Analysis of Water Furnace Geothermal Heat Pump Sites in New York State with Symphony Monitoring Systems

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Analysis of Water Furnace Geothermal Heat Pump Sites in New York State with Symphony Monitoring Systems

Final Report

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Abstract

Detailed data were collected from 49 Water Furnace ground source heat pumps located in New York State with the Symphony monitoring systems installed. The detailed performance data was used to quantify the annual performance of the installed systems. The measured data were used to determine average temperatures from the ground loop heat exchanger as well as to determine average seasonal efficiencies, energy savings, and cost savings. The results demonstrated that the average loop temperatures were about 40˚F across all the Upstate NY sites. No definitive performance differences between loop type were found. Average seasonal heating COPs were 3.6, including the impact of fans, pumps and auxiliary heat. The overall results show that a hypothetical house with an average heating load (50 MMBtu per year) that switched from fuel oil heating to geothermal can be expected to save about \$680 per year ±\$119, at the 95% confidence level.

Keywords

ground source heat pumps; geothermal thermal heat pumps; field monitoring; performance verification

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Acronyms and Abbreviations

COP	coefficient of performance
DHW	domestic hot water
DOE	US Department of Energy
EER	energy efficiency ratio
EIA	U.S. Energy Information Administration
ETAC	Emerging Technologies and Accelerated Commercialization (NYSERDA program)
EWT	entering water temperature
ft	feet
GHP	geothermal heat pump, or ground-source heat pump
GW	gigawatts
kW	kilowatts
kWh	kilowatt hours
LWT	leaving water temperature
m/s	meters per second
MMBtu	million British thermal units
MW	megawatts
NYS	New York State
NYISO	New York State Independent System Operator
NYSERDA	New York State Energy Research and Development Authority
P95	95% confidence interval
SEER	seasonal energy efficiency ratio
W	watts

Summary

This report evaluates data from 49 residential Water Furnace geothermal heat pump systems located in Upstate New York that have the Symphony monitoring system installed. Nearly all the sites provided nearly 12 months of data. For all but one of these systems, further information was obtained from the installer about the ground loop and the house.

S.1 On-Site Verification

For three of the heat pump units, handheld instruments were used to verify the Symphony readings. This comparison showed the following trends for the Symphony readings relative to our handheld readings:

- Loop flow rates were typically higher by 10-15%
- Compressor power was 10% lower than expected for dual stage units and 9-15% higher than expected for the inverter driven units
- Auxiliary heat power was lower by nearly 10%
- Loop temperature differences were very close to the handheld readings

Assuming the handheld readings are more accurate, these systematic measurement biases imply that the heating COPs and capacity reported by Symphony could be higher than the true values. Additionally, measured seasonal heating COPs were systematically higher than published performance data, which would seem to corroborate this finding.

S.2 Loop Temperatures

Various loop types are included in this sample of GHP systems. While vertical bore loops tended to have slightly warmer temperatures than horizontal loops, the trends were not definitive. The average weighted entering loop temperature for all the loops in the heating mode was 40°F. About one-third of the systems had minimum temperatures that dropped below 30°F at some point. Four of the systems dropped below 25°F.

S.3 Seasonal Heating COPs

Seasonal heating COPs were corrected using a factor developed by comparing measured efficiency at steady state conditions to expected efficiency from the manufacturers published or expected data. The average corrected seasonal heating COP after factoring in both pumping power and resistance heat was 3.6. Seasonal COPs were higher at sites with warmer average entering water temperatures. Sites with higher heating loads had heating COPs closer to the average.

S.4 Pumping Energy

Pumping energy varies widely, from 3% to 30% of compressor energy. There were some problems in the pump power reported by Symphony, especially for dual stage units. Still, variable speed units with properly commissioned variable speed pumping had pumping energy toward the lower end of the range. The overall trends showed that pumping power had a noticeable impact on the seasonal heating COP, reducing it from 4.0 to 3.5 as pump power increases from 5% to 20% of compressor power.

S.5 Utility Impacts

The load shape for residential GHPs would be beneficial for New York’s utility grid:

- GHP energy use is highest on the coldest days, with a slight peak in the early morning hours. Generally, system-wide demand for the grid is moderate for these days and this winter load can easily be met with existing resources.
- GHP energy use still increases on the hottest summer days, but the peak demand is significantly attenuated compared to traditional (air-source) cooling technologies. Replacing one million air conditioners with geothermal heat pumps would reduce the State’s summer peak by more than 1 GW.

S.6 Heating Cost Savings

GHP system heating energy costs were compared to various base case system costs that use different fuels. The study used local fuel and electric costs for winter months in 2016. Results showed heating cost savings were primarily a function of the annual heating load. Using fuel oil as the base fuel, the heating cost savings were $680 per year assuming an annual heating load of 50 MMBtu. The 95% confidence interval for heating savings was ±$119 per year across the range of loads. Heating savings were $212 per year compared to a base system using natural gas and $1,459 per year compared to a base system using propane.

When cost savings for cooling are considered, the total annual savings increase to $760 (using fuel oil as the base heating fuel) at a 50 MMBtu annual heating load. The 95% confidence interval for total savings increases from ±$171 per year.

These results are good news for investors in the residential geothermal retrofit market. Annual energy cost savings can be predicted to within $100 simply by accurately knowing the heating fuel use for an existing home—despite the observed variations in system performance. If other issues such as loop design and pumping strategy can be better understood and controlled, then the certainty of cost savings can be even further improved.

1 Introduction

1.1 Background

Water Furnace is a leading manufacturer of ground-source—or geothermal—heat pumps (GHPs). Numerous Water Furnace systems are installed in New York State. Many of their high-performance dual-stage and variable-speed heat pump systems include the Symphony monitoring system. This monitoring system has been built into the unit controls since 2012. It records data at 10-second intervals and then transmits that data to a server via the homeowner's WiFi internet connection. Data are saved in a database and presented on a website that summarizes both current and historic performance. The Symphony monitoring system has three options:

- Electrical energy consumption monitoring (kW/kWh for each component)
- Refrigeration monitoring (pressures and temperatures for the system)
- Performance monitoring (water flows and temperatures, air-side temperatures)

More than 190 heat pumps with Symphony systems were installed throughout the State as of August 2016. For some of the systems, data collection started as early as April 2015. The 190 systems offer a large data set to evaluate the performance of residential geothermal systems.

1.2 Goals

This large data set was analyzed to quantify the seasonal heating and cooling efficiency of these GHP systems. It also provides the ability to quantify the profile of ground loop temperatures for a large sample of residential systems, and therefore, to further understand the impact loop configuration and design details have on entering fluid temperatures and seasonal performance.

The data sets for each site were analyzed to understand the performance of GHPs. This analysis supports NYSERDA's market transformation activities under the Emerging Technologies and Accelerated Commercialization (ETAC) program. The data analysis effort seeks to answer the following research questions:

- **Utility Impacts.** What impact do residential GHPs have on the electric utility grid? What is the load profile across the day during various seasons of the year?

- **Finance Community.** What is the range of performance (e.g., loop temperatures, seasonal efficiency, annual energy use and savings, and resulting cash flows) for the sample of systems at 95% confidence intervals (P95)? Can performance variations be correlated to (or predicted by) basic system characteristics that are known with high certainty (such as ground loop details, heat pump sizing, or annual loads)?
- **Thermal Measurement.** Do the flow and temperature sensors used in the Symphony system determine thermal loads with a high enough confidence level for tracking and billing ground loop performance in third-party ownership arrangements?

This report analyzes the performance data from these systems and attempts to answer these questions.

2 Site and System Characteristics

Forty-nine of the Water Furnace GHP sites in the State were included in this study (Table 1). The selection criteria were based on the number of months of available data, the percentage of data available (related to the quality of the communications connection), and whether the more detailed data set was collected at the site. In addition to the detailed data provided by the Symphony system, GHP installers were contacted to gather further information for each site, including house size and ground loop details. Information was obtained on all but one of the homes. The loop type code listed in Table 1 is described in Table 2. Further details about each site are included in Appendix A.

Table 1. Site and GHP System Characteristics

Site ID	Model	City	Application	Loop Type	Months of Data	Percentage of Available Data
s01	NVV060	Scottsville	retrofit	H2	12	98%
s03	NVV036	Macedon	retrofit	H2	11	82%
s04	NVV048	Ballston Spa	retrofit	V1	12	100%
s05	NVV060	Bloomfield	retrofit	H2	12	99%
s06	NVV036	Amsterdam	retrofit	V1	12	84%
s07	NDH064	Troy	retrofit	HS	12	93%
s08	NDV049	Niskayuna	retrofit	V1	12	99%
s09	NDV049	Niskayuna	retrofit	V1	12	100%
s10	NVV060	Lima	retrofit	H2	12	96%
s11	NVV060	Victor	new	H4	12	92%
s13	NVV060	Lima	retrofit	H2	12	87%
s14	NDV072	Victor	new	H6	6	85%
s15	NVV048	Honeoye Falls	retrofit	H2	11	86%
s17	NVV048	Stillwater	new	HS	12	94%
s18	NVV048	Honeoye Falls	retrofit	V2	12	82%
s19	NVV060	Keuka Park	new	V2	12	94%
s20	NVV060	East Aurora	new	HS	12	94%
s21	NVV048	Prattsburgh	retrofit	HS	12	99%
s22	NDV064	Troy	retrofit	V1	12	100%
s23	NDV038	East Amherst	new	HS	12	91%
s24	NVV048	Ashville	retrofit	HS	12	99%
s25	NVV048	Saratoga Springs	new	HS	12	93%
s26	NVV060	Wyoming	retrofit	HS	12	94%
s27	NVV060	Buffalo	retrofit	HS	12	93%
s28	NVV036	Blossvale	retrofit	H2	12	93%
s29	NDV064	Altamont	retrofit	V1	11	91%
s30	NDV064	Cassadaga	retrofit	HS	12	97%

Table 1 continued

Site ID	Model	City	Application	Loop Type	Months of Data	Percentage of Available Data
s31	NVV060	Ballston Spa	new	Pd	11	81%
s32	NVV036	Akron	retrofit	HS	12	99%
s33	NVV036	Hector	retrofit	V1	12	89%
s34	NVV048	Rexford	retrofit	V1	12	92%
s35	NDV072	Ballston Spa	retrofit	Pd	12	72%
s36	NVV036	Hornell	retrofit	HS	12	96%
s37	NDV049	Greenwich	retrofit	HS	12	95%
s38	NDV026	Chestertown	retrofit	V1	12	95%
s39	NVH036	Lake George	retrofit	H2	12	99%
s40	NDV038	Saratoga Springs	retrofit	V2	12	89%
s41	NVV048	Millerton	retrofit	Op	12	93%
s42	NVV060	Penn Yan	retrofit	V2	12	87%
s43	NVV060	Amsterdam	retrofit	V2	12	92%
s44	NDH049	Penn Yan	retrofit	HS	12	92%
s45	NVV036	Penn Yan	retrofit	HS	12	97%
s46	NVV036	Albion	N/A	N/A	12	98%
s47	NDV049	Trumansburg	retrofit	V2	12	90%
s48	NVV036	Rhinebeck	retrofit	V1	12	98%
s49	NVV048	Glens Falls	retrofit	V1	12	93%
s50	NDV038	Ticonderoga	retrofit	Op	12	89%
s51	NVV036	Lake George	new	V1	12	99%
s52	NVV036	Gansevoort	retrofit	V2	12	99%

Note: There are no site details for S46, so that site was excluded from some of the analysis. All these units included detailed "Performance Data" as described in the next section.

Table 2. Description of the Ground Loop Code

Loop Code	Loop Description
H2	Horizontal Loop with 2 pipes in trench
H4	Horizontal Loop with 4 pipes in trench
H6	Horizontal Loop with 6 pipes in trench
HS	Horizontal Loop with Slinky
V1	Vertical Loop (1 U-bend per bore)
V2	Vertical Loop (2 U-bends per bore)
Pd	Pond Loop
Op	Open Loop

3 Symphony Monitoring System

The Symphony monitoring features are available on the Water Furnace Series 5 dual-stage heat pumps (model numbers beginning with ND) as well as the Series 7 variable-speed heat pumps (model numbers beginning with NV). The standard ND units offer energy monitoring, while in the standard NV unit, Aurora™ controls offer both refrigeration and energy monitoring. Additional monitoring options are available for both series (Table 3). The sites listed in Table 1 all had the performance monitoring feature, control option "D" for dual stage units and "K" for variable speed units.

Table 3. Symphony Monitoring Options for Each Unit Type

	Control Option	Energy (E)	Refrigeration (R)	Performance (P)
Series 5 / ND (dual stage)	Std	X		
	"C"	X		X
	"D"	X	X	X
Series 7 / ND (variable speed)	Std / "J"	X	X	
	"K"	X	X	X

Note: The control option designation is represented by a digit in the part number.

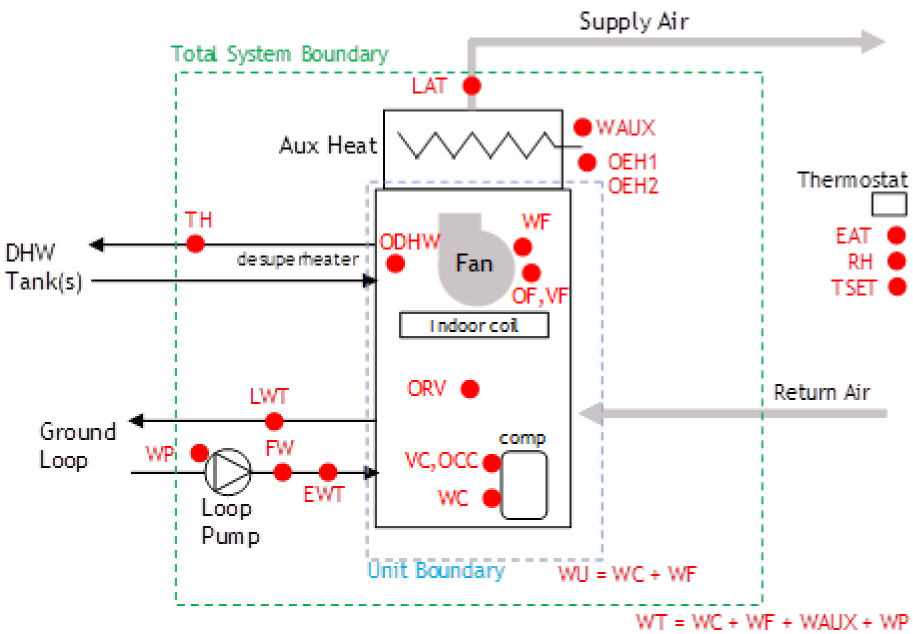
The data points collected by the various Symphony monitoring options are listed in Table 4 below. The points are schematically shown in Figure 1. These sensor locations were confirmed during the on-site verification efforts (see Appendix B).

Table 4. Data Points in the Symphony Monitoring System

Data Type	Symphony Name	Symphony Description	CDH Variable
	id		
	logtime	date time	
	logtimeepoch		
	activeinputsatlockout		
	activeoutputsatlockout		
C	actualcompressorspeed	Act Comp Speed	VC
C	aircoiltemp	FP2	TCOIL
C	airflowcurrentspeed	Fan Speed	VF
	airflowpwmdutycycle		
	aocalarm		
M	aocambienttemp	AOC Ambient Temp	TAO1
	aocderatingstatus		
	aocdrivestatus		
M	aocenteringwatertemp	AOC EWT	EWT1
	aocsafemodestatus		
C	aurorainputdh	DH	SDH
	aurorainputes		
C	aurorainputg	G	SG
C	aurorainputh	H	SH
	aurorainputhps		
	aurorainputlps		
	aurorainputls		
C	aurorainputo	O	SO
C	aurorainputw	W	SW
C	aurorainputy1	Y1	SY1
C	aurorainputy2	Y2	SY2
	auroraoutputacc		
	auroraoutputalm		
C	auroraoutputcc	CC	OCC
C	auroraoutputcc2	CC2	OCC2
C	auroraoutputeh1	EH1	OEH1
C	auroraoutputeh2	EH2	OEH2
C	auroraoutputf	Fan Relay	OF
	auroraoutputl		
C	auroraoutputrv	RV	ORV
E	auxcurrent	Aux Current	
E	auxpower	Aux Power	WAUX
R	coaxtemp	Clg LL	TLQC
E	compressor1current	Comp1 Current	
E	compressor2current	Comp2 Current	
E	compressorpower	Comp Power	WC
R	condensertemp	Sat Cond	TSATC
	currentecmspeed		
C	desiredcompressorspeed	Des Comp Speed	VC_SET
C	dhwsetpoint	HW Setpoint	TH_SET
	digitaloutputk1		
	digitaloutputk2		
	digitaloutputk3		
	digitaloutputk5		
C	digitaloutputk6	DHW Relay	ODHW
R	dischargepressure	Disch Press	PDIS
R	dischargetemp	Disch Temp	TDIS
C	eev1openingpct	EEV1 Open %	VEEV1
C	eev2openingpct	EEV2 Open %	VEEV2
P	enteringwatertemp	EWT	EWT
E	estimatedlinevoltage	Line Voltage	
R	evaporatortemp	Sat Evap	TSATE
E	fancurrent	Blower Current	
E	fanpower	Fan Power	WF
C	fp1inputreading	FP1	
C	fp2inputreading	FP2	
R	heatingliquidlinetemp	Htg LL	TLQH
P	heatofextrej	HE / HR (KBtuh)	QL
C	hotwatertemp	HW Temp	TH
R	htgclgsubcooling	Htg/Clg SC	T_SC
	internalinputs		
	lastfault		
P	leavingairtemp	LAT	LAT
P	leavingwatertemp	LWT	LWT
	lockedout		
	lockoutstatuscode		
	lockoutstatuslast		
E	looppumppower	Pump Power	WP
P	looppumppressure	Loop Press	DPL
	modeofoperation		
R	suctionlinetemp	Suct Temp	TSUC
R	suctionpressure	Suct Press	PSUC
R	superheat	SH	T_SH
	totalamps		
E	totalunitpower	Total Power	WT
	tstatactiveoutputs		
C	tstatactivesetpoint	Active Setpoint	TSET
	tstatcoolingsetpoint		
C	tstatdehumidsetpoint	Dehumid Setpoint	DSET
	tstatheatingsetpoint		
C	tstathumidsetpoint	Humid Setpoint	HSET
	tstatmode		
P	tstatoutdoorairtemp	OAT	TAO
C	tstatrelativehumidity	Dehumid %	RH
P	tstatroomtemp	EAT	EAT
	universalinput1		
C	variablespeedpumppwr	Loop Pump PWM	
	vspumppwmoutput		
C	vspumpspeedpct	Loop Pump Speed	VP
P	waterflowrate	FLOW	FW

Key to Data Types: E – Energy; R – Refrigeration; P – Performance; C – Control; M – Misc. Also see Figure 1.

Figure 1. Schematic of Heat Pump System with Measured Data Points Shown



Most of these points are direct measurements by temperature sensors, flow meters, and refrigerant pressures. Refrigeration saturation temperatures, superheat temperatures, and subcooling temperatures are determined using the measured readings combined with refrigerant property calculations. Temperature sensors are 10k thermistors. Water flow is measured with a Grundfos vortex-shedding flow meter. Component statuses are used to determine the runtime of components and control settings. The power readings are inferred or determined by various means:

- Compressor current is directly measured and used to infer power (dual stage).
- The compressor inverter reports the power determined by its internal calculations (variable speed).
- Fan current is measured and used with user-entered site voltage to infer power. For variable speed fans, a correlation is used to relate current to power (to account for the changing power factor).
- Pump power is read directly from the pump's variable speed drive, or for constant speed pumps, it is inferred from the user-entered pump information and the pump activation command.
- The heat rejection/extraction is calculated from the flow and temperatures along with user-entered fluid characteristics (which are supposed to be entered by the installer at setup).

The Symphony monitoring system transmits instantaneous, 10-second data back to the server in near real time. It does not have a large on-board storage buffer, so if the internet connection resets or is lost for more than six minutes, some data records are lost.

3.1 Calculated Quantities

The heat rejection or extraction to and from the ground loop was integrated using

Equation 1 $$QW = \sum_{j=1}^{N} qw_j \cdot \Delta t = \sum_{j=1}^{N} k \cdot FW_j \cdot (EWT_j - LWT_j) \cdot \Delta t$$

where:

- QW = Total heat extraction or rejection (Btu)
- qw = Heat extraction or rejection rate (Btu/h)
- EWT = Entering water temperature (°F)
- LWT = Leaving water temperature (°F)
- FW = Water flow rate (gpm)
- K = Product of specific heat and density for fluid in loop (e.g., ~500 for water at 60°F, or 477 for 20% glycol at 40°F) (Btu/gpm·°F·h)
- Δt = Time increment (1/360 hours for 10-second data)

The jth value corresponds to each 10-second reading. N is the number of intervals over the period of interest (i.e., hour, day, month, or season). If the flow (FW) does not return to zero when the pump is off, pump status is included in the calculation to ensure measurements are not skewed by measurement errors when the heat pump is off.[1]

The study separately sums (or integrate) positive and negative values of qw_j to find the total heat extraction (QWE) and heat rejection (QWR) for each period of interest.

The total electric use for the heat pump unit can be determined by summing the power in each interval:

Equation 2 $$WU = \sum_{j=1}^{N} wu_j \cdot \Delta t$$

where:

- WU = Total power use for heat pump unit (kWh), including compressor and fan
- wu = Power for the heat pump unit (kW)
- Δt = Time increment (1/360 hour for 10-second data)

[1] It is confirmed that heat transfer values calculated and reported by the Symphony system do ignore erroneous small flow values and also matched independently-calculated values. Therefore, the Symphony heat transfer values were used in all calculations.

The jth value corresponds to each 10-second reading. N is the number of intervals over the period of interest (i.e., hour, day, month, or season). The energy associated with heating (WUH) and cooling (WUC) can also be determined by summing values when the heat pump is in each particular mode.

Similarly, the total system energy use (WT) can be determined by adding in the auxiliary heating element power (WAUX) and pumping power (WP) to the unit power (WU). As for the unit power, the total power can be segregated into the energy associated with cooling (WTC) and the energy associated with heating (WTH).

The heating and cooling output for any period of interest can also be determined by

Equation 3 $$QH = QWE + (WUH + WAUX) \cdot 3413$$

Equation 4 $$QC = QWR - WUC \cdot 3.413$$

QH includes space heating as well as any heat provided to the hot water load by the desuperheater. The calculation for cooling output (QC) includes a slight error when the desuperheater operates, since approximately 2 MBtu/h less heat is rejected to the loop. The impact of this was disregarded for the analysis in this report.

The heating COP and cooling EER of the heat pump “unit” can be determined for the period of interest:

Equation 5 $$COP_{htg} = \frac{QH}{WUH}$$

Equation 6 $$EER_{clg} = \frac{QC}{WUC}$$

The unit COP—which can be compared to manufacturers published specifications—would only be meaningful for periods when auxiliary heat is off. These equations result from first law of thermodynamics analysis (i.e., heat balance, on the heat pump unit). The COP is dimensionless, and EER has units of Btu/Wh. The calculations ignore the small amount of heat dissipated from the compressor shell as well as any control power (these items are generally small).

The heating COP can be determined for the total system by replacing WUH in the denominator with WTH. Similarly, for the total system cooling EER, WUC is replaced with WTC in the denominator. Note that in both cases, the values of QH and QC in the numerator are not changed, since the pump does not affect the unit heat balance.

3.1.1 Determining Weighted Average Temperatures

Load-weighted average temperatures can be determined for each site for any period of interest. Load-weighted average temperatures for the ground loop will put more weight on temperatures that occur when loads are higher, while time-weighted temperatures equally average or weight all temperatures when the unit is on. The calculations are of the following form:

Equation 5

$$\boldsymbol{T_{load-wt} = \frac{\sum_{j=1}^{N} q_j \cdot T_j}{\sum_{j=1}^{N} q_j}}$$

Where j corresponds to each interval and q_j is the appropriate load (or power use). For the data presented in this report, weighting was applied to the average data for each 15-minute interval.

4 Analysis and Results

The 10-second data was used for each site to analyze various aspects of system performance (see Appendix F for an initial analysis that used 10-second data). To make the data more useable and understandable, the data was averaged or summed into 15-minute intervals to facilitate the higher-level analysis. Daily average values were calculated using weighted averages of 15-minute data where appropriate. Most of the plots and tables in this section use either the 15 minute or daily data to understand performance.

4.1 On-Site Measurement Verification

Two homes were used to compare the readings from the Symphony sensors to our independent, handheld instruments. The first home in Niskayuna had two dual stage GHPs on one ground loop (S8 and S9) while the Akron house (S32) had a variable speed unit. Appendix B provides an in-depth look at the system details and measurements taken at each home. Table 5 summarizes the general differences observed in comparing these readings to our handheld instruments.

Table 5. Summary of Bias Errors Observed for Each GHP System (n=3)

	S08 (Dual Capacity)	S09 (Dual Capacity)	S32 (Variable Speed)
Compressor Power	-12% low, -10% high	-11% low, -9% high	15% low, 9% high
Fan Power	-3 to +8 Watts -2% to +6%	-31 to +7 Watts -9% to +4%	-10 to -20 Watts -5% to -9% high speed
Pump Power	Incorrect*	Incorrect*	1 to 6 Watts 2% to 15%
Auxiliary Heat			0.9 kW -9%
Loop Flow	1.8 to 1.9 gpm 14 to 20%	1.6 to 1.8 gpm 16%	0.8 to 1 gpm 7% to 17%
Loop Temperatures	-0.8 to -1.0°F	-0.8 to -1.0°F	+0.5 to -1.4°F
Loop Temp Diff	-0.1 to -0.2°F	-0.2°F	0 to 1.9°F (TXV hunting)
Entering Air	0.6°F	1.3 to 1.9°F	1.1°F

* The assumed pump was not installed, so the Symphony-reported pump power was incorrect.

The data in the table above shows that the Symphony power readings reported for the compressor on the dual speed unit were lower than our Fluke meter readings by approximately 10%. However, the compressor power reported by Symphony using the inverter was elevated by 9-15%. Fan power from Symphony, which is inferred from measured fan current and a user-entered voltage parameter,[2] was relatively close to our Fluke meter reading (within 10%). Pump power for the Symphony is determined via on a lookup table based on user-entered pump details for dual stage units. For variable speed units, the pump power is read from the pump's variable speed drive. Sites S8 and S9 have staged pumping arrangements, making the pump power reported by Symphony incorrect (and off by a factor of two). For the variable speed system at S32, the inferred pump power was close to the measured value. The auxiliary heat power from Symphony system was also 9% lower than the power measured with the Fluke meter.

The loop flow reported by the Symphony systems was consistently 10% to 15% higher than the flow measured with Fuji ultrasonic flow meter. At site S32, a differential pressure reading was also used to predict flow using the published unit specifications. The pressure-based flow prediction was closer to the ultrasonic reading than to the Symphony flow reading. Generally, temperature readings from the Symphony were close to our handheld sensor readings. In terms of loop differential temperatures, the agreement was within 0.2°F for the dual stage units. The agreement was much poorer for the variable speed unit, where TXV hunting (i.e., pulsing of refrigerant flow due to control instability) caused temperature fluctuations that made taking the differential readings difficult with a single probe (i.e., using the same sensor in different locations at different times).

Overall, the general systematic biases of higher loop flow and lower power readings tend to make Symphony-based estimates of COP and EER higher than was implied by our measurements. These trends are not definitive since they are only based on comparative measurements from three units, so they should be considered preliminary.

[2] The installers did not enter the observed voltage at either of these sites. However, the measured voltages at these sites were only 1-2% higher than the default value of 240 V.

As shown by the uncertainty analysis at the end of Appendix B, the calculated probable (unbiased) errors based on practical uncertainties for individual measurements was determined. The probable uncertainties are ±12.3% for heating capacity (QH) and ±14.6% for COP. These uncertainty levels are consistent with historic expectations for field monitoring efforts.

4.2 Detailed Results for each GHP System

The data for all 49 sites was analyzed with at least 11 months of data. At one site, not all the required information about the ground loop and house was available, so only loop temperatures were analyzed. The detailed plots and tables generated for each GHP site are described in Appendix C. A web link to the PDF file for each site is provided in that appendix, and a detailed description of each plot in the PDF file is given as well.

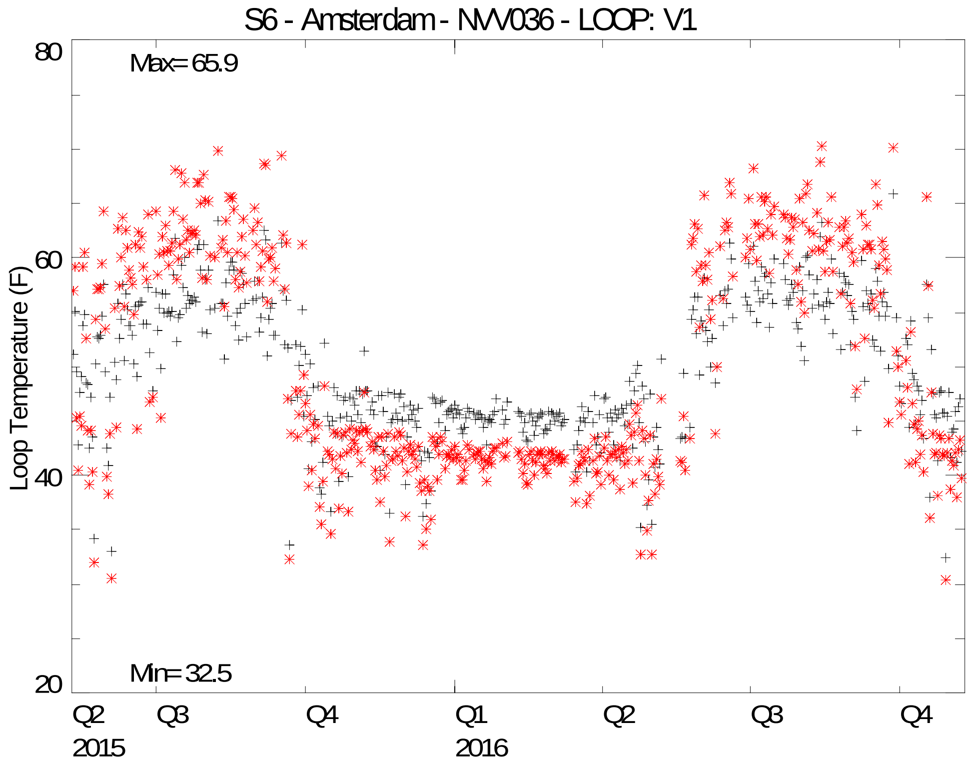
A summary of all the compiled seasonal and annual metrics for each site are given in Appendix D. The sections that follow highlight the major findings from that data.

4.3 Ground Loop Temperatures

The key factor driving efficiency of a geothermal heat pump is the entering water temperature from the ground loop. The heat pump pulls water from the ground loop heat exchanger and sends back colder water in the winter (heating mode) and returns warmer water in the summer (cooling mode). The two plots in Figure 2 show the temperature profile across the year for two different vertical bore loops at sites S6 and S8. Figure 3 shows the loop temperature profiles for S1 with a horizontal loop with two pipes per trench (H2) and S20 with a horizontal slinky loop (HS). The daily average, weighted entering water temperature is shown as a plus sign ('+') and the daily average leaving temperature is shown as an asterisk ('*'). The minimum and maximum entering water temperatures (based on daily data) are also shown on each plot. The horizontal loops in Figure 3 show temperatures that approach the freezing point fairly quickly, while the vertical loops in Figure 2 maintain a more constant temperature across the winter. The temperatures from vertical bore loops approximately corresponds to the deeper far-field temperature of the Earth, and the temperature variations or scatter reflect the differences in the day-to-day loading.

Table 6 lists the loop temperatures observed at each site. The minimum temperature is the average of the four lowest values in the 15-minute data set. The maximum temperature is the average of the four highest readings in the 15-minute data set. The average temperatures corresponding to heating and cooling are the weighted average using the compressor power.

Figure 2. Daily Loop Temperatures for S6 and S8 (Vertical Ground Loops)



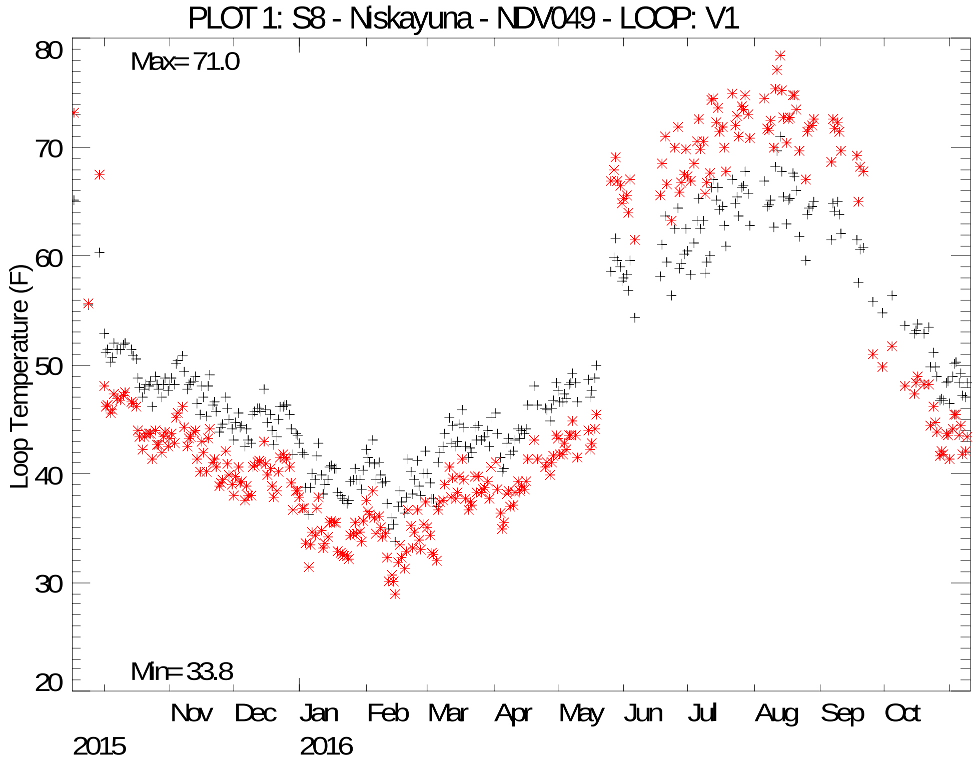
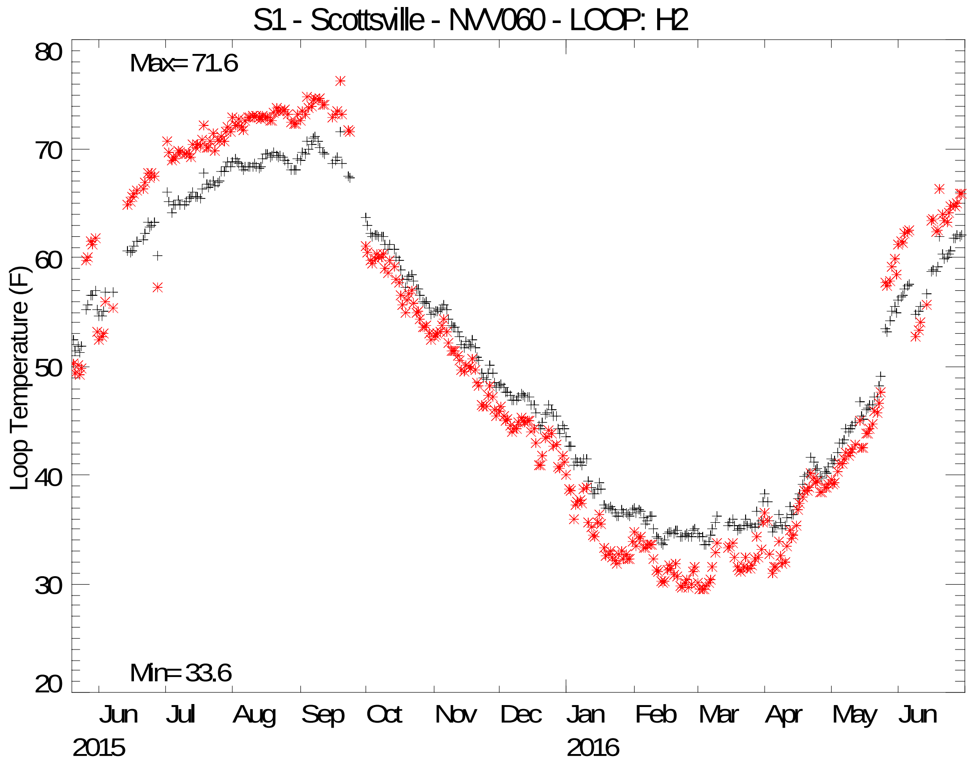


Figure 3. Daily Loop Temperatures at S1 (Horizontal Loop) and S20 (Horizontal Slinky Loop)



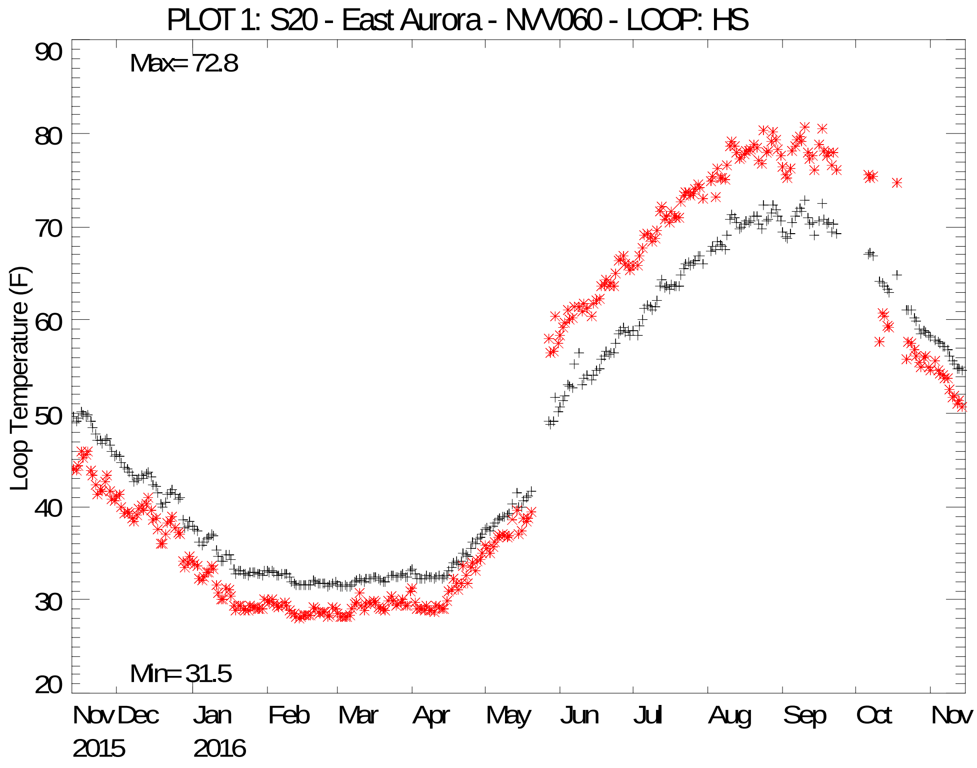


Table 6. Loop Temperatures for Each Site

Site ID	Model	Loop Type	Minimum EWT (°F)	Avg. EWT in Heating (°F)	Avg. EWT in Cooling (°F)	Maximum EWT (°F)
s01	NVV060	H2	33.3	40.1	66.2	74.6
s03	NVV036	H2	30.6	36.7	70.3	80.0
s04	NVV048	V1	32.4	41.1	64.5	73.4
s05	NVV060	H2	31.4	39.0	70.2	79.7
s06	NVV036	V1	41.9	47.2	58.5	69.6
s07	NDH064	HS	35.7	44.5	59.9	67.8
s08	NDV049	V1	31.6	42.4	64.3	76.0
s09	NDV049	V1	31.2	41.3	64.1	75.9
s10	NVV060	H2	31.2	40.4	73.4	83.7
s11	NVV060	H4	29.9	35.2	77.7	93.8
s13	NVV060	H2	29.5	33.8	72.5	84.9
s14	NDV072	H6				
s15	NVV048	H2	28.7	31.5	70.9	80.2
s17	NVV048	HS	31.2	39.5	70.4	81.9
s18	NVV048	V2	39.6	44.2	56.6	67.2
s19	NVV060	V2	38.9	47.8	71.7	85.5
s20	NVV060	HS	31.1	36.2	65.8	75.1
s21	NVV048	HS	28.9	35.3	70.8	79.8
s22	NDV064	V1	24.5	33.8	71.0	82.5
s23	NDV038	HS	27.4	31.3	67.8	85.8
s24	NVV048	HS	35.4	41.4	61.3	66.1
s25	NVV048	HS	28.7	34.5	74.5	84.8
s26	NVV060	HS	31.3	37.9	66.5	75.1
s27	NVV060	HS	52.1	55.1	56.0	71.5
s28	NVV036	H2	34.5	42.0	64.4	67.9
s29	NDV064	V1	31.9	40.9	58.2	67.9
s30	NDV064	HS	29.9	37.5	69.9	81.3
s31	NVV060	Pd	34.7	38.9	75.0	82.5
s32	NVV036	HS	32.2	40.1	63.2	73.2
s33	NVV036	V1	29.8	42.1	70.3	85.5
s34	NVV048	V1	38.5	46.4	66.7	77.9
s35	NDV072	Pd	33.3	39.7	73.6	82.1
s36	NVV036	HS	31.7	41.7	73.1	82.8
s37	NDV049	HS	29.1	37.7	67.4	79.4
s38	NDV026	V1	24.8	34.3	61.1	70.8
s39	NVH036	H2	25.4	32.9	56.2	67.7
s40	NDV038	V2	24.9	34.2	74.1	89.1

Table 6 continued

Site ID	Model	Loop Type	Minimum EWT (°F)	Avg. EWT in Heating (°F)	Avg. EWT in Cooling (°F)	Maximum EWT (°F)
s41	NVV048	Op	46.2	50.4	50.4	65.3
s42	NVV060	V2	36.3	41.9	56.1	61.8
s43	NVV060	V2	41.9	46.8	53.6	61.7
s44	NDH049	HS	31.4	40.3	72.6	82.9
s45	NVV036	HS	33.9	41.3	69.8	78.0
s46	NVV036	?	34.7	41.1	67.2	72.7
s47	NDV049	V2	29.7	39.6	58.4	68.2
s48	NVV036	V1	45.2	49.8	60.2	70.1
s49	NVV048	V1	24.7	34.4	62.5	86.0
s50	NDV038	Op	46.3	48.3	49.8	63.2
s51	NVV036	V1	34.6	42.6	66.6	84.3
s52	NVV036	V2	29.7	36.8	73.4	86.1

Note: The minimum and maximum are the average of the four highest and four lowest values in the 15-minute data, respectively. The average in heating and cooling are weighted averages using compressor power. S14 had only six months of data, in non-winter months, so it was excluded.

Figure 4 compares the loop temperatures for all the sites with different symbols used for each loop type. The weighted-average loop temperatures entering the heat pump in the heating mode are shown as the bottom dotted line while the weighted average temperature in cooling is shown as the top dotted line. The minimum and maximum values from Table 6 are shown with a solid line. Sixteen of the loops had minimum temperatures below 30°F, nine below 29°F and four were below 25°F.

Figure 5 shows the distribution of temperatures as well as the overall average temperature for each loop type in the heating mode. The average value and number of points are shown on the plot for each loop type. Generally, the vertical loops performance slightly better than the horizontal loops. Though, the difference between the loop types is not as definitive as might be expected. This implies loop sizing and total loads can play as large a role as the type of loop in determining overall loop temperature. The open loops (Op) had warmer temperatures, as would be expected. Figure 6 compares the minimum and weighted average entering water temperatures and provides another way to consider loop sizing and loading. The average in the heating mode is typically 5-10°F warmer than the minimum; the minimum is usually the key design parameter for the loop. The differential between the average and the minimum depends on both the loop type and the loop sizing or loading.

Figure 4. Comparing Loop Temperatures at All Sites

(Min and Max are solid lines; dotted lines are averages for cooling and heating respectively)

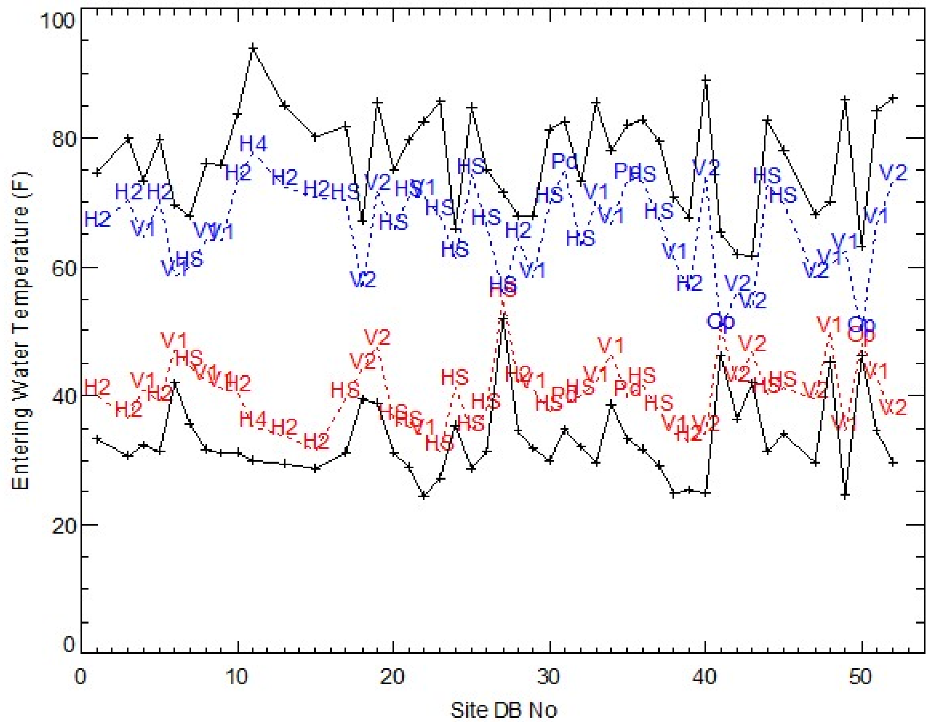


Figure 5. Comparing Entering Water Temperatures for Different Loop Types

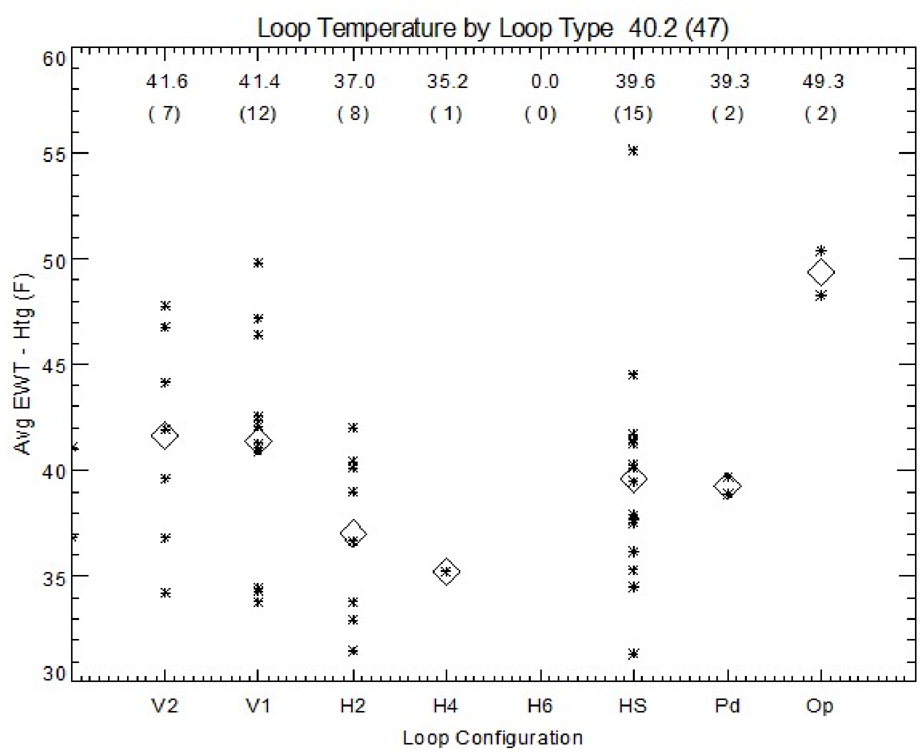


Figure 6. Comparing Minimum and Average Entering Water Temperatures for Different Loop Types (*=vertical bores; ◊= horizontal loops; Δ= other loops)

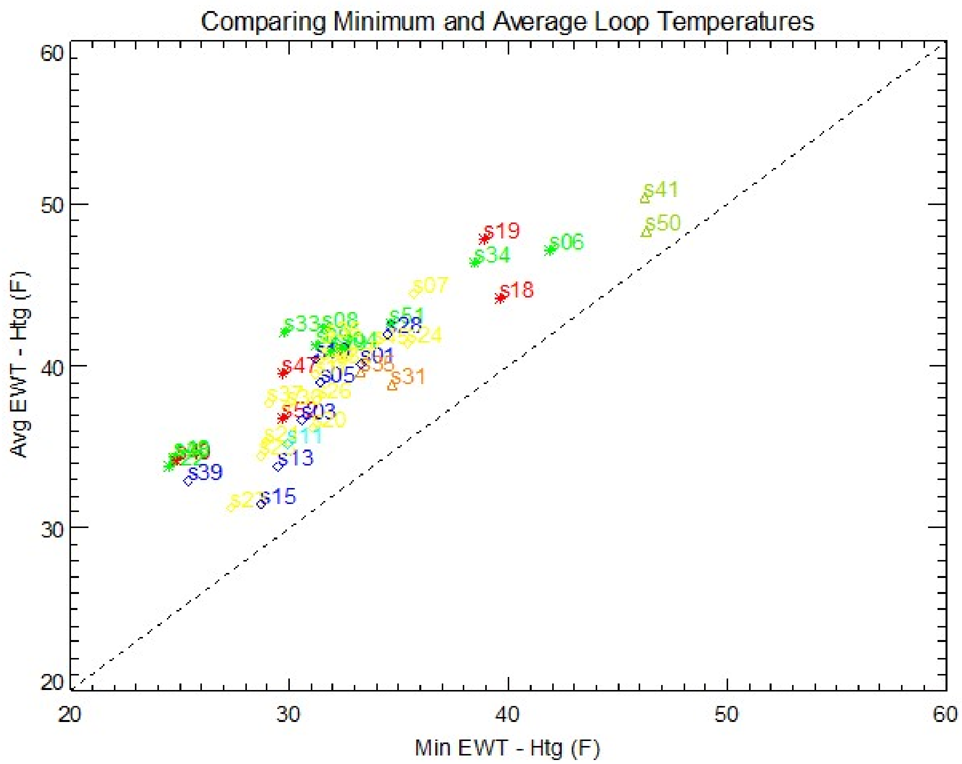


Figure 7 shows the overall distribution of seasonal average entering water temperatures in the heating mode. Table 7 lists the statistics for the distribution. The overall average for the 49 sites in heating is 40.2°F and the median is 40.1°F. Based on this distribution, there is 95% confidence that the average loop temperature for any site will fall between 30 and 50°F. Using the manufacturers data for dual stage heat pumps from Appendix E, the seasonal heating COPs for the heat pump unit implied by these loop temperatures would be in the range of 3.8 and 4.5.

Figure 7. Histogram of Entering Loop Temperatures in the Heating Mode

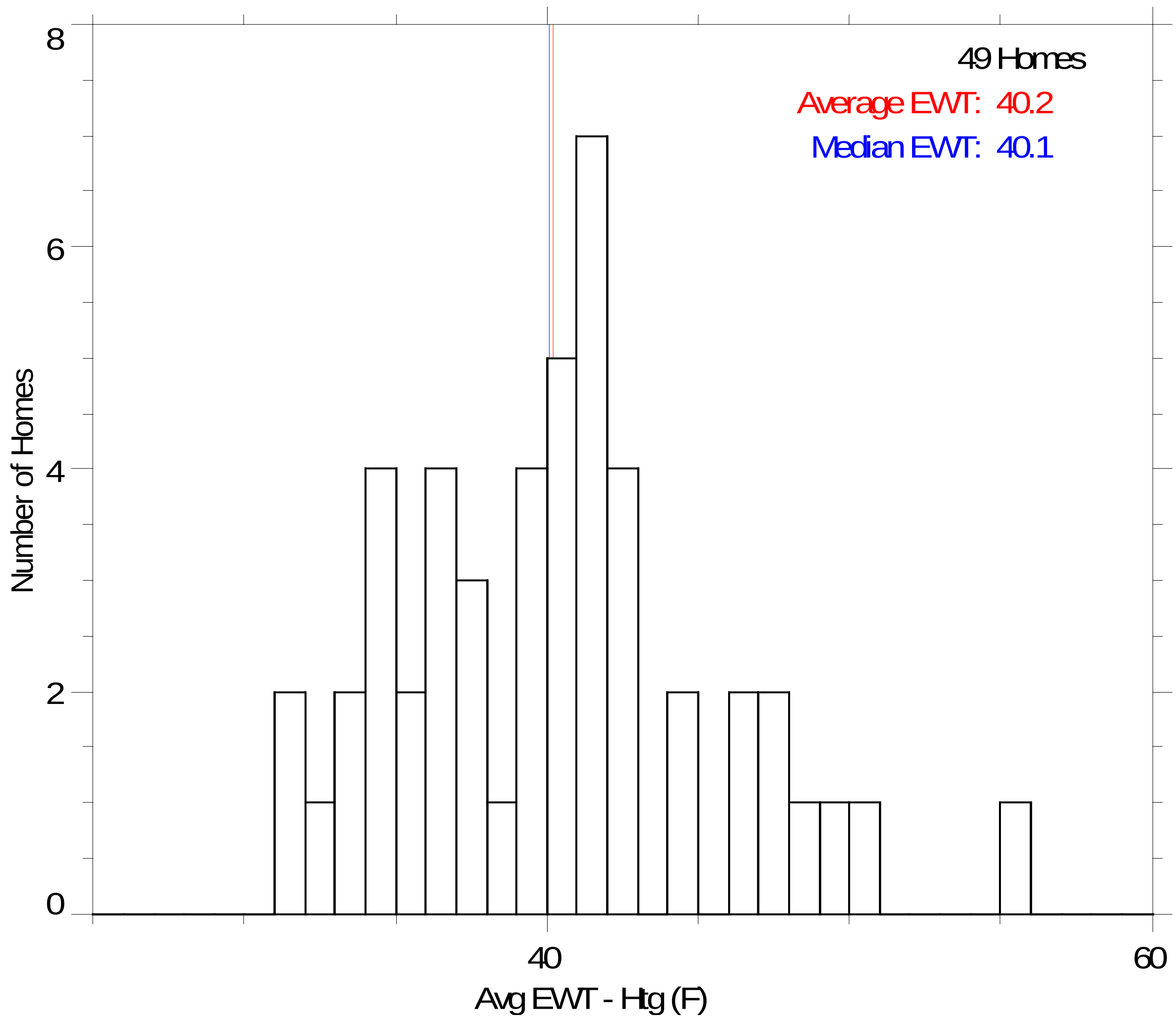


Table 7. Summary Statistics for Loop Temperatures

Statistic		Value
Mean		40.2°F
Median		40.1°F
Number of Sites		49
Standard Deviation (sd)		5.2°F
95% Confidence Interval for Mean ±1.96·sd/√N		38.7 – 41.6
95% CI for Expected Range of Loop Temperatures ±1.96·sd		30.1 – 50.3
Check: No of sites within CI Range		47 of 49 (96%)
Corresponding Unit COP	- Variable 50% speed	3.85 to 4.36
	- Variable 100% speed	3.79 to 4.80
	- Dual Capacity 2nd stage	3.77 to 4.53

Note: Corresponding COP range determined using 95% CI expected range and data from Appendix E.

