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Memorandum

To: Tom Eckman, Northwest Power and Conservation Council and Regional Technical Forum (RTF); Ken Eklund, Idaho Office of Energy Resources; Kacie Bedney, Bonneville Power Administration (BPA)

Date: December 14, 2009

Re: Analysis of Hallowell Cold Climate Heat Pump Data, McCall, ID and Portland, OR

In September 2008, Ken Eklund requested assistance from the RTF in analyzing a set of data taken in spring, 2008 on a 4-ton Hallowell Cold Climate Heat Pump located in McCall, ID. The system was installed in October 2007 under contract with the Idaho Office of Energy Resources with funding from Idaho Power and the Northwest Energy Efficiency Alliance for the express purpose of monitoring its performance. Bonneville Power Administration had been monitoring the system since October 31, 2007 using the Micro DataLogger system from Architectural Energy Corporation. Ecotope wrote a technical memo in November 2007 after making a visit to the McCall site. At that point, Ecotope noted the performance of the system was very poor (see Table 1). This conclusion was based on the data that had been collected by BPA and on measurements of system airflow that were taken during the site visit.

Table 1: Summary of Test Results
(Onetime tests done on November 27, 2007; outdoor air temperature 35º F during tests.)

Mode 1 airflow (SCFM)	783
Mode 1 temp. rise (ºF)	17
Mode 1 thermal output (Btu/hr)	14380
Mode 1 OD unit current (amps)	8.5
Mode 1 indoor unit current (amps)*	2.1
Calculated Mode 1 COP	1.6
Mode 2 airflow (SCFM)	989
Mode 2 temp. rise (ºF)	24.5
Mode 2 thermal output (Btu/hr)	26169
Mode 2 OD unit current (amps)	15.1
Mode 2 indoor unit current (amps)**	4.1
Calculated Mode 2 COP	1.6
Mode 3 airflow (SCFM)	1016
Mode 3 temp. rise (ºF)	40
Mode 3 thermal output (Btu/hr)	43886
Mode 3 OD unit current (amps)	30.5
Mode 3 indoor unit current (amps)	4.5
Calculated Mode 3 COP	1.7

*External static pressure for Mode 1: 0.56” water column; 0.3” on supply side
**External static pressure for Mode 2: 0.88” water column; 0.5” on supply side
Supply, return and outdoor temperatures reported by AEC MDLs were spot checked and found accurate.

Observations from November 2007 On-Site Tests

Because of the control setup on this unit, staging is controlled by the combination of calls from the thermostat and outdoor temperature. Therefore, it may be that the "Modes" identified in Table 1 do not correspond exactly to the Modes described in the Hallowell literature. That being said, the measurements were taken when airflow rates had stabilized and the system had operated for at least 10 minutes at the measured airflows noted in the table. The main observation is that COP is poor at all three airflow rates.

Airflow is limited in Mode 2 (and therefore must also be in Mode 3, although the external static pressure was not measured in Mode 3) by high external static pressure (due mostly to inadequate supply-side duct cross-sectional area). The design heating load of the home and air requirements suggest a 2.5-3 ton system would be more appropriate. The Hallowell system needs to move maximum air at coldest outdoor conditions. With the current duct system, it is unlikely 1600 SCFM could be delivered. The current air handler board settings are on the lowest CFM for heat pump operation per the manufacturer's rep adjustment. Changing pin settings could result in more airflow but given the indoor unit is already drawing close to 1 kW to move about 1000 SCFM, it is not advisable to operate the fan at such high power usages and static pressures. However, the low airflow probably compromises heat transfer.

