June 2018

CASE STUDY 1

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 (ccASHP) in six homes. Research staff monitored a new-to-the-market ccASHP that was not 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 a ccASHP installed in one unit of a recently completed St. Paul duplex.

Site Characteristics

- Duplex built in 2016
- Lower unit has the basement and 1st floor
- 2,800 square feet finished area
- Located in St. Paul, Minnesota
- Two occupants

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 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 2.5 ton cold climate air source heat pump was installed, which is equipped with a 10 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 °F	COP at 17 °F	COP at 5 °F
		Cooling	Heating					
Mitsubishi Electric	PUZ-HA30NHA5	28,400	32,000	17.0	9.7	3.62	1.9	1.76

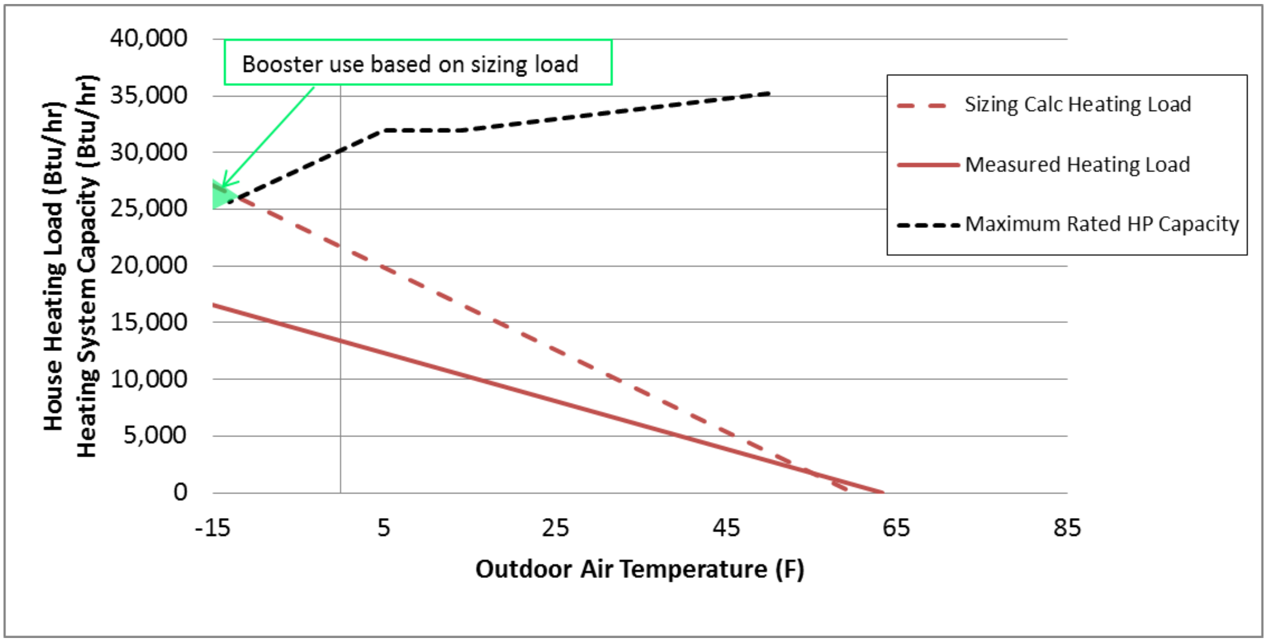
Figure 1-Indoor Unit

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 outdoor temperatures well below 0 ºF. The electric resistance 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. The green section in Figure 3 (below) shows the capacity that the booster would provide to meet the heating load above the black line, which shows the heat pump capacity. At this site, only a small fraction of the heating load was expected to require booster capacity. Additionally, the measured HVAC heating load (red solid line) was considerably lower than the calculated load (red dashed line). This was at least in part due to occupants' use of an additional heating source (a gas fireplace).