4.4 Energy Use and Component Runtimes

The annual energy use of the GHP system and its components are summarized for each site in Table 8 and Figure 8. The compressor uses most of the energy, but the fan and pump also have a significant impact. The power reading for the compressor is determined from current and voltage measurements, while fan power is determined from current readings and user-entered voltage. Pump power is determined from a simple lookup for constant speed pumps and based on the drive-reported power for the variable speed pump. For at least one verified location (S8 and S9), the unit did not use the expected pump and the actual pump power measured was much greater. Therefore, the reported pump power for dual stage units is thought to be unreliable in some cases. Some of the sites used a significant amount of auxiliary heat (i.e., the onboard resistance elements). For more than six sites, the auxiliary heater used more than 500 kWh for the season and accounted for 5 to 10% of the total annual energy use.[3] This auxiliary heater use seems mostly linked to how home owners controlled the heat pump, though reduced heat pump capacity at lower loop temperatures may have played a secondary role.

Table 8. Energy Use Breakdown of System on an Annual Basis

Site ID	Model	Loop Type	Total (kWh)	Compressor (kWh)	Fan (kWh)	Pump (kWh)	Aux. Heat (kWh)
s01	NVV060	H2	6,689	4,690	545	1,375	79
s03	NVV036	H2	3,924	2,788	219	907	10
s04	NVV048	V1	8,847	5,923	1,702	647	574
s05	NVV060	H2	8,723	6,423	733	1,538	29
s06	NVV036	V1	1,936	1,748	85	100	2
s07	NDH064	HS	4,369	3,048	595	722	4
s08	NDV049	V1	4,910	3,555	370	985	-
s09	NDV049	V1	4,774	3,280	552	942	-
s10	NVV060	H2	8,266	5,800	981	1,384	103
s11	NVV060	H4	8,316	5,812	1,021	1,219	263
s13	NVV060	H2	12,270	7,986	2,097	1,625	562
s14	NDV072	*H6					
s15	NVV048	H2	5,943	4,445	428	910	160
s17	NVV048	HS	4,275	3,265	787	219	5
s18	NVV048	V2	3,208	2,137	364	707	0
s19	NVV060	V2	6,846	4,984	520	1,340	2

[3] Water Furnace design guidance recommends sizing the geothermal systems so that the auxiliary elements use 10% of total system power use.

Table 8 continued

Site ID	Model	Loop Type	Total (kWh)	Compressor (kWh)	Fan (kWh)	Pump (kWh)	Aux. Heat (kWh)
s20	NVV060	HS	6,838	6,021	521	270	26
s21	NVV048	HS	7,796	6,182	866	225	523
s22	NDV064	V1	9,043	6,239	1,435	1,346	23
s23	NDV038	HS	3,353	2,543	223	551	36
s24	NVV048	HS	771	640	98	33	-
s25	NVV048	HS	5,275	3,764	459	1,013	38
s26	NVV060	HS	9,488	6,809	1,228	422	1,029
s27	NVV060	HS	5,741	4,666	979	-	96
s28	NVV036	H2	2,112	1,928	184	-	-
s29	NDV064	V1	5,654	4,415	510	661	67
s30	NDV064	HS	8,272	6,337	1,202	661	72
s31	NVV060	Pd	4,641	3,959	140	169	373
s32	NVV036	HS	3,981	3,629	214	138	1
s33	NVV036	V1	1,229	946	114	153	14
s34	NVV048	V1	6,050	4,315	1,176	500	58
s35	NDV072	Pd	10,923	8,472	1,283	819	349
s36	NVV036	HS	3,514	2,959	297	180	79
s37	NDV049	HS	5,726	4,310	99	1,222	95
s38	NDV026	V1	2,638	1,901	233	504	-
s39	NVH036	H2	4,402	3,612	422	368	-
s40	NDV038	V2	2,472	1,775	62	389	245
s41	NVV048	Op	1,912	1,709	203	-	-
s42	NVV060	V2	5,249	3,664	563	993	29
s43	NVV060	V2	2,083	1,704	329	50	0
s44	NDH049	HS	4,805	3,346	413	1,046	-
s45	NVV036	HS	3,546	3,074	327	145	-
s46	NVV036	?	4,719	3,902	240	478	99
s47	NDV049	V2	6,026	4,340	555	1,078	53
s48	NVV036	V1	3,685	2,826	804	51	4
s49	NVV048	V1	5,718	4,740	783	195	-
s50	NDV038	Op	1,375	1,130	190	-	54
s51	NVV036	V1	3,222	2,549	266	353	54
s52	NVV036	V2	4,140	3,791	9	245	95

Note: Each site shown has at least 11 months of the data. The loop type is not known for the sites in shaded cells.

Figure 9 shows the portion of energy attributable to heating and cooling operation. Generally, the energy is 80% for heating and 20% cooling. At two sites, energy use for cooling was higher than for heating.

Figure 8. Breakdown of Annual Energy Use for GHP Systems by Site (data from Table 8)

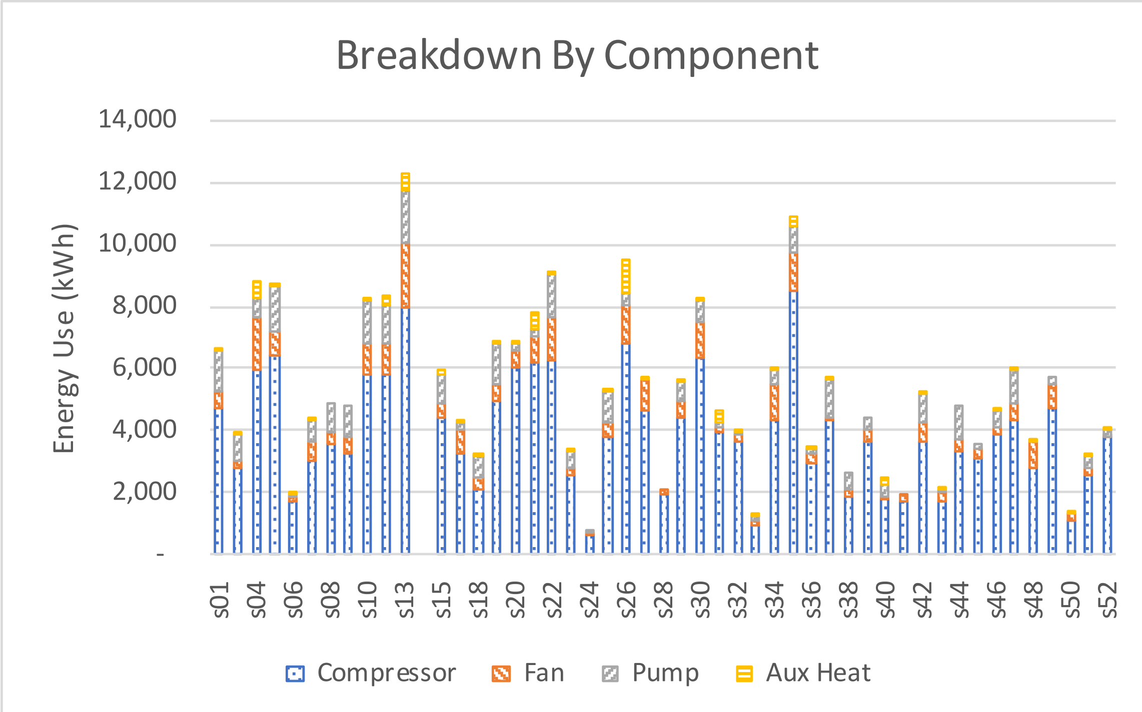


Figure 9. Allocation of Annual Energy Use for GHP Systems Between Heating and Cooling

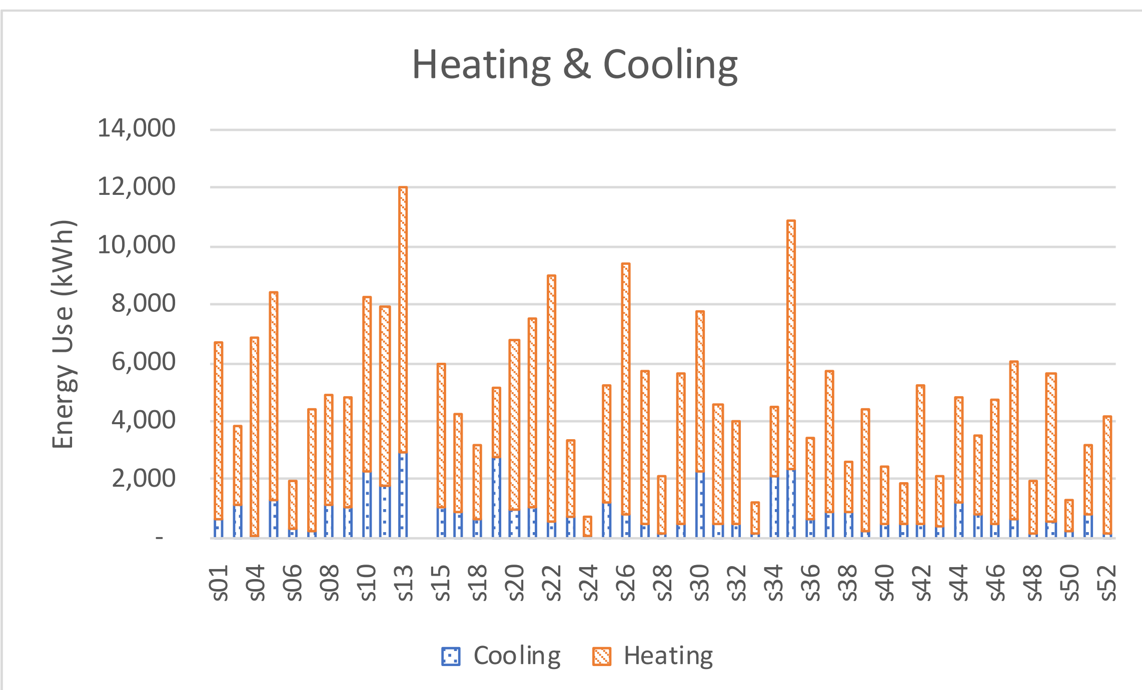


Table 9 lists the runtimes of the major components in the system. For dual stage units, two compressor runtimes are given that correspond to first and second stage. The domestic hot water (DHW) runtime indicates when the DHW pump operates to pull water from the hot water tank (this pump runs when the compressor is on and the entering water temperature from the tank is low enough to absorb heat). The runtime is also shown for both auxiliary heat stages.

Table 9. Breakdown of Component Runtimes for GHP Systems

Site ID	Model	Loop Type	Compressor Runtime (hrs, Stage 1 / Stage 2)	Fan Runtime (hrs)	DHW Runtime (hrs)	Aux. Heat Stage 1 (hrs)	Aux. Heat Stage 2 (hrs)
s01	NVV060	H2	4,781	4,875	4,714	11	9
s03	NVV036	H2	3,480	3,528	3,265	2	1
s04	NVV048	V1	5,905	5,964	4,881	90	63
s05	NVV060	H2	5,537	6,743	5,237	5	3
s06	NVV036	V1	3,344	3,392	-	0	0
s07	NDH064	HS	1,556 / 53	3,048	1,555	1	0
s08	NDV049	V1	2,086 / 251	2,163	-	-	-
s09	NDV049	V1	1,996 / 142	2,059	-	0	0
s10	NVV060	H2	4,810	4,930	4,652	16	10
s11	NVV060	H4	4,199	6,156	4,048	90	75
s13	NVV060	H2	5,280	7,193	3,781	87	70
s14	NDV072	H6					
s15	NVV048	H2	3,241	3,291	2,728	24	18
s17	NVV048	HS	4,545	7,793	-	1	0
s18	NVV048	V2	2,844	3,262	2,261	0	0
s19	NVV060	V2	4,685	4,797	1,946	0	0
s20	NVV060	HS	5,102	5,247	4,401	4	3
s21	NVV048	HS	4,537	4,618	1,016	82	70
s22	NDV064	V1	2,912 / 506	5,093	-	42	29
s23	NDV038	HS	2,335 / 114	2,360	2,264	6	4
s24	NVV048	HS	1,553	1,616	1,540	-	-
s25	NVV048	HS	4,273	4,667	4,047	7	3
s26	NVV060	HS	4,039	4,959	3,449	166	99
s27	NVV060	HS	3,745	3,750	3,625	14	10
s28	NVV036	H2	4,330	4,419	4,275	0	-
s29	NDV064	V1	1,945 / 111	3,052	-	6	4
s30	NDV064	HS	2,799 / 385	2,882	2,458	10	7
s31	NVV060	Pd	3,271	3,545	-	57	41
s32	NVV036	HS	4,281	4,322	3,405	0	0

Table 9 continued

Site ID	Model	Loop Type	Compressor Runtime (hrs, Stage 1 / Stage 2)	Fan Runtime (hrs)	DHW Runtime (hrs)	Aux. Heat Stage 1 (hrs)	Aux. Heat Stage 2 (hrs)
s33	NVV036	V1	2,007	2,062	-	2	2
s34	NVV048	V1	4,618	6,513	-	9	6
s35	NDV072	Pd	2,407 / 368	2,667	-	33	21
s36	NVV036	HS	4,470	4,512	-	10	10
s37	NDV049	HS	2,648 / 246	2,693	-	16	11
s38	NDV026	V1	2,965 / 125	3,015	-	11	6
s39	NVH036	H2	4,702	4,762	4,511	22	21
s40	NDV038	V2	1,706 / 251	1,789	1,680	27	18
s41	NVV048	Op	1,553	4,133	1,086	44	41
s42	NVV060	V2	3,530	4,258	3,089	4	4
s43	NVV060	V2	2,346	2,410	-	0	-
s44	NDH049	HS	2,215 / 182	2,252	-	-	-
s45	NVV036	HS	5,161	5,213	2,672	-	-
s46	NVV036	?	4,822	6,153	4,603	20	5
s47	NDV049	V2	2,284 / 166	4,377	1,896	9	5
s48	NVV036	V1	5,223	7,725	-	1	0
s49	NVV048	V1	4,347	7,766	3,333	91	73
s50	NDV038	Op	1,189 / 83	1,370	-	8	7
s51	NVV036	V1	4,275	4,315	4,003	6	3
s52	NVV036	V2	3,988	4,025	2,120	13	12

Note: Each site shown has at least 11 months of the data. The loop type is not known for the sites in shaded cells.

The desuperheater pump ran as much as 5,000 hours across the year at some sites. The expected performance data from Appendix E shows that the desuperheater can provide approximately 2 MBtu/h. This implies that the heat pump's contribution to water heating could have provided as much as 10 MMBtu of its annual heating output to the DHW tank.

4.5 Bias and Errors for Heating COP

The formulas shown in the beginning of this section to calculate heating COP and cooling EER for each GHP unit. As was described, on-site verification measurements implied the loop flow rate from the Symphony system was somewhat higher than what was measured with CDH's ultrasonic flow meter. Other sensors also had some systemic bias as well.

One means to assess the inaccuracies and systematic biases in the measured data from Symphony is to compare the measured unit COP and EER to the expected performance from the Water Furnace performance data tables (see Appendix E). By using the measured entering water temperature with the manufacturer's data tables, the expected COP for each 15-minute interval can be determined and compared to the measured COP. The expected COP and EER for the unit in these tables both assume a minimal amount of fan power (slightly greater than the fan power required to provide zero static as per standard AHRI/ISO 13256). However, the actual measured fan power is most likely larger than the value assumed in the Water Furnace data tables, so the measured COP should be somewhat lower than the expected value. Figure 10 compares the measured and expected unit heating COPs at low- and high-speed operation for this dual stage unit. The data are shown for each 15-minute interval when the compressor has operated at that stage for the entire interval, or at approximately steady state conditions. For Unit S8 at the first stage, the average measured COP is 4.79 while the expected COP (determined using EWT in each interval) was 4.05. The ratio of measured-to-expected COP is 1.18 in this case.[4] Similarly, at high stage operation, the average measured COP is 4.34 and the averaged expected COP is 3.82, resulting in a measured-to-expected ratio of 1.14. Plots like this are provided for each GHP system in the PDF files at the internet web link (see Appendix C).

A similar analysis was completed for the variable speed units. The expected data for those units is only available at 100% and 50% speed. There is generally very limited data available at 100% speed. Therefore, the data was further filtered to only include 15-minute intervals when the speed is near 50% (or compressor speed, VC, between 5.5 and 6.5).

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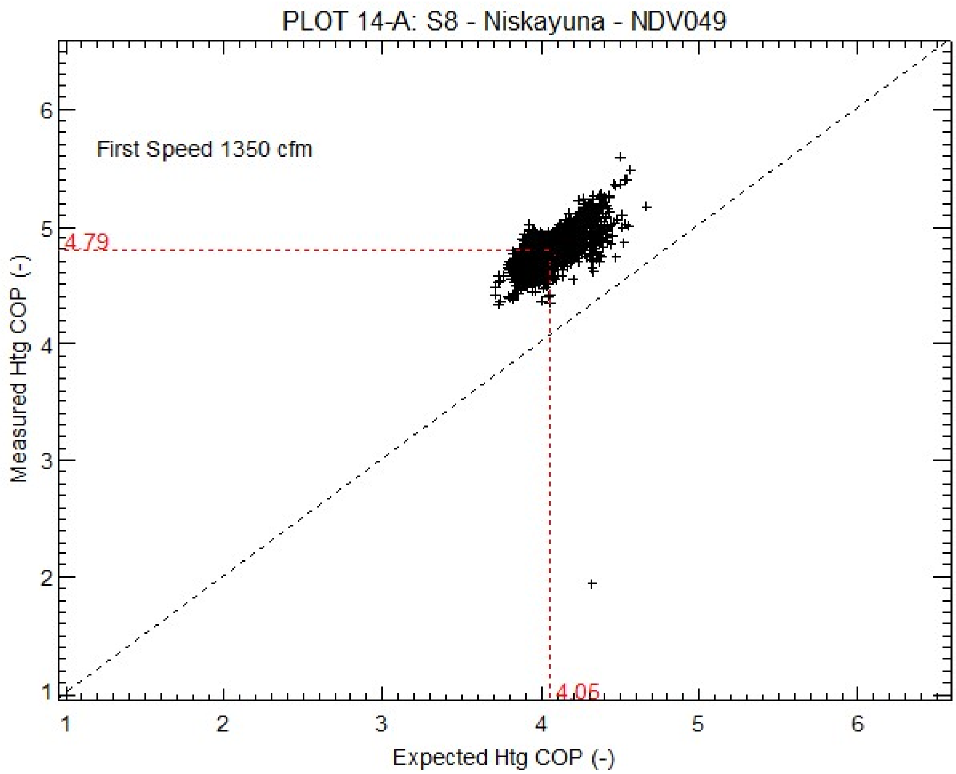
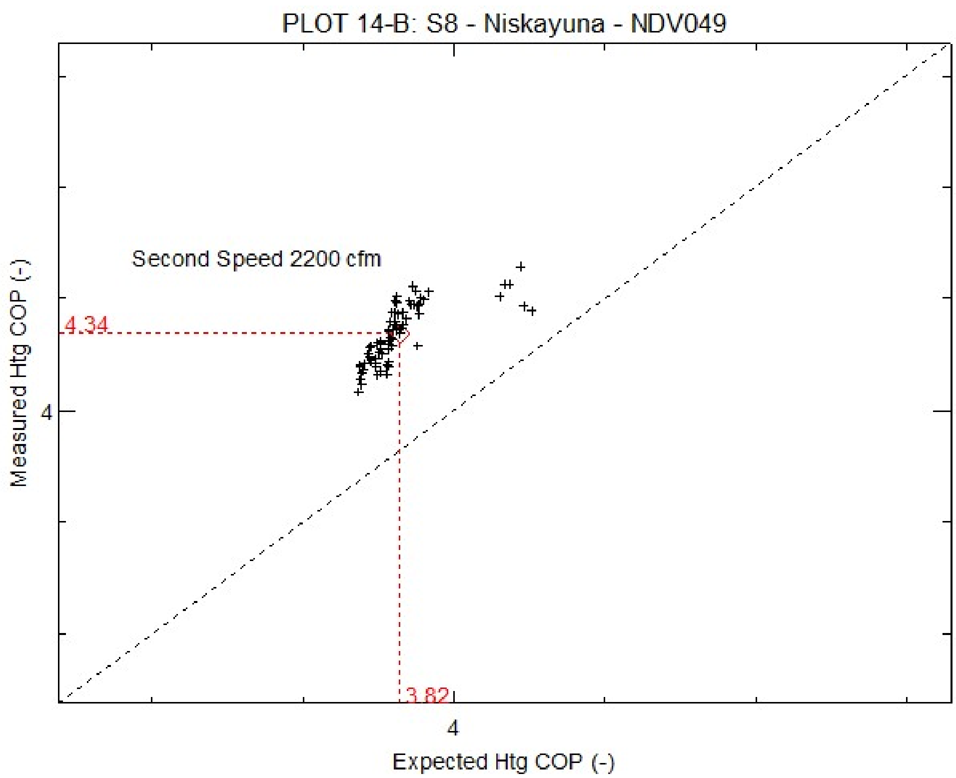
[4] By taking the ratio of the averages, a correlation coefficient is essentially determined, or a linear regression model with the offset forced to be zero.

Figure 10. Comparing Measured and Expected Heating COPs for Site S8 at Low/First and High/Second Speeds





The top of Figure 11 compares the ratio of the measured-to-expected ratios for heating COP at steady state conditions for all the sites. The bottom of Figure 11 shows the same analysis for cooling EERs (a similar process to that described above was also implemented for unit cooling EER). For dual stage systems (the diamond symbols), the plot shows that ratio for high speed operation. For variable speed units, the plot shows that ratio at 50% speed. The ratios vary widely from 0.8 to 2.2, indicating that measured heating COP can be 20% lower than the expected values, or as high as 2.2 times the expected values. The error is somewhat proportional to the COP value itself, which makes sense: the unrealistically high measured COPs of eight or more strongly implies that the measured data are incorrect. Similarly, the more realistic COPs around 3.5 to 4 have a measured-to-expected ratio near unity.

Variable speed units showed some of the highest measured-to-expected ratios. This may have occurred because the loop temperature difference was often observed to be lower for variable speed units at part load conditions (see PLOT 19 for each site, as described in Appendix C). The measurement uncertainty for loop heat extraction (and rejection) becomes much higher when the loop temperature difference is smaller. The uncertainty analysis in Appendix B show that probable error for heating capacity goes from ±12.3% at full load operation to ±21% at low load conditions.

Figure 12 compares measured-to-expected ratios for heating and cooling together. There is considerable scatter and only a few systems fall within the ±25% range for both heating and cooling. The average ratios are just over 1.25 for heating and just below 0.9 for cooling.[5]

Therefore, as a correction to the measured unit COPs for each site, the measured-to-expected ratio determined from steady state conditions is used to correct all the data over the season for that site. The resulting correction is

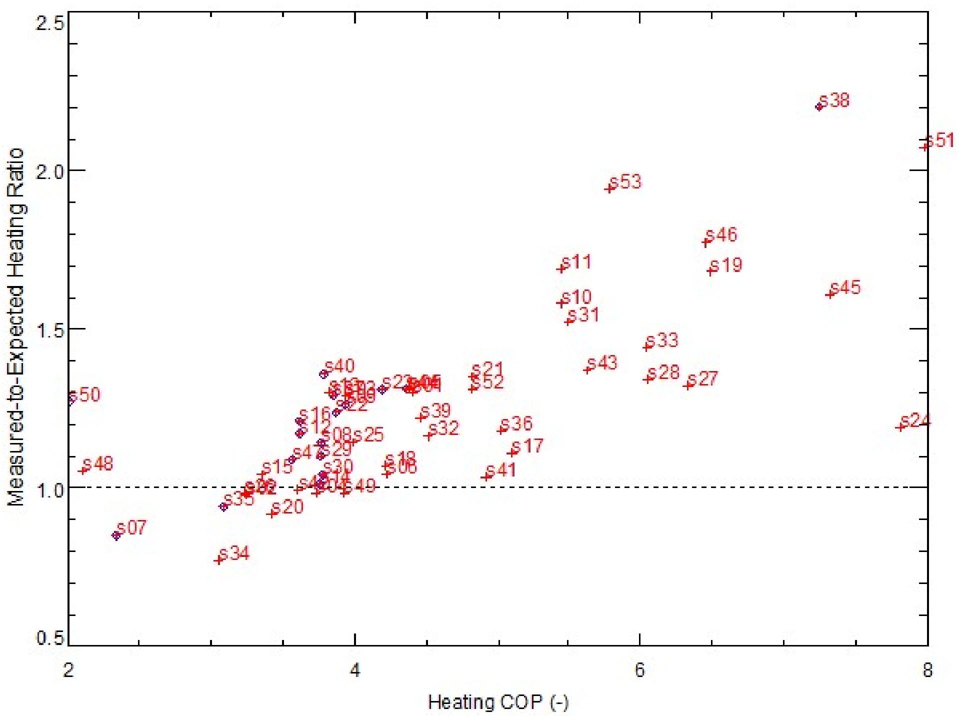
$$\text{Corrected Unit COP} = \frac{\text{Measured Unit COP}}{\text{measured-to-expected heating ratio}}$$

$$\text{Corrected Unit EER} = \frac{\text{Measured Unit EER}}{\text{measured-to-expected cooling ratio}}$$

[5] The measured-to-expected cooling ratio is most likely less than one because the measured performance corresponds to entering air wet bulb conditions. These are consistently lower than the nominal value of 67°F, which is the basis for the expected value. The lower entering wet bulb lowers the measured cooling efficiency.

Figure 11. Comparing Measured-to-Expected Ratio for all Sites for Heating and Cooling

(diamonds are dual stage units)



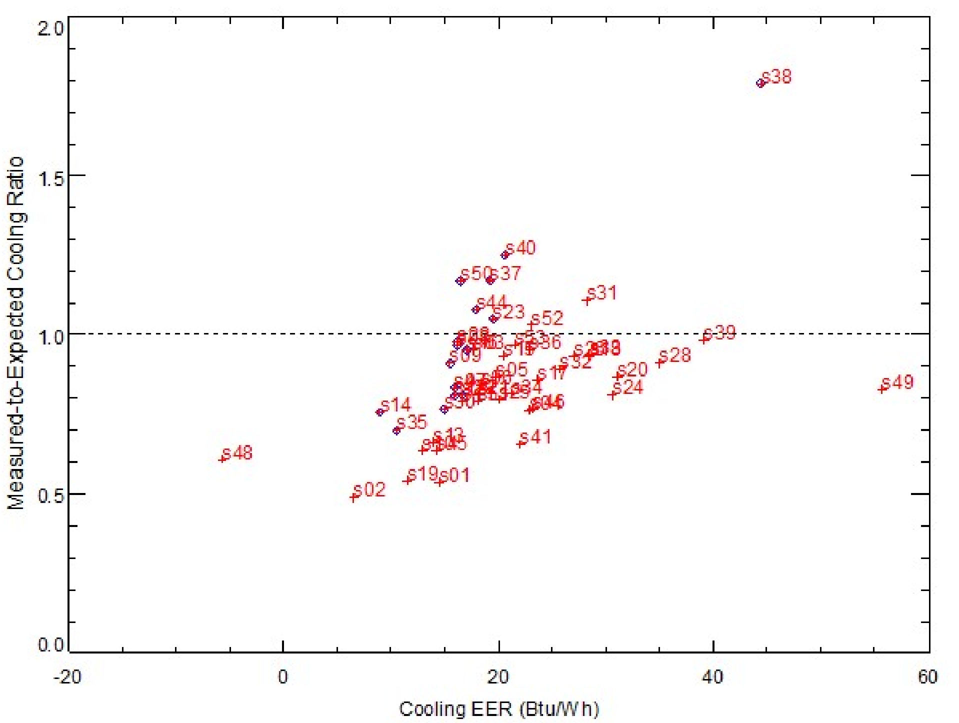
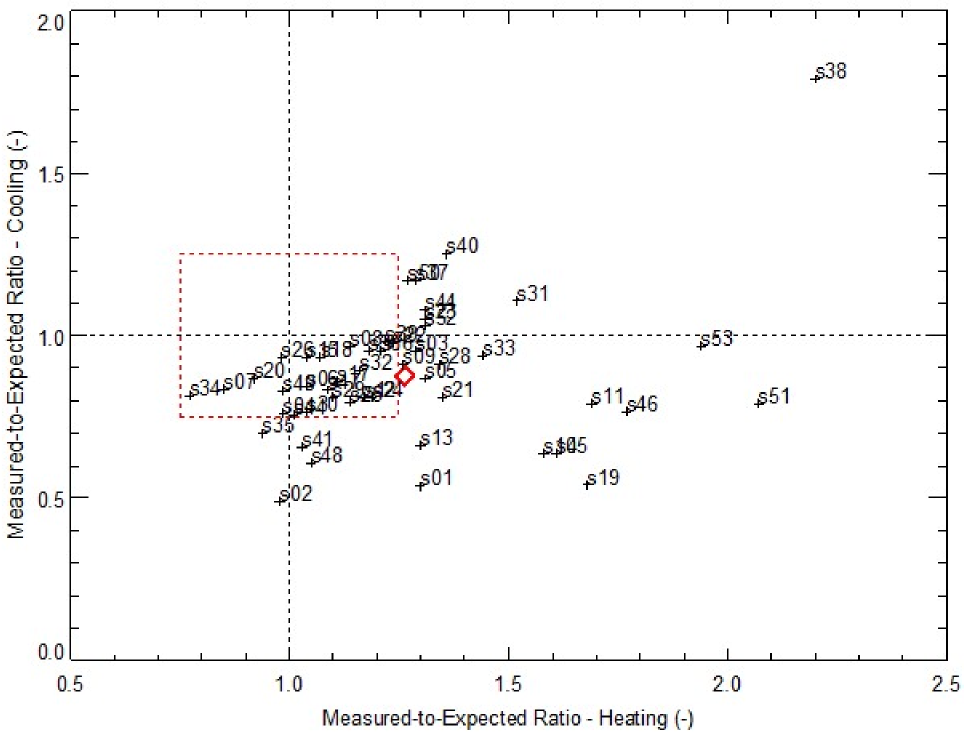


Figure 12. Comparing Measured-to-Expected Ratios for Heating and Cooling for all Sites



This correction process was applied to the seasonal data for each site and then applied to the seasonal unit COPs and EERs. The total system COPs and EERs for the system were recalculated based on these corrections. The next section shows the result of applying these corrections.

4.6 Corrected Heating COPs and Cooling EERs

The total system heating COPs shown for individual sites in Appendix D and the PDFs for each site (described in Appendix C) present the uncorrected measured heating COPs and cooling EERs. Table 10 lists the uncorrected and corrected heating COPs—on both a unit and a system basis—along the measured-to-expected COP ratio (M-to-E Heating Ratio). The process was used to correct the seasonal data. At some sites, data were not available to determine the M-to-E ratio, so those rows are left blank.

Table 10. Seasonal Heating COPs—Before and After Correction

Site ID	Model	Loop Type	Measured Seasonal System COP	Measured Seasonal Unit COP	M-to-E Heating Ratio	Corrected Seasonal Unit COP	Corrected Seasonal System COP
s01	NVV060	H2	4.41	5.63	1.30	4.33	3.39
s03	NVV036	H2	3.94	5.15	1.29	3.99	3.06
s04	NVV048	V1	3.73	4.33	0.98	4.42	3.81
s05	NVV060	H2	4.39	5.35	1.31	4.08	3.35
s06	NVV036	V1	4.23	4.47	1.04	4.29	4.07
s07	NDH064	HS	2.34	2.80	0.85	3.30	2.75
s08	NDV049	V1	3.76	4.71	1.14	4.13	3.30
s09	NDV049	V1	3.93	4.90	1.26	3.89	3.12
s10	NVV060	H2	5.44	6.65	1.58	4.21	3.45
s11	NVV060	H4	5.45	6.67	1.69	3.94	3.24
s13	NVV060	H2	3.82	4.66	1.30	3.58	2.95
s14	NDV072	H6	3.76	4.26	1.01	4.22	3.72
s15	NVV048	H2	3.35	4.08	1.04	3.92	3.22
s17	NVV048	HS	5.10	5.39	1.11	4.85	4.60
s18	NVV048	V2	4.21	5.40	1.07	5.05	3.94
s19	NVV060	V2	6.49	8.07	1.68	4.81	3.86
s20	NVV060	HS	3.42	3.58	0.92	3.89	3.72
s21	NVV048	HS	4.83	5.33	1.35	3.95	3.60
s22	NDV064	V1	3.87	4.56	1.24	3.68	3.12
s23	NDV038	HS	4.19	5.08	1.31	3.88	3.20
s24	NVV048	HS	7.81	8.16	1.19	6.85	6.56
s25	NVV048	HS	3.99	4.98	1.14	4.37	3.50
s26	NVV060	HS	3.23	3.72	0.98	3.80	3.29
s27	NVV060	HS					
s28	NVV036	H2	6.06	6.06	1.34	4.52	4.52
s29	NDV064	V1	3.76	4.31	1.10	3.92	3.42
s30	NDV064	HS	3.78	4.15	1.04	3.99	3.63
s31	NVV060	Pd	5.50	6.19	1.52	4.07	3.65
s32	NVV036	HS	4.51	4.68	1.16	4.03	3.89
s33	NVV036	V1	6.04	6.99	1.44	4.86	4.20
s34	NVV048	V1	3.05	3.39	0.77	4.41	3.96
s35	NDV072	Pd	3.09	3.44	0.94	3.66	3.28
s36	NVV036	HS	5.03	5.43	1.18	4.60	4.27
s37	NDV049	HS	3.85	5.00	1.29	3.87	2.99
s38	NDV026	V1	7.25	8.96	2.20	4.07	3.30
s39	NVH036	H2	4.46	4.87	1.22	3.99	3.65

Table 10 continued

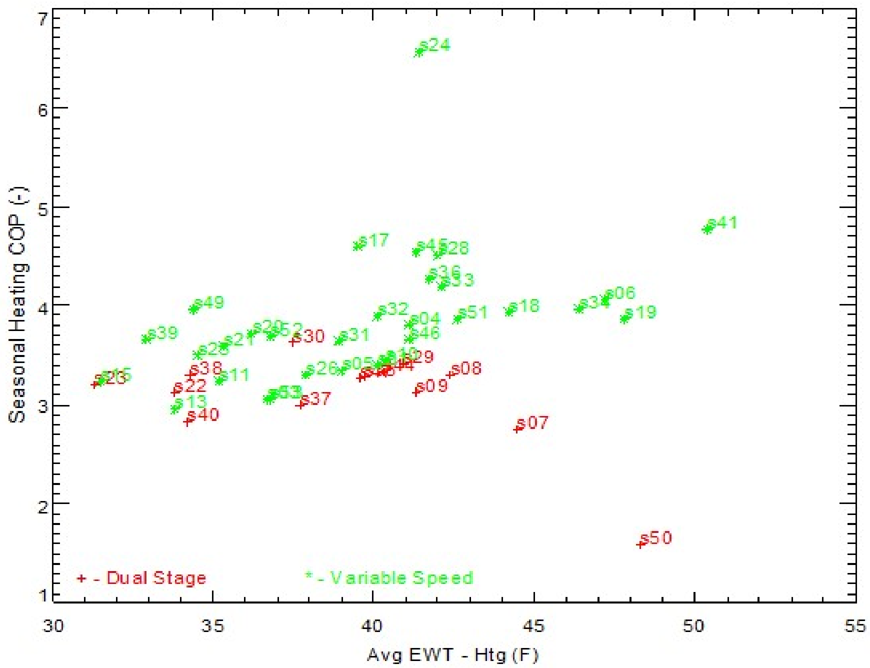
Site ID	Model	Loop Type	Measured Seasonal System COP	Measured Seasonal Unit COP	M-to-E Heating Ratio	Corrected Seasonal Unit COP	Corrected Seasonal System COP
s40	NDV038	V2	3.79	5.10	1.36	3.75	2.82
s41	NVV048	Op	4.92	4.92	1.03	4.78	4.78
s42	NVV060	V2					
s43	NVV060	V2					
s44	NDH049	HS	4.36	5.58	1.31	4.26	3.33
s45	NVV036	HS	7.32	7.63	1.61	4.74	4.55
s46	NVV036	?	6.46	7.35	1.77	4.15	3.66
s47	NDV049	V2	3.56	4.38	1.09	4.02	3.27
s48	NVV036	V1					
s49	NVV048	V1	3.92	4.06	0.99	4.10	3.96
s50	NDV038	Op	2.00	2.06	1.27	1.62	1.59
s51	NVV036	V1	7.98	9.17	2.07	4.43	3.87
s52	NVV036	V2	4.82	5.23	1.31	3.99	3.69

Note: Only includes data where the loop type is known and the M-to-E ratio could be determined. M-to-E ratio is determined at high speed for dual stage units and 50% speed for variable speed units.

The plots in Figure 13 show the trends for the corrected COPs as a function of average EWT. As expected, there is a general trend of higher COPs for systems with higher EWTs. In the top of Figure 13, the symbols indicate the type of unit, while the plot on the bottom uses different symbols to indicate the type of ground loop. COPs are typically higher for variable speed units than for dual stage units at a given EWT. There are generally no discernable differences between the loop types. The top of Figure 14 shows distribution of COPs for the different loop types. The bottom of the plot shows overall distribution of corrected heating COPs.

Figure 13. Corrected Heating COPs versus Entering Water Temperatures in Heating (by unit and loop type)

(*=vertical bores; ◊= horizontal loops; Δ= other loops)



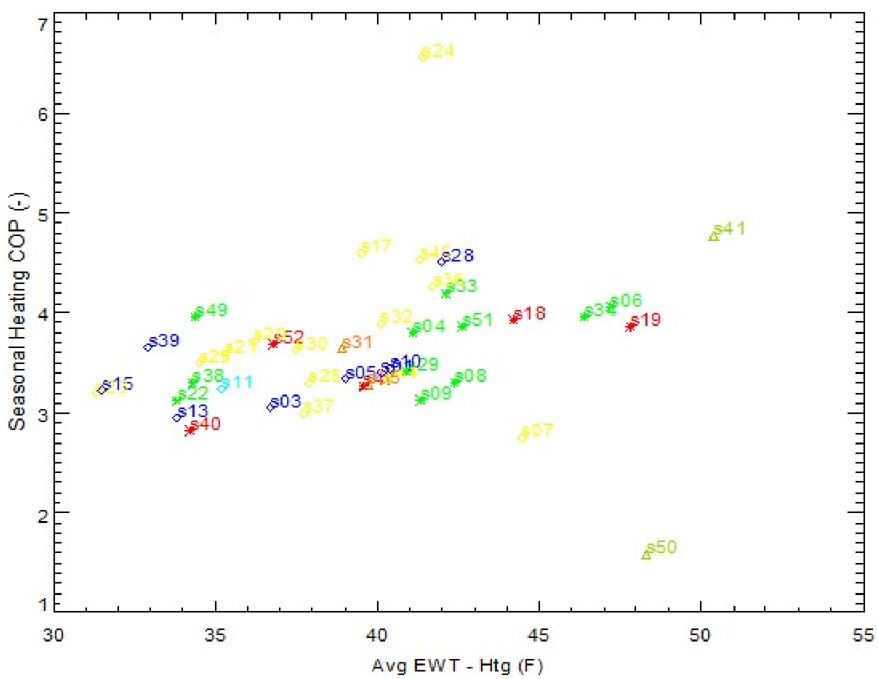
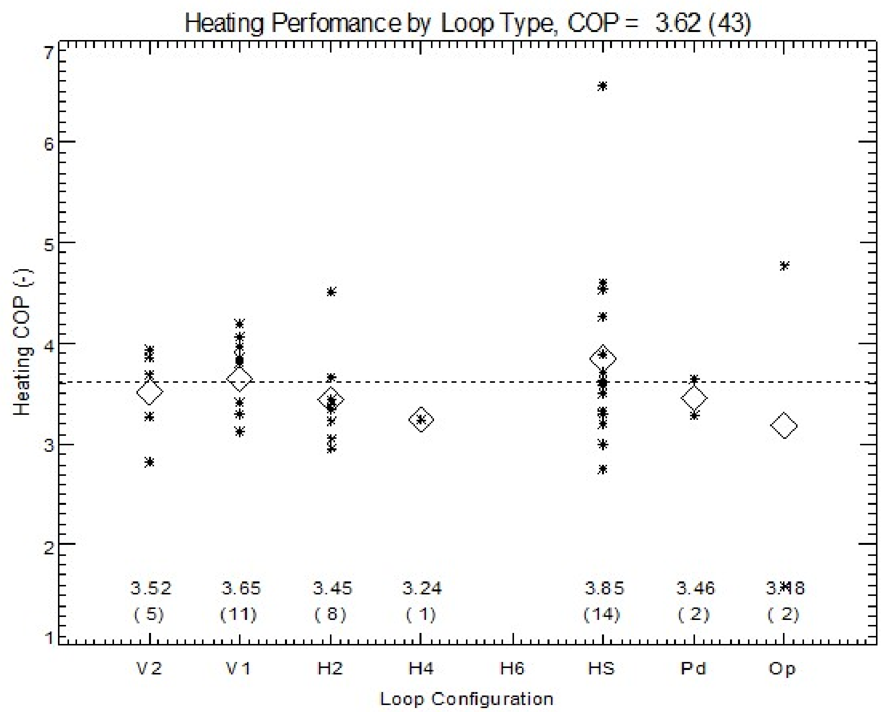


Figure 14. Distribution of Corrected Heating COPs—by Loop Type and for Total Sample



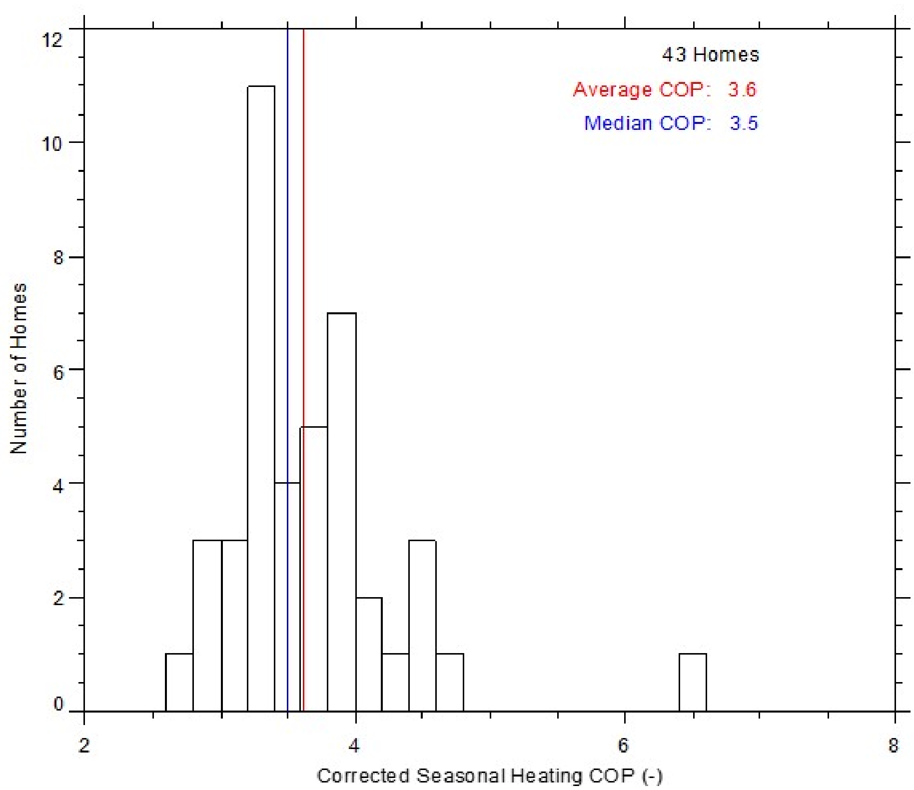


Table 11 shows uncorrected and corrected cooling EERs as well as the measured-to-expected EER ratio (M-to-E Cooling Ratio). The plots in Figure 15 show the trends for the corrected EERs as a function of average EWT. As expected, there is a general trend of lower EERs for systems with higher EWTs. In the top plot, the symbols indicate the type of unit while the plot on the bottom uses different symbols to indicate the type of ground loop. EERs are typically higher for variable speed units than for dual stage units at given EWT. There are generally no discernable differences between the loop types. The top plot in Figure 16 shows distribution of EERs for the different loop types. The bottom of the plot shows overall distribution of corrected cooling EERs.

Table 11. Seasonal Cooling EERs—Before and After Corrections

Site ID	Model	Loop Type	Measured Seasonal System EER (Btu/Wh)	Measured Seasonal Unit EER (Btu/Wh)	M-to-E Cooling Ratio	Corrected Seasonal System EER (Btu/Wh)	Corrected Seasonal Unit EER (Btu/Wh)
s01	NVV060	H2	14.6	18.3	0.53	34.6	27.5
s03	NVV036	H2	17.6	22.9	0.96	23.9	18.4
s04	NVV048	V1	22.9	24.7	0.76	32.4	30.1
s05	NVV060	H2	19.7	24.0	0.87	27.6	22.7
s06	NVV036	V1	18.4	19.4	0.84	23.1	21.9
s07	NDH064	HS	15.9	19.1	0.84	22.7	19.0
s08	NDV049	V1	16.2	20.3	0.97	20.9	16.7
s09	NDV049	V1	15.5	19.3	0.91	21.2	17.0
s10	NVV060	H2	13.0	15.6	0.64	24.3	20.3
s11	NVV060	H4	16.6	19.5	0.79	24.7	21.1
s13	NVV060	H2	14.0	16.1	0.66	24.5	21.2
s14	NDV072	H6	9.0	10.2	0.76	13.4	11.8
s15	NVV048	H2	20.6	24.3	0.93	26.1	22.1
s17	NVV048	HS	23.6	24.9	0.86	29.0	27.5
s18	NVV048	V2	28.5	36.5	0.94	38.8	30.3
s19	NVV060	V2	11.5	14.4	0.54	26.6	21.4
s20	NVV060	HS	31.0	32.3	0.87	37.1	35.6
s21	NVV048	HS	18.0	18.6	0.81	22.9	22.3
s22	NDV064	V1	16.2	19.1	0.98	19.5	16.6
s23	NDV038	HS	19.5	23.3	1.05	22.2	18.6
s24	NVV048	HS	30.6	31.9	0.81	39.4	37.7
s25	NVV048	HS	20.1	24.8	0.79	31.5	25.4
s26	NVV060	HS	27.0	28.3	0.93	30.4	29.0
s27	NVV060	HS					
s28	NVV036	H2	35.0	35.0	0.91	38.5	38.5

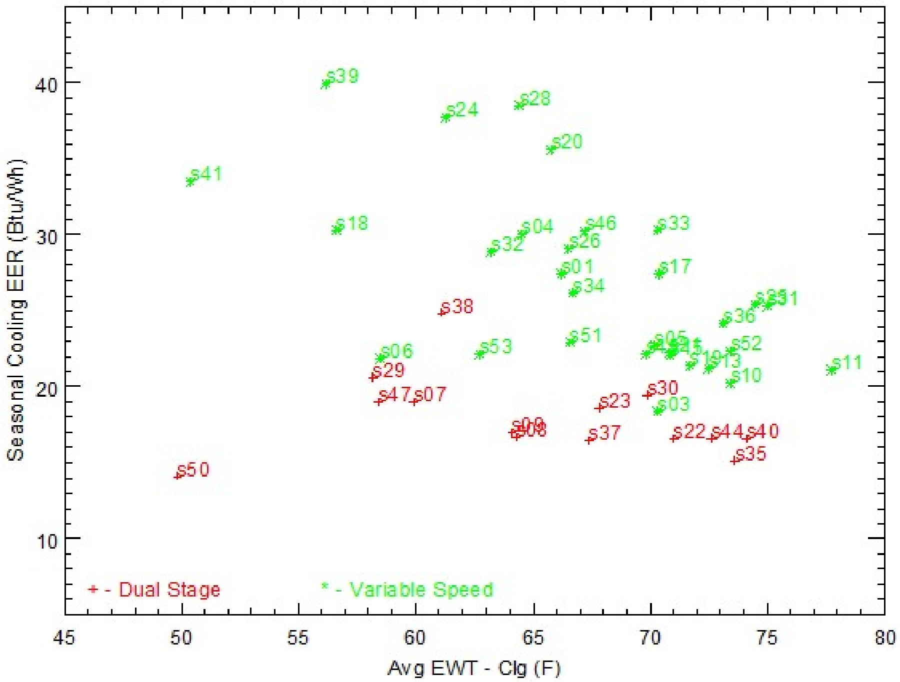
Table 11 continued

Site ID	Model	Loop Type	Measured Seasonal System EER	Measured Seasonal Unit EER (Btu/Wh)	M-to-E Cooling Ratio	Corrected Seasonal System EER	Corrected Seasonal Unit EER (Btu/Wh)
s29	NDV064	V1	16.7	18.9	0.81	23.3	20.6
s30	NDV064	HS	15.0	16.3	0.77	21.1	19.4
s31	NVV060	Pd	28.1	29.2	1.11	26.3	25.3
s32	NVV036	HS	25.7	26.7	0.89	29.9	28.9
s33	NVV036	V1	28.5	32.5	0.94	34.6	30.3
s34	NVV048	V1	21.2	23.1	0.81	28.5	26.2
s35	NDV072	Pd	10.6	11.4	0.70	16.3	15.1
s36	NVV036	HS	23.0	24.2	0.95	25.5	24.2
s37	NDV049	HS	19.3	24.5	1.17	20.9	16.5
s38	NDV026	V1	44.4	54.9	1.79	30.7	24.8
s39	NVH036	H2	39.2	42.7	0.98	43.6	40.0
s40	NDV038	V2	20.7	24.6	1.25	19.7	16.6
s41	NVV048	Op	22.1	22.1	0.66	33.5	33.5
s42	NVV060	V2					
s43	NVV060	V2					
s44	NDH049	HS	17.9	22.9	1.08	21.2	16.6
s45	NVV036	HS	14.2	14.8	0.64	23.1	22.2
s46	NVV036	?	23.2	25.9	0.77	33.6	30.2
s47	NDV049	V2	16.0	19.5	0.84	23.2	19.0
s48	NVV036	V1					
s49	NVV048	V1	55.6	57.6	0.83	69.4	67.0
s50	NDV038	Op	16.5	16.5	1.17	14.1	14.1
s51	NVV036	V1	18.1	20.4	0.79	25.8	23.0
s52	NVV036	V2	23.0	24.4	1.03	23.7	22.3

Note: Only includes data where the loop type is known and the M-to-E ratio could be determined. M-to-E ratio is determined at high speed for dual stage units and 50% speed for variable speed units

Figure 15. Corrected Cooling EERs vs. Entering Water Temperatures in Cooling (by unit and loop type)

(*=vertical bores; ◊= horizontal loops; Δ= other loops)



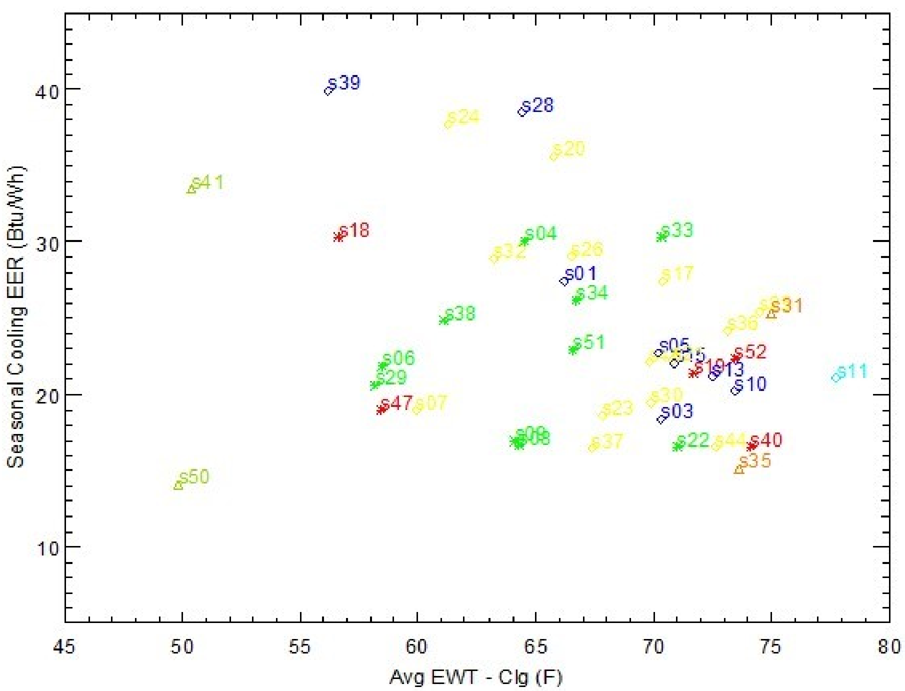
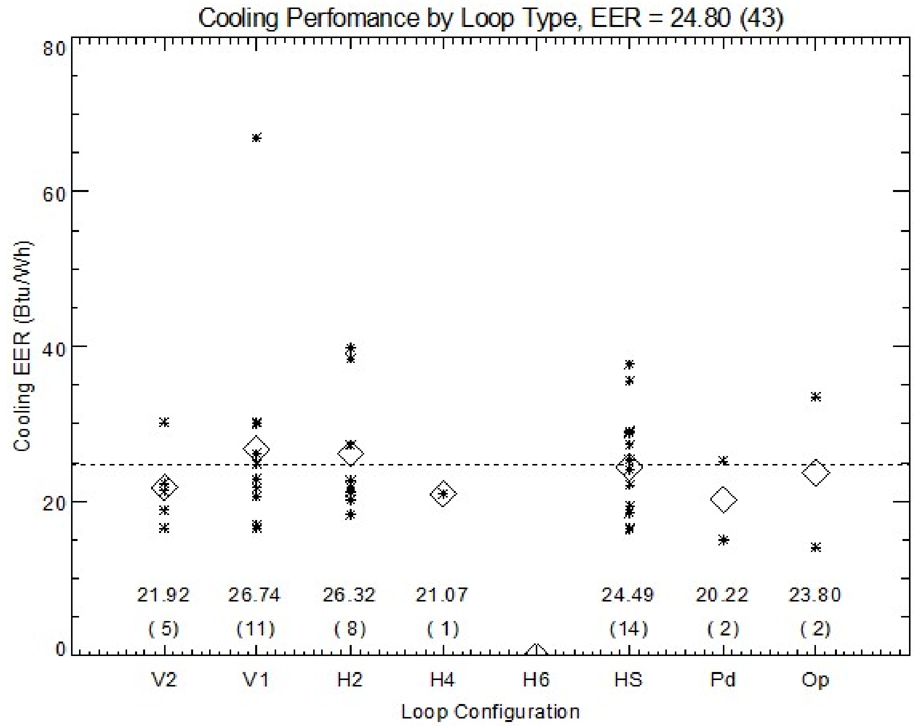


Figure 16. Distribution of Corrected Cooling EERs—by Loop Type and for Total Sample



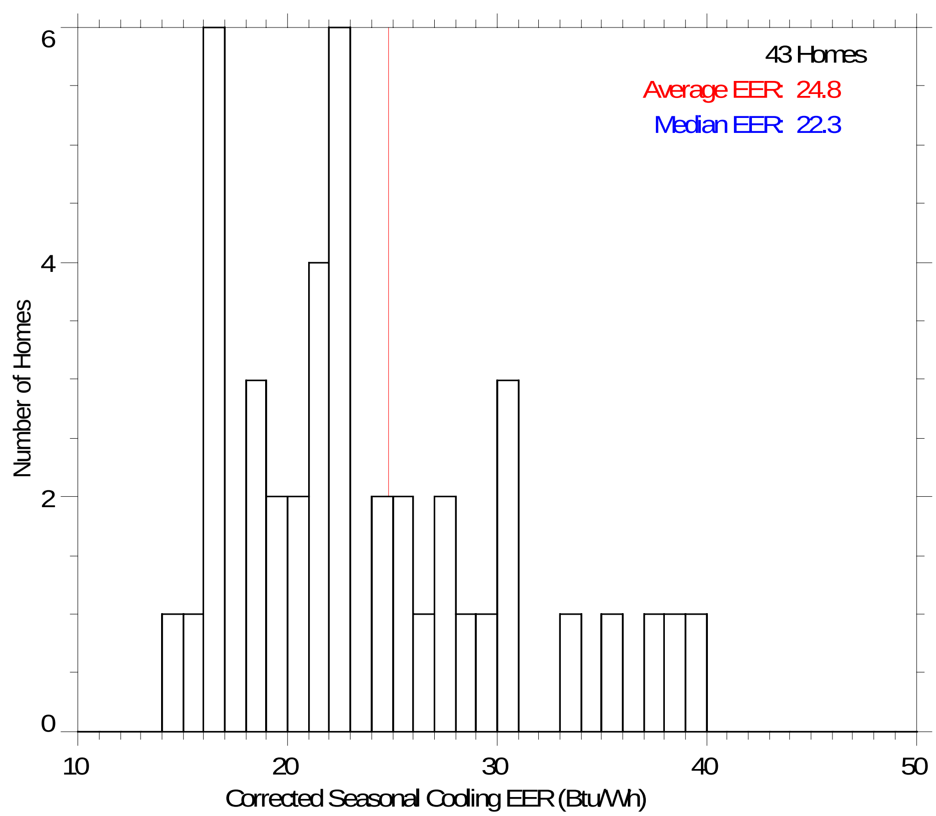
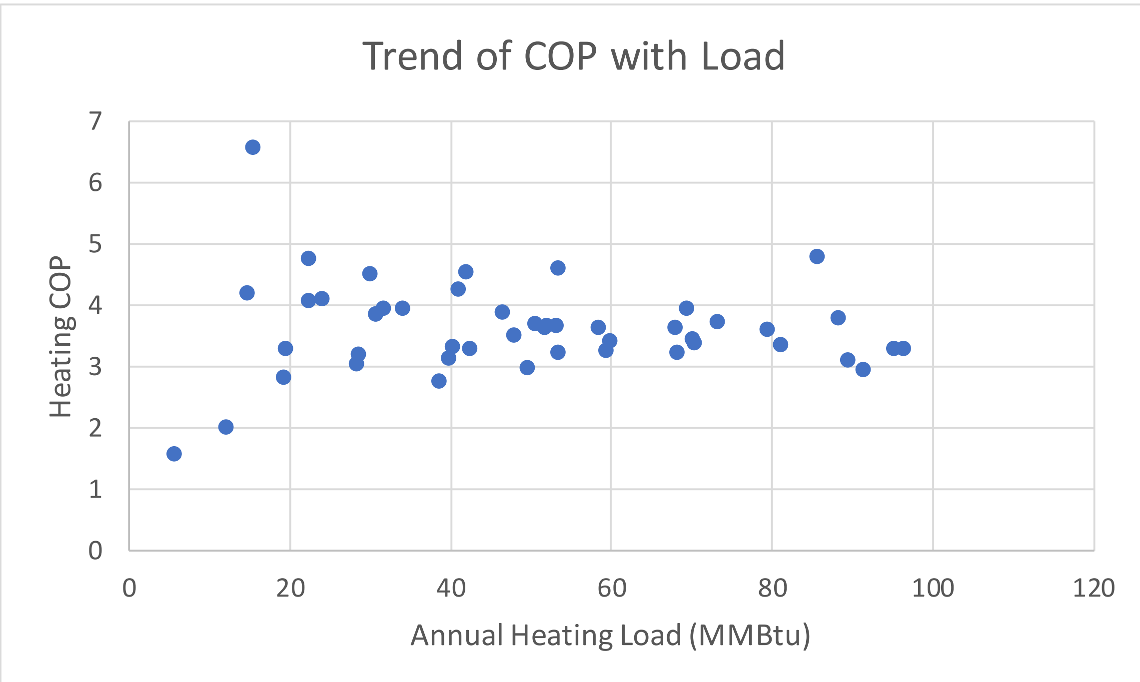


Figure 17 shows how the seasonal heating COP (corrected) varies with annual heating load.[6] The heating COPs are highly variable for some of the low load cases, perhaps due to short operating cycles (S50, open loop) or due to low loop temperature differences for variable speed units (S24 and S48). Overall, this implies that the uncertainties in determining COP may diminish for systems that are more fully loaded. The COPs at more normal levels of loading (i.e., over 40 MMBtu) are more consistent with expectations.