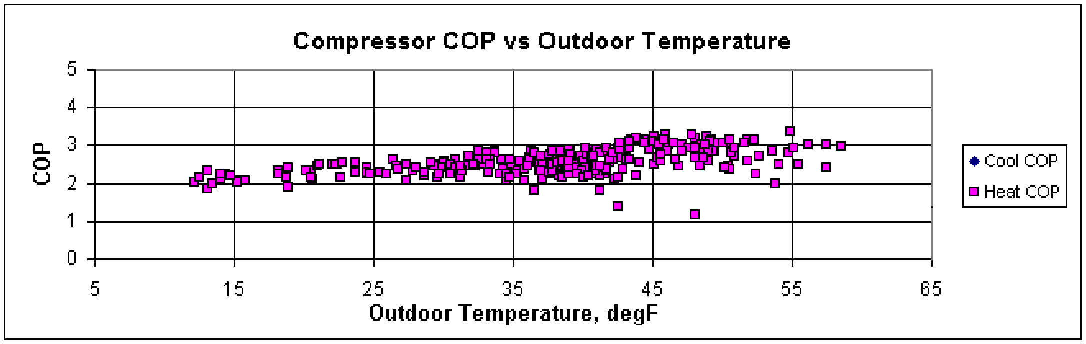
Ecotope obtained the power measurements directly by measuring current through one leg at the outdoor disconnect in Mode1 and Mode 2. Ecotope did not take this measurement in Mode 3 but instead looked at the maximum accumulated kW on the MDL datalogger over one monitoring period and divided by voltage to get the reported amps. It agreed closely with BPA's 1 minute data that for that Mode collected at a similar outdoor temperature to that measured during the one-time tests (about 35º F).

November 2007 Analysis

Ecotope did not have detailed output tables from Hallowell so was unsure of what to expect. Their color brochure suggested there should be a 99º F supply delivery temperature in Mode 1 at around 30º F. Ecotope measured about 95º F at 35 º F outdoor temperature. Ecotope also did not have detailed energy input tables, but Hallowell suggests a COP of 3.6 at 47 ºF for Mode 1 operation. Looking at the 1 minute data gathered by BPA in early November, there was some milder weather that includes temperatures around 50º F. In these conditions, even after longer operation cycles (about 20 minutes), the calculated COP in Mode 1 is about 2.0.

For further comparison, Ecotope includes data from a 3 ton heat pump installed in 2005 in Boise, Idaho. This data was collected as part of the State Technology Advancement Collaborative on Air Conditioners and Heat Pumps. This system uses the Bristol Twin Single compressor used by the Hallowell (but does not have a booster compressor like the Hallowell does). Figure 1 shows the system COP when only the compressor was operating for a two-week period in early February 2007. Each point is calculated for an hour where the compressor has operated by itself. This chart does not include periods where auxiliary heat is used or defrost has occurred.

