June 2018

CASE STUDY 2

Field Test of Cold Climate Air Source Heat Pumps

BACKGROUND

This field study is an extension of the recently completed CARD field study of flex fuel and ductless cold climate air source heat pumps (ccASHPs) in six homes. Research staff monitored a new-to-the-market ccASHP that wasn't available at the launch of the CARD study. This system was installed in two occupied Minnesota homes. The ccASHP systems were provided by Mitsubishi Electric Cooling & Heating and installed by a licensed contractor. This case study reports on the results of an installation in a single-family Minneapolis home. The ccASHP replaced an existing forced air furnace and split system air conditioner.

Site Characteristics

- Two-bedroom, one bath, 1.5 story single-family home
- Bungalow built in 1924
- 1,600 square feet
- Located in Minneapolis, Minnesota
- Two occupants
- 26,000 Btu/hr measured heating load at -11ºF

FIELD WORK

The project team installed detailed monitoring equipment to determine installed performance of the cold climate air source heat pump. Data was gathered at a one-second resolution and downloaded daily via a cellular modem connection. The instrumentation allowed for measurement of system temperatures, component runtime, energy consumption, energy delivery, and real-time coefficient of performance (COP).

Equipment

A 3-ton cold climate air source heat pump was installed, which is equipped with an 18 kW electric resistance booster heater. The system included a wireless programmable Wi-Fi enabled thermostat and lockout controls on the booster heater to limit the runtime and allow the heat pump to meet the majority of the heating load.

Table 1. CcASHP manufacturer specifications

Make	Model	Rated Capacity (Btu/h)		SEER	HSPF	COP at 47 ºF	COP at 17 ºF	COP at 5 ºF
		Cooling	Heating					
Mitsubishi Electric	PUZ-HA36NHA5	33,000	38,000	17.8	11.0	3.48	2.62	1.82

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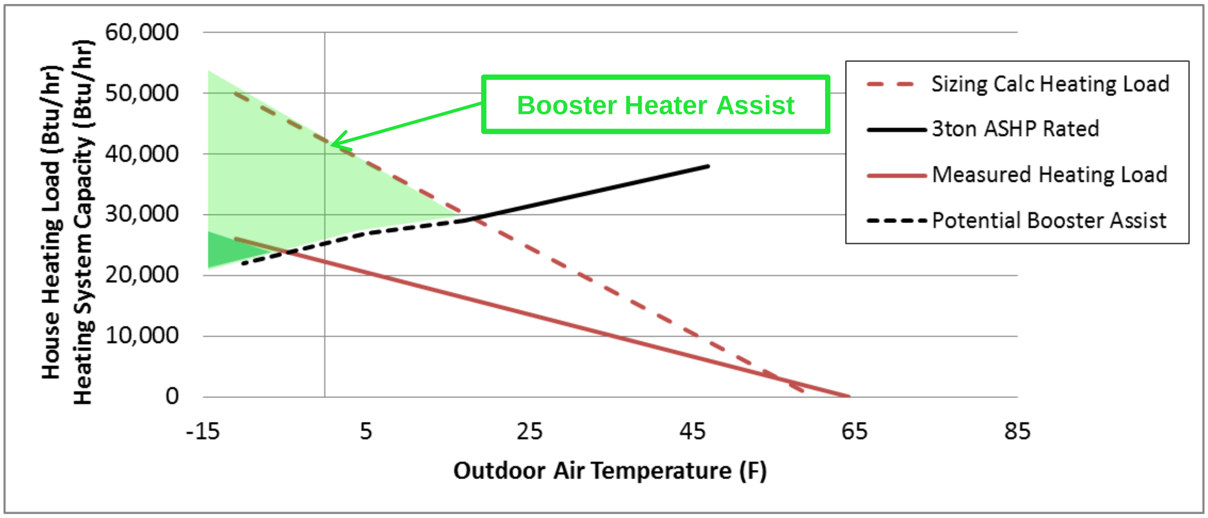
Figure 1. Indoor Unit

Figure 2. Outdoor Unit

Sizing

The system was sized based on the home's heating load (as opposed to cooling load) and resulted in an increase in capacity of 1 ton. The system includes an inverter-driven compressor that allows the system to modulate its capacity and meet the load of the home down to very low outside air temperatures. The electric resistance booster was a non-original equipment manufacturers product (or OEM) in order to test different options of lockout and auxiliary heat configurations. This booster was controlled based on supply air temperature and outdoor air temperature to limit the total runtime. The heat pump was still allowed to run during boost events to provide a fraction of the heating load to the home. Figure 3 (below) shows the house heating load and the heat pump capacity over the range of heating season outdoor temperatures. The house heating load calculated during the equipment sizing (dashed red line) was considerably larger than the measured heating requirements of the home (solid red line). This was likely due to the oversizing safety factor and the occupant's usage patterns and behaviors. The lower than expected usage has reduced the fraction of booster heat necessary at this site.