Figure 17. Trend of Seasonal Heating COP as a Function of Annual Heating Load



4.7 Variations in Pumping Power

The amount of pumping power reported by Symphony varied considerably across the sites, ranging from more than 1,600 kWh at S13 to 33 kWh at S24 (see Table 8). As shown by Figure 18, the pump power in percentage terms ranges from more than 30% of the compressor energy to 2% of the compressor energy.

6 Where the annual heating load is determined from the total GHP electric use and the corrected COP, as defined in a section below.

As part of the on-site measurements (Appendix B) it was observed that the pumping power was not always reported correctly. At sites S8 and S9, two stage pumps were installed and controlled, so the assumptions made by the Symphony controller about pump power were incorrect. The Symphony-reported power for S8 was always 472 Watts while the actual measured power was 240 and 440 Watts at low and high stage. At most sites, there was no detailed information about the installed pump model and control method. However, the dual stage units are more likely to have two-stage pumps installed in series that are controlled separately from the heat pump; so, the Symphony-reported pumping power is thought to be most questionable for dual stage units. The variable speed units are thought to more consistently use the speed signals and commands provided by the heat pump controls; therefore, the Symphony-reported data for these units is thought to be more believable. Many of the variable speed systems had seasonal pumping energy that was under 10% of compressor energy, though some were also near 20%.

Figure 18. Variation of Annual Pumping Energy with Annual Compressor Energy for Different Units

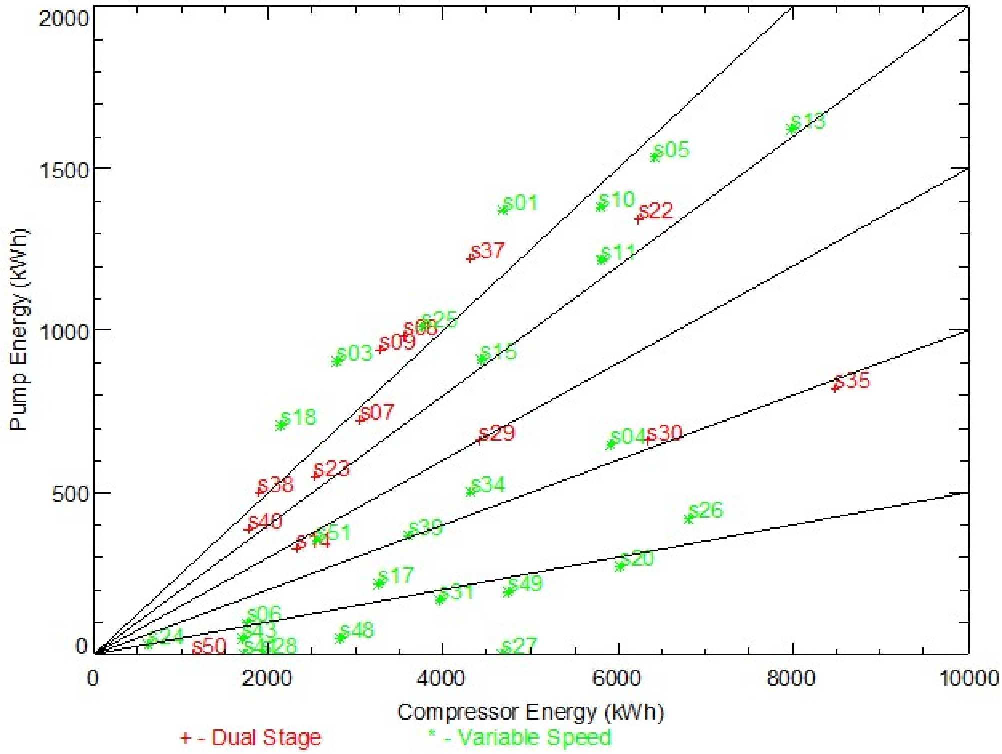
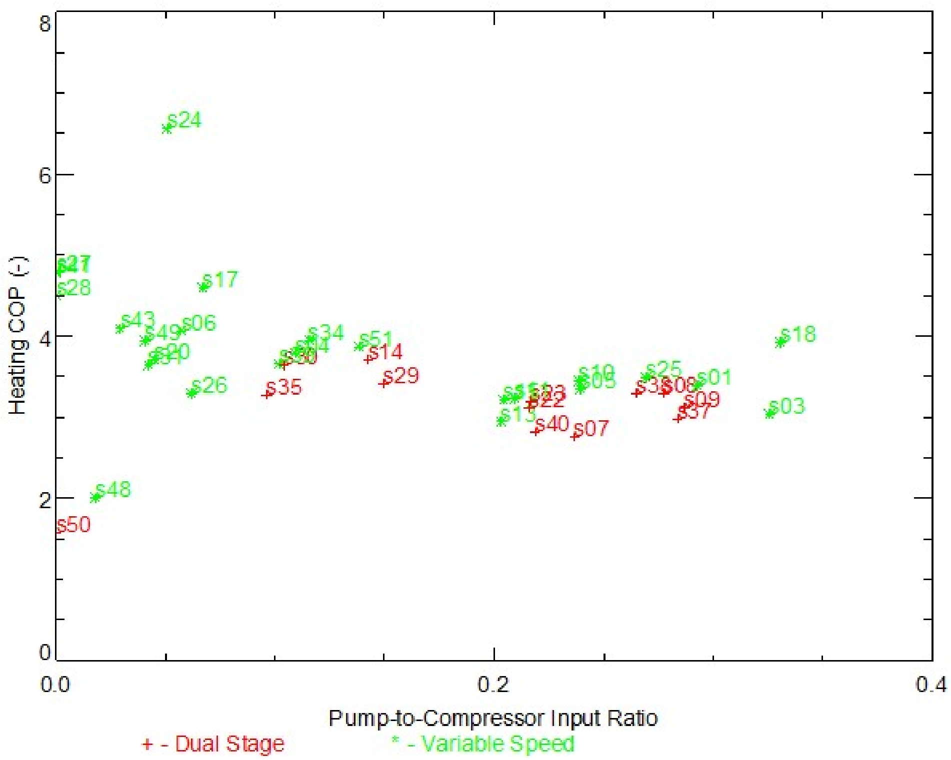


Figure 19 shows how the corrected seasonal system heating COP varies with the pump-to-compressor energy ratio. At ratios near 0.05, the average COP is near 4.0. As the ratio approaches 0.2, the average COP drops closer to 3.0. While the pumping energy reported by Symphony may be questionable in some cases, this overall trend appears to reinforce the importance of minimizing pumping power to improve COP.

Figure 19. Variation of Corrected System Heating COP with Pump-to-Compressor Energy Input Ratio



The on-site measurements from Site S8, a dual stage unit where the contractor installed two staged pumps in series, confirmed the relatively poor performance of this pumping arrangement and control strategy compared to variable speed operation. Table 12 shows the pumping power determined by the on-site measurements. The pump-to-compressor power ratio was 13% at high stage and 11% at low stage.

Table 12. Measured Pumping Power for a Dual Stage Unit (S8) with Two Stage Pumps

	Low Stage Compressor	High Stage Compressor
Flow (gpm)	9.5	13.6
Normalized Flow (gpm/ton)	3.2	3.4
Pump Power (W)	240	430
Compressor Power (W)	2100	3200
Pump-to-Compressor Power Ratio	11.4%	13.4%

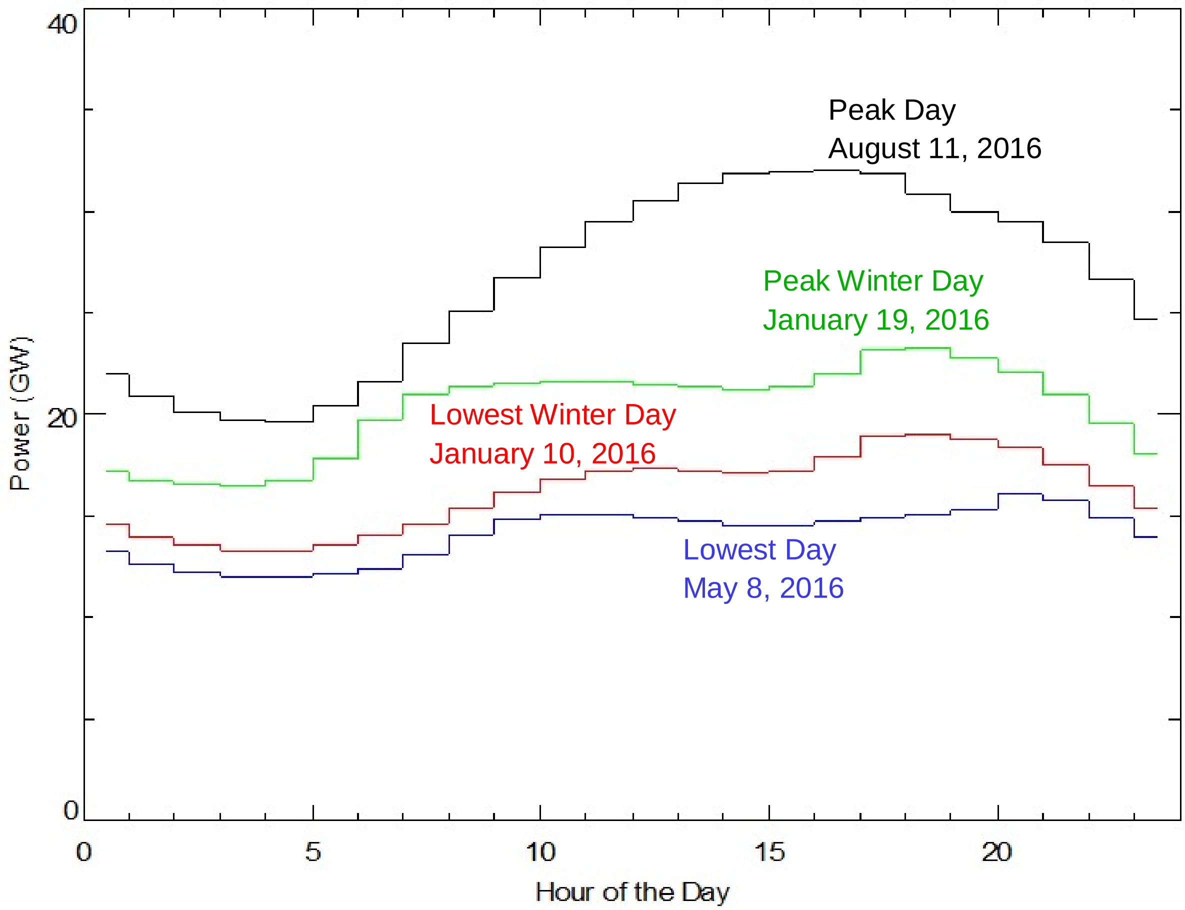
Notes: Normalized flow per nominal ton. Low stage capacity is assumed to be 73% of high stage.
All measurements taken with CDH handheld instruments.

4.8 Electric Demand Impacts

Adding geothermal heat pumps into the building stock will potentially impact the electric demand on the utility grid in various ways. The total electric demand for the State is shown in Figure 20 for the peak day of the year in 2016. The NYISO[7] load exceeded 32,000 MW at 4 p.m. on August 11. This peak is primarily driven by air conditioning load on this hot day. In contrast, the load on May 8 was the low for the year and ranged from 12,000 to 15,000 MW. During the month of January, the peak day was just over 23,000 MW at 6 p.m. The lowest day in January was just slightly above the low for the year in May.

[7] NYISO (New York Independent System Operator) manages the flow of power in the electric grid in the State.

Figure 20. NY State Electric Load Profiles for Various Days in 2016



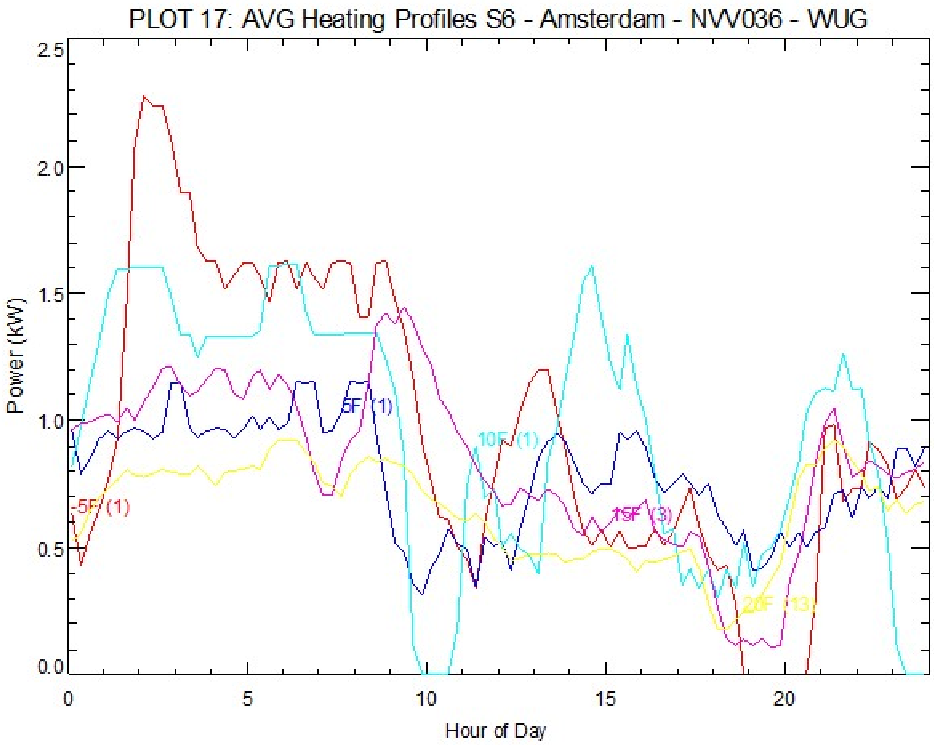
Geothermal heat pumps will result in a similar load shape as air conditioners for the summer, though with a potentially 40-50% lower electric demand per ton because of their higher cooling efficiency as shown by the data in Figure 16.[8] The winter load shape for geothermal heat pumps has the potential to "fill in" the early morning valley in the State's current electric load profile.

8 The seasonal EERs of 22-24 Btu/h are nearly double the nominal SEER's of conventional air conditioners.

The plots in Figure 21 show the average electric load profiles for sites S6 and S20, respectively. Each line on the plot as average profile for a group of days at each site where the daily average outdoor temperature was within a narrow range. For instance, the highest line on the top plot for S6 is the average profile for days when the average outdoor temperature was near −5°F (i.e., between −7.5 and −2.5°F). In this case, there was only one day in the range, as indicated by the number in parentheses. The average profile for days with different outdoor temperatures are shown with different lines on the plot.

Similarly, the average electric load profiles for summer days are shown in Figure 22 for sites S6 and S20. The top-most line on the plot shows the average profile for days when the average daily temperature was near 80°F (i.e., between 77.5 and 82.5°F). In this case the average profile is made using data for five days for S6 and for 18 days for S20. At both sites, there were not any days where average temperature exceeded 82.5°F.

Figure 21. Winter Demand Profiles at Various Temperatures for S6 and S20



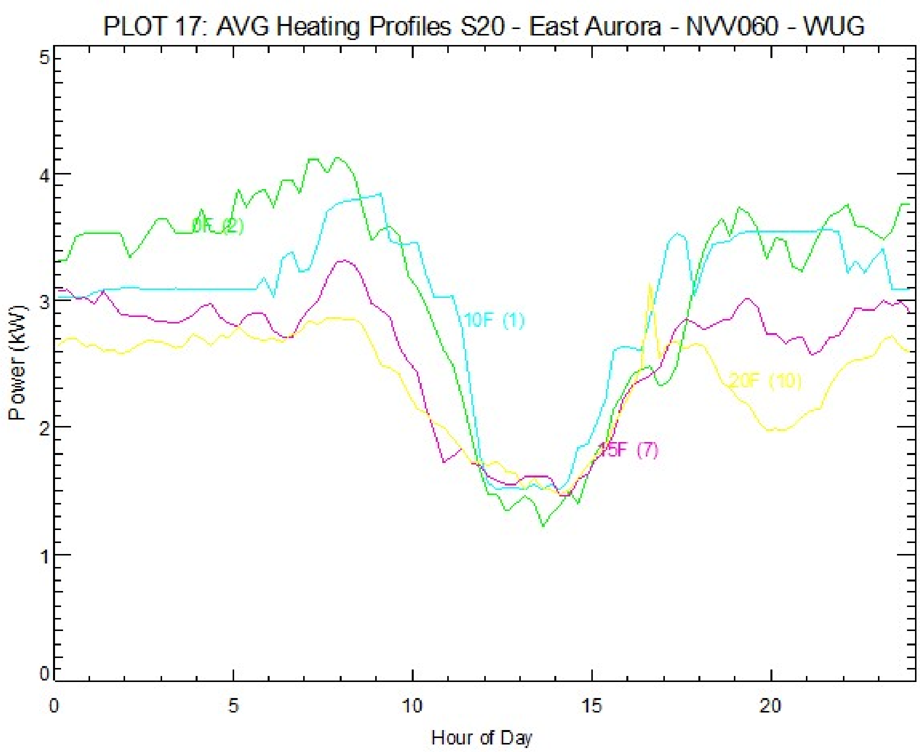
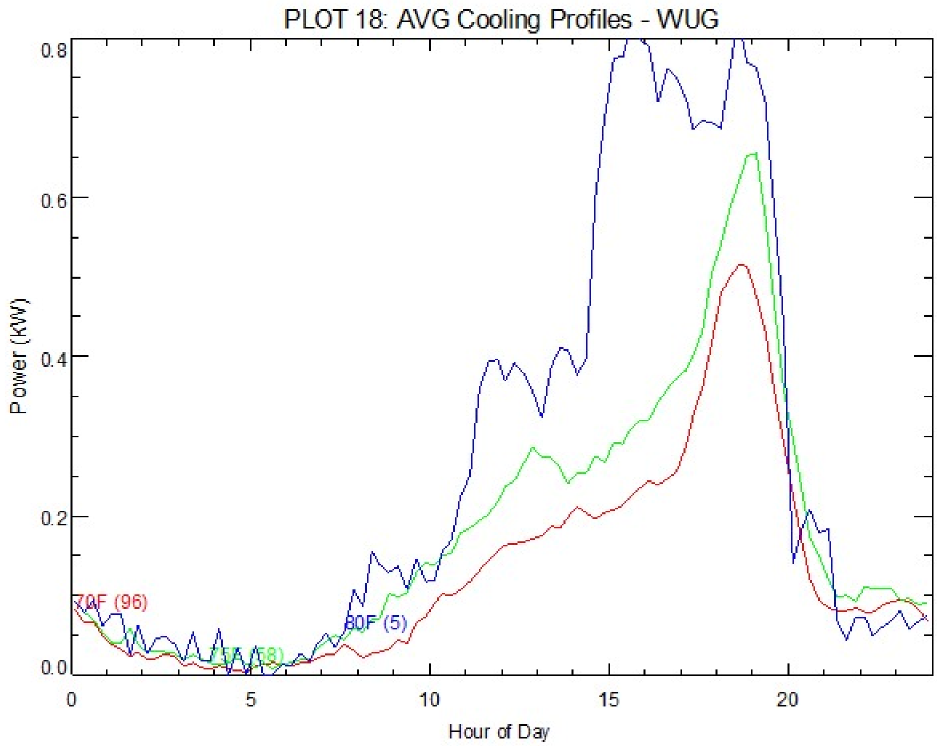
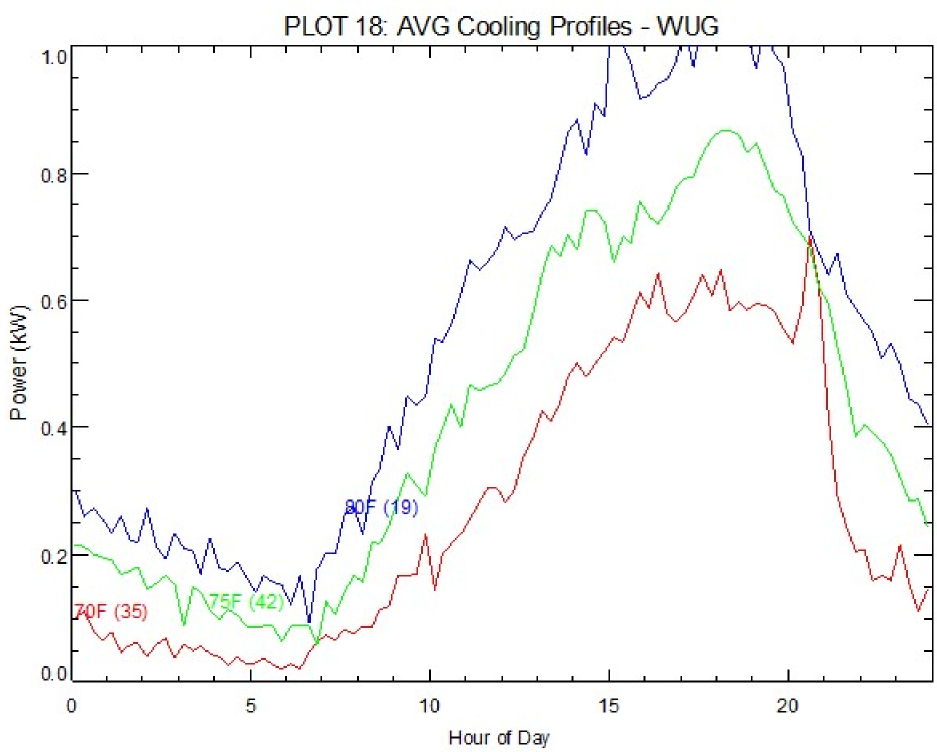


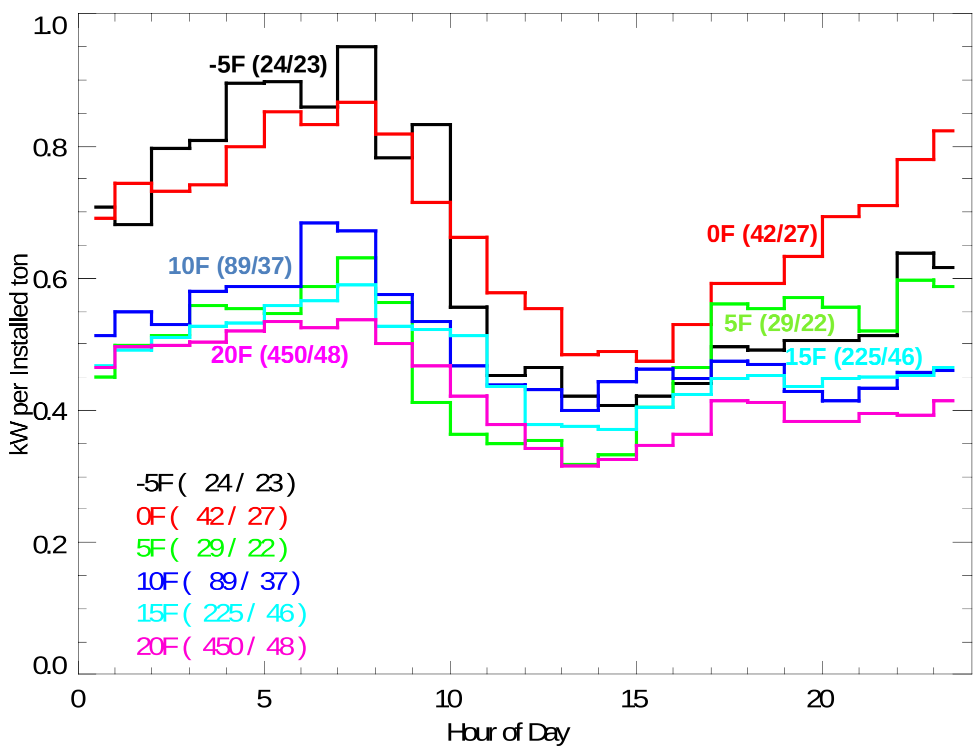
Figure 22. Summer Demand Profiles at Various Temperatures for S6 and S20





The demand profile at each site depends on the size of the heat pump and the load of the house. One way to normalize the electric load profile and compare several sites is to divide demand by the nominal size of each heat pump (i.e., the cooling capacity in tons). Figure 23 shows the average profiles in the heating season based on averaged data from several sites, in units of kW per installed ton (hourly values are given in Table 13). The highest line shows the average profile when ambient temperatures are near -5°F. The average profile includes 24 days from 23 different sites. Similarly, the second line shows the average of 42 days (from 27 sites) when the ambient temperature was near 0°F. The plot shows that the profile at -5°F has the highest peak and that the profile subsides as the temperature increases later in the day.

Figure 23. Average Winter Electric Demand Profiles at Various Outdoor Temperatures



The average profiles for the summer period are shown in Figure 24 (hourly values are given in Table 13). The top-most line represents the average of 83 days (from 16 different sites) where daily average temperature was around 85°F. Similarly, the second line down represents the average from more than 995 days from 50 sites where the temperature was near 80°F. The summer profiles subside at lower temperatures as expected.

Figure 24. Average Summer Electric Demand Profiles at Various Outdoor Temperatures

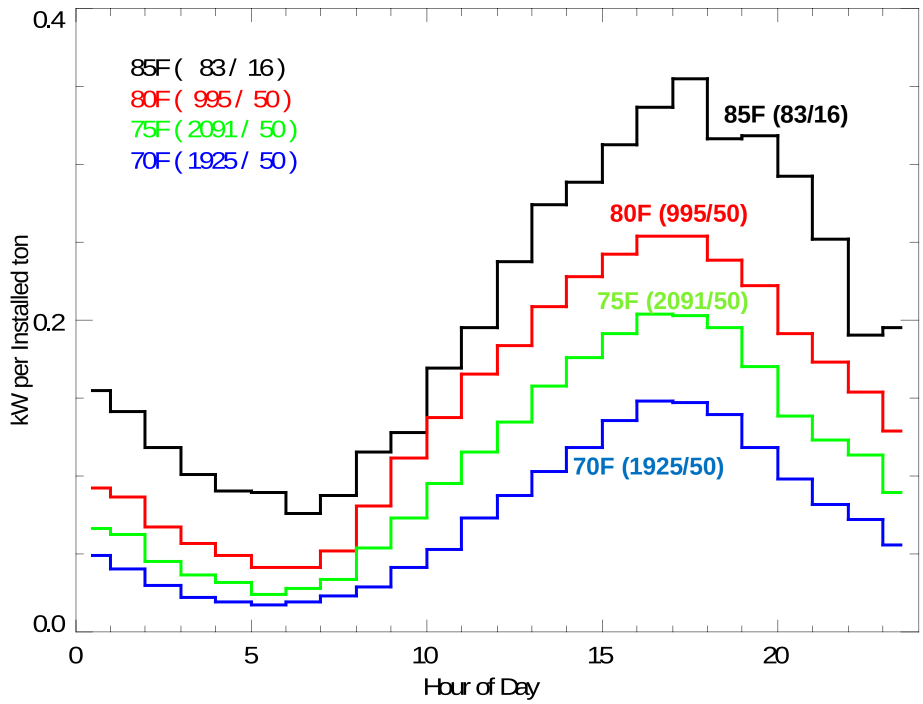


Table 13. Average kW per Installed ton for Both Summer and Winter Profiles

(from Figures 23 and 24)

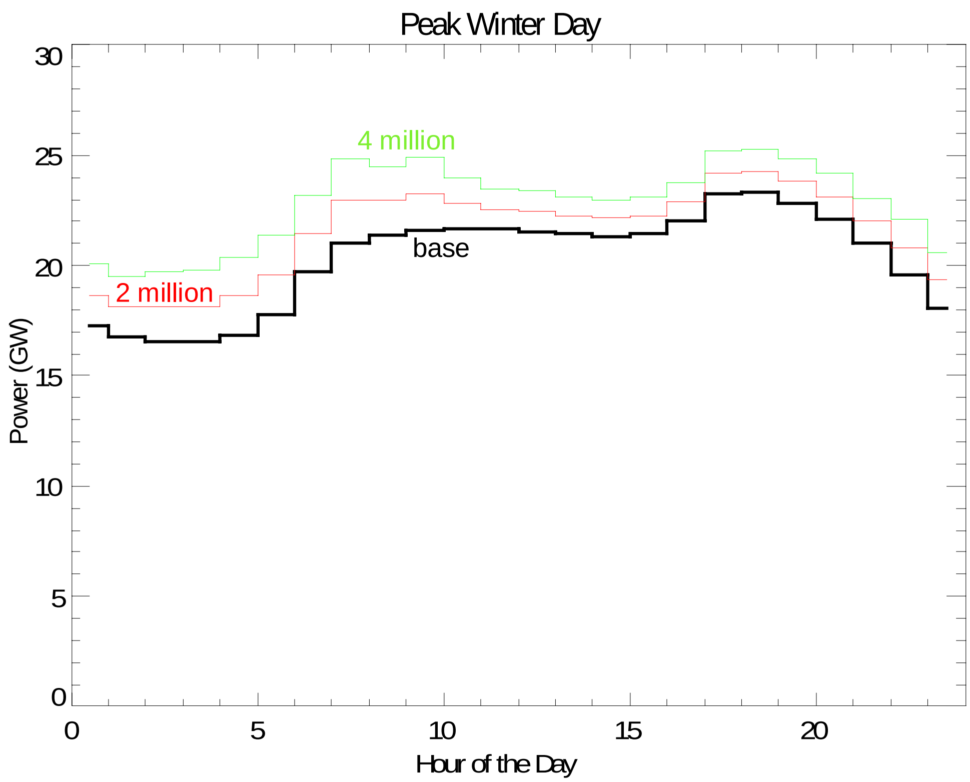
	Outdoor Temperature (F)						Outdoor Temperature (F)					
Hour	**-5**	**0**	**5**	**10**	**15**	**20**	**85**	**80**	**75**	**70**	**65**	**60**
1	0.71	0.69	0.45	0.51	0.47	0.46	0.15	0.09	0.07	0.05	0.05	0.05
2	0.68	0.74	0.50	0.55	0.49	0.50	0.14	0.09	0.06	0.04	0.04	0.04
3	0.80	0.73	0.51	0.53	0.51	0.50	0.12	0.07	0.05	0.03	0.03	0.03
4	0.81	0.74	0.56	0.58	0.53	0.50	0.10	0.06	0.04	0.02	0.02	0.02
5	0.90	0.80	0.56	0.59	0.53	0.52	0.09	0.05	0.03	0.02	0.02	0.02
6	0.90	0.85	0.55	0.59	0.56	0.53	0.09	0.04	0.02	0.02	0.02	0.02
7	0.86	0.83	0.59	0.68	0.57	0.53	0.08	0.04	0.03	0.02	0.02	0.02
8	0.95	0.87	0.63	0.67	0.59	0.54	0.09	0.05	0.03	0.02	0.02	0.02
9	0.78	0.82	0.56	0.58	0.53	0.50	0.12	0.08	0.05	0.03	0.03	0.03
10	0.83	0.72	0.41	0.53	0.52	0.47	0.13	0.11	0.07	0.04	0.04	0.04
11	0.56	0.66	0.37	0.47	0.51	0.42	0.17	0.14	0.10	0.05	0.05	0.05
12	0.45	0.58	0.35	0.44	0.44	0.38	0.20	0.17	0.12	0.07	0.07	0.07
13	0.47	0.55	0.36	0.43	0.38	0.34	0.24	0.18	0.14	0.09	0.09	0.09
14	0.42	0.48	0.32	0.40	0.38	0.32	0.27	0.21	0.16	0.10	0.10	0.10
15	0.41	0.49	0.33	0.44	0.37	0.33	0.29	0.23	0.18	0.12	0.12	0.12
16	0.42	0.48	0.41	0.46	0.40	0.35	0.31	0.24	0.19	0.14	0.14	0.14
17	0.44	0.53	0.47	0.45	0.42	0.36	0.34	0.25	0.20	0.15	0.15	0.15
18	0.50	0.59	0.56	0.47	0.45	0.42	0.36	0.25	0.20	0.15	0.15	0.15
19	0.49	0.59	0.55	0.47	0.45	0.41	0.32	0.24	0.20	0.14	0.14	0.14
20	0.51	0.63	0.57	0.43	0.44	0.38	0.32	0.22	0.17	0.12	0.12	0.12
21	0.51	0.69	0.56	0.41	0.45	0.38	0.29	0.19	0.14	0.10	0.10	0.10
22	0.51	0.71	0.52	0.43	0.45	0.40	0.25	0.17	0.12	0.08	0.08	0.08
23	0.64	0.78	0.60	0.46	0.45	0.39	0.19	0.15	0.11	0.07	0.07	0.07
24	0.62	0.82	0.59	0.46	0.46	0.42	0.20	0.13	0.09	0.06	0.06	0.06

The kW per installed ton peaks at about 0.36 on the hottest days. The rated kW per ton for these units is typically 0.6 (or an EER of approximately 20 Btu/Wh). The factor of 60% between the observed and rated kW per ton is due to equipment sizing as well as diversity of equipment operation in many homes.[9]

The potential wintertime impact on adding additional GHP units to the State utility grid is shown in Figure 25. The demand impact for -5°F average profile from Figure 23 is added on top of the NYISO peak winter profile from Figure 20. At 4 million tons of additional GHP capacity, the morning peak just starts to exceed the current late afternoon peak that is currently on the utility grid. Adding 4 million tons (or approximately one million units) still results in a manageable winter load on the grid.

Figure 25. Impact of Additional GHP Winter Load on the New York Grid

(adding 2 and 4 Million Installed tons)



9 Diversity factors of 60-70% are typically observed for the impact of residential air conditioners on the electric utility grid.

Given that that the EER of conventional cooling systems are about twice the level of GHP units, the impact on the utility grid would be reduce peak demand by 0.36 kW per installed ton of GHP capacity. Therefore, the installation of 1 million units (at four tons each) would remove about 1 GW from NY's summer peak.

4.9 Implied Heating Cost Savings

The heating cost savings from a GHP system depend on the heating fuel used in the base case, the heating COPs, and the magnitude of the heating load. The key assumptions used for the analysis in this section are listed in Table 14. The electric costs for various utilities in the winter are listed in Table 15. Table 16 calculates the cost savings for each GHP system compared to a base case fuel oil heating system. The base seasonal heating efficiency for fuel oil is assumed to be 83%. The base heating system electric use is assumed to be the fan use for the GHP system in the heating mode. The assumed energy costs are 0.115 per kWh and $2.56 per gallon.

Table 14. Assumptions Used to Determine Cost Savings

Parameter		Assumed Value
Heating System Efficiency	- Fuel Oil	83%
	- Natural Gas	78%
	- Propane	76%
Base System Electric Use (fan, pumps, etc)		Measured fan GHP use
Fuel Costs	- Electric ($ per kWh)	0.115 (NiMo & NYSEG, winter)
	- Fuel Oil ($ per gal)	2.56 (upstate, winter)
	- Natural Gas ($ per therm)	1.00 (statewide, winter)
	- Propane ($ per gal)	2.64 (upstate, winter)

Note: Assumed efficiencies are generally from NYS TRM but de-rated by 2% to reflect seasonal performance.

Table 15. Winter Electric Costs for Different Electric Utilities in NY State

Utility	Average Residential Price ($/kWh)
Central Hudson Gas & Elec Corp	0.165
Niagara Mohawk Power Corp.	0.116
New York State Elec & Gas Corp	0.115
Orange & Rockland Utilities Inc	0.195
Long Island Power Authority	0.178
Consolidated Edison Co-NY Inc	0.255

Notes: From EIA Form 826 data for 2016 for residential (Jan-Apr, Nov-Dec). The average for Niagara Mohawk and NYSEG is 0.115/kWh. The cost savings are calculated using the equations that follow.

Baseline Heating Costs = $\frac{\text{[total kWh] x COP *3.413 x [\$/gal]}}{\text{[Heating Eff] x [139 MBtu/gal]}}$

GHP Incremental Costs = ([total kWh] – [fan kWh]) x [$/kWh]

Heating Cost Savings = Baseline Heating Costs – GHP Incremental Costs

Table 16. Determining Heating Costs Savings Compared to Fuel Oil

Site ID	Total Heating (kWh)	Corrected System Heating COP	Heating Load (MMBtu)	Heating Oil Use (gallons)	Total Heating w/o Fan (kWh)	Heating Cost Savings
s01	6,070	3.39	70.3	609.6	5,575	$919
s03	2,721	3.06	28.4	246.1	2,570	$334
s04	6,788	3.81	88.2	764.6	5,482	$1,327
s05	7,096	3.35	81.1	703.3	6,500	$1,053
s06	1,613	4.07	22.4	194.0	1,542	$319
s07	4,121	2.75	38.7	335.4	3,560	$449
s08	3,759	3.30	42.4	367.3	3,476	$540
s09	3,727	3.12	39.7	344.2	3,295	$502
s10	5,963	3.45	70.2	608.3	5,256	$953
s11	6,169	3.24	68.2	591.3	5,411	$891
s13	9,070	2.95	91.3	791.6	7,520	$1,162
s14						
s15	4,858	3.22	53.5	463.3	4,508	$668
s17	3,398	4.60	53.3	462.3	2,773	$865
s18	2,540	3.94	34.1	295.8	2,252	$498
s19	2,339	3.86	30.8	267.2	2,161	$435
s20	5,761	3.72	73.1	634.0	5,323	$1,011
s21	6,483	3.60	79.6	689.6	5,763	$1,103
s22	8,400	3.12	89.5	775.6	7,067	$1,173
s23	2,617	3.20	28.6	248.1	2,443	$354
s24	696	6.56	15.6	135.1	607	$276
s25	4,021	3.50	48.0	416.3	3,671	$643
s26	8,568	3.29	96.3	835.0	7,459	$1,280
s27	5,225	4.80	85.6	742.0	4,334	$1,401
s28	1,955	4.52	30.2	261.3	1,785	$464
s29	5,134	3.42	60.0	519.7	4,670	$793
s30	5,475	3.63	67.9	588.7	4,679	$969
s31	4,160	3.65	51.8	448.9	4,035	$685
s32	3,499	3.89	46.5	402.8	3,311	$651
s33	1,039	4.20	14.9	128.9	942	$222
s34	2,352	3.96	31.8	275.4	1,895	$487
s35	8,510	3.28	95.3	825.7	7,510	$1,250

Table 16 continued

Site ID	Total Heating (kWh)	Corrected System Heating COP	Heating Load (MMBtu)	Heating Oil Use (gallons)	Total Heating w/o Fan (kWh)	Heating Cost Savings
s36	2,812	4.27	40.9	354.8	2,575	$612
s37	4,870	2.99	49.7	430.8	4,786	$553
s38	1,739	3.30	19.6	165.5	1,585	$242
s39	4,173	3.65	52.1	440.6	3,773	$694
s40	1,993	2.82	19.2	162.3	1,942	$192
s41	1,380	4.78	22.5	190.3	1,233	$345
s42	4,702	3.65	58.5	495.1	4,198	$785
s43	1,712	4.11	24.0	203.0	1,442	$354
s44	3,543	3.33	40.3	341.0	3,239	$501
s45	2,710	4.55	42.0	355.9	2,461	$628
s46	4,260	3.66	53.2	450.2	4,043	$688
s47	5,330	3.27	59.5	503.5	4,839	$732
s48	1,764	2.00	12.1	102.1	1,379	$103
s49	5,132	3.96	69.4	587.2	4,429	$994
s50	1,046	1.59	5.7	48.0	901	$19
s51	2,330	3.87	30.8	260.3	2,138	$420
s52	4,018	3.69	50.6	428.0	4,009	$635

Note: The fuel oil heating efficiency is 83%. Electric costs are 11.5¢ per kWh. Fuel Oil Cost is $2.56 per gallon.

The range of annual heating cost savings for the all the sites is shown in Figure 26. Figure 27 shows that the heating cost savings are primarily a function of the annual heating load served by the GHP unit. The dotted line is the best fit linear model determined from linear regression. The standard deviation of the data about the line is $59.60. Therefore, the linear model (corresponding to the dotted line on Figure 27) predicts the annual heating cost savings as a function of heating load to within ±$119 at the 95% confidence level.

$$=\text{Annual Heating Cost Savings} = -7.6 + 13.76 \times [\text{annual heating load (MMBtu)}]$$

For example, applying these curves at an annual heating load of 50 MMBtu (which is close to the average for the sites), the predicted heating savings by the linear model are $680, and there is a 95% probability the savings will be between $561 and $799.

Figure 26. Distribution of Cost Savings—Fuel Oil

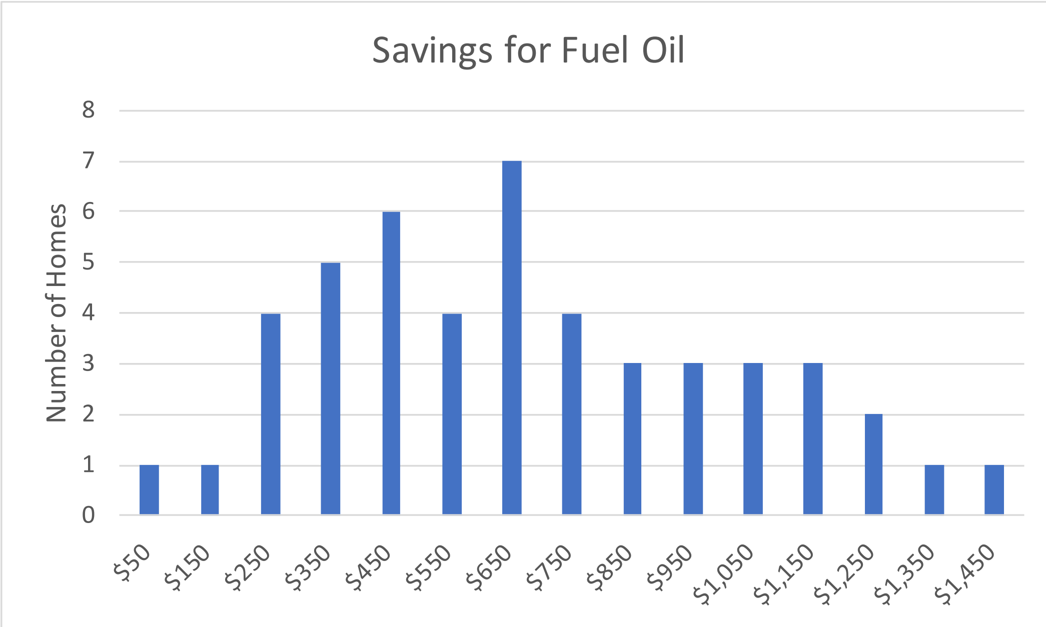
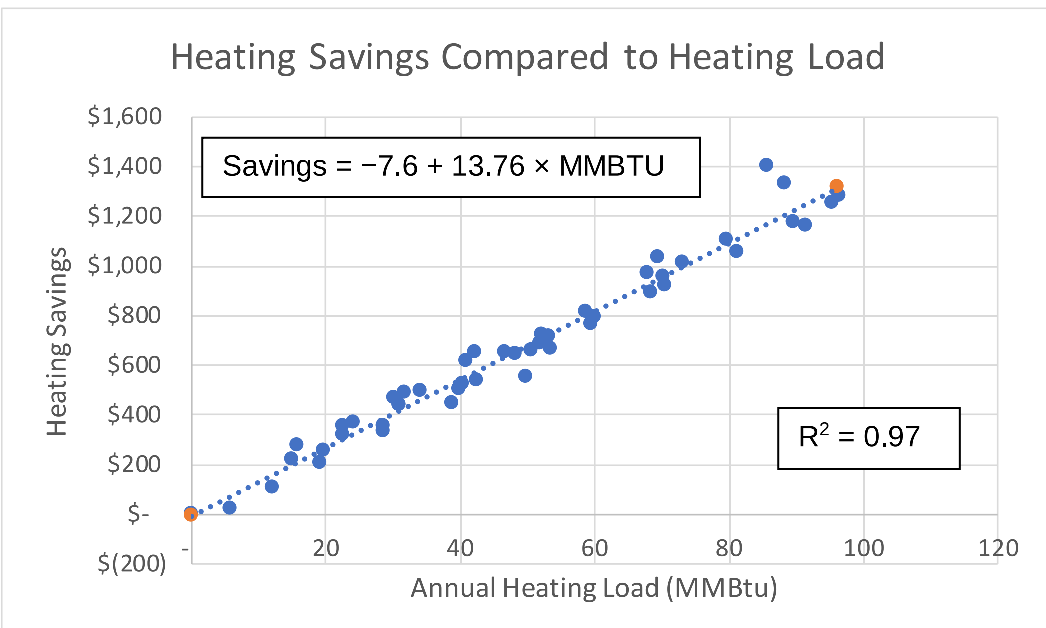


Figure 27. Trend of Heating Cost Savings with Annual Heating Load—Fuel Oil



Figures 28 and 29 show the trends of heating cost savings with load using Natural Gas and Propane as the base case fuel. The efficiency assumptions listed in Table 14 were used for each fuel. The savings at an annual load of 50 MMBtu goes from $680 for fuel oil to $212 for natural gas and $1,459 for propane. Again, the data has the same standard deviation as was shown above fuel oil, so the expected variation of data about the line in each case is still ±$119 at the 95% confidence level.

