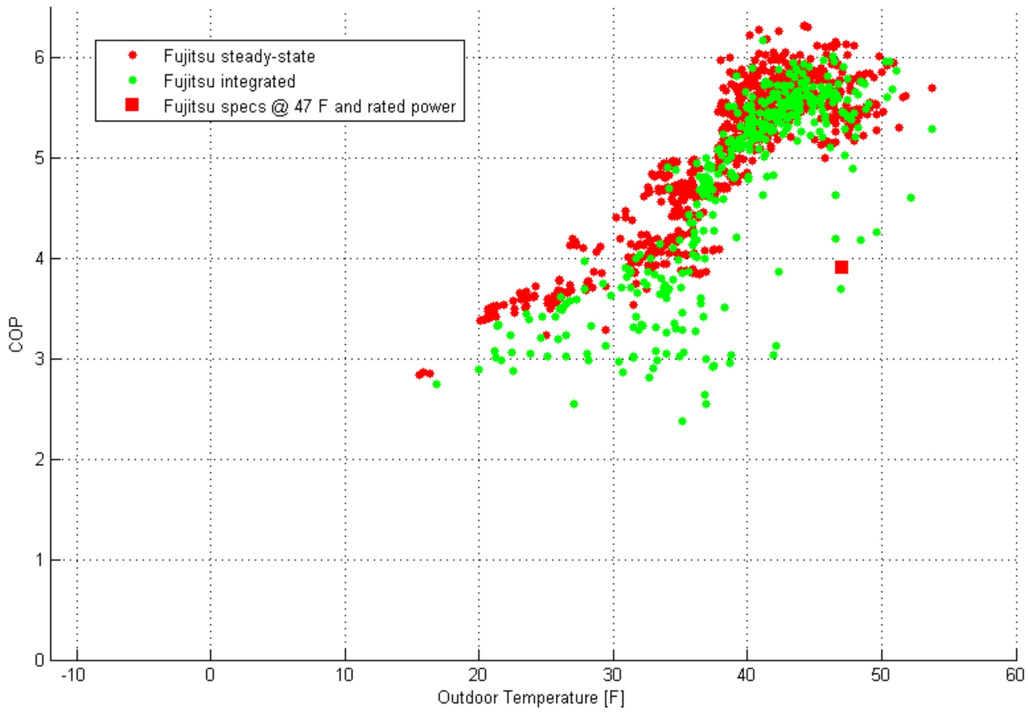


Figure 15: COP versus outside temperature for the Fujitsu heat pump.

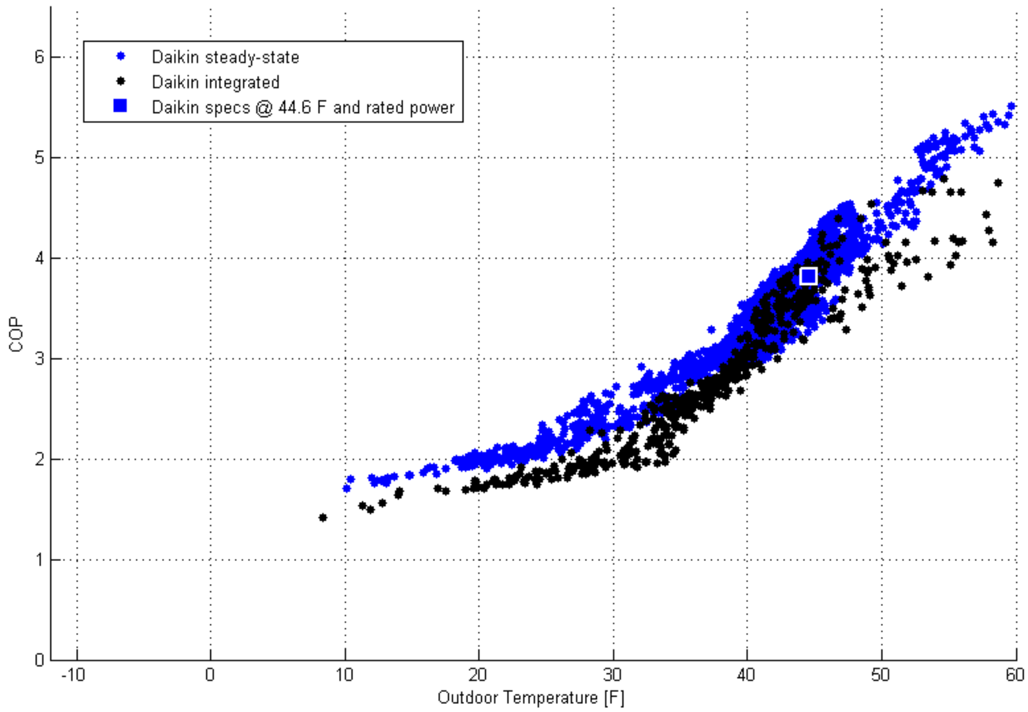


Figure 16: COP versus outside temperature for the Daikin heat pump.

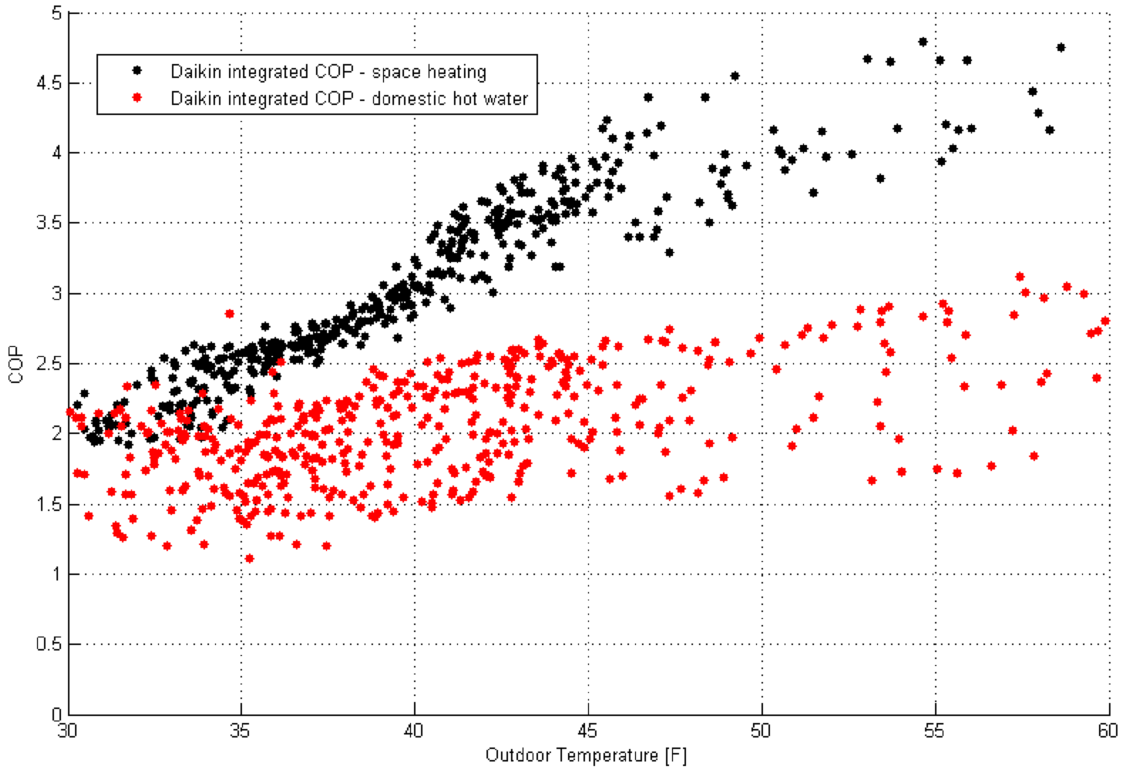


Figure 17: COP versus outside temperature for the Daikin heat pump for space heating and domestic hot water.

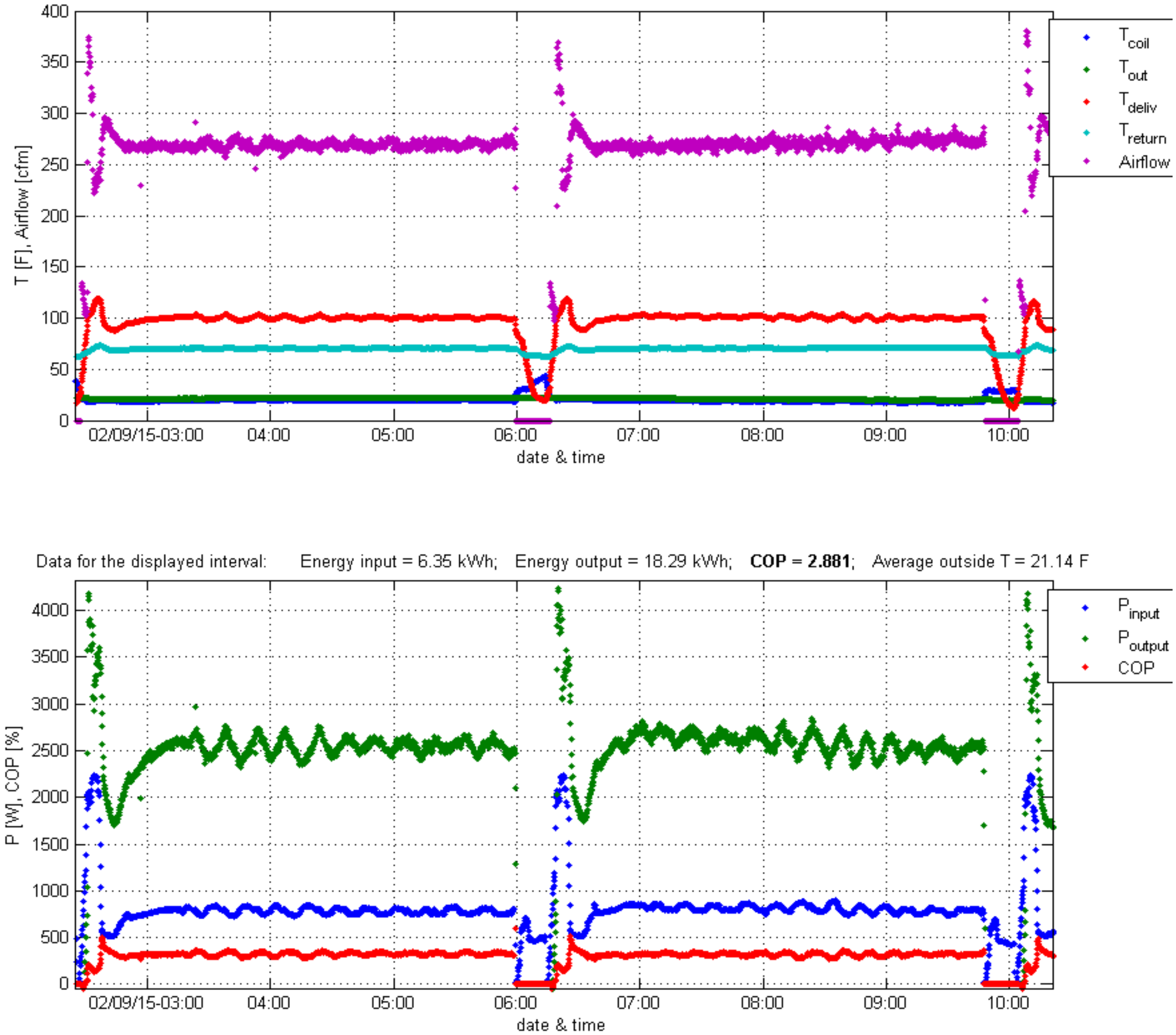


Figure 18: Example of cycling due to defrost for the Fujitsu heat pump.

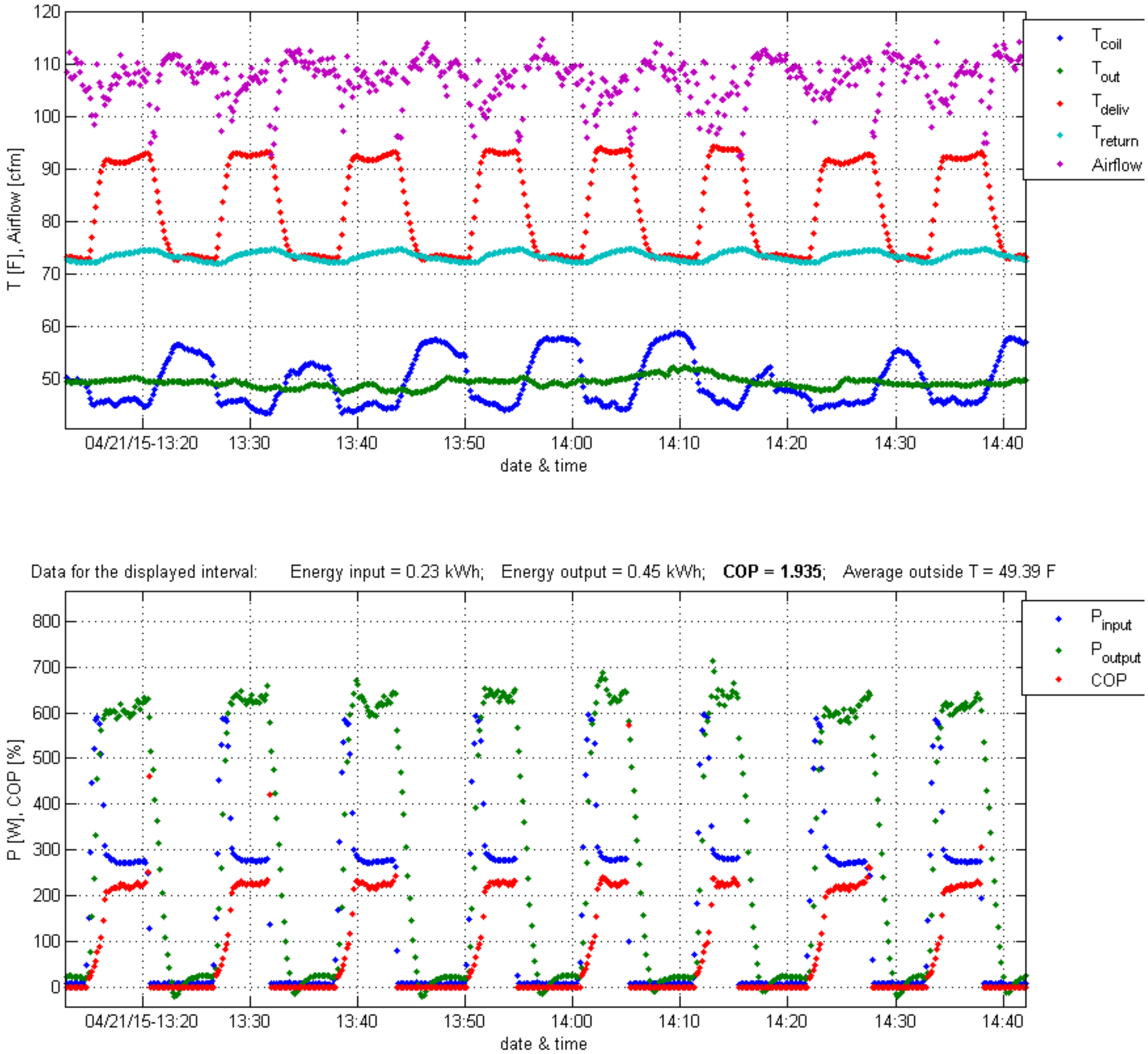
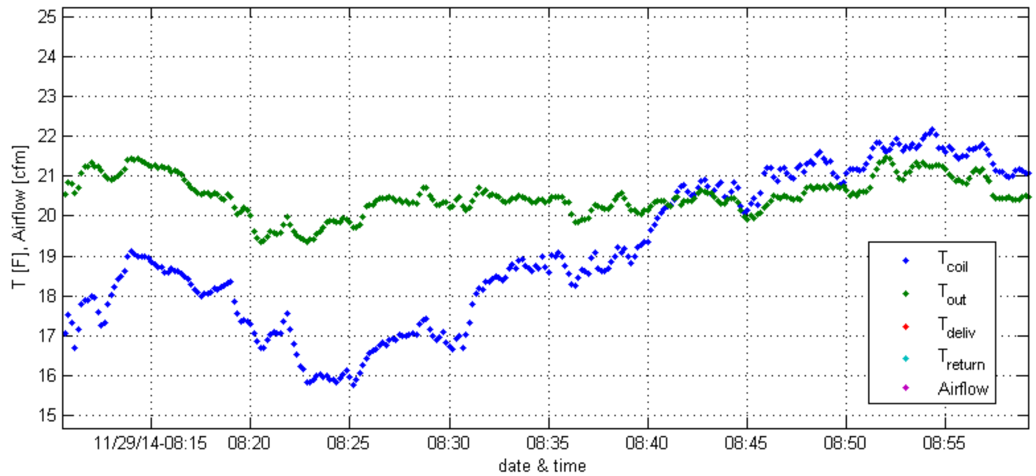


Figure 19: Fujitsu heat pump short-cycling in low-load conditions.



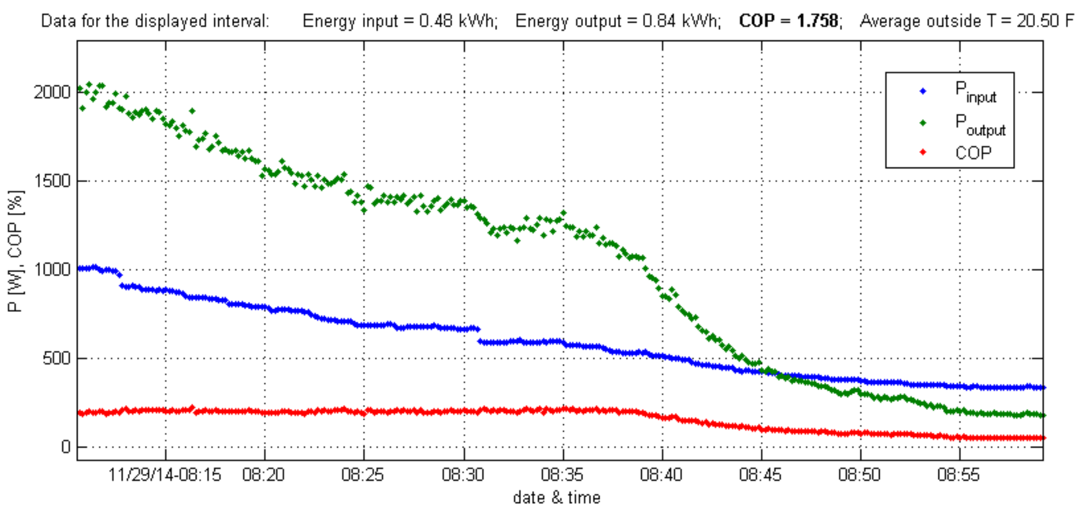


Figure 20: Example of a rare situation when the Mitsubishi COP drops to below 1 to approximately 0.6.

The overall COPs for the three heat pumps are shown in Table 8. The stated COPs cannot be used for a direct comparison of the heat pump models because of the different climates in which they are installed. For this reason, the table also shows the average temperatures, as determined by the outside temperature sensors. It was mentioned earlier that the outside temperature sensor for the Fujitsu heat pump was occasionally affected by the sun, so the average temperature of 40°F, as determined by the sensor, might be a slight overestimation of the actual outside temperature, but the weather data from PAWG weather station at the Wrangell airport for the same period also shows the average temperature of 40°F (The Weather Channel, 2015), suggesting that the occasional higher temperature reading of the outside temperature sensor at the heat pump due to the effect of the sun had a minimal impact on the long-term average temperature. The COP for the Mitsubishi heat pump of about 1.6 is a value that also represents the seasonal COP because it is an extremely efficient house that needs no heat (the heat pump is turned off) outside the stated data period. This is not the case for the Fujitsu and Daikin heat pumps, where the stated overall COPs for the data periods are likely an underestimation of seasonal COPs because the data periods represent colder portions of the year.

Table 8: Overall COPs

	Data period	Average outside T during the data period	Overall COP for the data period
Mitsubishi	10/05/2014 – 04/18/2015	28 °F	1.6
Fujitsu	12/03/2014 – 05/07/2015	40 °F	4.5
Daikin	11/24/2014 – 05/31/2015	39 °F	2.6

The only system tested over a wide range of heat load conditions was the heat pump in Dillingham, as that heat pump was accessible to a researcher from this project throughout the winter. Figure 21 shows the output power as a function of the outdoor temperature for the Mitsubishi heat pump. The displayed data represents all 10-min average data collected during the project while the heat pump was running. The blue samples represent collected data, while the red line represents Mitsubishi specifications for the maximum output power. The Figure does not include samples with output power less than 10 W.

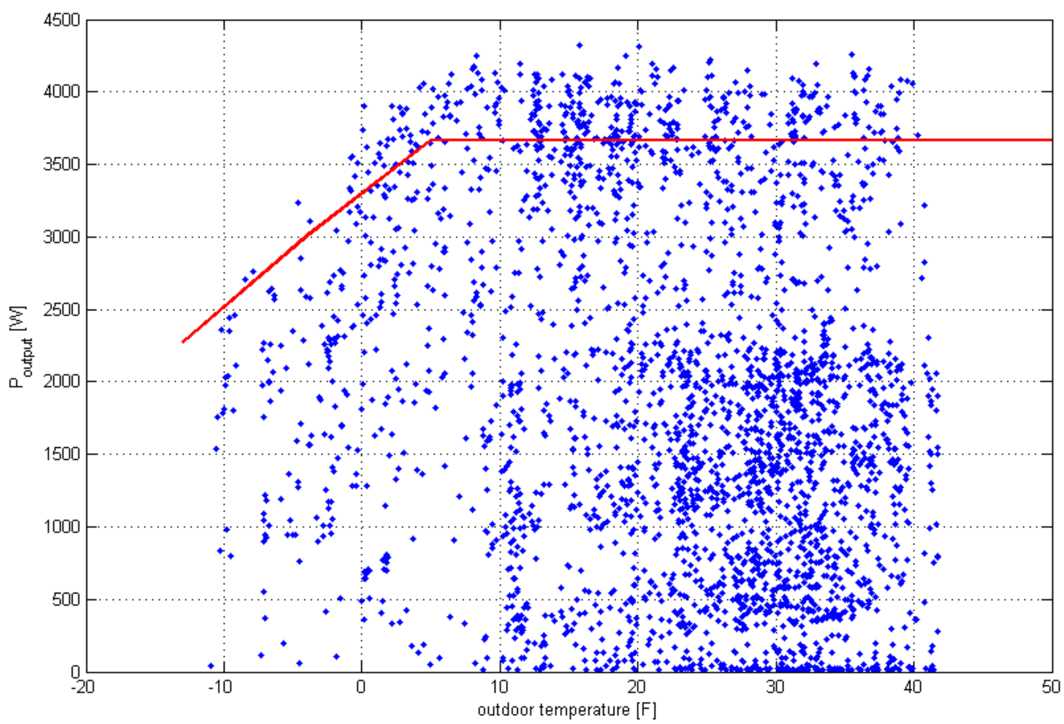


Figure 21: Output power as a function of the outdoor temperature for the Mitsubishi heat pump.

Discussion

As shown in Figure 18, a heat pump cycles in sub-freezing outdoor conditions due to the need for defrost. As shown in Figure 19, a heat pump can cycle in warm outdoor conditions due to operating below the minimum heat load for the appliance, as each heat pump has a limit to how low the compressor speed can go. Because of both of these types of cycles, the integrated performance of a heat pump can be significantly lower than the steady-state performance. This can be seen in Figure 13, which shows the steady-state and integrated COPs as a function of the outdoor temperature for all three heat pumps.

Fujitsu specifies that the studied heat pump operates with a COP of 3.91 at the rated conditions, which means the outdoor temperature of 47°F and a heat load of 16,000 Btu/hr (4,692 W). As seen in Figure 13, the measured steady-state COP at 47°F is in an approximate range of 5 to 6, which means it is significantly above the manufacturer specified 3.91. This is due to significantly lower heat load (~ 1,500 W) than the rated one (4,692 W). As shown in the Lab Test Report for Fujitsu 12RLS and Mitsubishi FE12NA (Winkler, 2011), the Fujitsu heat pump at low-load conditions performs more efficiently than specified at rated conditions. Their report shows that the Fujitsu 12RLS in low-load conditions can achieve a steady-state COP of around 4.5 at an outdoor temperature of 35°F, which is in agreement with our findings showing a steady-state COP in the approximate range of 4 to 5 at an outdoor temperature of 35°F for the Fujitsu 12RLS2 heat pump.