Figure 1. Capacity vs. outside air temperature



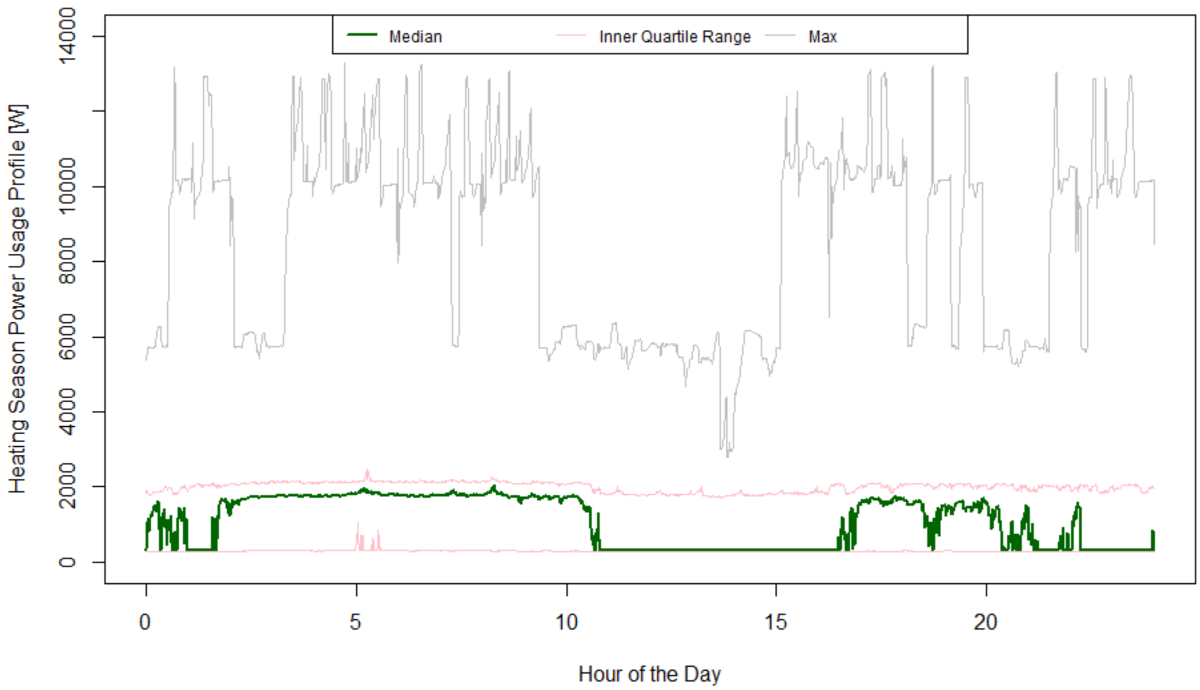
FINDINGS

Detailed data was measured during the winter of 2017/2018 and was 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 the homeowner satisfaction. There were no comfort complaints during the study and the system was able to meet the house heating load at extreme outside conditions.

The monitored unit was the lower half of a duplex that was built in 2016. The home was fully insulated with spray foam insulation, which resulted in the building having a much lower annual heating load than an average building of that size. Based on customer preference the system operated at a constant thermostat temperature setpoint during the duration of the project. This led to long heat pump runtimes and few booster heater events.

The site saw an energy reduction of 57% and an overall cost increase, versus a natural gas furnace. Figure 4 shows the usage profile for the cold climate air source heat pump system. The figure shows the median use (green), the range for the 25th and 75th percentile usage (pink), and the maximum use (grey). The median operating power for the system (heat pump and booster heater) was 1,805 watts, and for the heat pump without the booster the median power use was 1,803 watts. The maximum usage for the system was 13,274 watts and only a 6,377 watt maximum for the heat pump. The booster heater had a very large capacity, but was infrequently used. The heat pump ran at minimum capacity about 78% of the time it was in operation. The air source heat pump only required booster heat for 2% of its total runtime. During the monitoring period the measured outdoor air temperature was below 0 °F for 71.5 hours. The air source heat pump and booster system was operational for 53% of those hours and 24 of those minutes required booster heating, about 1% of the heating system runtime below 0 °F. Although not part of this analysis, the site was in the process of installing solar panels to further reduce the overall utility cost.

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



Conclusions

Performance data was collected for the cold climate air source heat pump from December 2017 through May of 2018, which included 5,382 heating degree days (HDD) 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 5). These performance curves were used with typical Minneapolis/St. Paul weather data (TMY3) and performance curves for baseline heating systems to calculate the weather normalized annual system performance for this home (Table 2).

