Air Source Heat Pumps in Cold/Arctic Climates

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Abstract

Air source heat pumps (ASHPs) are space-conditioning appliances that use vapor-compression technology to provide both heating and cooling to buildings. Several companies offer cold-climate ASHPs that can provide space heating at outdoor temperatures around zero degrees Fahrenheit or even lower. These cold climate models offer a range of options, including air-to-water models for hydronic distribution systems, air-to-air models for forced air distribution systems, and ductless mini-splits that distribute heat through individual indoor units. While significant data gaps continue to exist regarding the performance of ASHPs in cold/Arctic climates, several studies have been completed in Alaska and other Arctic regions that provide important insights. The purpose of this paper is to summarize existing knowledge regarding installations of ASHPs in cold/Arctic climates and provide practical guidelines for future installations.

Background

High energy use for heating buildings in Arctic regions provides ample motivation for identifying new technologies that reduce energy consumption and associated costs. Air source heat pumps (ASHPs) designed for cold climate operation have the potential to achieve that goal in some situations. As shown in Figure 1, ASHPs use 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 building's interior. 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 have the potential to not only reduce energy use, but they can also reduce the complications of combustion safety and fuel handling, plus they require little maintenance. Some ASHP models also provide the ability to both heat and cool a building with the same appliance.

In general, the efficiency of an ASHP decreases with decreasing outside temperature, which poses challenges to using ASHPs in cold climates. The efficiency of a heat pump is described by the Coefficient of Performance (COP). COP expresses how many units of energy in the form of heat are supplied to the building for every unit of electrical energy supplied to the heat pump. For instance, an ASHP with a COP of 2 provides two units of heat to the building for every unit of electrical energy that it uses.

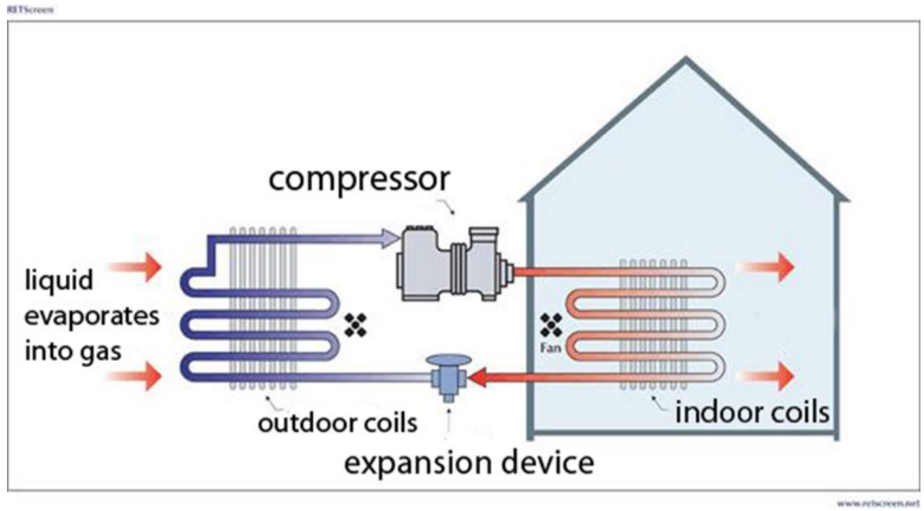

Figure 1. An ASHP in heating mode. Image courtesy of RETScreen [1].

Cold Climate Performance of ASHPs

To the knowledge of the authors, the most recent review of existing field studies on the installed performance of ASHPs was done by Mitchell et al. in 2018 [2]. It found that, in general, manufacturer specifications tend to over-predict the heat pump field efficiency. While the emphasis of this review was on cold climates, it included field studies also from non-Arctic regions. The following paragraphs highlight several studies specifically from Arctic regions.

The Energy Solutions Centre has conducted two studies reviewing ASHPs in the Yukon. The first study [3], published in 2010, aimed to inform people and entities considering installing an ASHP. 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 here:

- 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 [4], 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.

CCHRC and its partners performed detailed field monitoring of three ASHPs in Alaska in 2014-2015 [5]. It included two DHPs as well as one air-to-water ASHP. Selected practical examples of collected real-life data follow:

As shown in Figure 2, a heat pump cycles in sub-freezing outdoor conditions due to the need for defrost. This decreases the efficiency of the heat pump.