The opposite was found for the Mitsubishi heat pump compared to the Fujitsu heat pump with respect to the operation at low-load conditions. As seen in Figure 20, the COP drops significantly when the Mitsubishi heat pump transitions into operation in low-load conditions. This is also the reason for the wide range of the steady-state COP in Figure 13; the lower portion of the steady-state Mitsubishi data represents its operation in low-load conditions, while the upper portion represents its operation at maximum load conditions. As seen in Figure 13, Mitsubishi's specifications for the COP at maximum load conditions are in agreement with the experimental results in this study. However, as also seen in Figure 13, Mitsubishi specifies a significantly higher COP at rated conditions compared to the maximum load conditions, indicating that the COP should increase as heat load decreases, which is the opposite of what was found in this study. For the rated conditions, an outdoor temperature of 17°F and heat load of 6,700 BTU/hr (1,965 W), Mitsubishi specifies that the COP should be 3.02, which is significantly above any sample measured in this study (see Figure 13).

As seen on the right side of Figure 20, in rare situations the COP for the Mitsubishi heat pump can drop to below 1 in low-load conditions. COPs below 1 mean that the output power is lower than the input power, as also seen in Figure 20. COPs below 1 also mean that instead of extracting heat from the outside air, heat is being supplied to the outside air, which is also indicated in Figure 20 where the ASHP coil temperature is greater than the outdoor temperature. This issue is likely due to the controls for this specific heat pump. The researchers attempted several times to discuss this problem with Mitsubishi, but no response was received addressing the issue. Williamson & Aldrich (2015) found integrated daily COP values of less than 1 for related Mitsubishi models (FE12 and FE18), but the report doesn't indicate whether it was also found for steady-state samples, or whether the COP values below 1 were purely due to defrost penalty (Williamson & Aldrich, 2015).

For the Daikin heat pump shown in Figure 17, the integrated COP for the DHW is significantly lower than the integrated COP for space heating. There are two main reasons for this: 1) For hot water, the heat pump operates with a higher temperature lift; 2) The hot water heating is typically happening in relatively short cycles, which increases the impact of inefficiencies associated with transitions. The most frequent length of the heating cycle is around 30 minutes.

Another important fact to mention about Daikin is that the distribution of the Altherma line was discontinued in the United States in 2015. The model may be sold again in the future, but when is uncertain, according to a representative at Stinebaugh & Company, the Daikin distributer in Alaska (M. Lloyd, personal communication, November 18, 2015). This fact combined with the relatively low COP for DHW and high cost of the air-to-water heat pump systems suggests that it is worth considering whether using a ductless system in combination with a heat pump water heater could be a more economical solution than using an air-to-water heat pump for combined DHW and space heating needs. This solution is utilized in the Dillingham house that uses the Mitsubishi ASHP in combination with a GE GeoSpring heat pump water heater.

An interesting observation from Figure 13 is that the Daikin data is more tightly grouped than the data for the two DHPs. There are two main reasons for this: 1) Measuring water flow in a pipe has less random error than measuring air flow in a DHP; 2) For a given outdoor temperature, the Daikin heat pump is bringing the water to a set temperature instructed by the outdoor reset parameters, and thus operating with the same temperature lift regardless of the return temperature, which might change with different heating needs due to different internal heat gains and possibly other factors. This is unlike the ductless systems where the return air temperature is relatively constant and what changes with different heating needs is the supply temperature, which results in changes in the temperature lift and thus efficiency.

Table 8 shows the overall COPs for the studied periods. The overall COP for the Mitsubishi heat pump was found to be about 1.6. This is in agreement with the overall COP of about 1.7 found for the same heat pump in the same building for the same period in a separate project using a building heat loss simulation combined with data collected for the electrical energy consumption of the heat pump, measured with a meter that is different from the one used for the ASHP study in this report. The overall COP of 1.6 is also in reasonable agreement with results found by Williamson & Aldrich (2015) in their study of related Mitsubishi models FE12 and FE18 in homes in New England. The overall COP of the six Mitsubishi heat pumps covered in the results of that report ranged from about 1.1 to about 2.3. The same report includes one Fujitsu ductless heat pump. It is a Fujitsu 15RLS2 and the overall COP was found to be about 1.7. This is significantly lower than the overall COP of about 4.5 found in this study for the Fujitsu 12RLS2. This is partly due to significantly lower temperatures during the monitoring period in New England. Another report found an average seasonal COP of about 2.8 for six heat pumps in Eastern Idaho, a climate similar to Wrangell (Ecotope, Inc., 2012). However, the report does not provide a breakdown by heat pump model, so a direct comparison to our results is not possible.

Mitsubishi specifies that the heat pump “features 100% heating capacity at 5°F, 82% at -4°F, and 62% at -13°F”. It also specifies that the maximum heating capacity is 12,500 Btu/hr (~ 3,666 W). As seen in Figure 21, the measured heat pump performs better than specified by Mitsubishi with respect to the maximum heating capacity.

As explained earlier, it was not possible to test the studied heat pumps at their cutoff temperature due to a warmer than average winter in Alaska in the 2014-2015 season. However, notes are available for the Mitsubishi heat pump in Dillingham in a situation that occurred in February 2013, prior to this study. It was windy and the outside temperature was about -5°F, and the heat pump stopped operating. The power lamp on the indoor unit was flashing in a pattern that indicated an outside thermistor error, per the Mitsubishi troubleshooting guide. When temperatures rose, the heat pump did not start working until the power breaker was cycled off and on. A possible explanation of this situation is that due to a combination of a low outdoor temperature and high wind, the heat pump wasn't able to defrost, which resulted in very low coil temperatures to achieve sufficient heat transfer across the ice, and the very low coil temperatures resulted in the thermistor error. The problem has not occurred again. This experience suggests that even though it is rare, possible issues can occur when operating the heat pump close to its cutoff temperature.

Some information is also available for the Fujitsu heat pump with respect to the low temperature cutoff. A Fujitsu engineer was contacted to discuss the behavior of the Fujitsu heat pump at the low end of its temperature operating range, -5°F (T. Young, personal communication, July 15, 2014). The engineer explained that the heat pump doesn't actually cut off, it continues to work below -5°F, but the defrost cycle may not be able to keep up and the frost build-up could damage the heat pump.

One important thing to note is that the three heat pumps monitored in detail in this study are a small sample and the results presented here are for these specific heat pumps. Caution should be exercised when generalizing these findings. For example, it is not clear whether the issue with the Mitsubishi heat pump operating in some rare situations in low-load conditions with a COP below 1 is a problem common to the whole series or just the unit that was tested. Several attempts were made to discuss this problem with Mitsubishi with no success.

General monitoring

Researchers monitored 30 residential or light commercial ASHPs over the winter of 2014-2015 with a general survey technique. The purpose of this component of the project was to provide a broad picture of ASHPs that have been installed in Alaska and other cold climates. The thirty heat pumps monitored represent a diverse selection of ASHP models installed in nine locations.

Objectives

Specifically, the general monitoring of ASHPs was to address the following questions:

1. Are building owners using ASHPs for heating satisfied with them?
2. Where do regional climatic conditions constrain year-round operation?
3. What is the effect of retrofit ASHPs on the peak power demand and total winter electrical energy demand of a building's heating appliance?

Methodology

For this part of the project, researchers sought ASHPs installed in homes and buildings in Alaska that were currently in use. Due to the diversity of ASHPs, buildings, and locations that participated in the monitoring, the data varied by installation. This section describes the user recruitment process as well as the types of data collected.

Recruitment

To locate ASHPs for general monitoring, project staff circulated a recruitment bulletin to organizations and businesses that currently work with ASHPs, including research institutions, HVAC distributers, HVAC contractors, utilities, energy raters, and housing authorities. Due to time and budget constraints, researchers aimed to locate up to 30 ASHPs to participate in the monitoring.

The recruitment bulletin, which appears in Appendix B, provided potential participants with information on project goals, funders, and expectations of volunteers. Participants were asked to complete two interviews on topics including building and ASHP characteristics, ASHP performance, and reasons for choosing an ASHP. Monitoring of the electrical consumption of the ASHP was accomplished either indirectly via electric bills, or directly via a monitoring device, when available.

Data sources

There are three types of data that could potentially be collected from each site: homeowner interviews, indirect electric monitoring, and direct electric monitoring. Researchers approached each site with the goal of collecting data from all three categories; however, in some cases only certain types of data collection were feasible. This section describes the different types of data, as well as the procedure for collection.

Homeowner interviews

Project staff interviewed participants twice during the study, once over the summer of 2014 before the monitoring began, and once after the monitoring period ended in May 2015. The initial interviews addressed five primary topics:

1. General information about the building, including square footage, insulation values, and occupancy
2. Information about the air source heat pump, including make/model, size, use, installation date, required maintenance, and retrofit information
3. Approximate costs, if known, for system installation and maintenance
4. Homeowner experience and satisfaction with the heat pump
5. Building monitoring details

The goal of these interviews was to evaluate homeowner satisfaction, installation and maintenance costs, and homeowner impressions of the quality of heat and its cost effectiveness. Additionally, the interviews served to complement electrical data by providing information on the building, occupancy, thermostat settings, backup heating appliances, and other factors that may influence energy usage. Finally, the initial interviews informed participants about the project, and gave them an opportunity to learn more about the project goals and speak with project staff.

During the second round of interviews, researchers reviewed the winter heating season with the participants. They gathered information about any repairs that were needed for the heat pumps, any maintenance that was completed, any changes to the building or ASHP system, and whether or not the backup appliances were used during the monitoring period.

Researchers recorded information from the interviews, which were conducted in person or by telephone. To ensure the privacy of the names and addresses of participants, each site was assigned a label based on the location and type of heat pump system. Researchers used these labels exclusively during data aggregation and analysis for the purpose of future reporting.

Weather data

Weather data complemented electrical data in the analysis for direct and indirect monitoring. Researchers gathered weather data, including monthly heating degree days, maximum temperatures, and minimum temperatures from The Weather Channel's Weather Underground Historical Weather website, which can be accessed here: http://www.wunderground.com/history. The data for each location was gathered from a weather station located at the nearest airport.

Effect of cooling

This project focused on the use of ASHPs as heating devices for communities with hydropower. Their use for cooling represents an increase in energy use in general, because most Alaska residences do not have air-conditioning. The installation of an ASHP as a retrofit or in a new building represents an opportunity to use electricity to cool where it did not exist before. However, this increase in energy use comes in the summer, at a time when hydropower reserves are at their fullest and are capable of handling increased demand.

For the direct electric monitoring analysis, researchers did not include data that would potentially represent ASHP use for cooling because there were no cooling degree days during the monitoring period.

For the indirect electric monitoring, researchers included months that had cooling degree days because cooling degree days were minimal and occurred in months that also had heating degree days. Also, this electric monitoring was aiming to provide a broader picture of the potential effects of the ASHP on electric use, even in cases where it may represent an increase.

Researchers from this project recommend that cooling use be monitored directly in climates with higher numbers of cooling degree days and/or for projects that directly monitor the ASHP during the non-heating season in order to distinguish the electric use of the two modes. One method of measuring the cooling impact was to install a vapor line temperature sensor, as described in Ecotope's 2012 report (Baylon & Geraghty, 2012).

Indirect electric monitoring

Indirect electric monitoring consisted of collecting electric bills for the building from the local utility. Where possible, utilities provided researchers with up to five years of electric use information for each building being monitored, from 2010 to the present. In some cases, five years of records were not available, either because the building was built less than five years ago, or because the current owner had moved in after 2010. Bills were collected in May 2015. For analysis and reporting purposes, the data from the bills was transferred to files that only used the site's label, so that names and addresses of study participants were not used.

The goal of the indirect electric monitoring was to provide a rough first-order comparison between electric consumption before and after retrofit heat pump installations. Researchers expected to observe a decrease in electrical consumption for buildings that converted to an ASHP from an electric heating appliance, and an increase in electrical consumption for buildings that converted to an ASHP from an oil-fired heating appliance.

This method of analysis leaves much to be desired because several factors other than heating appliances can affect monthly electrical usage: occupancy, weather, changes in the operation of the heating appliance, other seasonal appliance loads, and backup heating use. A more complete list of biases that can affect billing data can be found in a report by Ecotope, Inc. (Baylon, Storm, & Robison, 2013). Thus, researchers addressed as many of these topics in the interviews as possible to complement the indirect electric monitoring.

Further, researchers matched monthly electrical use with heating degree days (HDD) in an attempt to partially account for the effect of varying temperatures. However, this method has some uncertainty as the period for obtaining the HDD did not exactly match the billing period. For Juneau homes, the electric bills did not include the dates of the billing period, so HDD was obtained by calendar month and matched to the corresponding billing month. Thus, the uncertainty in the billing period HDD is unknown. For remaining retrofit homes, located in Wrangell and Sitka, the electric bills did include the starting and ending dates of the billing period. Thus, the uncertainty of obtaining the HDD is +/- the HDD for two days, the first and last dates of the billing period. These dates were counted twice, in billing periods for the starting and ending months. For instance, if a billing period was from January 5 to February 4, then the HDD for January 5 was counted both in the December billing period ending on that day, and the January billing period starting on that day. Researchers also matched the electrical use for the entire pre-ASHP and post-ASHP periods with the HDD. This provides a larger average and less uncertainty than doing it by month since the period for the electric use and HDD is larger.

In both cases, researchers compared the pre- and post-ASHP electrical use and HDD dependence. For monthly data, a linear regression provided the basis for the comparison. For the entire pre-ASHP and post-ASHP periods, researchers compared the ratio of electric use to HDD.

Direct electric monitoring

The goal of the direct electric monitoring was to measure the seasonal energy consumption and the peak electrical usage of the ASHP. There were two different strategies used to measure the electrical usage of ASHPs: in Juneau, the Alaska Electric Light and Power Company (AEL&P) provided and installed turtle meters for monitoring participants; in Wrangell and Sitka, project partners installed "efergy" meters on ASHPs.

Turtle meters

Turtle meters report daily electrical energy use and peak demand to the utility. AEL&P uses them to calculate rates for customers on a demand rate schedule and to learn more about the electrical usage of larger electric appliances like ASHPs and electric vehicles. The meters must be installed on a 4-jaw meter base that connects to the power line leading to the appliance. For this project, AEL&P contracted a local electrician to install meter-bases on the Juneau ASHPs, then an AEL&P technician installed the turtle meter. AEL&P collected the data from the turtle meters and transferred it to research staff in May 2015.

Daily electric use and peak demand data are accompanied by a timestamp, which allows for calculation of monthly total electric use. Researchers took the monthly usage by calendar month (rather than billing period) in order to match with HDD. Similarly, the load factor period is calculated using the timestamps from the turtle meters to be as close to the calendar month as possible. The peak demand has some uncertainty associated with the accuracy of the turtle meter, which reports peak demand in increments of 0.25 kW.

Efergy meters

Efergy meters are commercially available meters that monitor the electric use of a building or appliance. For this project researchers used the e2 classic model based on Wrangell Municipal Light & Power recommendations, having previously used this model to demonstrate the electric use of the ASHP in their front office to customers who had questions about heat pumps. The meters rely on current transformers attached to the ASHP circuit and are capable of displaying and storing peak and cumulative electric usage. The meters assume a power factor of 1.0 and calculate apparent power in volt-amps by multiplying measured current with the voltage for the ASHP, which is manually entered by the user. For this reason, there is some uncertainty associated with the meters and to have an idea of the uncertainty, the data from the efergy installed on the Wrangell ML&P DHP was compared with the data from the electrical sensors used for the detailed monitoring of that heat pump for this project. The comparison was done for months December 2014 to March 2015 using the five minute averages from the detailed monitoring sensors to calculate monthly electrical usage. On average, the efergy reported a monthly usage within 9.5% of the monthly electric usage from the detailed monitoring sensors.

The meters were originally installed by project partners in Wrangell, Sitka, Ketchikan, Petersburg, and Whitehorse. However, errors in installation or data gathering meant that researchers were only able to acquire data from selected buildings in Wrangell and Sitka. The data was gathered in the summer of 2015 by project staff members or by the homeowner if they were interested in learning to use the free software included with the device to continue monitoring their system after the study ended. Homeowners were allowed to keep the meters for their own use after the study period ended.

Analysis

Researchers summed electrical data by month to quantify the total energy use alongside the HDD. This was done using a commercial software program for the turtle meters, and automatically by the efergy meters. Different sites have different amounts of electrical data, because the monitoring devices were installed at different times.

Both meters were able to identify the peak electrical use of the ASHP in a given month. Researchers paired this data with daily temperature to see if there was a correlation between peak use and outside air temperatures.

Researchers also calculated load factors for the Juneau homes to give the peak use additional context for AEL&P customers on a demand billing rate. Load factors, or the average power divided by the peak power, represent the percentage of hours at peak usage in a period of time that would be needed to use the measured amount of electricity in that time period. As the load factor increases, the dollars per kWh typically decreases for customers on the demand rate.

$$Load\ factor = \frac{Electrical\ energy}{Peak\ power\ demand * Time\ period} = \frac{kWh}{kW_p * hours}$$

Researchers calculated the load factor by month:

$$Monthly\ load\ factor = \frac{kWh}{kW_p * hours\ in\ month}$$

Results

The aim of the general monitoring was to obtain a broad picture of ASHP use in Alaska and Whitehorse; thus, the ASHPs monitored were from several different locations, encompassed both small commercial and residential installations, and consisted of three different types – ductless heat pumps (DHPs), air-to-air ducted heat pumps, and air-to-water heat pumps.

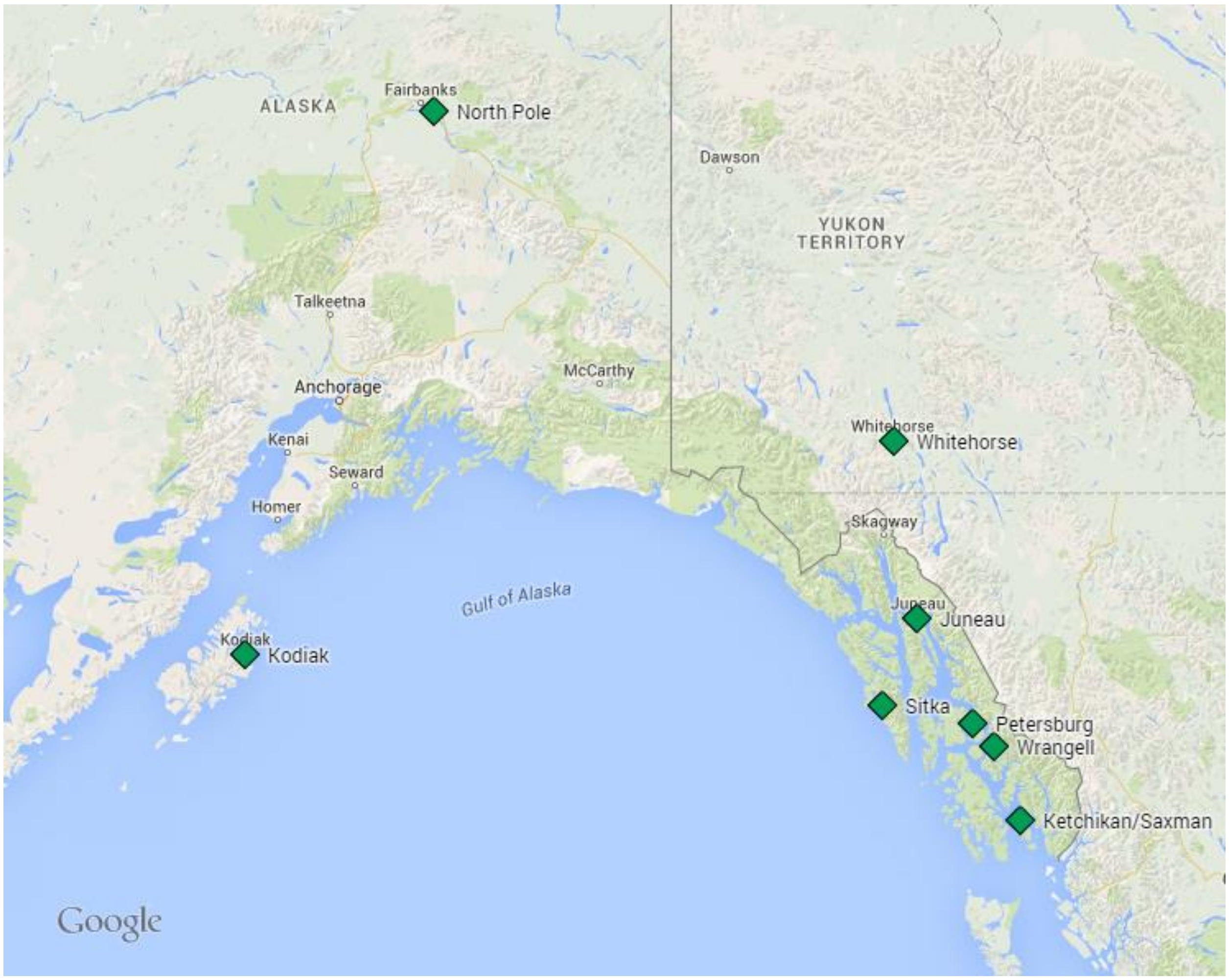


Figure 22: The general monitoring sites.

The monitoring sites were located in Alaska and Whitehorse, Canada, with the majority of the sites in Southeast Alaska. Twenty-four of the ASHPs were located in residences and consisted of 12 DHPs, 10 air-to-water systems, and two air-to-air systems. The remaining six sites, two air-to-water systems, one air-to-air system, and three DHPs, were located in commercial buildings. Table 9 shows the locations and types of ASHPs in the general monitoring. Twenty of these systems were retrofits, and the remaining ten were located in newly constructed buildings. There are two ASHPs, both retrofit installations, acting as displacement systems, or heating appliances that are only meant to displace a portion of the heating load covered by a separate heating system. One of these systems is a DHP that is displacing one zone of a forced air furnace in a residence. The homeowner intends to eventually replace the remaining zones with more DHPs. The other displacement system is located in a large commercial building with multiple heating systems for the different parts of the building.

Table 9: The locations and types of ASHPs in the general monitoring.

Location	Residential	Commercial	Total
Juneau	DHP: 3 Air-to-water: 6 Air-to-air: 0 Total: 9		DHP: 3 Air-to-water: 6 Air-to-air: 0 Total: 9
Ketchikan	DHP: 1 Air-to-water: 1 Air-to-air: 0 Total: 2	DHP: Air-to-water: 1 Air-to-air: 0 Total: 1	DHP: 1 Air-to-water: 2 Air-to-air: 0 Total: 3
Kodiak	DHP: 0 Air-to-water:2 Air-to-air: 0 Total: 2		DHP: 0 Air-to-water: 2 Air-to-air: 0 Total: 2
North Pole		DHP: 1 Air-to-water: 0 Air-to-air: 0 Total: 1	DHP: 1 Air-to-water: 0 Air-to-air: 0 Total: 1
Petersburg	DHP: 1 Air-to-water: 0 Air-to-air: 0 Total: 1	DHP: 1 Air-to-water: 0 Air-to-air: 0 Total: 1	DHP: 2 Air-to-water: 0 Air-to-air: 0 Total: 2
Saxman		DHP: 0 Air-to-water: 1 Air-to-air: 0 Total: 1	DHP: 0 Air-to-water: 1 Air-to-air: 0 Total: 1
Sitka	DHP: 3 Air-to-water: 1 Air-to-air: 0 Total: 4		DHP: 3 Air-to-water: 1 Air-to-air: 0 Total: 4
Whitehorse	DHP: 0 Air-to-water: 0 Air-to-air: 2 Total: 2		DHP: 0 Air-to-water: 0 Air-to-air: 2 Total: 2
Wrangell	DHP: 4 Air-to-water: 0 Air-to-air: 0 Total: 4	DHP: 1 Air-to-water: 0 Air-to-air: 1 Total: 2	DHP: 6 Air-to-water: 0 Air-to-air: 0 Total: 6
Total	DHP: 12 Air-to-water: 10 Air-to-air: 2 Total: 24	DHP: 3 Air-to-water: 2 Air-to-air: 1 Total: 6	DHP: 15 Air-to-water: 12 Air-to-air: 3 Total: 30

The heat pumps in this study are from six different manufacturers: Daikin Altherma, Fujitsu, Mitsubishi, Cool Fire, Goodman, and Trane. The majority of the heat pumps were made by Fujitsu, Mitsubishi, and Daikin Altherma.

Table 10: Manufacturers represented in the general monitoring.

Heat Pump Type	Manufacturer and number of installations
DHP	Fujitsu: 9 Mitsubishi: 6
Air-to-water	Daikin Altherma: 11 Cool Fire: 1
Air-to-air	Mitsubishi: 1 Goodman: 1 Trane: 1

Homeowner interviews

All 30 ASHP sites participating in the general monitoring completed initial interviews in the summer of 2014, and final interviews occurred in May 2015, after the winter monitoring period. In the initial interviews, homeowners and building operators shared building and ASHP characteristics, operation details, costs, and information about what they liked and did not like about their system. In the final interviews, study participants recounted how their ASHP performed during the winter of 2014-2015.