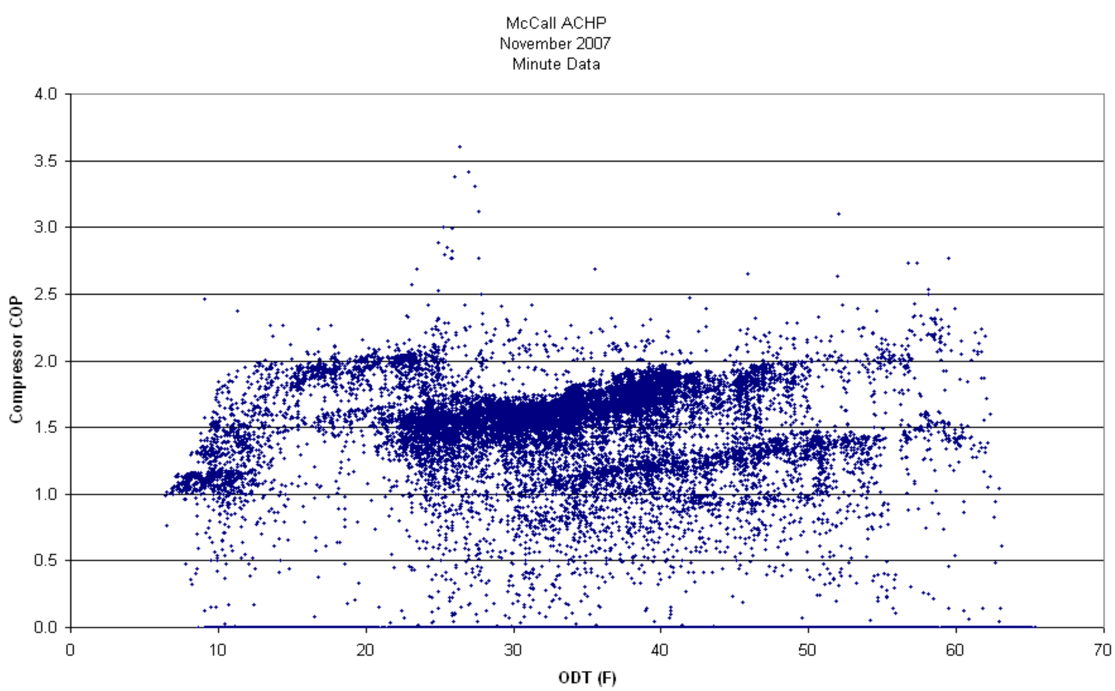
Figure 1: COP vs Outdoor Temperature



The Boise weather is milder than McCall; however, this monitoring period includes a useful range of outdoor temperatures that overlap well with recent (November 2007) McCall weather. It is clear that the COP in most instances is above 2 (even in colder bins); the average compressor-only COP for this monitoring period is about 2.5. As mentioned above, the best COP measured at the McCall site was about 2.0 (in Mode 1).

By comparison, the BPA data collected during November 2007 shows that the COP for compressor-only operation is between 1.0 and 2.0 (Figure 2). This direct comparison shows that in the warmer temperature bins, the McCall Hallowell system is performing about 1 COP point below the Boise system even though they are operating the same nominal capacity twin single compressor. Also note the Boise heat pump does slightly better than the McCall system at 10 to 15º F.

Figure 2: McCall ACHP, November 2007 Minute Data



New Data Analysis, McCall, ID Results

These data and observations about system sizing and external static pressure were sent to Hallowell in December, 2007. Hallowell considered replacement of the outdoor unit, but instead replaced the defrost board and adjusted system charge on the unit in February, 2008. Subsequently more performance data were collected later in 2008.

Data were provided by BPA in late October 2008 that covered an entire year of operation. The data were still in 1 minute format; Ecotope aggregated to 15 minute averages to speed analysis.

To follow the format used in November 2007, Ecotope broke out operation by Modes 1, 2, and 3; these Modes corresponded to discrete measured CFM levels at the indoor unit (as determined by looking at the amps measured on the indoor unit circuit). Mode 1 is the most common Mode observed during milder temperatures, whereas Mode 3 (which should involve both the primary and boost compressors, according to Hallowell) is most often seen at ambient temperatures below the mid-20s F.

Ecotope restricted analysis to cases where the delta T between supply and return air was at least 15º F (indicating a "warmed up" system) and also to cases where the COP was less than 4 (which will exclude some amount of tail cycle where the compressor is off but heat is still harvested). Overall one would expect these exclusions to help the COP somewhat.

Table 2: Summary of 2008 Operation

Mode	# of Observations[1]	Average Compressor Power (kW)	Average Air Hander (amps)	Average COP
1	1187	2.31	2.15	1.72
2	168	3.44	4.11	1.46
3	791	3.97	4.50	1.53

[1] 15 minute averages

COPs are still very poor at less than 2.0, on average. These data include times both before and after the repairs done in February 2007. Ecotope took a look at some of the one-minute data from periods later than February 2007 but did not note any systematic improvement in COP. So it may be the defrost operation was fixed but defrost is a very small part overall of the system energy usage (as noted by scanning through the one-minute data and noting the very modest amount of defrost-related energy). Ecotope also calculated COP when strip heat is added in (mostly in Mode 2 and 3) and found the overall effect was about a 5% reduction in COP.

Ecotope did not calculate the total thermal output of the system nor calculate an Energy Use Index (EUI) for the house. These would be interesting exercises. Ecotope has noted over several years that Hallowell has a tendency to downplay COP but focus on the limited amount of strip heat needed in colder bins. It appears this is the case in this system; however, the overall COP is remarkably poor even in milder temperature bins.