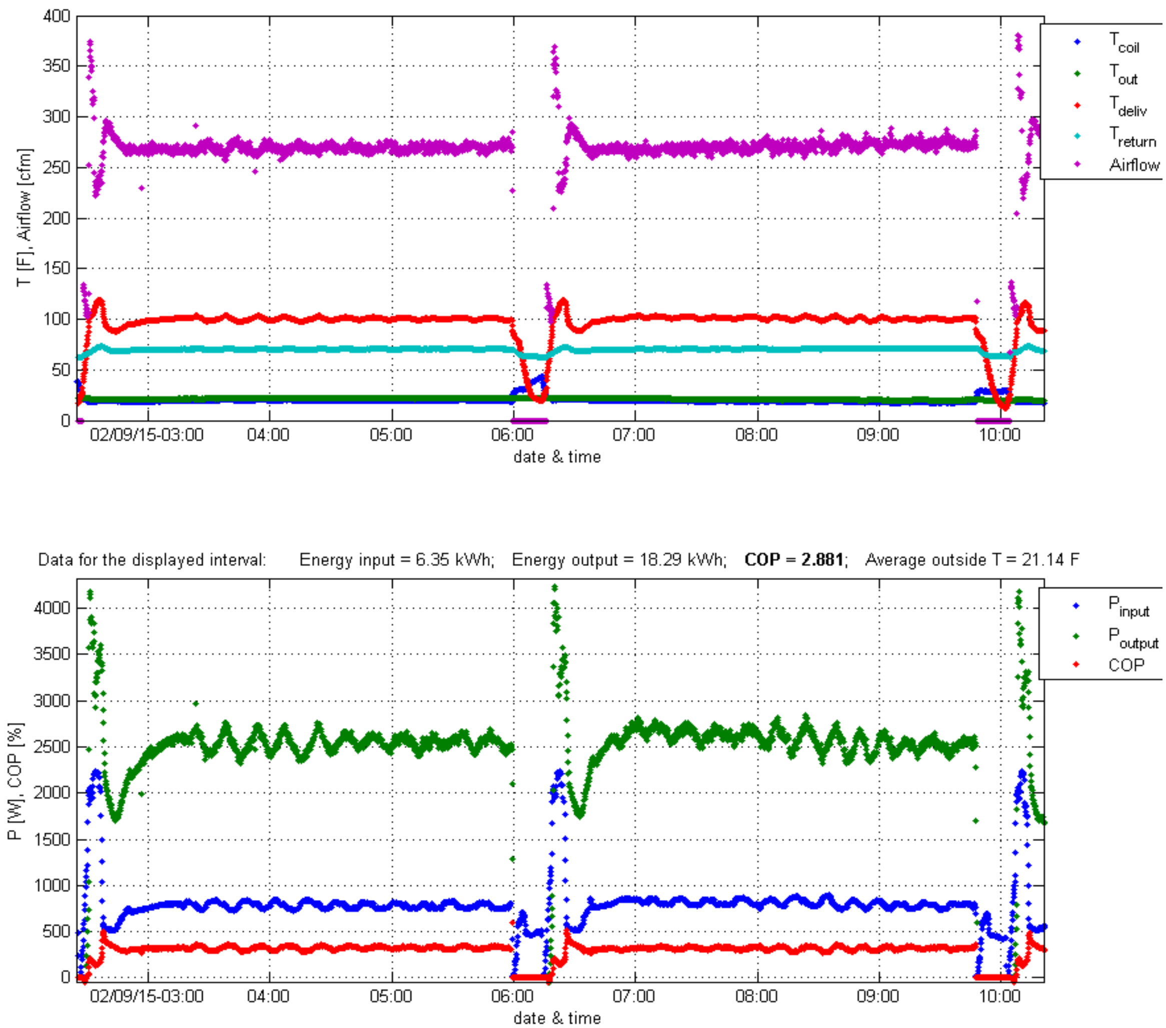

Figure 2. Example of cycling due to defrost. During the defrost, there is no heat provided to the building and all the input energy goes to defrosting ice built up on the outdoor coils.

As shown in Figure 3, a heat pump can cycle on and off in warmer 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. This cycling decreases the efficiency of the heat pump.