Figure 5. Coefficient of performance vs. outside air temperature

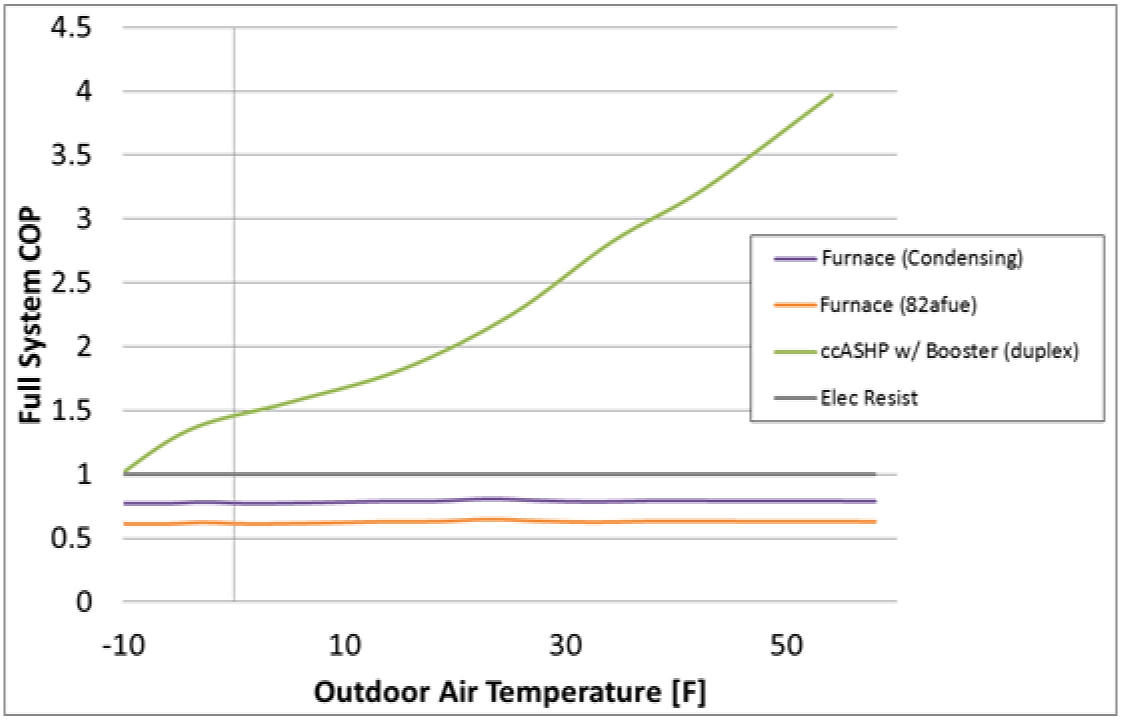


Table 2. A comparison of the weather normalized annual performance for several heating systems in this St. Paul duplex.

	Heating Load, MMBtu	Annual COP	Electric Use, KWh	LPG Use, therms	Natural Gas Use, therms	Total Energy Use, MMBtu	Annual Operating Costs[1] $	Emission[2] CO_2 Eqiv. Lbs
ccASHP w/ ER boost	37.4	1.83	5,994	0	0	20.5	$779	6,844[3]
Electric Resistance	37.4	0.99	10,964	0	0	37.4	$1,425	12,519
LPG Furnace	37.4	0.79	299	463	0	47.3	$832	6,908
Natural Gas Furnace	37.4	0.79	299	0	463	47.3	$479	5,751

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 the NSP value of 0.894 lbs/kWh[1] the ccASHP with ER booster annual emissions would be 5359 equiv. lbs, a 10% reduction over the natural gas furnace.

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

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 57% reduction of furnaces and 45% compared to electric resistance). The ccASHP also showed cost and emission reductions compared to electric resistance heating or an LPG 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. The state-wide space heating emissions factor was 1.14 equivalent pounds per kWhr in 2017. A ccASHP with electric boost will have the same carbon emissions as a natural gas furnace at an emissions factor of 0.95 lbs/kWh. Minnesota electrical grid plans will reach these in the next five to ten years[2], while Xcel Energy's Northern States Power (NSP) emissions factor has already surpassed that level at 0.894 lb/kWh.

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 maintaining a low cost electrically heated home. The heat pump was able to meet over 98% of the annual heating needs of the central system and the booster heater added the remaining 2%. The property owner was happy with the system performance and anticipates new solar panels drastically decrease or eliminate the mechanical heating costs for this home.

Performance Highlights

- The insulation and energy measures at this site were effective. The design heating load on the mechanical system in this 2,800 sq. ft. unit was only 15,759 Btu/hr. The occupants occasionally used some supplemental heating (fireplace) which was not monitored in detail.
- Condensing furnace would use 473 therms and 298 kWh (47 MMBtu) to heat this home.
- All-electric heat pump uses 5,994 kWh (20 MMBtu):
  - 57% reduction in homeowner site energy.
  - Breakeven on co2 emissions vs propane.
  - An annual system COP of 1.82.
  - 98% of annual heating load met by heat pump without electric resistance boost.
  - Average system performance below 0 ºF was a COP of 1.27 and a delivered capacity of 23,200 Btu/hr.

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