Figure 28. Trend of Heating Cost Savings with Annual Heating Load—Natural Gas

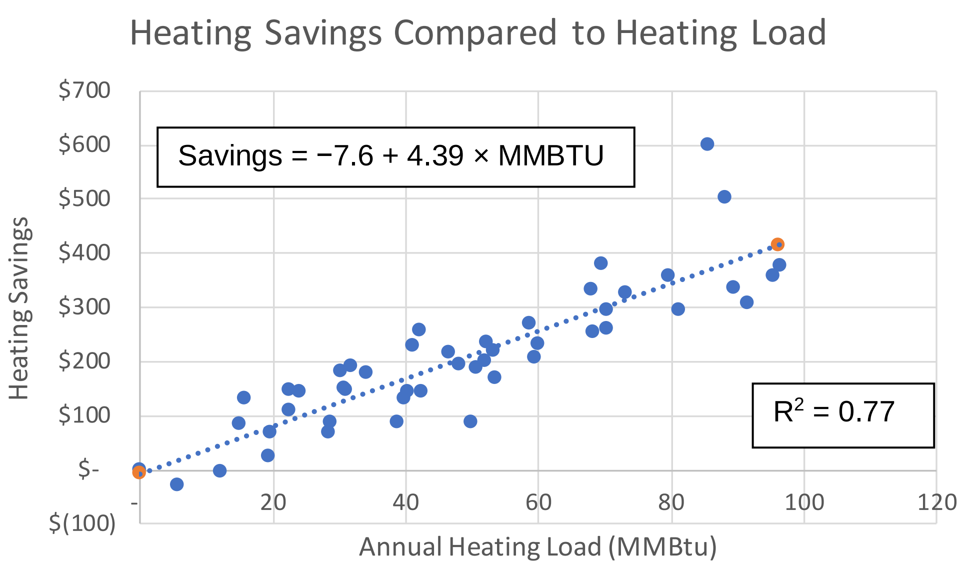
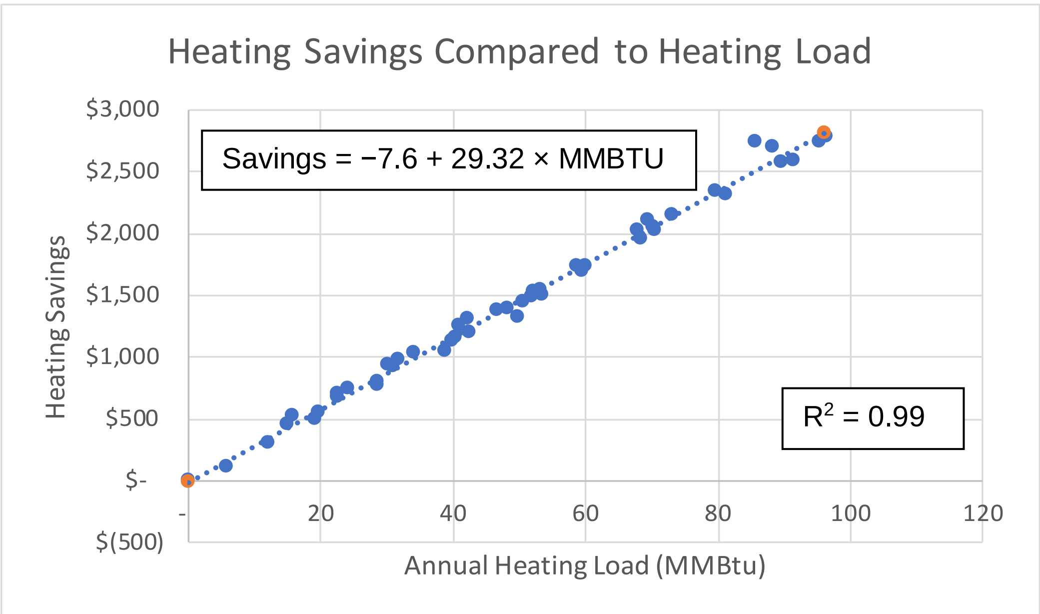


Figure 29. Trend of Heating Cost Savings with Annual Heating Load—Propane



The resulting cost savings are strongly a function of electricity and fuel costs. The following three tables show the sensitivity of cost savings to electric and fuel prices using the results from S31 in Table 16, which has annual heating load near the median for all the homes. Lower electric costs and higher fuel costs increase the savings. If electricity is 20% lower and fuel costs are 20% higher, then the cost savings increase by 47% for oil, a factor of 2.1 for natural gas and 32% for propane.

Table 17. Sensitivity of Cost Savings for Fuel Oil, Natural Gas, and Propane

		Electric Cost				
		80%	**90%**	**100%**	**110%**	**120%**
Fuel Oil Cost	**80%**	$548	$502	$455	$409	$363
	90%	$663	$617	$570	$524	$478
	100%	$778	$732	$685	$639	$593
	110%	$893	$847	$800	$754	$707
	120%	$1,008	$962	$915	$869	$822

Note: 100% costs correspond to $0.115/kWh and $2.56/gal. Determined using data for S31.

		Electric Cost				
		80%	**90%**	**100%**	**110%**	**120%**
Gas Cost	**80%**	$160	$114	$67	$21	$(26)
	90%	$226	$180	$134	$87	$41
	100%	$293	$246	$200	$154	$107
	110%	$359	$313	$266	$220	$174
	120%	$426	$379	$333	$286	$240

Note: 100% costs correspond to $0.115/kWh and $1.00/therm. Determined using data for S31.

		Electric Cost				
		80%	**90%**	**100%**	**110%**	**120%**
Propane Cost	**80%**	$1,193	$1,147	$1,101	$1,054	$1,008
	90%	$1,389	$1,342	$1,296	$1,250	$1,203
	100%	$1,584	$1,538	$1,492	$1,445	$1,399
	110%	$1,780	$1,734	$1,687	$1,641	$1,594
	120%	$1,976	$1,929	$1,883	$1,836	$1,790

Note: 100% costs correspond to $0.115/kWh and $2.64/gal. Determined using data for S31.

4.10 Implied Cooling Cost Savings

A similar process was applied to determine the seasonal cooling savings. The corrected seasonal average EER (from Table 11) is used to estimate the cooling load from the cooling electric use. Then, the base case electric use for a conventional (air-cooled) cooling system is determined using a seasonal average cooling EER of 12 Btu/Wh, which approximately corresponds to a rated SEER of 15 Btu/Wh. The average and median cost savings are $81 and $63, respectively, assuming an electric cost of $0.115 per kWh.

Table 18. Determining Cooling Cost Savings

Site ID	Total Cooling (kWh)	Corrected System EER (Btu/Wh)	Cooling Load (MMBtu)	Base Case Cooling (kWh)	Cooling Savings
s01	628	27.48	17.3	1,438	$93
s03	1,148	18.37	21.1	1,757	$70
s04	73	25.00	1.8	153	$9
s05	1,306	22.70	29.7	2,471	$134
s06	314	21.89	6.9	573	$30
s07	264	18.98	5.0	418	$18
s08	1,169	16.72	19.5	1,628	$53
s09	1,057	16.99	17.9	1,495	$50
s10	2,256	20.25	45.7	3,808	$178
s11	1,776	21.07	37.4	3,117	$154
s13	2,969	21.22	63.0	5,249	$262
s14					
s15	1,072	22.11	23.7	1,974	$104
s17	852	27.47	23.4	1,950	$126
s18	604	25.00	15.1	1,259	$75
s19	2,810	21.39	60.1	5,008	$253
s20	993	25.00	24.8	2,068	$124
s21	1,053	22.26	23.5	1,954	$104
s22	582	16.58	9.6	804	$26
s23	735	18.57	13.7	1,138	$46
s24	63	25.00	1.6	131	$8
s25	1,192	25.41	30.3	2,523	$153
s26	839	29.05	24.4	2,030	$137
s27	516	25.00	12.9	1,075	$64
s28	155	25.00	3.9	322	$19
s29	467	20.59	9.6	802	$38

Table 18 continued

Site ID	Total Cooling (kWh)	Corrected System EER (Btu/Wh)	Cooling Load (MMBtu)	Base Case Cooling (kWh)	Cooling Savings
s30	2,261	19.43	43.9	3,661	$161
s31	446	25.33	11.3	942	$57
s32	485	28.91	14.0	1,167	$79
s33	181	25.00	4.5	376	$23
s34	2,139	26.18	56.0	4,666	$291
s35	2,383	15.11	36.0	3,001	$71
s36	606	24.16	14.6	1,220	$71
s37	852	16.46	14.0	1,169	$36
s38	890	24.82	22.1	1,842	$109
s39	242	25.00	6.0	504	$30
s40	479	16.56	7.9	661	$21
s41	488	25.00	12.2	1,017	$61
s42	502	25.00	12.6	1,046	$63
s43	371	25.00	9.3	773	$46
s44	1,251	16.56	20.7	1,726	$55
s45	802	22.17	17.8	1,481	$78
s46	450	25.00	11.3	938	$56
s47	677	19.03	12.9	1,074	$46
s48	178	25.00	4.4	370	$22
s49	526	25.00	13.1	1,096	$66
s50	241	14.12	3.4	284	$5
s51	837	22.97	19.2	1,602	$88
s52	119	22.33	2.6	221	$12

Note: Electric costs are 11.5¢ per kWh. All corrected EERs over 30 Btu/Wh were set to a default value of 25 Btu/Wh. The baseline cooling unit efficiency is assumed to be a seasonal average 12 Btu/Wh, including actual fan power.

Figure 30 shows cooling savings are also correlated with annual cooling load, though the degree of scatter is relatively greater than was observed for heating—mostly due to the greater variations in the cooling EERs. The average cooling load was 19 MMBtu. At this load, the linear model predicts cooling savings of about $80 per year. The confidence interval for the data about the line is ±$39 at the 95% certainty level (P95).

Because there is significant correlation between heating loads and cooling loads, the total savings from both heating and cooling also correlate reasonably well to heating load alone. Figure 31 shows total heating and cooling savings combined have slightly more scatter than the heating savings shown in Figure 27 (for fuel oil). The coefficient of determination (R-squared) decreases, from 0.97 to 0.95, and the expected confidence interval at the P95 level increases, from ±$119 to ±$171. Using the linear model at an annual heating load of 50 MMBtu using fuel oil, predicted cost savings increase from $680 for heating alone to $760 when cooling is added in.

Figure 30. Trend of Cooling Cost Savings with Annual Cooling Load

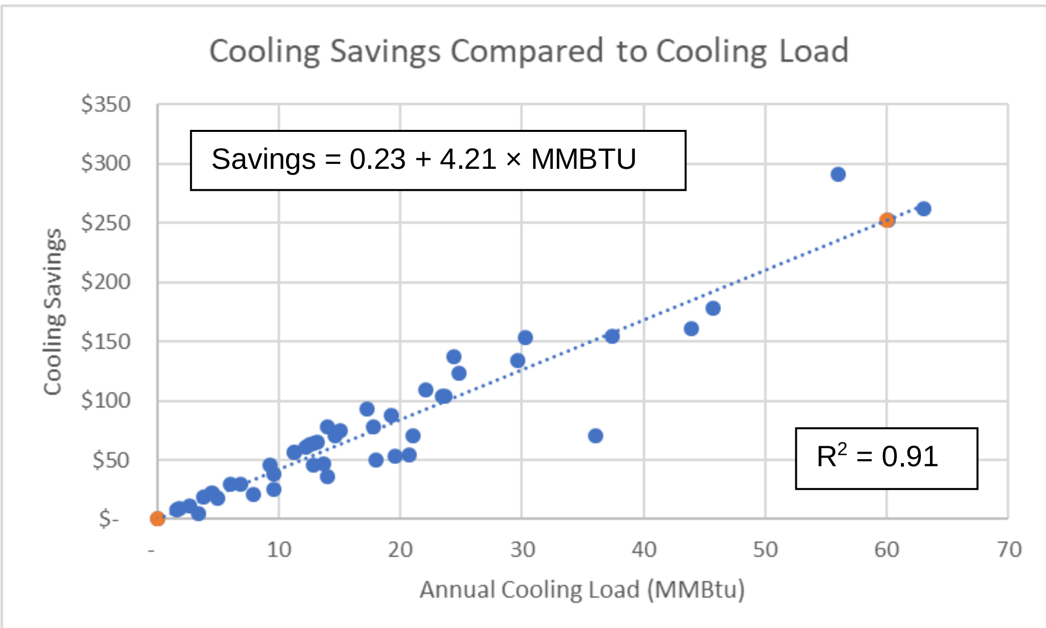
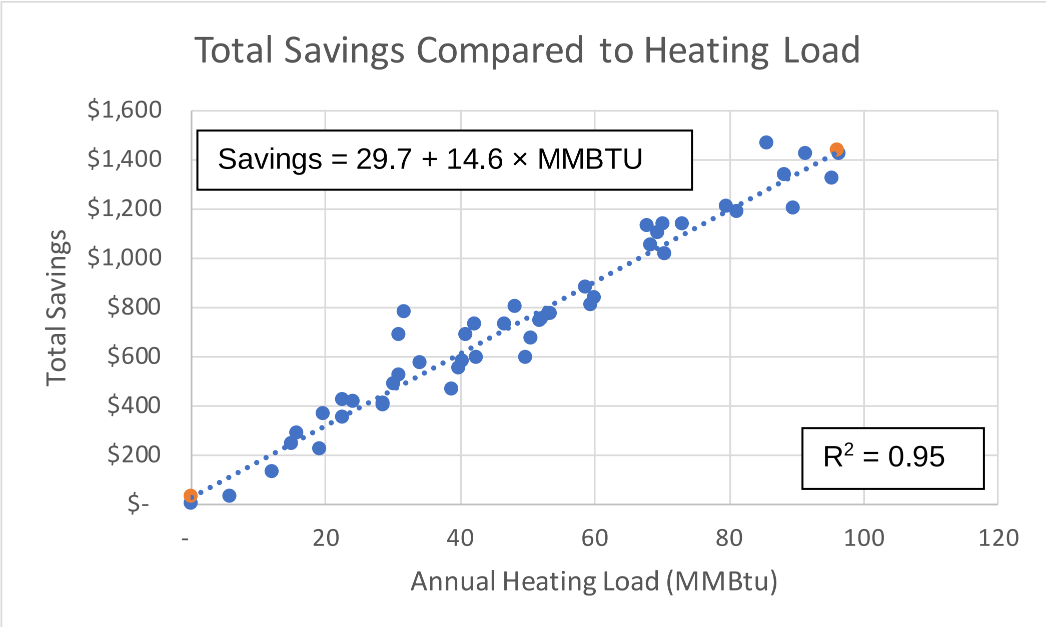


Figure 31. Trend of Total (Heating and Cooling) Cost Savings with Annual Heating Load



5 Summary and Conclusions

This report evaluated data from 49 Water Furnace geothermal heat pump systems in homes in Upstate New York that had the Symphony monitoring system installed. Nearly all the sites had close to 12 months of data available. For all but one if these systems, information was obtained from the installer about the ground loop and the house.

5.1 On-Site Verification

At two houses (covering three heat pump units) handheld instruments were used on-site to verify the Symphony readings. This preliminary comparison showed the following overall trends for the Symphony readings relative to our handheld instrument readings:

- Loop flow rates were higher than expected by 10-15%.
- Compressor power was lower than expected by approximately 10% for dual stage units and higher than expected by 9-15% for the inverter driven units.
- Fan power readings were within ±10%.
- Pump power readings were based on the pump current and were found to be correct for the one variable speed unit with a variable speed pump; however, they were incorrect where unexpected pumps were used with separate control relays that bypassed the Symphony system.
- Auxiliary heat power was lower by 9%.
- Loop temperature differences were very close to the handheld readings.

Assuming our handheld readings were more accurate, these systematic measurement biases might imply that the heating COPs and capacity reported by Symphony could be higher than the true values. However, these results are based on measurements from only three units and are preliminary. An upcoming project on Long Island will complete on-site verification at four additional sites.

5.2 Thermal Loop Measurements

The uncertainty associated with measuring ground loop heat transfer rates with the Symphony system appear higher than would be expected when using a thermal or BTU meter. Both our on-site measurements and the observed relationship between measured and expected efficiencies point to potential systematic biases in measured heat transfer rates. The upcoming project on Long Island will further compare Symphony readings to conventional BTU meters (Onicon System 40 meters) at 10 sites.

As with all thermal measurements, ground loops with high flow rates and low temperature differences exacerbate thermal measurement uncertainties. Variable speed heat pumps often have especially low loop temperature differences at lightly loaded conditions, which further increases the uncertainty of the thermal measurements.

5.3 Loop Temperatures

Various types of loops are included in the sample of GHP systems. While vertical bore loops tended to have slightly warmer loop temperatures than horizontal loops in the heating season, the trends were not definitive. The average weighted entering loop temperature for all the loops in the heating mode was 40°F. The 95% confidence interval for entering loop temperatures in the heating mode was 30 to 50°F. About one-third of the systems had minimum temperatures that at some point dropped below 30°F and only four of the systems dropped below 25°F.

5.4 Systematic Biases and Seasonal Heating COPs

The measured unit heating COPs at steady state conditions were compared to COPs from the manufacturers published or expected data. Generally, the measured COPs were higher than the expected values. From this analysis, simple correction factors were developed that were used to correct the seasonal system heating COP for the unit at each site. This systematic correction resulted in COP values and overall performance trends that were more consistent with expectations.

After applying these corrections, the average seasonal system heating COP for all the sites, including both pumping power and resistance heat, was 3.6. Most sites had seasonal COPs between 2.5 and 4.5. Seasonal COPs were higher at sites with warmer average entering water temperatures, as would be expected. Sites with higher heating loads had heating COPs closer to the average. Many of the sites with unexpectedly high or low COPs also had very low heating loads—implying that measurement uncertainties were even higher for lightly loaded systems. Long periods of part load operation for variable speed systems, where loop temperature differences were sometimes very small, may also explain at least some of the unexpected COPs observed.

5.5 Pumping Energy

Pumping energy varies widely from 3% to 30% of compressor energy. Though it is unclear if all the Symphony-reported pumping data is credible. Variable speed units with properly commissioned variable speed pumping were towards the lower end of the range. Systems where pumping was 5% of compressor power tended to have seasonal heating COPs around 4.0. Systems where pumping power was 20% of compressor power had heating COPs near 3.5.

5.6 Utility Impacts

The load profile measured for geothermal heat pumps show the expected trend of higher electrical demand at peak summer and peak winter conditions. The results from several sites and several days were combined to get an average daily demand profile at various outdoor temperatures. Even after factoring in the impact of auxiliary heat, the peak power on days that average -5°F was shown to 0.95 kW per installed ton (peaking in the morning). The impact of adding a million new GHP units (at 4 tons each) in NY homes would still have a manageable impact on the State's peak winter demand profile.

The average peak demand for the GHP units on peak summer days was about 0.36 kW per installed ton—or about half the expected value to conventional air conditioning systems. The installation of a million units (at 4 tons each) to replace conventional cooling systems would shave more than 1 GW off peak summer demand profile.

5.7 Heating and Cooling Cost Savings

The GHP system heating energy costs were compared to base case systems using various fuels using local fuel and electric costs for winter months in 2016 from NYSERDA and EIA. Heating cost savings were primarily a function of the annual heating load. Using fuel oil as the base fuel, the heating cost savings were $680 per year assuming an annual heating load of 50 MMBtu. The 95% confidence interval for heating savings was ±$119 across the range of loads. Heating savings were $212 per year using natural gas as the base fuel and $1,459 using propane as the base (with the same confidence interval).

While the differences in heating COP presumably drive the variations in energy cost savings, the results show that the variations are generally modest. This implies that investors can predict annual energy savings for residential geothermal heat pump retrofits to within ±$100 by simply knowing the existing heating load for a home.

The savings are highly sensitive to the price of fuel and electricity. If electricity costs are 20% lower and fuel costs are 20% higher, the savings increase by 47% for fuel oil, by a factor of 2.1 for natural gas, and by 32% for propane. Cost savings from cooling typically provide an additional $60-80 to annual cost savings.

5.8 NYSERDA Incentive Program Recommendations

The findings from this study highlight a few key metrics that NYSERDA could use in its geothermal program to ensure adequate performance for incentivized systems:

- Loop temperature: Loop temperatures for well-designed systems do not typically drop below 25°F. In this study, only four of 49 sites (8%) had minimum temperatures that dropped under 25°F during any 15-minute interval in the winter period.
- Pump power: This can have a big impact on heating COP. Systems were observed where annual pumping power was 30% of compressor energy use. For good system designs, pumping power should not be more than 12% of total system power at full load conditions. This corresponds to pumping power that is approximately 14% of compressor energy use. For dual stage or variable speed heat pumps, the pump-to-compressor percentage at lower stages should decrease below the full load value.

5.9 Recommendations for Future Work

Future studies should focus on the following areas to improve GHP performance and demonstrate the efficacy of the Symphony monitoring system to reliably track and confirm system performance and cost savings.

- The upcoming Long Island study should install BTU meters for comparison to Symphony readings.
- The upcoming Long Island study should carefully document the details of the installed system to
    - Fully understand the pumping system, including installed pump size and model, control approach, etc. to ensure that the Symphony-reported pumping power is accurate.
    - Fully document loop design calculations and heat pump sizing calculations for each site.

5.10 Lessons for Tracking Financial Performance

These preliminary results imply the Symphony monitoring system may not be an adequate substitute for a BTU meter when measuring thermal performance in the field. However, the larger question may be whether loop thermal performance is the most important parameter to track when confirming cost savings in third party financial arrangements for residential applications. The findings show that the most important factor in determining cost savings is the size of the thermal load (either heating or cooling). The second most important factor is the seasonal efficiency of the heat pump.

Other lower cost means of estimating the magnitude of the thermal load on the home could include measuring heat pump electric use (even using lower cost surrogates for electric use) or runtime at each stage or output level. Then simple measurements of entering loop temperatures over the season could be combined with published performance data for the heat pump to estimate seasonal efficiency. Runtime or power data can be used with published specs on heat pump capacity to determine thermal loads.

This approach potentially could be accomplished with lower cost monitoring systems more widely applied in full scale deployments. In the end, the uncertainty of determining cost savings and financial performance for a fleet of systems could be similar to methods that might use more costly monitoring methods, including BTU meters.

Appendix A: Details for Each Water Furnace Geothermal Heat Pump Site

Appendix A

Details for Each Water Furnace Geothermal Heat Pump Site

Notes:

- We did not obtain site details for S46.

Table A-1. General Sites Characteristics

Site ID	Unit ID	Model	City	Application
s01	001EC015B0E1	NVV060	Scottsville	retrofit
s03	001EC01BD91B	NVV036	Macedon	retrofit
s04	001EC015B0DE	NVV048	Ballston Spa	retrofit
s05	001EC01F5AEF	NVV060	Bloomfield	retrofit
s06	001EC015B150	NVV036	Amsterdam	retrofit
s07	001EC01A977C	NDH064	Troy	retrofit
s08	001EC009A0E4	NDV049	Niskayuna	retrofit
s09	001EC015B585	NDV049	Niskayuna	retrofit
s10	001EC015B0C9	NVV060	Lima	retrofit
s11	001EC02AE846	NVV060	Victor	new
s13	001EC02AD761	NVV060	Lima	retrofit
s14	001EC015BC5E	NDV072	Victor	new
s15	001EC02AE7AA	NVV048	Honeoye Falls	retrofit
s17	001EC009A10B	NVV048	Stillwater	new
s18	001EC02AE81E	NVV048	Honeoye Falls	retrofit
s19	001EC015ACC9	NVV060	Keuka Park	new
s20	001EC01D6397	NVV060	East Aurora	new
s21	001EC009A22D	NVV048	Prattsburgh	retrofit
s22	001EC01A970E	NDV064	Troy	retrofit
s23	001EC015B64B	NDV038	East Amherst	new
s24	001EC01D622D	NVV048	Ashville	retrofit
s25	001EC02AD789	NVV048	Saratoga Springs	new
s26	001EC015BC55	NVV060	Wyoming	retrofit
s27	001EC015B59A	NVV060	Buffalo	retrofit
s28	001EC01D6219	NVV036	Blossvale	retrofit
s29	001EC02B2B2B	NDV064	Altamont	retrofit
s30	001EC0143424	NDV064	Cassadaga	retrofit
s31	001EC01D6540	NVV060	Ballston Spa	new
s32	001EC015B560	NVV036	Akron	retrofit
s33	001EC015B55A	NVV036	Hector	retrofit
s34	001EC01BE361	NVV048	Rexford	retrofit
s35	001EC02AF2D3	NDV072	Ballston Spa	retrofit
s36	001EC015B543	NVV036	Hornell	retrofit
s37	001EC014341B	NDV049	Greenwich	retrofit
s38	001EC02AE837	NDV026	Chestertown	retrofit
s39	001EC015B65D	NVH036	Lake George	retrofit
s40	001EC02AF5D2	NDV038	Saratoga Springs	retrofit
s41	001EC02B274C	NVV048	Millerton	retrofit
s42	001EC01F34D1	NVV060	Penn Yan	retrofit
s43	001EC01F31A8	NVV060	Amsterdam	retrofit
s44	001EC02AD7C9	NDH049	Penn Yan	retrofit
s45	001EC009A1FB	NVV036	Penn Yan	retrofit
s46	001EC01A9747	NVV036	Albion	na
s47	001EC02B2DFD	NDV049	Trumansburg	retrofit
s48	001EC015B5A7	NVV036	Rhinebeck	retrofit
s49	001EC015B552	NVV048	Glens Falls	retrofit
s50	001EC02B27E5	NDV038	Ticonderoga	retrofit
s51	001EC015B0F0	NVV036	Lake George	new
s52	001EC015B0A0	NVV036	Gansevoort	retrofit

Table A-2. Ground Loop Details at Each Site

Site ID	Loop Type	Loop Code	No. of Circuits	Circuit Length (ft)	Pipe Diam (in)	Depth (ft)	Fluid & Freeze Point (F)
s01	H2	-	-	-	-	-	M
s03	H2	-	-	-	-	-	M
s04	V1	2-600-6-300	2	600	1.25	300	PG-20
s05	H2	-	-	-	-	-	M
s06	V1	1-900-6-450	1	900	1.25	450	PG-20
s07	HS	5-800-4-6	5	800	0.75	6	PG-20
s08	V1	3-800-6-400	3	800	1.25	400	PG-20
s09	V1	3-800-6-400	3	800	1.25	400	PG-20
s10	H2	-	-	-	-	-	M
s11	H4	-	-	-	-	-	M
s13	H2	-	-	-	-	-	M
s14	H6	-	-	-	-	-	M
s15	H2	-	-	-	-	-	M
s17	HS	4-800-4-6	4	800	0.75	4	PG-20
s18	V2	-	-	-	-	-	M
s19	V2	2-400	2	-	-	-	M-20
s20	HS	7-600-x-8	7	600	-	8	M-15
s21	HS	7-600-4-x	7	600	0.75	-	M-20
s22	V1	2-750-6-375	2	750	1.25	375	PG-20
s23	HS	6-500-x-x	6	500	-	-	M-15
s24	HS	6-600-x-8	6	600	-	8	M-15
s25	HS	4-800-4-6	4	800	0.75	6	PG-20
s26	HS	7-600-x-8	7	600	-	8	M-15
s27	HS	Open	-	-	-	-	Open
s28	H2	-	-	-	-	-	15
s29	V1	2-750-6-375	2	750	1.25	375	PG-20
s30	HS	7-600-x-8	7	600	-	8	M-15
s31	Pd	5-800-4-12	5	800	0.75	12	PG-20
s32	HS	4-600-4-8	4	600	0.75	8	M-15
s33	V1	1-450	1	-	-	-	M-20
s34	V1	2-750-6-375	2	750	1.25	375	PG-20
s35	Pd	6-500-4-10	6	500	0.75	10	PG-20
s36	HS	5-600-4-x	5	600	0.75	-	M-20
s37	HS	4-600-4-6	4	600	0.75	6	PG-20
s38	V1	2-400-6-200	2	400	1.25	200	PG-20
s39	H2	1-xxx-6-x	1	-	1.25	-	M-10
s40	V2	2-xxx-6-xxx	2	-	1.25	-	M-10
s41	Op	Artesian	-	-	-	-	N
s42	V2	2-450	2	450	-	-	M-20
s43	V2	2-400-6-xxx	2	400	1.25	-	M-10
s44	HS	5-600-4-x	5	600	0.75	-	M-20
s45	HS	4-600-4-x	5	600	0.75	-	M-20
s46	not known						
s47	V2	2-375	2	-	-	-	M-20
s48	V1	2-300-6-300	2	300	1.25	300	N
s49	V1	1-450-6-xxx	1	450	1.25	-	M-10
s50	Op	-	-	-	-	-	-
s51	V1	1-400-6-xxx	1	400	1.25	-	M-10
s52	V2	1-xxx-5-xxx	1	-	1.00	-	M-10

See page A-5 for descriptions of table entries

Table A-3. Details of House Loads and DHW Hookup at each Site

Site ID	Floor Area (sq ft)	DHW Hookup Location	No of IZ2 Zones	HP Unit Size (tons)	Design Heating Load (MBtu/h)	Design Cooling Load (MBtu/h)
s01	2,600	Preheat Tank	-	5	62.0	32.0
s03	2,000	Preheat Tank	-	3	35.0	29.0
s04	4,748	Preheat Tank	4	4	56.5	16.8
s05	2,500	Preheat Tank	-	5	65.0	40.0
s06	2,378	None	-	3	24.5	13.2
s07	3,024	None	3	5	66.5	32.5
s08	2,279	None	3	4	53.8	19.2
s09	1,732	None	3	4	45.0	14.7
s10	2,400	Preheat Tank	-	5	64.0	40.0
s11	3,200	Preheat Tank	2	5	75.0	45.0
s13	2,300	Preheat Tank	-	5	60.0	32.0
s14	3,000	Preheat Tank	2	6	75.0	45.0
s15	2,300	Preheat Tank	-	4	45.0	30.0
s17	4,209	None	4	4	49.2	28.6
s18	2,500	Preheat Tank	2	4	50.0	38.0
s19	2,400	None	-	5	-	-
s20	5,455	Preheat Tank	-	5	62.3	34.2
s21	1,600	None	-	4	-	-
s22	2,654	Preheat Tank	3	5	65.4	33.4
s23	1,800	Preheat Tank	-	3	36.0	18.0
s24	1,381	Preheat Tank	-	4	42.0	28.0
s25	5,326	Preheat Tank	4	4	44.5	24.5
s26	4,594	Preheat Tank	2	5	84.6	59.7
s27	3,076	Preheat Tank	2	5	82.0	43.0
s28	1,400	Preheat Tank	-	3	47.5	15.0
s29	3,123	None	-	5	60.9	19.0
s30	1,560	Preheat Tank	-	5	52.0	49.0
s31	6,187	None	4	5	72.2	28.6
s32	1,700	Preheat Tank	-	3	-	-
s33	1,300	Preheat Tank	-	3	-	-
s34	4,350	None	4	4	43.3	32.8
s35	4,184	Preheat Tank	-	6	86.5	35.5
s36	1,300	Preheat Tank	-	3	-	-
s37	3,068	None	-	4	47.0	20.7
s38	1,900	None	-	2	23.7	10.1
s39	2,027	-	-	3	53.8	32.4
s40	1,800	-	-	3	38.7	21.1
s41	3,766	Preheat Tank	-	4	54.7	33.7
s42	2,200	Preheat Tank	-	5	-	-
s43	4,000	-	2	5	68.9	60.8
s44	1,650	None	-	4	-	-
s45	1,450	Preheat Tank	-	3	-	-
s46	-	-	2	3	-	-
s47	1,800	Preheat Tank	-	4	-	-
s48	3,224	Preheat Tank	5	3	19.0	12.6
s49	2,400	-	3	4	59.3	31.2
s50	3,000	-	-	3	33.9	17.8
s51	2,600	-	-	3	47.3	31.6
s52	1,800	-	-	3	-	-

Legend for Loop Details			
Key	**Description**	**Loop Code**	
H2	Horizontal 2 Pipes	Number of Circuits – Length of Circuit – Circuit Pipe Diameter – Depth	
H4	Horizontal 4 Pipes		
H6	Horizontal 6 Pipes		
HS	Horizontal Slinky	**Key**	**Pipe Diameter**
V1	Vertical w/ 1 loop in Bore	4	0.75 in
V2	Vertical w/ 2 loop in Bore	5	1 in
Pd	Pond	6	1.25 in
Key	**Fluid Type and Freeze Point (F)**		
M	Methanol		
PG	Propylene Glycol		
N	None		

"No of IZ2 zones" indicate the number of separate thermostat-controlled dampers used in each home.

Sites with a separate pre-heat tank connected to the unit desuperheater are indicated. "None" indicates no tank is present to pre-heat entering the domestic water heater (DHW). Blank entries indicate water heating option is not known.

Plotting Trends in the Characteristics Data

Figure A-1 and Figure A-2 compare some of the site characteristics. The design loads are not strictly related to the size of the house, as shown by Figure A-1. Figure A-2 implies that the size of the heat pump is generally selected to meet the design heating load. This usually results in heat pump with more than the design cooling capacity. However, this summertime oversizing is not a problem since the unit's can operate at low stage or low speed in the cooling mode.

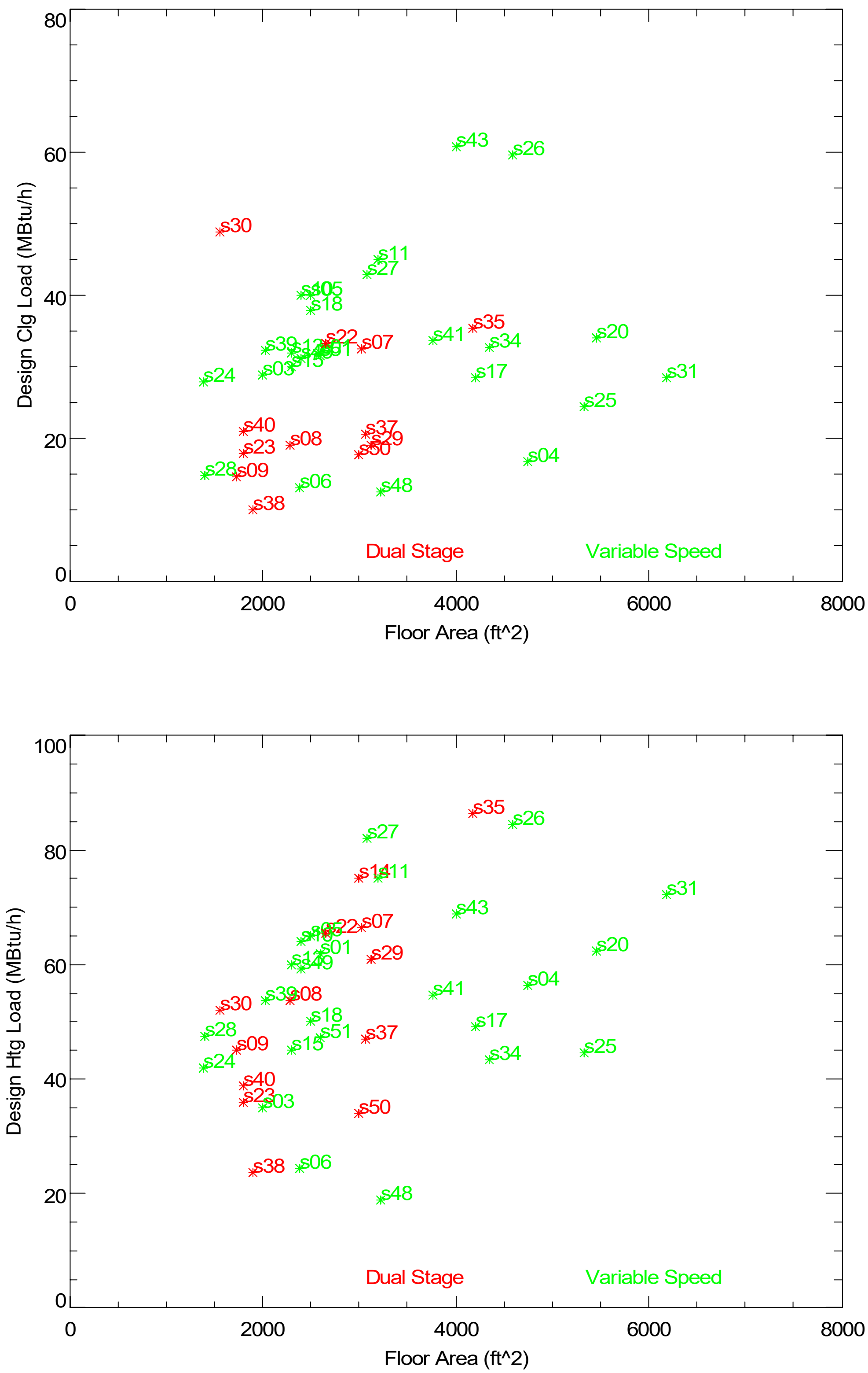
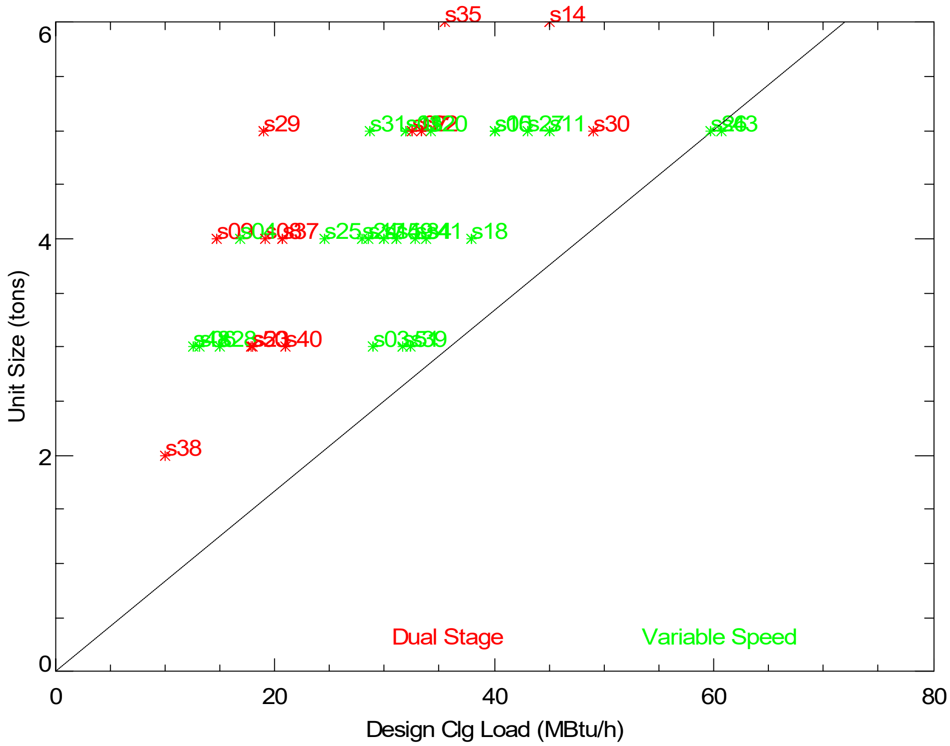


Figure A-1. Comparing Design Heating and Cooling Loads to House Floor Area



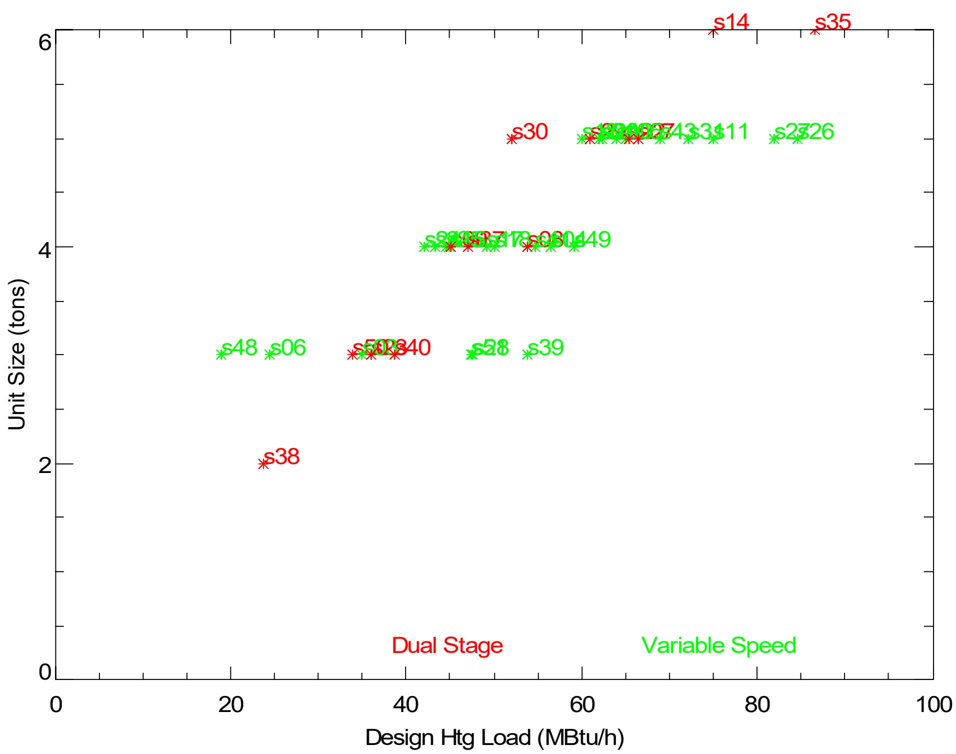


Figure A-2. Comparing Selected Heat Pump Unit Size to Design Heating and Cooling Loads

Appendix B: On-Site Verification for Water Furnace Symphony System

Appendix B: On-Site Verification for Water Furnace Symphony System

Overview

CDH staff visited two GHP sites and used our independent instruments to check the data readings from the Symphony system. The hand-held instruments we used are listed in Table B-1.

Table B-1. On-Site Verification Measurements

Measurements	CDH Instrument	Accuracy
Power use (kW) of each component (unit, pump, compressor, fan)	Fluke 39 Power Meter (true power)	±1% of reading for Watts
Pipe temperatures (water and refrigerant)	Fluke 51 II Temp Sensor (surface or insertion)	~ ±1.4°F (approx. half for ΔT)
Water flow rates	Fuji Portiflow FSCS Transit Time Ultrasonic	~ ±0.25 gpm @ 1 inch
Air Temperatures and Humidity	TSI VelociCalc T9545	±0.5°F and ±3% RH
Airflow rate	TSI VelociCalc T9545 (equal area traverse)	±3% of reading

At each site we took various measurements with these handheld meters and directly compared them to the Symphony readings at the same moment to confirm the validity of the Symphony measurements. For each measurement, multiple pairs (or trials) of Symphony and handheld readings were collected so that the average difference can be determined.

- The Fluke power meter was used to take power readings for the compressor, fan, pump and auxiliary resistance heater that were directly compared to the Symphony power readings (WC, WF, WP, WAUX). The Fluke meter has a 200 amp CT, so readings under 1 amp were not as accurate
- Insertion probes were used to measure the entering and leaving loop temperatures with the handheld meter and compared to surface mount Symphony readings. Both absolute temperature readings and temperature differences were compared.
- The loop water flow rate was measured with the Fuji Ultrasonic flow meter and compared to the Symphony readings. The Fuji (transit time) meter was able to get a reading on the 1 inch copper pipe in the unit.
- The Fluke handheld meters were used to confirm air temperatures on the Symphony system. The relative humidity readings were confirmed with the TSI probe.

Below we summarize and compare the handheld readings and Symphony readings to evaluate the accuracy of the instrumentation included with the Symphony package.

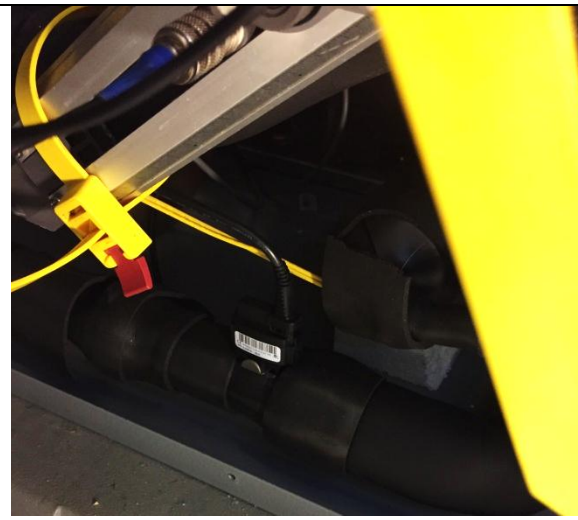
Niskayuna House (S8 & S9)

	Unit #1 / East / Left	Unit #2 West / Right
Database ID	S8 / 001EC009A0E4	S9 / 001EC015B585
HP Model	NDV049 / 5 series	NDV049 / 5 series

This house has two 4-ton dual capacity (5 series) heat pumps installed on a ground loop that includes three 400-ft deep vertical wells (150 bore ft per ton). The units each serve a separate area of the house (2,279 sq ft for Unit #1 and 1,732 sq ft for Unit #2). Each unit has three zone dampers that are controlled by zone thermostats. The units do not have electric resistance heat instead have hot water coils that are connected to a propane wall-hung “combi” boiler that also provides water heating. The AUX relay on Water Furnace unit drives the solenoid valve to engage the heating coil. The heat pumps DO NOT supply heat to a DHW tank. The system includes a dual unit pumping station with two pumps in series to each heat pump (four pumps total). In low stage operation, only one pump is used. In high stage heat pump operation two pumps are engaged. The pumping station includes a non-pressurized reservoir. The geothermal system replaced two 100 MBtu/h propane furnaces. The house is located on the bank of the Mohawk River in Niskayuna.

Figure B-1. Two Heat Pumps installed at Niskayuna

Solenoid Valves controlling HW coils for auxiliary heat

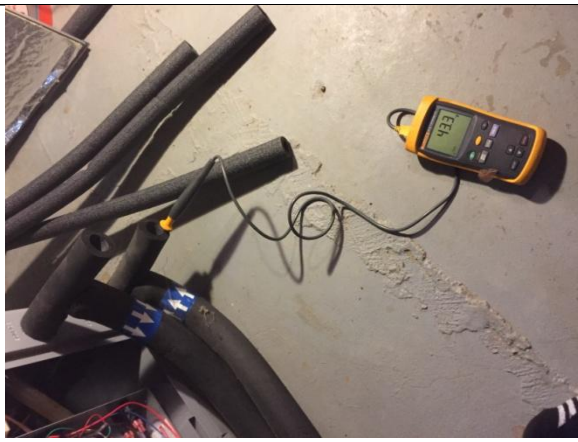


Grunfos flow meter

Wires to Symphony thermistor under foam tape insulation

Closeup of Grunfos flow meter
VFS 10-200 1 G (97842273-02-410-21165)

Figure B-2. Controls and Symphony Sensors in the Water Furnace Unit



Fluke temperature sensor installed in petze plug for entering water

Fuji ultrasonic flow meter installed on 1 inch copper line:
Diameter 1.125 in, wall: 0.05 in, Copper type L (or 1-1/8 inch ACR)

Figure B-3. CDH Handheld Sensors Used for Verification

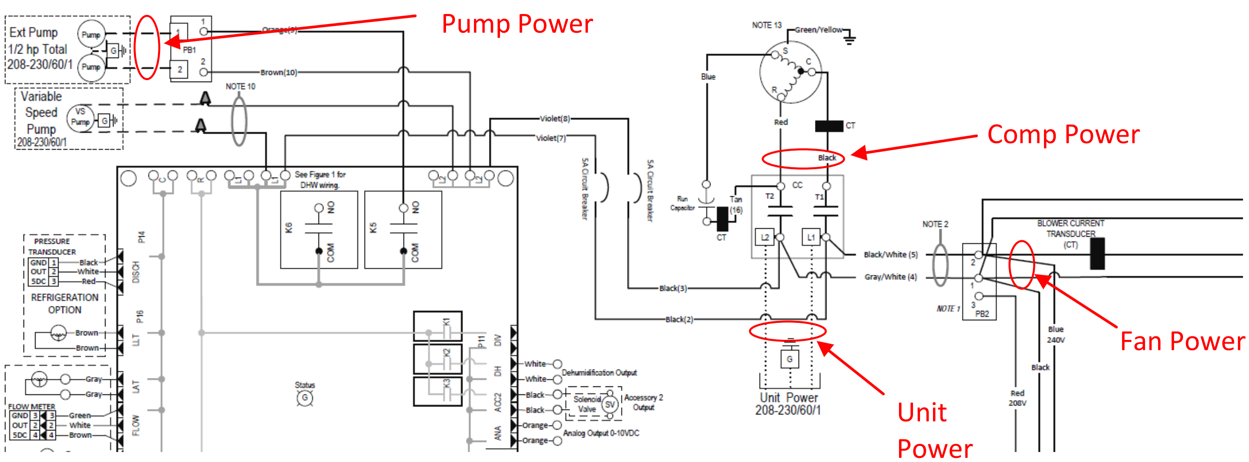


Figure B-4. Locations for Handheld Power Readings

S8 / Unit #1

WATER TEMPERATURES	trial 1		trial 2		trail 3		trial 4	
	symph	fluke	symph	fluke	symph	fluke	symph	fluke
Leaving Water Temp (F)	38.5	39.3	38.5	39.4				
Entering Water Temp (F)					42.8	43.7	42.6	43.7
Temp Difference (F)	trial 1 - 3 AND trial 2 - 4				4.3	4.4	4.1	4.3
Error or Difference		-0.8		-0.9		-0.9		-1.1

WATER FLOW	low speed		low speed		high speed		high speed	
	symph	Fuji	symph	Fuji	symph	Fuji	symph	Fuji
Water Flow (gpm)	11.4	9.5	11.3	9.5	15.5	13.6	15.5	13.6
Error or Difference		1.9		1.8		1.9		1.9
		20%		18%		14%		14%

AIR TEMPERATURES	high speed		high speed	
	symph	fluke	symph	fluke
Entering Air Temp (F)	69.9	69.3	69.9	69.3
Error or Difference		0.6		0.6

AIR TEMPERATURES	low speed		low speed		high speed	
	symph	fluke	symph	fluke	symph	fluke
Leaving Air Temp (F)	96.3	98.2	97	99.1	108	112
Error or Difference		-1.9		-2.1		-4

S9/Unit #2

WATER TEMPERATURES	trial 1		trial 2	
	symph	fluke	symph	fluke
Leaving Water Temp (F)	37.1	37.8		
Entering Water Temp (F)			42.4	43.3
Temp Difference (F)			5.3	5.5
Error or Difference		-0.7		-0.9

WATER FLOW	high speed		high speed		high speed		high speed		high speed		low speed	
	symph	Fuji	symph	Fuji	symph	Fuji	symph	Fuji	symph	Fuji	symph	Fuji
Water Flow (gpm)	12.7	11.8	12.9	11.1	12.9	11.1	12.8	11	12.8	11	11.4	9.8
Error or Difference		0.9		1.8		1.8		1.8		1.8		1.6
		8%		16%		16%		16%		16%		16%

AIR TEMPERATURE	high speed		high speed		high speed	
	symph	fluke	symph	fluke	symph	fluke
Entering Air Temp (F)	69.8	67.9	69.9	68.6	70.9	69.3
Error or Difference		1.9		1.3		1.6

AIR TEMPERATURE	high speed		high speed		high speed		low speed	
	symph	fluke	symph	fluke	symph	fluke	symph	fluke
Leaving Air Temp (F)	106.7	105.6	106.3	106.7	107.1	107.4	97.8	97.9
Error or Difference		1.1		-0.4		-0.3		-0.1

S8 / Unit #1

POWER	low speed		low speed		high speed		high speed		
	symph	fluke	symph	fluke	symph	fluke	symph	fluke	
Total Unit (amps)	11.1	11.8	11.3		15.7	16.8	15.8	16.7	
Total Unit (W)	2,402	2,500	2,429		3,500	3,800	3,513		
Compressor (amps)	10	9.4	10.2	10	14.6	14.2	14.7	14.4	
Compressor (W)	1,793	2,040	1,819	2,100	2,891	3,200	2,904	3,200	-12% low, -10% high
Fan (amps)	1.1	1.15	1.1	1.14	1.1	1.16	1.1	1.16	
Fan (W)	137	140	138	130	137	140	137	130	-2% to 6%
Pump (amps)		1.12		1.1		1.8		1.85	
Pump (W)	472	250	472	240	472	430	472	440	7-10% at high speed,
Sum of Components		2,430		2,470		3,770		3,770	100% at low speed

Off-cycle power: 0.15 amps, 31 Watts, 243 V, 0.85 PF
"Sum of Components" and "Total Unit" are identical for the Symphony data, so table cells are empty.

S9 / Unit #2

POWER	low speed		low speed		low speed		high speed		high speed		
	symph	fluke	symph	fluke	symph	fluke	symph	fluke	symph	fluke	
Total Unit (amps)	11.8	12.4	12.4		12.4	12.7	15.9	16.9	15.8	16.9	
Total Unit (W)	2,551	2,700	2,479	2,700	2,626	2,700	3,535	3,800	3,456	3,800	
Compressor (amps)	9.5	9.45	10.1	9.9	10.2	10.1	13.9	13.7	14	13.9	
Compressor (W)	1,762	1,950	1,819	2,060	1,835	2,100	2,777	3,000	2,797	3,100	-11% low, -9% high
Fan (amps)	2.3	2.7	2.3	2.76	2.2	2.8	2	2.47	1.8	1.8	
Fan (W)	317	360	330	340	319	350	286	290	187	180	-9% to 4%
Pump (amps)		0.75				0.74		1.45		1.4	
Pump (W)	472	183	330	177	472	173	472	340	472	330	40% at high speed
Sum of Components		2,493		2,577		2,623		3,630		3,610	
		92.3%		95.4%		97.1%		95.5%		95.0%	

Off-cycle power: 0.11 amps, 15 Watts, 243 V, 0.56 PF
Sum of Components" and "Total Unit" are identical for the Symphony data, so table cells are empty.

Observations for S8 and S9

Power

- Symphony compressor power readings are 9-10% lower at high speed and 11-12% lower at low speed
- Symphony fan power readings are close to actual readings: -2 to +6% for S8, -9 to +4% for S9
- Symphony pump power was incorrect because separate relay controls with staged pumps were added to the units. The Symphony reading was based off on the (unused) pump speed command. The Symphony reading was always 472 W; the Fluke readings were 172 W and 340 W at low and high speed, respectively.

Flow

- The Symphony loop flow was consistently higher than the ultrasonic flow. For S8 the flow was 1.8-1.9 gpm higher (+14% with two pumps, +18-20% with one pump). For S9 the flow was always 1.8 gpm higher (+16%) with two pumps and 1.6 gpm higher (+16%) with one pump.

Water Temperatures

- The Symphony temperature sensors are installed on the surface of the copper pipe and well-insulated and sealed with foam tape. The Symphony temperature readings were typically within 1°F of the Fluke, in absolute terms. The temperature difference measurements were much closer: within 0.1-0.2°F or 5% for S8, and within 0.2°F or 4% for S9.

Air Temperatures

- The entering air readings from the Symphony is measured at the thermostat while the Fluke sensor was in the return duct for the unit.   In spite of different locations, the readings were within 0.6°F at S8 and were within 1.3-1.9°F for S9.
- The leaving air temperature readings were within 2-4°F at S8 and within 1°F at S9. Generally, the location of the leaving air sensor can have a significant impact on the resulting reading.

