NYSERDA CHP Assessment Report

ASSESSING THE CHP PLANT AT THE NY PRESBYTERIAN HOSPITAL

NY Presbyterian Hospital

NYSERDA New York State Energy Research and Development Authority

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BACKGROUND

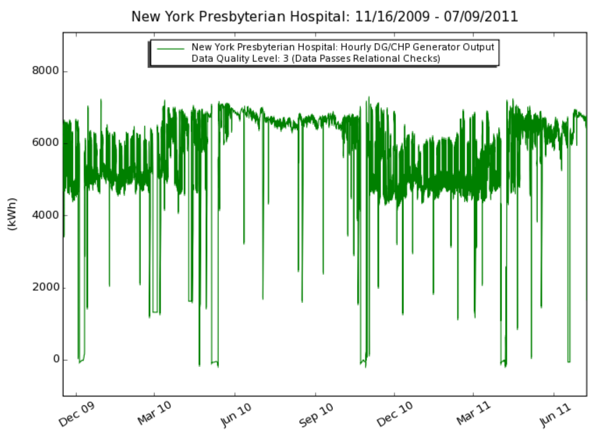
The New York State Research and Development Authority (NYSERDA) web-based DG/CHP data system has been providing performance information on CHP systems for the past ten years. This system includes monitored performance data and operational statistics for NYSERDA's Distributed Generation (DG)/Combined Heat and Power (CHP) demonstration projects including:

- Monitored Hourly Performance Data
- Operational Reliability and Availability Data
- Characteristics of Each Facility and its Equipment

The Monitored Hourly Performance Data portion of the database allows users to view, plot, analyze, and compare performance data from one or several different DG/CHP sites in the NYSERDA portfolio. It allows DG/CHP operators at NYSERDA sites to enter and update information about their system. The database is intended to provide detailed, highly accurate performance data that can be used by potential users, developers, and other stakeholders to understand and gain confidence in this promising technology.

The Operational Reliability Data portion of the database is intended to allow individual facility managers to better understand reliability, availability, and performance of their particular units and also determine how their facilities compare with other units. Information on reliability and availability performance will enable potential onsite power users to make a more informed purchase decision, and will help policy makers quantify reliability benefits of customer-sited generation.

NYSERDA's web-based DG/CHP data system provides general equipment information and detailed performance data, however, data alone does not provide the complete picture with respect to CHP systems design or performance. This report seeks to explain the performance data presented in the two fundamental output graphs: kW/h versus time and Useful MBtu/h versus time.



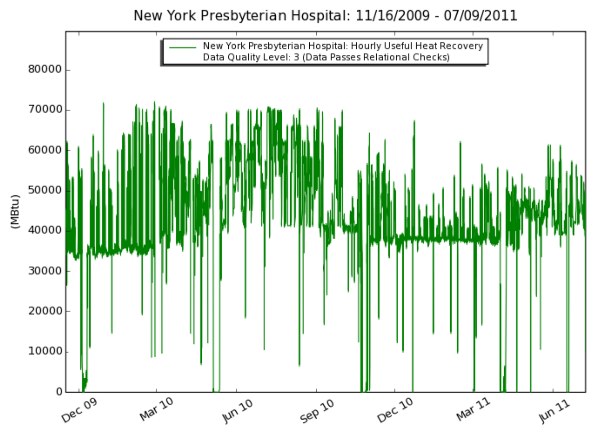


FIGURE NYSERDA CHP WEBSITE PERFORMANCE GRAPHS

This report provides explanation for system performance trends and anomalies by further assessing the data supporting these two graphs and, where necessary, conducts interviews of the developers, owners and operators.

THE SITE

FIGURE NEW YORK PRESBYTERIAN HOSPITAL

The New York Presbyterian Hospital is one of New York's largest and most inclusive hospitals with over 13,000 employees and 2,400 patient beds. NYPH's downtown campus, known as the New York Weill Cornell Medical Center, is a teaching hospital affiliated with Cornell University.

THE SYSTEM

A single 7.5 MW gas turbine generator set was installed at the facility to provide electricity to various load centers across the campus. Heat recovered from the turbine exhaust is used to produce high pressure steam. The system can provide 60% or more of the site's electrical power at a CHP efficiency approaching 85% LHV.

NYPH's electric demand can exceed 11,000 kW. Thermal loads are dominated by space conditioning requirements. Steam is used for space heating and to provide air conditioning using steam driven centrifugal chillers. Consequently, there is continuous demand for steam that can at times exceed 200,000 lbs/hr.

The hospital produces steam and chilled water with a central utilities plant (CUP) located in the Annex Building on 70th Street. All of the campus' electricity was supplied by energy marketers and delivered by Con Edison. Steam, chilled water and electricity are distributed throughout the campus in a vast piping and raceway network located beneath the buildings.

The magnitude of the loads favored use of a combustion turbine as the prime mover. Turbines are generally compact despite the large generating capacity that can be provided. Most stationary turbines also have a multi-fuel capability, a feature critical in hospitals. The turbine installed at NYPH can operate on natural gas or #2 fuel oil; the same fuels used in the existing boilers. The turbine operates in parallel with both the electric utility and steam plant. A synchronous generator was used so the turbine could continue operating in the event of a blackout.

FIGURE SOLAR TURBINES TAURUS 7-T10301S NATURAL GAS FUELED TURBINE GENERATOR SET

NYPH's CHP system is configured using a single 7.5 MW turbine generator set. The turbine is fired primarily on natural gas that is supplied to the site at 60 psig. A booster compressor is used to increase the gas pressure to a level suitable to fuel the turbine. Electricity is produced at 4,160 volts and distributed to load centers across the campus. Automatic controls modulate the electrical output to follow the site load. No power is exported to the grid. Waste heat from the turbine exhaust is used to produce steam at 185 psig in a heat recovery steam generator (HRSG). The installation includes an auxiliary duct burner that can be used to increase the steam output from the HRSG during periods of peak consumption. This limits the need to operate the existing boilers

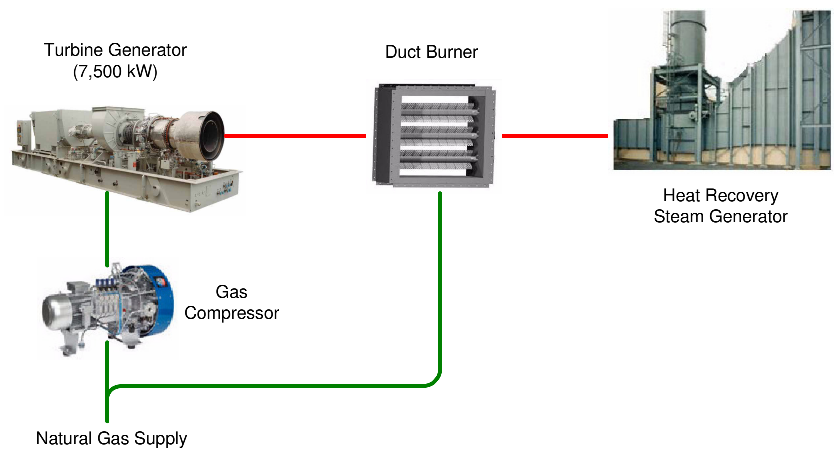


FIGURE SIMPLIFIED CHP SCHEMATIC

FIGURE TYPICAL PACKAGE GAS TURBINE INSTALLATION

FIGURE TYPICAL HEAT RECOVERY STEAM GENERATOR

OPERATING SUMMARY

Table presents annual data showing the combustion turbine-based CHP systems electric efficiency at 26.4% (HHV) range. This efficiency is lower than expected, especially in the winter when the turbine operates at less than its full load output. At full load in the summer the turbine electrical efficiency reaches 27.5% on an HHV basis (the expected ISO efficiency is 30.4% HHV).   The fuel conversion efficiency and useful thermal efficiency are both inordinately high because the full thermal output from the HRSG is measured but the incremental fuel input to the duct burner is not measured (i.e., natural gas use only includes the turbine).   The high thermal efficiency is indicative of good use of exhaust heat combined with high duct burner efficiency.   Figure shows peak power production occurring at several times across all seasons indicating the use of turbine inlet cooling to keep power production from falling off during higher ambient days (the plots in Appendix B confirm the use of turbine inlet cooling in the summer period).

Table presents the measured data from the website for a one year period.

As mentioned above, the high thermal recovery is in-part due to the presence of a duct burner which supplements the recovered useful heat energy year-round. This accounts for high thermal to power ratios (MBtu Thermal/MBtu Power) that vary slightly from 2.04 in November to 2.58 in August. Figure 7 presents the power generated and useful thermal energy in terms of efficiency for each month.

TABLE SYSTEM EFFICIENCY[1]

	Hours of Good (Pwr) Data	Net Electric Output (kWh)	Natural Gas Use (MCF)	Useful Heat Output (MMBtu)	Electrical Efficiency	Useful Thermal Efficiency	Fuel Conversion Efficiency
January-10	744	3,946,496	50,086.3	29,129.3	26.4%	57.0%	83.4%
February-10	602	3,237,741	41,881.7	26,524.0	25.9%	62.1%	88.0%
March-10	649	3,869,587	48,642.1	32,838.4	26.6%	66.2%	92.8%
April-10	579	3,605,515	45,145.7	27,557.0	26.7%	59.8%	86.6%
May-10	744	3,853,234	46,964.4	29,896.7	27.5%	62.4%	89.9%
June-10	720	4,904,253	59,470.3	41,115.6	27.6%	67.8%	95.4%
July-10	721	4,778,849	58,500.2	42,038.0	27.3%	70.5%	97.8%
August-10	720	4,746,939	58,715.0	38,514.9	27.1%	64.3%	91.4%
September-10	720	4,752,083	58,134.9	34,497.5	27.4%	58.2%	85.5%
October-10	703	3,603,395	44,619.1	25,134.7	27.0%	55.2%	82.2%
November-10	718	3,959,486	50,632.6	30,772.0	26.2%	59.6%	85.7%
December-10	744	3,852,130	50,319.9	29,363.4	25.6%	57.2%	82.8%
January-11	744	3,838,235	50,256.8	29,032.6	25.6%	56.6%	82.2%
February-11	672	3,518,399	45,700.3	26,313.4	25.8%	56.4%	82.2%
March-11	720	3,814,945	49,265.3	28,652.4	25.9%	57.0%	82.9%
April-11	704	3,411,463	42,257.6	23,924.3	27.0%	55.5%	82.5%
May-11	721	4,569,872	55,725.8	32,836.6	27.4%	57.8%	85.2%
June-11	703	4,259,736	52,100.6	30,323.0	27.4%	57.1%	84.4%
July-11	743	4,951,831	60,243.5	34,728.0	27.5%	56.5%	84.0%

[1] Efficiency data is collected using all data points flagged as high quality data. Generally there is good correlation between the data quality of net electric output, natural gas use and useful heat rejection. Anomalies do occur, particularly with respect to natural gas use which causes distortions in the results. If efficiency results are out of normal range, the most likely cause is poor quality concurrent data which can be corroborated by the Site Data Quality table located in the Lessons Learned section of this report.

