Albany Medical Center – M&V Verification

Background

The Albany Medical Center has installed a Mercury 50-6000R natural gas fired turbine CHP system that will produce 4.5 MW[1] of electrical power. The turbine is outfit with a heat recovery steam generator (HRSG) that can produce 12,500 lb/h of steam at 100-psig using only the turbine exhaust, or up to 54,600 lb/h of 100-psig steam when the HRSG duct burner is firing. The turbine and HRSG duct burner are fueled by natural gas at a rate of 40.8 MMBtu/h LHV (43,849 CFH) for the turbine alone, and 88.5 MMBtu/h (95,140 CFH) with the turbine and duct burner operating. Based on the supplied energy balance, the system has a rated CHP efficiency of 69% LHV without the duct burner firing, and 79% LHV with the duct burner firing.

System Instrumentation

Instrumentation for monitoring the M&V was provided by Rovisys, who also provided the plant control system (PCS) and system integration to facilitate data transfer to CDH Energy.

Table 1 lists the monitoring points identified as necessary for system performance characterization, and are further documented in the monitoring and verification (M&V) plan for the system. Figure 1 displays the location of the monitored points on a simplified system schematic.

Table 1. AMC CHP System – Data Point List

Data Point	Description	Units
WG	Gas Turbine Gross Electrical Output	kW
WPAR1	Parasitic Load MCC-1 GTG1/HRSG-1	kW
WPAR2	Parasitic Load MCC-4 Gas Compressor	kW
FS_gross	HRSG Gross Steam Flow	lb/h
FS_DA	DA Steam Flow	lb/h
PS	DA Steam Temperature	PSIG
TC	HRSG Condensate Temperature	deg C
FG	Turbine Gas Consumption	lbm/h
FGB	Duct Burner Gas Consumption	lbm/h

Interval data are collected on a 15-minute basis and transferred to nightly to the CDH Energy server by the Rovisys system.

[1] ISO Rating at 59°F.