Airflow

- The airflow was not measured on these units since the fluctuations due to zone dampers installed on this system were expected confound any attempt to make airflow comparisons.

Akron House (S32)

Database ID	S32 / 001EC015B560
HP Model	NVV036 / 7 series

This house has one 3-ton variable speed (7 series) heat pump installed on a ground loop that is a horizontal slinky with four circuits buried 8 ft deep (each circuit has 600 ft ¾ inch piping; the loop fluid is 23% methanol). The unit heats and cools the 1700 sq ft house. The heat pump desuperheater is connected to a 50-gallon pre-heat tank (element not connected). The unit has a 10 kW auxiliary (or backup) electric resistance heater. The system includes a variable speed pumping station with one pump.

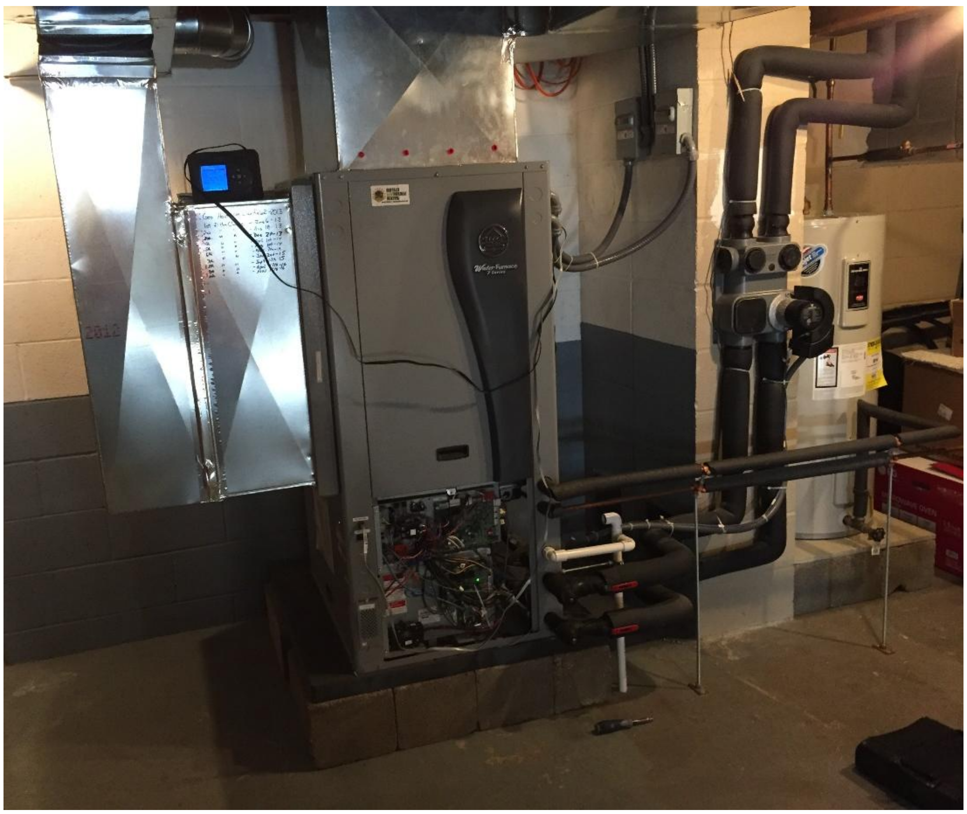


Figure B-5. Heat Pump installed at Akron

Variable speed Pump (Grunfos VS Magna)

Grunfos Flow Meter
VFS 10-200L G V2.0
97842273-02-228-01031

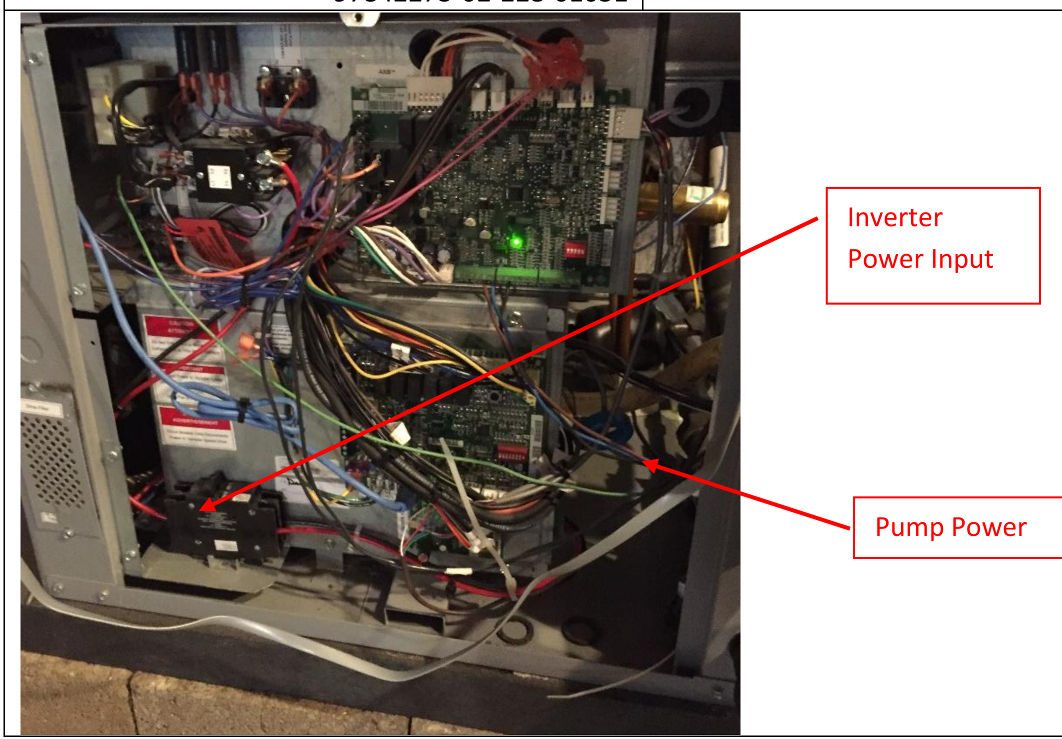
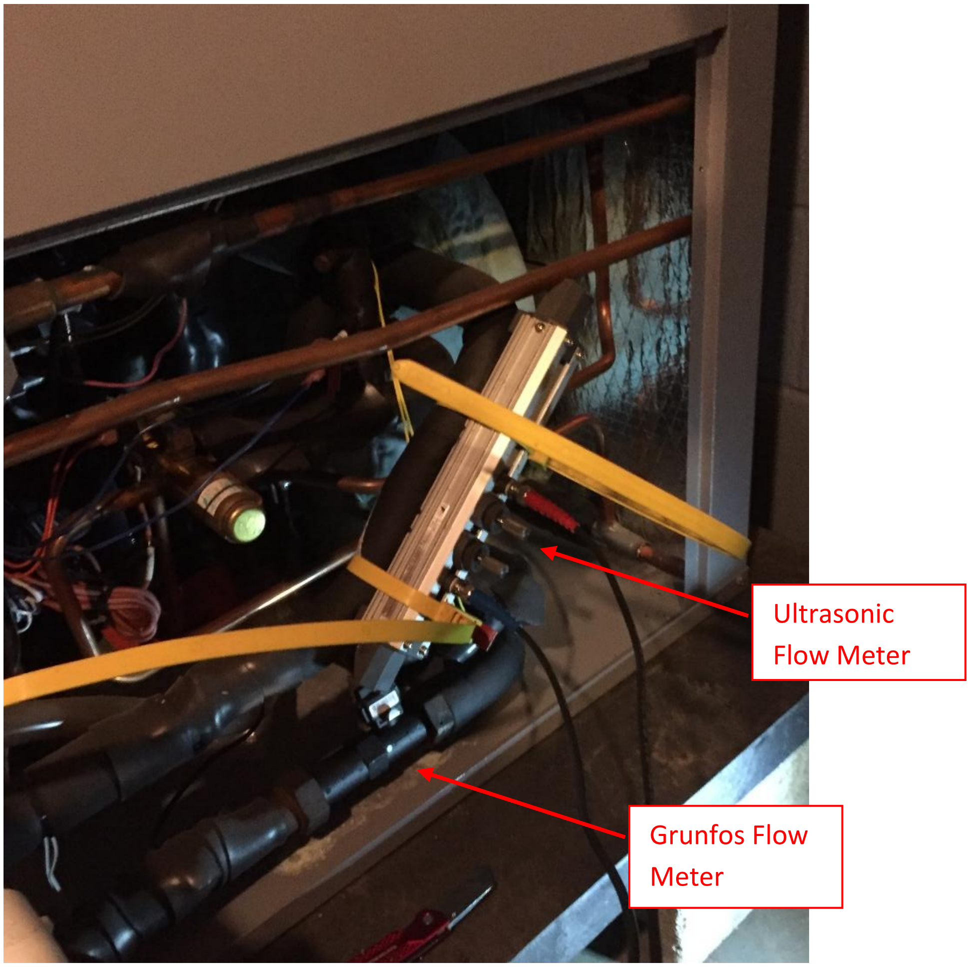


Figure B-6. Controls and Symphony Sensors in the Water Furnace Unit



Fuji ultrasonic flow meter installed on 1 inch copper line: Diameter 1.125 in, wall 0.05 in, Copper type L (or 1-1/8 inch ACR) Head spacing: 0.306 in

Figure B-7. Ultrasonic Flowmeter and Symphony Flow Meter in the Water Furnace Unit

POWER	Speed: Comp - 3				Speed: Comp - 6, Fan - 4, and Pump - 43%				Speed: Comp - 9, Fan - 6, and Pump - 53%				Speed: Comp - 12, Fan - 7, and Pump - 60%				
	symph	fluke	symph	fluke	symph	fluke	symph	fluke	symph	fluke	symph	fluke	symph	fluke	symph	fluke	
Total Unit (amps)	0		0		0		0		0		0		0		0		
Total Unit (W)	747	900	746	900	1,350	1,450	1,345	1,440	2,151	2,200	2,129	2,200	3,098	3,000	3,120	3,000	
Compressor (amps)																	
Compressor (W)	689	600	682	600	1,276	1,180	1253	1,180	1,923	1,780	1921	1,790	2,836	2,600	2843	2,600	15% low speed, 9% high speed
Fan (amps)																	
Fan (W)	39	40	39	30	39	50	40	40	144	160	145	140	210	230	210	220	-5% to -9% at high speed
Pump (amps)																	
Pump (W)	20	19	20	19	39	35	39	34	62	56	62	56	85	80	82	80	
Sum of Components	748	659	741	649	1,354	1,265	1,332	1,254	2,129	1,996	2,128	1,986	3,131	2,910	3,135	2,900	
	100.1%	73.2%	99.3%	72.1%	100.3%	87.2%	99.0%	87.1%	99.0%	90.7%	100.0%	90.3%	101.1%	97.0%	100.5%	96.7%	

AUXILIARY POWER	symph	fluke
Volts		242
Amps	35.6	39.3
Kilowatts	8.20	9.5
		-1.3
		-14%

Off-cycle power: 1.3 amps, 59 Watts, 246 V, 0.18 PF

WATER TEMPERATURES	trial 1 Speed: 3		trial 2 Speed: 6		trial 3 Speed: 6		trial 4 Speed: 6		trial 5 Speed: 12	
	symph	fluke	symph	fluke	symph	fluke	symph	fluke	symph	fluke
Leaving Water Temp (F)	37.8	37.3	36.7	37.9	36.9	38.3	36.5	35.9	36.3	37.1
Entering Water Temp (F)	40.3	39.8	40.8	40.3	40.8	40.3	41	40.3	40.8	40.1
Temp Difference (F)	2.5	2.5	4.1	2.4	3.9	2	4.5	4.4	4.5	3
Error or Difference LWT		0.5		-1.2		-1.4		0.6		-0.8
Error or Difference EWT		0.5		0.5		0.5		0.7		0.7
Error or Difference Delta-T		0		1.7		1.9		0.1		1.5

	Speed 12	
	symph	fluke
Entering Air Temp (F)	70.3	69.2
Error or Difference		1.1

	Speed 12		Speed 12	
	symph	fluke	symph	fluke
Leaving Air Temp (F)	78.3	85	78.6	90.1
Error or Difference		-6.7		-11.5

WATER FLOW	Pump speed: 32%			Pump speed: 43%			Pump speed: 53%			Pump speed: 60%			Pump speed: 80%		
	symph	Fuji	P - Guage	symph	Fuji	P - Guage	symph	Fuji	P - Guage	symph	Fuji	P - Guage	symph	Fuji	P - Guage
Water Flow (gpm)	5.4	4.6	5.2	6.9	6.1	6.5	8.1	7.3	7.7	9.1	8.1	8.5	12	11.2	11
Error or Difference		0.8			0.8			0.8			1			0.8	
		17%			13%			11%			12%			7%	

Observations for S32

Power

- Symphony compressor power readings are 6-9% lower at high speed and 14% lower at low speed
- Symphony fan power readings are 5-9% lower at high speed, within a few Watts at low speed.
- The Symphony reading was based off on the pump speed command to the variable speed pump. The Symphony reading was always within a few Watts of the Fluke over the range of pump speeds.

Flow

- The Symphony loop flow was consistently higher than the ultrasonic flow. The flow was 0.8 to 1.0 gpm higher over the range of flows (+17% at low speed, to +7% at high speed). Buffalo Geothermal also measured the pressure difference across the heat pump and used performance tables to predict flow. The flow predicted from delta-P was in between the Symphony and ultrasonic readings, but slightly closer to the ultrasonic readings.

Water Temperatures

- The Symphony temperature sensors are installed on the surface of the copper pipe and well-insulated and sealed with foam tape. The Symphony temperature readings were typically within 1°F of the Fluke, in absolute terms. The entering temperature readings were typically closer, since these readings were more stable. The leaving water temperature readings were observed to fluctuate about 1-3°F over a 1-2 minute cycle – this variation was attributed to "hunting" of the expansion device on the variable speed system. As a result, we saw significant variations in the measured delta-T measurements, since these readings were taken at different times. Due to these temperature variations, the temperature difference measurements were off as much as 2°F or 50%. We believe the measurement comparisons on the dual capacity units at S8 and S9 are more representative of sensor accuracy.

Air Temperatures

- The entering air readings from the Symphony is measured at the thermostat while the Fluke sensor was in the return duct for the unit. Despite different locations, the readings were within 1°F.
- The leaving air temperature readings were significantly different for this unit: the Symphony readings was 6 to 12°F lower than Fluke reading. Generally, the location of the leaving air sensor can have a significant impact on the resulting reading.

Airflow

We attempted to conduct a velocity traverse of the supply duct to measure the airflow. However, we found to much stratification across the duct to obtain a meaningful measurement.

Summary Estimates of Practical Uncertainty

The measurement uncertainties can be propagated for each calculated quantity Y that is determined from independent measurements X_1, X_2, to X_n using:

Probable error of Y = ΔY = $\sqrt{+\left(\Delta x_1 \cdot \frac{dY}{dx_1}\right)^2 + \left(\Delta x_2 \cdot \frac{dY}{dx_2}\right)^2 \ldots. + \left(\Delta x_n \cdot \frac{dY}{dx_n}\right)^2}$

This process can be applied to calculated quantities such as heating and cooling output, power, coefficient of performance (COP), energy efficiency ratio (EER), etc. In Table B-2 we develop estimates of uncertainty –using the results above – that can be applied to each Symphony measurement (Δx_1, Δx_2, … Δx_n).

Table B-2. Summary of Practical Error and Bias for Symphony Readings (based readings from 3 units)

Measurements	Practical Error of Symphony Readings	General Bias of Symphony Readings
Compressor Power	±10% of reading over range of speeds	Lower
Fan Power	±5% of reading over range of speeds	Lower
Water Temperatures – Absolute	~ ±1°F	-
Water Temperatures – Delta	~ ±0.2°F or 5%	Lower
Water flow rates	±1.5 gpm or 15% over range	Higher
Entering Air Temperatures	~ ±1°F	-
Leaving Air Temperatures	~ ±6°F	-

This process was applied to calculated quantities such as heating and cooling output, power, coefficient of performance (COP), energy efficiency ratio (EER), etc.

QL = 0.49 x [flow] x [delta-T]

		Eng Units	Nominal Value	Error, err	New Y	dY/dx	err*dY/dx
Independent	flow	gpm	12	1.5	23.15	2.205	3.31
	delta-T	F	4.5	0.4	24.11	5.880	2.35
Dependent	Loop Heat	MBtu/h	26.46			Probable Error:	4.06
							15.3%

QH = 0.49 x [flow] x [delta-T] + ([Comp Pwr] + [Fan Pwr]) x3.413/1000

		Eng Units	Nominal Value	Error, err	New Y	dY/dx	err*dY/dx
Independent	flow	gpm	12	1.5	30.11	2.205	3.31
	delta-T	F	4.5	0.4	31.07	5.880	2.35
	Comp Pwr	W	1900	190	32.77	0.003	0.65
	Fan Pwr	W	140	7	33.40	0.003	0.02
Dependent	QH	MBtu/h	33.42			Probable Error:	4.11
							12.3%

COP = (490 x [flow] x [delta-T]/3.413 + [Comp Pwr] + [Fan Pwr]) / ([Comp Pwr] + [Fan Pwr])

		Eng Units	Nominal Value	Error, err	New Y	dY/dx	err*dY/dx
Independent	flow	gpm	12	1.5	4.33	0.317	0.48
	delta-T	F	4.5	0.4	4.46	0.845	0.34
	Comp Pwr	W	1900	190	5.19	-0.002	(0.39)
	Fan Pwr	W	140	7	4.81	-0.002	(0.01)
Dependent	Unit COP	-	4.80			Probable Error:	0.70
							14.6%

For variable speed operation we observed lower temperature differences at part load conditions. This implies that water flow is not decreasing a quickly as capacity.

If we assume at part load that: capacity = 34%, water flow = 67%, power = 34% then delta T drops to 2°F.

The table below shows that the uncertainty on the heating capacity increases from ±12.3% to ±21% as the heating capacity drops.

Partload Performance Point

QH = 0.49 x [flow] x [delta-T] + ([Comp Pwr] + [Fan Pwr]) x3.413/1000

		Eng Units	Nominal Value	Error, err	New Y	dY/dx	err*dY/dx
Independent	flow	gpm	8	1.5	8.83	0.980	1.47
	delta-T	F	2	0.4	8.73	3.920	1.57
	Comp Pwr	W	650	65	10.07	0.003	0.22
	Fan Pwr	W	70	3.5	10.28	0.003	0.01
Dependent	QH	MBtu/h	10.30			Probable Error:	2.16
							21.0%

Appendix C: Description of Plots for Each Site

Appendix C

Description of Plots for Each Site

Summary plots and tables for each site are available on the web at:

http://cloud.cdhenergy.com/ghp_wf/ User/Pass: wfghp/statesymph

A PDF file for each site is available there. A description of each Table and Plot is given below.

Table 1 – Summary of Monthly Data

Details site operation and data availability on a monthly premise. Provides an overview of how the particular system performed throughout the given data period for the site. Summaries are provided for monthly and annual system loads, power output and use, efficiencies, operating hours, and changing system inputs such as entering and leaving water and air temperatures.

Plot 1 – Daily Average Loop Temperatures. The daily, energy-weighted, average temperature is shown for entering water (to the heat pump) and leaving temperature (from the heat pump). The entering temperature is shown with black '+' symbols and leaving water temperatures are shown with red '*' symbols. The daily maximum and minimum entering temperatures for the period are given on the plots.

The leaving temperature is warmer than the entering temperature in the summer and colder in the winter.

Plot 2 – Daily Average Air Temperatures. The daily, energy-weighted, average air temperatures are shown for entering air (at the thermostat) and leaving air from the heat pump unit. The entering temperature is shown with black '+' symbols and leaving temperatures are shown with red '*' symbols for heating days and blue '*' symbols for cooling days.

Plot 3 – Daily Energy Use per Component. The daily electric consumption of each component is shown with a different color.

Plot 4 – Daily Runtime for each Component. The daily runtime of each component is shown with a different color. Series 5 (dual capacity) units have power separate for the base compressor and the 2nd stage (comp and comp2). The electric heat has two stages (EH1, EH2).

Plot 5 – Daily Average Compressor and Fan Speed. The average daily speed for the variable speed compressor and Fan are given. Series 5 (dual capacity) units only show fan speed.

Plot 6 – Pump Speed vs. Flow. The daily average pump speed is plotted against the daily average flow.

Plot 7 – Daily Average Heating and Cooling COPs. The average COP for each day are plotted on the same scale. Heating COPs are red and cooling COPs are blue.

Plot 8 – Daily Heating and Cooling Loads vs. Outdoor Temperature. The average heating and cooling load (in MBtu/h) across the day are shown as red and blue, respectively. The outdoor temperature data normally comes from the nearest weather station via Weather Underground (WUG) or from the

Symphony system (SYMPH). If the design heating and cooling loads are known, they are shown on the plot as a large ◊ (-5°F for heating, 95°F for cooling).

Plot 9 – Daily Electric Use vs. Outdoor Temperature. The daily electric use for total unit (including AUX heat) is plots verses temperature. The outdoor temperature data normally comes from the nearest weather station via Weather Underground (WUG) or from the Symphony system (SYMPH).

Plot 10 – Heating COP vs. EWT (15-minute data). The plot shows the heating COP vs. entering water temperature (EWT). On a variable speed unit symbols are shown with different colors for each compressor speed. For dual stage units, the points are shown as **black** for the 1st stage and red for the 2nd stage.

Plot 11 – Heating COP vs Speed or Stage (15-minute data). The plot shows the heating COP vs. compressor speed (series 7) or unit stage fraction (series 5). For series 5 units, Plot 11-A will indicate the 1st stage fraction, while Plot 11-B will indicate the 2nd stage fraction.

Plot 12 – Cooling EER vs. EWT (15-minute data). The plot shows the cooling EER vs. entering water temperature (EWT). On a variable speed unit symbols are shown with different colors for each compressor speed. For dual stage units, the points are shown as **black** for the 1st stage and blue for the 2nd stage.

Plot 13 – Cooling EER vs Speed or Stage (15-minute data). The plot shows the cooling EER vs. compressor speed (series 7) or unit stage fraction (series 5). For series 5 units, Plot 13-A will indicate the 1st stage fraction, while Plot 13-B will indicate the 2nd stage fraction.

Plot 14 – Comparing Measured and expected COPs (15-minute data). This plot compares the measured heating COP to the expected heating COP based on the published performance data from Water Furnace. Separate plots are given for:

- measured COP (compressor speed between 5.5 and 6.5) compared to “50% Part Load” tables
- measured COP (comp speed over 11.5) compared to “100% Full Load” tables
- measured COP (1st stage full on) compared to “First Stage” tables (Plot 14-A)
- measured COP (2nd stage full on) compared to “2nd Stage” tables (Plot 14-B)

The 15-minute data that meets the criteria are shown on the plot as black symbols. The red ◊ and dotted lines show the average of all the data on the plot.

Plot 15 – Comparing Measured and expected EERs (15-minute data). This plot compares the measured cooling EER to the expected cooling EER based on the published performance data from Water Furnace. Separate plots are given for:

- measured EER (compressor speed between 5.5 and 6.5) compared to “50% Part Load” tables
- measured EER (comp speed over 11.5) compared to “100% Full Load” tables
- measured EER (1st stage full on) compared to “First Stage” tables (Plot 15-A)
- measured EER (2nd stage full on) compared to “2nd Stage” tables (Plot 15-B)

The 15-minute data that meets the criteria are shown on the plot as black symbols. The blue ◊ and dotted lines show the average of all the data on the plot.

Plot 16 – Daily Demand Profile for each Month. The average daily electric use profile is shown for each month. Each monthly plot shows the average profile as well as the maximum and minimum values corresponding to each hour for the month. The shaded region shows plus and minus one standard deviation about the average.

Plot 17 – The Average Demand Profile Corresponding to Temperature Bins - Winter. This plot groups the daily data based on temperature bins centered at 0F, 10°F, 20°F, 30°F, 40°F and 50°F. The days are grouped according to the average daily temperature. The number of days used to make each daily average profile is shown in parentheses. This plot indicates the impact that the GHP system has on the electric grid (in the winter).

Plot 18 – The Average Demand Profile Corresponding to Temperature Bins - Summer. This plot groups the daily data based on temperature bins centered at 60°F, 70°F, 80°F and 90°F. The days are grouped according to the average daily temperature. The number of days used to make each daily average profile is shown in parentheses. This plot indicates the impact that the GHP system has on the electric grid (in the summer).

Plot 19 – Loop Delta-T vs. Loop Flow (15-minute data). This plot shows the variation of the water-side temperature difference with the loop flow rate. Heating and cooling data are shown with red and blue data points, respectively. The data show how the unit controls function as different speeds and stages.

Plot 20 – Fan Speed vs. Compressor Speed (15-minute data). This plot shows how the fan is controlled relative to the compressor. Heating and cooling data are shown with red and blue data points, respectively. In "trajectory" can be different for heating and cooling. Some cooling data can have relatively lower fan speeds in an effort to improve humidity control. This plot is not shown for series 5 sites.

Plot 21 – Entering Water Temperatures vs. Set Point (15-minute data). This plot shows the relationship between the entering water temperature and set point. Entering water temperatures when the unit is heating are shown with red, while entering water temperatures while the unit is cooling are shown with blue data points.

Appendix D: Summary Metrics for All GHP Sites

Appendix D - Summary Metrics for All GHP Sites

The tables that follow summarize all key metrics that were determined for each site. Tables D-1 and D-2 come from the summary tables given for each site in Appendix C. The values in Table D-3 are based on the 15-minute data.

Table D-1. Summary of Annual Metrics for each Site (from Tables in Appendix C)

Site	Months with Data	Valid Records	Days with HP On	Avg EWT Htg (F)	Avg EWT Clg (F)	Heat Extract (MMBtu)	Heat Reject (MMBtu)	Heating Load (MMBtu)	Cooling Load (MMBtu)	Total Htg COP (-)	Total Clg EER (Btu/Wh)	Total Heating (kWh)	Total Cooling (kWh)	Total System (kWh)	Comp (kWh)	Fan (kWh)	Pump (kWh)	AUX Hea (kWh)
s01	12	98%	338	44.0	65.6	74.9	10.5	91.3	9.1	4.4	14.6	6,070	628	6,689	4,690	545	1,375	79
s03	11	82%	266	40.4	67.4	29.8	23.3	36.6	20.2	3.9	17.6	2,721	1,148	3,924	2,788	219	907	10
s04	12	100%	357	42.6	57.4	69.3	42.5	86.5	1.7	3.7	22.9	6,788	73	8,847	5,923	1,702	647	574
s05	12	99%	355	42.0	68.7	88.0	33.1	106.3	25.8	4.4	19.7	7,096	1,306	8,723	6,423	733	1,538	29
s06	12	84%	312	45.1	56.0	18.1	6.8	23.3	5.8	4.2	18.4	1,613	314	1,936	1,748	85	100	2
s07	12	93%	238	46.0	59.4	21.0	5.0	32.9	4.2	2.3	15.9	4,121	264	4,369	3,048	595	722	4
s08	12	99%	288	43.9	62.9	37.8	22.1	48.3	18.9	3.8	16.2	3,759	1,169	4,910	3,555	370	985	-
s09	12	100%	290	43.3	62.9	39.7	19.1	50.0	16.3	3.9	15.5	3,727	1,057	4,774	3,280	552	942	-
s10	12	96%	337	44.0	72.8	94.0	35.5	110.7	29.2	5.4	13.0	5,963	2,256	8,266	5,800	981	1,384	103
s11	12	92%	319	38.2	72.7	99.0	33.9	114.7	29.6	5.4	16.6	6,169	1,776	8,316	5,812	1,021	1,219	263
s13	12	87%	301	36.3	69.7	91.3	51.8	118.1	41.6	3.8	14.0	9,070	2,969	12,270	7,986	2,097	1,625	562
s14	6	85%	110	67.9	88.6	1.4	31.9	1.5	23.9	3.8	9.0	119	2,653	2,798	2,323	143	332	-
s15	11	86%	214	34.3	69.9	41.2	24.7	55.6	22.0	3.4	20.6	4,858	1,072	5,943	4,445	428	910	160
s17	12	94%	314	41.0	68.1	48.0	22.8	59.2	20.1	5.1	23.6	3,398	852	4,275	3,265	787	219	5
s18	12	82%	263	45.0	55.7	30.3	18.6	36.5	17.2	4.2	28.5	2,540	604	3,208	2,137	364	707	0
s19	12	94%	346	48.4	71.8	66.2	49.8	51.8	32.4	6.5	11.5	2,339	2,810	6,846	4,984	520	1,340	2
s20	12	94%	320	38.7	64.1	49.5	34.0	67.3	30.8	3.4	31.0	5,761	993	6,838	6,021	521	270	26
s21	12	99%	301	37.5	70.4	85.9	27.3	106.8	19.0	4.8	18.0	6,483	1,053	7,796	6,182	866	225	523
s22	12	100%	294	35.9	69.2	86.9	11.3	110.9	9.5	3.9	16.2	8,400	582	9,043	6,239	1,435	1,346	23
s23	12	91%	292	34.1	65.7	29.9	16.4	37.5	14.3	4.2	19.5	2,617	735	3,353	2,543	223	551	36
s24	12	99%	190	42.6	61.5	16.5	2.2	18.5	1.9	7.8	30.6	696	63	771	640	98	33	-
s25	12	93%	309	37.2	72.9	44.6	27.3	54.7	23.9	4.0	20.1	4,021	1,192	5,275	3,764	459	1,013	38
s26	12	94%	293	39.6	63.6	66.9	25.3	94.5	22.7	3.2	27.0	8,568	839	9,488	6,809	1,228	422	1,029
s27	12	93%	268	55.2	56.1	95.1	20.8	112.9	19.0	6.3	36.8	5,225	516	5,741	4,666	979	-	96
s28	12	93%	306	44.5	63.5	33.7	5.9	40.4	5.4	6.1	35.0	1,955	155	2,112	1,928	184	-	-
s29	11	91%	255	43.2	56.6	51.0	9.2	65.9	7.8	3.8	16.7	5,134	467	5,654	4,415	510	661	67

Table D-1. Summary of Annual Metrics for each Site (from Tables in Appendix C) - CONTINUED

Site	Months with Data	Valid Records	Days with HP On	Avg EWT Htg (F)	Avg EWT Clg (F)	Heat Extract (MMBtu)	Heat Reject (MMBtu)	Heating Load (MMBtu)	Cooling Load (MMBtu)	Total Htg COP (-)	Total Clg EER (Btu/Wh)	Total Heating (kWh)	Total Cooling (kWh)	Total System (kWh)	Comp (kWh)	Fan (kWh)	Pump (kWh)	AUX Hea (kWh)
s30	12	97%	342	39.3	69.9	55.1	47.3	70.6	33.8	3.8	15.0	5,475	2,261	8,272	6,337	1,202	661	72
s31	11	81%	253	41.1	74.0	64.8	14.5	78.1	12.5	5.5	28.1	4,160	446	4,641	3,959	140	169	373
s32	12	99%	329	42.4	62.7	42.4	14.1	53.9	12.5	4.5	25.7	3,499	485	3,981	3,629	214	138	1
s33	12	89%	230	44.7	59.5	18.4	5.7	21.4	5.1	6.0	28.5	1,039	181	1,229	946	114	153	14
s34	12	92%	339	45.5	65.2	22.5	72.3	24.5	45.4	3.1	21.2	2,352	2,139	6,050	4,315	1,176	500	58
s35	12	72%	231	42.0	72.8	62.9	32.7	89.6	25.2	3.1	10.6	8,510	2,383	10,923	8,472	1,283	819	349
s36	12	96%	350	43.9	71.5	40.0	17.3	48.3	13.9	5.0	23.0	2,812	606	3,514	2,959	297	180	79
s37	12	95%	338	40.0	66.4	50.8	18.8	64.0	16.4	3.9	19.3	4,870	852	5,726	4,310	99	1,222	95
s38	12	95%	338	36.2	59.1	38.1	42.6	43.0	39.6	7.3	44.4	1,739	890	2,638	1,901	233	504	-
s39	12	99%	341	35.2	53.4	50.3	10.2	63.5	9.5	4.5	39.2	4,173	242	4,402	3,612	422	368	-
s40	12	89%	261	37.2	72.3	20.0	11.3	25.8	9.9	3.8	20.7	1,993	479	2,472	1,775	62	389	245
s41	12	93%	196	48.3	50.5	18.5	12.5	23.2	10.8	4.9	22.1	1,380	488	1,912	1,709	203	-	-
s42	12	87%	294	43.1	55.1	45.1	13.2	57.9	11.9	3.6	23.7	4,702	502	5,249	3,664	563	993	29
s43	12	92%	302	47.9	53.4	27.1	15.9	32.9	14.7	5.6	39.6	1,712	371	2,083	1,704	329	50	0
s44	12	92%	330	42.3	70.4	43.4	25.7	52.8	22.4	4.4	17.9	3,543	1,251	4,805	3,346	413	1,046	-
s45	12	97%	351	43.4	68.0	59.4	14.2	67.7	11.4	7.3	14.2	2,710	802	3,546	3,074	327	145	-
s46	12	98%	301	44.4	65.6	80.7	12.1	93.9	10.5	6.5	23.2	4,260	450	4,719	3,902	240	478	99
s47	12	90%	317	42.5	57.2	49.9	12.7	64.8	10.8	3.6	16.0	5,330	677	6,026	4,340	555	1,078	53
s48	12	98%	353	37.1	51.8	7.9	4.0	12.7	(1.0)	2.1	(5.7)	1,764	178	3,685	2,826	804	51	4
s49	12	93%	323	37.6	59.3	51.6	31.0	68.7	29.2	3.9	55.6	5,132	526	5,718	4,740	783	195	-
s50	12	89%	214	47.6	50.4	3.6	5.4	7.2	4.0	2.0	16.5	1,046	241	1,375	1,130	190	-	54
s51	12	99%	335	43.8	64.8	57.3	18.0	63.5	15.2	8.0	18.1	2,330	837	3,222	2,549	266	353	54
s52	12	99%	257	38.9	72.0	53.2	3.1	66.1	2.7	4.8	23.0	4,018	119	4,140	3,791	9	245	95

Table D-2. Summary of Annual Metrics for each Site (from Tables in Appendix C)

Site	Comp1 (hrs)	Comp2 (hrs)	Fan (hrs)	DHW Pump (hrs)	EH1 (hrs)	EH2 (hrs)	Min EWT (F)	Max EWT (F)	EAT Avg in Htg (F)	EAT Avg in Clg (F)	LAT Avg in Htg (F)	LAT Avg in Clg (F)
s01	4,781	-	4,875	4,714	11	9	33.3	74.6	71.2	75.7	76.3	48.2
s03	3,480	-	3,528	3,265	2	1	30.6	80.0	71.6	73.5	84.9	55.4
s04	5,905	-	5,964	4,881	90	63	32.4	73.4	71.9	73.3	84.7	53.7
s05	5,537	-	6,743	5,237	5	3	31.4	79.7	72.6	73.2	89.8	52.6
s06	3,344	-	3,392	-	0	0	41.9	67.6	69.5	71.9	83.7	50.9
s07	1,556	53	3,048	1,555	1	0	35.7	67.0	65.6	75.4	77.0	54.5
s08	2,086	251	2,163	-	-	-	31.6	76.0	67.7	75.5	87.7	43.2
s09	1,996	142	2,059	-	0	0	31.2	75.9	67.8	74.7	87.2	45.5
s10	4,810	-	4,930	4,652	16	10	31.2	83.6	66.5	70.9	82.1	47.3
s11	4,199	-	6,156	4,048	90	75	29.9	93.8	71.6	73.3	85.6	61.0
s13	5,280	-	7,193	3,781	87	70	29.5	84.9	68.6	69.9	85.7	52.3
s14	702	133	710	564	-	-	61.0	102.4	70.3	73.1	96.0	47.5
s15	3,241	-	3,291	2,728	24	18	28.7	80.2	67.2	73.9	90.5	49.4
s17	4,545	-	7,793	-	1	0	31.2	81.9	70.8	74.6	75.6	62.6
s18	2,844	-	3,262	2,261	0	0	39.6	66.7	70.0	78.1	78.6	59.2
s19	4,685	-	4,797	1,946	0	0	38.9	85.5	66.9	69.8	82.9	41.2
s20	5,102	-	5,247	4,401	4	3	31.1	75.0	71.5	72.6	81.7	53.4
s21	4,537	-	4,618	1,016	82	70	28.9	79.8	70.6	75.3	90.2	40.0
s22	2,912	506	5,093	-	42	29	24.5	82.5	68.8	74.4	86.6	49.9
s23	2,335	114	2,360	2,264	6	4	27.4	85.8	68.2	74.0	79.6	47.7
s24	1,553	-	1,616	1,540	-	-	35.4	66.1	55.0	79.8	58.5	58.1
s25	4,273	-	4,667	4,047	7	3	28.8	84.8	70.2	72.0	81.6	52.7
s26	4,039	-	4,959	3,449	166	99	31.3	74.2	66.9	76.4	86.3	47.4
s27	3,745	-	3,750	3,625	14	10	52.1	69.7	66.1	74.8	87.5	52.2
s28	4,330	-	4,419	4,275	0	-	34.5	67.9	69.9	75.8	77.4	54.7
s29	1,945	111	3,052	-	6	4	31.9	67.3	68.2	75.7	87.8	51.3

Table D-2. Summary of Annual Metrics for each Site (from Tables in Appendix C) - CONTINUED

Site	Comp1 (hrs)	Comp2 (hrs)	Fan (hrs)	DHW Pump (hrs)	EH1 (hrs)	EH2 (hrs)	Min EWT (F)	Max EWT (F)	EAT Avg in Htg (F)	EAT Avg in Clg (F)	LAT Avg in Htg (F)	LAT Avg in Clg (F)
s30	2,799	385	2,882	2,458	10	7	29.9	81.3	74.0	75.2	85.4	43.5
s31	3,271	-	3,545	-	57	41	34.7	82.5	67.4	75.0	77.2	60.8
s32	4,281	-	4,322	3,405	0	0	32.2	73.2	68.3	77.2	80.3	59.6
s33	2,007	-	2,062	-	2	2	29.8	73.3	63.2	78.3	74.9	55.1
s34	4,618	-	6,513	-	9	6	38.5	77.9	70.5	74.7	84.9	58.4
s35	2,407	368	2,667	-	33	21	33.3	82.1	70.4	72.4	78.1	50.0
s36	4,470	-	4,512	-	10	10	31.7	82.8	70.3	75.6	79.9	49.2
s37	2,648	246	2,693	-	16	11	29.1	79.4	70.4	75.6	84.5	43.1
s38	2,965	125	3,015	-	11	6	24.8	70.8	63.0	68.2	76.2	46.6
s39	4,702	-	4,762	4,511	22	21	25.4	65.3	70.7	75.5	82.2	60.9
s40	1,706	251	1,789	1,680	27	18	24.9	89.1	68.4	77.9	75.1	47.9
s41	1,553	-	4,133	1,086	44	41	46.3	65.0	57.7	74.4	80.0	61.5
s42	3,530	-	4,258	3,089	4	4	36.3	59.8	70.9	70.1	90.7	54.7
s43	2,346	-	2,410	-	0	-	41.9	61.0	65.8	74.1	76.0	54.4
s44	2,215	182	2,252	-	-	-	31.4	82.9	68.0	68.3	83.6	48.3
s45	5,161	-	5,213	2,672	-	-	33.9	78.0	69.9	71.3	82.8	48.0
s46	4,822	-	6,153	4,603	20	5	34.7	72.7	69.3	74.4	87.5	51.8
s47	2,284	166	4,377	1,896	9	5	29.7	68.2	68.7	74.4	84.5	59.9
s48	5,223	-	7,725	-	1	0	45.2	68.8	69.6	72.0	82.4	52.4
s49	4,347	-	7,766	3,333	91	73	24.7	79.0	70.9	75.1	84.9	70.5
s50	1,189	83	1,370	-	8	7	47.0	62.3	56.4	75.6	75.4	51.1
s51	4,275	-	4,315	4,003	6	3	34.6	84.3	68.1	70.2	78.7	52.5
s52	3,988	-	4,025	2,120	13	12	29.7	86.1	63.8	75.8	79.5	57.3

Table D-3. Summary of Annual Metrics for each Site (calculated from the 15-minute data)

	Heating COP Measured-to-Expected Ratio			Cooling EER Measured-to-Expected Ratio			Peak Demand (kW)		Entering Water Temperatures (EWT)				Entering Air Temp (EAT)		
Site	Variable Speed @ 50%	Stage 1	Stage 2	Variable Speed @ 50%	Stage 1	Stage 2	Winter	Summer	Max EWT (F)	Min EWT (F)	AVG EWT in Heating (F)	AVG EWT in Cooling (F)	AVG EAT in Heating (F)	AVG EAT in Cooling (F)	AVG LAT in Heating (F)
s01	1.30	-	-	0.53	-	-	7.8	4.3	74.6	33.3	40.1	66.2	71.3	75.6	77.5
s03	1.29	-	-	0.96	-	-	8.6	2.1	80.0	30.6	36.7	70.3	71.7	73.1	86.4
s04	0.98	-	-	0.76	-	-	11.5	7.1	73.4	32.4	41.1	64.5	71.8	72.5	85.6
s05	1.31	-	-	0.87	-	-	10.4	7.1	79.7	31.4	39	70.2	72.9	73.3	91.3
s06	1.04	-	-	0.84	-	-	3.3	3.5	69.6	41.9	47.2	58.5	69.5	71.8	83.7
s07	-	0.78	0.85	-	0.72	0.84	5.1	4.6	67.8	35.7	44.5	59.9	65.6	75	80.8
s08	-	1.18	1.14	-	0.86	0.97	3.5	2.9	76.0	31.6	42.4	64.3	67.6	75.5	88.3
s09	-	1.24	1.26	-	0.78	0.91	3.6	3.1	75.9	31.2	41.3	64.1	67.8	74.7	87.1
s10	1.58	-	-	0.64	-	-	12.5	4.7	83.7	31.2	40.4	73.4	66.5	71	83.2
s11	1.69	-	-	0.79	-	-	7.3	3.6	93.8	29.9	35.2	77.7	71.5	73.4	86.8
s13	1.30	-	-	0.66	-	-	12.3	3.8	84.9	29.5	33.8	72.5	68.8	70.2	88.4
s14	-	0.93	1.01	-	0.69	0.76	4.8	5.4	103.0	61.0	67	90.6	70.4	73.1	98
s15	1.04	-	-	0.93	-	-	11.5	9.7	80.2	28.7	31.5	70.9	67.1	73.6	91.8
s17	1.11	-	-	0.86	-	-	7.2	2.3	81.9	31.2	39.5	70.4	70.5	74.6	76.3
s18	1.07	-	-	0.94	-	-	6.1	1.8	67.2	39.6	44.2	56.6	69.8	78.2	79.6
s19	1.68	-	-	0.54	-	-	6.1	4.5	85.5	38.9	47.8	71.7	67	70	84.5
s20	0.92	-	-	0.87	-	-	12.6	3.3	75.1	31.1	36.2	65.8	71.8	72.5	82.4
s21	1.35	-	-	0.81	-	-	11.6	10.2	79.8	28.9	35.3	70.8	70.8	75.3	92.1
s22	-	1.28	1.24	-	0.88	0.98	4.5	4.2	82.5	24.5	33.8	71	69	74.3	90.2
s23	-	1.37	1.31	-	0.88	1.05	8.5	5.9	85.8	27.4	31.3	67.8	68.2	73.8	79.2
s24	1.19	-	-	0.81	-	-	2.8	2.4	66.1	35.4	41.4	61.3	55.4	79.2	59.2
s25	1.14	-	-	0.79	-	-	9.1	2.5	84.8	28.7	34.5	74.5	70.3	72.1	81.3
s26	0.98	-	-	0.93	-	-	12.7	12.8	75.1	31.3	37.9	66.5	66.9	75.5	89.4
s27	1.32	-	-	-	-	-	12.3	2.0	71.5	52.1	55.1	56	66.3	74.7	88
s28	1.34	-	-	0.91	-	-	1.7	1.0	67.9	34.5	42	64.4	70.1	75.5	78.6
s29	-	1.08	1.10	-	0.74	0.81	14.6	4.0	67.9	31.9	40.9	58.2	68.2	74.9	89.2

Table D-3. Summary of Annual Metrics for each Site (calculated from the 15-minute data) - CONTINUED

	Heating COP Measured-to-Expected Ratio			Cooling EER Measured-to-Expected Ratio			Peak Demand (kW)		Entering Water Temperatures (EWT)				Entering Air Temp (EAT)		
Site	Variable Speed @ 50%	Stage 1	Stage 2	Variable Speed @ 50%	Stage 1	Stage 2	Winter	Summer	Max EWT (F)	Min EWT (F)	AVG EWT in Heating (F)	AVG EWT in Cooling (F)	AVG EAT in Heating (F)	AVG EAT in Cooling (F)	AVG LAT in Heating (F)
s30	-	1.11	1.04	-	0.79	0.77	12.2	6.3	81.3	29.9	37.5	69.9	74.1	74.8	86.6
s31	1.52	-	-	1.11	-	-	11.8	2.8	82.5	34.7	38.9	75	67.1	75.8	78.4
s32	1.16	-	-	0.89	-	-	3.1	1.6	73.2	32.2	40.1	63.2	68.3	77.2	81.1
s33	1.44	-	-	0.94	-	-	9.9	2.1	85.5	29.8	42.1	70.3	65.8	72.2	79.4
s34	0.77	-	-	0.81	-	-	11.7	3.8	77.9	38.5	46.4	66.7	70.6	74.8	87.6
s35	-	0.94	0.94	-	0.60	0.70	17.1	6.4	82.1	33.3	39.7	73.6	70.4	72.3	77.9
s36	1.18	-	-	0.95	-	-	8.8	1.8	82.8	31.7	41.7	73.1	70.3	75	81.3
s37	-	1.31	1.29	-	1.06	1.17	9.7	7.7	79.4	29.1	37.7	67.4	70.1	75.6	84.6
s38	-	2.35	2.20	-	1.77	1.79	1.5	1.4	70.8	24.8	34.3	61.1	62.8	68.1	76.2
s39	1.22	-	-	0.98	-	-	3.0	2.6	67.7	25.4	32.9	56.2	70.9	74.6	84.3
s40	-	1.33	1.36	-	1.11	1.25	12.1	4.6	89.1	24.9	34.2	74.1	68.4	78	76.4
s41	1.03	-	-	0.66	-	-	4.5	3.4	65.3	46.2	50.4	50.4	61.4	75.1	91.3
s42	0.99	-	-	-	-	-	9.3	3.4	61.8	36.3	41.9	56.1	71.1	70.2	93.7
s43	1.37	-	-	-	-	-	3.3	1.1	61.7	41.9	46.8	53.6	65.5	74.1	78.1
s44	-	1.41	1.31	-	1.05	1.08	3.3	3.1	82.9	31.4	40.3	72.6	67.9	68.3	83.1
s45	1.61	-	-	0.64	-	-	3.1	2.0	78.0	33.9	41.3	69.8	69.9	71	84
s46	1.77	-	-	0.77	-	-	7.5	1.9	72.7	34.7	41.1	67.2	69.6	74.3	90.2
s47	-	1.12	1.09	-	0.84	0.84	10.0	3.7	68.2	29.7	39.6	58.4	68.6	74.5	87.9
s48	1.05	-	-	0.61	-	-	6.3	1.7	70.1	45.2	49.8	60.2	69.7	72.5	87.4
s49	0.99	-	-	0.83	-	-	4.2	3.6	86.0	24.7	34.4	62.5	70.6	75.7	89
s50	-	0.45	1.27	-	0.28	1.17	7.6	2.4	63.2	46.3	48.3	49.8	58.6	74.7	77
s51	2.07	-	-	0.79	-	-	13.4	2.5	84.3	34.6	42.6	66.6	68.2	70.2	79.6
s52	1.31	-	-	1.03	-	-	10.5	2.7	86.1	29.7	36.8	73.4	70.3	75.7	87.8

Appendix E: Expected Performance Data from Water Furnace Units

Appendix E - Expected Performance Data from Water Furnace Units

Water Furnace provides performance data in tables of the following form. The table on page E-1 corresponds to high speed and the table on page E-2 to low speed compressor operation for one of the dual speed units.