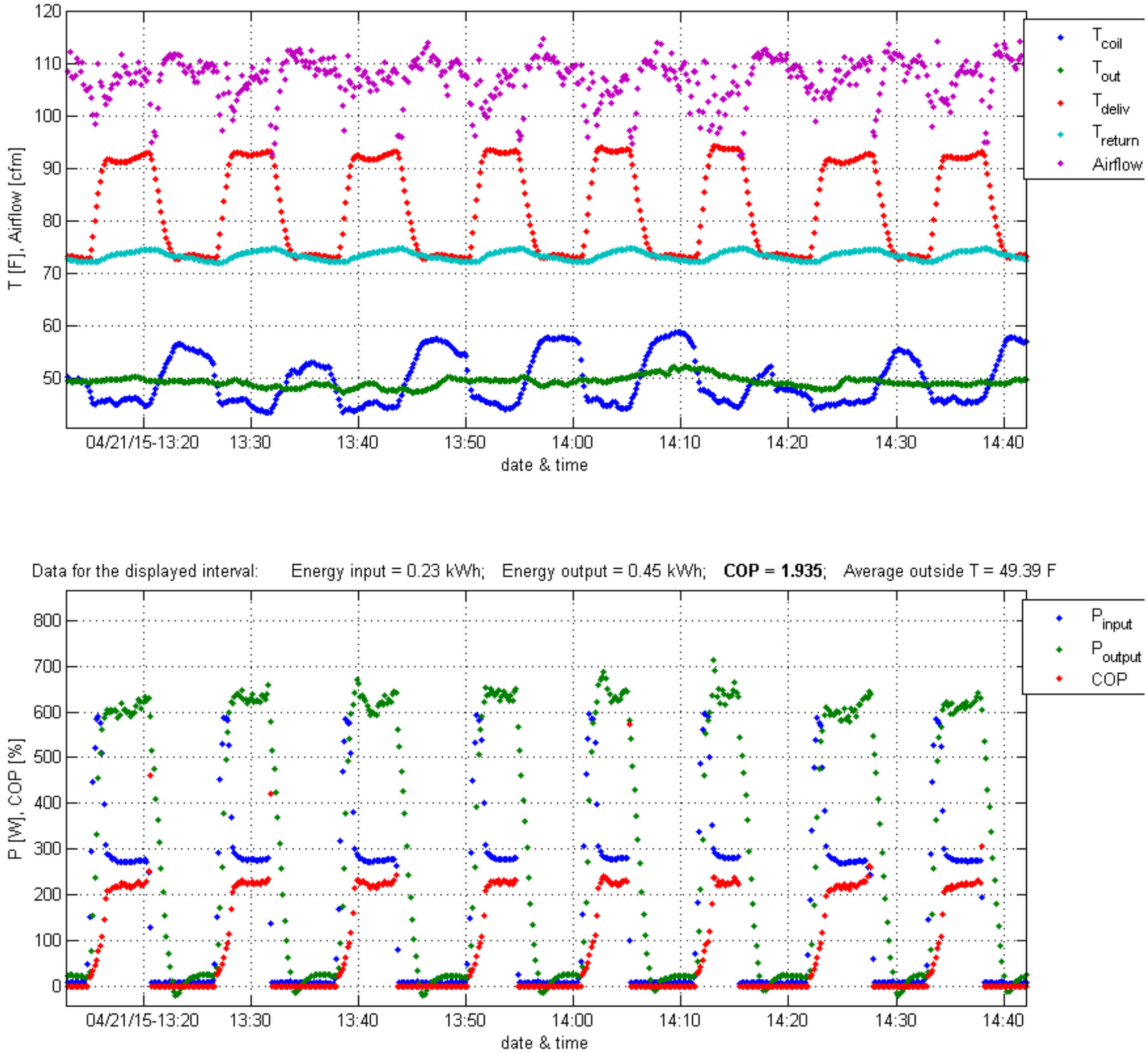

Figure 3. ASHP short-cycling in low-load conditions.

Because of both of these types of cycles (defrost cycling shown in Figure 2 and short-cycling in low-load conditions shown in Figure 3), the integrated performance of a heat pump can be significantly lower than the steady-state performance. This can be seen in Figure 4, which shows the steady-state and integrated COPs as a function of the outdoor temperature for all three heat pumps included in the study.

Figure 5 shows that the maximum heating capacity decreases as the outdoor temperature decreases.