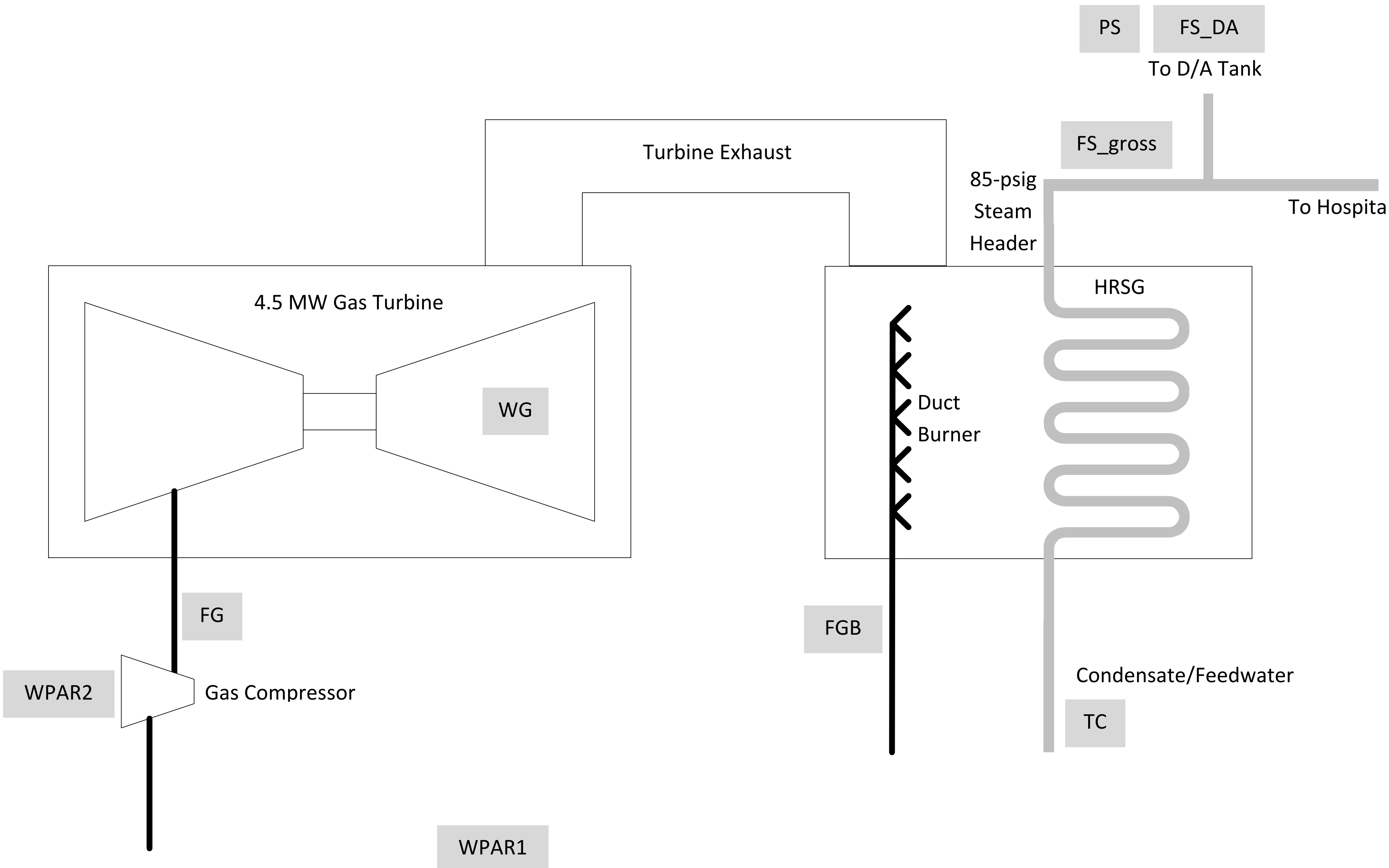


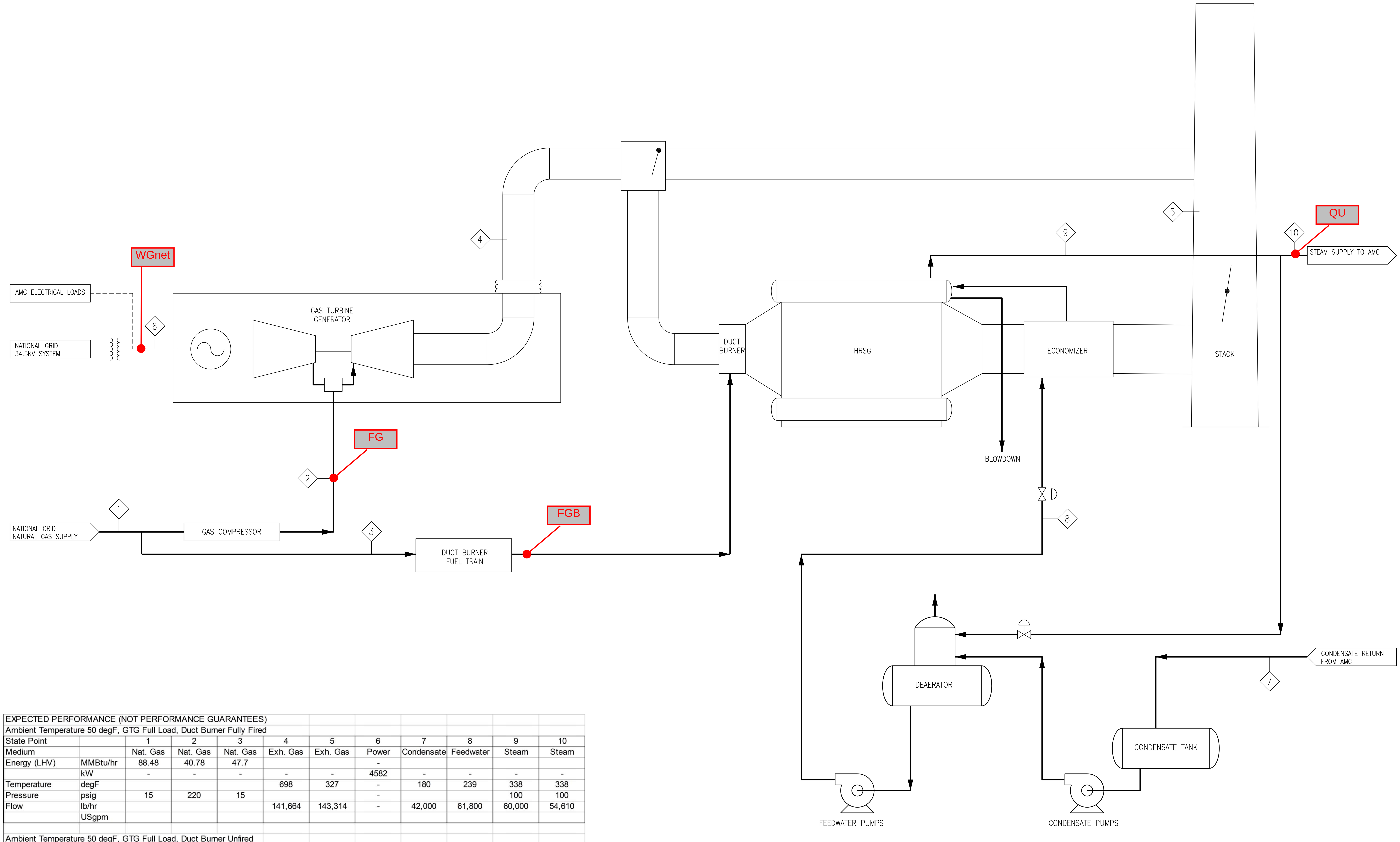
Figure 1. AMC CHP System Schematic

Due to the system size, operating voltages, and measurement accessibility issues, no independent verification of the energy flow measurements can be performed using handheld equipment. Verification of system performance measurements was determined by comparing the observed operation to rated or design performance values for each of the energy streams measured.

The following drawing was supplied with the design package, listing the design output for electricity and steam, as well as the natural gas input for the system, all listed at 50°F.

Table 2. Energy Flow Design Values

Energy Flow	**Anticipated Design Value at 50°F**
Gross Turbine Power Output	4,582 kW
Turbine Fuel Input	40.78 MMBtu/h LHV
Duct Burner Fuel Input	47.7 MMBtu/h LHV
Gross Steam Output	13,756 PPH (unfired), 60,000 PPH (fired)
Net Steam Output (minus Deaerator)	12,250 PPH (unfired), 54,610 PPH (fired)
Condensate Temperature	180°F
Steam Header Pressure	100-psig
Gross FCE (no parasitic loads, net steam production)	70.3% LHV (unfired), 81.6% LHV (fired)



EXPECTED PERFORMANCE (NOT PERFORMANCE GUARANTEES)

Ambient Temperature 50 degF, GTG Full Load, Duct Burner Fully Fired

State Point		1	2	3	4	5	6	7	8	9	10
Medium		Nat. Gas	Nat. Gas	Nat. Gas	Exh. Gas	Exh. Gas	Power	Condensate	Feedwater	Steam	Steam
Energy (LHV)	MMBtu/hr	88.48	40.78	47.7			-				
	kW	-	-	-	-	-	4582	-	-	-	-
Temperature	degF				698	327	-	180	239	338	338
Pressure	psig	15	220	15			-			100	100
Flow	lb/hr				141,664	143,314	-	42,000	61,800	60,000	54,610
	USgpm										

Ambient Temperature 50 degF, GTG Full Load, Duct Burner Unfired

State Point		1	2	3	4	5	6	7	8	9	10
Medium		Nat. Gas	Nat. Gas	Nat. Gas	Exh. Gas	Exh. Gas	Power	Condensate	Feedwater	Steam	Steam
Energy (LHV)	MMBtu/hr	40.78	40.78	0			-				
	kW	-	-	-	-	-	4582	-	-	-	-
Temperature	degF				698	321	-	180	239	338	338
Pressure	psig	15	220	15			-			100	100
Flow	lb/hr				141,664	141,664	-	9,630	14,169	13,756	12,520
	USgpm										

No.	Submittal / Revision	App'd	By	Date
PA	ISSUED FOR INFORMATION		RM	8/20/10

BETTE CRING CONSTRUCTION GROUP

COGEN POWER TECHNOLOGIES A BETTE & CRING COMPANY

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Designed: Drawn: CRG Checked:

ALBANY MEDICAL CENTER
D/B CHP FACILITY

PROCESS FLOW DIAGRAM
COGENERATION SYSTEM

Issue Date: 06/21/10 Project No.: 6161 Scale: NONE

M-101

Figure 2 through Figure 9 display the observed operation of the system from April 1 – September 30, 2013, when turbine output exceeds 2,500 kW.