Portland, OR System Results

A 2.5 ton Hallowell system located in Portland, OR was instrumented by BPA in October, 2007 and 1-minute data were collected for over a year. Two site visits were undertaken by Ecotope and BPA in December 2008, and January 2009 to measure system CFM so that the Coefficient of Performance (COP) could be calculated.

The system can operate in five different modes (not including defrost), but two of the modes would be expected to occur only very rarely in the Portland climate. The system has a primary and secondary compressor; the primary compressor can employ one of two modes of compression. Modes M1 and M2 refer to how many cylinders are employed by the primary compressor; these modes are designed to operate under most weather conditions that apply in Portland (that is temperatures down to 25º F). Mode M3 adds one resistance element to full operation of the primary compressor. This mode is employed when there is a second stage heat call from the indoor thermostat and outdoor temperature is between 25º F and 35º F. Since performance of the compressor is of primary importance, Ecotope did not evaluate performance of the system in Mode M3.

The quickest way to summarize COP would be to express it versus outdoor temperature. There are two problems with this approach, the primary one being that the homeowner said that at least one of the temperature sensors on the outdoor unit had malfunctioned at some point during the monitoring. It was not clear if this was the primary outdoor sensor or the coil sensor (that would control defrost) but because there was some doubt, Ecotope did not summarize COP versus outdoor temperature. Also, it was not clear which airflow would be running through the system at a given outdoor temperature (since the mode of operation was not assured).

The solution to clearing up the possible inaccuracy was to evaluate the typical power readings for the outdoor unit in Modes M1 and M2. This was done at the site visits in December and January. Once these readings were taken, and once the proper system CFM was paired with each mode, it was straightforward to calculate and express COP by Modes M1 and M2.

Summary of Portland Results

The Table 3 shows the summaries for periods where Modes M1 and M2 could be conclusively identified (by looking at the outdoor unit power reading). Note the COP summaries are based on 1 minute data (hence the large number of observations). Measured airflow is 620 CFM for Mode M1 and 910 CFM for Mode M2 (TrueFlow air handler meter used).

Table 3: Summary of Portland Results

Mode	Observations*	Mean COP	Mean thermal output Btu/hr)	Mean delta T** (º F)
M1	48546	2.14	11650	17.4
M2	18537	2.03	22225	22.6

*Number of 1 minute data points used in summary
**Supply air temperature – return air temperature

The results for this system are not encouraging. If the average COPs are multiplied by the 3.413 conversion factor to move from units of COP to HSPF, the implied HSPF is about 7.0, which is slightly above the pre-2006 federal minimum standard for air-source heat pumps (6.8). It is true that in bins colder than 25º F, the Hallowell system would employ the boost compressor and avoid use of electric resistance heat. But the number of hours in those bins is very limited in Portland.

It is not clear why the system is performing as it is. One issue is that at the higher airflow (Mode M2), the air handler is working against almost one inch water column of external static pressure. This increases the fan energy and also means airflow is less than desired. The manufacturer of the fan coil only guarantees the airflow up to 0.6" external static pressure then indicates a downward adjustment must be made for extra external static pressure. Using the conversion predicts an airflow that turns out very close to what was measured. The airflow limitation and added fan energy are certainly part of the issue for Mode M2 but do not explain the poor performance in Mode M1.

To improve efficiency, the system would have to either increase output or decrease input. Ecotope does not have detailed performance information from Hallowell, but one notable item is the average output in each of the modes; Mode M1 shows average output of about 11,600 Btu/hr and Mode M2 shows average output of 22,200 Btu/hr. It would be helpful to know what outputs Hallowell expects for these modes as well as the expected input power so that possible improvements could be identified.

Conclusions

The McCall system's efficiency is very disappointing. It is due in part to the airflow problem. Without resolution of this problem, it is hard to know for sure how the rest of the system is really doing. Results from the Portland, OR site show a similar pattern.

The overall efficiency of each system is considerably less than one would expect from a standard, properly sized air–source heat pump when compared at the same outdoor temperature conditions. Based on these field tests, the Hallowell system cannot be considered a superior heating technology.