ND038 - Dual Capacity with Variable Speed or 5-Speed ECM High Speed (1250 cfm)

EWT °F	Flow Rate GPM	WPD		HEATING - EAT 70°F							COOLING - EAT 80/67 °F							
		PSI	FT/HD	Airflow CFM	HC MBtu/h	Power kW	HE MBtu/h	LAT °F	COP	HWC Mbtu/h	Airflow CFM	TC Mbtu/h	SC Mbtu/h	S/T Ratio	Power kW	HR Mbtu/h	EER	HWC Mbtu/h
20	5.0	1.3	3.0	Operation not recommended							Operation not recommended							
	7.0	2.3	5.2	Operation not recommended														
	9.0	3.5	8.1	1050	25.2	2.21	17.7	92.2	3.34	2.9								
				1250	26.0	2.28	18.2	89.3	3.34	2.6								
30	5.0	1.2	2.9	Operation not recommended							Operation not recommended							
	7.0	2.2	5.1	1050	28.8	2.24	21.1	95.4	3.77	3.1	1050	39.3	25.2	0.64	1.43	44.2	27.4	-
				1250	29.6	2.31	21.7	91.9	3.76	2.8	1250	40.0	27.5	0.69	1.51	45.1	26.5	-
	9.0	3.4	7.9	1050	29.2	2.26	21.5	95.8	3.79	3.2	1050	39.5	25.2	0.64	1.39	44.3	28.4	-
				1250	30.2	2.33	22.3	92.4	3.80	2.9	1250	40.5	27.5	0.68	1.46	45.5	27.7	-
40	5.0	1.2	2.8	Operation not recommended							Operation not recommended							
	7.0	2.1	4.9	1050	32.7	2.32	24.8	98.8	4.12	3.4	1050	40.6	26.4	0.65	1.60	46.0	25.4	-
				1250	33.7	2.37	25.6	95.0	4.16	3.1	1250	41.3	28.8	0.70	1.67	47.0	24.7	-
	9.0	3.3	7.6	1050	33.3	2.35	25.3	99.4	4.16	3.5	1050	40.9	26.4	0.65	1.55	46.2	26.4	-
				1250	34.4	2.40	26.2	95.5	4.21	3.2	1250	41.8	28.8	0.69	1.62	47.3	25.8	-
50	5.0	1.2	2.7	1050	35.3	2.36	27.3	101.1	4.39	3.7	1050	39.7	25.1	0.63	1.84	46.0	21.5	1.9
				1250	36.4	2.39	28.2	96.9	4.46	3.4	1250	41.8	27.9	0.67	1.94	48.4	21.5	2.0
	7.0	2.1	4.8	1050	36.6	2.41	28.4	102.3	4.45	3.8	1050	40.5	25.4	0.63	1.74	46.5	23.3	1.8
				1250	37.8	2.44	29.4	98.0	4.53	3.5	1250	42.6	28.2	0.66	1.82	48.8	23.4	1.9
	9.0	3.2	7.4	1050	37.4	2.43	29.1	103.0	4.51	3.9	1050	40.9	27.1	0.66	1.69	46.7	24.1	1.7
				1250	38.6	2.47	30.2	98.6	4.59	3.6	1250	43.1	30.1	0.70	1.78	49.2	24.2	1.8
60	5.0	1.1	2.6	1050	38.7	2.47	30.3	104.1	4.60	4.2	1050	39.4	25.8	0.66	2.00	46.2	19.7	2.3
				1250	40.0	2.48	31.5	99.6	4.72	3.8	1250	41.3	28.7	0.70	2.09	48.4	19.8	2.4
	7.0	2.0	4.6	1050	40.5	2.54	31.8	105.7	4.68	4.3	1050	40.4	26.1	0.65	1.90	46.8	21.3	2.2
				1250	41.8	2.55	33.1	100.9	4.80	4.0	1250	42.3	29.0	0.69	1.98	49.0	21.4	2.3
	9.0	3.1	7.2	1050	41.4	2.56	32.7	106.5	4.74	4.4	1050	40.7	27.5	0.68	1.85	47.1	22.0	2.0
				1250	42.8	2.57	34.0	101.7	4.88	4.1	1250	42.8	30.6	0.71	1.94	49.4	22.1	2.2
70	5.0	1.1	2.5	1050	42.1	2.57	33.4	107.2	4.80	4.7	1050	39.2	26.6	0.68	2.15	46.5	18.2	2.9
				1250	43.6	2.57	34.8	102.3	4.96	4.3	1250	40.9	29.5	0.72	2.23	48.5	18.3	3.0
	7.0	1.9	4.5	1050	44.3	2.66	35.2	109.1	4.88	4.8	1050	40.2	26.9	0.67	2.06	47.2	19.5	2.7
				1250	45.8	2.66	36.7	103.9	5.04	4.4	1250	41.9	29.8	0.71	2.13	49.2	19.7	2.9
	9.0	3.0	6.9	1050	45.5	2.69	36.3	110.1	4.95	5.0	1050	40.6	28.0	0.69	2.01	47.4	20.2	2.5
				1250	47.0	2.68	37.9	104.8	5.14	4.6	1250	42.4	31.0	0.73	2.09	49.5	20.3	2.8
80	5.0	1.1	2.5	1050	45.4	2.72	36.2	110.1	4.89	5.2	1050	37.5	26.1	0.70	2.34	45.4	16.0	3.6
				1250	47.0	2.70	37.8	104.8	5.10	4.8	1250	39.0	29.0	0.74	2.41	47.2	16.1	3.8
	7.0	1.9	4.3	1050	48.1	2.83	38.4	112.4	4.98	5.4	1050	38.5	26.4	0.69	2.26	46.2	17.0	3.3
				1250	49.7	2.80	40.1	106.8	5.20	5.0	1250	40.0	29.2	0.73	2.33	48.0	17.2	3.6
	9.0	2.9	6.7	1050	49.5	2.87	39.7	113.6	5.05	5.6	1050	38.9	27.0	0.69	2.21	46.4	17.6	3.1
				1250	51.2	2.83	41.5	107.9	5.31	5.1	1250	40.5	30.0	0.74	2.28	48.3	17.8	3.4
90	5.0	1.0	2.4	1050	48.8	2.87	39.0	113.0	4.97	5.9	1050	35.8	25.5	0.71	2.53	44.4	14.1	4.4
				1250	50.5	2.83	40.8	107.4	5.23	5.4	1250	37.0	28.4	0.77	2.59	45.9	14.3	4.7
	7.0	1.8	4.2	1050	51.8	3.00	41.6	115.7	5.06	6.0	1050	36.8	25.9	0.70	2.46	45.2	15.0	4.1
				1250	53.7	2.95	43.6	109.8	5.33	5.6	1250	38.2	28.7	0.75	2.52	46.8	15.1	4.5
	9.0	2.8	6.5	1050	53.5	3.05	43.1	117.1	5.14	6.2	1050	37.2	26.1	0.70	2.42	45.5	15.4	3.9
				1250	55.3	2.97	45.2	111.0	5.46	5.8	1250	38.6	28.9	0.75	2.47	47.0	15.6	4.3
100	5.0	1.0	2.3	Operation not recommended							Operation not recommended							
	7.0	1.7	4.0								1050	34.6	25.0	0.72	2.73	43.9	12.7	5.1
											1250	35.7	27.7	0.78	2.77	45.2	12.9	5.5
	9.0	2.7	6.2								1050	35.0	24.9	0.71	2.68	44.1	13.1	4.8
											1250	36.1	27.6	0.76	2.72	45.4	13.3	5.3
110	5.0	1.0	2.2								Operation not recommended							
	7.0	1.7	3.9								1050	32.4	24.1	0.74	2.99	42.6	10.8	6.2
											1250	33.3	26.7	0.80	3.01	43.5	11.0	6.8
	9.0	2.6	6.0								1050	32.7	23.7	0.73	2.94	42.7	11.1	5.8
											1250	33.6	26.2	0.78	2.97	43.7	11.3	6.4
120	5.0	0.9	2.1								Operation not recommended							
	7.0	1.6	3.7								1050	30.6	23.3	0.76	3.31	41.9	9.2	7.5
											1250	31.1	25.3	0.81	3.39	42.7	9.2	8.1
	9.0	2.5	5.8								1050	30.8	23.3	0.76	3.20	41.8	9.6	7.0
											1250	31.5	25.3	0.80	3.30	42.8	9.5	7.7

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ND038 - Dual Capacity with Variable Speed or 5-Speed ECM Low Speed (1050 cfm)

EWT °F	Flow Rate GPM	WPD PSI	WPD FT/HD	HEATING - EAT 70°F Airflow CFM	HC MBtu/h	Power kW	HE MBtu/h	LAT °F	COP	HWC Mbtu/h	COOLING - EAT 80/67 °F Airflow CFM	TC Mbtu/h	SC Mbtu/h	S/T Ratio	Power kW	HR Mbtu/h	EER	HWC Mbtu/h
20	4.0	0.9	2.1	Operation not recommended							Operation not recommended							
	6.0	1.7	4.0															
	8.0	2.9	6.7	900	17.6	1.63	12.1	88.1	3.17	2.5								
				1050	18.4	1.67	12.7	86.2	3.22	2.3								
30	4.0	0.9	2.0	Operation not recommended							Operation not recommended							
	6.0	1.7	3.9	900	19.2	1.58	13.8	89.8	3.57	2.4	900	29.5	19.1	0.65	0.74	32.0	40.1	---
				1050	20.0	1.62	14.5	87.7	3.62	2.2	1050	30.0	20.9	0.70	0.78	32.6	38.7	---
	8.0	2.8	6.5	900	20.5	1.62	14.9	91.0	3.71	2.5	900	29.7	19.1	0.64	0.71	32.1	41.5	---
				1050	21.3	1.66	15.6	88.8	3.76	2.3	1050	30.4	20.9	0.69	0.75	33.0	40.5	---
40	4.0	0.8	1.9	Operation not recommended							Operation not recommended							
	6.0	1.6	3.8	900	22.5	1.60	17.0	93.1	4.11	2.5	900	30.8	20.6	0.67	0.81	33.5	37.8	-
				1050	23.3	1.63	17.7	90.5	4.17	2.3	1050	31.3	22.5	0.72	0.85	34.3	36.8	-
	8.0	2.7	6.3	900	23.7	1.64	18.1	94.4	4.23	2.6	900	31.0	20.6	0.66	0.79	33.7	39.3	-
				1050	24.5	1.67	18.8	91.6	4.29	2.4	1050	31.7	22.5	0.71	0.83	34.5	38.4	-
50	4.0	0.8	1.9	900	24.8	1.63	19.3	95.5	4.47	2.6	900	31.3	21.1	0.67	0.91	34.4	34.2	1.0
				1050	25.6	1.65	20.0	92.6	4.55	2.4	1050	32.2	23.4	0.73	0.93	35.4	34.5	1.1
	6.0	1.6	3.7	900	25.7	1.63	20.1	96.4	4.62	2.7	900	31.6	21.2	0.67	0.89	34.6	35.5	0.9
				1050	26.5	1.65	20.8	93.3	4.70	2.5	1050	32.5	23.5	0.72	0.91	35.6	35.8	1.0
	8.0	2.6	6.1	900	26.9	1.67	21.2	97.7	4.73	2.8	900	32.1	21.8	0.68	0.88	35.1	36.4	0.9
				1050	27.7	1.69	21.9	94.4	4.81	2.5	1050	33.0	24.1	0.73	0.90	36.1	36.7	1.0
60	4.0	0.8	1.8	900	28.1	1.67	22.4	98.9	4.94	2.9	900	30.5	20.8	0.68	1.04	34.0	29.4	1.3
				1050	28.8	1.68	23.1	95.4	5.03	2.6	1050	31.3	23.1	0.74	1.06	35.0	29.7	1.4
	6.0	1.5	3.6	900	29.3	1.67	23.6	100.1	5.15	3.0	900	30.8	21.0	0.68	1.01	34.2	30.5	1.3
				1050	29.9	1.68	24.2	96.4	5.24	2.7	1050	31.6	23.2	0.73	1.03	35.1	30.7	1.4
	8.0	2.5	5.9	900	30.3	1.70	24.5	101.2	5.21	3.0	900	31.3	21.5	0.69	1.00	34.7	31.3	1.2
				1050	31.0	1.71	25.1	97.3	5.30	2.8	1050	32.2	23.8	0.74	1.02	35.6	31.5	1.3
70	4.0	0.8	1.8	900	31.4	1.71	25.6	102.3	5.39	3.2	900	29.7	20.6	0.69	1.16	33.6	25.6	1.9
				1050	32.0	1.71	26.2	98.3	5.49	2.9	1050	30.5	22.8	0.75	1.18	34.5	25.8	2.0
	6.0	1.5	3.5	900	32.8	1.70	27.0	103.7	5.64	3.3	900	30.0	20.7	0.69	1.13	33.8	26.6	1.7
				1050	33.4	1.70	27.6	99.4	5.75	3.0	1050	30.8	22.9	0.74	1.15	34.7	26.8	1.9
	8.0	2.5	5.7	900	33.6	1.74	27.7	104.6	5.67	3.4	900	30.5	21.2	0.70	1.12	34.3	27.2	1.6
				1050	34.2	1.74	28.3	100.2	5.78	3.1	1050	31.3	23.5	0.75	1.14	35.2	27.5	1.8
80	4.0	0.7	1.7	900	35.0	1.77	29.0	106.0	5.80	3.6	900	28.1	19.8	0.70	1.33	32.6	21.1	2.5
				1050	35.5	1.76	29.5	101.3	5.91	3.3	1050	28.9	21.9	0.76	1.36	33.5	21.3	2.7
	6.0	1.4	3.3	900	36.7	1.76	30.7	107.7	6.12	3.7	900	28.3	19.9	0.70	1.30	32.8	21.9	2.4
				1050	37.1	1.74	31.1	102.7	6.24	3.4	1050	29.1	22.0	0.76	1.32	33.6	22.0	2.6
	8.0	2.4	5.5	900	37.2	1.79	31.1	108.3	6.08	3.8	900	28.8	20.4	0.71	1.29	33.2	22.4	2.2
				1050	37.6	1.78	31.5	103.1	6.20	3.5	1050	29.6	22.6	0.76	1.31	34.1	22.6	2.5
90	4.0	0.7	1.6	900	38.6	1.83	32.3	109.7	6.19	4.0	900	26.5	18.9	0.71	1.50	31.6	17.6	3.4
				1050	38.9	1.81	32.7	104.3	6.31	3.7	1050	27.2	20.9	0.77	1.53	32.4	17.7	3.6
	6.0	1.4	3.2	900	40.5	1.81	34.4	111.7	6.56	4.2	900	26.7	19.0	0.71	1.46	31.7	18.2	3.2
				1050	40.8	1.79	34.7	106.0	6.70	3.8	1050	27.4	21.1	0.77	1.49	32.5	18.4	3.4
	8.0	2.3	5.3	900	40.7	1.85	34.4	111.9	6.46	4.3	900	27.1	19.5	0.72	1.45	32.1	18.7	2.9
				1050	40.9	1.82	34.7	106.1	6.59	4.0	1050	27.9	21.6	0.77	1.48	32.9	18.9	3.3
100	4.0	0.7	1.6	Operation not recommended							Operation not recommended							
	6.0	1.3	3.1								900	24.9	18.6	0.75	1.68	30.6	14.8	4.1
											1050	25.6	20.6	0.80	1.72	31.4	14.9	4.5
	8.0	2.2	5.1								900	25.3	19.1	0.75	1.67	31.0	15.2	3.8
											1050	26.0	21.1	0.81	1.70	31.8	15.3	4.2
110	4.0	0.7	1.5								Operation not recommended							
	6.0	1.3	3.0								900	23.1	18.1	0.79	1.90	29.6	12.1	5.2
											1050	23.7	20.1	0.85	1.94	30.3	12.2	5.7
	8.0	2.1	4.9								900	23.4	18.6	0.79	1.88	29.9	12.4	4.8
											1050	24.1	20.6	0.85	1.92	30.7	12.6	5.4
120	4.0	0.6	1.5								Operation not recommended							
	6.0	1.2	2.9								900	22.2	18.8	0.85	2.18	29.7	10.2	6.5
											1050	22.6	20.4	0.90	2.24	30.3	10.1	7.0
	8.0	2.0	4.7								900	22.4	18.8	0.84	2.11	29.6	10.6	6.0
											1050	22.9	20.4	0.89	2.18	30.3	10.5	6.7

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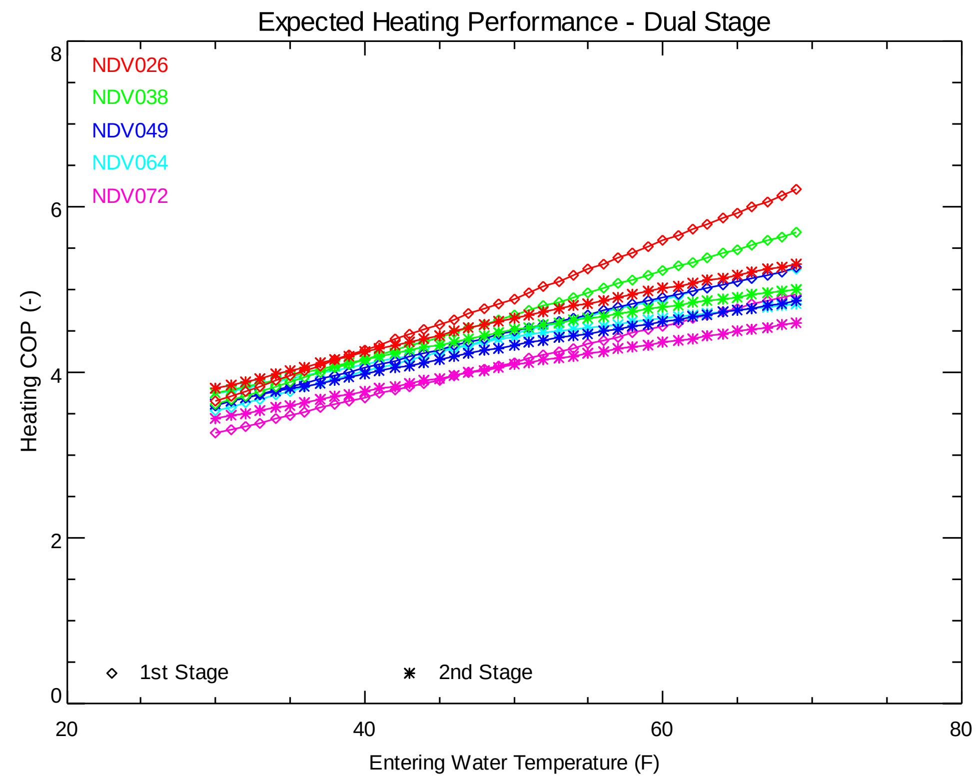
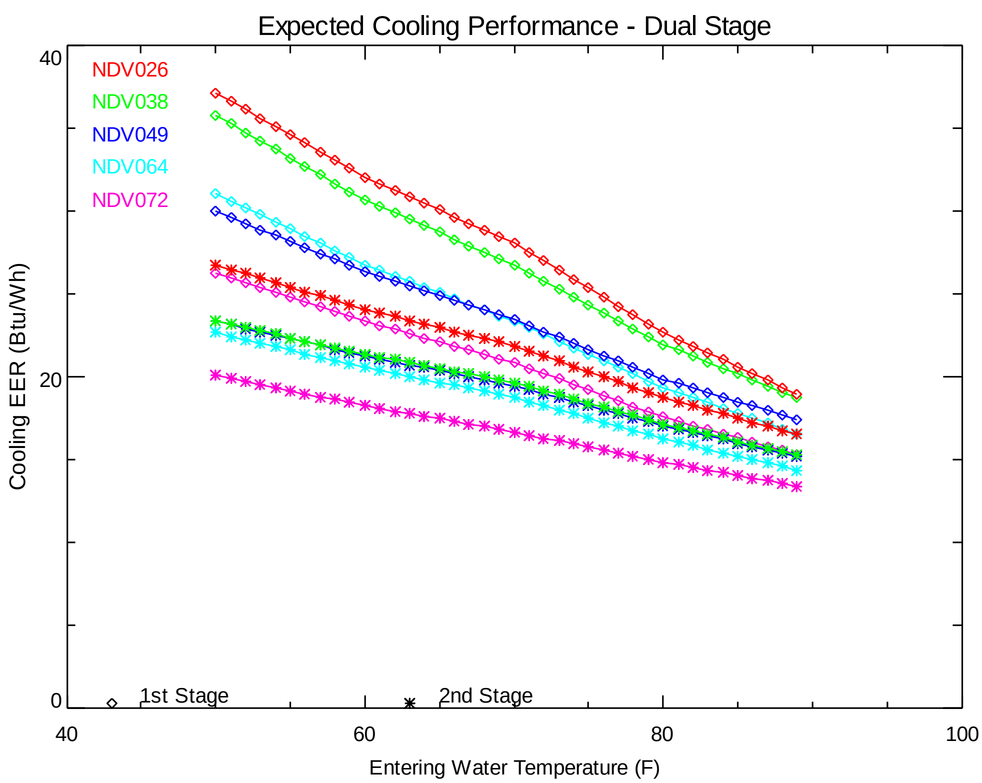
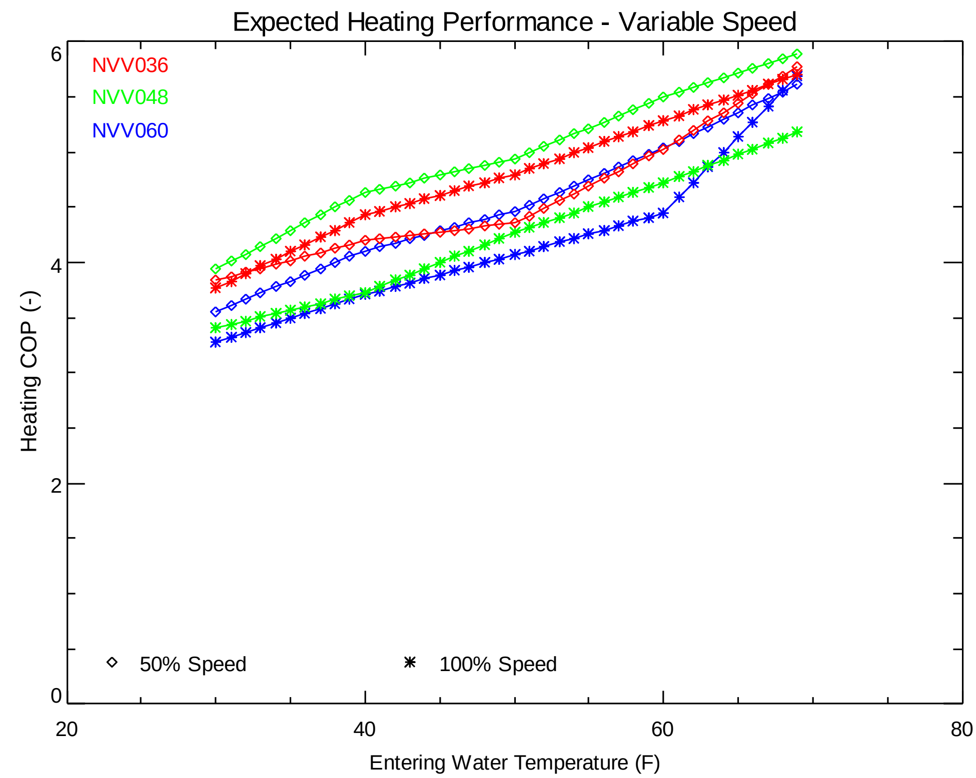
The plots on page E-3 show the resulting performance curves for heating COP and cooling EER for the heat pump unit (compressor and fan, assuming the stated airflow at zero static). The units are shows with different colors while the low speed and high speed performance are shown with different symbols.

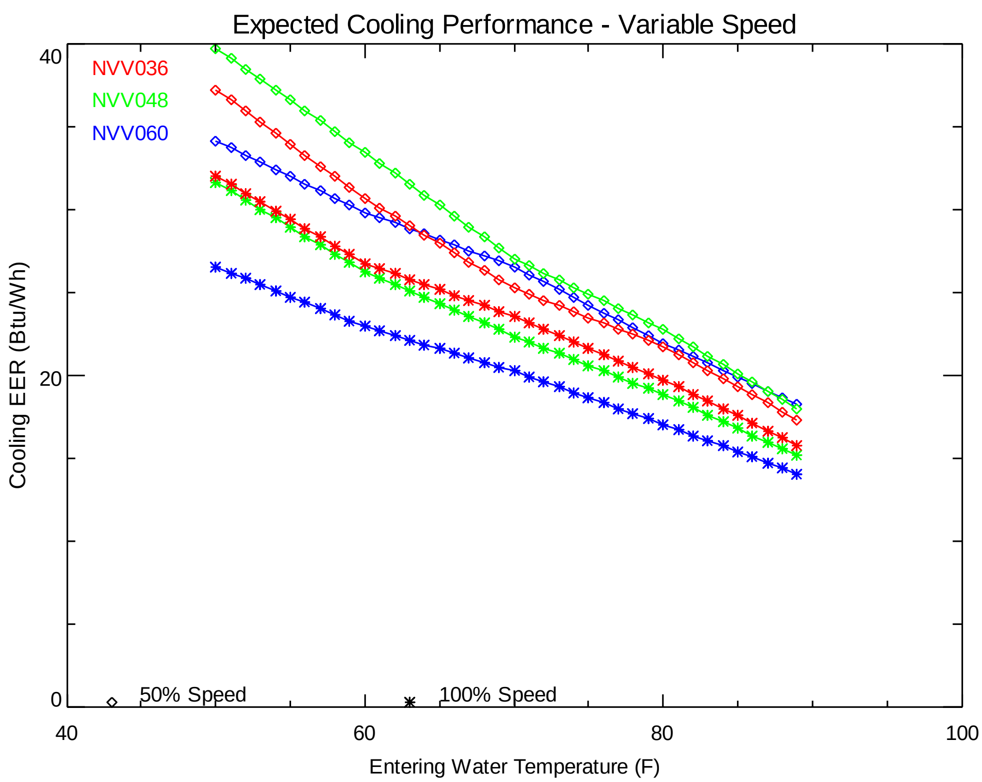
The plots on page E-4 show same performance data for the variable speed (series 7) units at 100% Full Load and 50% Part Load.


Expected Heating Performance - Dual Stage
NDV026
NDV038
NDV049
NDV064
NDV072
1st Stage
2nd Stage
Heating COP (-)
Entering Water Temperature (F)
0
2
4
6
8
20
40
60
80


Expected Cooling Performance - Dual Stage
NDV026
NDV038
NDV049
NDV064
NDV072
1st Stage
2nd Stage
Cooling EER (Btu/Wh)
Entering Water Temperature (F)
0
20
40
40
60
80
100



Expected Heating Performance - Variable Speed
NVV036
NVV048
NVV060
50% Speed
100% Speed
Heating COP (-)
Entering Water Temperature (F)
0
2
4
6
20
40
60
80



Expected Cooling Performance - Variable Speed
NVV036
NVV048
NVV060
50% Speed
100% Speed
Cooling EER (Btu/Wh)
Entering Water Temperature (F)
0
20
40
40
60
80
100

Legend and Notes

Abbreviations and Definitions

cfm = airflow, cubic feet/minute
EWT = entering water temperature, Fahrenheit
gpm = water flow in gallons/minute
WPD = water pressure drop, psi and feet of water
EAT = entering air temperature, Fahrenheit (dry bulb/wet bulb)
HC = air heating capacity, MBtu/h
TC = total cooling capacity, MBtu/h
SC = sensible cooling capacity, MBtu/h
kW = total power unit input, kilowatts
HR = total heat of rejection, MBtu/h
HE = total heat of extraction, MBtu/h
HWC = hot water generator capacity, MBtu/h
EER = Energy Efficient Ratio
= Btu output/Watt input
COP = Coefficient of Performance
= Btu output/Btu input
LWT = leaving water temperature, °F
LAT = leaving air temperature, °F
TH = total heating capacity, MBtu/h
LC = latent cooling capacity, MBtu/h
S/T = sensible to total cooling ratio

Notes to Performance Data Tables

The following notes apply to all performance data tables:

- Performance ratings are based on 80°F DB/67°F WB EAT for cooling and 70°F DB EAT for heating.
- Three flow rates are shown for each unit. The lowest flow rate shown is used for geothermal open loop/well water systems with a minimum of 50°F EWT. The middle flow rate shown is the minimum geothermal closed loop flow rate. The highest flow rate shown is optimum for geothermal closed loop systems and the suggested flow rate for boiler/tower applications.
- The hot water generator numbers are based on a flow rate of 0.4 gpm/ton of rated capacity with an EWT of 90°F.
- Entering water temperatures below 40°F assumes 15% antifreeze solution.
- For non-standard EAT conditions, apply the appropriate Correction Factor tables.
- Interpolation between EWT, gpm, and cfm data is permissible, extrapolation is not.

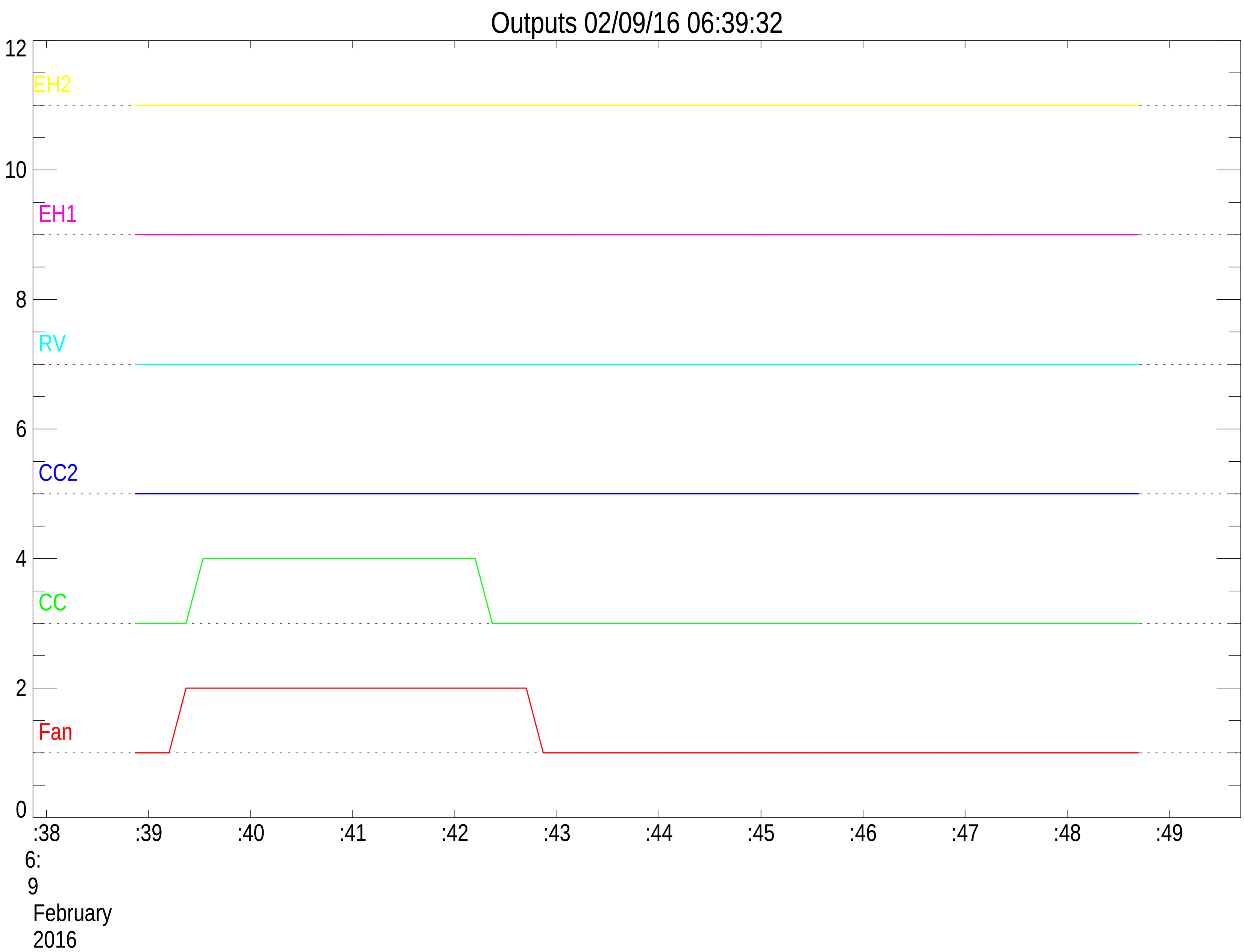
Appendix F: - Initial Analysis of Short-Time Step Data at S32

Appendix F – Initial Analysis of Short-Time Step Data at S32

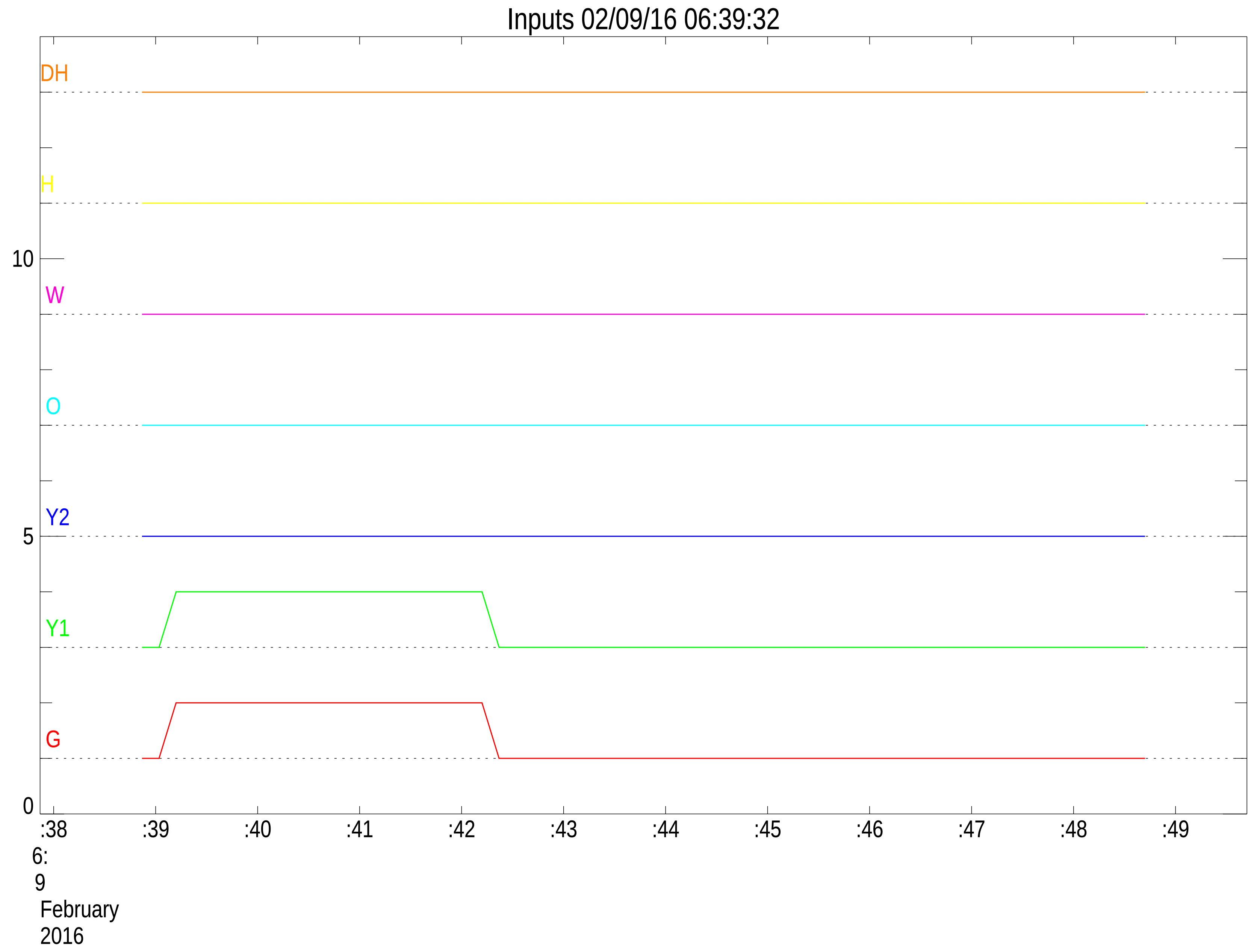
We evaluated the 10 second data from an NVV036 variable speed unit at site S32 in Akron to understand transient system performance and confirm the data could be properly aggregated in to 15-minute data. The plots on the following pages plot the 10 second data over three different 10 minute internals when the heat pump unit started up at:

- February 9 at 6:39:32 am
- February 9 at 7:00:13 am
- February 9 at 7:55:33 am

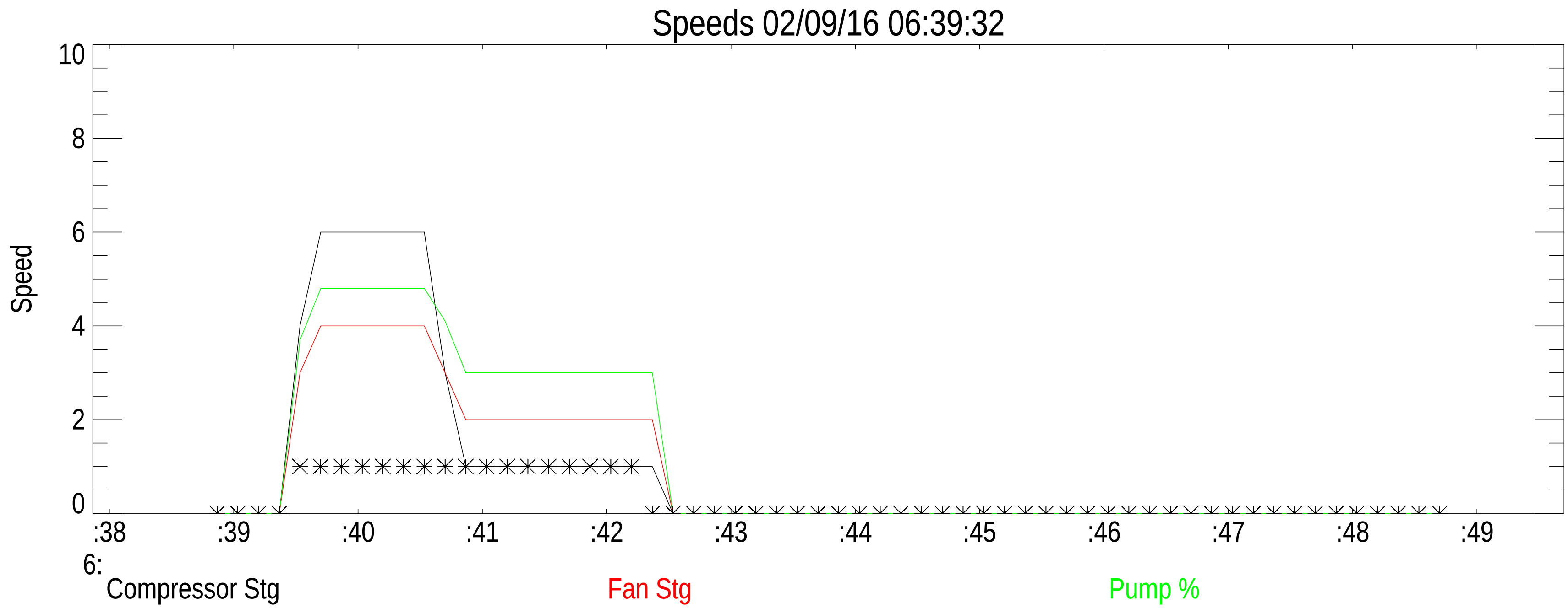
The data point labels on the plots correspond to the names given in Table 4 of the main report. Various aspects of transient performance at startup are apparent from the plots.

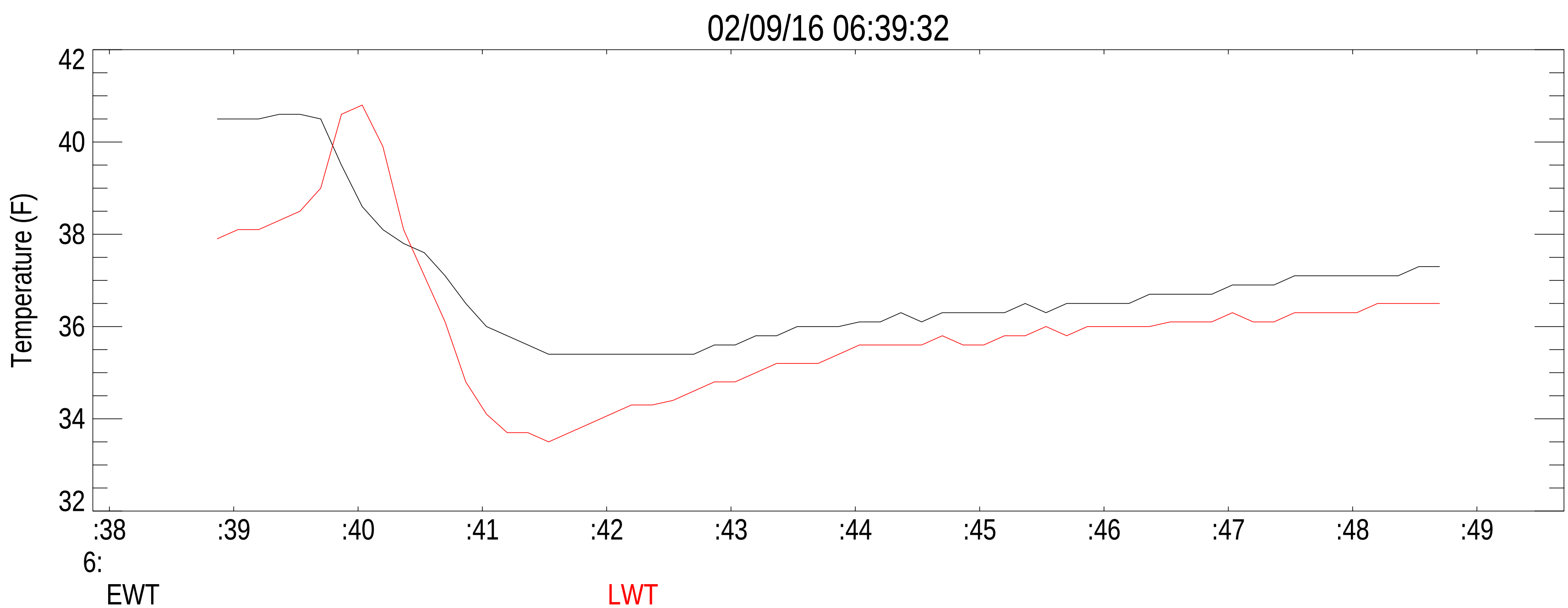


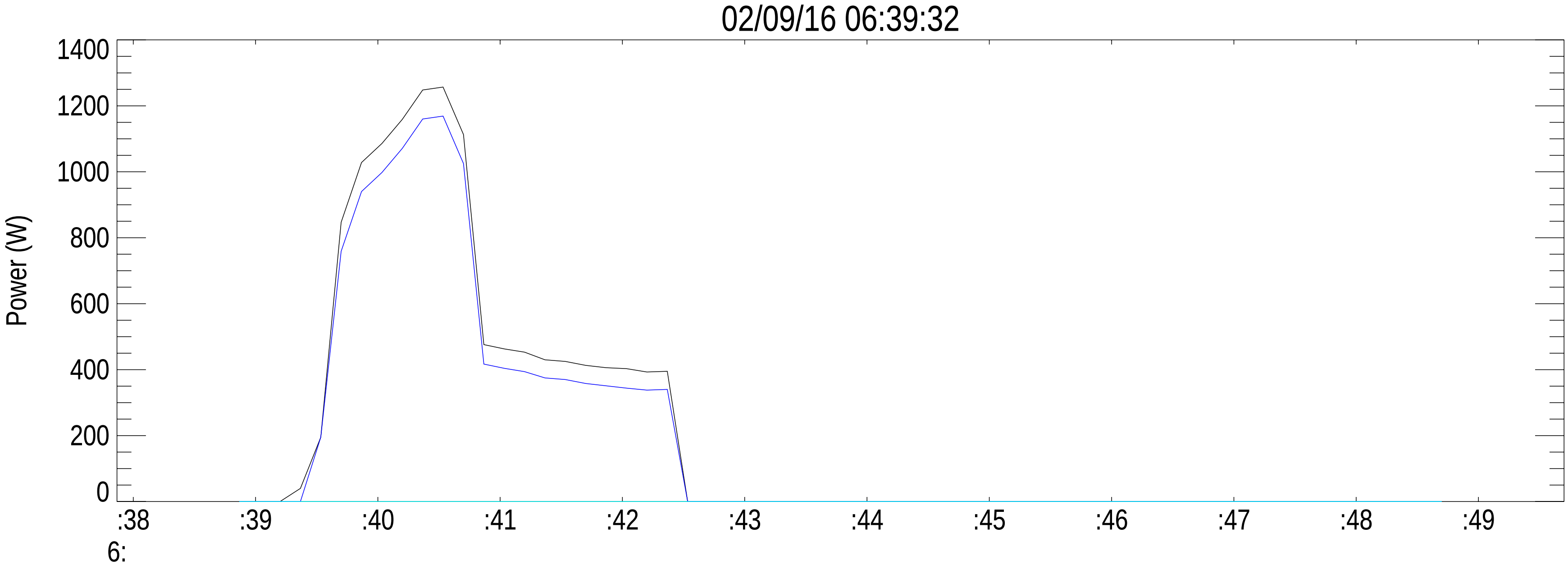
Outputs 02/09/16 06:39:32
12
10
8
6
4
2
0
EH2
EH1
RV
CC2
CC
Fan
:38
:39
:40
:41
:42
:43
:44
:45
:46
:47
:48
:49
6:
9
February
2016

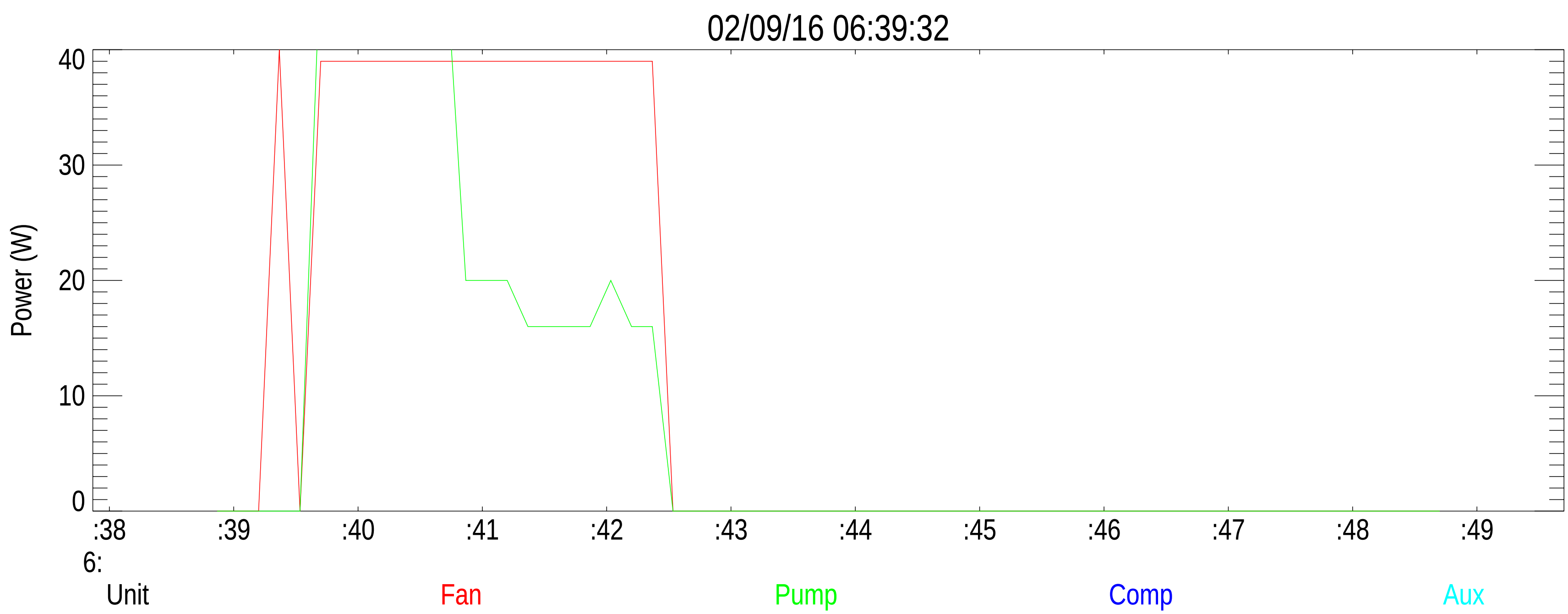


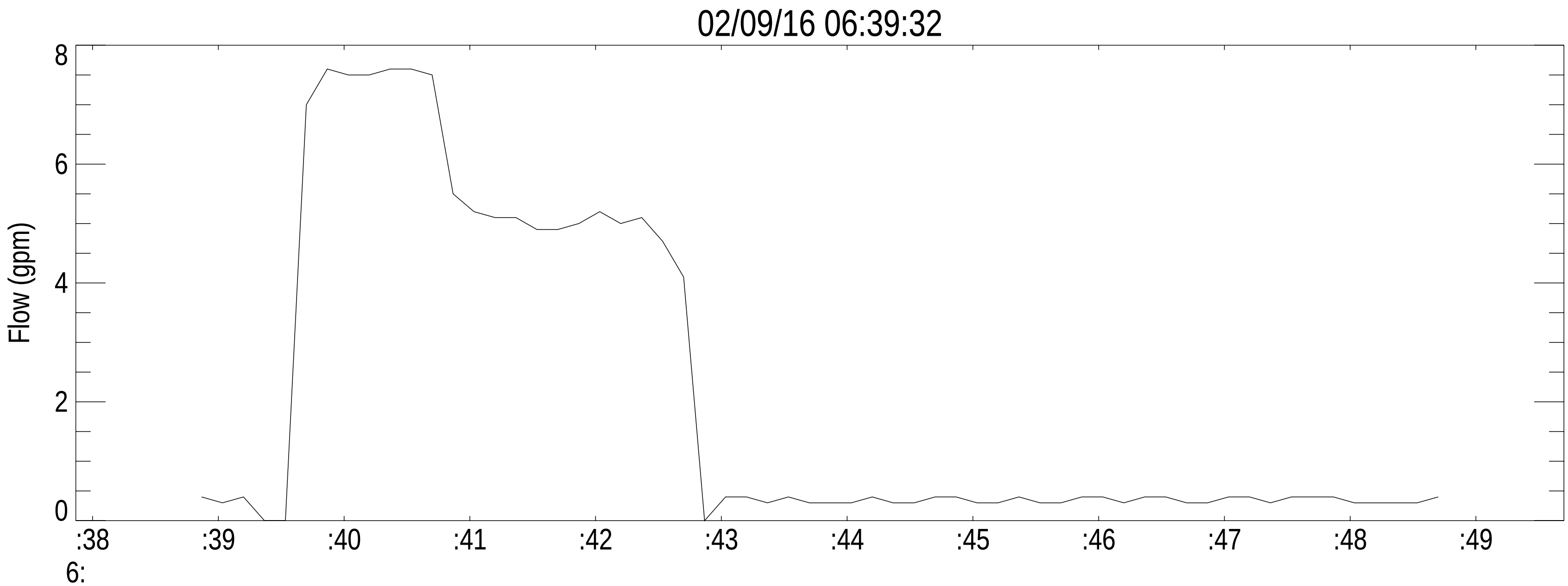
Inputs 02/09/16 06:39:32
DH
H
W
O
Y2
Y1
G
10
5
0
:38
:39
:40
:41
:42
:43
:44
:45
:46
:47
:48
:49
6:
9
February
2016

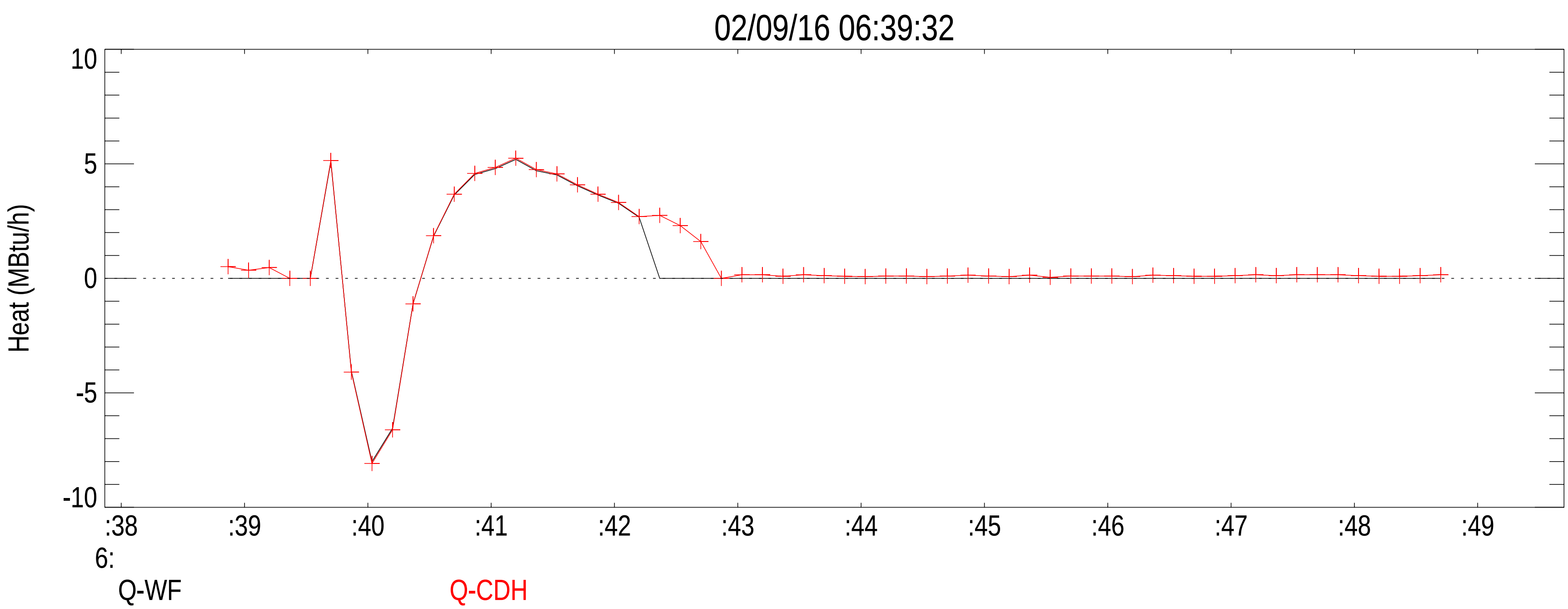

Speeds 02/09/16 06:39:32
Speed
10
8
6
4
2
0
:38
:39
:40
:41
:42
:43
:44
:45
:46
:47
:48
:49
6:
Compressor Stg
Fan Stg
Pump %

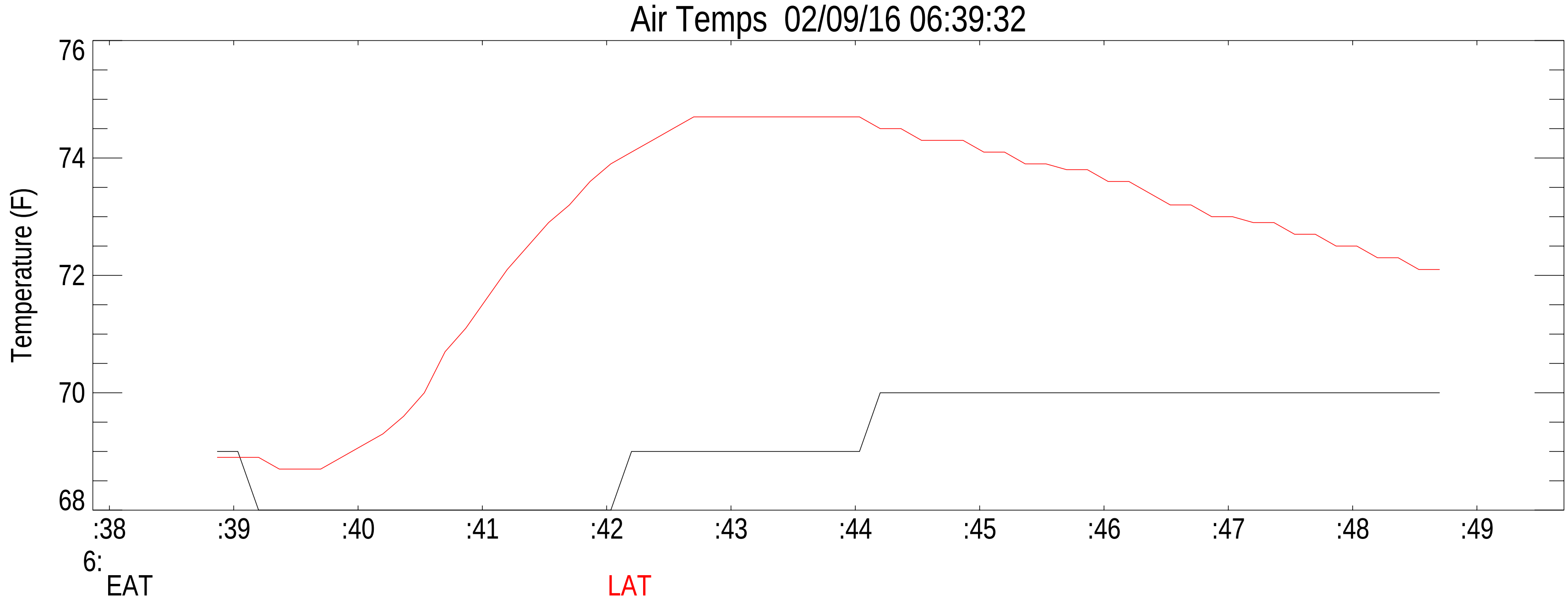

02/09/16 06:39:32
Temperature (F)
42
40
38
36
34
32
:38
:39
:40
:41
:42
:43
:44
:45
:46
:47
:48
:49
6:
EWT
LWT


02/09/16 06:39:32
Power (W)
1400
1200
1000
800
600
400
200
0
:38
:39
:40
:41
:42
:43
:44
:45
:46
:47
:48
:49
6:

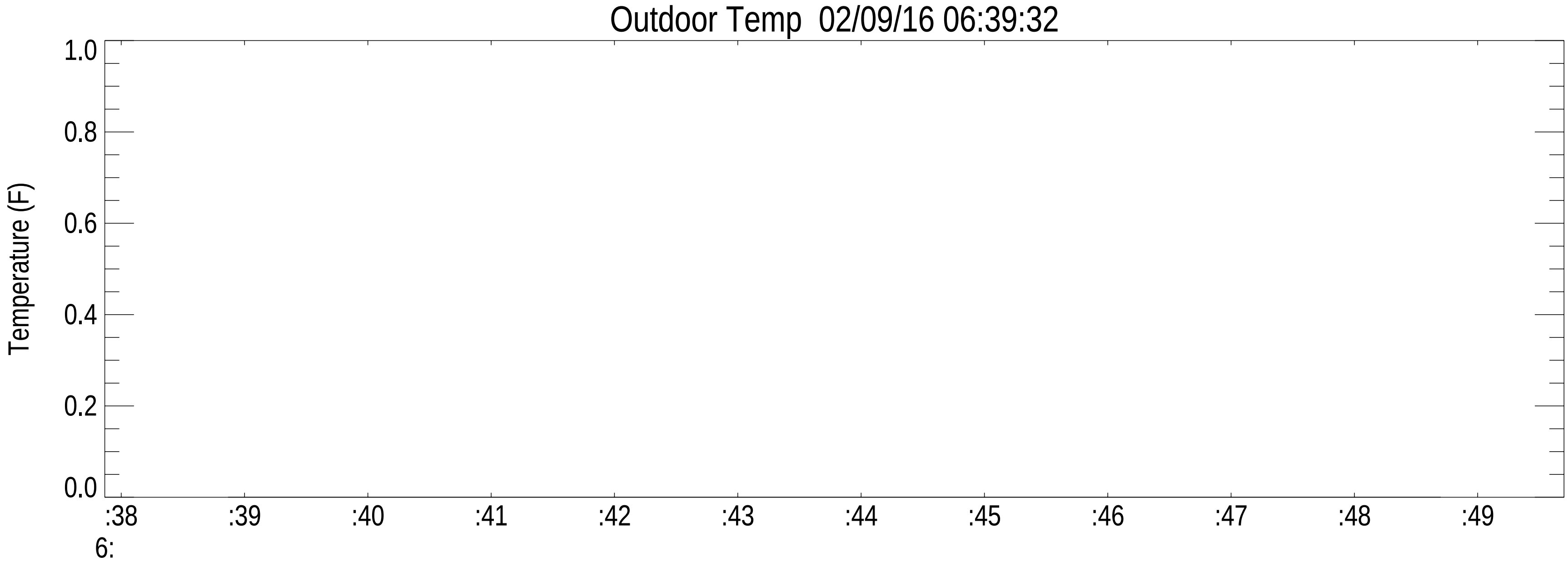

02/09/16 06:39:32
Power (W)
40
30
20
10
0
:38
:39
:40
:41
:42
:43
:44
:45
:46
:47
:48
:49
6:
Unit
Fan
Pump
Comp
Aux