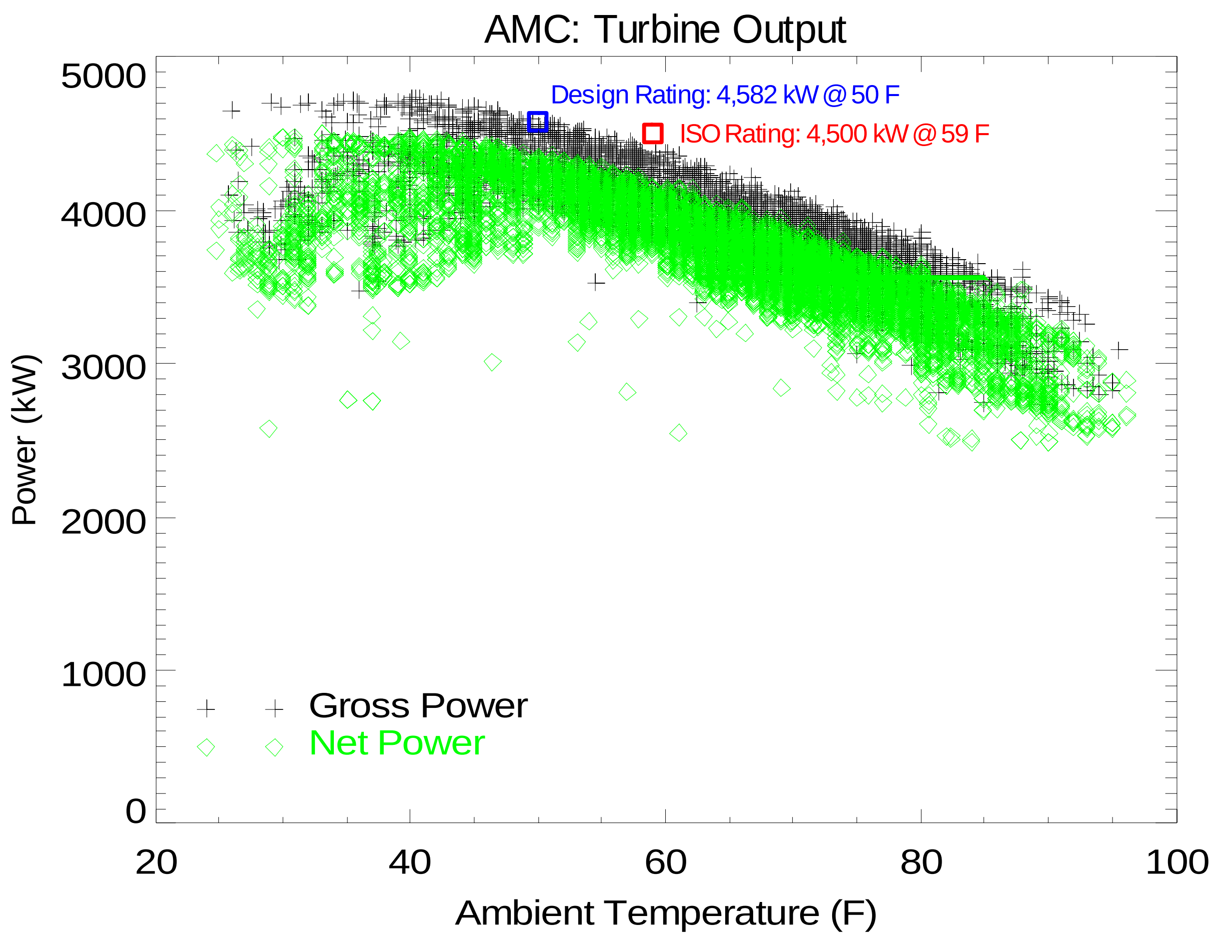

Figure 2. Turbine Power Variation with Ambient

Gross turbine power, measured by the 13 kV protective relay, matches the anticipated output very well. Including parasitic power decreases the net turbine output by approximately 250 kW.