Figure 3. Capacity vs. Outside Air Temperature

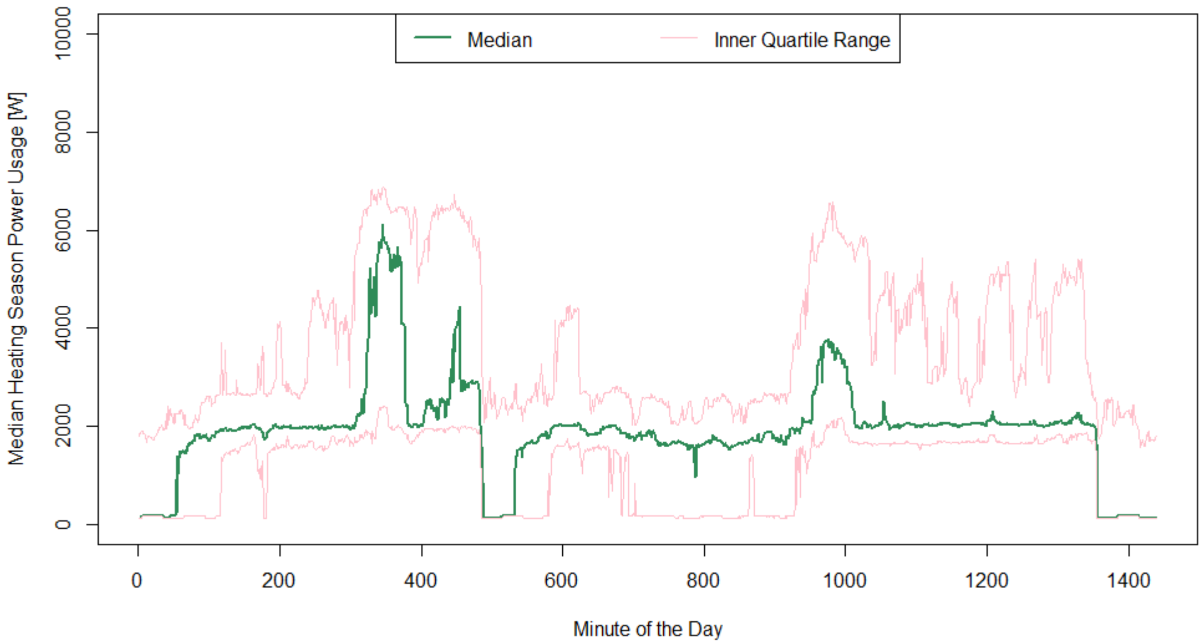


FINDINGS

Detailed data was measured during the winter of 2017/2018 and used for the analysis to characterize the performance of the system, which is summarized below. Generally the system met expectations, both in terms of the performance as well as homeowner satisfaction. There were no comfort complaints during the study and the system was fully able to meet the house heating load at extreme outside conditions.