Building and ASHP characteristics

The buildings monitored spanned a wide range of sizes and designs. On the residential side, the smallest building was 600 square feet and the largest was 3,800 square feet. Of the buildings that had AkWarm energy ratings, the range was Two Star Plus to Six Star (6 Star being the most efficient possible). Homeowners reported that the homes were occupied by one to seven people. The commercial buildings ranged in size from 3,500 square feet to 35,000 square feet – although the largest building was only partially heated with ASHPs. None of the commercial buildings had AkWarm ratings; however reported construction types ranged from standard 2x6 frame construction to super-insulated walls. Occupancy ranged from two people to 20 people.

Table 11: Building and operating characteristics for the general monitoring.

Characteristic	Residential	Commercial
Number of buildings monitored	24	6
Size range (square feet)	600 – 3,800	3,500 – 35,000
Occupancy range	1-7	2-20
ASHP heating capacity (tons)	1-5	12-25
Earliest installation	2010	2009
ASHP used for heating	24 / 24	6 / 6
ASHP used for cooling	10/ 24	3 / 6
ASHP used for DHW	7 / 24	1 / 6

Information on the ASHPs in these buildings also reflects great variety. On the residential end, the heating capacities of the ASHPs ranged from 1 ton to 5 tons. All 24 residential heat pumps are used for heating, with ten also being used for cooling, and seven being used for DHW. The first installation occurred in 2010 and is still in operation. All but one residence had a backup appliance, and seven residences had more than one backup appliance.

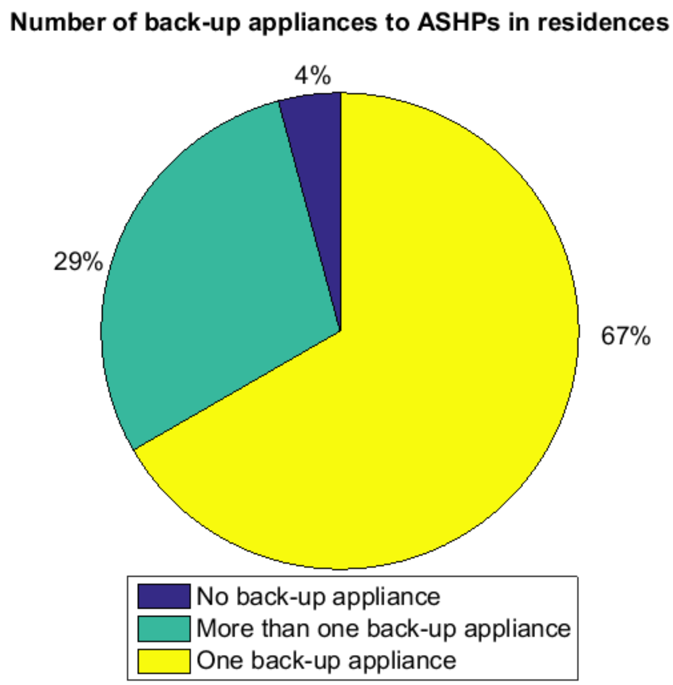


Figure 23: Residential backup appliance totals.

The most common backup appliances were wood stoves (in 8 homes) and electric resistance heat, either through baseboards or portable electric resistance heaters (in 7 homes) or electric resistance backup heat incorporated into the ASHP itself (5 homes). Other homeowners reported backup appliances including fireplaces, Toyo stoves, pellet stoves, electric boilers, masonry heaters, and oil-fired furnaces and boilers. Many of these appliances were formerly primary heating systems, and remained in the homes after the retrofit ASHP was installed.

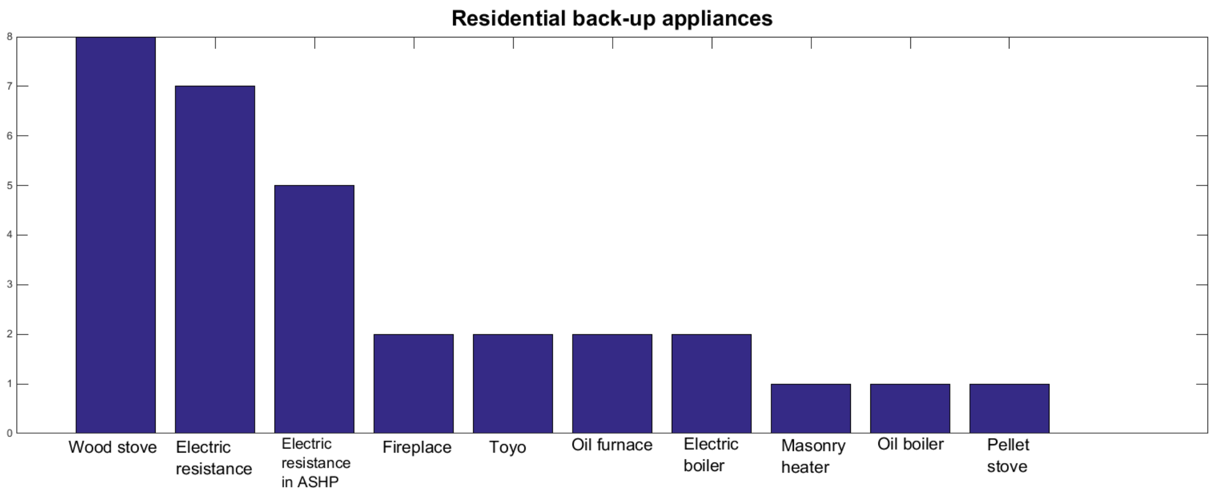


Figure 24: Backup appliance types in the general monitoring.

On the commercial side, the heating capacity of the ASHPs ranged from 12 to 25 tons. All six buildings used the ASHP for heating; three buildings reported also using the ASHP system for cooling, and one building also employed the appliance for DHW. The earliest installation was in 2009, and all are still in operation. All buildings had backup heating systems, and all six backup systems were different. Two of the buildings rely on ASHPs to offset only a portion of their heating loads, with the secondary heating system (Toyo stoves, electric boilers) capable of both fulfilling the remaining load and acting as the backup to the ASHP system. The other four buildings use the ASHP exclusively when possible. Three of these buildings have retrofit ASHP systems and the original heating systems remain as backup: oil and wood-fired boilers, electric baseboards, and an oil-fired unit heater. The final building has backup electric resistance heat incorporated into the ASHP heating system.

Installation

On the residential side, most homeowners (19) had their system installed by an HVAC contractor. The remaining five homeowners installed their systems on their own (one is a professional heat pump installer). Fourteen installations used sizing calculations to choose a heat pump model and seven installations used rule-of-thumb sizing. The remaining three homeowners were unsure of how their system was sized. Four homeowners out of the 24 reported having an issue with their ASHP installation:

- In one home with an air-to-water system, a pump had to be added after installation because hot water was taking a long time to arrive in the kitchen (a room farther from the heat pump than others).
- In three homes, the initial control settings had to be adjusted or tuned after operation began.

In all four cases, the installer made the adjustments and the homeowners were satisfied.

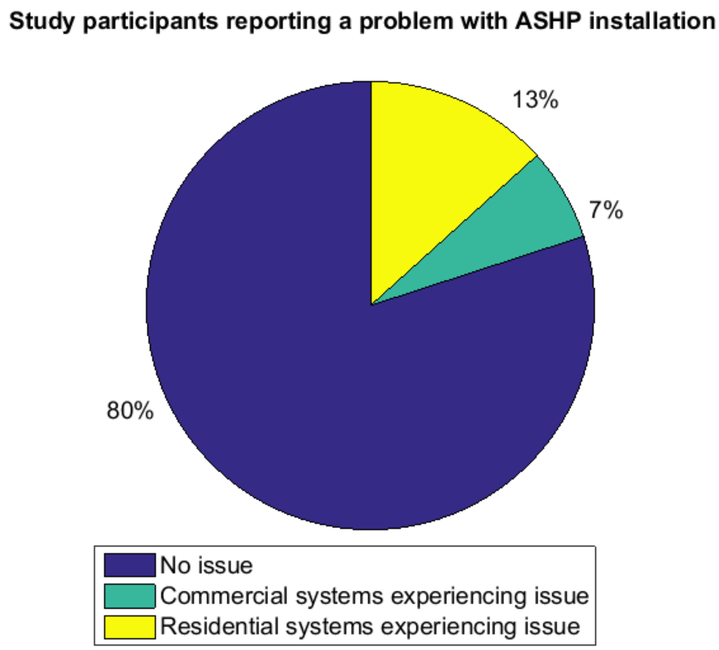


Figure 25: Participants reporting a problem with ASHP installation.

All six commercial systems were installed by HVAC contractors; two of these were also self-installs as they are located in buildings of HVAC contractors. Four of the systems were sized according to a sizing calculation, with the remaining two using rule-of-thumb sizing. There were two issues with these installs:

- The staff in one building was not trained to use the thermostats, which were more complicated than traditional thermostats. This caused a few issues that were resolved as staff learned how to use them properly.
- In one of the buildings with multiple integrated heating systems, there were some issues balancing the central control system in order for the heating systems to operate smoothly.

Operation

Homeowners reported a wide range of operating characteristics of their ASHP systems. First, thermostat setpoints ranged from the minimum of 40°F for rarely used areas of a home to the maximum of 88°F. Twenty-three of the 24 ASHPs feature programmable thermostats. Of these, 12 homeowners reported using the thermostat to run a setback to save energy. Seventeen homes had zoning, which was accomplished either through multiple indoor heads on a DHP or with the control system on a central ASHP system.

Twelve homeowners perform maintenance on their heat pump:

- Nine people change or clean their filters on a regular basis;
- Two people clean the outdoor coils in the summer; and
- One homeowner has an HVAC contractor perform a yearly service check on the heating system.

Eight people had experienced an issue requiring repair. All issues were fixed by HVAC contractors at no cost to the homeowner as they involved parts under warranty or minor repairs.

- Pumps failed and had to be replaced in 2 homes;
- Refrigerant system experienced leaks in 3 homes;
- Power fluctuations caused control systems to need re-set in 2 homes;
- And one defective breaker in a home caused a power surge that fried a circuit board in the heat pump; the circuit board was replaced at no cost.

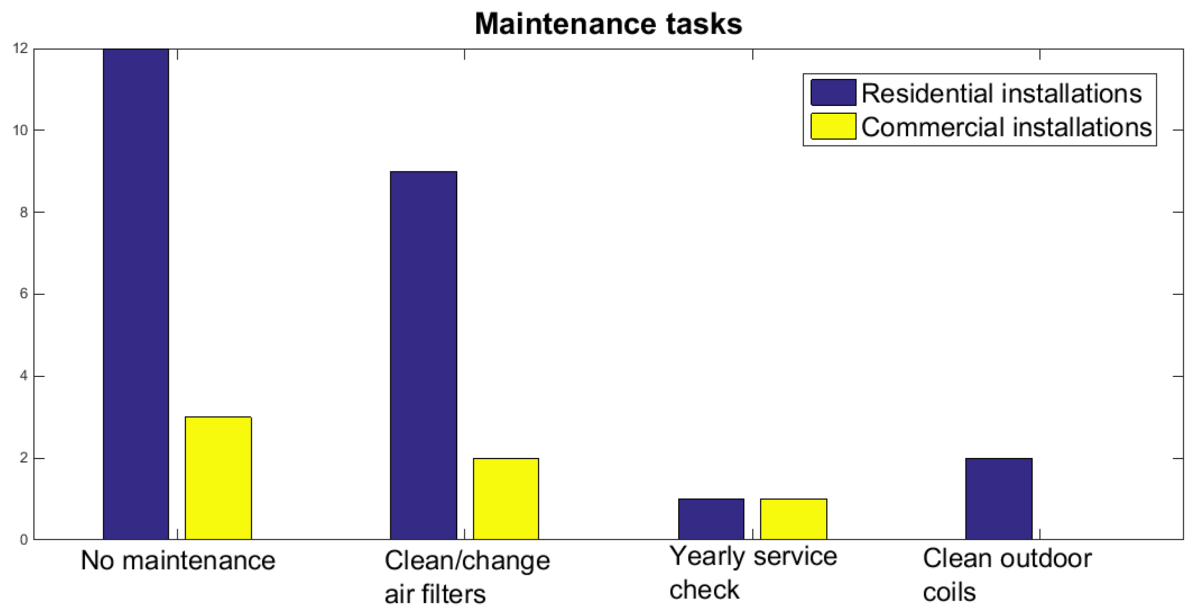


Figure 26: Maintenance tasks for ASHPs.

The range of operating characteristics for commercial systems is narrower. Thermostat set points ranged from 65°F to 70°F. All six systems employ zoning and have programmable thermostats, though only one thermostat is programmed to set back the temperature when the building is unoccupied.

Three businesses reported performing maintenance on their heat pumps:

- One system undergoes a yearly check-up.
- Building occupants change the filters on two of the systems.

There was only one repair needed in the history of the operation of the ASHPs. In North Pole, a climate that experiences cold days below the operating temperature of the heat pump, ice from the heat pump defrost cycles accumulated beneath the heat pump until the point that it caused the heat pump to tilt and break an electric connection that required repair. This occurred during the first winter of operation. Since then, building staff manually turn off the heat pump when the outside temperature falls below the operating temperature, and the outdoor units now sit on platforms to give ice from defrost room to accumulate.

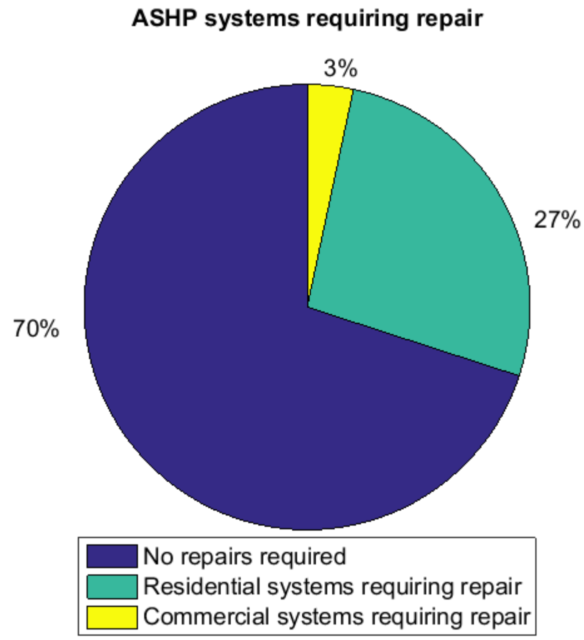


Figure 27: Repairs of ASHPs in the general monitoring.

Costs

The cost of installation of a residential ASHP system varies widely between DHPs and air-to-water heat pump systems that provide centralized heat. Installation cost also depends on several factors such as the size of the system, whether or not it is a retrofit or new building, if someone is doing a self-install, and if the distribution system cost is included. Nineteen homeowners were able to report installation costs. The lowest cost was $3,200 for a DHP consisting of a single outdoor unit paired with a single indoor head. This cost included equipment and labor, but is low because the installer was able to get the ASHP at wholesale cost. Other costs for similar systems were reported at $5,000 or more when installers went through a distributer to buy the equipment. On the other end, the highest reported installation cost was $34,000. This cost encapsulated the entire heating system for an entire house: a multi-zone air-to-water heat pump and associated equipment, piping for the distribution system, and labor to install both the heat pump and the distribution system. Thirteen people reported receiving a rebate for the installation of the ASHP, either for the heat pump itself or for retrofits that included the heat pump. Rebates included a federal tax credit, a local rebate, a rebate from a manufacturer, and rebates from the Alaska Housing Finance Corporation's Home Energy Rebate Program.

Homeowners reported zero costs for repairs of their systems and, for the most part, zero maintenance costs: only two homeowners reported maintenance costs which were the cost of replacing filters, others were able to clean existing filters at no cost.

Commercial system installation costs span an even wider range than the residential costs. The lowest installation cost was in a smaller building and was $3,700 for a DHP with a single outdoor unit and indoor unit. The higher costs ranged from $25,000 to $65,000 and these costs again included portions of the distribution systems. Only one business reported receiving a rebate, which came through the Alaska Energy Authority's program for commercial weatherization. There were no repair costs or maintenance costs reported – the previous section describes one repair that was needed but the building owner did not report the cost.

Participant impressions

Interviewees could choose not to answer questions or could provide multiple answers. Therefore, the results listed here do not reflect the number of participants interviewed exactly.

Participants had first heard of ASHPs from a number of different sources before deciding to install one. Most commonly, 11 people first heard details about ASHPs from contractors and seven people through word of mouth. Less common was learning about them through a conference or home show (four people) or through construction publications such as the Journal of Light Construction or Fine Homebuilding (three people). One participant first learned about them through a supplier.

Each participant also provided his or her likes and dislikes about the ASHP. These are system dependent, so they may contradict one other or pertain to one particular installation. The table below lists the impressions of the homeowners in order of popularity.

Table 12: Interviewees provided the reasons that they chose to install an ASHP.

Participant impressions of advantages of their ASHP system	Number reporting advantage (out of 30)
Quiet operation	14
Low energy costs	13
No reliance on oil (specific reasons included that systems had no soot, no combustion, smaller fuel price fluctuations, and less maintenance)	12
Efficient	11
Clean energy	8
No/little maintenance costs	6
One appliance can provide heating and cooling	5
Participant wanted to use/investigate the latest cold climate technology	5
ASHP provides consistent heat	5
System is compact and takes up little space	3
Controls are programmable	2
Ease of use	2
System has ability to filter air	1
System can circulate air	1

A total of eleven interviewees did not express any dislikes about their ASHP. Below are the disadvantages that were stated by some participants.

Table 13: Interviewees listed characteristics of ASHPs that they did not like.

Participant impressions of disadvantages of their ASHP system	Number reporting disadvantage (out of 30)
Complex control settings on the remote	4
ASHP doesn't work on the coldest days	3
Forced air distribution – the positioning of the vent can cause a person directly in front of it (say if it blows on a chair) to be too hot/cold	3
Noisy	3
Hard for the participant to fix because of the refrigeration system	2
Fan runs for a long time	2
The outdoor unit is not attractive	1
The outdoor unit defrost cycle produces a lot of water	1
Installation cost was very high	1
Operating cost was much higher than expected (energy costs too high)	1
The electronics makes it hard to troubleshoot if there is a problem	1
It takes a long time to recover the setback (when temperature is lowered for a period of time)	1

Interviewees with retrofit systems were asked to compare the system to their previous appliance. Seven systems were retrofits from electric resistance heat, eleven systems were retrofits from oil, and two systems were retrofit into homes that employed both electric resistance and an oil-fired appliance. Four of the buildings also used wood heat to supplement both before and after the retrofit. Participant observations, many similar to responses to the questions above, as well as the number of people who listed them, appear in Tables 14 and 15 below. Please note that interviewees were able to list as many comparisons as they wanted.

Table 14: Comparisons of ASHPs to oil-fired heating devices.

Pros of ASHP versus oil	Cons of ASHP versus oil
The ASHP has resulted in lower bills (7).	The ASHP has more complex settings (2).
The ASHP is quieter (6).	The outside unit gives off condensation (2).
The ASHP provides cleaner energy (4).	
There is no combustion (3).	
The ASHP can provide cooling also (3).	
No need to call and purchase oil for delivery (3).	
The ASHP provides more even heat than the oil-fired system did (3).	
The ASHP is cleaner, produces no soot (3).	
There is less maintenance (2).	
The ASHP is more efficient (2).	
There is no need to store oil on-site (2).	
The ASHP takes up less space (2).	
There is no diesel smell (1).	
The ASHP has more control settings (1).	
The ASHP can change the temperature of a room more quickly (1).	
The ASHP circulates air (1).	

Table 15: Comparisons of ASHPs to electric resistance devices.

Pros of ASHP versus electric resistance heat	Cons of ASHP versus electric resistance heat
The ASHP can provide cooling also (3).	Preferred radiant heat over blowing air (1).
The ASHP requires no maintenance (3).	The remote is more complicated (1).
The ASHP has a programmable thermostat (2).	
The ASHP has a higher efficiency (2).	
The ASHP takes up less space (2).	
The ASHP provides more consistent heat (2).	
The ASHP does not have water leaks (1).	
The ASHP can filter air (1).	

Finally, everyone was asked if they would have done anything differently. There was only one answer that was provided by more than one individual: three people said that if they could do it differently, they would put in different zoning. Other lessons learned included:

- Using a different size (smaller) water tank for DHW on an air-to-water system;
- Installing the outdoor unit allowing water from the defrost to be directed to a drain;
- Using a better control system to interface the ASHP with the other heating system in the building;
- Installing a backup heating system with a smaller capacity;
- Installing a backup heating system with a larger capacity;
- Installing a different size ASHP; and
- Applying for a rebate.

Monitoring period: winter 2014 – 2015

Finally, participants recalled their impressions of the winter of 2014 – 2015 in a final interview in the summer of 2015. No one reported any complaints about their system, and 29 of the 30 systems provided “adequate” or “expected” heat. In some cases, people knew that the ASHP would not be able to provide 100% of their heating load on the coldest days and planned ahead to use their backup heating system. In no case was the backup heating appliance used more than expected.

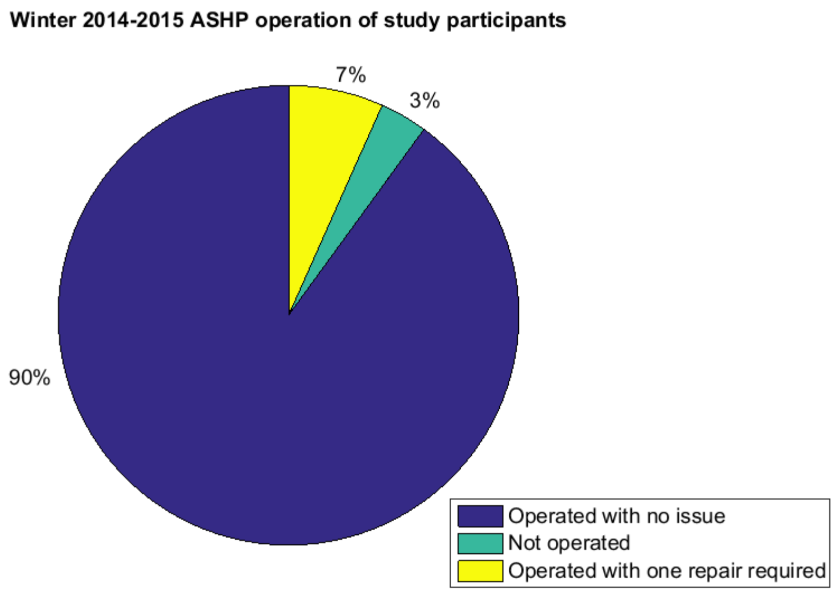


Figure 28: ASHP operation in the winter 2014-2015.

The remaining ASHP was not used during the monitoring period. The building occupants, an HVAC company, typically use the ASHP system during the shoulder seasons only, as winter temperatures are below the operating temperature range of the ASHP. In the fall, when temperatures near the operating limits of the heat pump, the occupants shut off the ASHP system and turn on the backup Toyotomi (Toyo) stoves. In the spring, as temperatures rise, they turn off the Toyo stoves and turn the ASHP back on for use for heating in the spring and cooling during the summer. However, the winter of 2014-2015 saw unusually high shoulder season temperatures and the building’s heat load in the fall was entirely met by waste heat from welding and other equipment in the building’s shop. By the time temperatures outside fell to where the building needed additional heat, it was far enough into winter that the building owners chose to forego the heat pump and use the Toyo stoves. In spring 2015, fast warming temperatures along with the drop in oil prices allowed the building owners to switch from operating the Toyos to using the heat pumps for cooling.

Two ASHPs required repairs during the winter of 2014-2015. One pump stopped working, and was fixed the same day. Another system had to be cleaned because it had rusted, and was fixed within a week. Neither repair had any cost to the homeowner.

Eleven people reported performing maintenance on their system. The majority (8 people) changed or cleaned filters. Remaining maintenance consisted of: hiring a plumber to do a well-check on their system (1); small control adjustments (1); and one person did a routine check-up of his system on his own.