Total preceding 12 months	**8612**	**49,278,512**	**617,971**	**364,093**	**26.7%**	**57.8%**	**84.4%**

Note: All efficiencies based on higher heating value of the fuel (HHV)

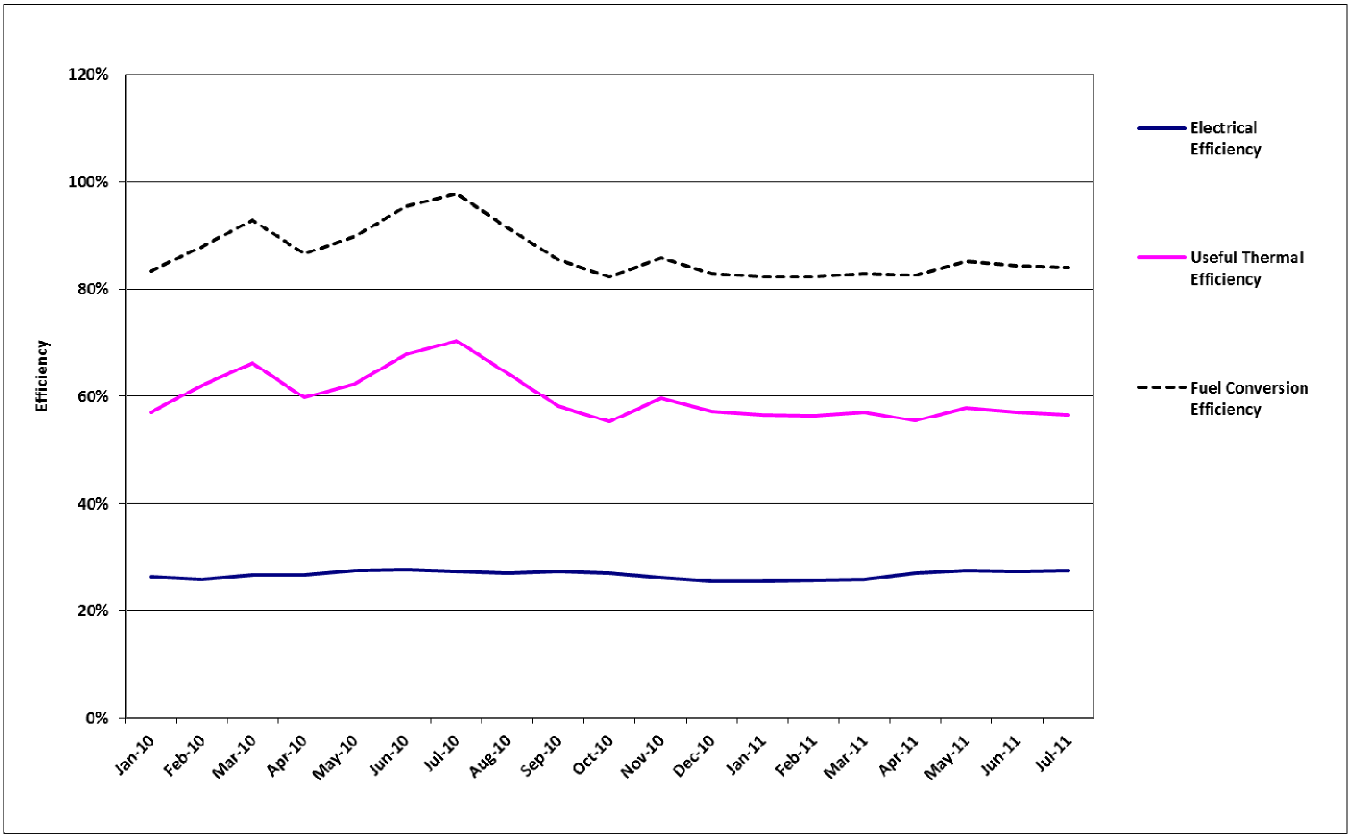


FIGURE ELECTRIC, THERMAL AND FUEL CONVERSION EFFICIENCY BY MONTH

Figure provides operating efficiency during the June 2010 – May 2011 time period showing relatively constant power generation efficiency.

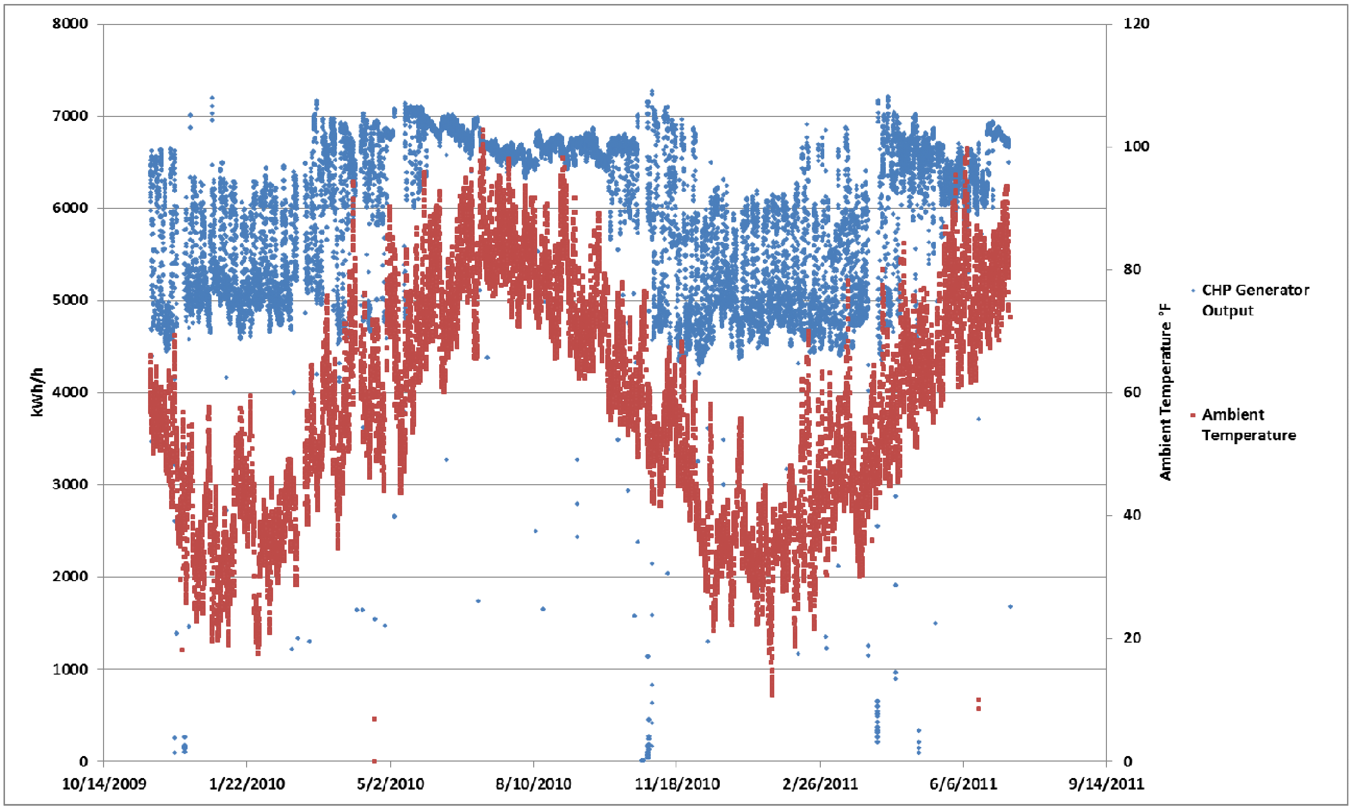


FIGURE AMBIENT TEMPERATURE

Ambient temperature and power data in Figure implies that turbine inlet cooling has been employed as peak performance occurs during the summer time high ambient conditions (the plots in Appendix B confirm this).

To understand the duct burner impact, Table assumes all steam generated above 32,300 lbs/hr[2] (38,631 MBtu/h) is produced by the duct burner calculated on a monthly basis. Table removes thermal energy attributed to the duct burner and recalculates useful thermal and fuel conversion efficiencies. Note April 2011 is an outlier because of several days with little or no fuel input data rendering April data bad and impacting the total numbers in this table.

TABLE ADJUSTING FOR DUCT BURNER FUEL INPUT

	Useful Heat Output (MMBtu)	Electrical Efficiency	Useful Thermal Efficiency	Fuel Conversion Efficiency
June-10	27,792.3	27.5%	57.5%	84.6%
July-10	27,817.4	27.6%	45.4%	72.7%
August-10	27,755.9	27.3%	46.1%	73.1%
September-10	27,608.6	27.1%	45.7%	72.4%
October-10	20,824.8	27.4%	34.8%	61.9%
November-10	27,203.5	27.0%	59.2%	86.0%
December-10	28,226.5	26.2%	54.1%	80.0%
January-11	28,450.4	25.6%	54.9%	80.3%
February-11	25,575.4	25.6%	49.3%	74.7%
March-11	27,329.3	25.6%	52.7%	78.1%
April-11	38,096.7	25.6%	73.5%	98.9%

[2] See Appendix B

May-11	27,586.8	25.6%	53.2%	78.6%
Total preceding 12 months	**334,267.7**	**26.5%**	**55.8%**	**84.2%**

OPERATING SUMMARY

The CHP system consists of one 7.5-MW combustion turbine coupled with a heat recovery steam generator with a nominal capacity of 7,500 kW at ISO conditions. During the 9,466 operating hours between November 16, 2009 and December 31, 2010 that met the range and relational checks 61% of this time, the CHP system delivered between 6 and 7 MW/hr (Figure).

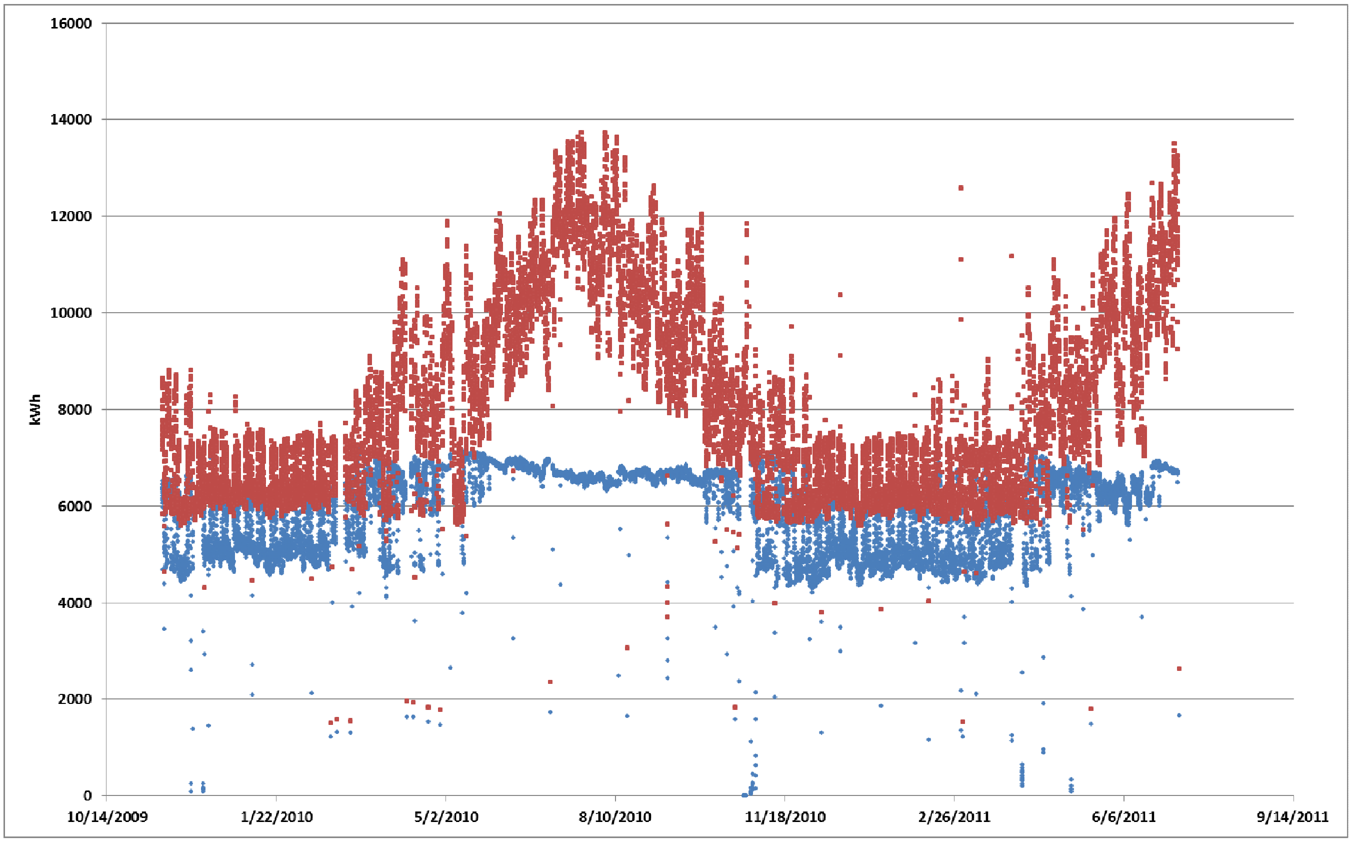


FIGURE CHP POWER GENERATED VERSUS BUILDING LOAD BY MONTH

Figure shows the electric load profile for the hospital is air conditioning dominated, rising from 5.7 to 8.9 MWh in the winter of 2010 to 10.8 to 13.8 MWh in the summer of 2010. The turbine electrical output follows the electric load in the winter and swing seasons and then runs essentially at or near full power output during the summer.