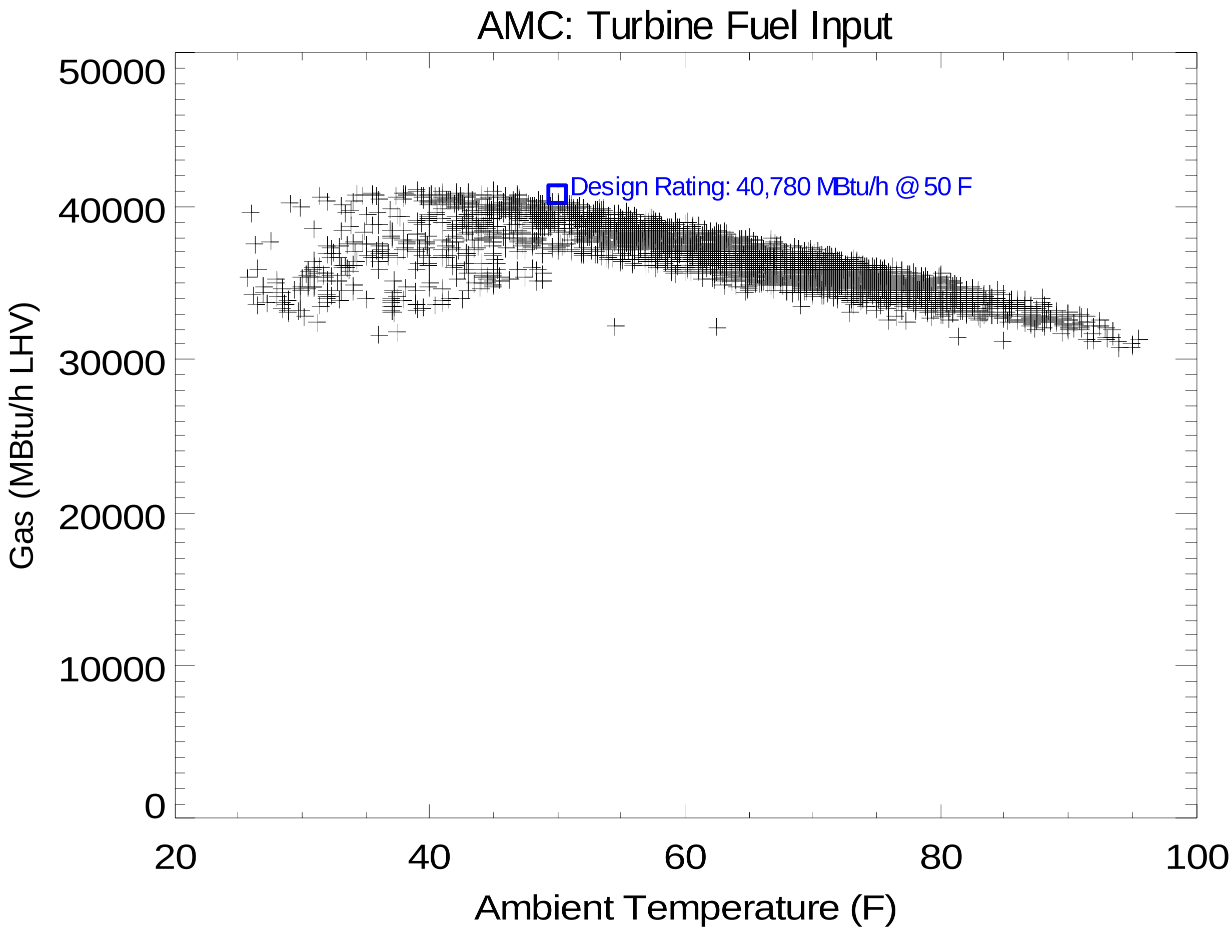

Figure 3. Turbine Fuel Input Variation with Ambient

Turbine fuel input matches the anticipated fuel input. Turbine fuel input falls off when turbine power decreases at lower ambient temperatures.

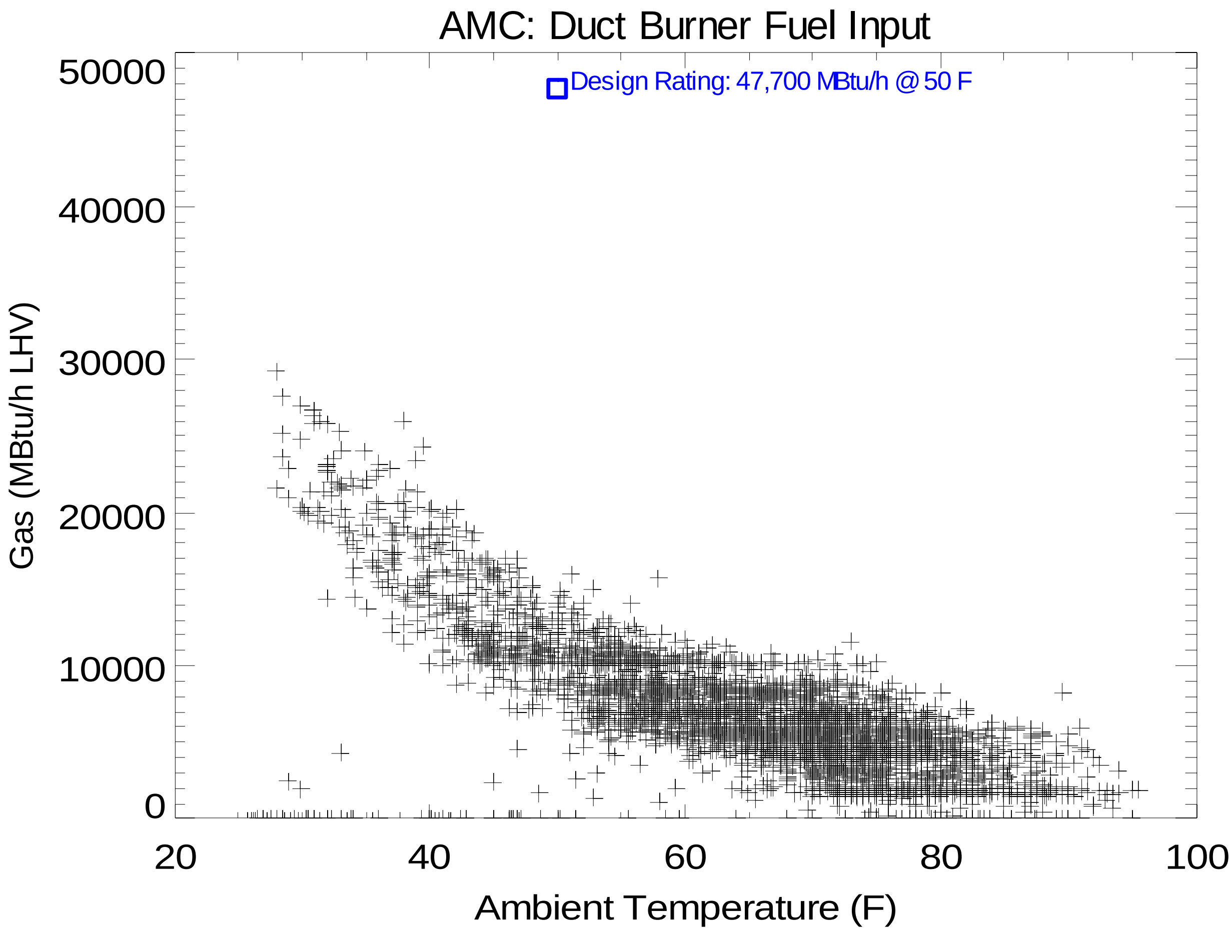

Figure 4. HRSG Duct Burner Fuel Input Variation with Ambient

Duct burner fuel input is substantially below the rated value, although the rated duct burner fuel consumption rate is for full firing of the burner. Operation to date has been at much lower firing rates.