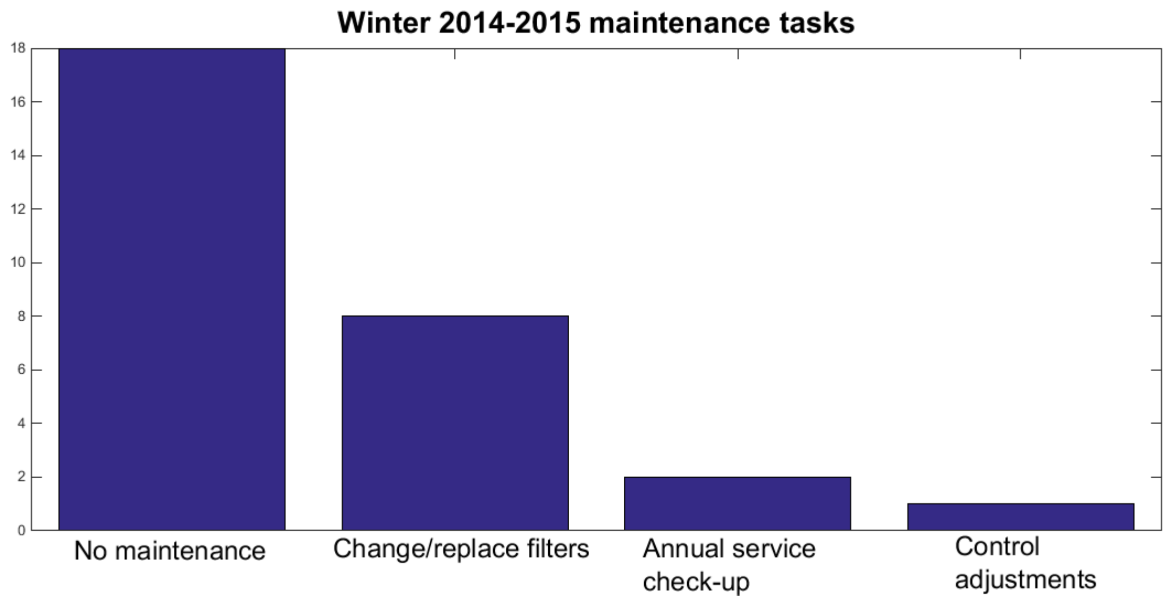


Figure 29: Maintenance tasks for the winter of 2014-2015.

Twelve people employed the use of their backup system over the course of the monitoring period. Two homes used a wood stove or fireplace occasionally for ambiance only. The remaining ten, or one third of participants, used the backup system to meet their heating load:

- Five people used wood stoves. Three of these people reported using the stove less than 10 times. One person used it each time the temperature fell below 20°F. The final person used ¾ cord of wood during the winter, compared to 4 cords of wood before installing the ASHP to replace an electric resistance heating system.
- One person used a Toyo stove roughly once a month to boost the heat when it was cold.
- One commercial building employed the electric resistance backup heat in the ASHP.
- One person turned on electric resistance heat for December, January, and February.
- Two homes employed their backup systems when temperatures fell below the operating limits of their ASHPs. One of these homes uses electric resistance backup heat, and the other employs an oil-fired boiler and a wood stove.

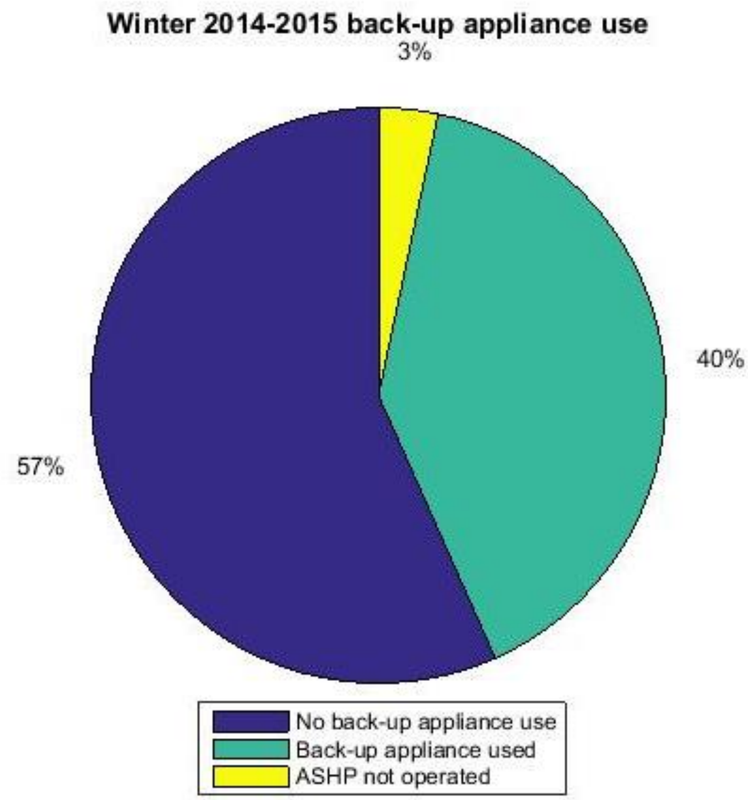


Figure 30: Backup appliance use in the winter of 2014 – 2015.

Indirect electric monitoring

Indirect electric monitoring was used to provide a rough comparison between electric use of buildings before and after being retrofit with an ASHP. A total of 20 of the 30 systems monitored were retrofit appliances. Seven systems were retrofits from electric resistance heat, eleven systems were retrofits from oil, and two systems were retrofit into homes that employed both electric resistance and oil-fired appliances. Four of the buildings also used wood heat to supplement both before and after the retrofit. In two of the buildings, the retrofit ASHP is a displacement system, so it did not replace the entire heating system, but rather displaced only a portion of the heating load.

Researchers were able to indirectly monitor 11 of the retrofit systems. In remaining cases, either electric bills could not be collected, or the homeowner was unable to provide sufficient information on the installation date. Neither of the displacement ASHPs was included in the indirect monitoring.

For each of the 11 retrofits, monthly electric usage from electric bills was plotted against HDD and fit with a linear regression. Also, electrical use for the entire pre-ASHP and post-ASHP periods was summed and compared to pre-ASHP and post-ASHP HDD. Example graphs are shown below, for a home in Juneau that was retrofit with an ASHP from electric baseboards. The graphs for each of the buildings, as well as details on the retrofit, appear in Appendix C.

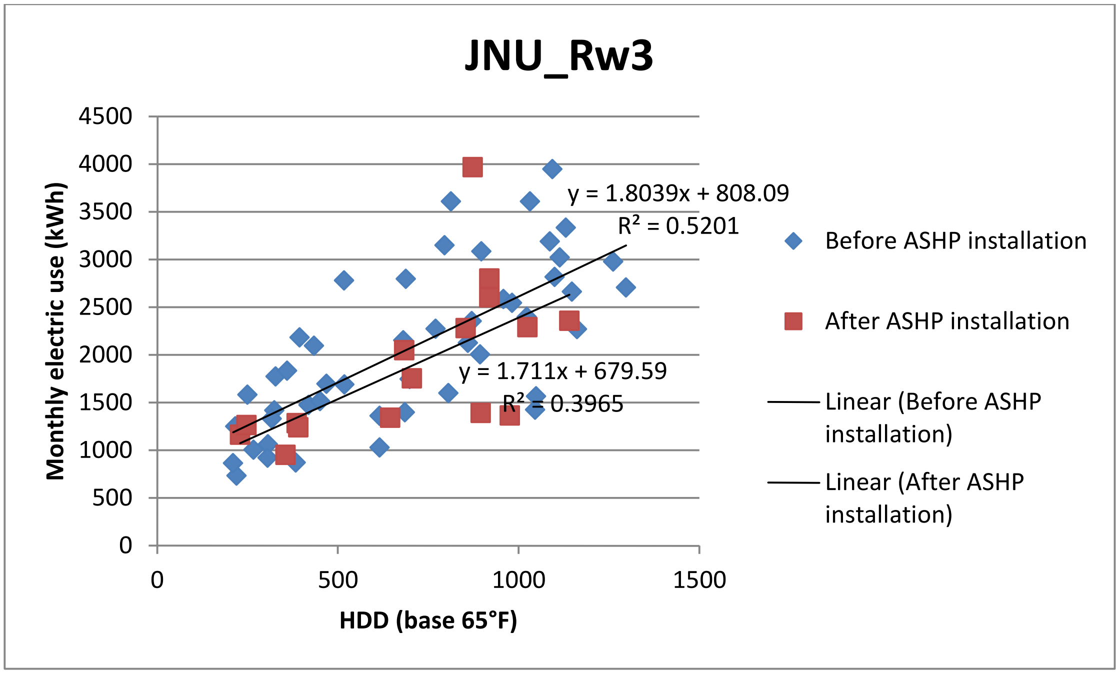


Figure 31: Sample graph of a building's monthly electric use versus HDD.

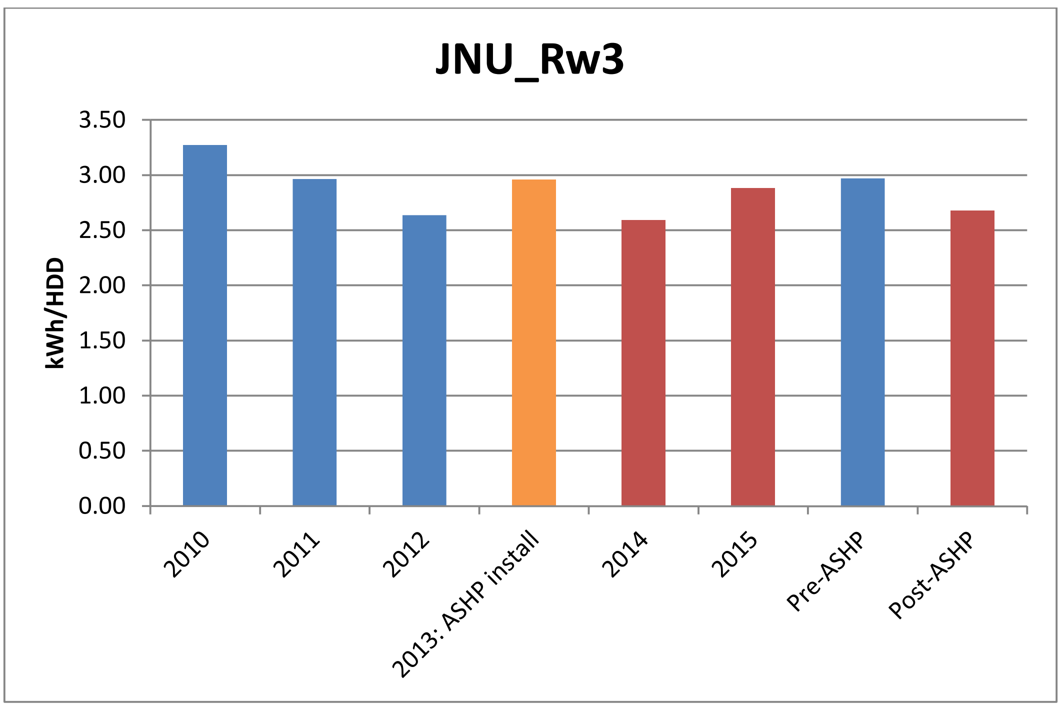


Figure 32: Sample graph of a building's ratio of electrical use to HDD for pre-ASHP and post-ASHP periods.

Table 16 lists the results from all the graphs, with each ASHP identified by a code used instead of the ASHP owner's name. An increase in the ratio of electric use to HDD indicates a stronger dependence between electric use and HDD – and is expected for a building converting from oil to an ASHP, which requires electricity. On the other hand, a decrease in the ratio indicates that electric use is less dependent on weather – expected for homes converting from electric resistance heat to ASHPs. The same is expected for the slope of the linear regression.

Table 16: Comparisons of electrical energy to HDD ratios before and after an ASHP retrofit.

Building	Pre-retrofit appliance + backup appliances	Change in pre and post electric use to HDD ratio	Change in pre and post linear regression slope	Results
JNU_Rw3	Electric baseboard Backup: Wood-fired appliance	Decrease	Decrease	Expected
SIT_Rd1	Electric unit heaters Backup: Wood-fired appliance	Increase	Decrease1	Conflict
SIT_Rd2	Electric baseboard Backup: Electric baseboard remains as backup	Decrease	Decrease	Expected
WRG_Rd1	Electric boiler Backup: Electric boiler remains as backup	Decrease	Decrease	Expected
WRG_Rd3	Electric heaters Backup: Wood-fired appliance	Decrease	Increase	Conflict
WRG_Cd	Electric baseboard Backup: Electric baseboard remains as backup	Decrease	Decrease	Expected
JNU_Rw5	Oil-fired boiler Backup: Wood-fired appliance	Increase	Increase	Expected
JNU_Rw6	Oil and electric furnace Backup: Furnace remains in home as backup appliance	Increase	Increase	Expected Homeowner reports mostly using oil pre-ASHP
JNU_Rd3	Oil furnace Backup: Furnace remains as backup	Increase	Increase	Expected
SIT_Rd3	Toyo stove and electric resistance Backup: Toyo and electric resistance remain as backup appliances	Increase	Decrease	Conflict Homeowner reports mostly using oil pre-ASHP
WRG_Rd4	Oil-fired furnace Backup: Electric resistance heaters	Decrease	Decrease	Not expected

This data demonstrates two points: first, retrofit billing analysis should involve more homes than were studied in this project to identify a trend; second, the installation of an ASHP does not guarantee the expected increase or decrease in electric usage. On the first point, a larger sample size would allow for data screening and more opportunity for a trend to emerge. In a heat pump study in the Northwest United States, a billing analysis of thousands of homes retrofit with ASHPs screened for homes that could meet a certain R^2 value (Baylon, Storm, & Robison, 2013), an approach that was not practical with this small sample size. The R^2 value is a coefficient of determination for linear regressions that indicates the strength of the dependence between the variables. Low R^2 values indicate that there is low strength of the dependence between HDD and electric use and in a larger study these homes could be screened out. The criteria used for the screening in Baylon, et. al. (2013) was $R^2 > 0.65$, criteria which was met for both pre- and post-ASHP linear regressions by only four of the eleven buildings in this study (SIT_Rd1, WRG_Rd1, WRG_Rd4, and WRG_Cd). Of these four, only two showed the expected result.

Second, there are many reasons that a building may not follow the expected trend, some of which are common in Alaska. For instance, backup appliances are prevalent, and many are wood-fired appliances which show no dependence on electricity. Wood-fired appliances are difficult to monitor because they do not operate on a thermostat so building owners instead choose when to use them based on temperature, convenience, and occupancy. The Home Energy Retrofit Program and Weatherization Program in Alaska have also allowed homeowners to make other energy efficiency changes to their buildings, which will cause a change in electric use that is independent of a change in the heating appliance.

Direct electric monitoring

Direct electric monitoring occurred in two cities, Wrangell and Juneau. Monitors placed on heat pumps recorded monthly electric use as well as peak usage. Researchers used this data to confirm commonly held notions about ASHPs installed in Alaska.

First, monthly electric energy was plotted versus HDD. Electric energy usage should increase with an increase in HDD because more heat is needed, and because ASHPs operate at lower efficiencies when the outside temperature is lower. As shown in Figure 33, this general trend was confirmed.

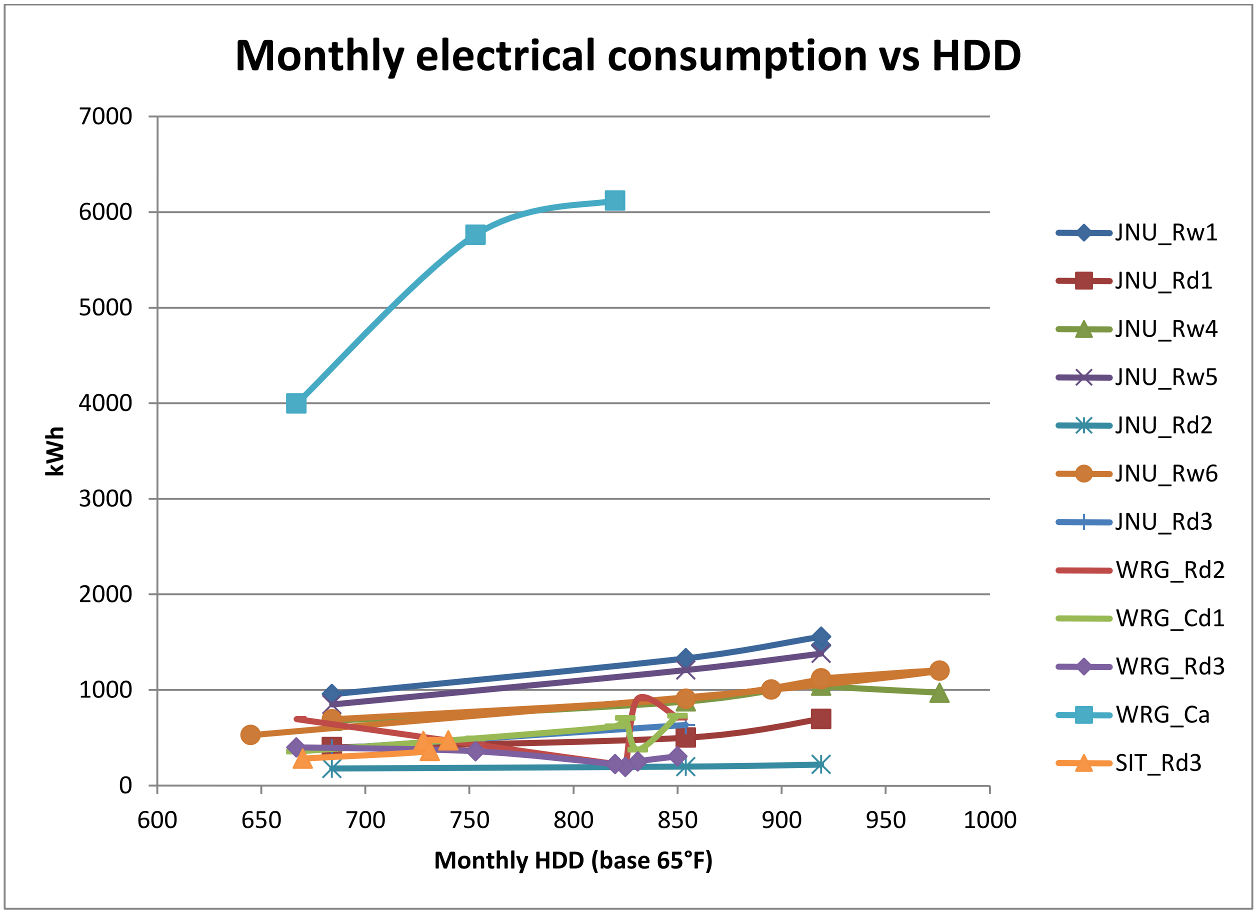


Figure 33: Monthly electrical consumption versus HDD

Figure 34 shows the linear trend lines for monthly load factors versus HDD for monitored ASHPs in Southeast Alaska. As seen in the Figure, the monthly load factors for the ASHPs show a general trend of increasing with increasing HDD. This is expected because monthly load factors increase with increasing energy usage. Load factors decrease with a higher peak usage, but peak usage is not necessarily dependent on cold temperatures, as shown in Figure 35. There are three heat pumps in this study that did not show a positive dependence between HDD and monthly load factor, and their trend lines are labeled in Figure 34. Two of these homes used their backup wood stove during the coldest months of monitoring period, which may be the reason that the ASHP load factor did not increase with lower temperatures. In the final home, the ASHP only provides a portion of the space heating, with the remainder provided by a pellet stove and electric baseboard. On the other hand, of the homes that showed that the ASHP monthly load factor had a positive dependence on HDD, no ASHPs were displacement systems and only three reported backup appliance use during the monitoring period and all said it was minimal. Two of the backup appliances were not electric: a propane fireplace and wood stove. The last one has backup electric resistance heat incorporated into the ASHP.

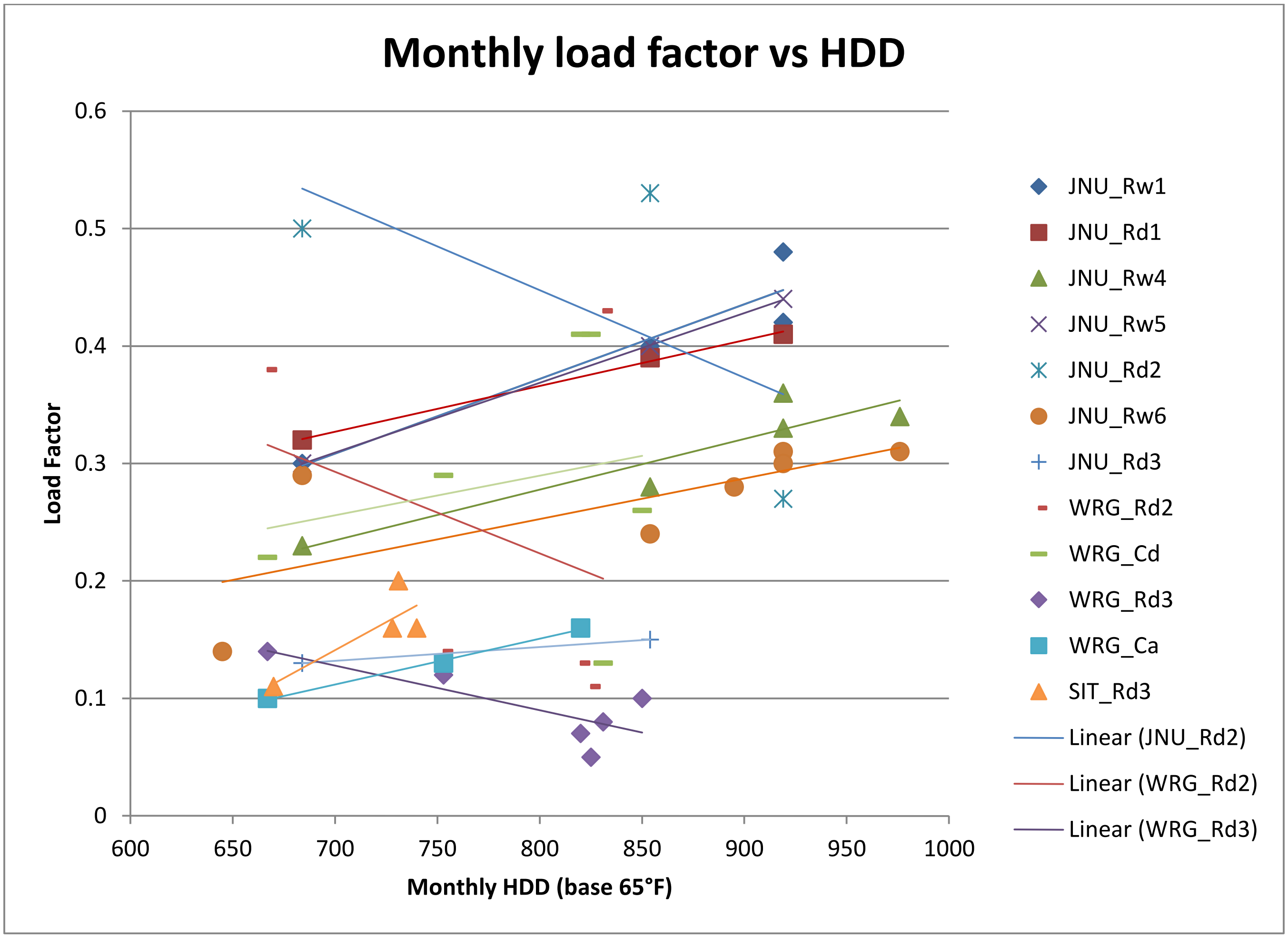


Figure 34: Monthly load factor versus HDD.

Monthly peak electric usage did not always occur on the day of the month that experienced the minimum temperature, as shown in Figure 35. This graph shows the dates of peak usage from ASHPs with turtle meters in Juneau, along with minimum temperatures for each month. Researchers did not include Wrangell and Sitka homes in this part of the analysis because the meters recording their peak usage only recorded the data of the last peak draw each month. In Juneau, the meters were capable of recording each instance.