POWER GENERATION AND USEFUL THERMAL ENERGY

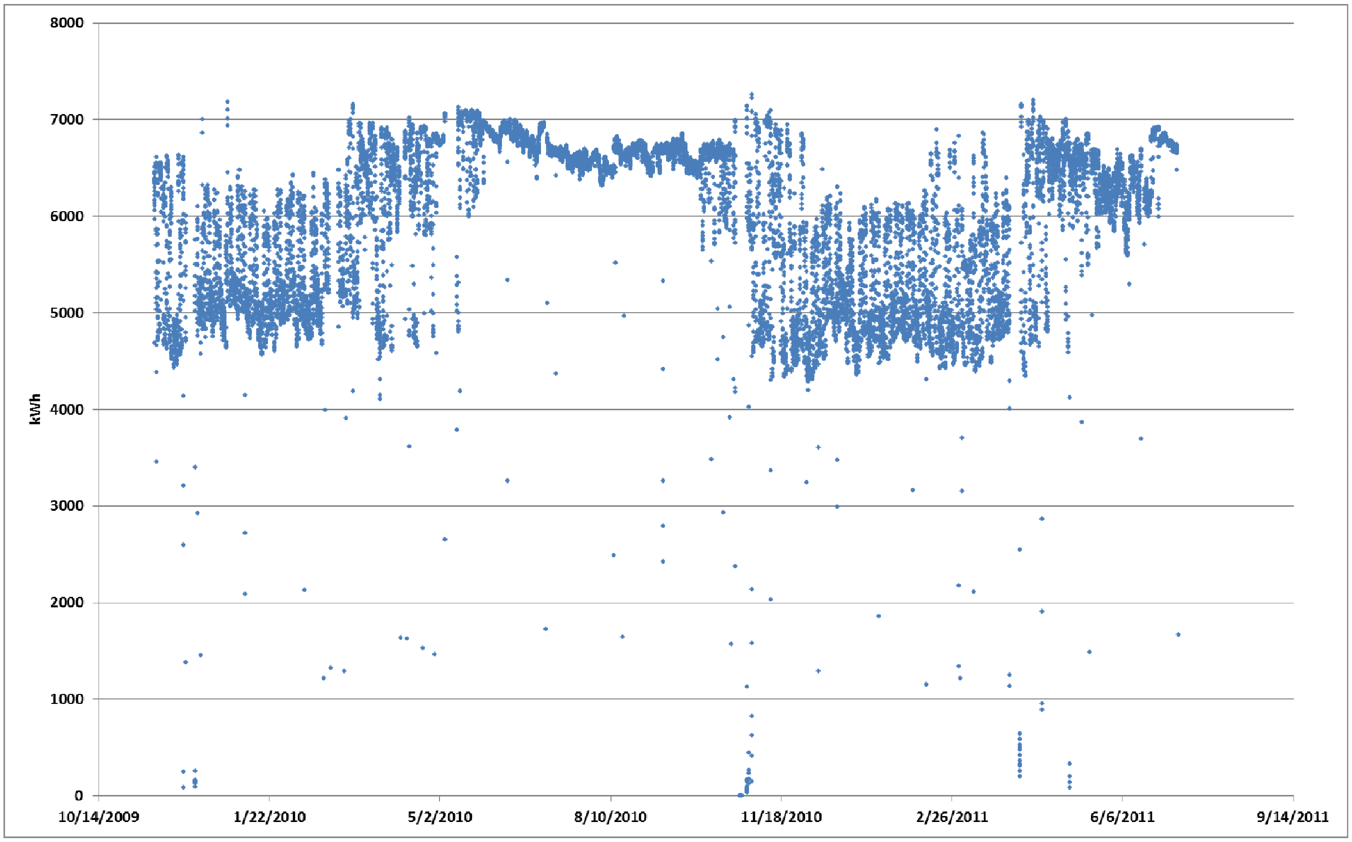


FIGURE CHP POWER OUTPUT VERSUS TIME

Figure shows the turbine operating at peak power during the summer to reduce high peak demand charges.

FIGURE CHP USEFUL THERMAL OUTPUT VERSUS TIME (MBTU/HR)

Figure shows thermal loading throughout the year indicating heating, hot water, steam and cooling loads are being served.

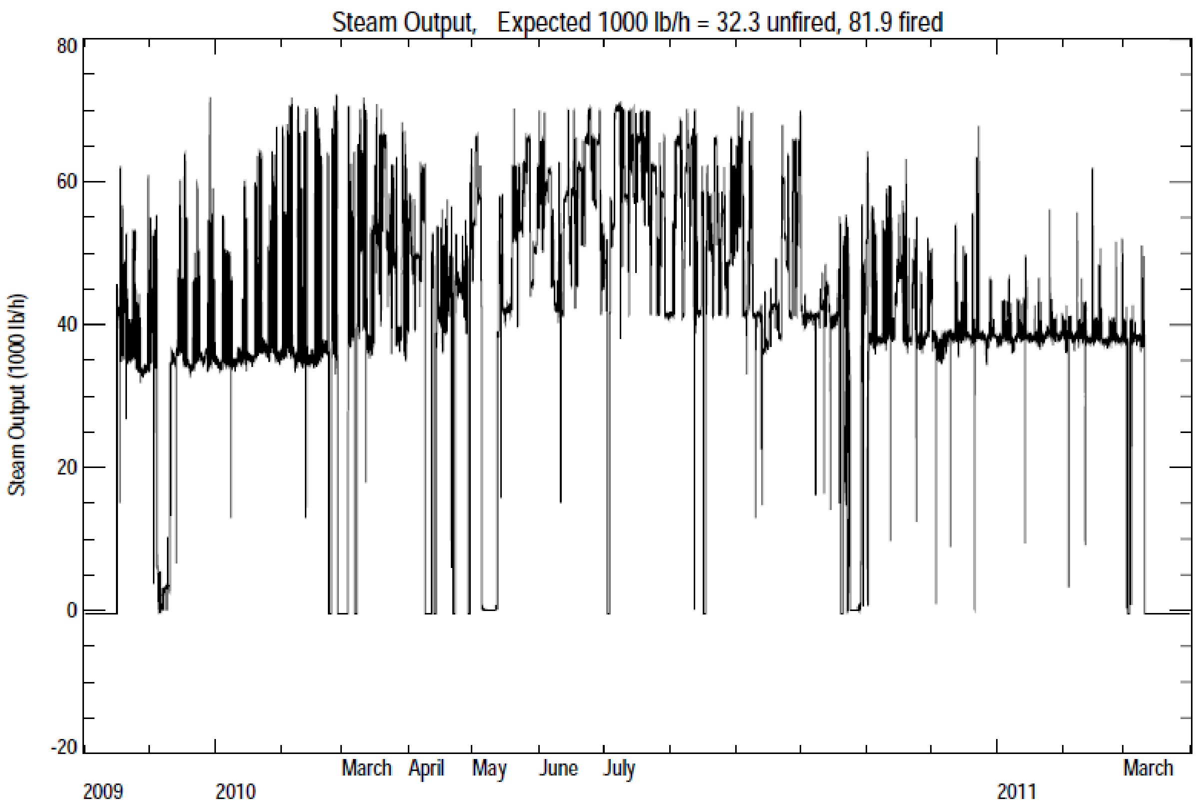


FIGURE STEAM OUTPUT

Steam capacity of the CHP plant is 32,300 lbs. /hr from the gas turbine HRSG and 81,900 lbs. /hr incorporating the duct burner at full capacity. The data presented in Figure and Figure represents the combined HRSG output. Clearly, Figure shows extensive use of HRSG's duct burner year-round.

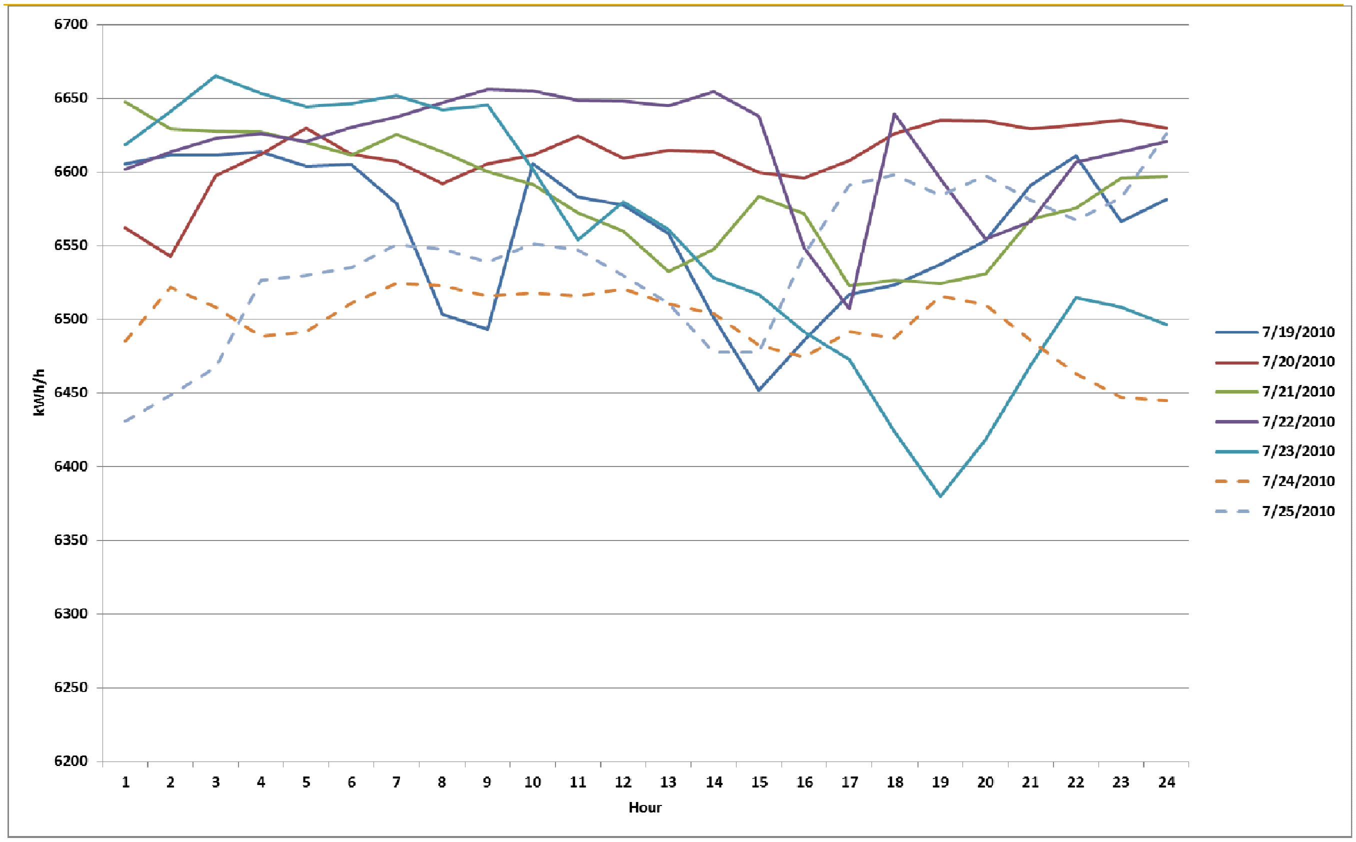


FIGURE CHP POWER OUTPUT VERSUS TIME

Figure covers the time period from July 19- 25, 2010 providing CHP system power output by hour of the day pattern for the time period. July 24 is a Saturday. Electric load following pattern for this hospital is exhibited in Figure . On weekends it has a slightly lower power requirement.