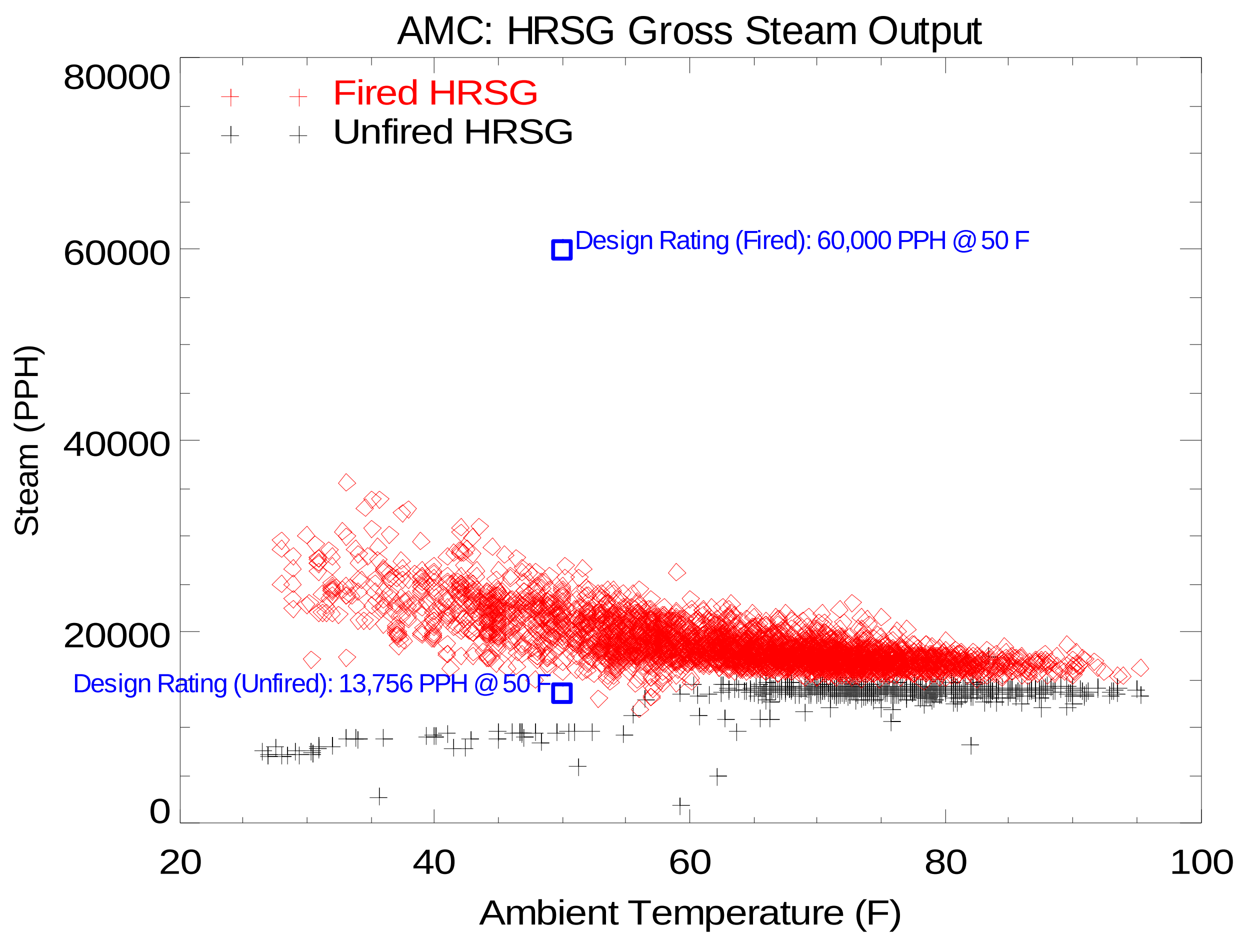

Figure 5. Steam Output Flow Variation with Ambient

Steam output from the HRSG is highly influenced by duct burner operation. Comparison to the rated value for the unfired HRSG displays good agreement with the design value. The increase in steam output resulting from the HRSG duct burner matches the observed firing rate of the HRSG duct burner, and is well below the design value. This further indicates that the HRSG duct burner is operating well below design capacity.

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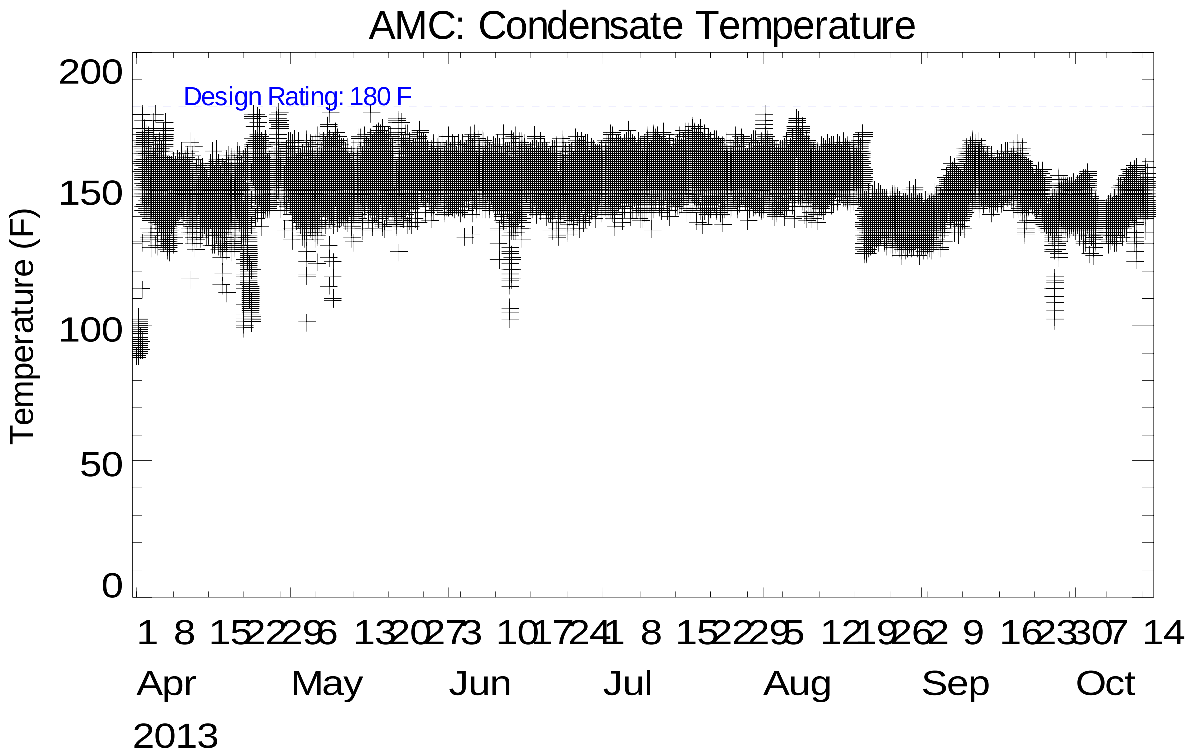

