NYSERDA CHP Assessment Report
Assessing the CHP Plant at Burke Rehabilitation Hospital

March 29, 2012

Burke Rehabilitation 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.

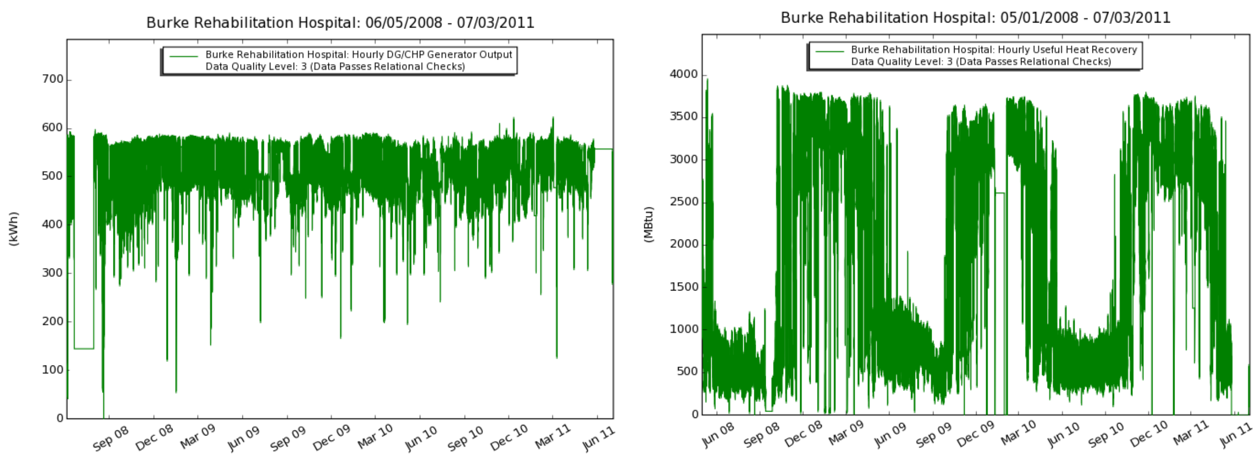

FIGURE 1 NYSERDA CHP WEBSITE PERFORMANCE GRAPHS

This report provides an 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 2 ADMINISTRATION BUILDING BURKE REHABILITATION HOSPITAL IN WHITE PLAINS, NEW YORK

Burke Rehabilitation Hospital is located in White Plains, NY. The hospital is dedicated to rehabilitative care and related medical research. The hospital consists of 17 buildings with a total floor space of 257,000 ft^2. In-patient capacity is 140 beds.

THE SYSTEM

The CHP system includes eight (8) Tecogen 75 kW units. The total gross power output is 600 kW. Thermal output from the units is used to meet various hot water loads in the facility. Dump radiators reject any unused heat from the engines. The heat recovery system can nominally provide 4,080 MBtu/h of heat to the facility loads (according to the drawings).

The generators are 480 VAC, 3-phase (wye) induction generators. The electrical service for the 8 generators combined is 1200 amps. The facility electrical service is 480 VAC, 3-phase at 3000 amps.

The generator power is fed into the main facility panel. A protective relay monitors generator output as well as the utility status to satisfy the Consolidated Edison inter-connection requirements.

Heat from the engine loop can be used to meet thermal loads in the facility via five heat exchangers (see Figure 2). The thermal loads include:

- Terminal Reheating – Loop P-4 (summer, 2,550 MBtu/h)
- Perimeter Space Heating - Loops P-5 and P-40 (winter, 5,550 & 5,550 MBtu/h)
- Makeup water pre-heating for DHW (year-round, 260 MBtu/h)
- Makeup water pre-heating for Laundry (year-round, 60 MBtu/h)