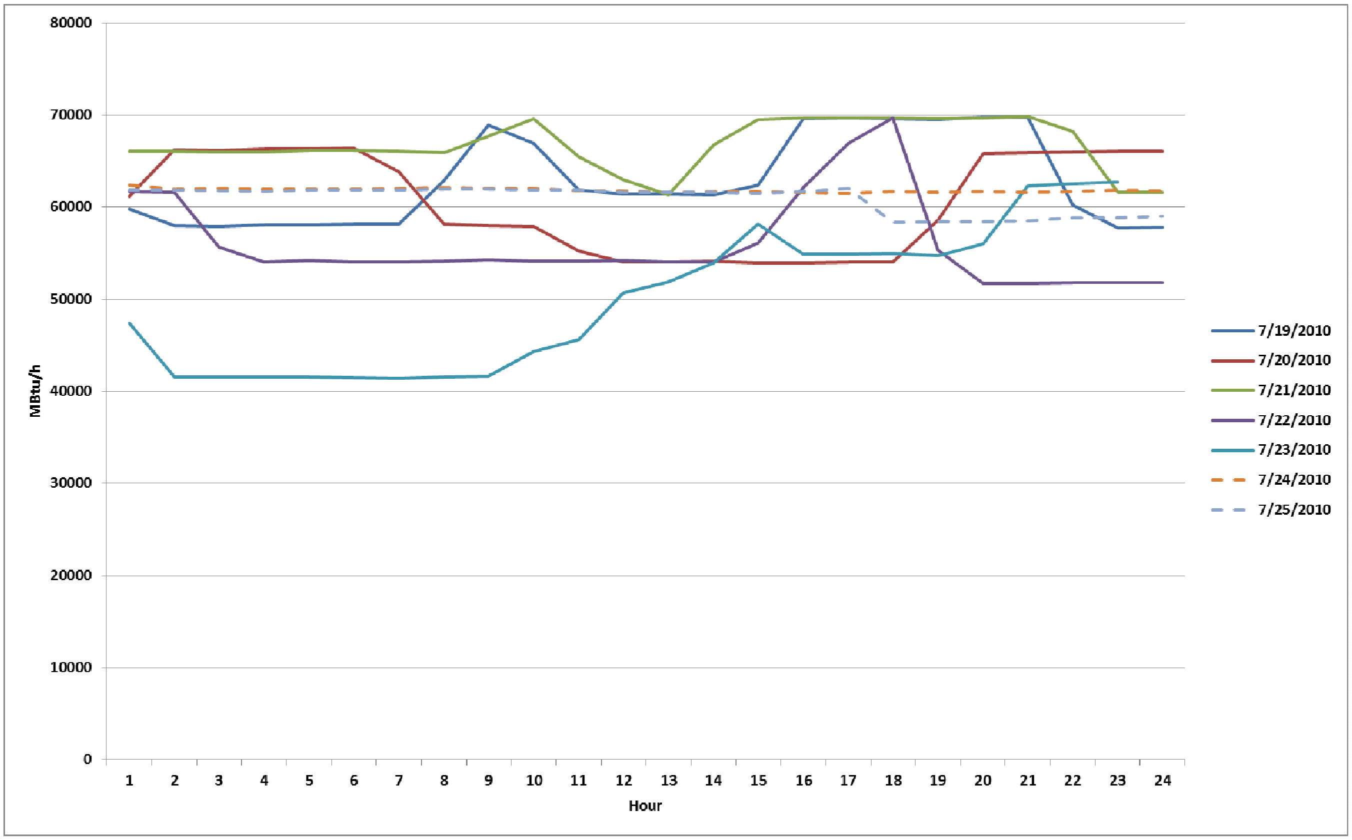


FIGURE CHP USEFUL THERMAL OUTPUT VERSUS TIME

Figure covers the time period from July 19 - 25, 2010 providing CHP system useful thermal energy output by hour of the day pattern for the time period. July 24 is a Saturday. 60,000 MBtu/h is significantly higher that the ~38,000 MBtu/h available from waste heat. This confirms that the duct burners are used year-round to meet the thermal load requirements of the hospital. Summertime use is driven by the absorption chiller operation.

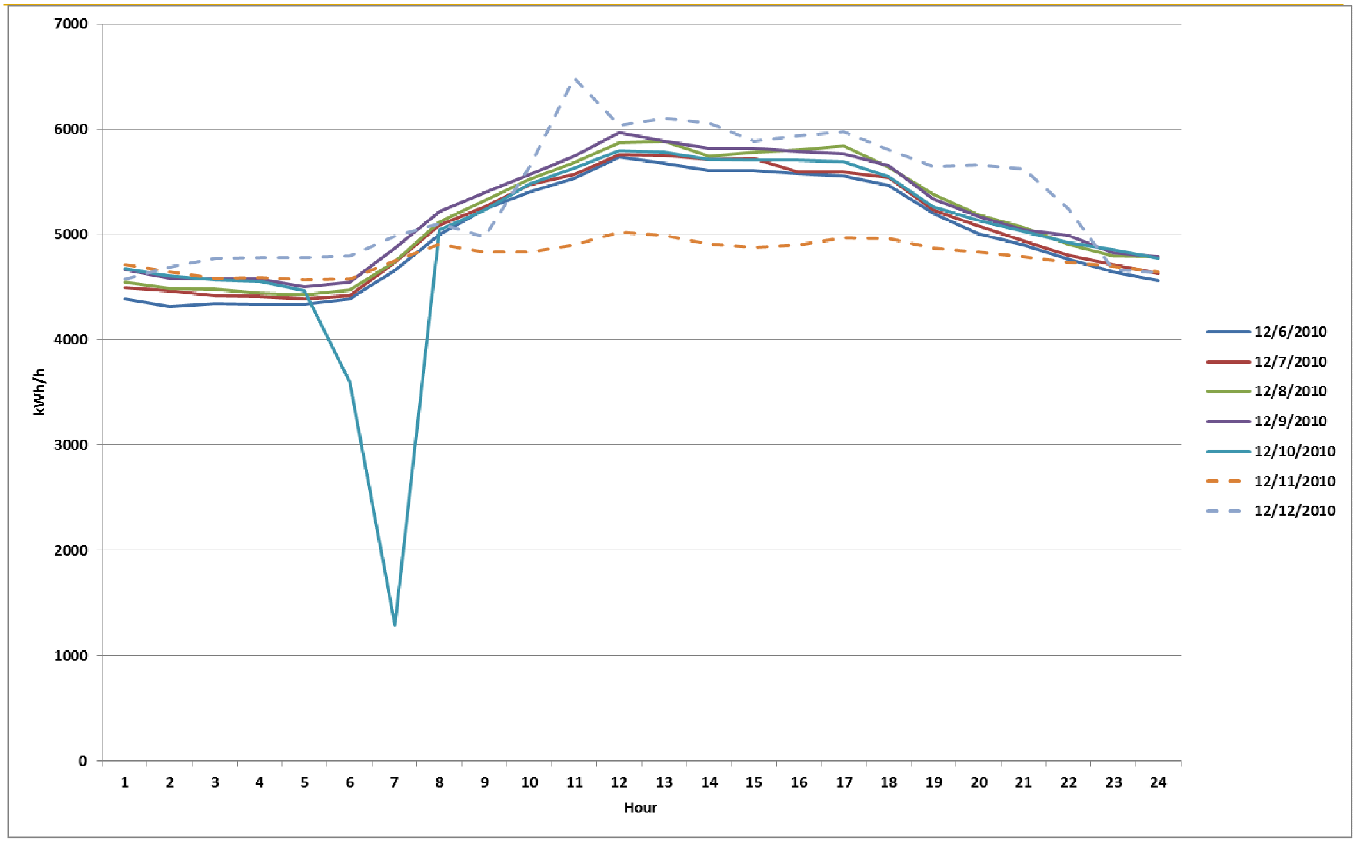


FIGURE CHP POWER OUTPUT VERSUS TIME

Figure covers the time period from December 6 - 12, 2010 providing CHP system power output by hour of the day pattern for the time period. December 11 is a Saturday. The weekend shows a flatter load profile than the weekdays. The electric load pattern in the winter appears to be in electric load following mode.

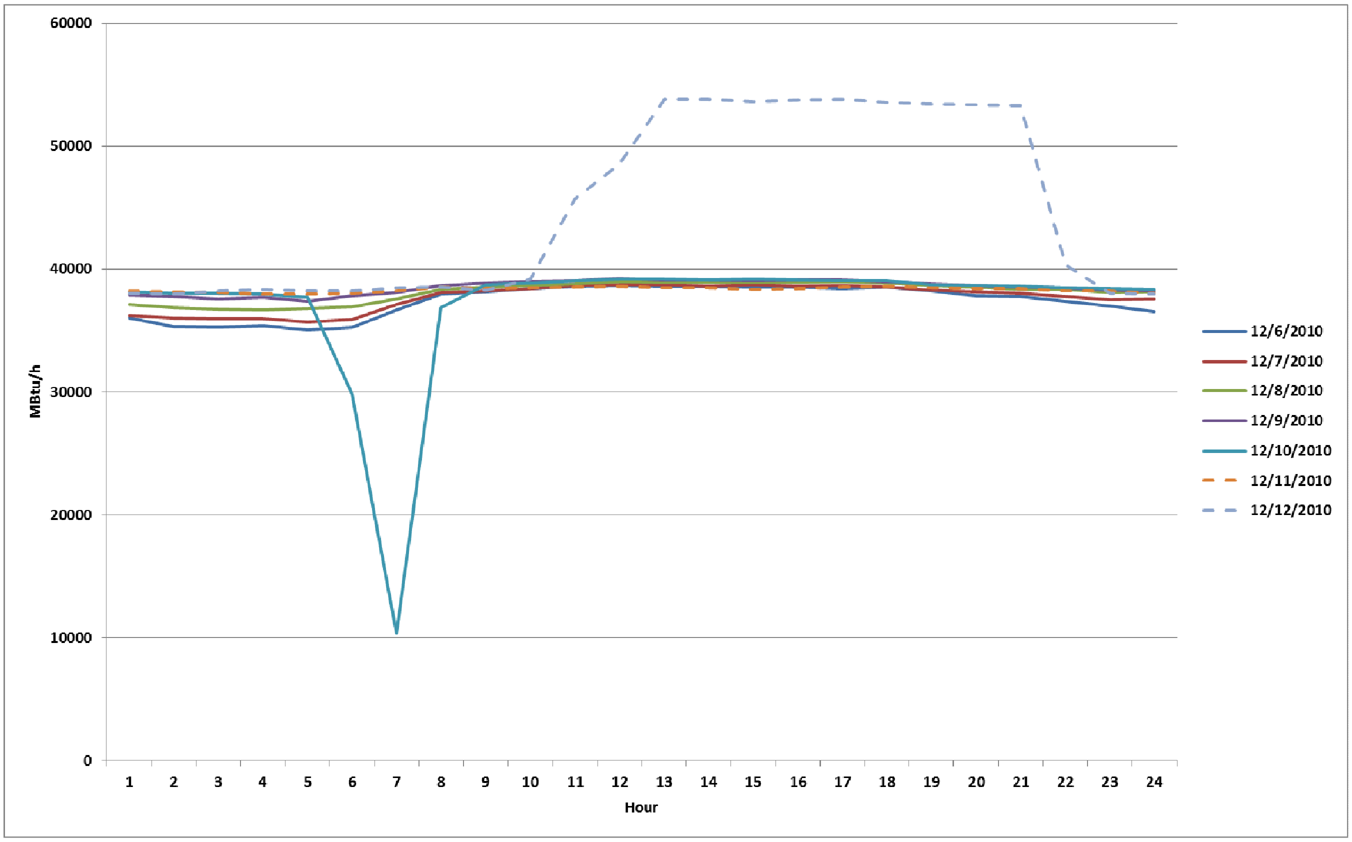


FIGURE CHP USEFUL THERMAL OUTPUT VERSUS TIME

The 24 hour useful CHP recovered heat thermal load profiles from December 6 - 12, 2010 (Figure). December 11 is a Saturday. The Friday drop in thermal energy is likely due to the system going down for short time. The Sunday rise in thermal use is load related. Generally the hospital steam loading is very consistent.