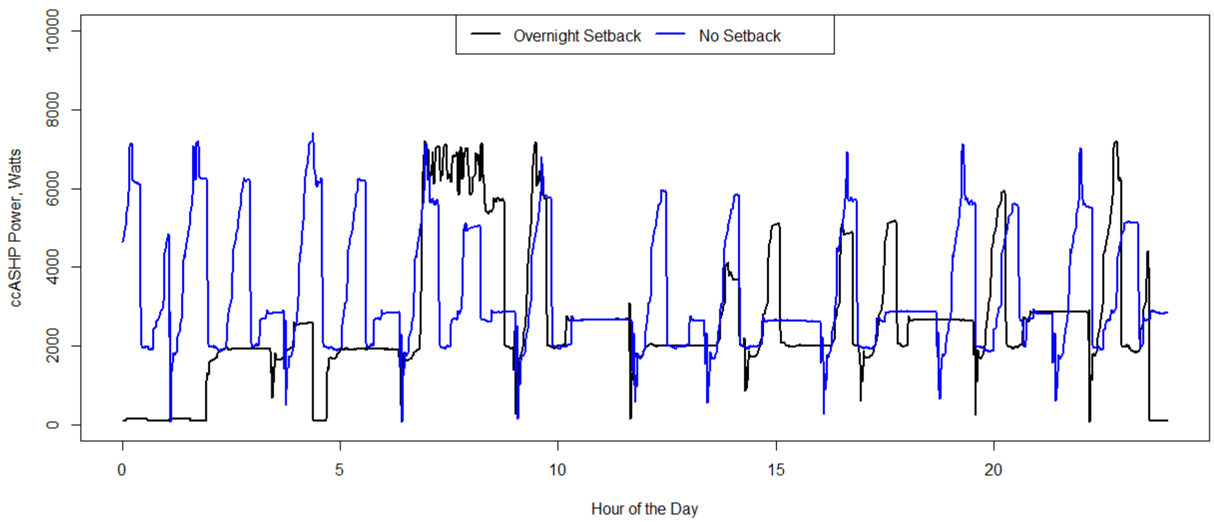
The homeowner programmed the thermostat for two setback periods; during the workday and overnight. This had an impact on the use profile of the heat pump because it had to increase the space temperature of the home eight degrees twice a day. This led to the heat pump running at higher capacities and more booster heat events, compared to maintaining a constant setpoint. Figure 4 shows the usage profile for the cold climate air source heat pump with setback. The figure shows the median use (green) and the range for the 25th and 75th percentile days. This figure also shows the increased power draw in the morning and evening, where the system is recovering from setback. The maximum power draw of the heat pump was 7,400 watts, while the maximum of whole system (heat pump plus booster heater) was much higher (20,210 watts) due to the high max power draw of the booster heater. The median power draw of the heating system was 2,275 watts.

Figure 4. Median energy use profile for space heating with a ccASHP



The homeowner's preference was to operate the home with a setback, both overnight and during the work day. The house was typically set at 70 ºF, both setbacks were 8 ºF. The standard overnight set back was seven hours, while the work day setback was for eight hours on weekdays. The homeowner was asked to forgo the setback a portion of the monitoring period. Figure 5 shows a comparison of the energy use profile by the cold climate air source heat pump system on two days with similar outdoor air temperature conditions (daily average OAT was 20ºF on both days). The figure shows that the maximum power consumption was not significantly different, but the ccASHP had an increased high use period during recovery from setback. This setback could have negative repercussions if recovery from setback is coincident with utility peak demand or an increased time of use rate for the homeowner.

Figure 5. Comparison of the heating system power use of two similar days with and without thermostat setback



Conclusions

Performance data was collected for the cold climate air source heat pump from December 2017 through May of 2018, which included 4,973 HDDs and temperatures as cold as -6 ºF. This data was used to create heating system performance curves for the ccASHP with electric resistance booster heat (Figure 6). These performance curves were used with typical Minneapolis weather data (TMY3) and performance curves for baseline heating systems to calculate the weather normalized annual system performance for this home (Table 2).