Figure 6. Condensate Return Temperature

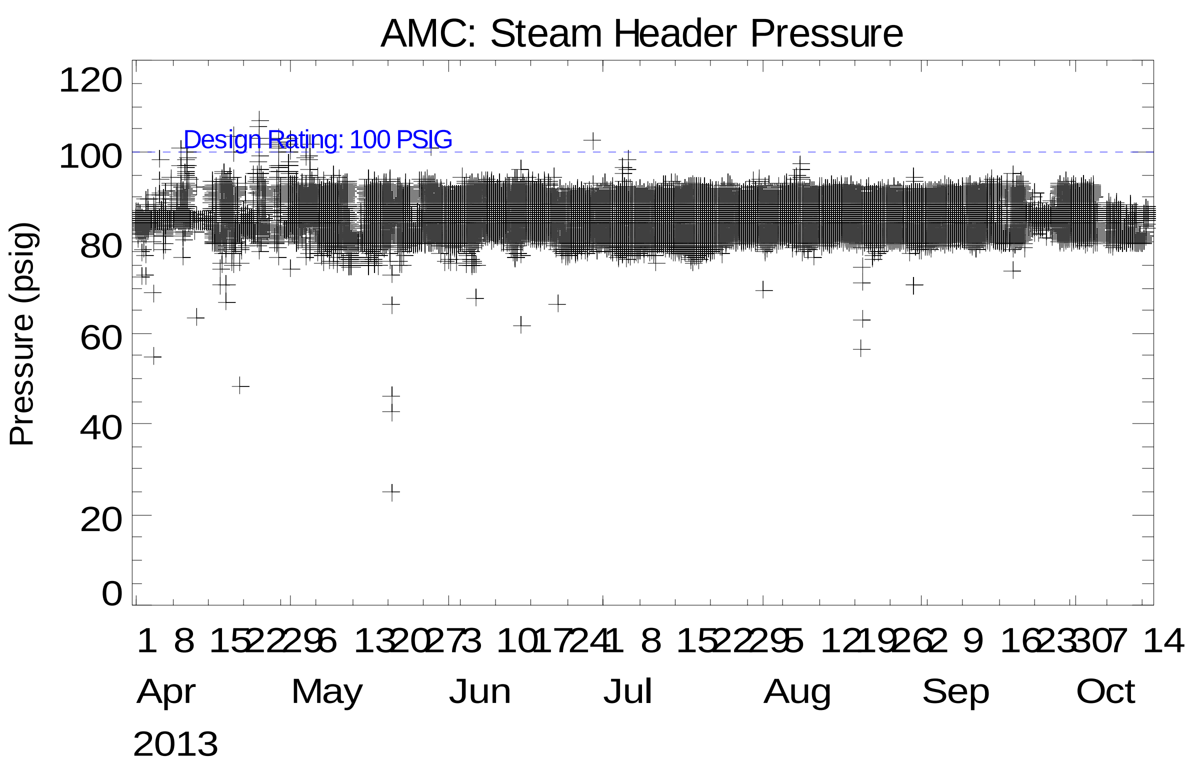

Figure 7. Steam Header Pressure

Steam conditions observed on site are substantially different than the design numbers. The average condensate return temperature is 150°F, much lower than the design value. This results in an increased enthalpy change to produce steam compared to the rated conditions for the HRSG. Similarly, the steam header pressure which the HRSG supplies steam to, was only 85-psig, compared to the 100-psig rated value. This reduction in steam pressure decreases the enthalpy change needed to create steam. The combination of the two changes in condensate and steam conditions result in a net increase of 28 Btu/lb of enthalpy difference at the HRSG compared to the design values. This is a difference of 2.6% more energy that must be provided by the HRSG to produce a pound of dry saturated steam.

Table 3. Comparing Observed Steam System Conditions to Design Assumptions

Rated Conditions (180°F Condensate, 100-psig Saturated Steam)	1,190 Btu/lb – 148.0 Btu/lb = 1,042 Btu/lb
Observed Conditions (150°F Condensate, 85-psig Saturated Steam)	1,187 Btu/lb – 117.0 Btu/lb = 1,070 Btu/lb
Difference	+28 Btu/lb (+2.6%)

Applying the rated steam conditions to the rated HRSG flow, and the measured steam conditions to the measured HRSG steam output, a comparison was made to the design HRSG heat recovery values. The resulting trend in total heat recovery was similar to the steam flow trend displayed in Figure 5. The low level of duct burner operation prevents the HRSG from achieving the rated level of heat recovery when firing. When unfired, the HRSG is operating very close to the design performance.