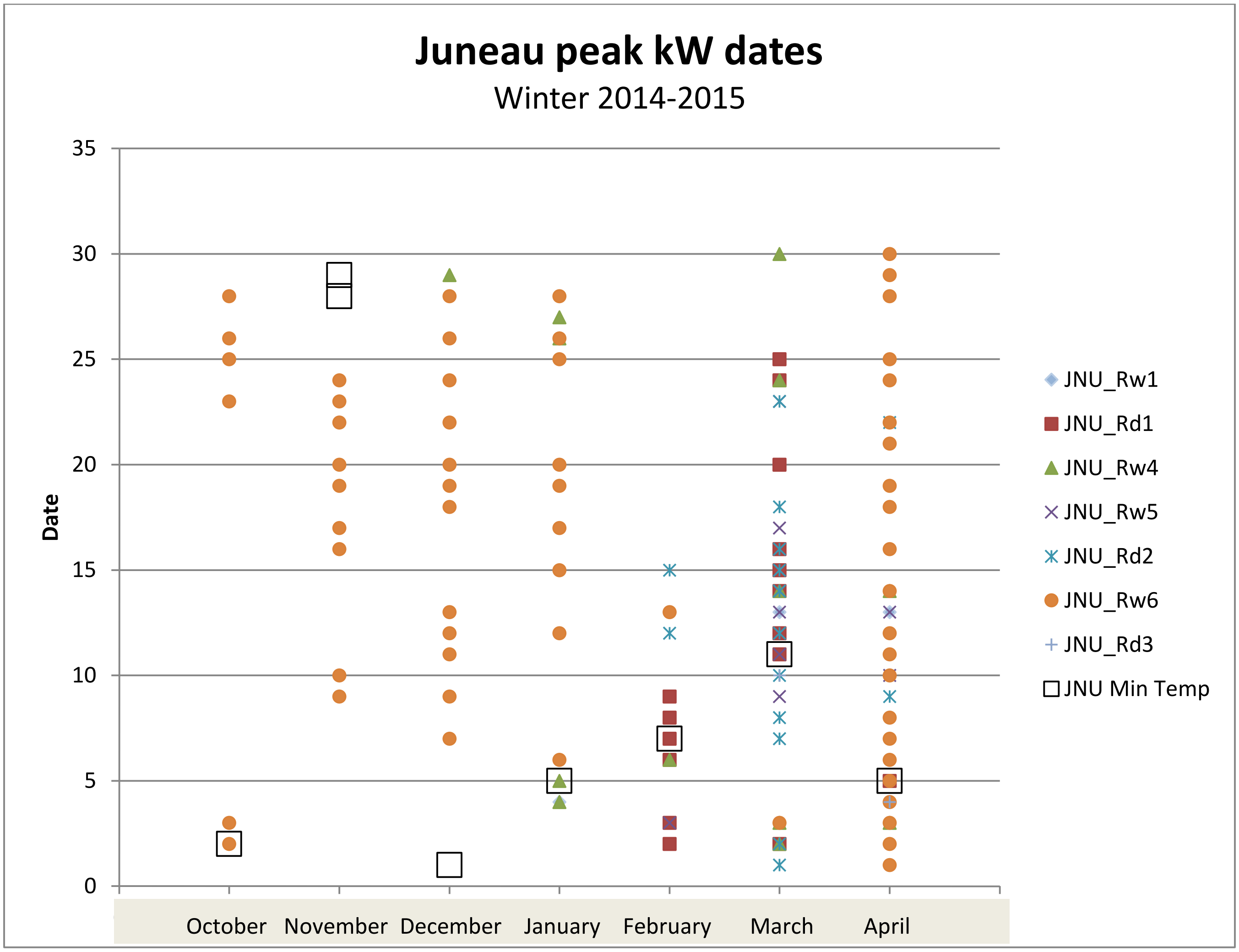


Figure 35: Dates of peak electric power draw from each heat pump.

There is some overlap of the peak power draw occurring on the coldest day of the month in Juneau, as shown in Figure 35, but this does not occur every month, or from each heat pump. For instance, one of the dates of peak power draw from ASHP JNU_RW6 occurred on the coldest day in October, but this did not occur in either November or December. Beginning in January, more turtle meters were installed on heat pumps. With the larger number of monitored heat pumps, there were heat pumps that drew their peak power on the coldest day of the month each month in the spring of 2015, but other peak power days occurred on days with warmer temperatures. Peak power usage of the ASHP can occur for reasons other than cold temperature, such as during ASHP start-up or during a defrost cycle. For example, Figure 18 shows an example of a high peak power draw right after a defrost cycle, despite a relatively low average load.

Discussion

General monitoring consisted of interviews with building owners that use ASHPs, the indirect monitoring of building electric usage through electric bills, and direct electric monitoring of ASHPs using turtle and efergy meters. Researchers used this data to create a broad picture of installed ASHPs in Alaska, especially in regard to three areas: consumer satisfaction, the need for a backup heating appliance, and the effect of retrofitting a home with an ASHP. Originally, the study was focused on ASHPs only in Wrangell; however, researchers were able to monitor additional retrofit installations in Juneau and Sitka.

Owner satisfaction

In general, ASHP owners using the appliances for heating are satisfied with them. During the winter of 2014-2015, 29 of the 30 systems provided “adequate” or “expected” heat. The final system was not operated. Two systems required repair during the monitoring period, and both were fixed at no cost to the building owner.

Participants in this study listed advantages and disadvantages of their systems. Top advantages included that the appliances operated quietly, that they reduced energy costs, that they were efficient, and that they provided “clean” energy. The extent of the last advantage is of course dependent on the source of electricity, but by and large, participants in this study were located in communities with hydropower. Another advantage reported by over one third of the participants was that an ASHP does not use fuel oil – more specifically, the appliances don’t produce soot, there are fewer fluctuations in fuel price, there is no combustion, and they require less maintenance. Interviewees also noted that ASHPs can provide both heating and cooling and require little or no maintenance.

Over one third of participants in this project did not list a disadvantage to their ASHP. The top complaint, noted by four interviewees, was that the remote used to control the system was overly complicated. The next most common complaints, listed by three people each, were that the ASHP did not work on the coldest days, that the forced air distribution could cause occupants to be uncomfortably hot or cold, and that the appliances were noisy.

People also had suggestions for how they would do things differently if they were to install another ASHP. Three of the thirty people suggested changing their zoning, and remaining changes included sizing the heat pump or backup system differently, using a different control scheme to interface between the ASHP and other heating appliances in the building, and installing the outdoor unit so the defrost moisture could be directed to a drain.

Other research projects have found high user satisfaction with ASHPs. In the Northwest United States, a research project sponsored by the Northwest Energy Efficiency Alliance (NEEA) conducted over 200 interviews of different market participants in a program that monitored DHPs to displace a portion of a home’s electric resistance heat. They found a high level of satisfaction among homeowners, with 96% stating benefits including comfort, ease of control, and air filtration (Ecotope, Inc., 2014). Similarly, in a study in the Northeast, 38 out of 40 participants rated their satisfaction with their DHP as 4 or 5 out of 5. Focus groups listed the main advantage of ASHPs as being the energy savings over electric resistance heat. Disadvantages included the high price of installation, confusing remotes, difficulties with temperature control, and the need for more training on how to use the heat pump (KEMA, Inc., 2009).

Backup appliances

Twenty-nine of the thirty buildings in the study had a backup heating strategy or appliance. These appliances included both older appliances left in the homes after retrofits, secondary appliances installed in homes, and electric resistance heat incorporated into the ASHP itself. The most common appliance was a wood stove, in eight homes, followed by electric resistance heat provided either by baseboards or portable electric heaters.

Only twelve of these study participants reported using their backup appliance during the winter of 2014 to 2015. Two of these used a wood-burning appliance for ambience; the remaining ten employed the backup heat to meet their heating load. Of those who did not use a backup appliance, many noted that the winter had been "warm." In fact, minimum temperatures for the winter in Southeast Alaskan locations did not dip below 0°F during the study period.

Table 17: Minimum temperatures for study locations during the winter of 2014-2015 (The Weather Channel, 2015).

Location	Minimum temperature during winter 2014-2015 (°F)
Juneau	6
Ketchikan/Saxman	19
Kodiak	13
North Pole	-47
Petersburg	14
Sitka	19
Whitehorse	-33
Wrangell	14

The system in North Pole did not operate last winter, and the two homeowners in Whitehorse used their backup systems when temperatures dropped below the operating range of their ASHPs. In other locations, the ASHPs did not turn off, and backup appliances were used to supplement heat from the ASHP.

In spite of the lower-than-expected use of backup systems during the monitoring period, authors still recommend that ASHPs be paired with a backup appliance in Alaska. Temperatures colder than those experienced during the winter of 2014-2015 can occur and being left with no functioning heating appliance has strong consequences for buildings and occupants at low temperatures. Furthermore, the main component of the heat pump, the compressor, is located outside. If the ASHP does require repair during the winter, it may be delayed due to inclement weather, and the backup appliance would be able to keep the building from freezing in the meantime.

Other studies in milder climates have also indicated a need for backup heat, although through interviews on occupant comfort, rather than by examining heat pump operating limits. A research project in the Pacific Northwest interviewed homeowners that had displaced some of their electric resistance heat with a DHP. While 96% of homeowners said the DHP was used on the coldest days of the year, only 77% felt that it was successful in maintaining a comfortable temperature on that day (Ecotope, Inc., 2014).

Retrofit ASHPs

Twenty of the thirty ASHPs in the general monitoring group were retrofit systems. Previous systems were both electric resistance and oil-fired and included both space heating appliances and whole-house systems. By and large, homeowners were satisfied with their change in appliance, and had very few complaints about the ASHP system. Some disadvantages people listed included that the ASHP had a more complicated control system and that the outdoor unit gave off condensation. On the other hand, participants listed numerous advantages to ASHPs, including lower utility bills, better efficiency, cleaner energy, and the ability to provide both heating and cooling. Those converting from oil-fired appliances also noted that they no longer had to purchase and store oil, and that ASHPs did not require combustion or produce soot.

The data from this study indicate that a larger sample size and more rigorous data collection of retrofits are necessary for more accurate conclusions about the effect of retrofits on total electric use in Alaska. Common assumptions about ASHP retrofits and electric use were not confirmed with this study. It is expected that a conversion from electric resistance heat to an ASHP would decrease overall electric use, and that a conversion from an oil-fired appliance to an ASHP would increase electric use. However, this study failed to confirm these expectations with the small sample of eleven retrofits that were studied. These assumptions have been confirmed by other studies in milder climates, though. A suite of research projects on using DHPs to displace electric resistance heat in Washington and Oregon found the heat pumps resulted in annual savings. These studies, conducted by Ecotope, Inc., used electric bill analysis in addition to a quad-metering strategy that measured the electric use of the heat pump, backup electric resistance heat, DHW appliance, and the whole house. The first study was a pilot project to establish the methodology (Geraghty, Baylon, & Davis, 2009). It was followed by two more studies that continued monitoring the original homes, and both studies found that electric savings persisted year to year (Ecotope, Inc., 2010), (Baylon, Larson, Storm, & Geraghty, 2012). More follow-up projects extended the metering to a larger number of homes throughout the Northwest, again finding a decrease in electric use for space heating when switching from electric resistance heat to a heat pump (Ecotope, Inc., 2014). Another study of DHPs in the northeast United States found savings when electric resistance heat was replaced with a heat pump (KEMA, Inc., 2009). For heat pumps that are displacing oil-fired appliances, a separate study in the Northeast United Sates identified an increase in electric energy demand (Steven Winter Associates, Inc., 2014).

On the other hand, directly monitoring the ASHPs themselves confirmed that their monthly electric use does increase with HDD. Monthly load factors generally increase with HDD as well, but this is building dependent because of the reliance of load factors on peak electric power, which do not necessarily occur on the coldest day. Both of these observations are important for building owners to consider when installing an ASHP, especially if they receive electricity from a utility with rates that vary seasonally and/or a utility that offers a demand rate. AEL&P in Juneau uses both of these rate structures to manage its hydropower resources, which in a typical year feature high reservoir levels during the summer rainy months, and low reservoir levels in the winter (Mesdag, 2014). In Juneau, rates are higher in the winter, when ASHPs are operating the most frequently, meaning they will cost more than an appliance that is used year-round. AEL&P also offers consumers a demand rate. If consumers record a peak demand of more than 20 kW in three or more consecutive months, they can switch to a demand rate schedule indefinitely (Mesdag, 2014). Demand rate schedules have the potential to offer customers a lower overall electric bill if they have a high load factor, which compares average power use to peak power use. Low load factors (<25%) use a small amount of average power relative to the peak and will result in higher bills on a demand rate schedule compared to a general rate schedule. In this study, only one ASHP recorded a peak power draw of more than 20kW, and it was an appliance in a commercial building in Wrangell.

ASHPs as an energy conservation measure in Wrangell, AK

Wrangell, AK is a small town located on the Zimovia Strait in Southeast Alaska. Electric power is provided to the community by Wrangell ML&P, which purchases the majority of its power from the Tyee Hydroelectric facility. Wrangell ML&P also has one diesel powered generator with a capacity of 5 megawatts (MW) that is used for supplemental power during peak loads and during down times for the maintenance of the hydropower plant (City and Borough of Wrangell, 2015). In 2006, Wrangell ML&P started a "heat rate" program that gives customers a reduced electricity cost of 8 cents/kWh instead of 12 cents/kWh if they install a second electric meter for electric heating. The heat rate program is ongoing as of late 2015 and includes residential, commercial, and city utility customers. The program and relatively high heating oil prices contributed to a 64% increase in annual electricity consumption and a corresponding peak load rise from 3.5 MW in 2006 to approximately 9 MW in 2012 (C. Hammer, personal communication, January 16, 2013). To illustrate trends of electricity demand over the past several years, the annual electricity sales from Wrangell ML&P are shown in Figure 36. The largest peak demands occur in winter, as shown by the monthly peak loads from 2012 to 2015 in Figure 37. Further increases in demand will result in large infrastructure investments because Wrangell ML&P will need to expand its diesel backup generation system. Thus, Wrangell ML&P is considering ways to manage demand to determine if it is possible to avoid the cost of additional generation equipment. One such demand management measure includes incentivizing ASHPs to displace electric resistance heat, which has the potential to reduce peak load and seasonal electricity demand.

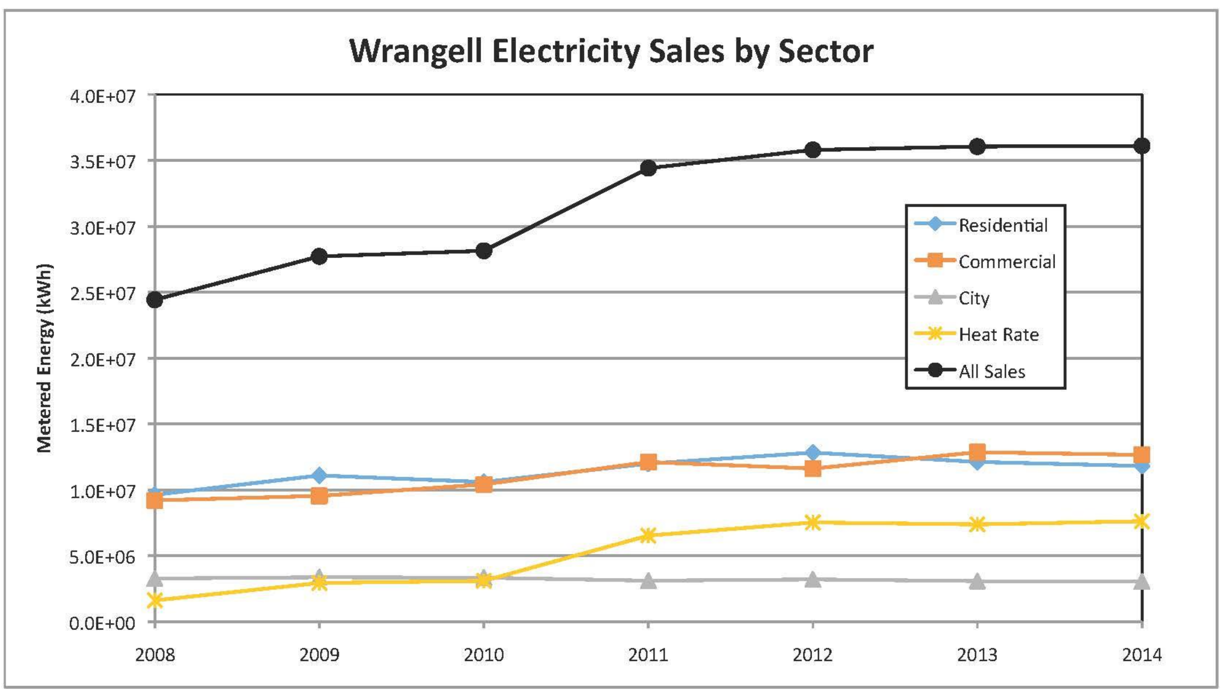


Figure 36: Annual electricity sales, total and by sector, for Wrangell ML&P (The City and Borough of Wrangell, 2015b).

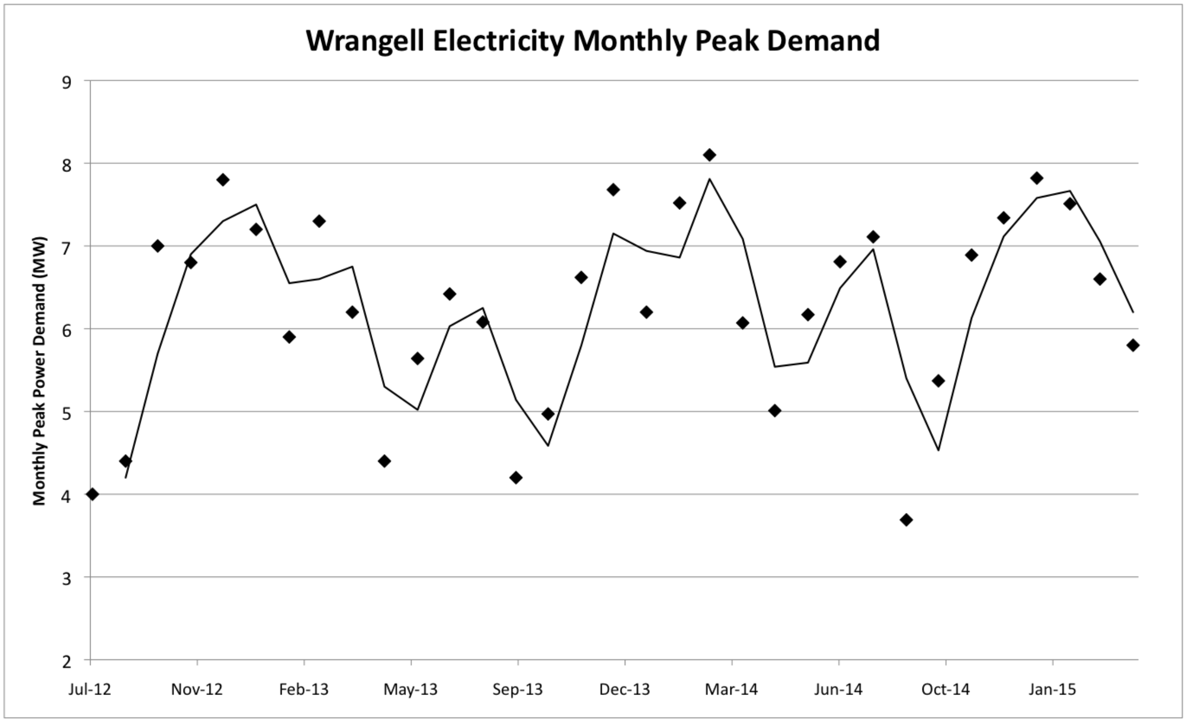


Figure 37: Monthly peak electricity demand for Wrangell ML&P (The City and Borough of Wrangell, 2015c).

Objectives

The goal of this portion of the project is to help Wrangell ML&P determine whether it can avoid the purchase of additional diesel-powered backup equipment through the development of a heat pump deployment plan. A program to replace electric resistance heat with ASHPs would need to offset 2 MW of winter-time electrical demand in order for Wrangell ML&P to avoid purchasing additional diesel generation equipment. To address this goal, this portion of the project aimed to answer the following questions:

1. For the monitored locations in Wrangell, what is the effect of replacing electric resistance heating with an ASHP on peak power demand and total winter electrical energy demand?
2. What is the theoretical potential of ASHPs to reduce power and energy demand by displacing electric resistance heat, assuming 100% adoption of the technology in Wrangell?
3. What percentage of Wrangell ML&P customers would need to switch from electric resistance heat to an ASHP to reduce power demand in Wrangell by 2 MW?

Background literature

The literature reviewed pertains specifically to the effects of ASHPs on electricity use for spacing heating in buildings, typically as part of utility sponsored programs intended to offset electric resistance heat. The type of ASHPs in the studies discovered for this review were exclusively DHPs deployed in residential buildings. The studies report savings attributable to DHP use in a wide variety of formats, such as electrical energy or cost savings. The formats reported in the original studies were retained in the summary below, unless noted otherwise.

Currently, the largest study of DHP performance in the U.S. was conducted by the Northwest Energy Efficiency Alliance for installations in the Pacific Northwest (Ecotope, Inc., 2014). Ecotope, Inc. evaluated the Northwest Ductless Heat Pump Pilot Project that ran from 2008 to 2009 and included 3,899 participants. The Pilot Project focused on displacement of existing heating methods; for example, a home heated with an electric resistance baseboard system retrofitted to include a DHP would use both heating methods, with the goal of the DHP displacing much of the electric resistance heating. They found that DHPs have strong customer acceptance, fit well into existing supply chains, and are able to meet space conditioning needs.

The Northwest Energy Efficiency Alliance documented an average annual energy savings of 1,892 kWh per home for the Pilot Project as determined by a billing analysis. When removing Pilot Project participants with supplemental heating that consisted of primarily wood heat from the analysis, the energy savings increased to 2,718 kWh per year, demonstrating that the presence of non-electric supplemental heating is significant and can reduce electric energy savings by 30% or more. They analyzed the billing sample population for the influence of "takeback effects" which were described as offset supplemental heat use, occupants selecting higher thermostat set points, and increased occupancy. In aggregate, these effects reduced average energy savings by 1,014 kWh per year to provide benefits for occupants other than energy savings. To better determine the energy savings possible by DHP displacement of electric resistance heat with minimal impacts from supplemental heating, a sample subpopulation was monitored directly and found to have an average energy savings of 3,887 kWh per year. This figure is estimated to be 3,049 kWh per year after accounting for the aforementioned takeback effects. The authors state that these direct monitoring results compare well to the results from the billing analysis once the takeback effects have been considered. The energy impacts of the DHPs being used to provide more cooling in the summer was evaluated separately, and did not impact the energy savings for heating stated above (Ecotope, Inc., 2014).

The neighboring Southeast Alaska community of Sitka recently implemented a combined approach of new hydroelectric power generation and electrical energy conservation measures to address imbalances in power demand and supply. The energy conservation measures included an Energy Star appliance rebate program for appliances and heaters. Agne (2013) provides a summary of this program and the resulting energy savings. The rebate program used approximately $100,000 to subsidize the replacement of 75 refrigerators, 58 washing machines, 40 heat pumps, 18 freezers, and 3 heat pump water heaters from February 2012 until program funding was exhausted in January 2013. Agne (2013) states that the replacement of these appliances, excluding heat pumps, provided 30,000 kWh in annual energy savings. The electrical energy savings attributable to heat pumps purchased as a result of the rebate program are difficult to estimate due to contradictions and errors within the reported findings. Agne (2013) reports that heat pumps in aggregate saved 4,750 kWh per year by displacing electric resistance heating. However, based on the stated inputs and an assumption of seasonal heat pump efficiency of 2.8 (per the discussion in the *Detailed monitoring* report section), the savings attributable to heat pumps are probably closer to 65,000 kWh annually, or an average of 1,387 kWh per DHP system. Based on the assumptions for power demand reduction stated in KEMA, Inc. (2009), the subsidized heat pump replacements would provide an aggregate demand reduction of approximately 9 kW if all the heat pumps displaced only electric resistance heat. These energy and power reductions are first-order approximations that are likely to be overestimates considering the aforementioned takeback effects explained in Ecotope, Inc. (2014).

Efficiency Maine (2013) reports on the heat pump pilot project of Bangor Hydro Electric Company and Maine Public Service Company. The utilities provided a $600 rebate for DHPs that were estimated to cost $3,500 for a single-zone system (i.e. one inside unit) and $4,500 for a two-zone system. Similar to other regional DHP incentive programs, it is assumed that the DHPs will serve to displace demand from the existing heating system, which was the case for all the pilot project installations. Efficiency Maine (2013) states that the average home space heating energy cost can be reduced from $3,321 to $1,416 annually by assuming a reduction in heating oil use from 900 gallons per year to 117 gallons plus the electricity necessary to run the DHP. The Maine heat pump installations in low-income homes focused on multi-family housing with electric heat. Through this program, 301 DHP systems were installed. Based on a preliminary assessment, the installations saved 23% in electrical energy use on average, or approximately $345 per year. The report does not make clear why the savings were substantially less than projected for the utility rebated DHP installations (Efficiency Maine, 2013).

A consortium of utilities that provide electrical service in Massachusetts and Connecticut conducted a pilot project implementing DHPs to displace electric resistance heating (KEMA, Inc., 2009). All DHPs deployed as part of this project were Mitsubishi Mr. Slim units, but the system heat output sizing varied by state. The Connecticut installations were all sized at a 24,000 BTU per hour nominal capacity whether or not that met all building heating and cooling needs, whereas the Massachusetts installations were multiple unit systems sized to handle entire heating and cooling needs specific to the building. The investigators used multiple methods to estimate annual heating savings and report their results in terms of energy and power demand reduced per unit of nominal DHP heating capacity (e.g. kWh electrical energy saved per MBTU of DHP heating capacity). The results ranged from 90 to 100 kWh per MBTU of DHP heating capacity for five locations within Massachusetts and Connecticut. For example, installations with a 24,000 BTU per hour capacity would have an annual electrical savings of 2,160 to 2,400 kWh. When the sample population was reduced to exclude homes with non-electric supplemental heat, the annual heating savings increased to 130 to 140 kWh per MBTU of DHP capacity. The reduction in electrical heating savings attributable to supplemental heating sources is roughly similar in magnitude to that found by the aforementioned Northwest Energy Efficiency Alliance pilot project in Ecotope Inc. (2014).