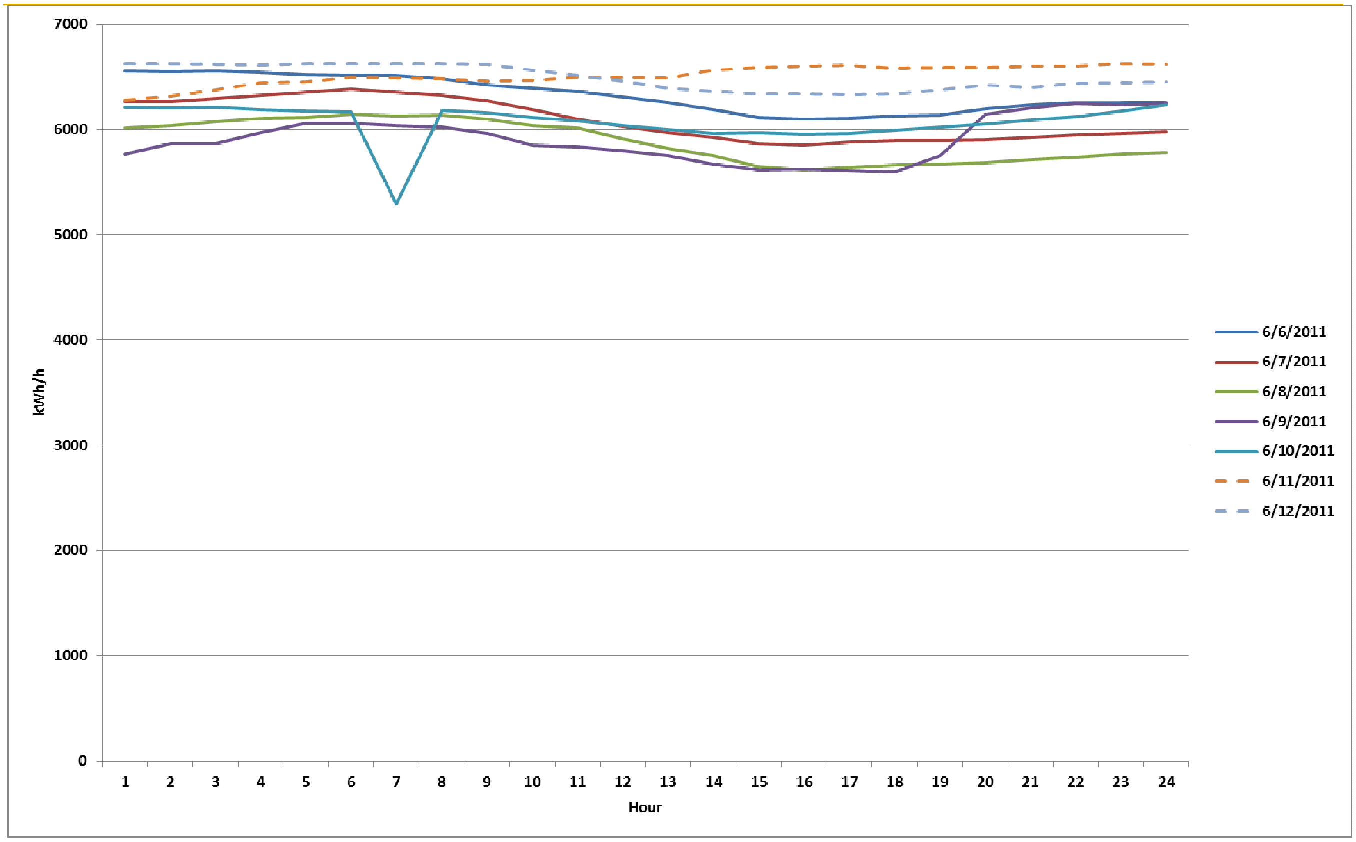


FIGURE CHP POWER OUTPUT VERSUS TIME

Figure covers the time period from June 6 – 12, 2011 providing CHP system power output by hour of the day pattern for the time period. June 11 is a Saturday. The figure shows consistent power 24/7.

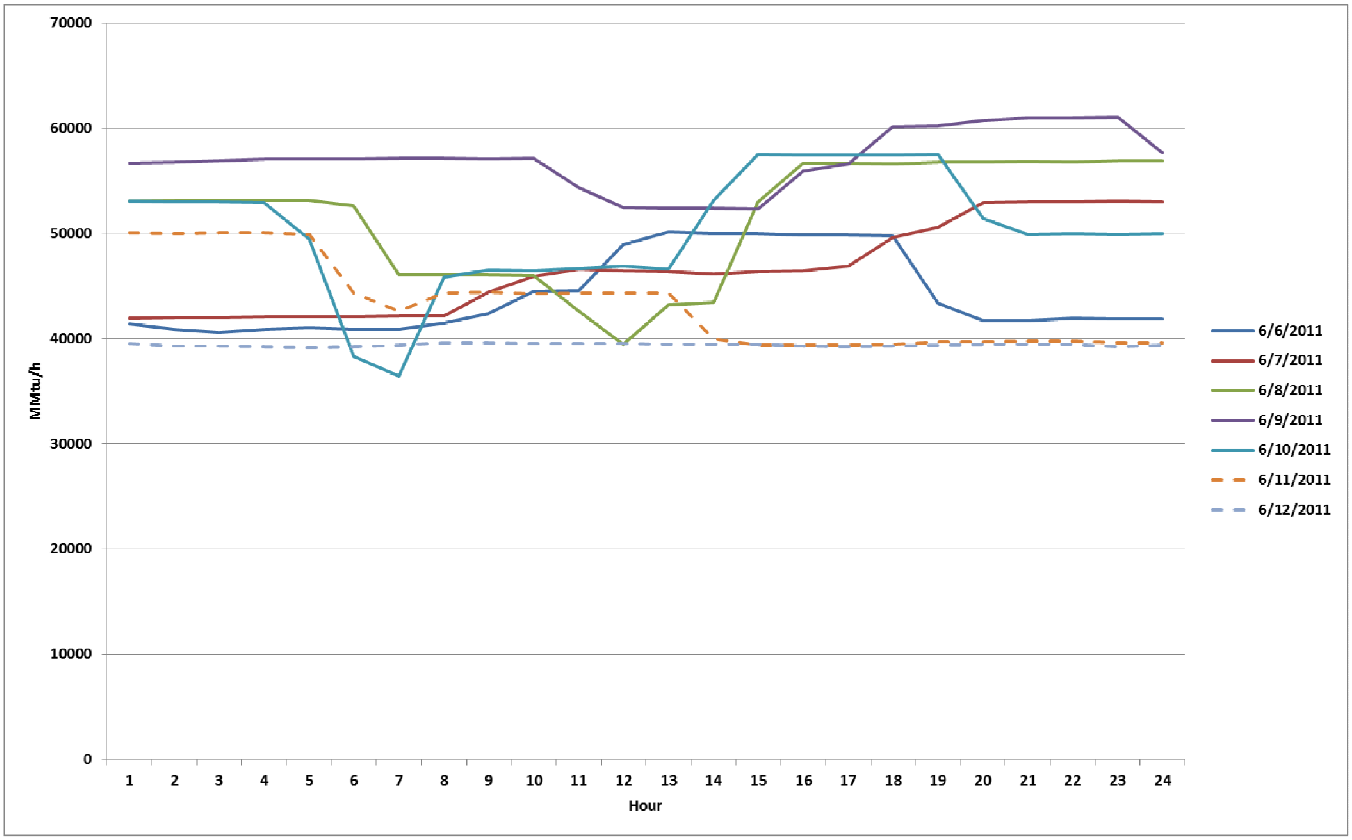


FIGURE CHP USEFUL THERMAL OUTPUT VERSUS TIME

The 24 hour useful CHP recovered heat thermal load profiles from June 6 – 12 (Figure). June 11 is a Saturday. Like Figure (July 2010), Figure (June 2011) shows high steam loading versus Figure (December 2010) indicating more summertime steam usage than wintertime to supply energy for space cooling to further reduce peak electric demand.

PERFORMANCE SUMMARY

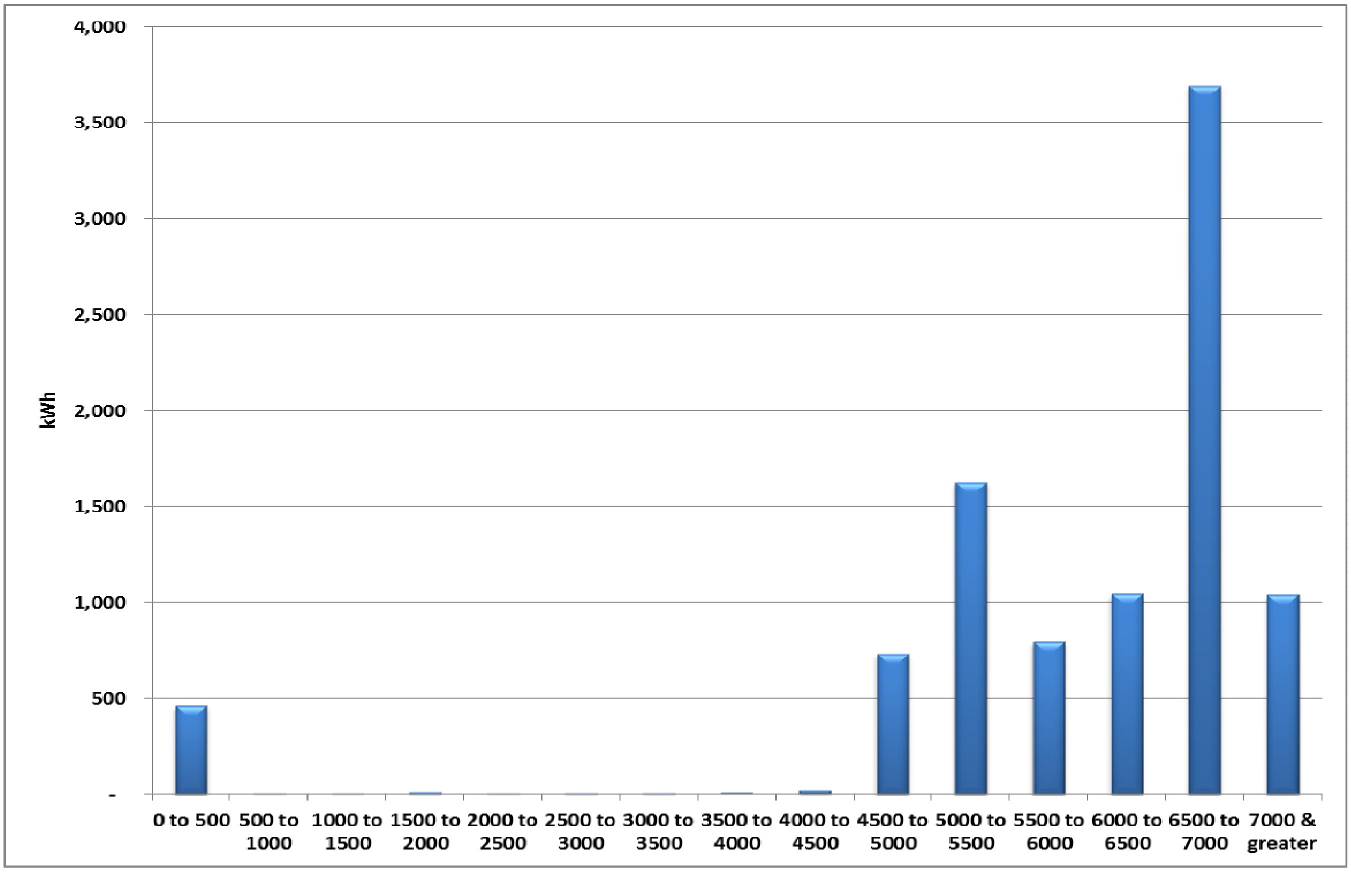


FIGURE PERFORMANCE BY POWER BINS

During the 9,466 operating hours between November 16, 2009 and December 31, 2010 that met the range and relational checks 61% of this time, the CHP system delivered between 6 and 7 MW/hr (Figure).