02/09/16 06:39:32
Flow (gpm)
8
6
4
2
0
:38
:39
:40
:41
:42
:43
:44
:45
:46
:47
:48
:49
6:

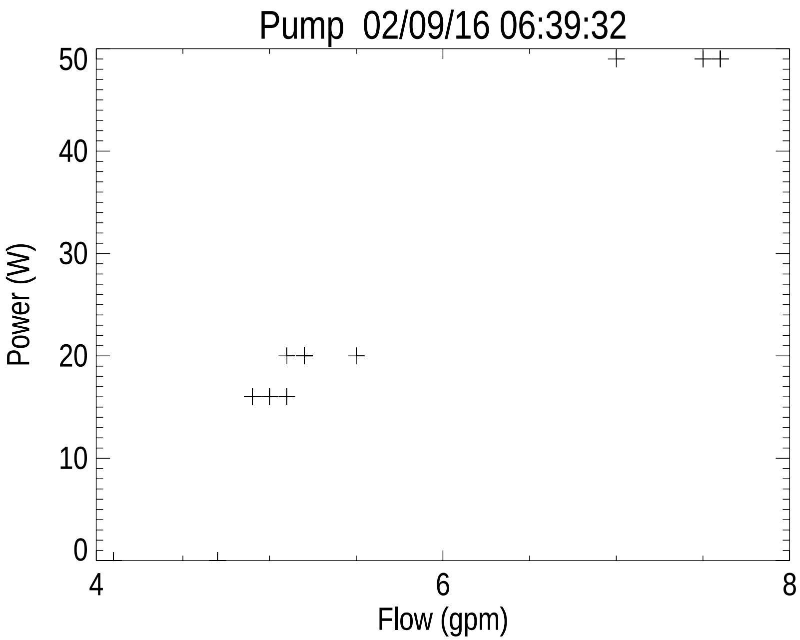

02/09/16 06:39:32
Heat (MBtu/h)
10
5
0
-5
-10
:38
:39
:40
:41
:42
:43
:44
:45
:46
:47
:48
:49
6:
Q-WF
Q-CDH

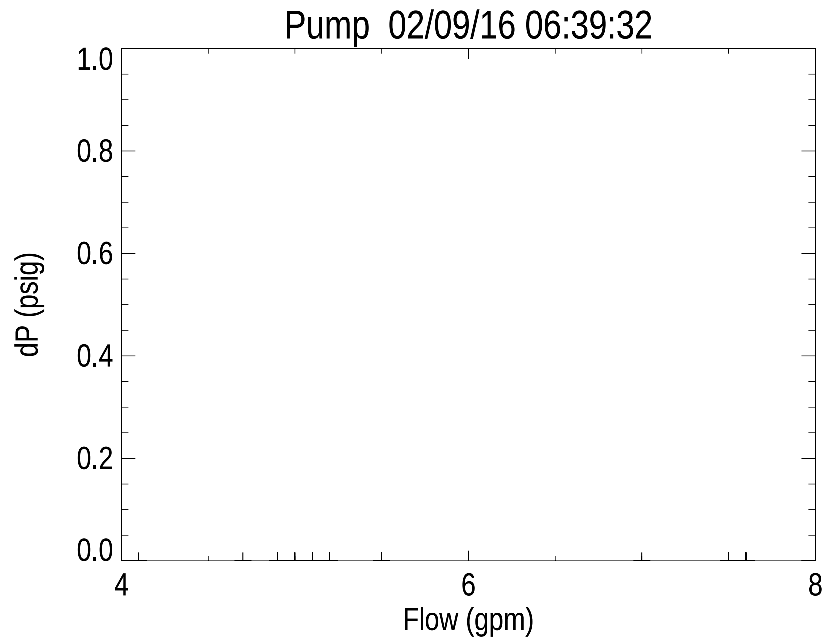


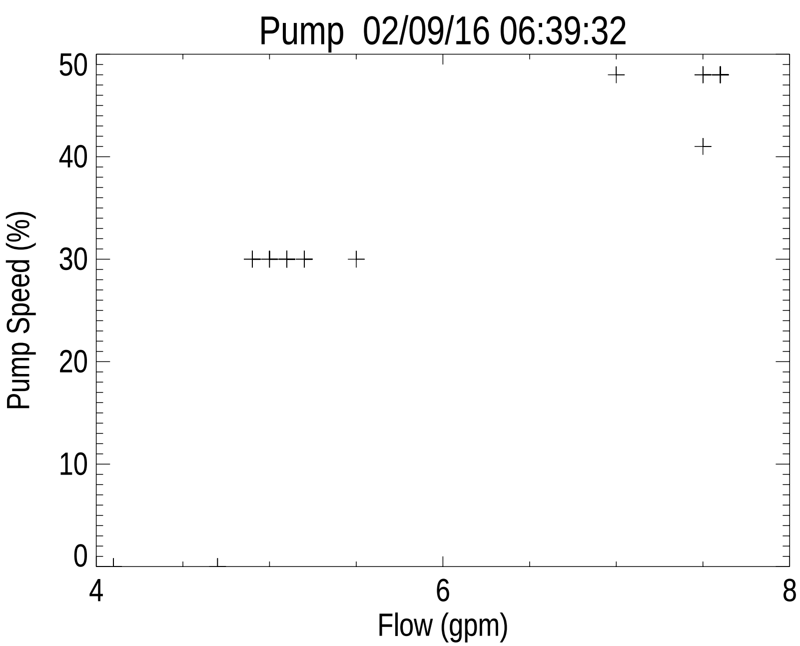
Air Temps 02/09/16 06:39:32
Temperature (F)
76
74
72
70
68
:38
:39
:40
:41
:42
:43
:44
:45
:46
:47
:48
:49
6:
EAT
LAT

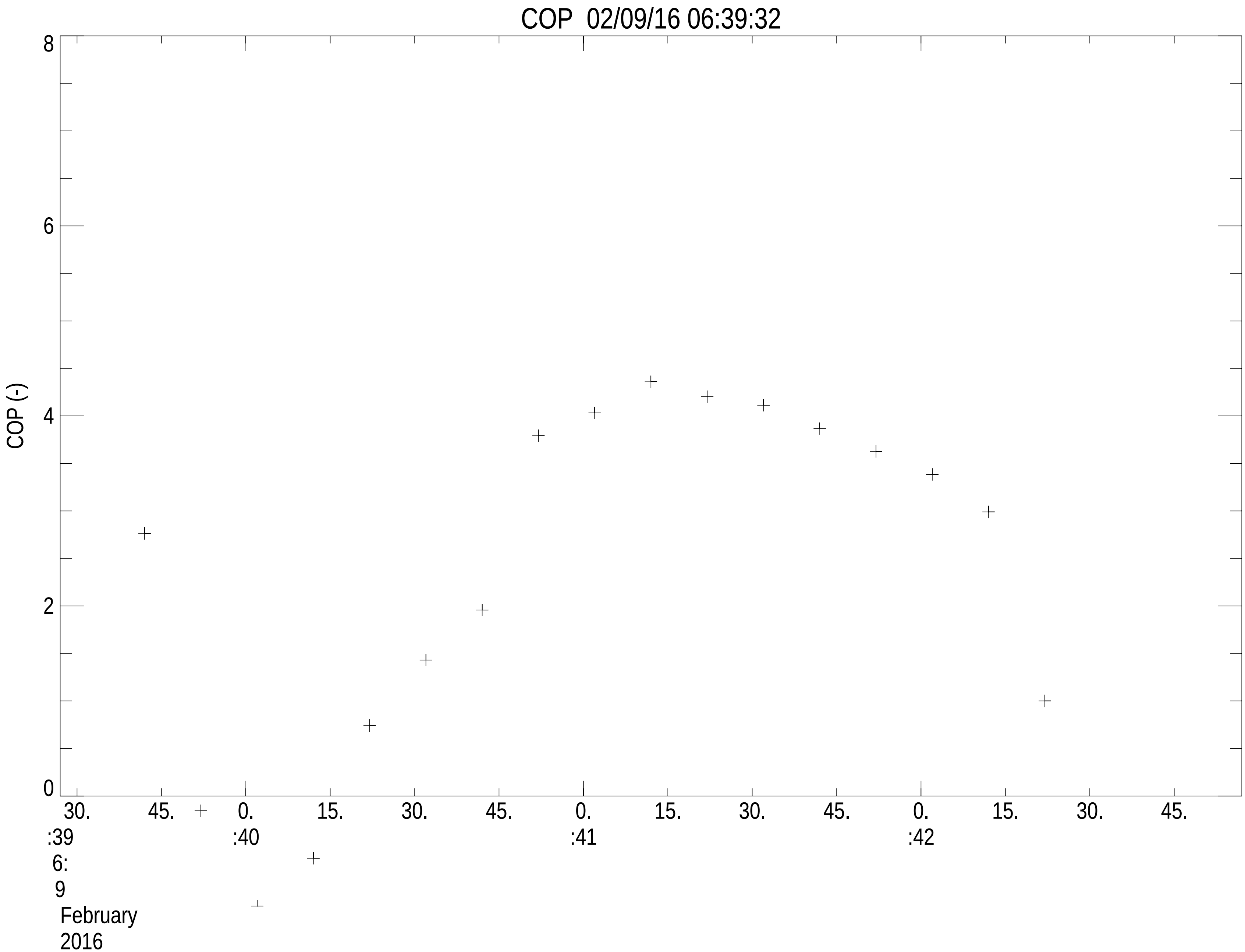


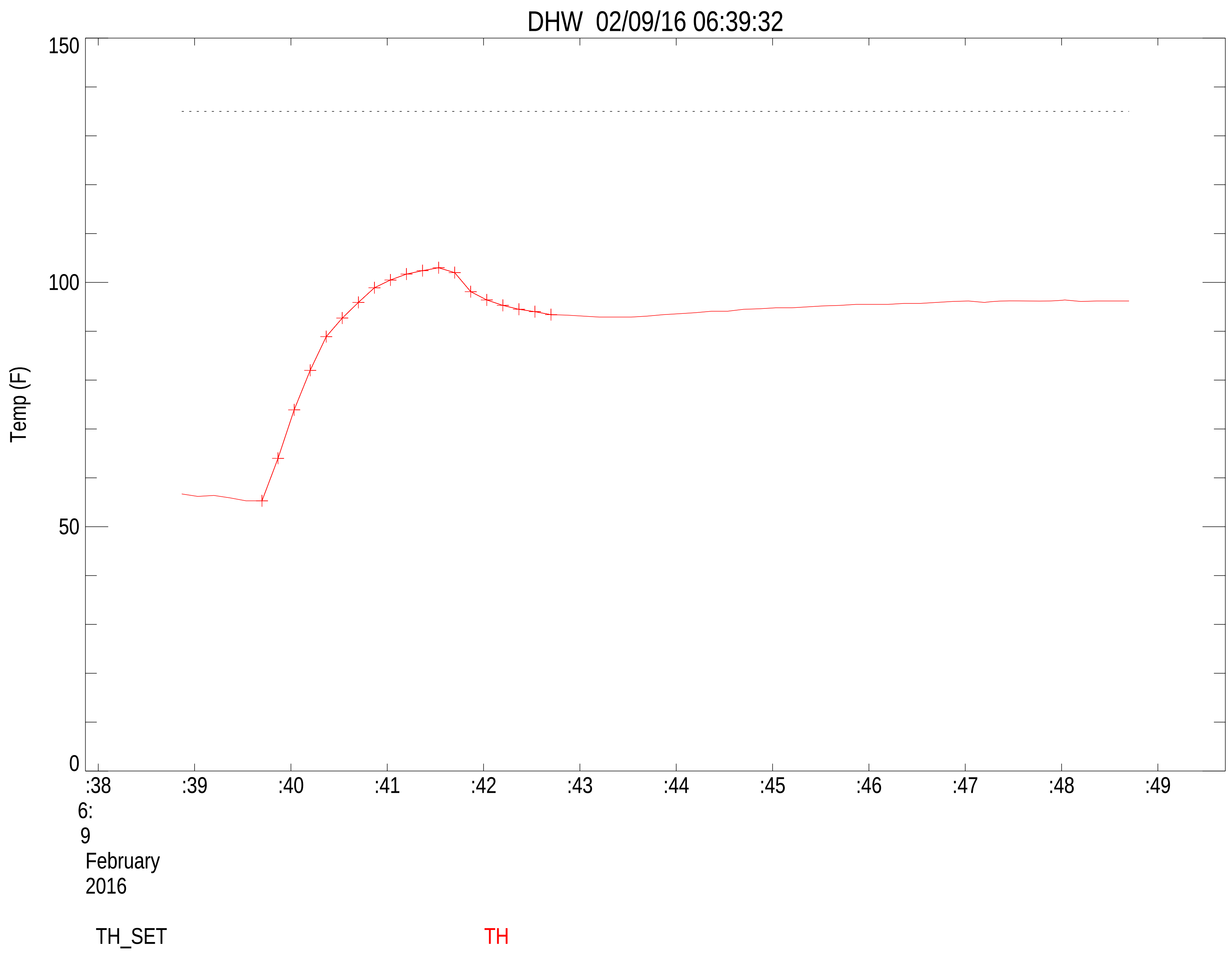
Outdoor Temp 02/09/16 06:39:32
Temperature (F)
1.0
0.8
0.6
0.4
0.2
0.0
:38
:39
:40
:41
:42
:43
:44
:45
:46
:47
:48
:49
6:

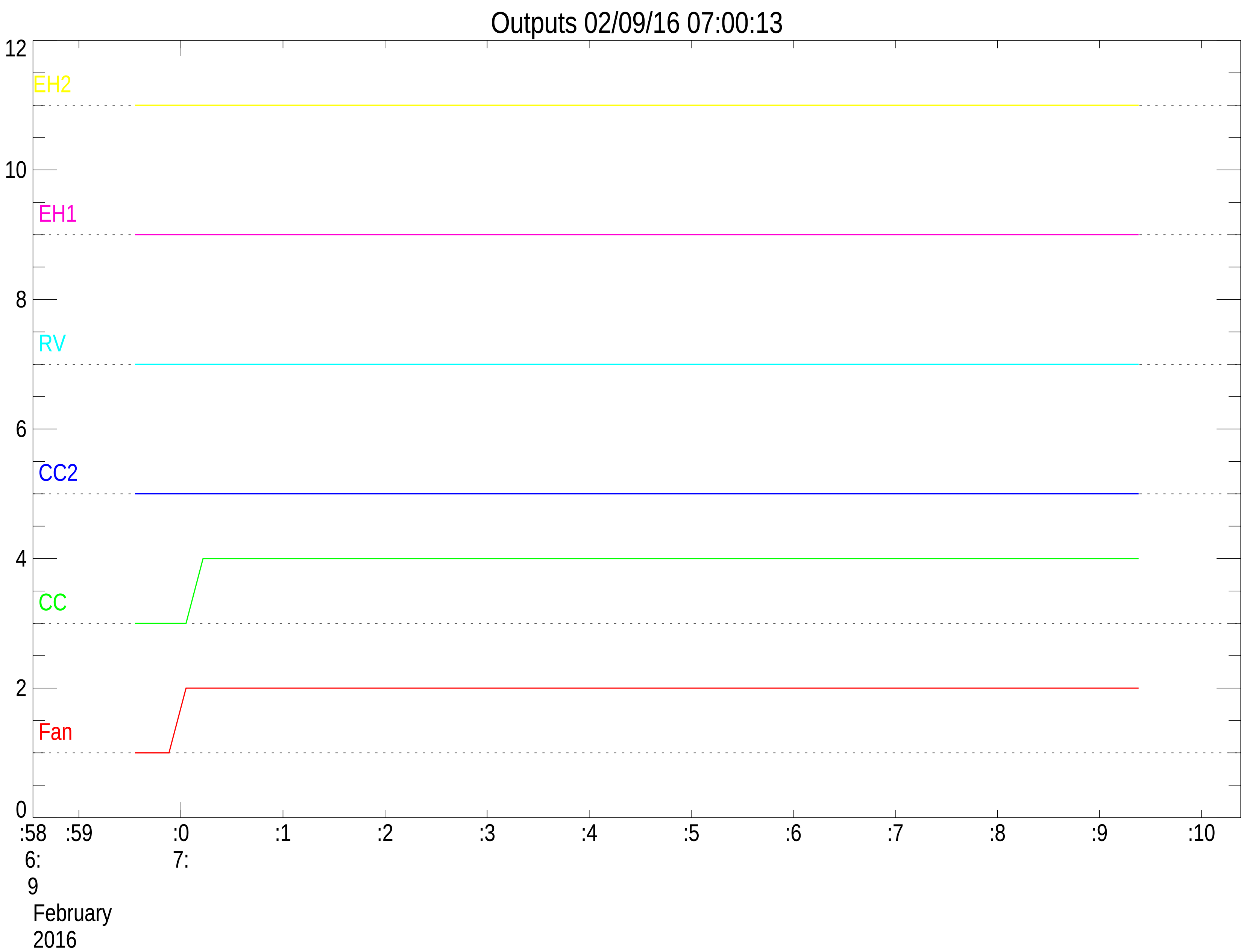

Pump 02/09/16 06:39:32
Power (W)
0
10
20
30
40
50
4
6
8
Flow (gpm)

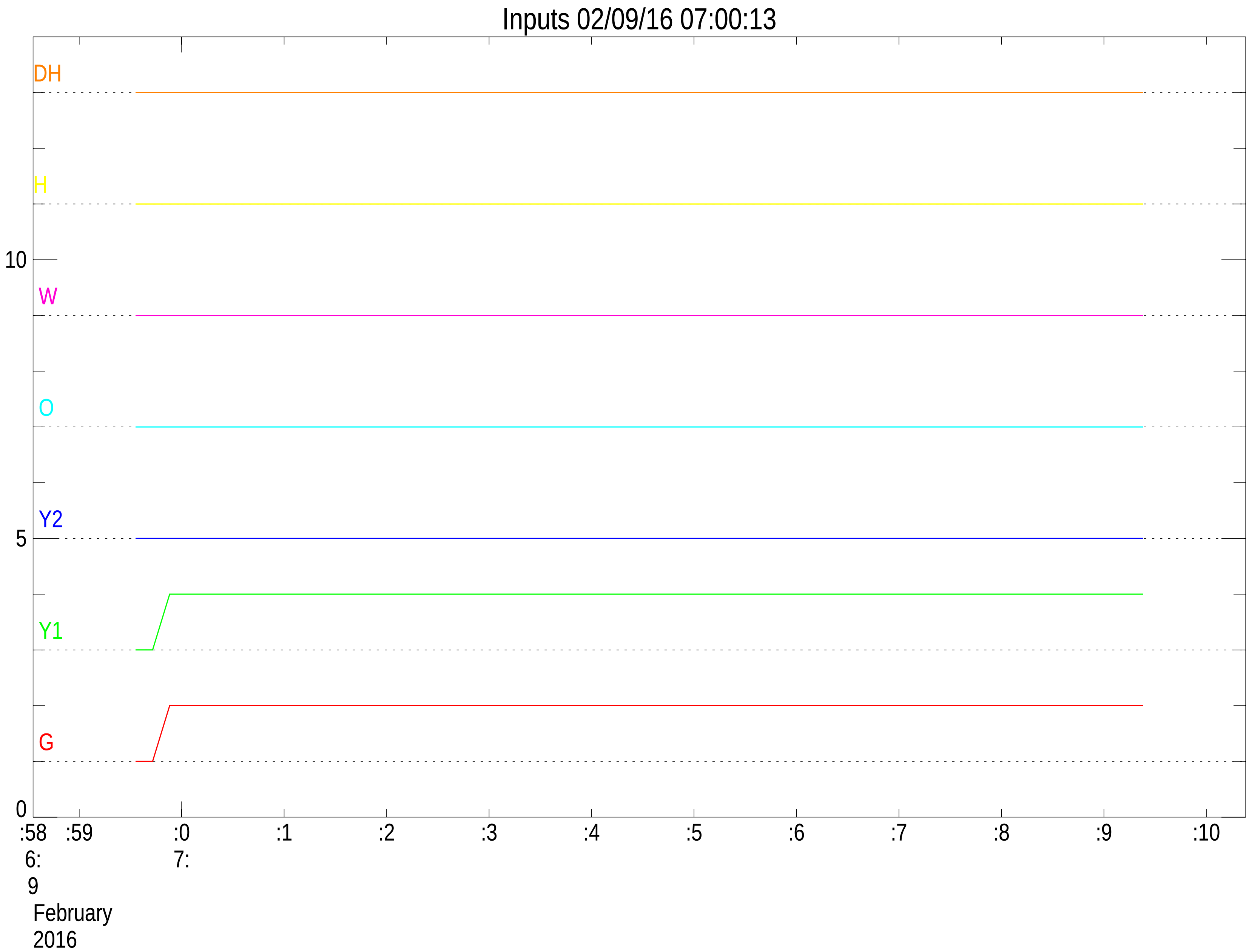

Pump 02/09/16 06:39:32
dP (psig)
0.0
0.2
0.4
0.6
0.8
1.0
4
6
8
Flow (gpm)

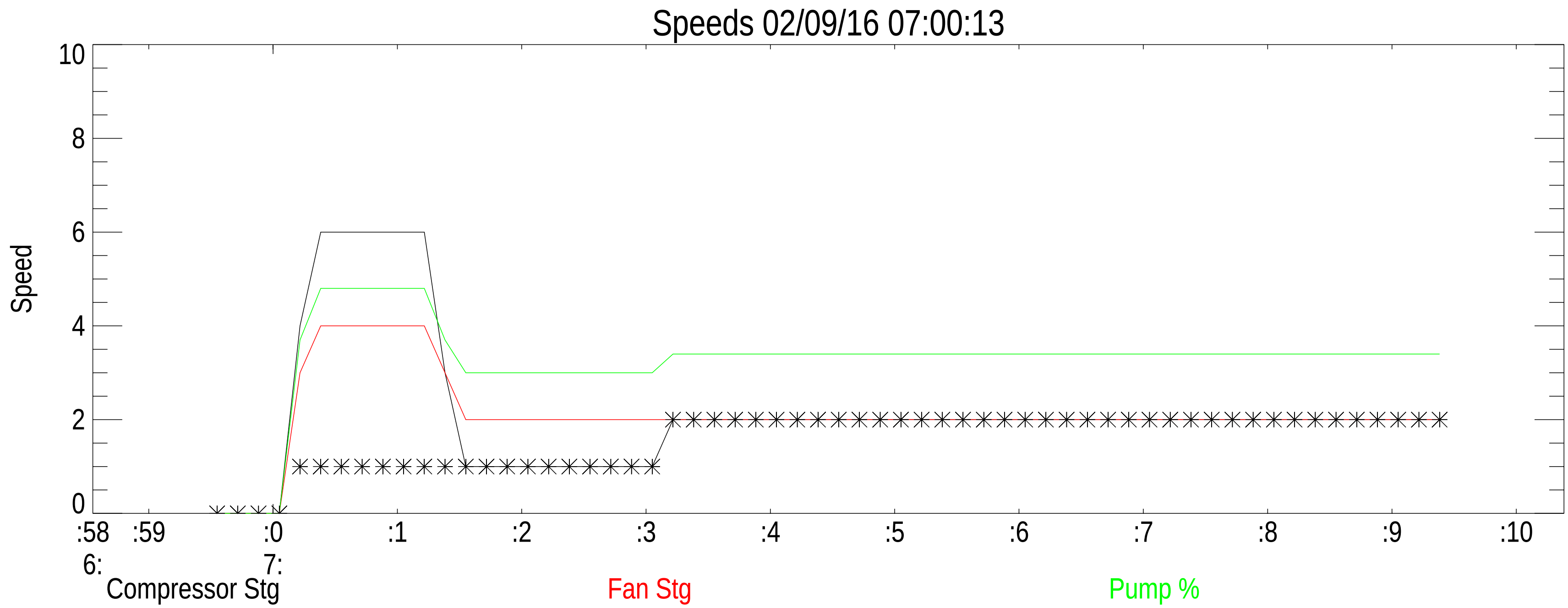

Pump 02/09/16 06:39:32
Pump Speed (%)
0
10
20
30
40
50
4
6
8
Flow (gpm)

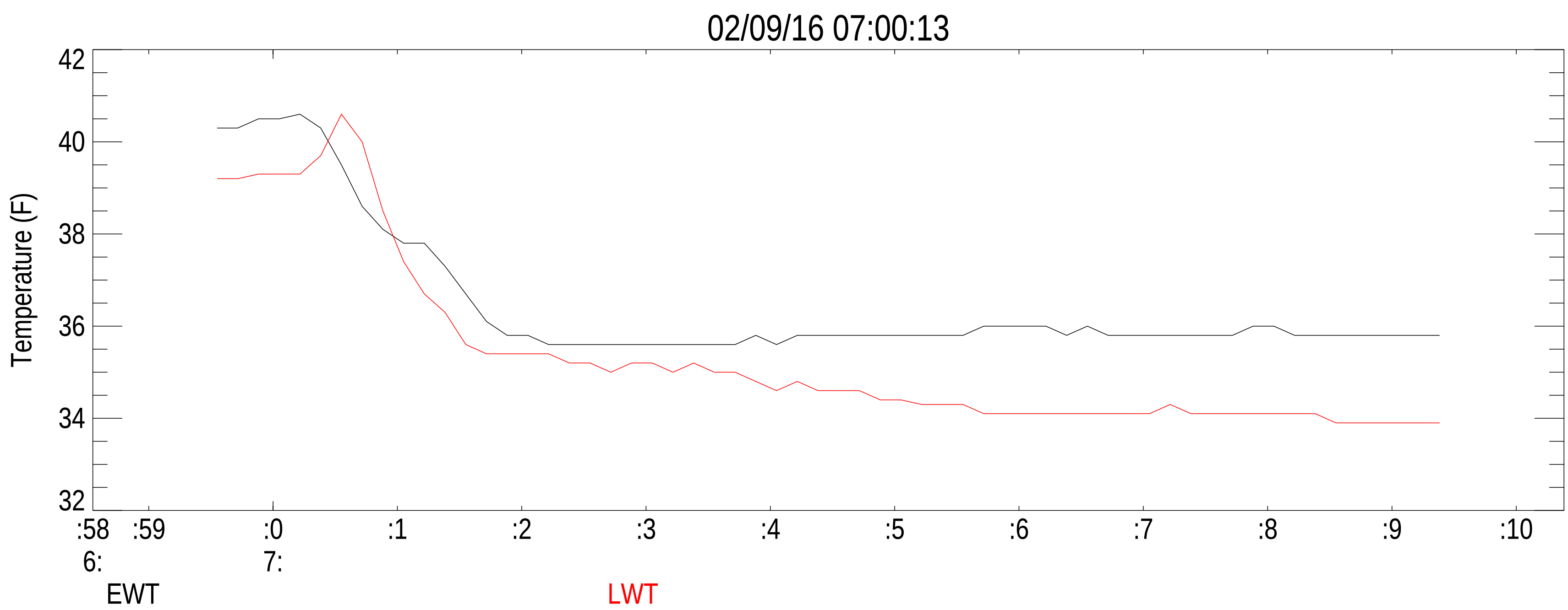

COP 02/09/16 06:39:32
COP (-)
0
2
4
6
8
30.
45.
0.
15.
30.
45.
0.
15.
30.
45.
0.
15.
30.
45.
:39
:40
:41
:42
6:
9
February
2016

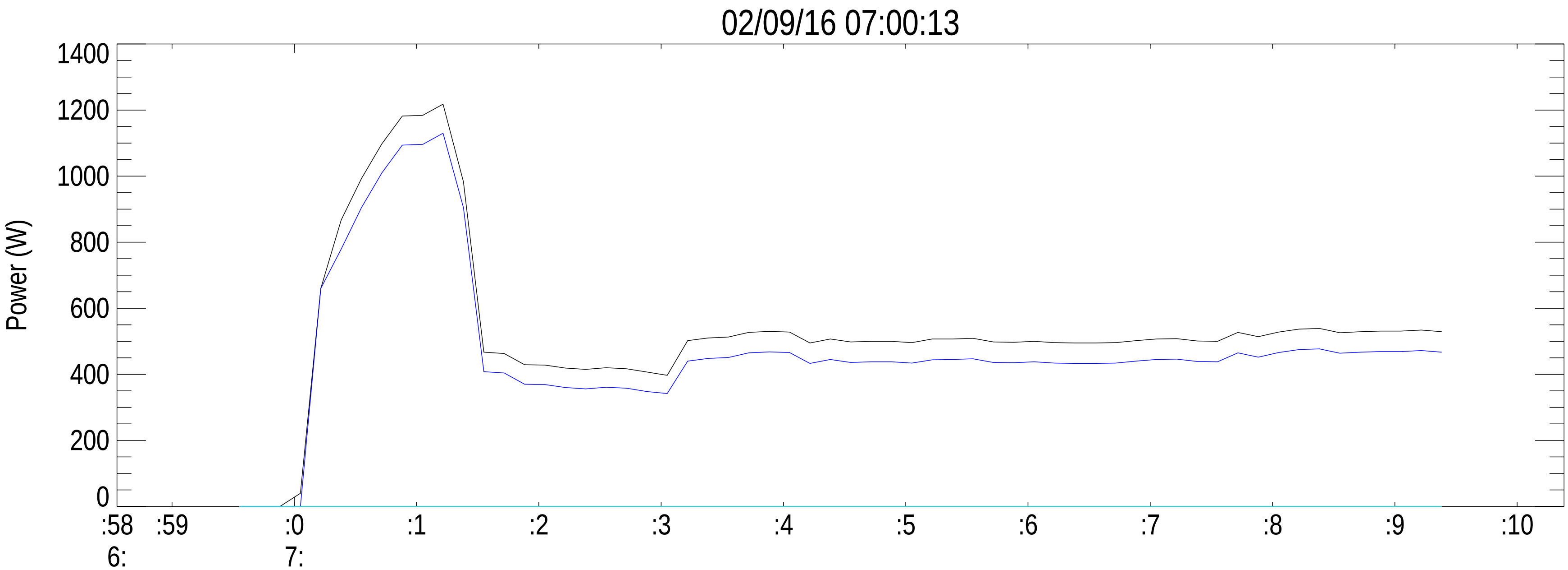

DHW 02/09/16 06:39:32
150
100
50
0
Temp (F)
:38
:39
:40
:41
:42
:43
:44
:45
:46
:47
:48
:49
6:
9
February
2016
TH_SET
TH

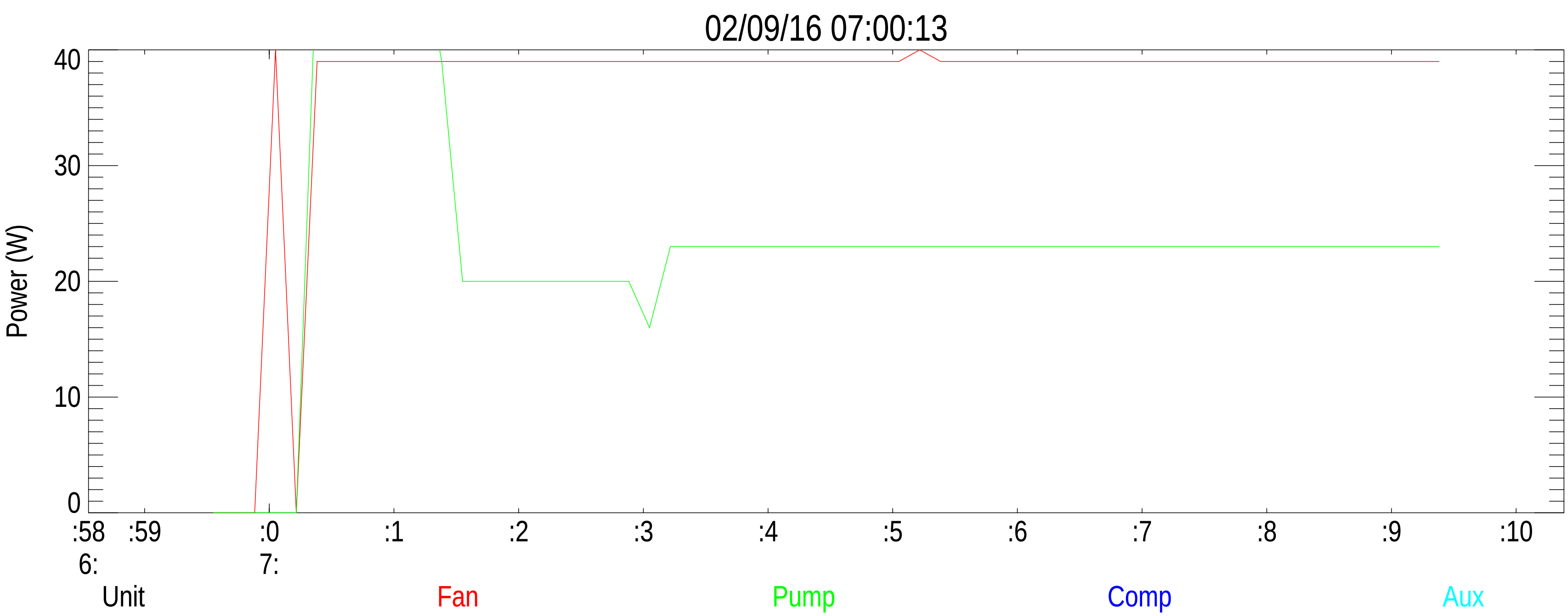

Outputs 02/09/16 07:00:13
12
10
8
6
4
2
0
EH2
EH1
RV
CC2
CC
Fan
:58
:59
:0
:1
:2
:3
:4
:5
:6
:7
:8
:9
:10
6:
9
February
2016
7:

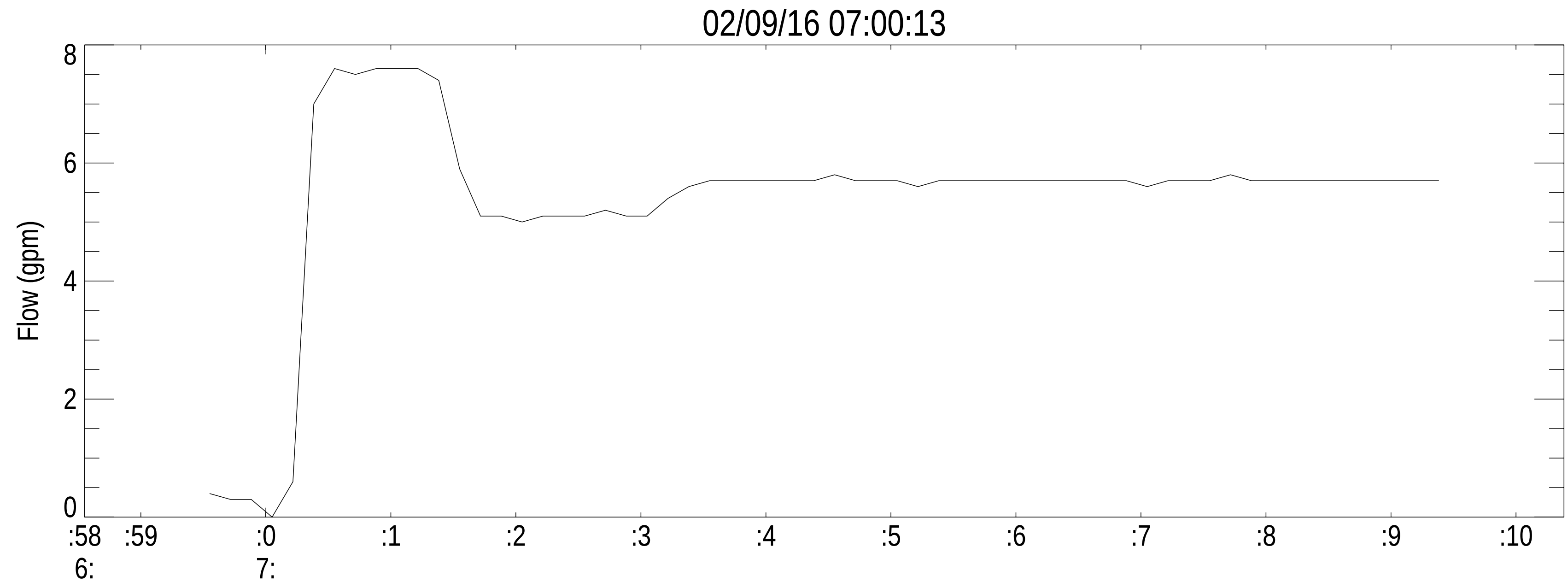

Inputs 02/09/16 07:00:13
DH
H
W
O
Y2
Y1
G
10
5
0
:58
:59
:0
:1
:2
:3
:4
:5
:6
:7
:8
:9
:10
6:
9
February
2016
7:

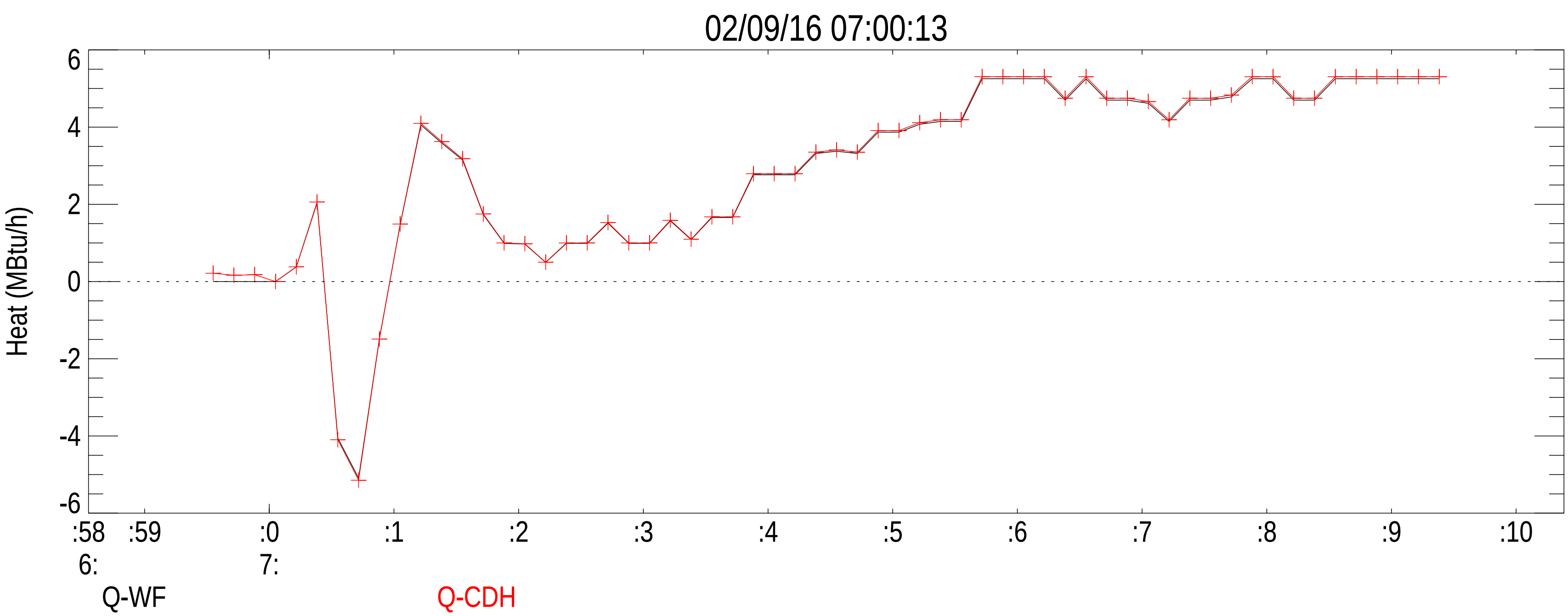

Speeds 02/09/16 07:00:13
Speed
0
2
4
6
8
10
:58
6:
:59
:0
7:
:1
:2
:3
:4
:5
:6
:7
:8
:9
:10
Compressor Stg
Fan Stg
Pump %

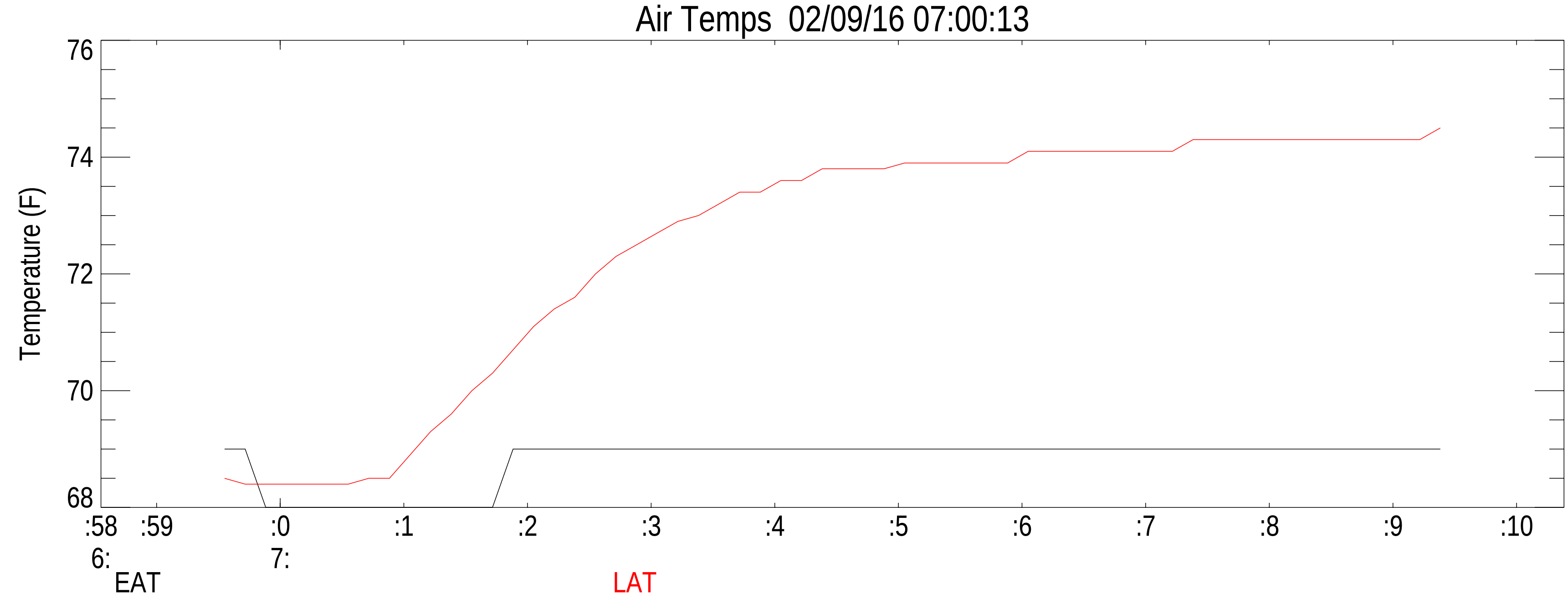

02/09/16 07:00:13
Temperature (F)
32
34
36
38
40
42
:58
6:
:59
:0
7:
:1
:2
:3
:4
:5
:6
:7
:8
:9
:10
EWT
LWT

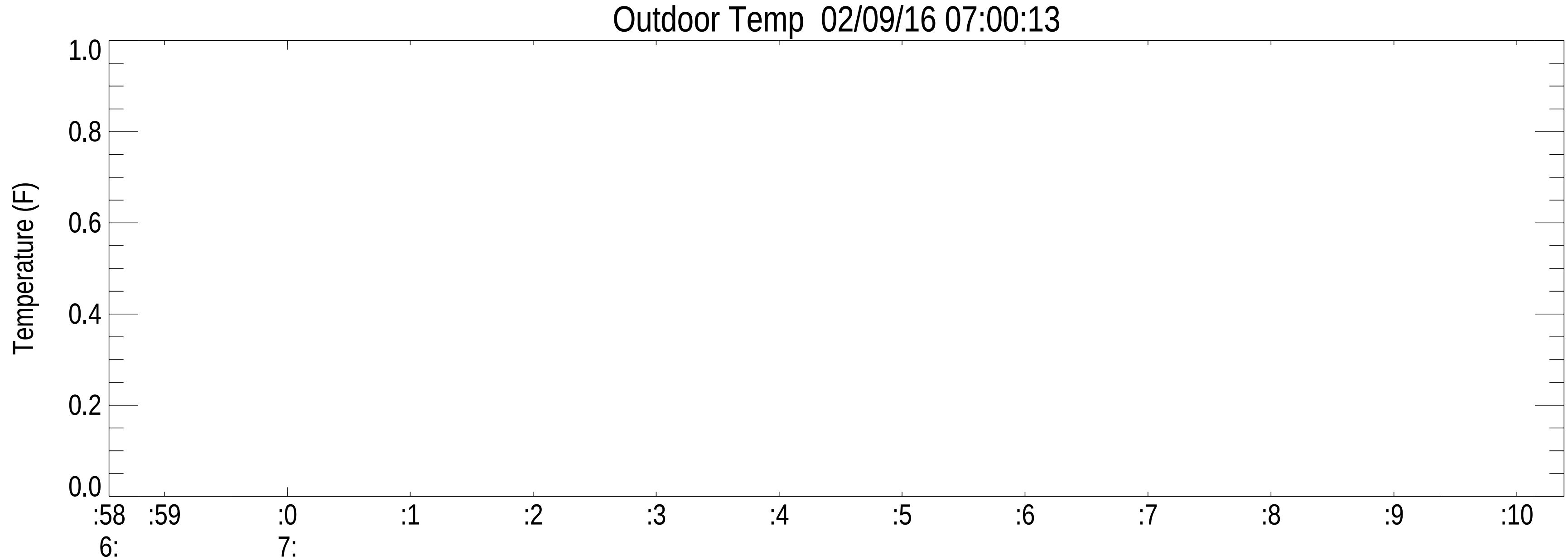

02/09/16 07:00:13
Power (W)
1400
1200
1000
800
600
400
200
0
:58
6:
:59
:0
7:
:1
:2
:3
:4
:5
:6
:7
:8
:9
:10

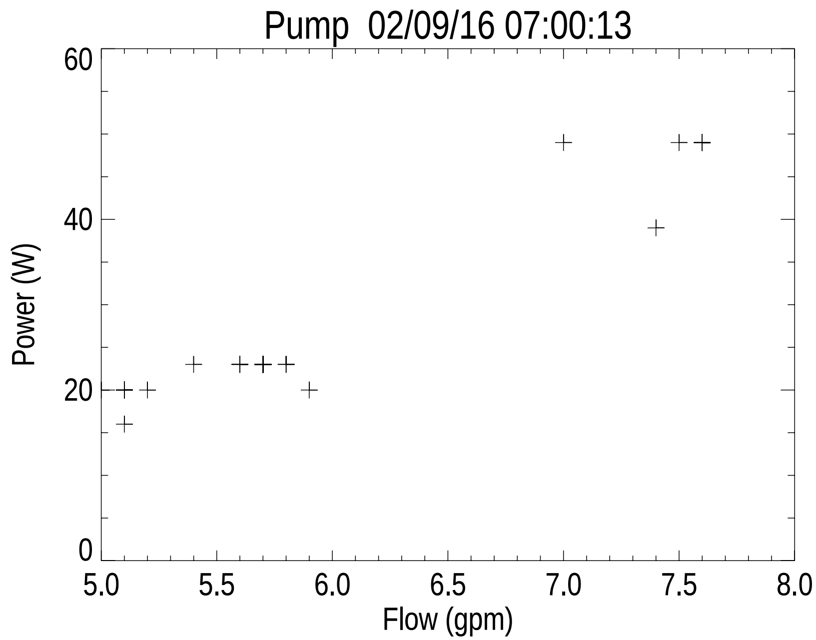

02/09/16 07:00:13
Power (W)
40
30
20
10
0
:58
6:
:59
:0
7:
:1
:2
:3
:4
:5
:6
:7
:8
:9
:10
Unit
Fan
Pump
Comp
Aux

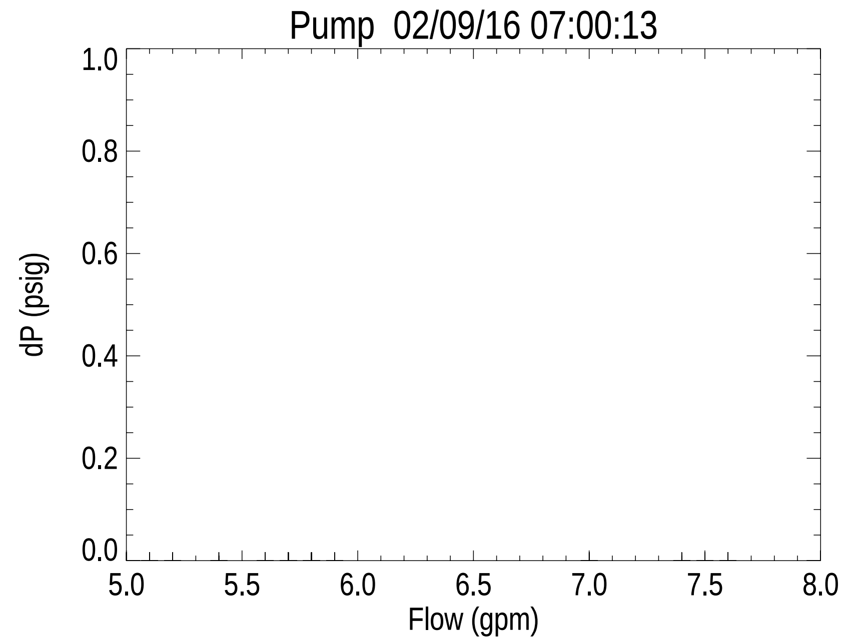

02/09/16 07:00:13
Flow (gpm)
8
6
4
2
0
:58
6:
:59
:0
7:
:1
:2
:3
:4
:5
:6
:7
:8
:9
:10

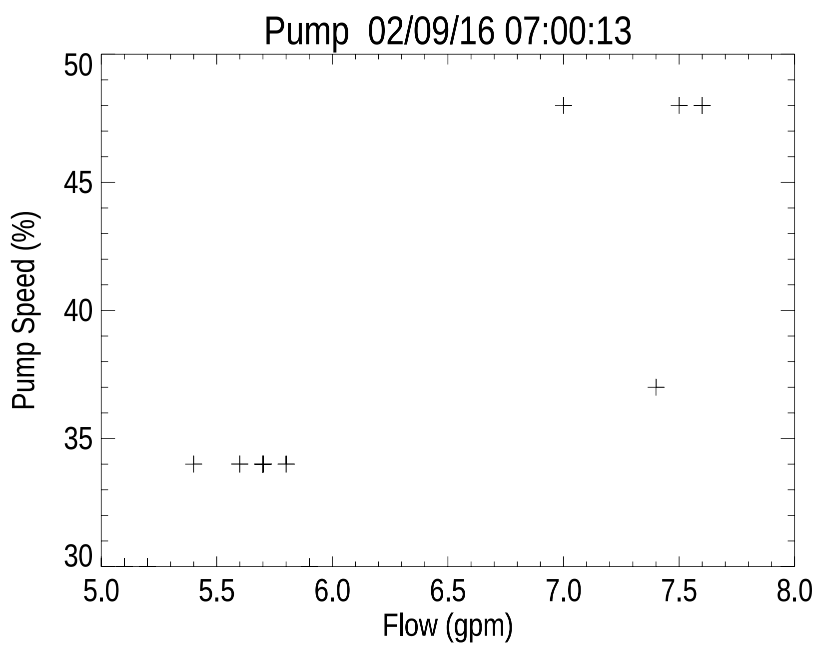

02/09/16 07:00:13
Heat (MBtu/h)
6
4
2
0
-2
-4
-6
:58
6:
:59
:0
7:
:1
:2
:3
:4
:5
:6
:7
:8
:9
:10
Q-WF
Q-CDH