The KEMA, Inc. (2009) report estimated the peak power demand reduction attributable to DHPs displacing electric resistance heat for the five Massachusetts and Connecticut study locations by two metrics. Winter on-peak demand was defined as non-holiday weekdays in December and January between 5-7p.m., for which demand reductions were estimated to range between 21 to 24 W per MBTU of DHP capacity. These demand reduction figures increased to 31 to 35 W per MBTU of DHP capacity when only considering homes without non-electric supplemental heat, such as a wood stoves. The winter seasonal peak demand was defined when the system load meets or exceeds 90% of the predicted seasonal peak; the demand reduction for this seasonal peak ranged from 12 to 20 W per MBTU of capacity. These demand reduction figures increase to 19 to 32 W per MBTU of DHP capacity when only considering homes without non-electric supplemental heat. The authors state they expected the seasonal peak demand reduction to be less significant because the seasonal peak loads were during the coldest temperatures, when the DHPs have less heat output capacity and lower efficiency.

The report doesn’t provide figures for cost savings, but interviewed contractors and participants in the DHP pilot project to determine their satisfaction with cost savings. Several claimed that the expected energy savings from the DHP retrofits had not been realized. Only 5 of 32 participants stated that their electricity bills decreased significantly, and 16 of the 32 said that their bills decreased somewhat. The investigators also convened focus groups of customers with DHPs to gather feedback. The participants had difficulty gauging the effect that DHPs had on their electric use, and only a few had compared their bills to determine whether they had decreased after the DHP was installed. Some participants even felt that the DHPs had no real impact on their electricity bills or even caused an increase in costs. While these reactions illustrate how people feel about DHPs in terms of energy savings, they don't provide much insight into the energy savings from DHPs in the sample population (KEMA, Inc., 2009).

A recent report prepared for the Northeast Energy Efficiency Partnership (Steven Winter Associates, Inc., 2014) summarizes electric resistance heat displacement results from prior DHP field studies. The average electrical energy use reduction is similar in magnitude across the studies, ranging from 2,700 kWh per year in Connecticut to 3,200 kWh per year in colder climate regions of the Northwestern states. All studies referenced show a broad range of variation around these averages, including some installations where electric energy use increased. They estimate for their region of interest that a hypothetical annual energy savings of 3,000 kWh will translate to a $459 operating cost savings for the customer. In assessing the on-peak power demand savings, they reference the KEMA, Inc. (2009) study to substantiate their Figure of 24 W per MBTU/hr of heat pump capacity and use a similar methodology to estimate the increase in electric power demand from a DHP displacing oil heating as 16 W per MBTU/hour of heat pump capacity.

Applying findings to Wrangell

To meet the 2 MW peak power demand reduction goal in Wrangell based on the literature findings, an estimated range of 62,500 to 166,667 MBTU/hour in DHP heating capacity must displace electric resistance heat. If the DHPs deployed in Wrangell are substantially similar to the DHP systems installed in Sitka during the Energy Star rebate program described in Agne (2013), this translates to 4,019 to 10,717 DHP systems with an average heating capacity of 15.6 MBTU/hour. These estimates are based on a power demand reduction for DHPs displacing electric resistance heat of 12 to 32 W for every MBTU of heat pump capacity (KEMA, Inc., 2009). The range of demand reduction estimates is broad since there are significant factors that vary amongst homes, such as the presence of non-electric supplemental heat, which has been shown to significantly reduce energy savings from DHP retrofits (KEMA, Inc., 2009; Ecotope, Inc., 2014). However, DHP retrofits can also lead to power demand increases, such as when heat pumps displace oil heat. Steven Winter Associates, Inc. (2014) estimates that that such retrofits increase power demand by 16 W per MBTU of DHP capacity. These assumptions are used to help answer questions from objectives #2 and #3 because the monitored systems for this project did not allow for Wrangell-specific estimates of power demand changes.

Considering the housing characteristics in Wrangell, it is apparent that DHP displacement of electric resistance heat in the residential sector is insufficient alone to meet the goal of reducing peak power demand by 2 MW. As of April 2015, there were 1,108 residential customers (The City and Borough of Wrangell, 2015b) and approximately 50% of all homes in Wrangell use electric resistance heat (C. Hammer, personal communication, Dec. 22, 2015). Therefore the number of homes that could be retrofitted with heat pumps to displace electric resistance heat (approximately 550) is about an order of magnitude less than the number of homes necessary to meet the power demand reduction goal. Heating system retrofits would need to extend beyond the residential sector into other building types, such as commercial or municipal buildings, to approach the power demand reduction goal. For example, there were 59 commercial and five City buildings in the Wrangell ML&P heat rate program as of April 2015. These buildings would require consideration of additional variables. For example, while DHP systems do not typically include electric resistance back up heat, commercial scale heat pump systems often have back up heating elements built in. Integrated electric resistance heating can negate the peak power demand reduction benefit of these systems.

The potential for DHPs to deliver the power demand reduction goal is further complicated by considering that a substantial fraction of buildings in Wrangell use heating oil. An estimated 50% of residential buildings in Wrangell use heating oil for space heating (C. Hammer, personal communication, Dec. 22, 2015). For the residential buildings included in the general monitoring of this study, seven used a heat pump to displace electric resistance heat, eleven displaced oil heat, and two displaced a combination of electric resistance and oil heat. Without a detailed assessment of building characteristics in Wrangell to inform a more refined analysis, a rough approximation is that a DHP displacing electric heat reduces power demand as much as an equivalent DHP displacing oil heat increases power demand. This indicates that the inventory of residential buildings that could increase electricity demand by DHP retrofits (from oil) is roughly equal to the inventory that could reduce electricity demand by DHP retrofits (from electric resistance heat).

The potential for ASHPs to reduce energy demand in Wrangell varies widely depending on the assumptions made. Literature estimates range from 1,892 kWh per year for the Northwest DHP Pilot Project (Ecotope, Inc., 2014) to up to 3,200 kWh per year for Connecticut homes assessed by Steven Winter Associates (2014). Assuming that all 50% of the housing units in Wrangell heated with electricity converted to DHPs, these literature findings indicate that the maximum aggregate energy savings potential from the housing sector might range between 1,048,000 to 1,773,000 kWh per year. Further potential for energy demand savings exist within the commercial and city heat rate program customers, however, there isn't sufficient information to support estimates for heat pump retrofits in these building sectors.

While the calculations above indicate a potential to reduce annual energy demand by 1,048,000 to 1,773,000 kWh in Wrangell by ASHPs displacing electric resistance heat, it is not likely that these estimates are attainable. As mentioned above, there is roughly equal potential for energy demand increases from ASHPs displacing oil heat. Furthermore, the billing analysis from the general monitoring population of this study show that the outcomes from ASHPs displacing oil or electric heat don't always result in a noticeable or expected change in electricity consumption.

Cold climate ASHPs have become a popular heating option for retrofit and new construction in Southeast Alaska because they have the potential to save money for many customers relative to electricity or oil (see Stevens, Craven, & Garber-Slaght (2013) for more background information). However, the findings of this study indicate that residential ASHP deployment in Wrangell is likely insufficient to meet electricity demand reduction goals. Other demand side management strategies may require consideration. One alternative approach recently pursued in Juneau involved gathering a broad range of local representatives alongside the electric utility to create a plan for future use of electricity that is consistent with multiple community goals (A. Mesdag, personal communication, Oct. 1, 2015). Assistance and facilitation for the plan development was provided at the Rocky

Mountain Institute’s 2015 Electricity Innovation Lab Accelerator. While the specific goal for energy management is different for Juneau, the means used to develop a plan could be emulated in Wrangell to ensure that attainable goals are identified with the support and assistance of other community representatives.

Conclusions

As air source heat pump manufacturers improve the performance of cold climate models, and the number of installations increase in Alaska, documentation on current installations will help homeowners and electric utilities make informed decisions and policies on how to incorporate the technology into current and future buildings. This research project gathered two types of data on ASHPs during the winter of 2014-2015: detailed performance data on three ASHPs and more general survey data on thirty other systems.

The intent of the project was to use the data collected alongside conclusions from ASHP studies outside of Alaska to address two questions about the appliances in this state. First, how do ASHPs perform in the cold climate of Alaska and are people satisfied with them? Second, what is their potential as an energy conservation strategy for smaller hydropower electric utilities, such as Wrangell ML&P?

Specific aspects of these questions are addressed through each of the three research components in this project and are documented in the previous sections of this report. Below, we conclude with more general statements about the current performance and potential of current ASHP technology in Alaska.

Manufacturer specifications for efficiency do not adequately characterize installed performance.
The in-situ measurements of efficiency did not always compare well to manufacturer specifications for efficiency, which justifies the need for third-party testing of individual models. Also, manufacturer specifications for efficiency mostly focus on steady-state performance. Integrated performance data is necessary to account for defrost cycles that occur at lower temperatures and to more accurately predict the seasonal COP of ASHPs in Alaska.

Considerable variations in efficiency exist among ASHP models.
While ductless heat pumps are often referred to as equivalent and interchangeable products, variations in efficiency among heat pumps models were shown not just in our study, but also in a different study involving a laboratory test of two different ductless heat pumps (Winkler, 2011). The same two models were studied in the field and similar differences in efficiency were found (Ecotope, Inc., 2011). The difference in efficiency can be exacerbated by different behavior at low-load conditions. While some heat pumps increase efficiency with a decreased load, our study showed that other heat pumps actually lose efficiency with decreased load. This difference in behavior between individual models also poses challenges to stating general expectations for heat pump efficiencies and energy savings potential.

Most ASHP users are satisfied with the appliances.
This is true regardless of make and model of the heat pump, for residential and commercial installations, for retrofit and new installations, and in all locations in this research project. In general monitoring interviews, 29 out of 30 ASHP users reported that the appliances provided “adequate” or “expected” heat during the monitoring period and all interviewees were able to list advantages of the systems. This large percentage of satisfied ASHP users was also identified in two DHP studies in the Northeast United States (KEMA, Inc., 2009) and the Northwest United States (Ecotope, Inc., 2014).

ASHP installations require a backup heating strategy in Alaska.

While it is possible for an ASHP to operate in absence of a secondary heating system in some locations of Alaska, it is not recommended. During the monitoring period, only 12 of the 29 operating systems employed their backup heating system. However, whether or not a building used the backup appliance was not location-dependent, but rather dependent on the operating settings and building condition. While the temperature never dropped below 0°F in Southeast Alaska in 2014-2015, it does in some winters. Also, there is anecdotal evidence suggesting that the heat pump can stop operating above the cutoff temperature in some situations; for example, if high wind reduces the defrost function in cold temperatures.

Another consideration should be given to the ability to quickly repair a broken unit. While typical fuel-fired heating systems are located inside buildings and thus the ability to repair them is not weather dependent, the main components of a heat pump are located outside, and a prompt repair of a broken unit could be hindered by the weather. Furthermore, the risk of not having a backup heating system is high in Alaska because of the cold weather. Impacts could include frozen pipes or even hypothermia for occupants if stuck in a cold house. However, the need for a backup heating system does not necessitate a new, separate appliance. In retrofit cases, many building owners have chosen to leave the older appliance in place for this purpose. Also, some ASHPs contain backup electric resistance heat within the appliance itself.

This research project was unable to draw a conclusion on the effect of retrofit ASHPs on a building's electricity use.

Other research projects have identified electrical energy savings for homeowners that use a DHP to displace a portion of electric resistance heat (KEMA, Inc., 2009; Ecotope, Inc., 2014; Efficiency Maine, 2013; Steven Winter Associates, 2014). Common assumptions are that a retrofit ASHP displacing electric resistance heat should reduce electrical energy use, and that a retrofit ASHP displacing an oil-fired appliance would increase electrical energy use. However, the small sample size of retrofit appliances in this study did not always adhere to these expectations when analyzed together with the climate heating degree days. Other studies have documented the significance of variables such as the presence of supplemental wood heat and changes in occupant behavior that can reduce energy savings (KEMA, Inc., 2009; Ecotope, Inc., 2014). A study with a larger sample size would be necessary to address these considerations and provide an estimate of changes in electrical use for buildings in Alaska converting to an ASHP appliance.

Electric utilities in Alaska considering ASHPs as part of an energy conservation strategy should broaden demand side management programs to include other conservation measures.

ASHPs can significantly reduce electric energy use when displacing electric resistance heat, however, the success of this strategy is largely dependent on the buildings being retrofitted. There have been some instances documented by Ecotope, Inc. (2014) in houses with supplemental wood heat where a DHP retrofit offset more the use of wood heat than electric resistance heat, leading to a net electric energy use increase. Furthermore, heat pumps have a relatively small effect on reducing peak power demand relative to electric resistance heat. For heat pumps with electric resistance backup, any potential peak power demand savings would presumably be eliminated.

Finally, while specific actions can be incentivized, such as the displacement of electric heat by ASHPs, trends in heating appliance use and fuel prices can overwhelm such effects and lead to behavior resulting in increased electric energy use, such as the displacement of oil heat by ASHPs. In communities such as Wrangell, there is an approximately equal amount of oil and electric resistance heat within the residential sector. This distribution of heating fuel use presents the risk of negating or greatly reducing the desired electric energy demand savings.

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Appendix A: Sample calculation with indoor humidity

Measuring indoor relative humidity (RH) when a heat pump is in cooling mode is important because of possible condensation and associated latent heat. In this project, the ASHPs were only monitored during the heating season. Researchers did not monitor indoor RH because the complexity added to the analysis would have only resulted in a minimal gain in accuracy.

For example, consider the calculations for the heat output of a DHP. The procedure begins by considering the flow of the intake air and water vapor mixture to the indoor unit. The flow is measured in units of cubic feet per minute (cfm). Assume this mixture has a temperature of 70°F and a relative humidity of 40%. This translates into a mixture with a ratio of 13.48 ft^3 per pounds of dry air and a humidity ratio of 0.00621 pounds of moisture per pounds of dry air (ASHRAE, 2009).

The calculation also requires the constants of the specific heat of dry air and the specific heat of water vapor (Lindeburg, 2006).

$$Specific\ heat\ of\ dry\ air = 0.24\frac{BTU}{lb_{air}°F}$$

$$Specific\ heat\ of\ water\ vapor = 0.45\frac{BTU}{lb_{water}°F}$$

The specific heat of the air and vapor mixture entering the heat pump is found by combining these with the humidity ratio of the mixture.

$$Specific\ heat\ mixture = 0.24\frac{BTU}{lb_{air}°F} + \ 0.00621\frac{lb_{water}}{lb_{air}} \times 0.45\frac{BTU}{lb_{water}°F} = 0.2428\frac{BTU}{lb_{air}°F}$$

The heat energy per unit volume per degree of the air and vapor mixture entering the heat pump:

$$\frac{Heat\ energy}{ft^3°F} = \frac{0.2428\frac{BTU}{lb_{air}°F}}{13.48\ \frac{ft^3}{lb_{air}}} = 0.01801\frac{BTU}{ft^3°F}$$

If the relative humidity is 70%, the mixture properties change to a ratio of 13.58 ft^3 per pound of dry air and a humidity ratio of 0.01095 pounds of moisture per pounds of dry air (ASHRAE, 2009).

The specific heat of the mixture is now:

$$Specific\ heat\ mixture = 0.24\frac{BTU}{lb_{air}°F} + \ 0.01095\frac{lb_{water}}{lb_{air}} \times 0.45\frac{BTU}{lb_{water}°F} = 0.2449\frac{BTU}{lb_{air}°F}$$

The heat energy per unit volume per degree of the air and vapor mixture entering the heat pump changes as well. However, the relative difference in this value and the one above is roughly 0.1% for the heat per °F per cubic foot of the entering air and vapor mix. This is negligible considering the larger inaccuracies in the procedure for measuring the heat output of the DHP, such as the inaccuracies in measuring the air flow.

$$\frac{Heat\ energy}{ft^3{}^\circ F} = \frac{0.2449\ \frac{BTU}{lb_{air}{}^\circ F}}{13.58\ \frac{ft^3}{lb_{air}}} = 0.01803\ \frac{BTU}{ft^3{}^\circ F}$$

Appendix B: Recruitment bulletin

The Cold Climate Housing Research Center will be conducting a study on air source heat pumps (ASHPs) over the coming winter. The research project, funded by the Alaska Energy Authority's Emerging Energy Technology Grant, will demonstrate ASHP technology in cold climates by monitoring existing ASHP installations in Alaskan buildings. Researchers hope to gather information about ASHP electrical usage and operational characteristics during the study. This information will help to inform electric utilities about the typical energy use of ASHPs and to inform homeowners about the qualitative performance of the appliances. CCHRC is currently recruiting homes or buildings with ASHPs as the primary heating system to participate in the study.

Volunteers would be expected to do the following:

1. Participate in an initial interview in July about the characteristics of the building such as square footage, occupancy, and general construction; characteristics of the ASHP such as make, model, and installation date and cost; and motivation for installing the ASHP.
2. Provide electric bills specific to the ASHP or for the building (if no separate meter for the ASHP) to the researchers for the period of the study.
3. Allow monitoring equipment to be installed on the ASHP that would track electrical usage, such as a utility submeter or a temporary monitoring device for electric current. Temporary monitoring devices will be removed at the conclusion of the study.
4. Provide, if possible, past heating bills for previous heating appliances.
5. Participate in a final interview in May 2015 about the performance of the ASHP over the winter, providing information on any maintenance issues and about whether the ASHP was able to provide adequate heat throughout the winter.

Names and addresses of volunteers will be kept confidential, and volunteers will be provided with a copy of the research report at the conclusion of the study. All interested parties should contact Vanessa Stevens [450-1762, vanessa@cchrc.org] for more participant information and questions.

Appendix C: Indirect monitoring graphs

Researchers used pre- and post-ASHP retrofit electric bills as well as weather data to visualize the effect of the retrofit on the electrical use of 11 buildings. The graphs for each location appear in this appendix. Buildings are labeled by identifiers that specific their location (Juneau, Sitka, or Wrangell), whether or not the building is residential (R) or commercial (C), and if the heat pump is a ductless heat pump (d) or an air-to-water system (w).

JNU_Rw3

Previous appliance: Electric baseboard

Installation of ASHP: December 2013

Wood-fired heat: Present

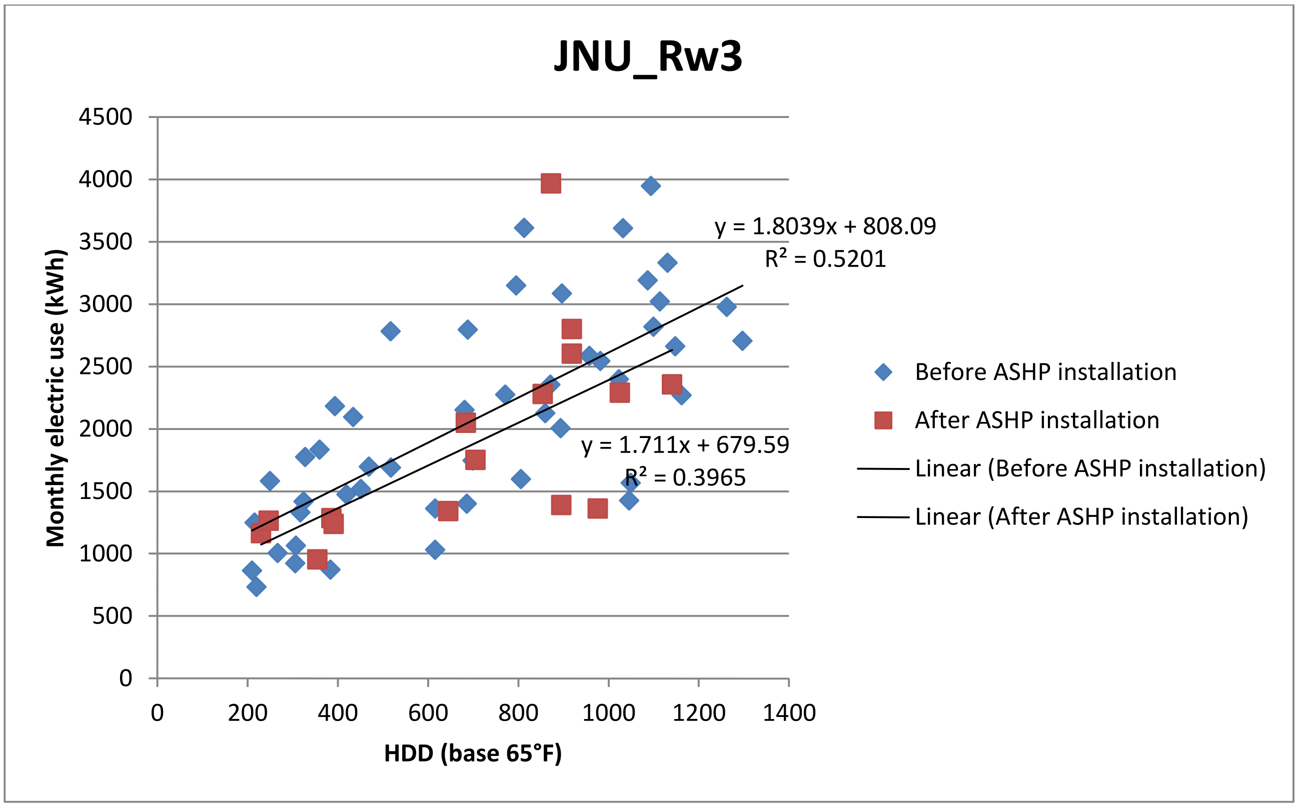

Figure 38: Monthly whole building electric use versus HDD for site JNU_Rw3.

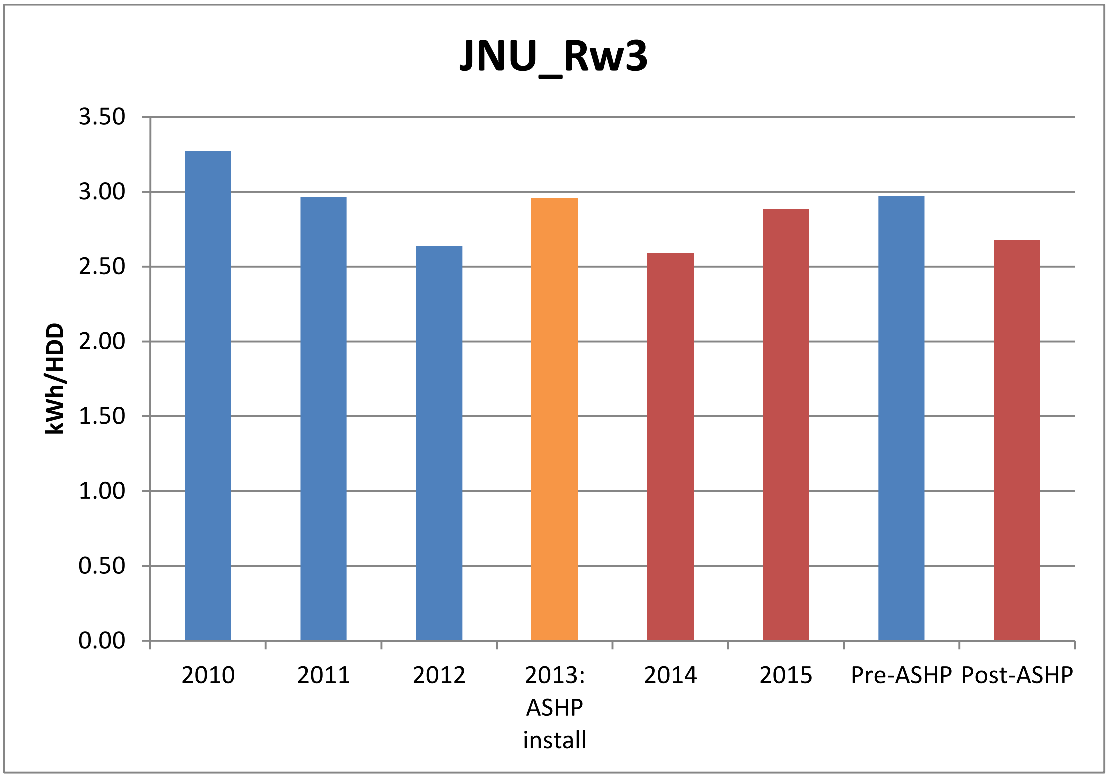

Figure 39: Annual ratio of electric use to HDD for site JNU_Rw3.