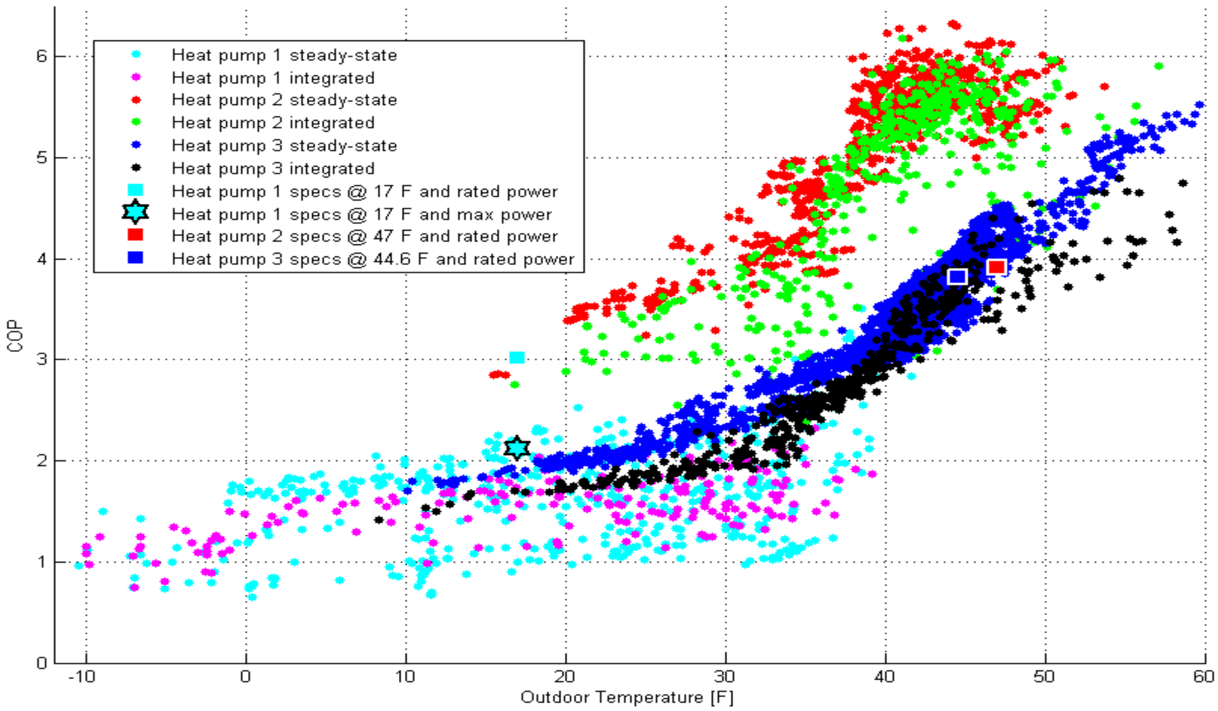

Figure 4. COP versus outdoor temperature for all three heat pumps.