LESSONS LEARNED

TABLE SYSTEM EFFICIENCY[3]

	Hours of Good (Pwr) Data	Net Electric Output (kWh)	Natural Gas Use (MCF)	Useful Heat Output (MMBtu)	Electrical Efficiency	Useful Thermal Efficiency	Fuel Conversion Efficiency
January-10	744	3,946,496	50,086.3	29,129.3	26.4%	57.0%	83.4%
February-10	602	3,237,741	41,881.7	26,524.0	25.9%	62.1%	88.0%
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April-10	579	3,605,515	45,145.7	27,557.0	26.7%	59.8%	86.6%
May-10	744	3,853,234	46,964.4	29,896.7	27.5%	62.4%	89.9%
June-10	720	4,904,253	59,470.3	41,115.6	27.6%	67.8%	95.4%
July-10	721	4,778,849	58,500.2	42,038.0	27.3%	70.5%	97.8%
August-10	720	4,746,939	58,715.0	38,514.9	27.1%	64.3%	91.4%
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April-11	704	3,411,463	42,257.6	23,924.3	27.0%	55.5%	82.5%
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Total preceding 12 months	**8612**	**49,278,512**	**617,971**	**364,093**	**26.7%**	**57.8%**	**84.4%**

Note: All efficiencies based on higher heating value of the fuel (HHV)

A single 7.5 MW gas turbine generator set was installed at the facility to provide electricity to various load centers across the campus. Heat recovered from the turbine exhaust, supplemented by a duct burner, is used to produce high pressure steam. The system can provide 60% or more of the site's electrical power. Waste heat is used to make steam for the site steam loop.

[3] Efficiency data is collected using all data points flagged as high quality data. Generally there is good correlation between the data quality of net electric output, natural gas use and useful heat rejection. Anomalies do occur, particularly with respect to natural gas use which causes distortions in the results. If efficiency results are out of normal range, the most likely cause is poor quality concurrent data which can be corroborated by the Site Data Quality table located in the Lessons Learned section of this report.

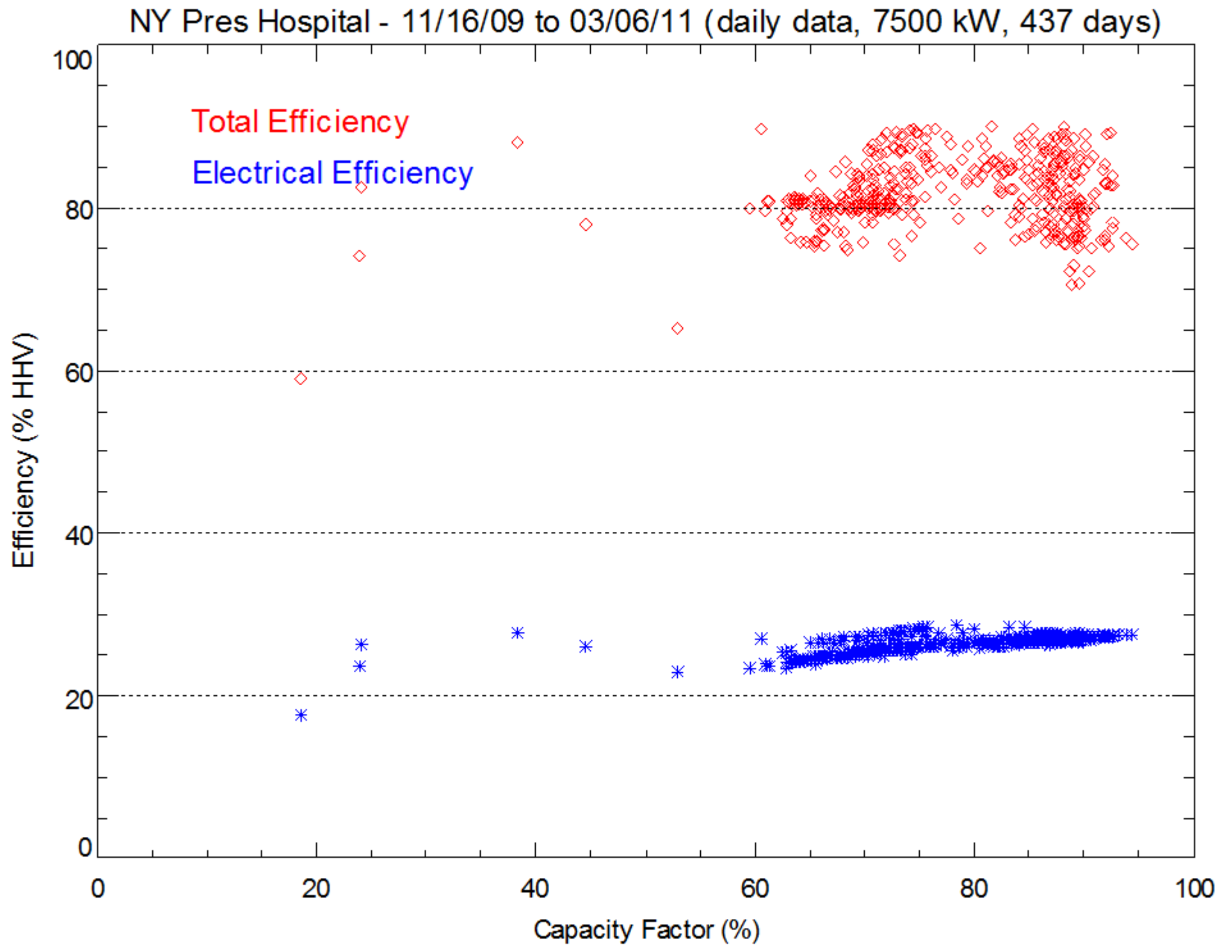

FIGURE CAPACITY FACTOR[4]

Capacity Factor (Figure 20) presents the CHP generated power efficiency over the time period (437 days). This Figure provides a very good overview of the CHP power capacity versus site power requirements and a good understanding of the useful thermal energy recovered. The Figure shows the system operating in electric load following mode between 60% and 95% of capacity performing at 26.7% power efficiency (HHV). The combustion turbine shows Brayton cycle performance plus parasitic degradation as capacity reduces. Note the two distinct part load curves for electric efficiency indicating lower performance during winter (higher efficiency due to denser air. The useful thermal energy to produce steam remains very high owing to high steam load requirement by the facility and that a duct burner is used to supplement the heat energy from the combustion turbine. Note the fuel to the duct burner is not accounted for in the data acquired which leads to the high system useful recovered thermal energy which is 57.8% thermally efficient (HHV).

The facility clearly uses steam to drive absorption chillers in the summer. The HRSG duct burners are used to meet that summertime steam load. The steam driven absorption chillers seem to be activated at the discretion of the operators.

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4 The data shown in the Capacity Factor graph passes all data quality checks and therefore, in some cases where data quality is poor, leaves out a significant amount of data points.

Gas turbines have poor electrical efficiency at part load. This system was sized so that the power output rarely falls below about 2/3 of full load output.

APPENDIX A: KEY DATA MEASURES AND QUALITY

The three key parameters contributing to system energy efficiency were DG/CHP Generator Output, DG/CHP Generator Gas Use and Useful Heat Recovery (total MBtu). These parameters were measured at this site as follows:

1. **DG/CHP Generator Output (total kWh)** The Generator Output comes from the columns labeled "Generator Output KWH" and "Parasitic Load KWH" in the data files from Norgen. The generator output minus the parasitic load is displayed as the total generator output. This 15-minute interval energy data is summed into hourly data.
2. **DG/CHP Generator Gas Use (total cubic feet)** The data for Generator Gas Input comes from the data point "Gas to Turbine Therms" in the data files from Norgen. This data is provided in therms for each 15-minute interval. It is converted into standard cubic feet of gas using the higher heating value and summed into hourly data. This data does not include the fuel used by the duct burners.
3. **Useful Heat Recovery (total MBtu)** The Useful heat Recovery is obtained from the columns of data labeled "Steam from HRSG KBtu" in the files obtained from Norgen. These points are provided in units of KBtu. This 15-minute data is summed into hourly data. Steam can be produced from both exhaust heat recovery and the duct fired burner (but duct burner fuel is not measured)

It is important to understand the significance of the data being reported. In this case, the natural gas meter to the CHP system does not capture the fuel supplied to the duct burner, yet the useful thermal energy measured captures the total of the useful recovered heat from the turbine plus the output of the duct burner. This provides reported recovered thermal energy in excess of what was actually recovered and does not account for the fuel to achieve this excess heat.

Clearly the results reported on this site do not reflect the performance of the CHP system as fuel, power and steam data is from combined sources:

1. Measured fuel combined combustion turbine, duct burners and high pressure boiler fuel. The combustion turbines, duct burners and high pressure boiler should all be sub metered.
2. Thermal output from the unfired Heat Recovery Steam Generators needs to be reported separately from the duct burner and boiler contribution.
3. Electric power output from the combustion turbines should be separated from the steam turbine generator.

The above instrumentation changes would provide a clear and more accurate picture of the system performance.