JNU_Rw5

Previous appliance: Oil boiler

Installation of ASHP: May 2014

Wood-fired heat: Present

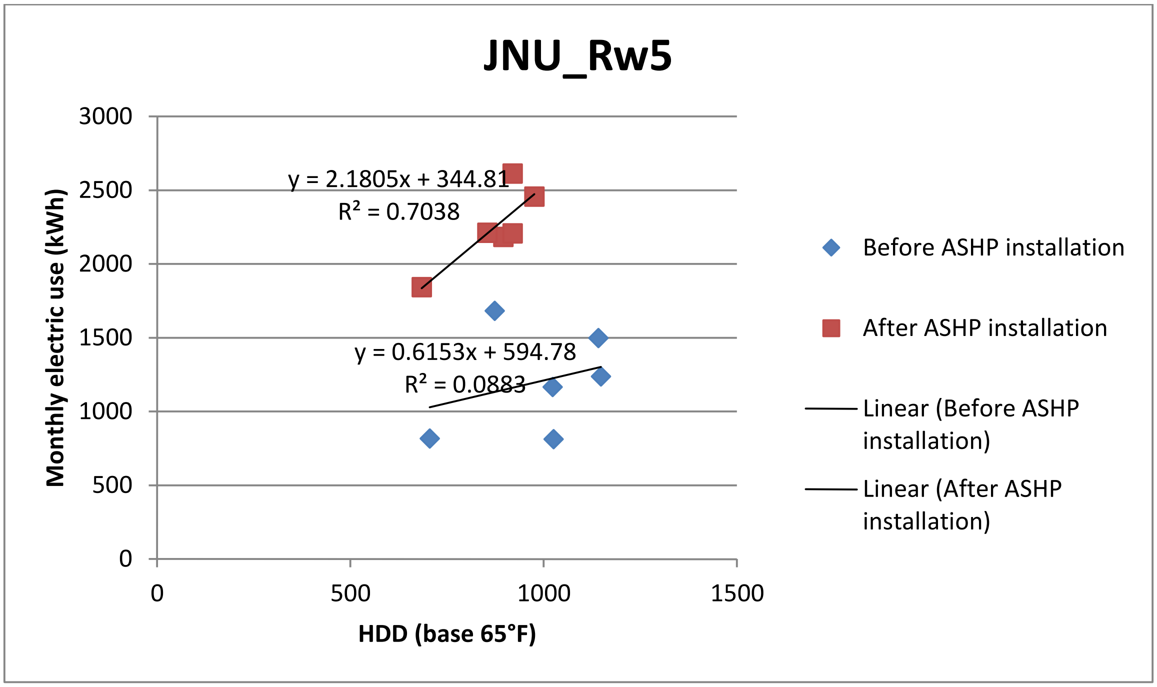

Figure 40: Monthly whole building electric use versus HDD for site JNU_Rw5.

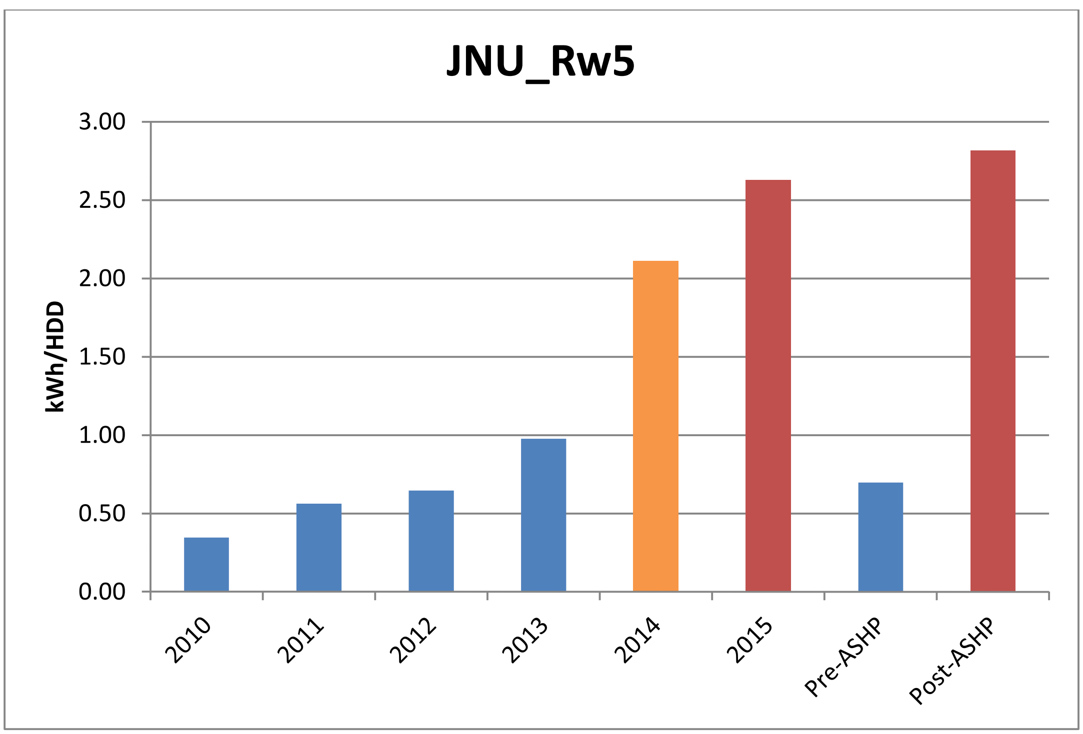

Figure 41: Annual ratio of electric use to HDD for site JNU_Rw5.

JNU_Rw6

Previous appliance: Oil/electric furnace

Installation of ASHP: September 2012

Wood-fired heat: None

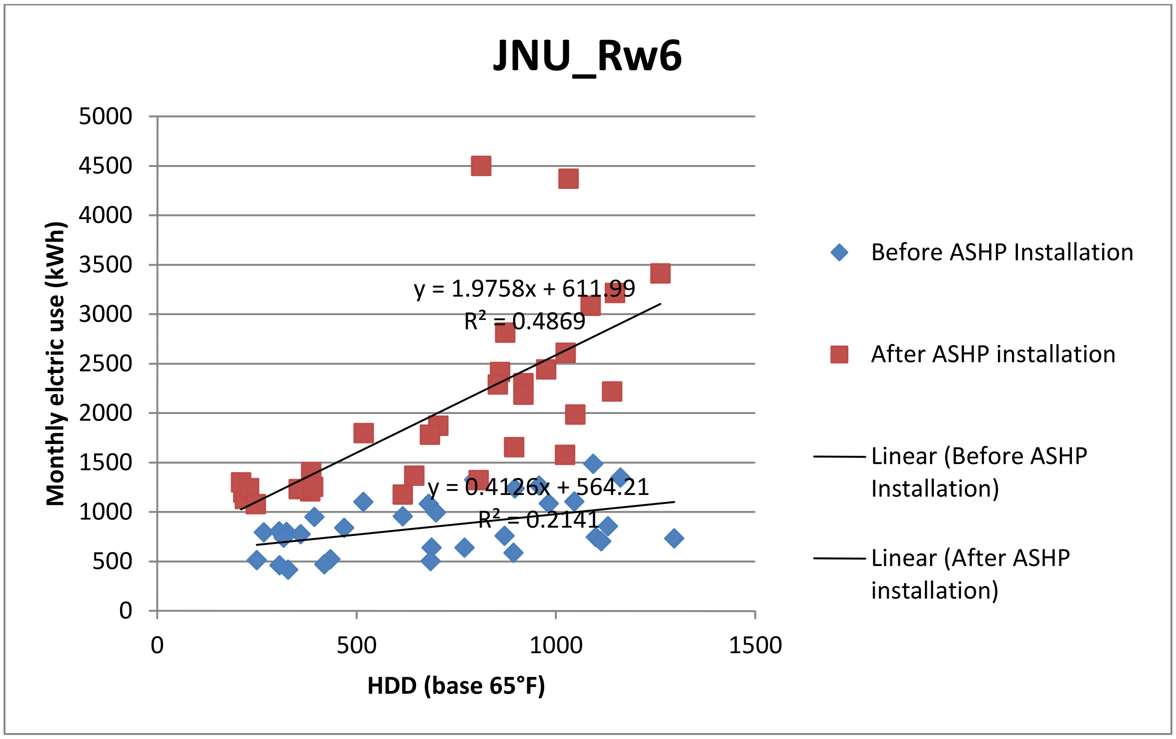

Figure 42: Monthly whole building electric use versus HDD for site JNU_Rw6.

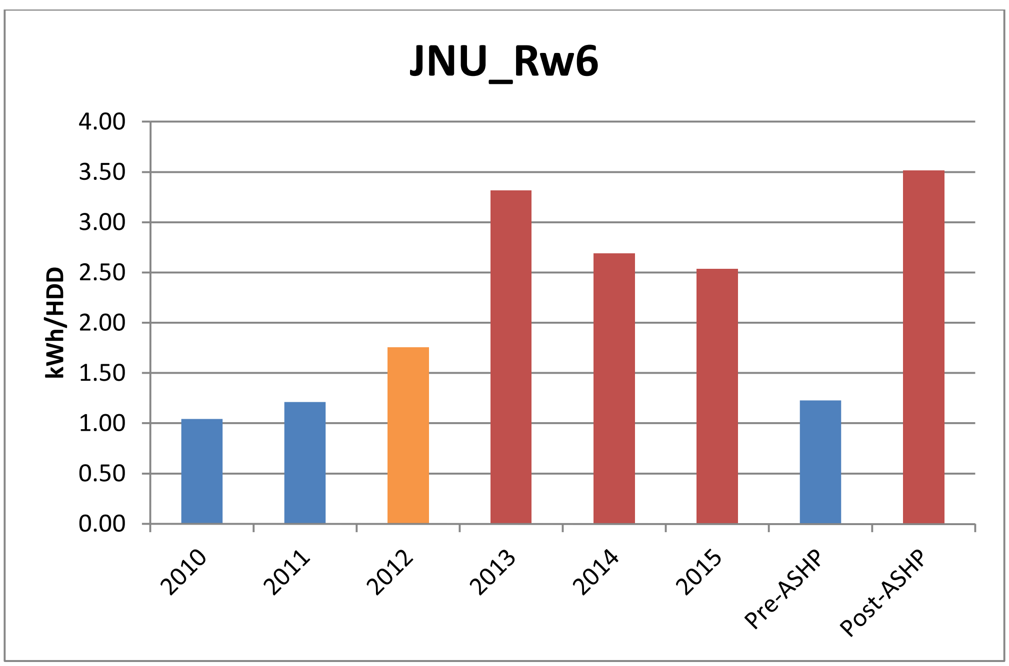

Figure 43: Annual ratio of electric use to HDD for site JNU_Rw6.

JNU_Rd3

Previous appliance: Oil furnace

Installation of ASHP: September 2013

Wood-fired heat: None

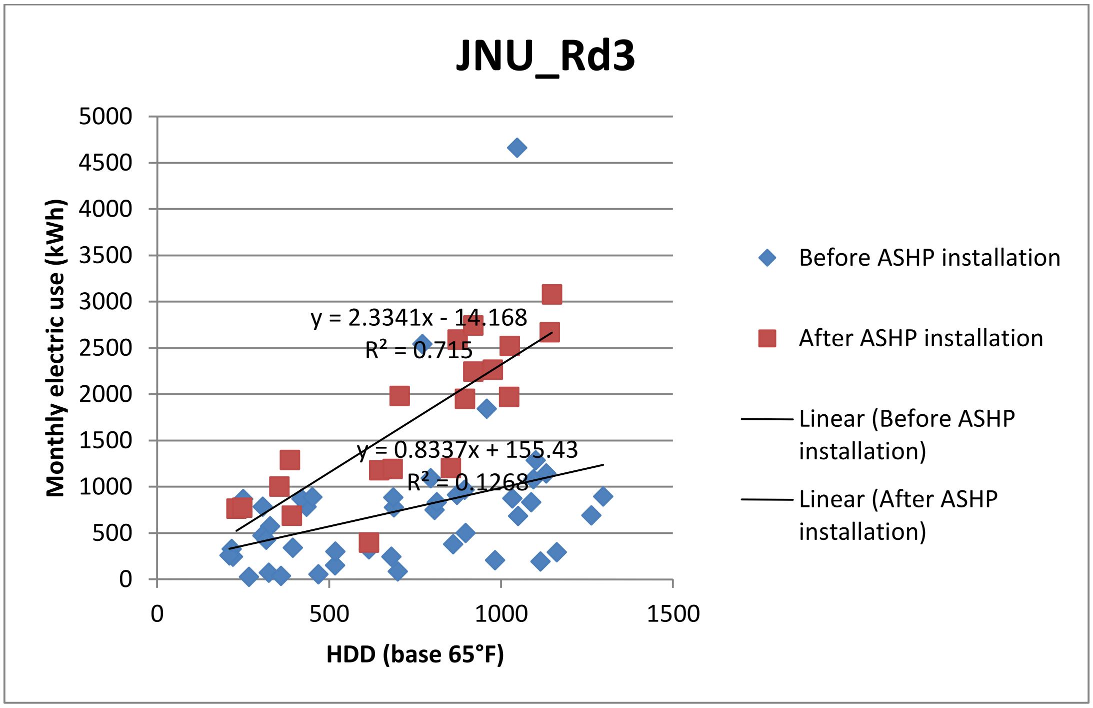

Figure 44: Monthly whole building electric use versus HDD for site JNU_Rd3.

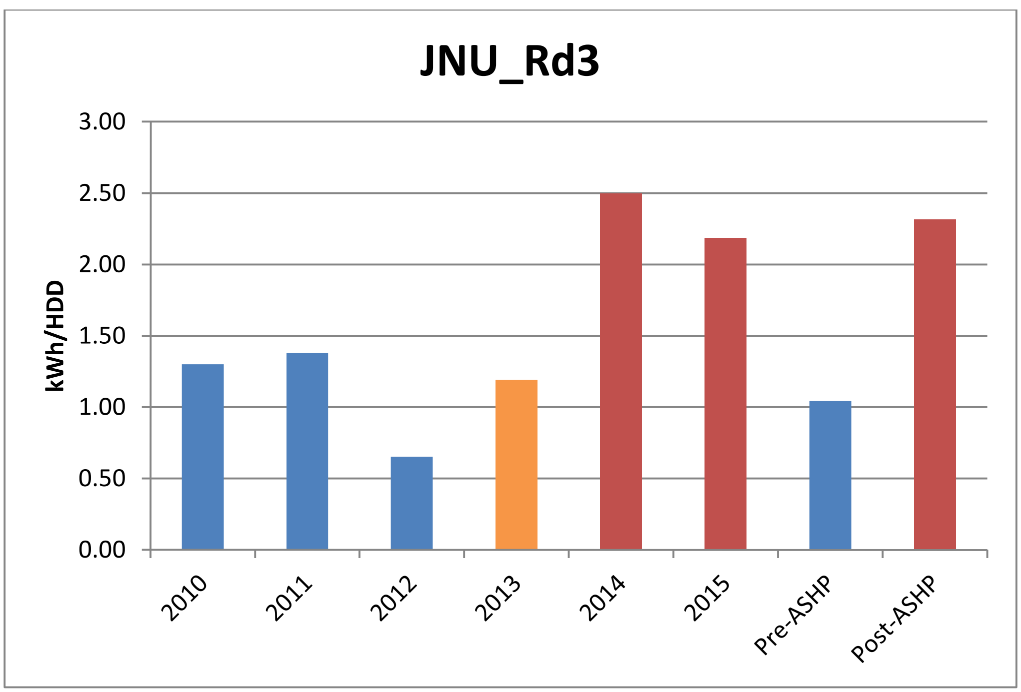

Figure 45: Annual ratio of electric use to HDD for site JNU_Rd3.

SIT_Rd1
Previous appliance: Electric unit heaters
Installation of ASHP: December 2012
Wood-fired heat: Present

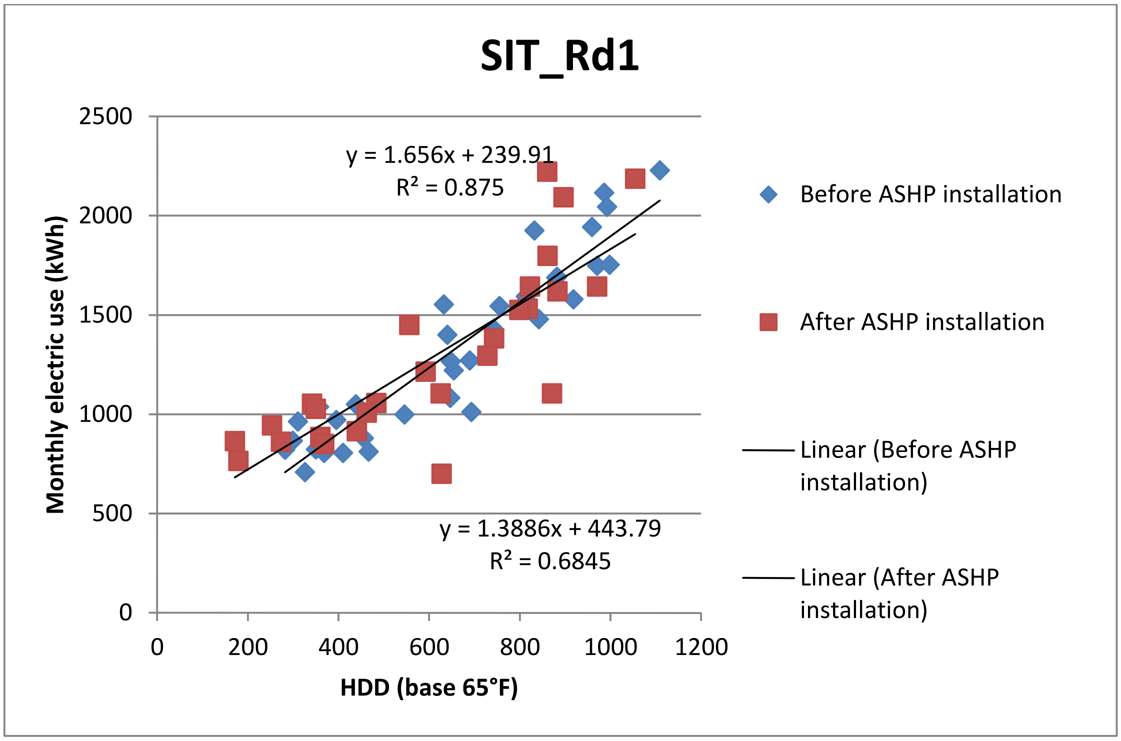

Figure 46: Monthly whole building electric use versus HDD for site SIT_Rd1.

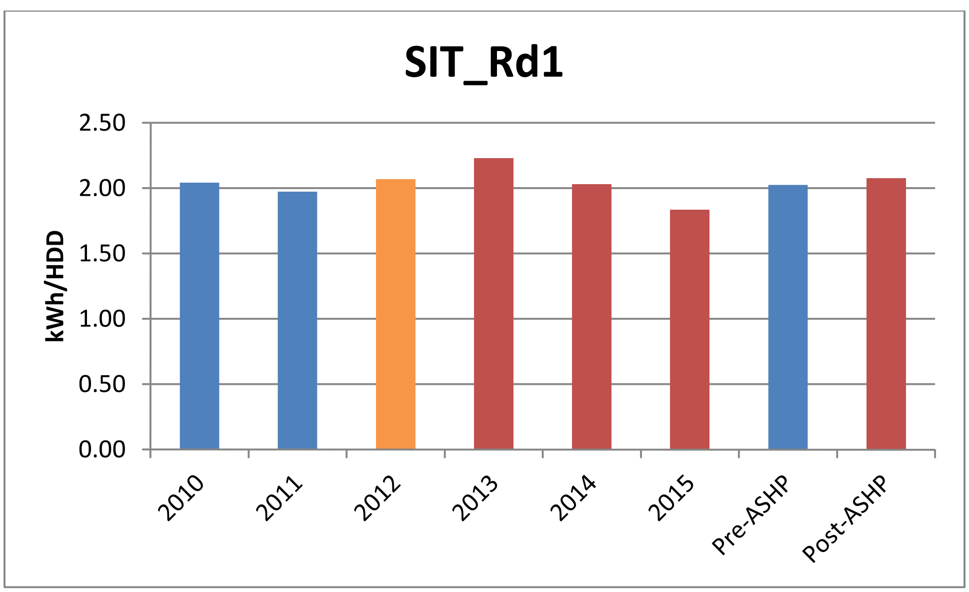

Figure 47: Annual ratio of electric use to HDD for site SIT_Rd1

SIT_Rd2

Previous appliance: Electric baseboard

Installation of ASHP: September 2014

Wood-fired heat: None

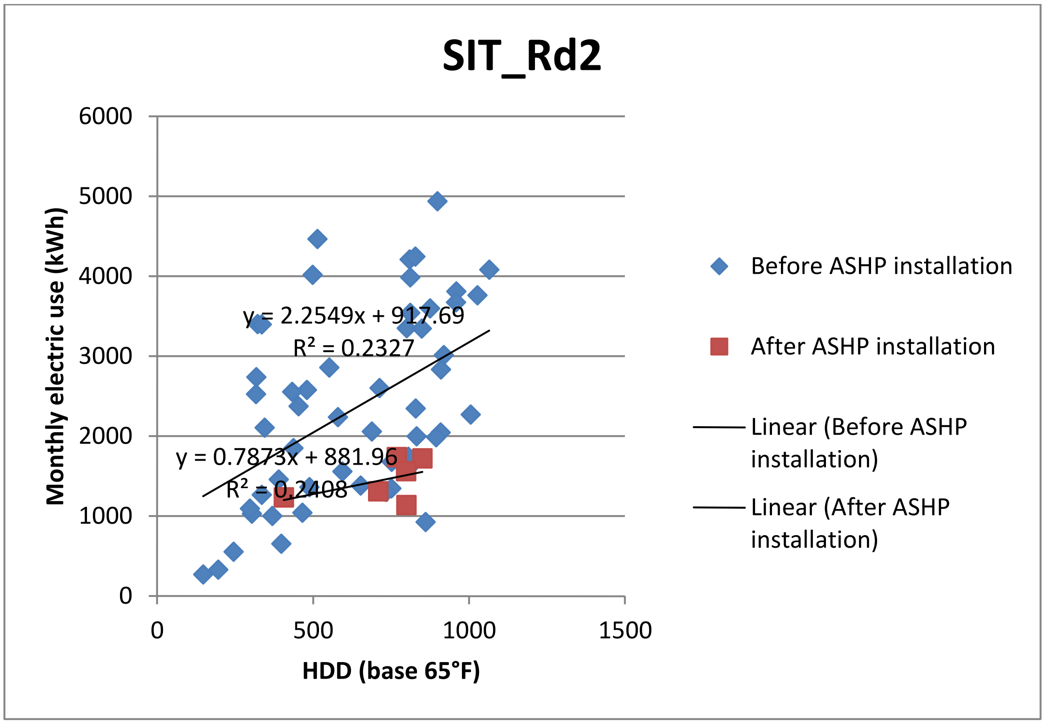

Figure 48: Monthly whole building electric use versus HDD for site SIT_Rd2.