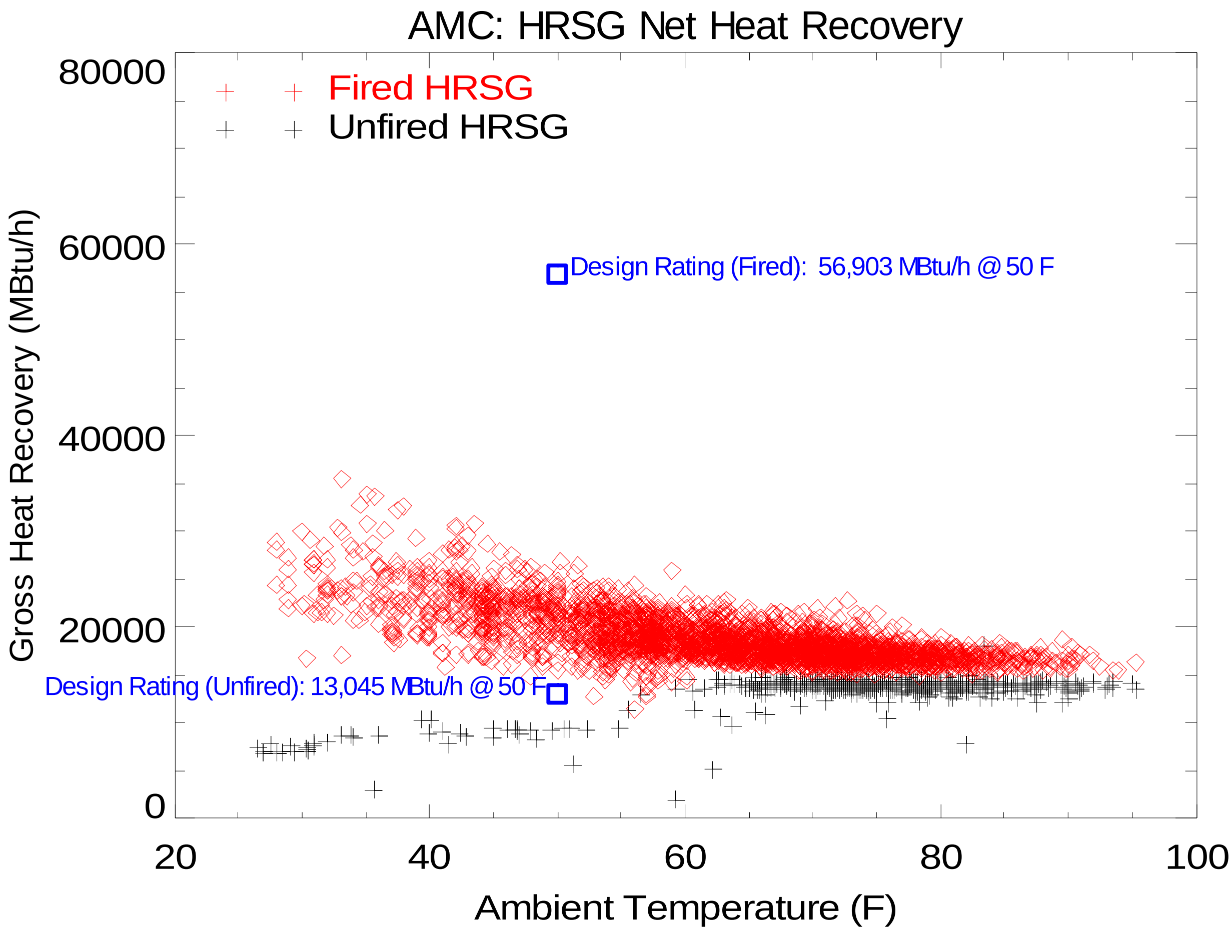

Figure 8. HRSG Heat Recovery Variation with Ambient

Combining the measured gross power, turbine and duct burner fuel consumption, and the net HRSG heat recovery, a comparison to the system design fuel conversion efficiency (FCE) was performed. For comparison to the design values, the gross turbine output is used, as the design numbers do not include an allotment for system electrical parasitic loads.

For comparison to the design values, FCE is defined as:

$$FCE = \frac{\sum^{N} QU + 3.413 \cdot \sum^{N} (WG)}{\sum^{N} FG_{tot}}$$

Where:	FCE	-	Annual fuel conversion efficiency (% LHV)
	QU	-	Useful heat recovery (MBtu or MBtu/h)
	FG_{tot}	-	Total natural gas input (MBtu LHV or MBtu/h LHV)
	WG	-	Gross output from gas turbine (kWh or kW)
	3.413	-	Conversion from kWh to MBtu