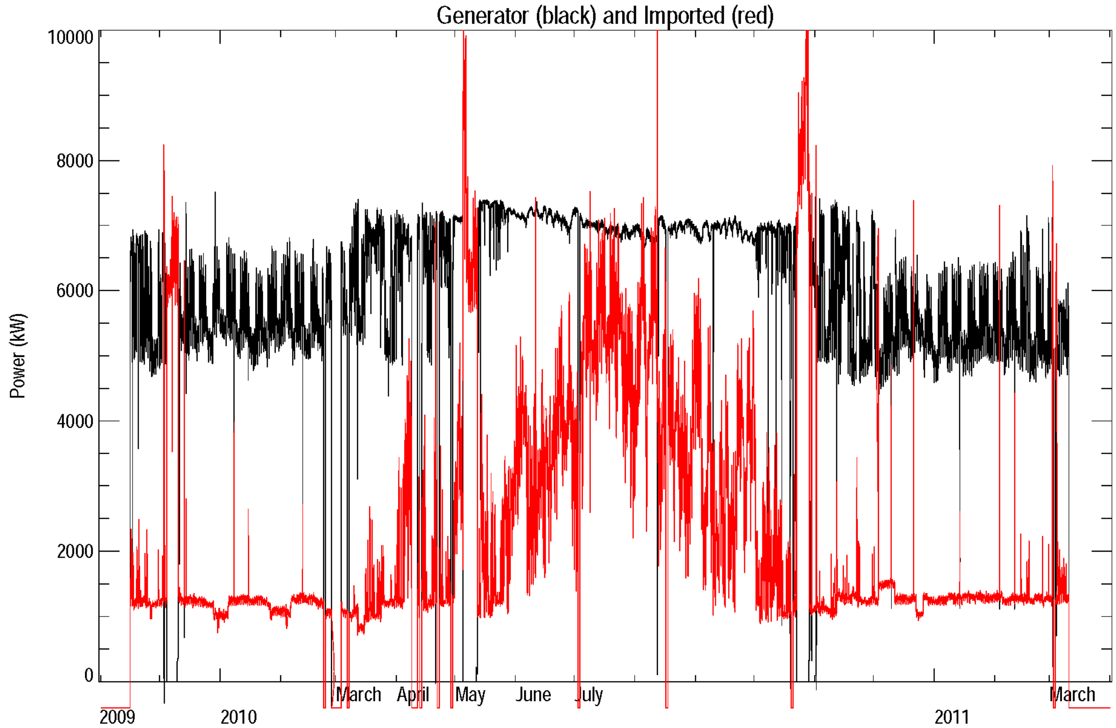
Table provides insight into the high data quality of this site.

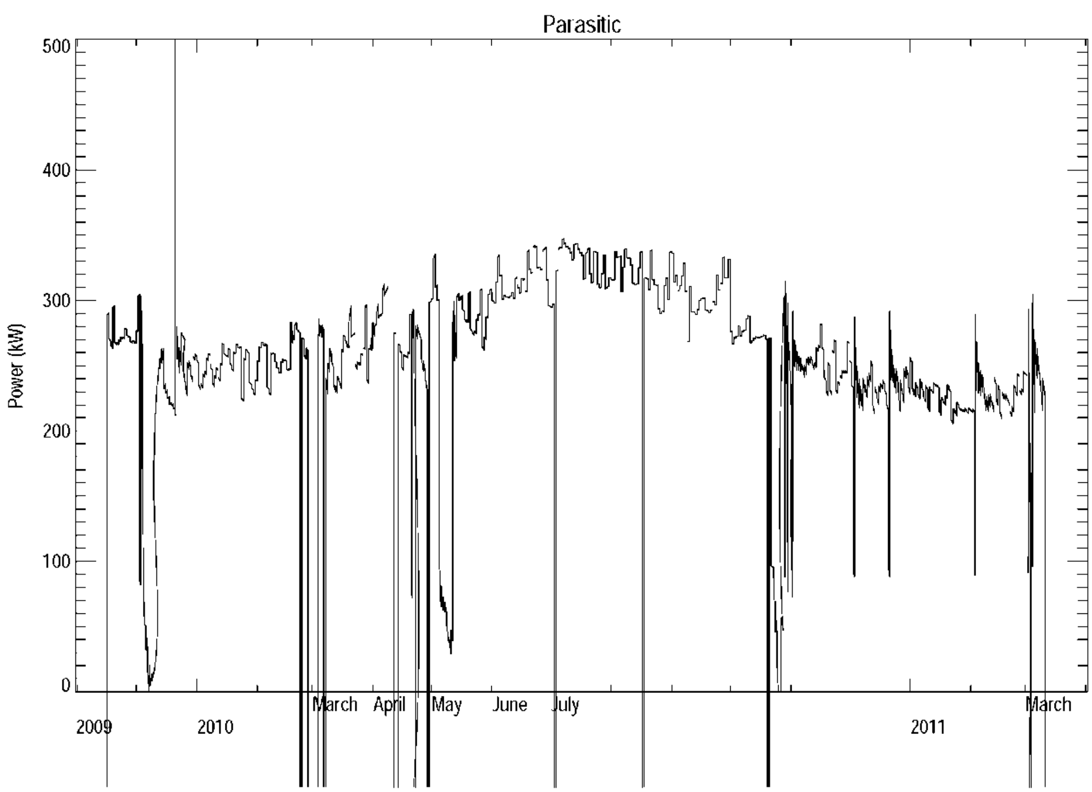
TABLE DATA QUALITY

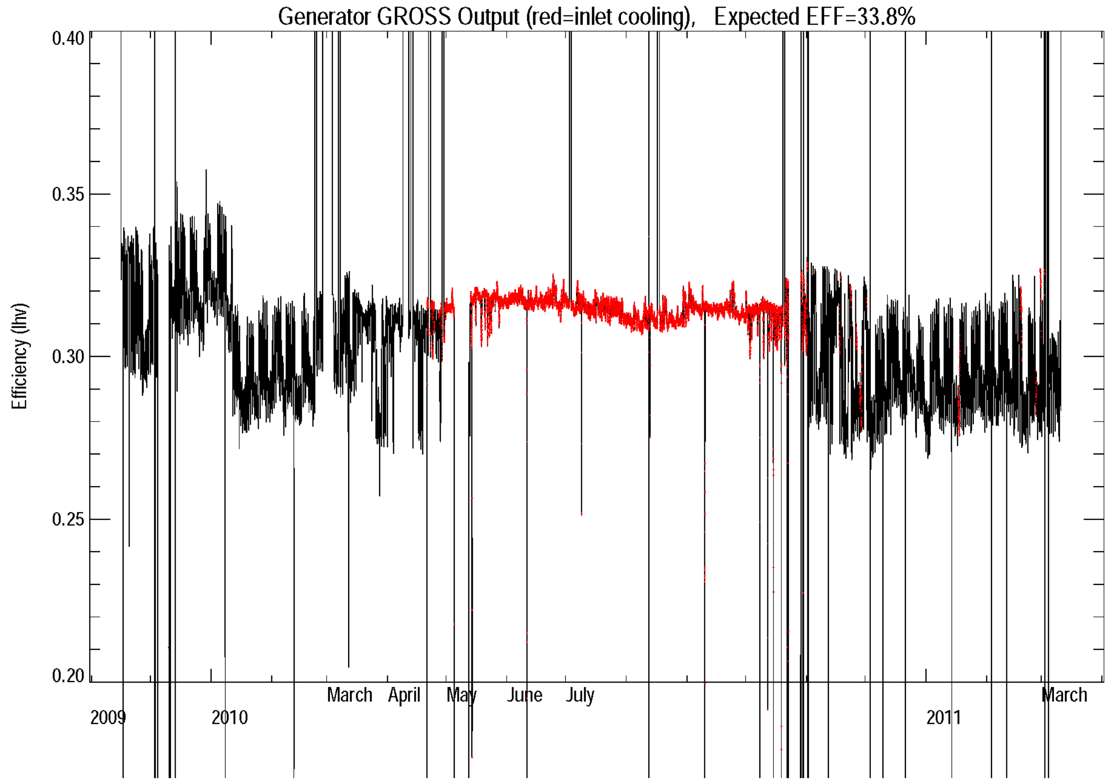
	Percentage of Good Data		
	Power	**Gas Use**	**Useful Heat**
January-10	100.0%	100.0%	100.0%
February-10	100.0%	100.0%	100.0%
March-10	100.0%	100.0%	100.0%
April-10	99.8%	100.0%	100.0%
May-10	100.0%	100.0%	100.0%

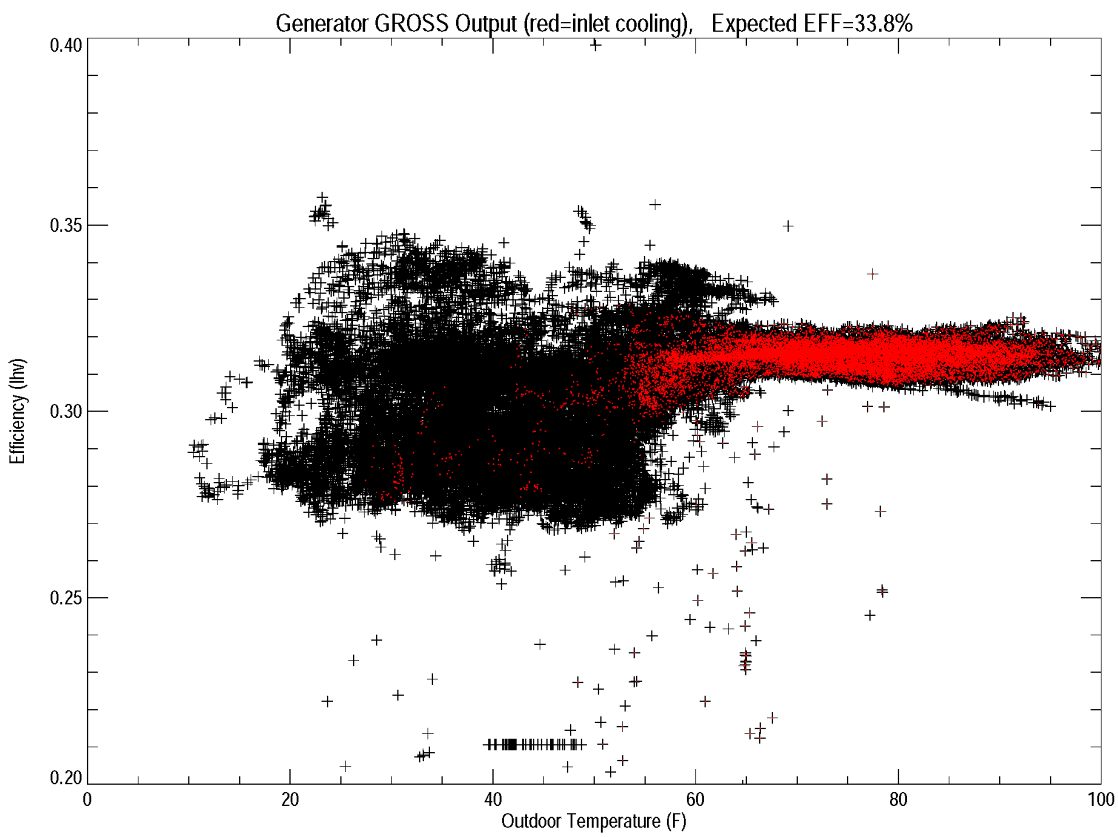
June-10	100.0%	100.0%	100.0%
July-10	100.0%	100.0%	100.0%
August-10	99.9%	100.0%	100.0%
September-10	100.0%	100.0%	100.0%
October-10	97.5%	100.0%	100.0%
November-10	99.7%	100.0%	100.0%
December-10	100.0%	100.0%	100.0%
January-11	100.0%	100.0%	100.0%
February-11	100.0%	100.0%	100.0%
March-11	100.0%	100.0%	100.0%
April-11	97.8%	100.0%	100.0%
May-11	100.0%	100.0%	100.0%
June-11	97.6%	100.0%	100.0%
July-11	100.0%	100.0%	100.0%