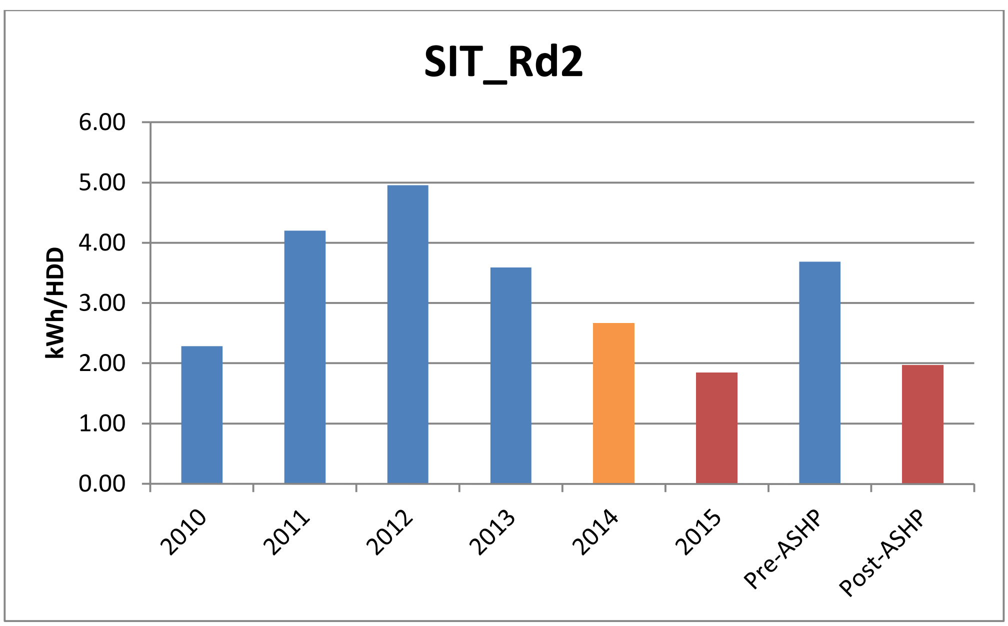

Figure 49: Annual ratio of electric use to HDD for site SIT_Rd2

SIT_Rd3

Previous appliance: Electric resistance heaters and Toyo stove

Installation of ASHP: June 2013

Wood-fired heat: None

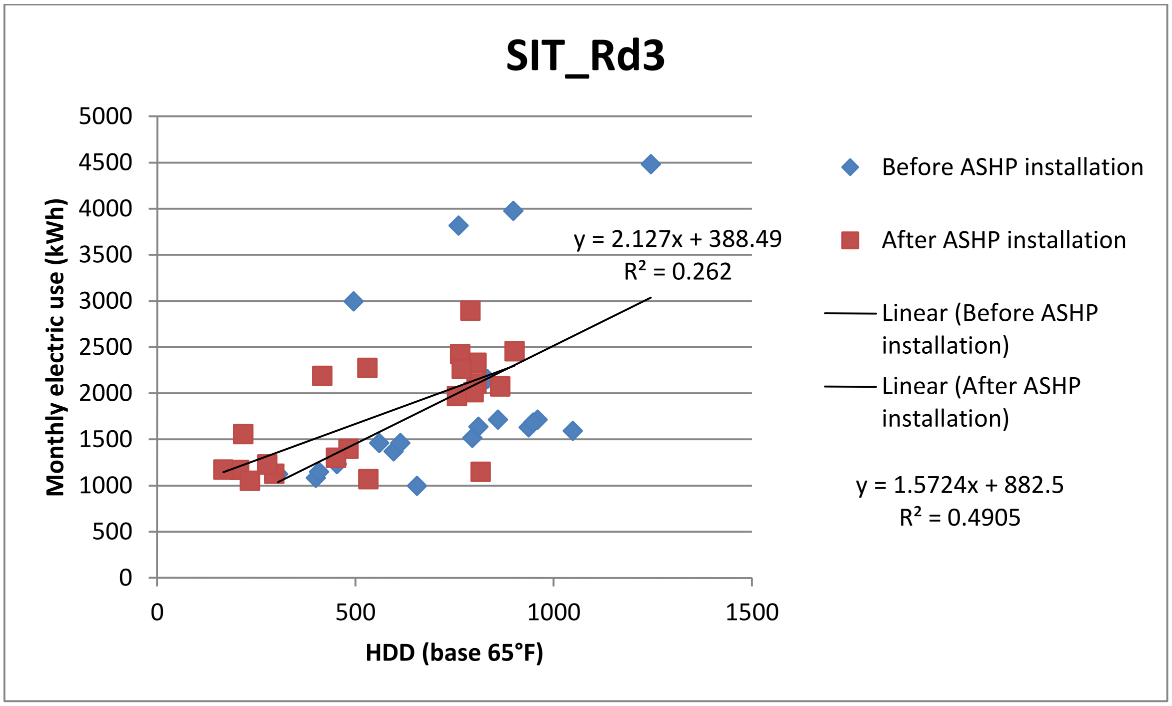

Figure 50: Monthly whole building electric use versus HDD for site SIT_Rd3.

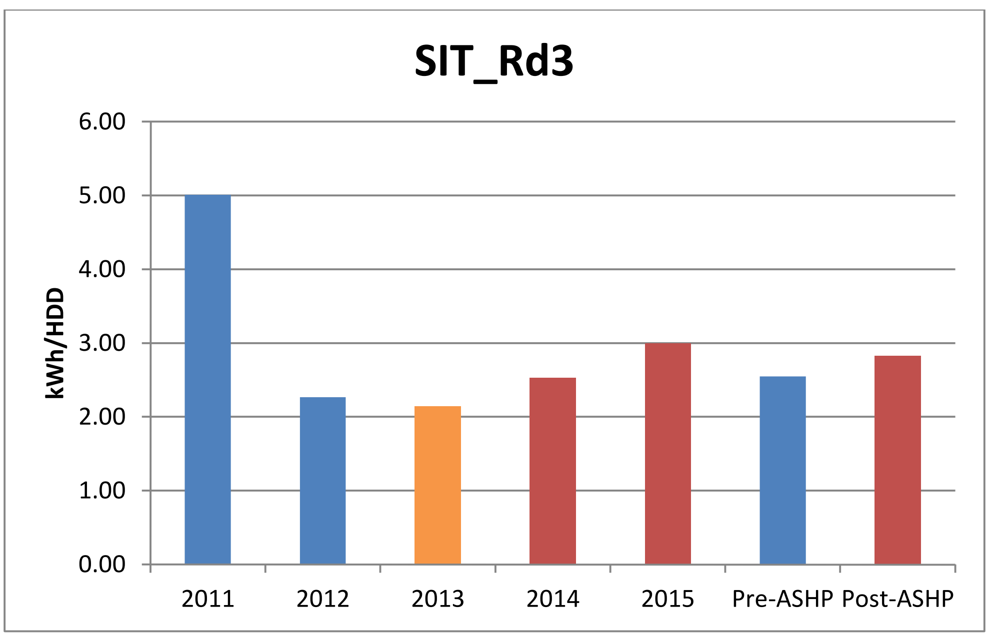

Figure 51: Annual ratio of electric use to HDD for site SIT_Rd3.

WRG_Rd1

Previous appliance: Electric boiler

Installation of ASHP: June 2014

Wood-fired heat: None

Note: This is an incentive electric meter specific to the home's electric heating systems, not the whole building. It includes the ASHP and the electric boiler, which provides the DHW.

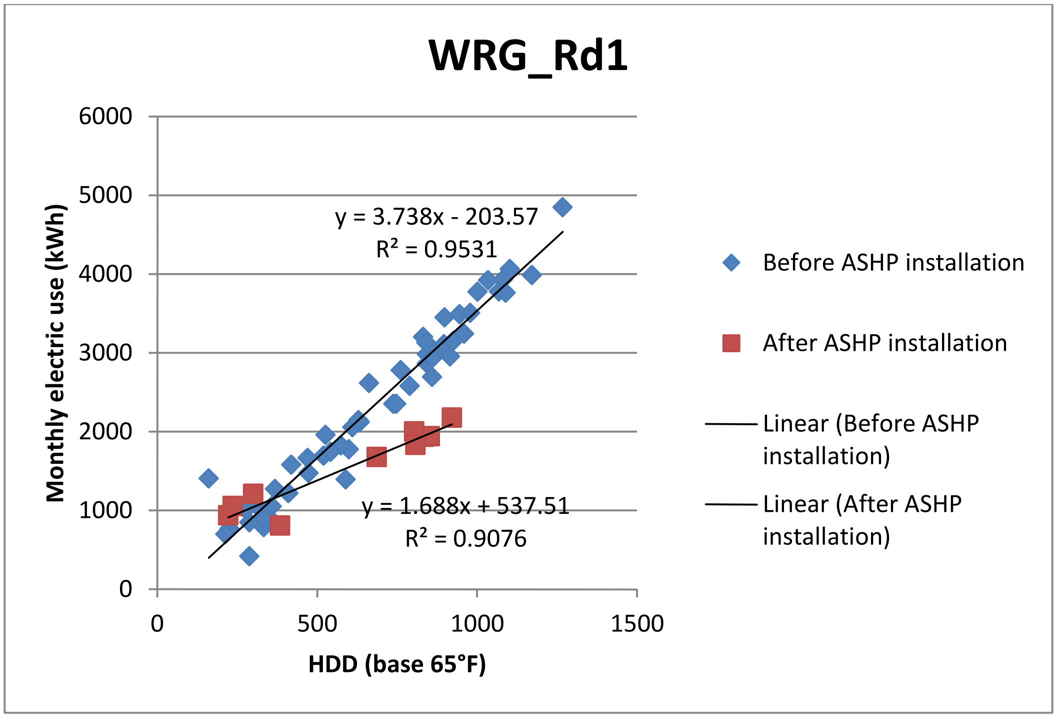

Figure 52: Monthly whole building electric use versus HDD for site WRG_Rd1.

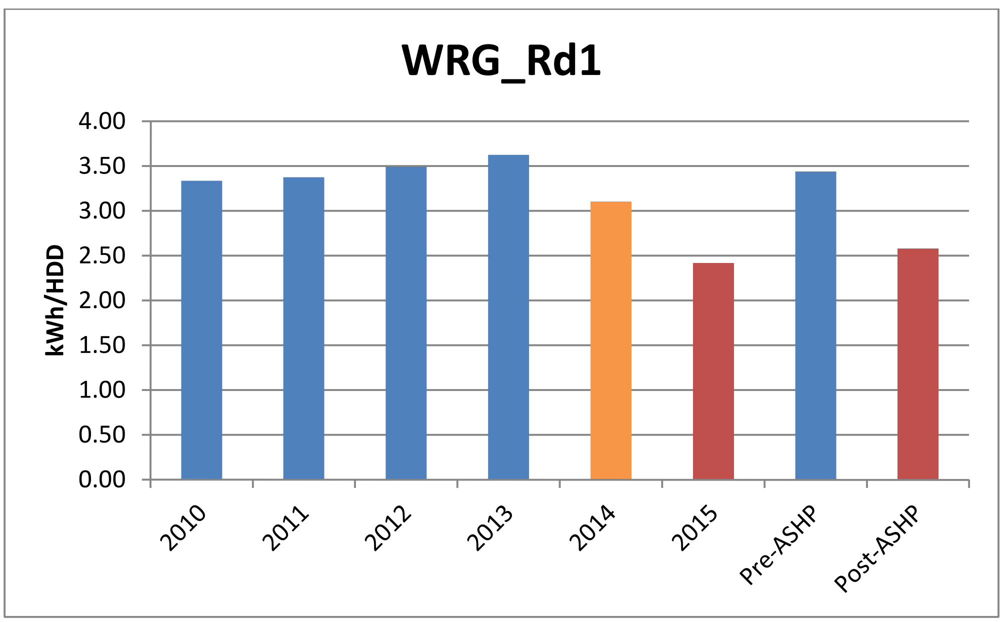

Figure 53: Annual ratio of electric use to HDD for site WRG_Rd1.

WRG_Rd3

Previous appliance: Electric heaters

Installation of ASHP: August 2013

Wood-fired heat: Present

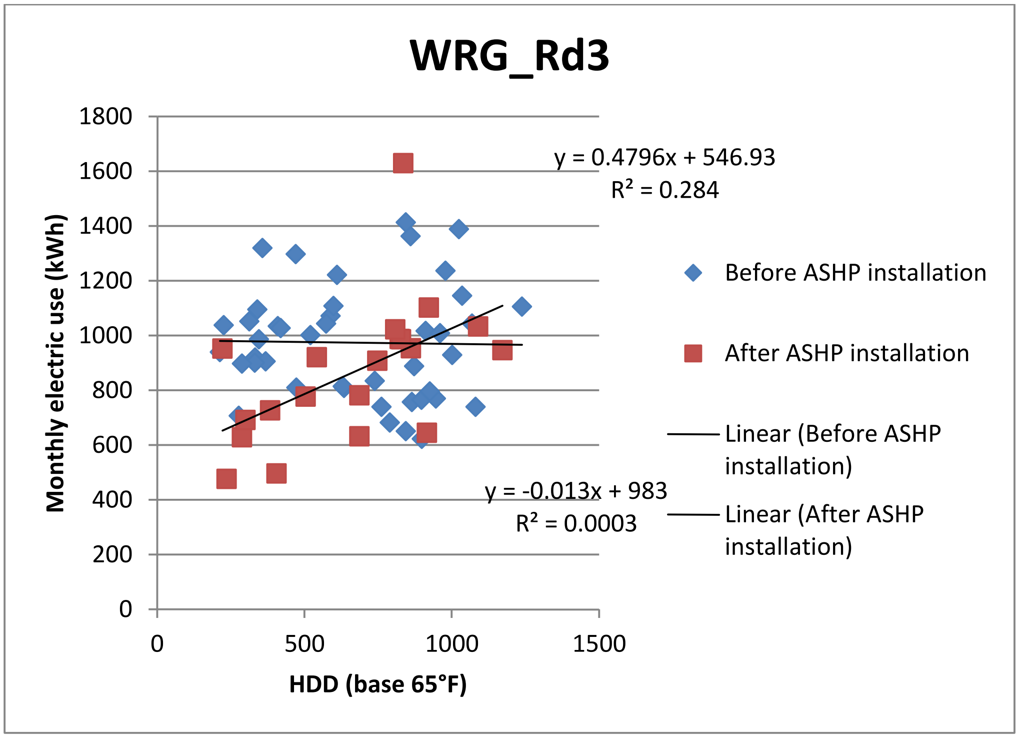

Figure 54: Monthly whole building electric use versus HDD for site WRG_Rd3.

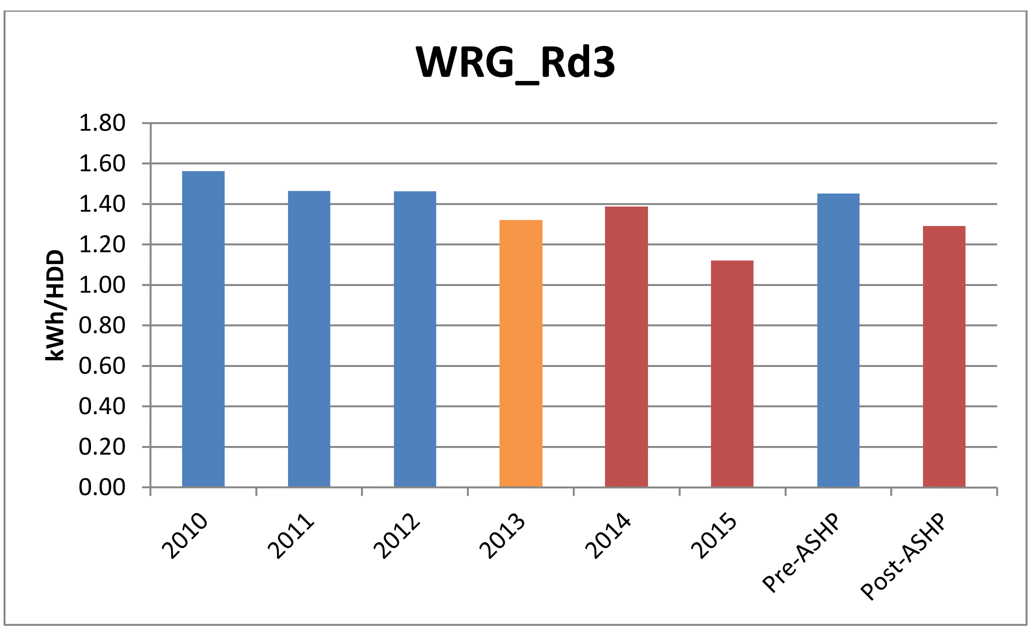

Figure 55: Annual ratio of electric use to HDD for site WRG_Rd3.

WRG_Rd4

Previous appliance: Oil furnace

Installation of ASHP: November 2013

Wood-fired heat: None

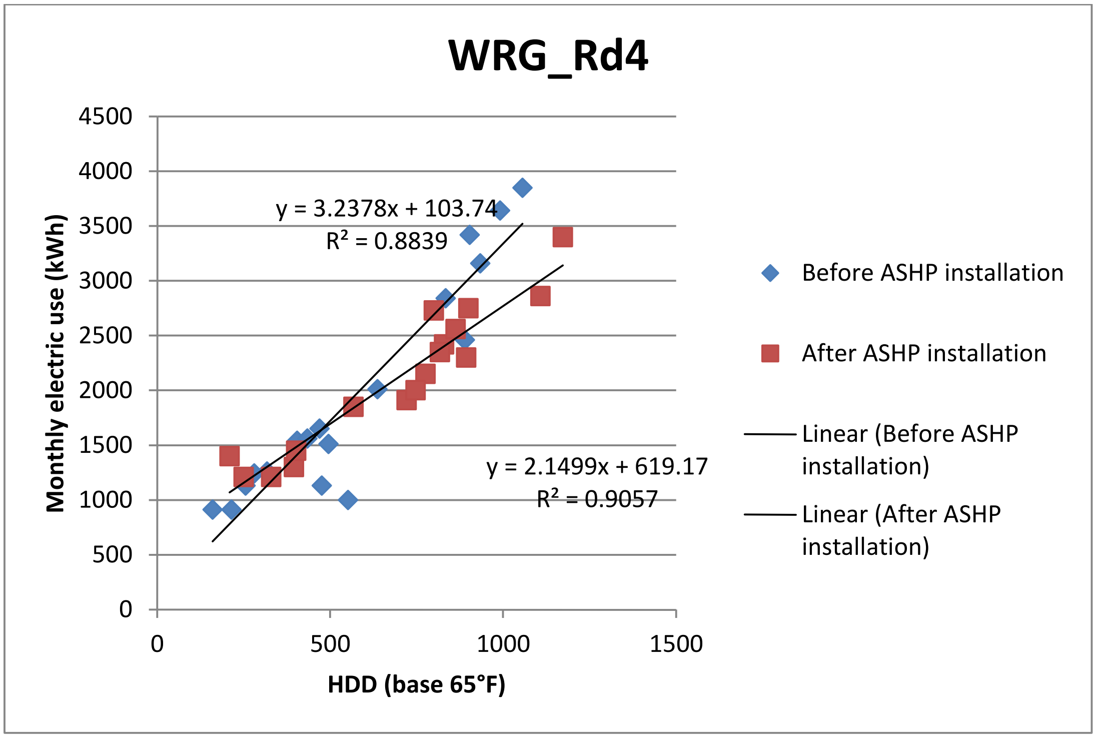

Figure 56: Monthly whole building electric use versus HDD for site WRG_Rd4.

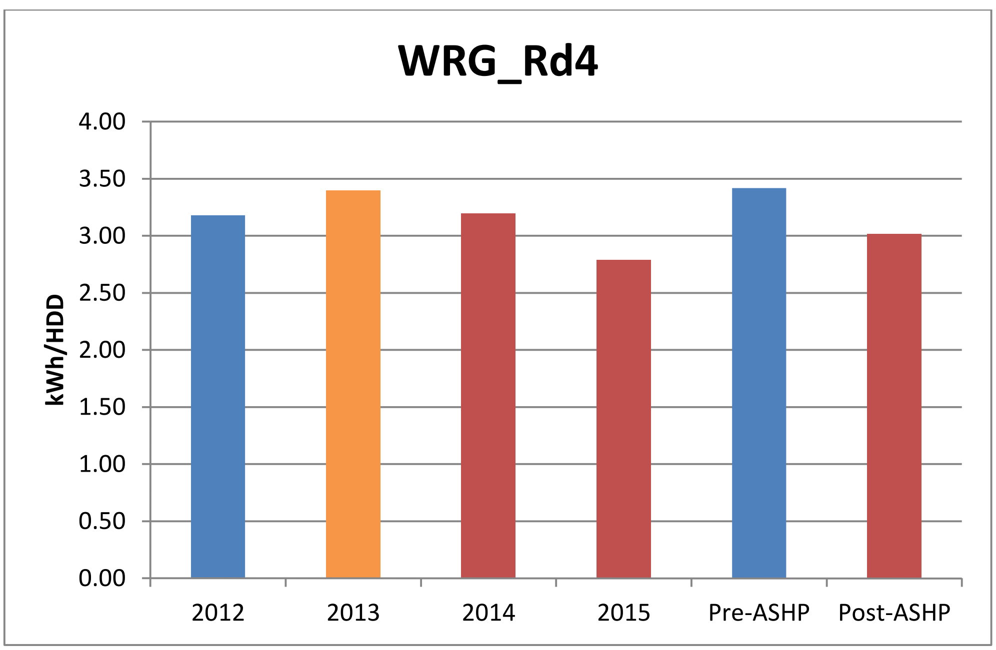

Figure 57: Annual ratio of electric use to HDD for site WRG_Rd4.

WRG_Cd

Previous appliance: Electric baseboard

Installation of ASHP: November 2013

Wood-fired heat: None

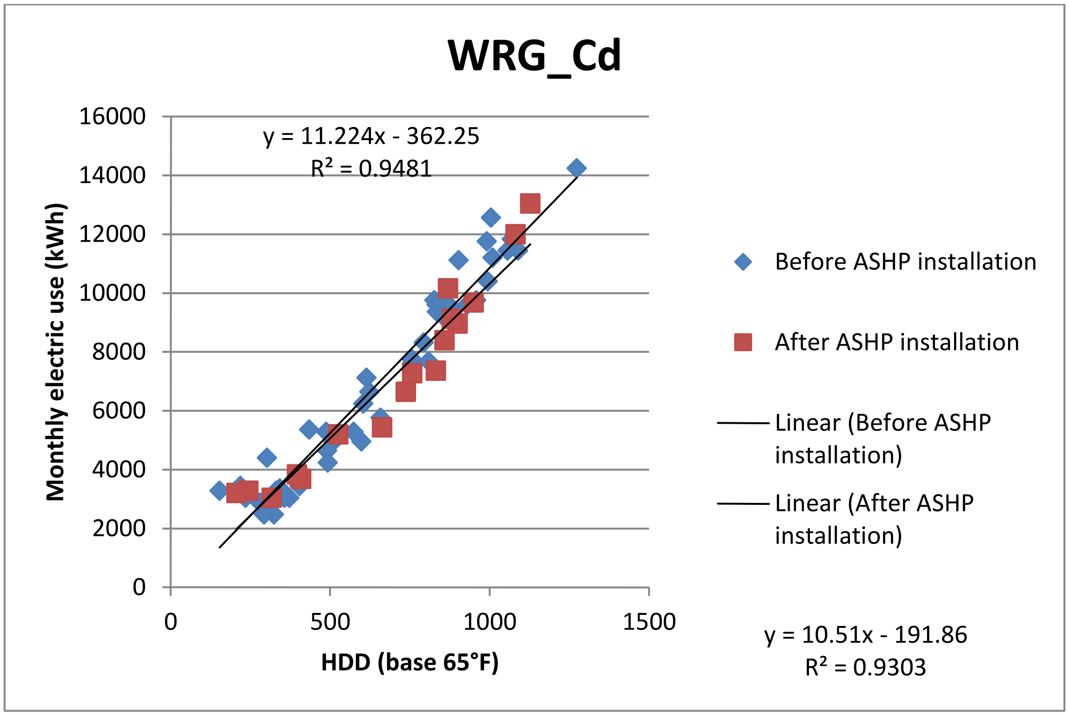

Figure 58: Monthly whole building electric use versus HDD for site WRG_Cd.

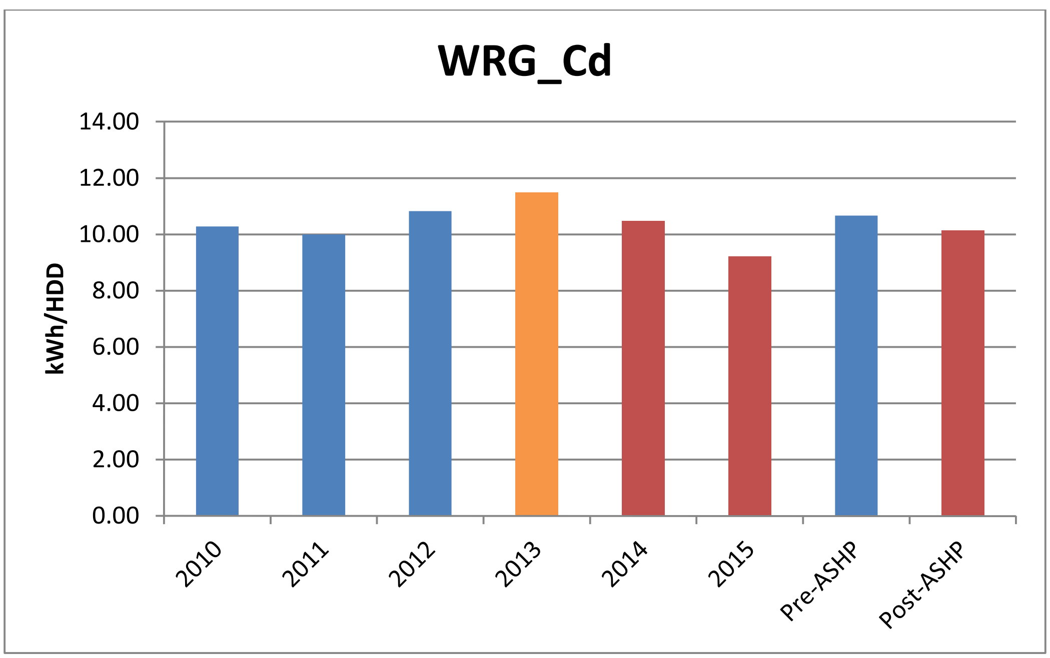

Figure 59: Annual ratio of electric use to HDD for site WRG_Cd.