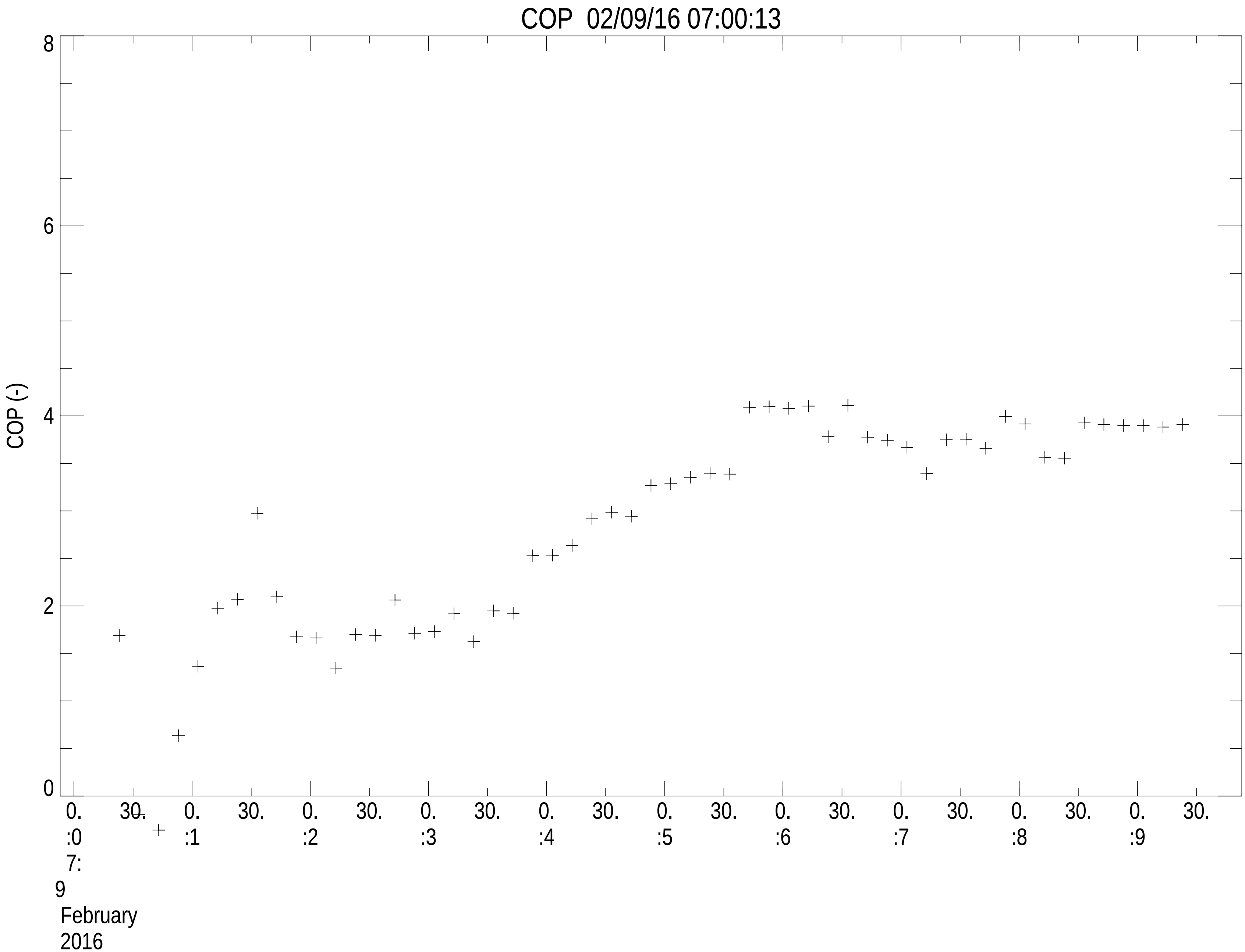

Air Temps 02/09/16 07:00:13
Temperature (F)
76
74
72
70
68
:58
6:
:59
:0
7:
:1
:2
:3
:4
:5
:6
:7
:8
:9
:10
EAT
LAT

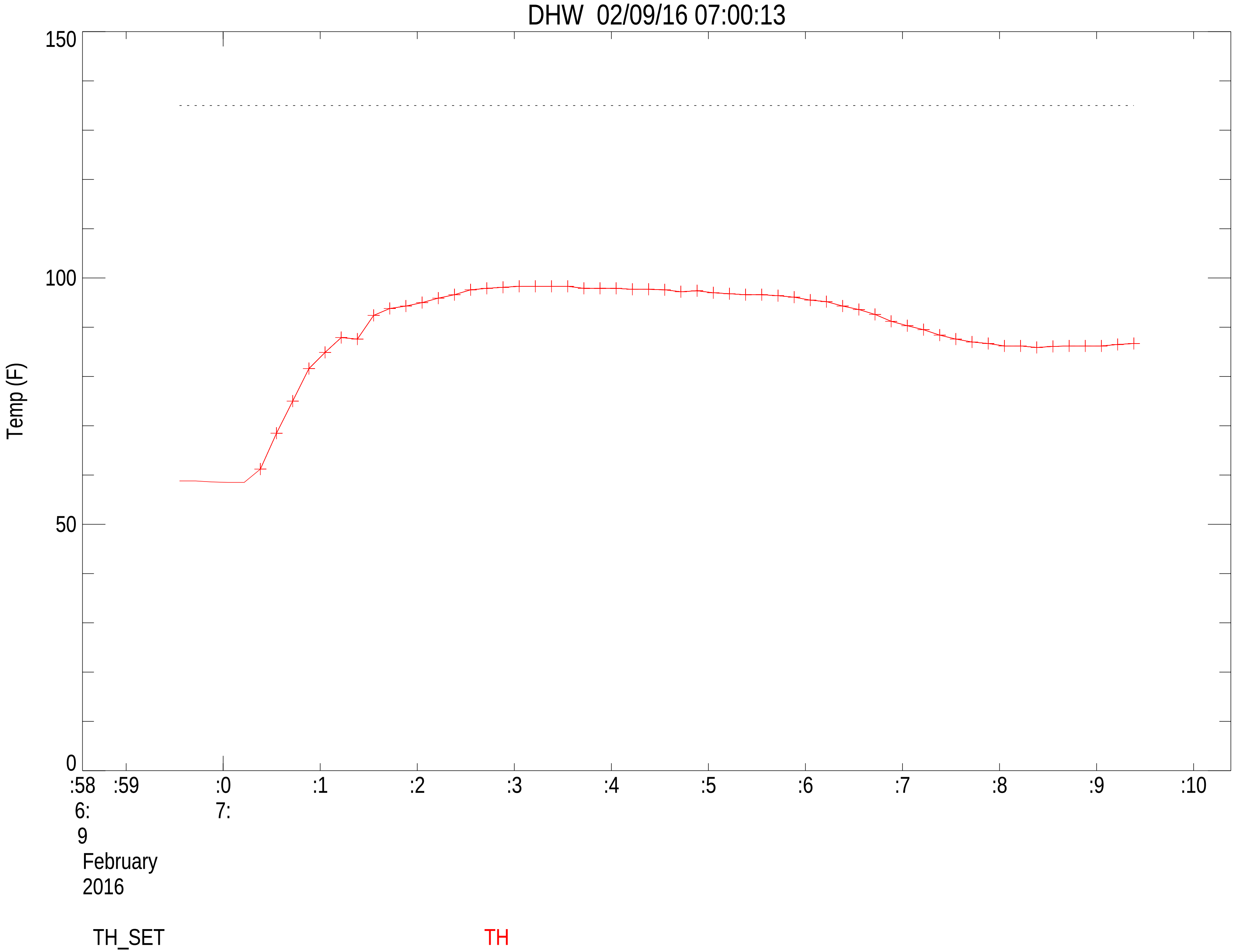

Outdoor Temp 02/09/16 07:00:13
Temperature (F)
1.0
0.8
0.6
0.4
0.2
0.0
:58
6:
:59
:0
7:
:1
:2
:3
:4
:5
:6
:7
:8
:9
:10

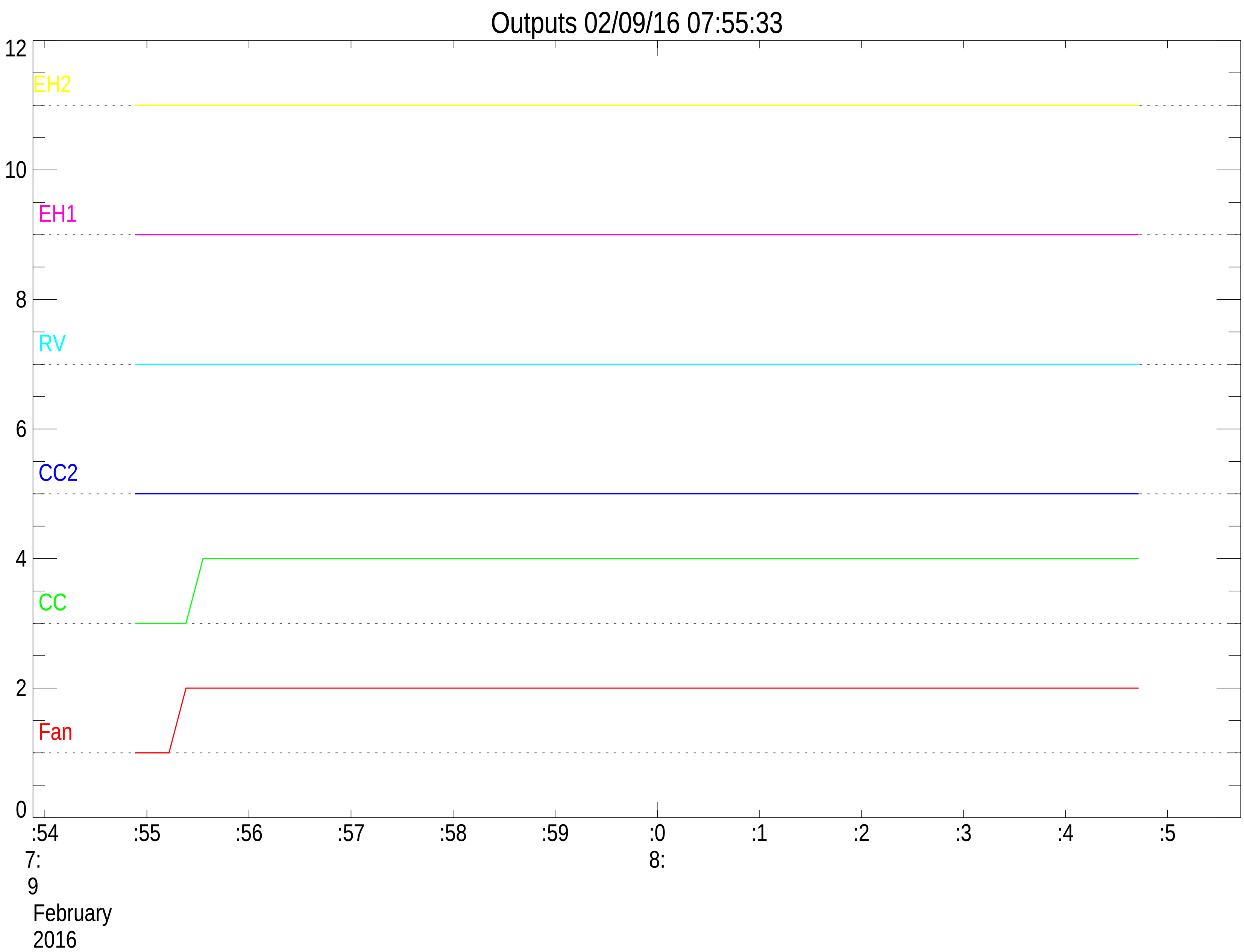

Pump 02/09/16 07:00:13
Power (W)
Flow (gpm)
0
20
40
60
5.0
5.5
6.0
6.5
7.0
7.5
8.0

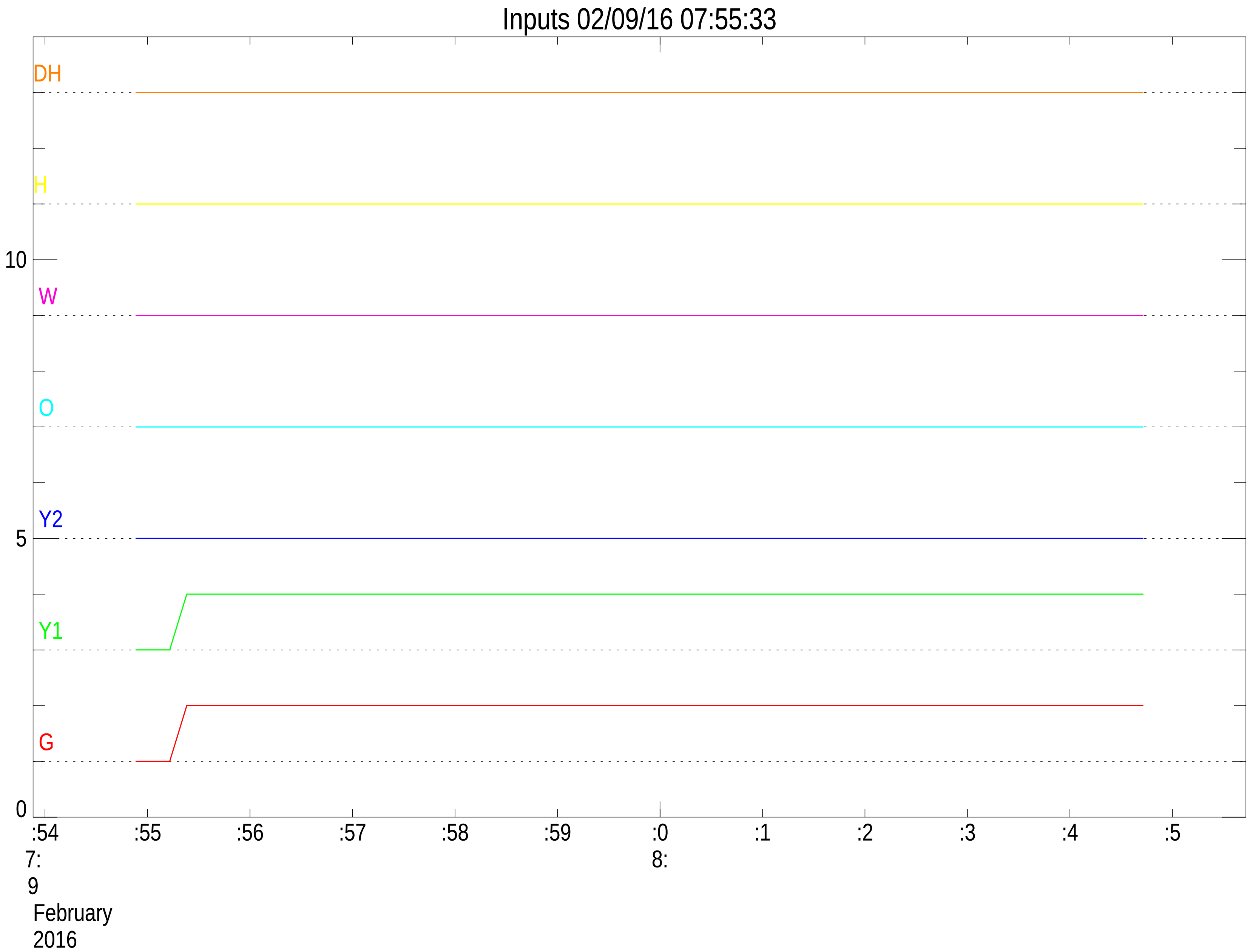

Pump 02/09/16 07:00:13
dP (psig)
Flow (gpm)
0.0
0.2
0.4
0.6
0.8
1.0
5.0
5.5
6.0
6.5
7.0
7.5
8.0

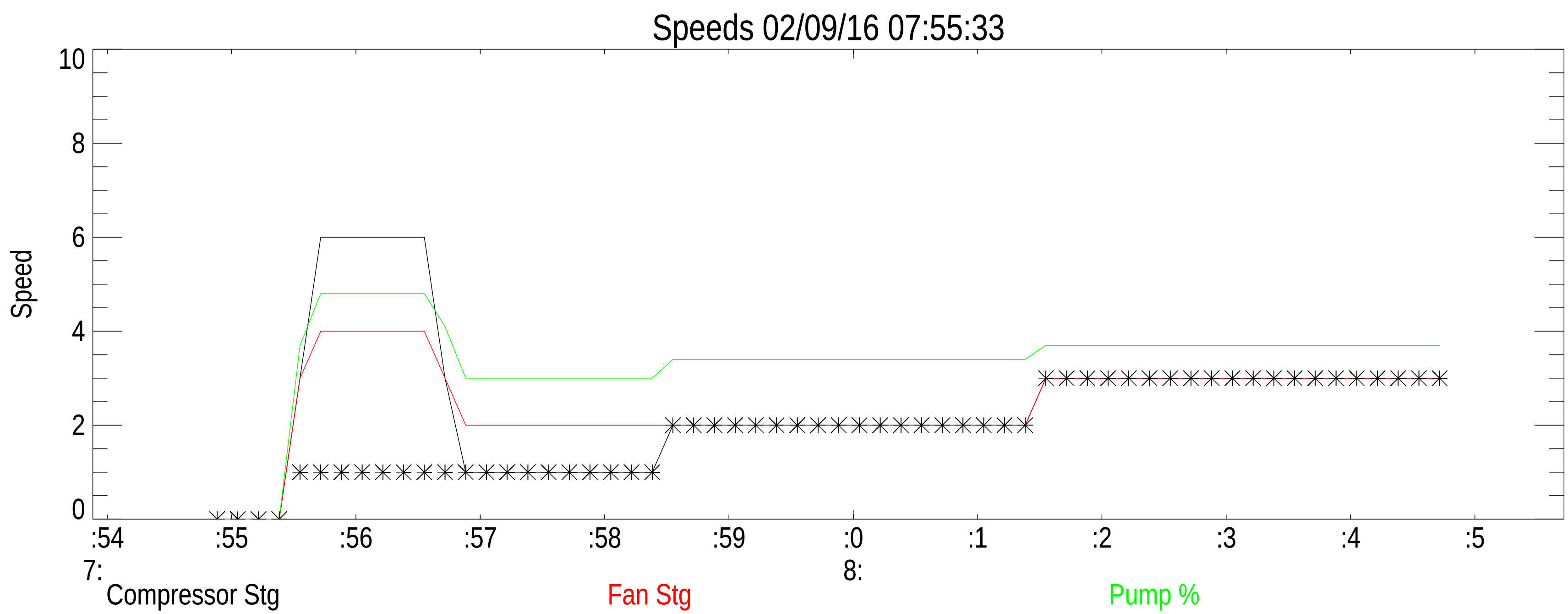

Pump 02/09/16 07:00:13
Pump Speed (%)
Flow (gpm)
30
35
40
45
50
5.0
5.5
6.0
6.5
7.0
7.5
8.0

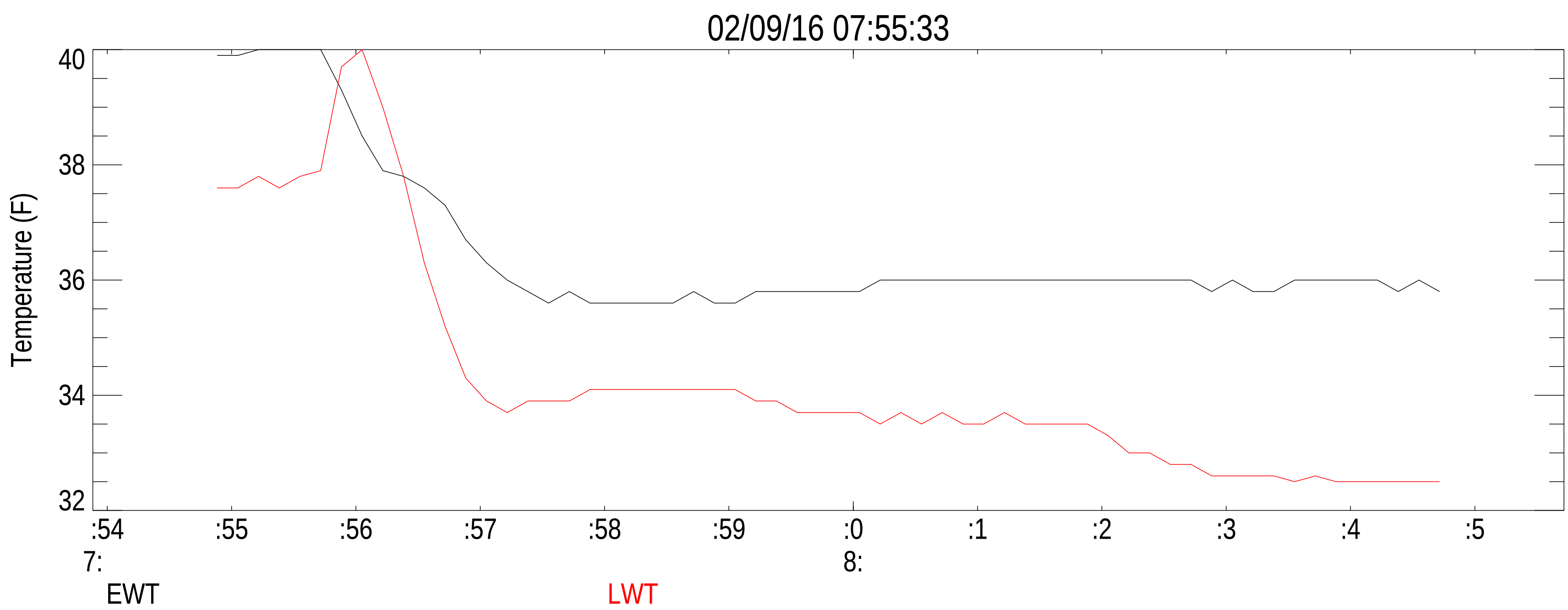

COP 02/09/16 07:00:13
COP (-)
0
2
4
6
8
0.
:0
7:
9
February
2016
30.
:1
:2
:3
:4
:5
:6
:7
:8
:9

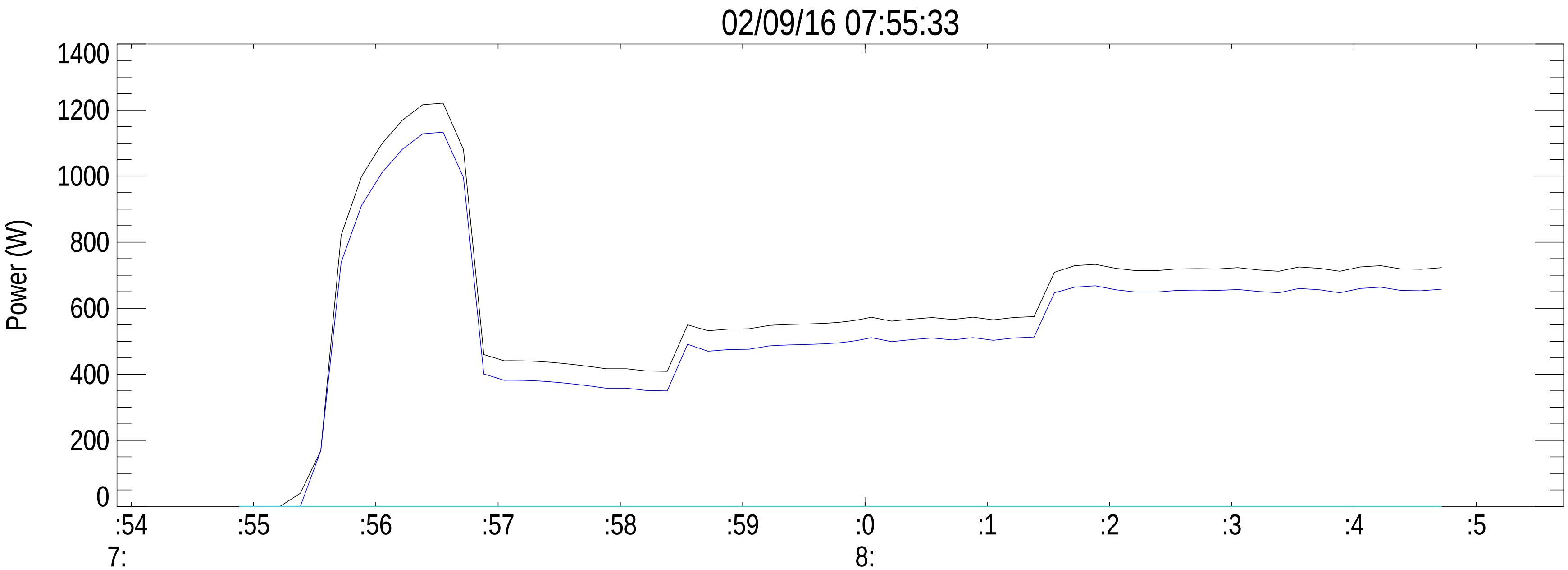

DHW 02/09/16 07:00:13
150
100
50
0
Temp (F)
:58
6:
9
February
2016
:59
:0
7:
:1
:2
:3
:4
:5
:6
:7
:8
:9
:10
TH_SET
TH


Outputs 02/09/16 07:55:33
12
10
8
6
4
2
0
EH2
EH1
RV
CC2
CC
Fan
:54
:55
:56
:57
:58
:59
:0
:1
:2
:3
:4
:5
7:
8:
9
February
2016

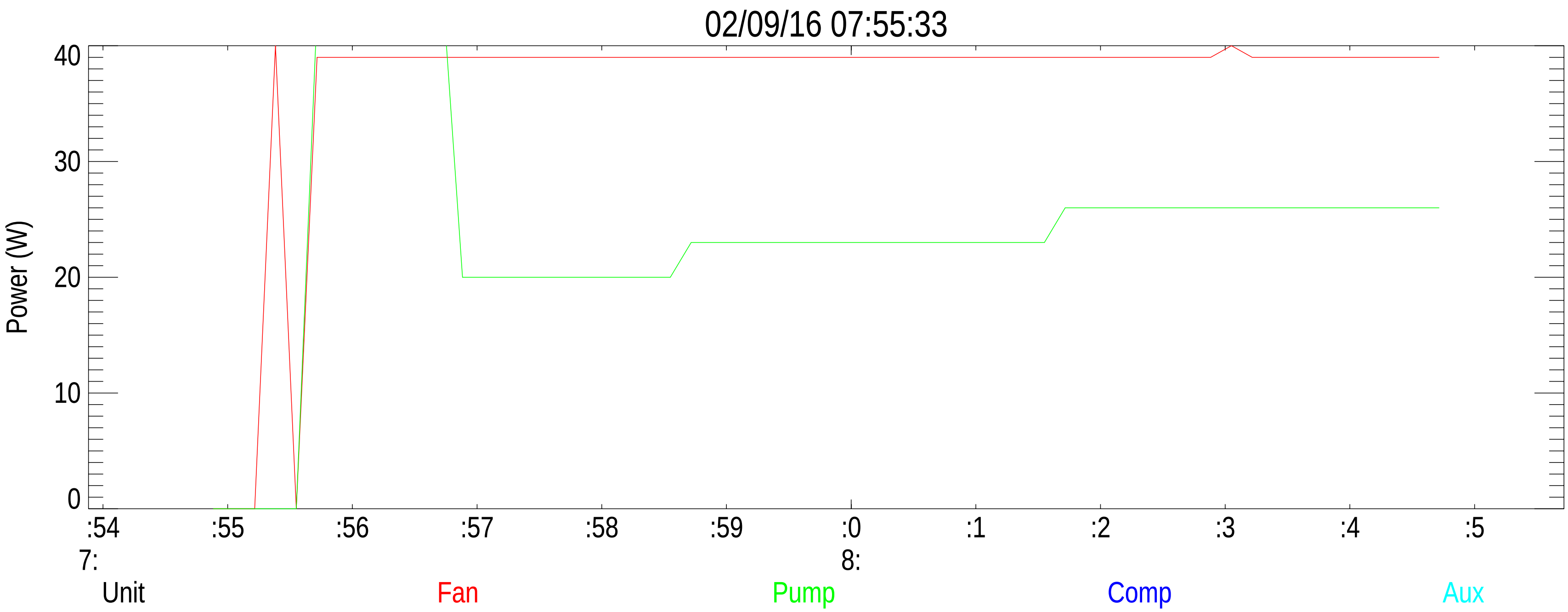

Inputs 02/09/16 07:55:33
DH
H
10
W
O
Y2
5
Y1
G
0
:54
:55
:56
:57
:58
:59
:0
:1
:2
:3
:4
:5
7:
8:
9
February
2016


Speeds 02/09/16 07:55:33
Speed
10
8
6
4
2
0
:54
:55
:56
:57
:58
:59
:0
:1
:2
:3
:4
:5
7:
8:
Compressor Stg
Fan Stg
Pump %

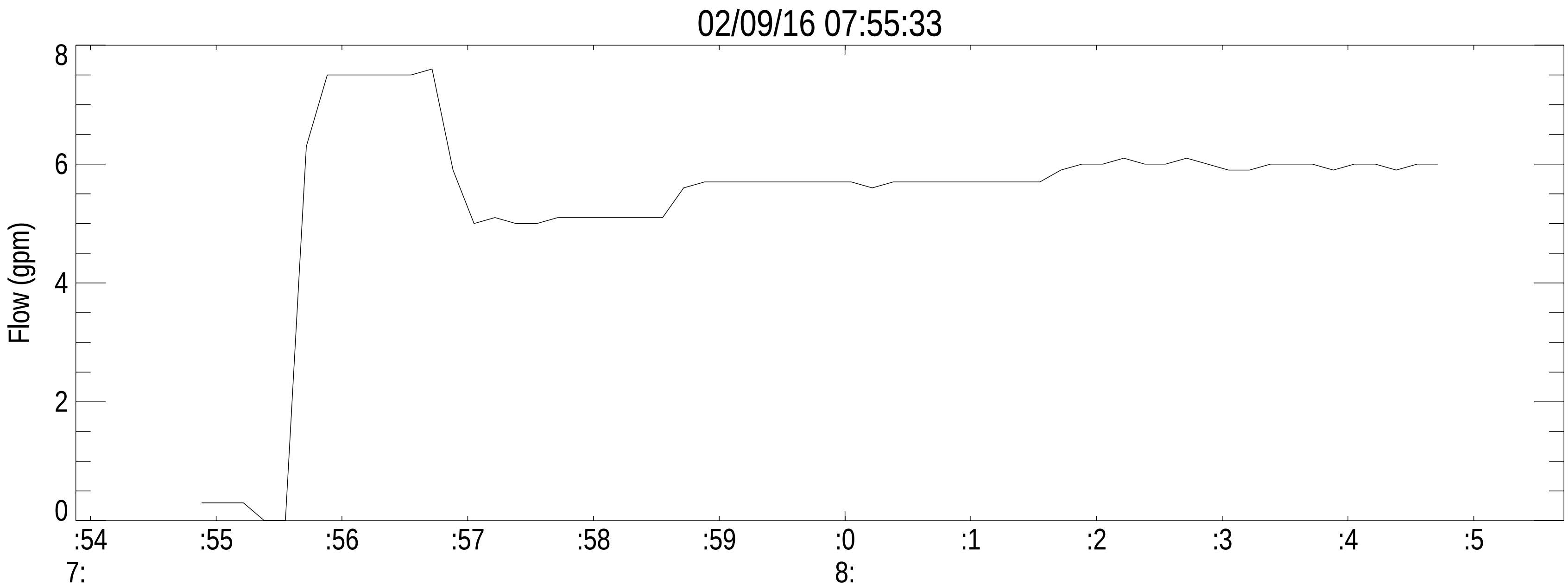

02/09/16 07:55:33
Temperature (F)
40
38
36
34
32
:54
:55
:56
:57
:58
:59
:0
:1
:2
:3
:4
:5
7:
8:
EWT
LWT

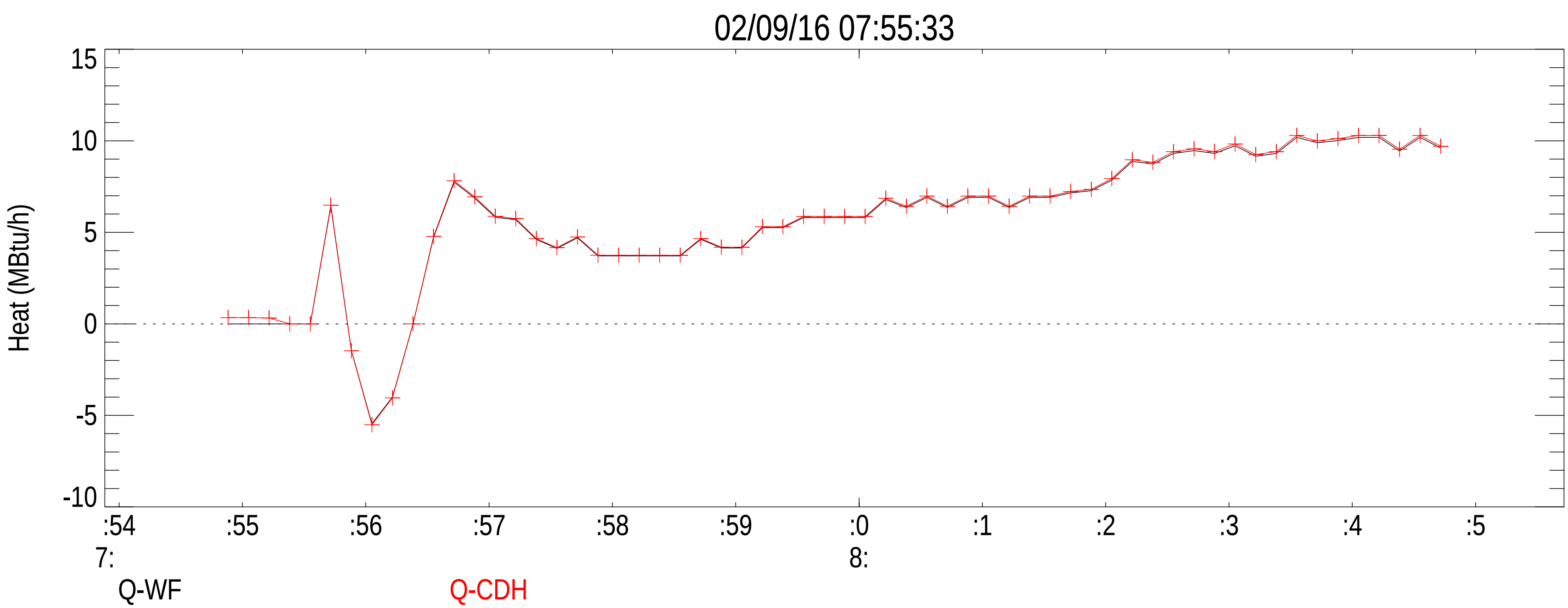


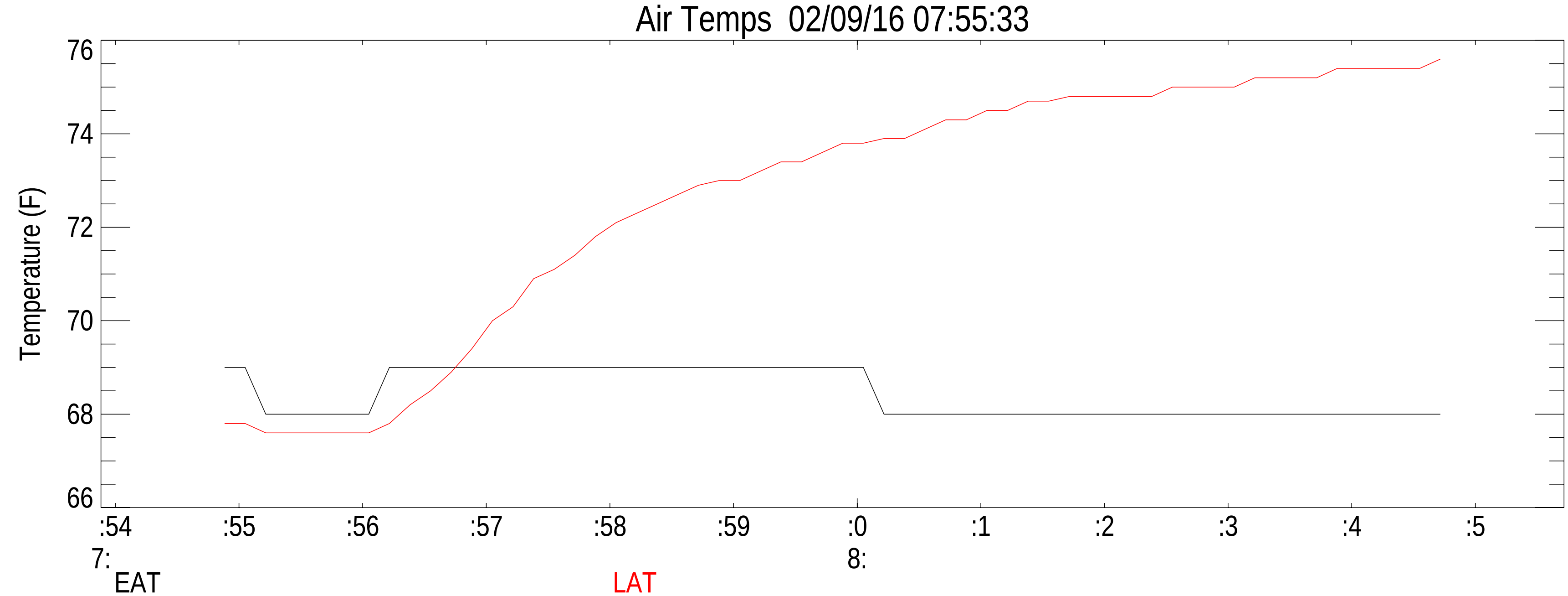
02/09/16 07:55:33
Power (W)
1400
1200
1000
800
600
400
200
0
:54
:55
:56
:57
:58
:59
:0
:1
:2
:3
:4
:5
7:
8:

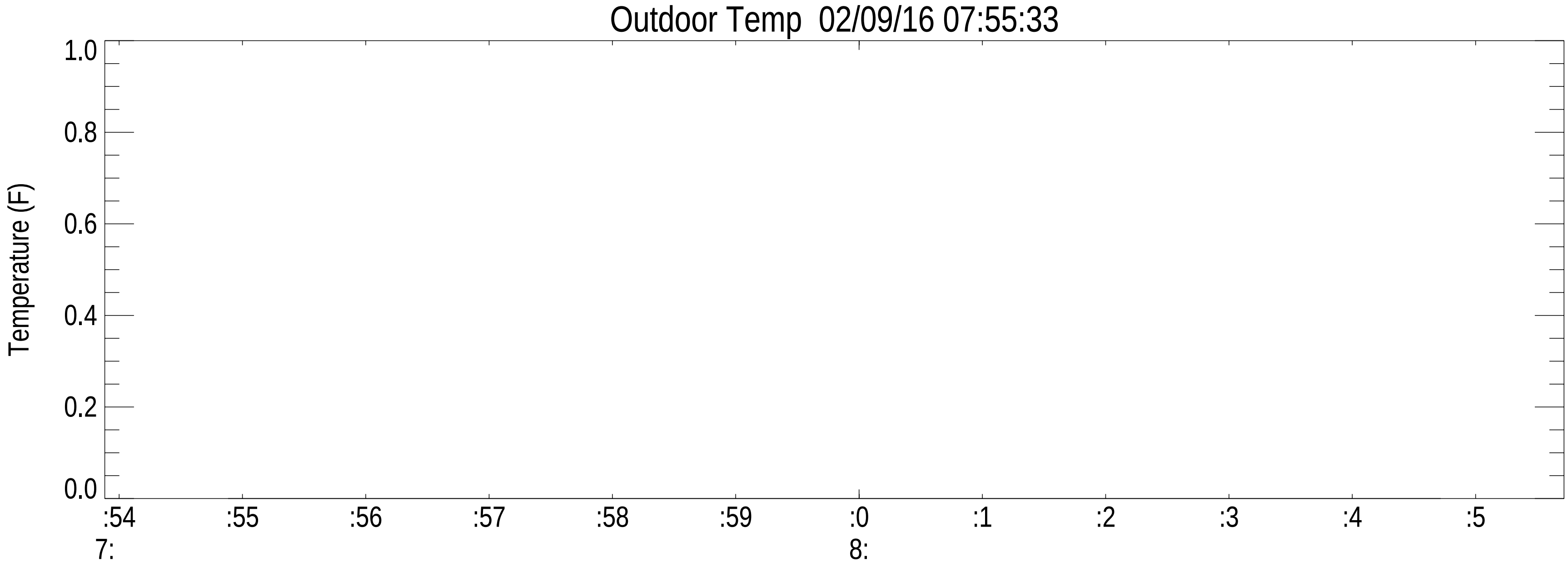


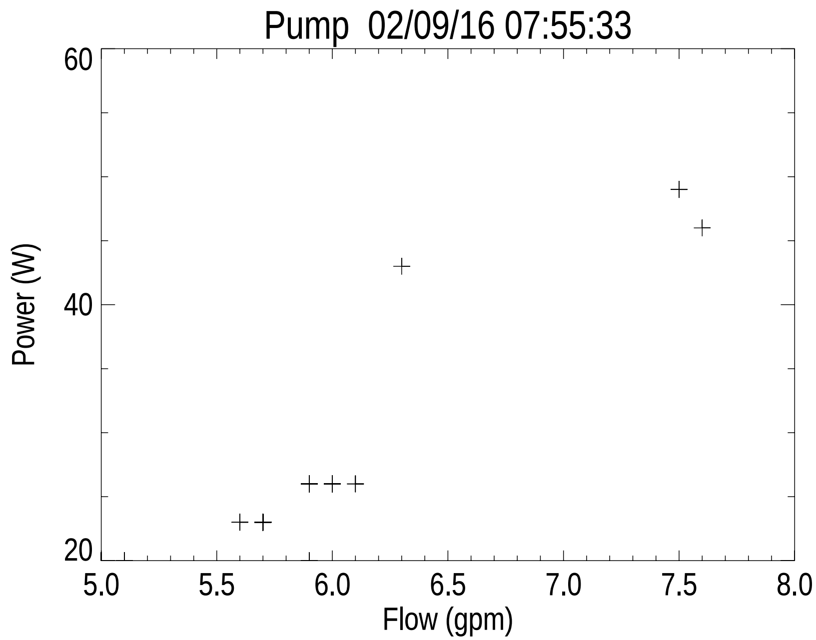
02/09/16 07:55:33
Power (W)
40
30
20
10
0
:54
:55
:56
:57
:58
:59
:0
:1
:2
:3
:4
:5
7:
8:
Unit
Fan
Pump
Comp
Aux

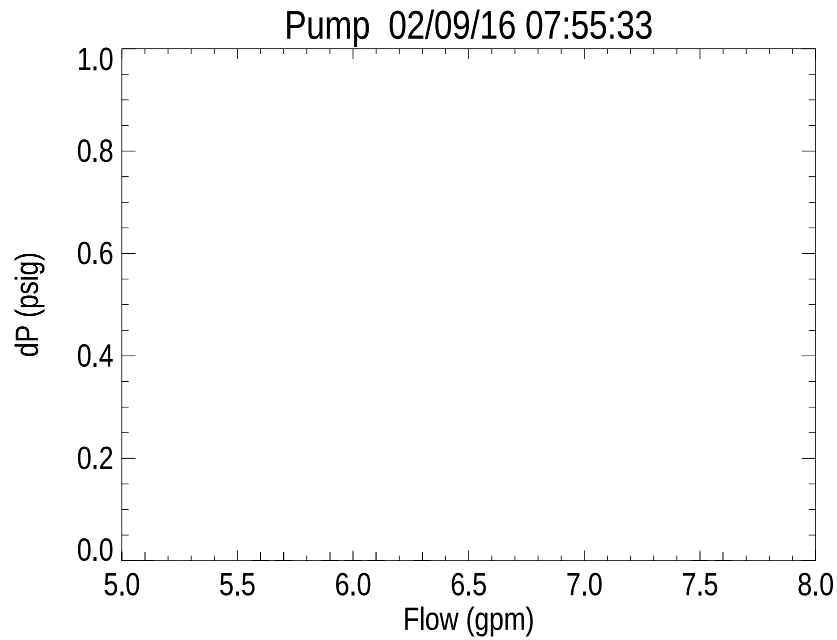

02/09/16 07:55:33
Flow (gpm)
8
6
4
2
0
:54
:55
:56
:57
:58
:59
:0
:1
:2
:3
:4
:5
7:
8:

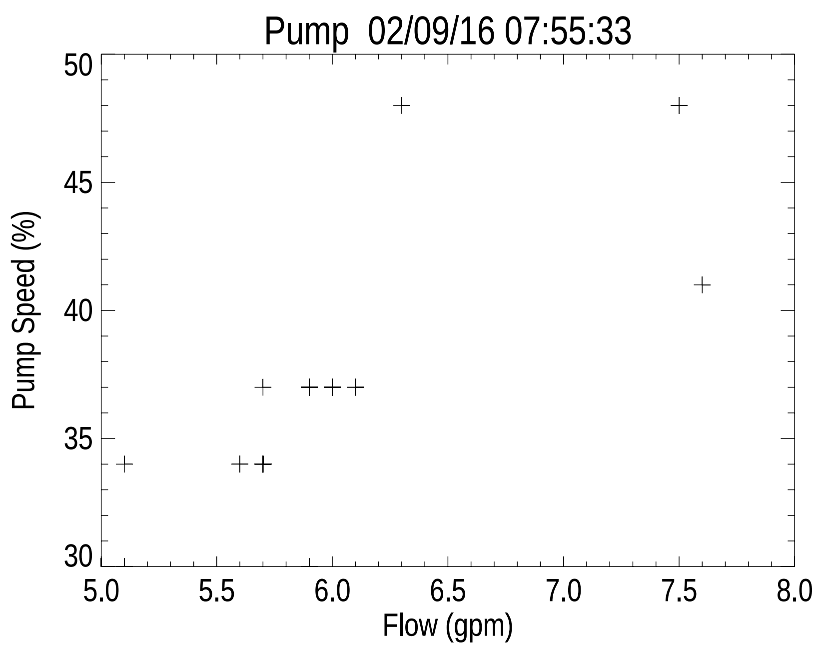

02/09/16 07:55:33
Heat (MBtu/h)
15
10
5
0
-5
-10
:54
:55
:56
:57
:58
:59
:0
:1
:2
:3
:4
:5
7:
8:
Q-WF
Q-CDH

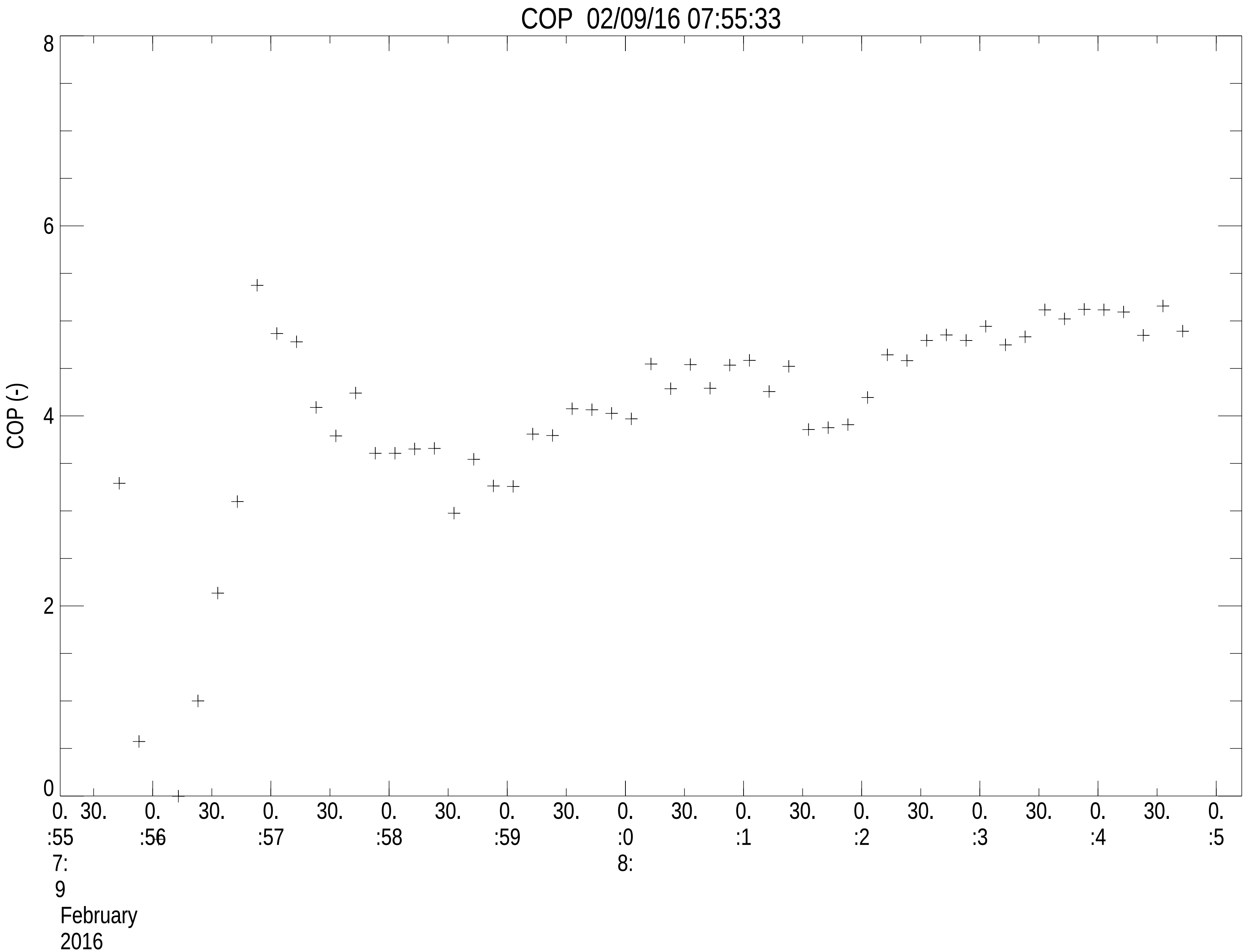

Air Temps 02/09/16 07:55:33
Temperature (F)
76
74
72
70
68
66
:54
:55
:56
:57
:58
:59
:0
:1
:2
:3
:4
:5
7:
8:
EAT
LAT

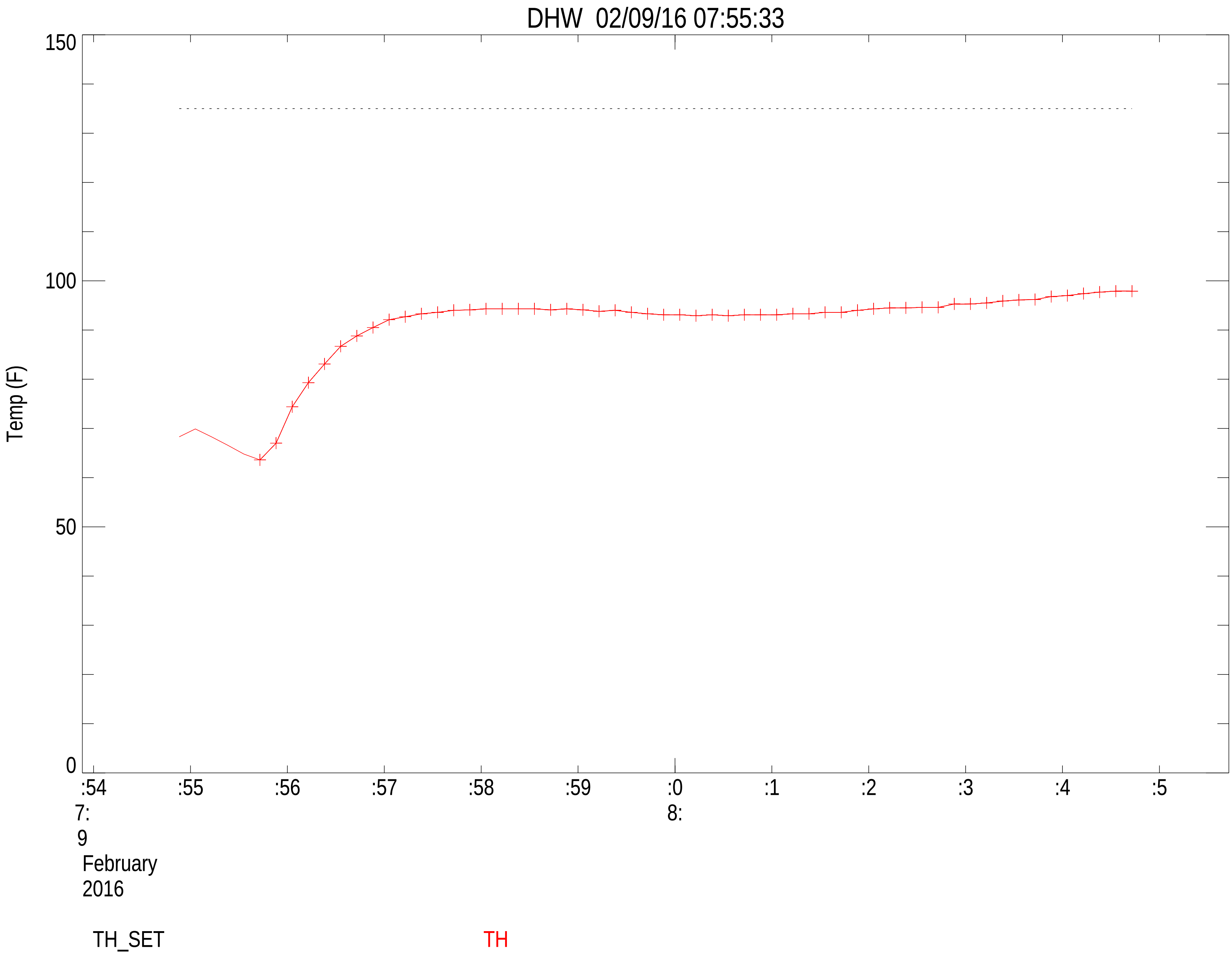

Outdoor Temp 02/09/16 07:55:33
Temperature (F)
1.0
0.8
0.6
0.4
0.2
0.0
:54
:55
:56
:57
:58
:59
:0
:1
:2
:3
:4
:5
7:
8:


Pump 02/09/16 07:55:33
Power (W)
Flow (gpm)
60
40
20
5.0
5.5
6.0
6.5
7.0
7.5
8.0


Pump 02/09/16 07:55:33
dP (psig)
Flow (gpm)
1.0
0.8
0.6
0.4
0.2
0.0
5.0
5.5
6.0
6.5
7.0
7.5
8.0


Pump 02/09/16 07:55:33
Pump Speed (%)
Flow (gpm)
50
45
40
35
30
5.0
5.5
6.0
6.5
7.0
7.5
8.0


COP 02/09/16 07:55:33
COP (-)
0
2
4
6
8
0.
:55
7:
9
February
2016
30.
0.
:56
30.
0.
:57
30.
0.
:58
30.
0.
:59
30.
0.
:0
8:
30.
0.
:1
30.
0.
:2
30.
0.
:3
30.
0.
:4
30.
0.
:5



DHW 02/09/16 07:55:33
150
100
50
0
Temp (F)
:54
:55
:56
:57
:58
:59
:0
:1
:2
:3
:4
:5
7:
9
February
2016
8:
TH_SET
TH

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