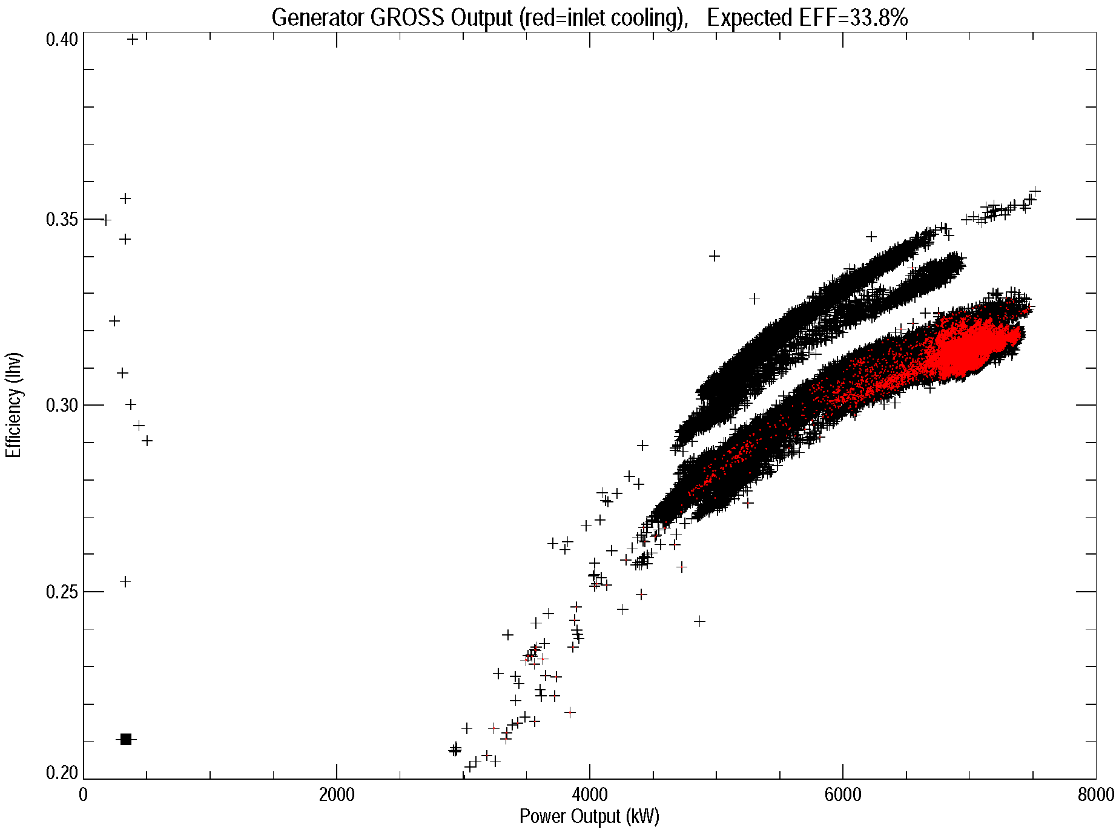
APPENDIX B – POWER AND GAS TURBINE INLET COOLING



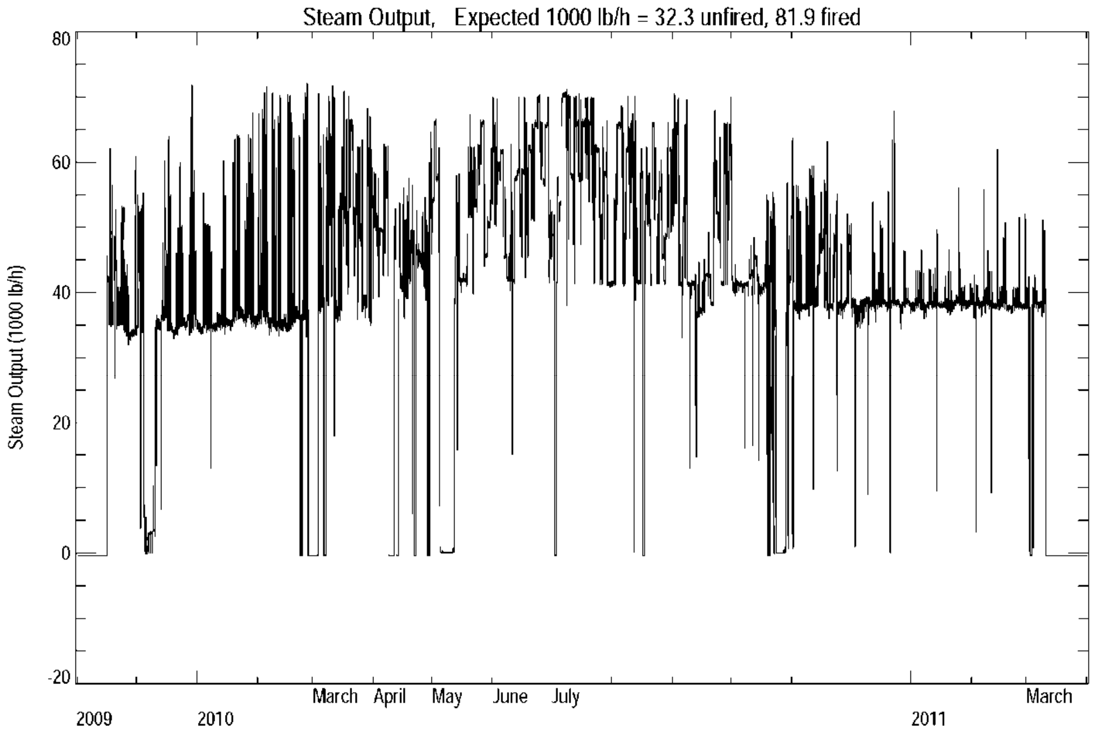


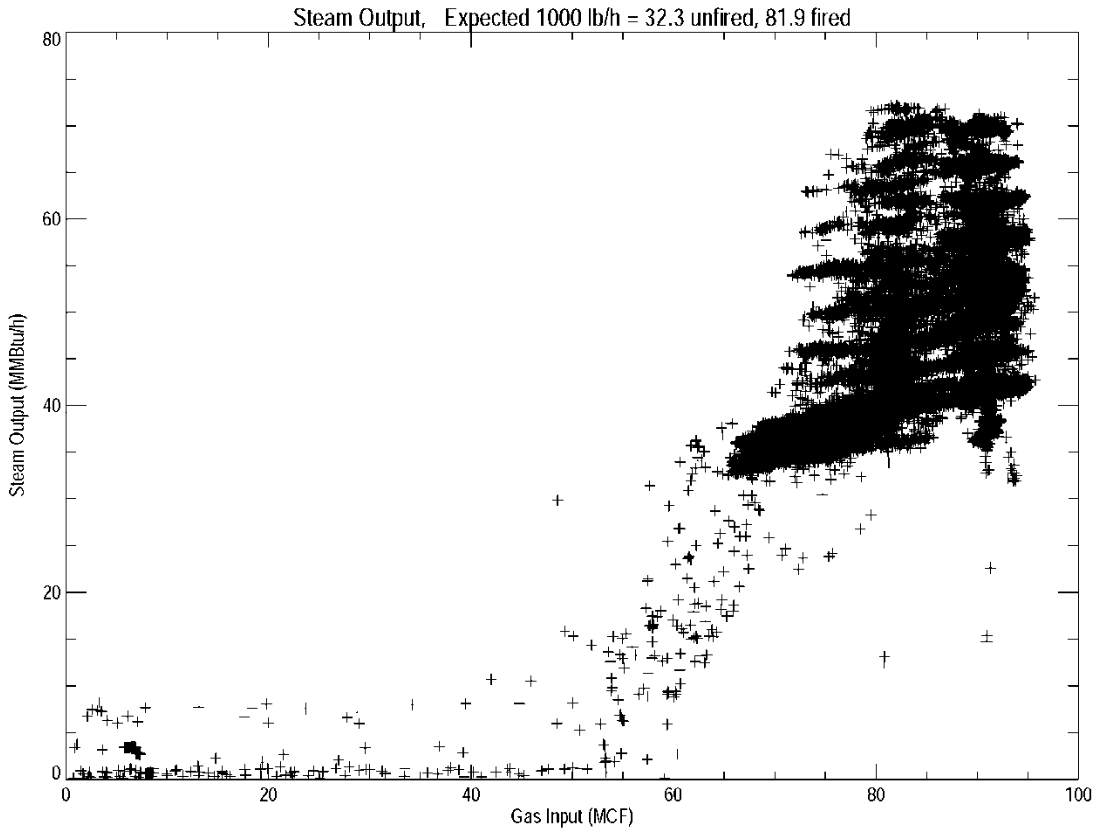

Generator GROSS Output (red=inlet cooling), Expected EFF=33.8%
Efficiency (lhv)
0.40
0.35
0.30
0.25
0.20
March
April
May
June
July
March
2009
2010
2011

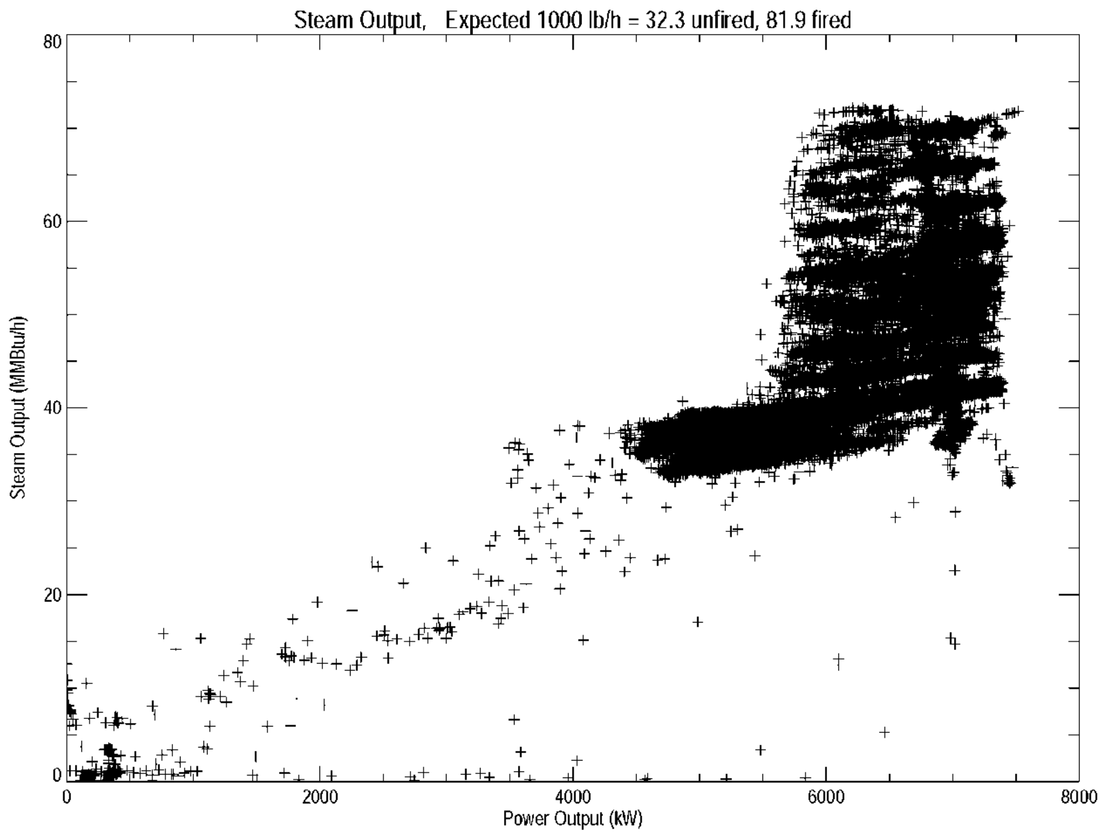

Generator GROSS Output (red=inlet cooling), Expected EFF=33.8%
Efficiency (lhv)
0.40
0.35
0.30
0.25
0.20
0
20
40
60
80
100
Outdoor Temperature (F)


Generator GROSS Output (red=inlet cooling), Expected EFF=33.8%
Efficiency (lhv)
0.40
0.35
0.30
0.25
0.20
0
2000
4000
6000
8000
Power Output (kW)

APPENDIX B – STEAM OUTPUT




Steam Output, Expected 1000 lb/h = 32.3 unfired, 81.9 fired
Steam Output (MMBtu/h)
Gas Input (MCF)
0
20
40
60
80
100
0
20
40
60
80


Steam Output, Expected 1000 lb/h = 32.3 unfired, 81.9 fired
Steam Output (MMBtu/h)
Power Output (kW)
0
2000
4000
6000
8000
0
20
40
60
80