Figure 6. Coefficient of Performance vs. Outside Air Temperature

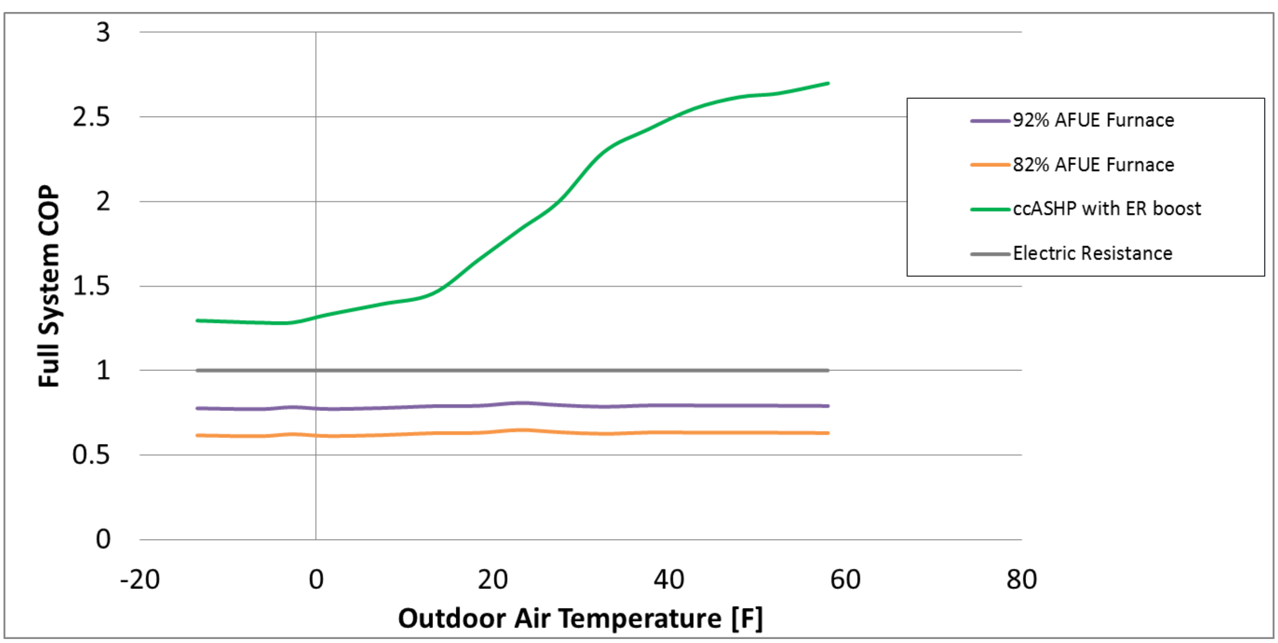


Table 1. A comparison of the weather normalized annual performance for several heating systems in this Minneapolis home.

	Heating Load	Annual COP	Electric Use	LPG use	Natural Gas Use	Total Energy Use	Annual Operating Costs[1]	Emissions[2] CO_2
	mmBtu	-	kWh	therms	therms	mmBtu	$	eqiv lbs
ccASHP w/ ER boost	63.1	1.84	10,075	0	0	34.3	$1,310	11,499[3]
Electric Resistance	63.1	0.99	18,491	0	0	63.0	$2,404	21,104
LPG Furnace	63.1	0.79	503	747	0	76.4	$1,404	11,650
Natural Gas Furnace	63.1	0.79	503	0	747	76.4	$807	9,699

1. Average residential pricing in 2017 for propane, natural gas, and electricity from Energy Information Administration were $0.13/kWh for electricity, $1.57/gallon for LPG, and $0.95/therm for natural gas.
2. Monthly average emissions in 2017 monthly were used. For electricity, 1.14 equivalent lb/kWh, 11.7 lb/therm for natural gas, and 13.0 lb/gal for LPG (See Edwards et al 2018).
3. Using Xcel Northern States Power value of 0.894 lbs/kWh[1] the ccASHP with ER booster annual emissions would be 9,007 equiv. lbs, a 2% reduction over the natural gas furnace.

The heating system performance comparison consists of three main metrics: energy use, operating costs, and emissions. The cold climate air source heat pump with electric resistance boost showed significant reduction in total energy use over all baseline systems (a 55% reduction of furnaces and 46% compared to electric resistance). The ccASHP also showed a cost and emission reductions compared to electric resistance heating or a liquefied petroleum gas furnace. At current costs a natural gas furnace still has lower operational costs and emissions than the ccASHP today. However, many utilities offer programs (or are considering programs) that have reduced rates based on time of day or type of use (i.e. space heating). Operating a ccASHP at a reduced rate of $0.075/ kWh or less will result in operational costs lower than a natural gas furnace. Additionally, Minnesota's electrical grid has and plans to continue reducing the grid emissions. This work will results in the ccASHP having comparable carbon emissions to a natural gas furnace in the next five to ten years[2].

The site saw an energy reduction of over 50% and the installation of an all-electric heat pump helped achieve the homeowner's goal of switching to an all-electric home. The heat pump was able to meet over 90% of the annual heating load and the booster heater added the remaining. However, the homeowner's operational cost increased compared to their previous natural gas furnace. The all-electric heating pump would require an electric rate of $0.065 per kWhr to achieve the same operational costs as a natural gas condensing furnace. Although not significant for this analysis, the homeowner is excited to add solar panels to the home, which should drastically decrease or eliminate the cost to run the cold climate air source heat pump.

[1] https://www.xcelenergy.com/staticfiles/xe-responsive/Company/Corporate%20Responsibility%20Report/CRR-Performance-Summary.pdf

[2] Edwards et al. 2018. "Brrrrr…! The Outlook for Beneficial Electrification in Heating Dominant Climates." ACEEE Summer Study on Building Efficiency. Asilomar, CA.

Performance Highlights

- The annual weather normalized heating load is 631 therms per year (63 MMBtu)
- Condensing furnace would use 750 therms and 500 kWh (76 MMBtu)
- All-electric heat pump uses 10,000 kWh (34 MMBtu)
    - 56% reduction in homeowner site energy
    - 7% cost savings vs. propane (60% increase vs. natural gas)
    - Breakeven on co2 emissions vs. propane
    - 91% of annual heating load met by heat pump without electrical resistance boost
    - Annual whole system COP of 1.85

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