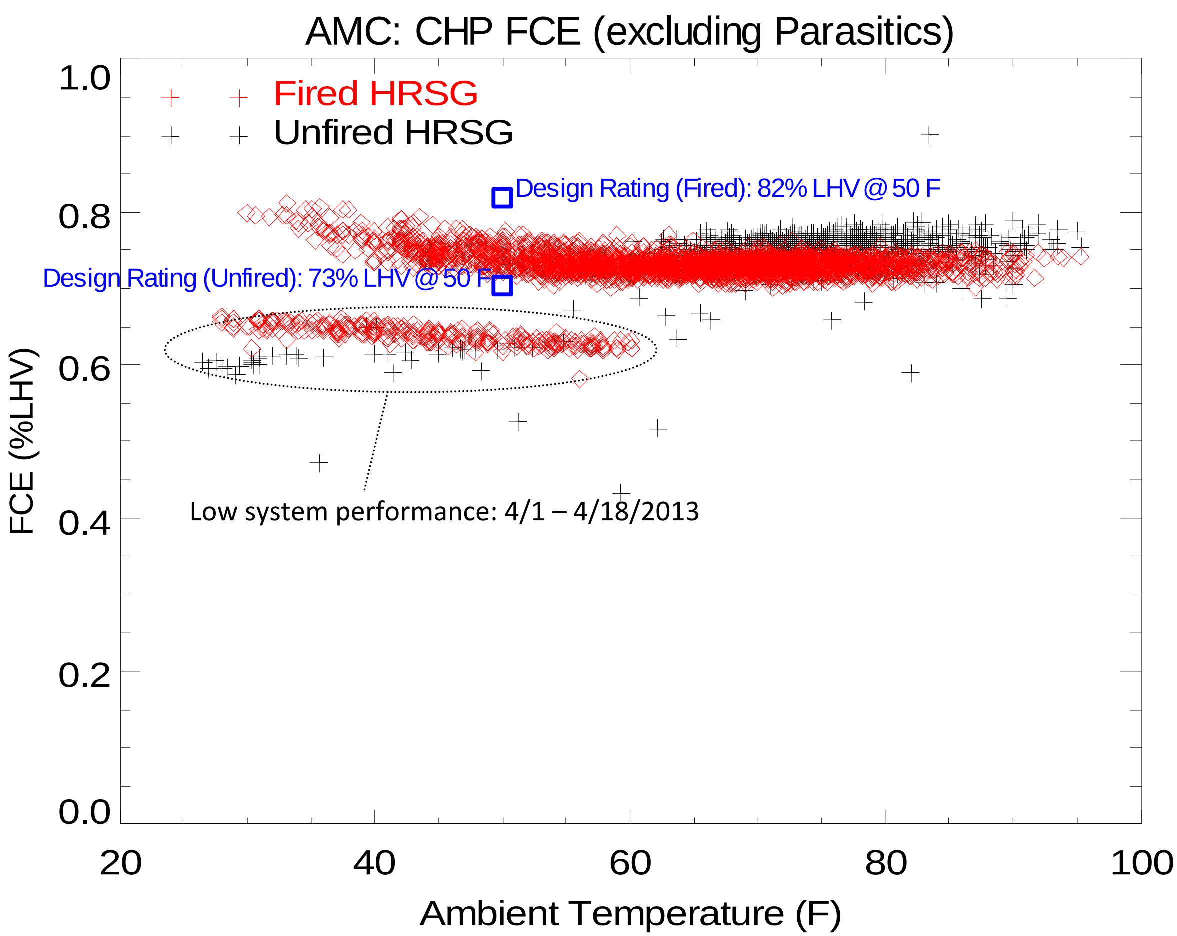

Figure 9. Gross CHP FCE Variation with Ambient Temperature

The observed FCE ranged from 60% LHV in early April, when the system was not operating optimally, up to 80% LHV at low ambient temperatures with the duct burner operating. After the system startup issues were corrected in April, the FCE range observed is primarily in agreement with both the unfired and fired design numbers for the system.

Finally the net FCE (including parasitic electrical losses) was evaluated. The design values do not have a corresponding entry for parasitic electrical losses, so no comparison to the design was made for the net FCE. The net FCE will be used for evaluation of the NYSERDA performance goals for the system. Net FCE after May 2013 has ranged from 69% LHV to 80% LHV, with comparable values for fired and unfired HRSG operation.

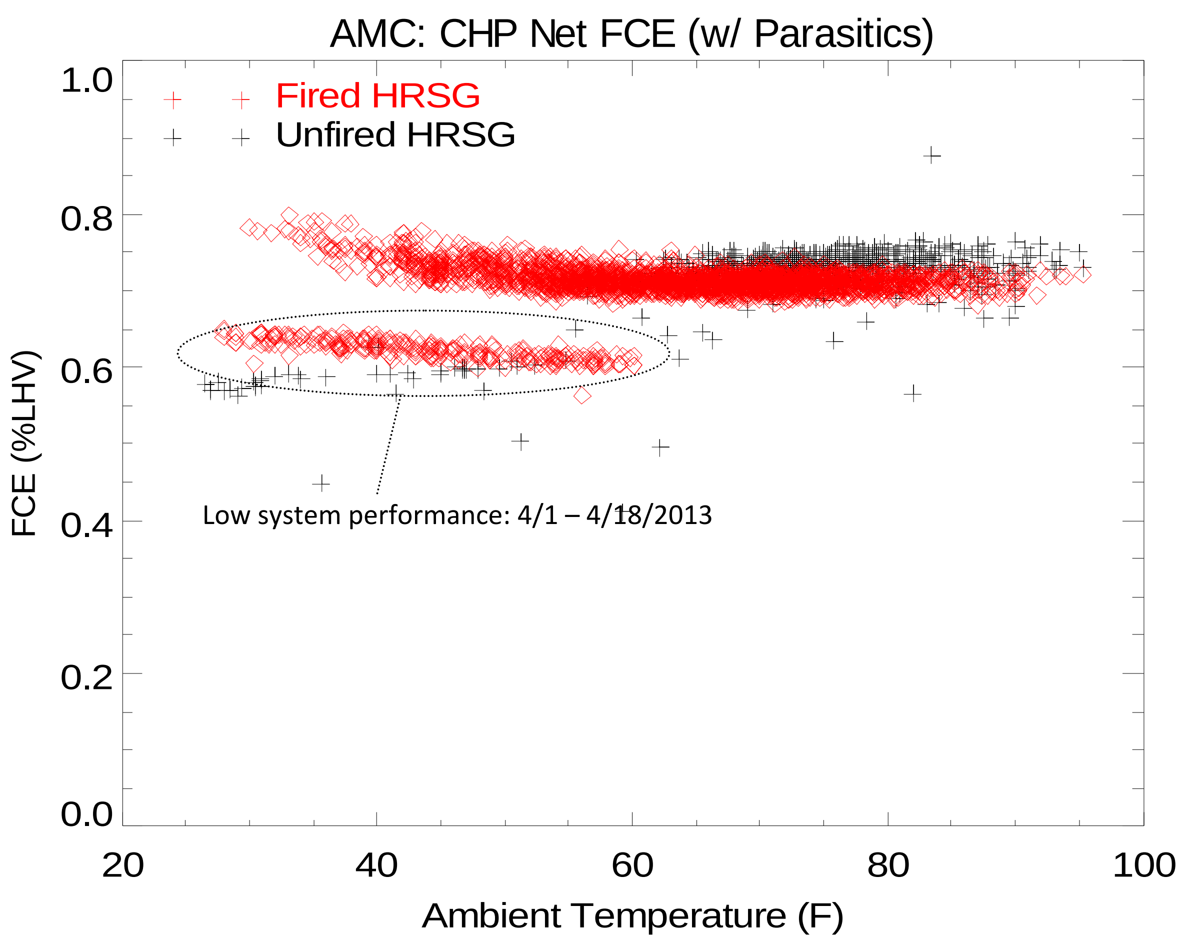

Figure 10. Net FCE Variation with Ambient, Including All Parasitic Electrical and Steam Losses

Conclusion

Performance of the AMC CHP system is in agreement with the design performance of the system. The performance data collected to date do not indicate substantial error in any of the energy stream measurements. Variations in CHP system performance from design primarily occur from operating constraints on the building/distribution side of the system, and not due to the operation of any of the CHP components, nor due to measurement error. Data are considered valid for performance evaluation after April 18, 2013.