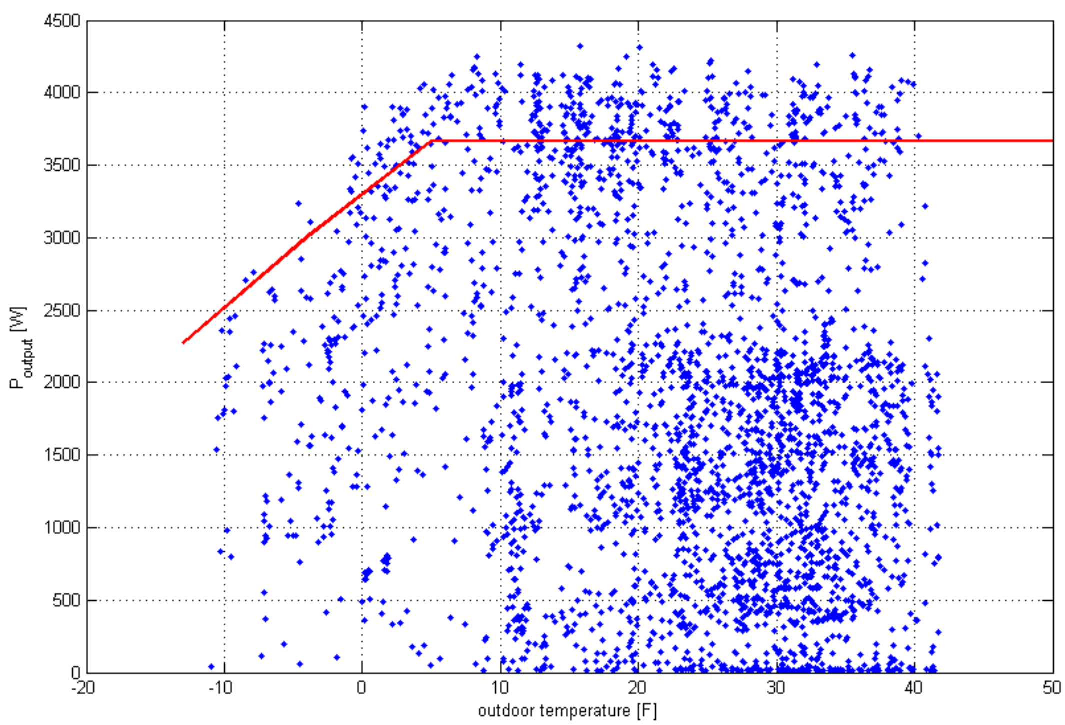

Figure 5. Measured ASHP output power as a function of the outdoor temperature. The red line represents manufacturer's specifications for the maximum output power.

Mitchell et al. [2] performed a detailed field monitoring of an ASHP in Seward, Alaska. The study found the COP to be significantly below the manufacturer's specifications.

Practical Considerations for Cold Climates

Performance of ASHPs in cold climates depends on many factors. Northeast Energy Efficiency Partnerships (NEEP) has valuable resources for installing and operating ASHPs in cold climates [6]. Analysis North maintains an online calculator to estimate the financial return of installing a mini-split heat pump in an Alaska home [7]. Additional practical considerations are summarized below.

Need for a backup heat source in cold climates

As shown in Figure 5, the capacity of an ASHP decreases as the outdoor temperature decreases. That is the opposite of the trend for the heat load of the building, which increases as the outdoor temperature decreases. Every heat pump model has a defined temperature operating range, with the coldest ones going down to about -20 °F. Therefore, it is strongly recommended that a building has a backup heat source in addition to the ASHP, as in very cold temperatures when heat is needed the most the ASHP output is reduced or none at all. In addition, due to the low efficiency at cold temperatures, the ASHP is the most expensive to operate at low temperatures and may not be cost-effective compared to other sources of heat.

Considerations of the source of electricity and its efficiency

Whether or not an ASHP is saving energy overall depends on its COP, the type and efficiency of the source that is providing the electricity for the ASHP, and the type and efficiency of the heating system that would be used if the ASHP wasn't used. For example, many rural Arctic communities use diesel for electricity generation as well as heating buildings via combustion heating appliances. In rural locations, a normal diesel-fired heating appliance is around 75% efficient, while a normal diesel power plant is around 30% efficient. It means that with a COP of around 2.5 (75% divided by the 30%) for the ASHP, the amount of diesel consumed in the power plant to supply the electricity for the heat pump is about the same as the amount of diesel that would have to be consumed in a diesel-fired heating appliance to provide the same amount of heat. It means that a COP greater than 2.5 for the ASHP is needed to save fuel in this specific example. As shown in Figure 4, a COP of 2.5 is very difficult to achieve in very cold temperatures.

Outside air cutoff temperature

Some ASHP models automatically turn off the heat pump when the outside temperature drops down to the lower end of their operating range. Other ASHP models continue to run even below the lower end of their temperature operating range, but their behavior is unknown as it operates outside the temperature range for which the ASHP was designed. Such operation can potentially void the warranty. In some situations, when an ASHP operation in very cold temperatures is desirable, it is advantageous to have an ASHP with a temperature operating range going down to very cold temperatures. On the other hand, where fuel savings is the desired outcome, it can be advantageous to have an ASHP with a higher cutoff temperature and have such an ASHP model that automatically turns itself off at the cutoff temperature. As the COP at very cold temperatures can be very low, such a feature can prevent the ASHP from inefficient operation and thus wasting fuel, assuming a more efficient backup heating system is available for those temperature and its thermostat is set to a slightly lower temperature than the ASHP thermostat, so when the ASHP cuts out and indoor temperature starts dropping, this backup heating system automatically turns on.

Sizing variable-speed ASHPs in cold climates

The COP of a variable-speed ASHP depends not only on the outdoor temperature, but it can also significantly depend on the heat load. Anecdotal data shows that partial loading, as opposed to full loading, increases the COP for some models of ASHP, while it decreases the COP for other models of ASHP [5]. These partial-loading effects have significant implications for sizing ASHPs, but third party data on the COP of ASHPs at different heat loads is scarce. Due to this lack of data, to the knowledge of the authors, there are currently no verified guidelines for sizing ASHPs in cold climates that take partial-loading effects on efficiency into consideration.

References

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