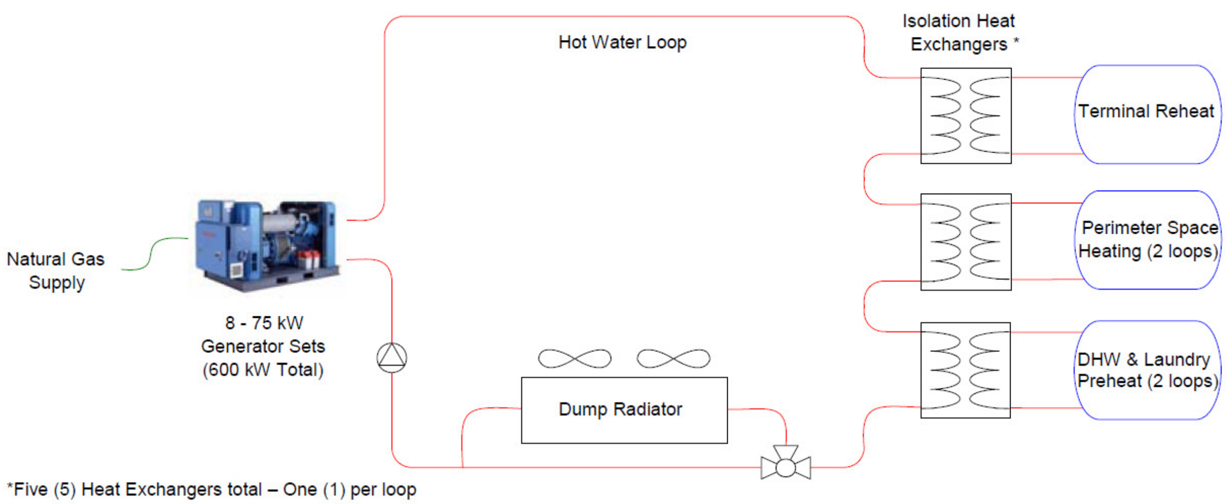

FIGURE 3 SIMPLIFIED HEAT RECOVERY (JACKET WATER / EXHAUST) FOR ONE OF THE EIGHT SYSTEMS

FIGURE 4 MECHANICAL ROOM SHOWING SEVERAL ENGINE GENERATORS

PERFORMANCE

The New York State Energy Research and Development Authority (NYSERDA) offers certain incentives to promote the installation of clean, efficient, and commercially available CHP Systems that provide summer on-peak demand reduction. Incentives are performance-based and correspond to the summer-peak demand reduction (kW), energy generation (kWh), and fuel conversion efficiency (FCE) achieved by the CHP system on an annual basis over a two-year measurement and verification (M&V) period.

OPERATING SUMMARY

Table 1 and Figure 5 show the fuel to power efficiency of the system is declining slightly over operating years. This suggests that a tune-up may be required to maintain peak engine/generator performance. The thermal load on the CHP plant varies by season of the year. Typically, the perimeter heating, DHW and laundry are the winter loads. In the summer, the loads are terminal reheat, DHW and laundry. Loads for the swing season are typically in between.

The engine generator efficiency (high –mid twenty percent range) is indicative of continuous operation and a good operating profile from the perspective of high power generation efficiency[1]. When engines cycle power generation efficiency will fall. In the case of this particular engine, performance in the low twenty percent range is a good indication of cycling performance.

[1] This is not necessarily good for overall system energy efficiency or good economic performance.

The large, seasonal swings in useful thermal energy recovered (easily identified in NYSERDA's web-based DG/CHP data system and also Figure 7 impact the installation's economics. Adding other thermal uses during the spring, summer and fall would significantly improve the performance of this system.

TABLE 1 SYSTEM EFFICIENCY[2]

	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
June-09	719	383,516	4,817	620	26.6%	12.6%	39.3%
July-09	741	364,579	4,557	584	26.8%	12.6%	39.3%
August-09	744	406,709	5,087	527	26.8%	10.2%	36.9%
September-09	708	351,246	4,391	397	26.8%	8.9%	35.6%
October-09	743	390,871	4,814	1,418	27.2%	28.9%	56.0%
November-09	715	374,677	4,607	1,804	27.2%	38.4%	65.6%
December-09	733	384,978	4,719	2,253	27.3%	46.8%	74.1%
January-10	694	362,057	4,497	733	26.9%	16.0%	42.9%
February-10	665	360,315	4,538	2,094	26.6%	45.2%	71.8%
March-10	743	377,078	4,705	2,076	26.8%	43.3%	70.1%
April-10	702	361,228	4,626	1,176	26.1%	24.9%	51.1%
May-10	713	360,964	4,593	663	26.3%	14.2%	40.4%
June-10	714	360,621	4,599	408	26.2%	8.7%	34.9%
July-10	732	371,416	4,780	413	26.0%	8.5%	34.5%
August-10	735	390,213	5,035	429	25.9%	8.3%	34.3%
September-10	720	366,826	4,747	457	25.9%	9.4%	35.3%
October-10	737	379,015	4,929	1,055	25.7%	21.0%	46.7%
November-10	713	384,726	4,913	2,182	26.2%	43.5%	69.7%
December-10	727	386,461	4,966	2,431	26.0%	48.0%	74.0%
January-11	638	341,659	4,405	2,040	26.0%	45.4%	71.3%
February-11	664	366,673	4,677	2,124	26.2%	44.5%	70.7%
March-11	523	284,162	3,672	1,542	25.9%	41.2%	67.1%
April-11	710	380,289	4,946	1,536	25.7%	30.4%	56.2%
May-11	566	298,944	3,982	547	25.1%	13.5%	38.6%
June-11	566	298,944	3,982	547	25.1%	13.5%	38.6%
July-11	729	342,492	4,516	221	25.4%	4.8%	30.2%
Total preceding 12 months	**8,028**	**4,220,403**	**54,772**	**15,109**	**25.8%**	**27.0%**	**52.8%**

2 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.

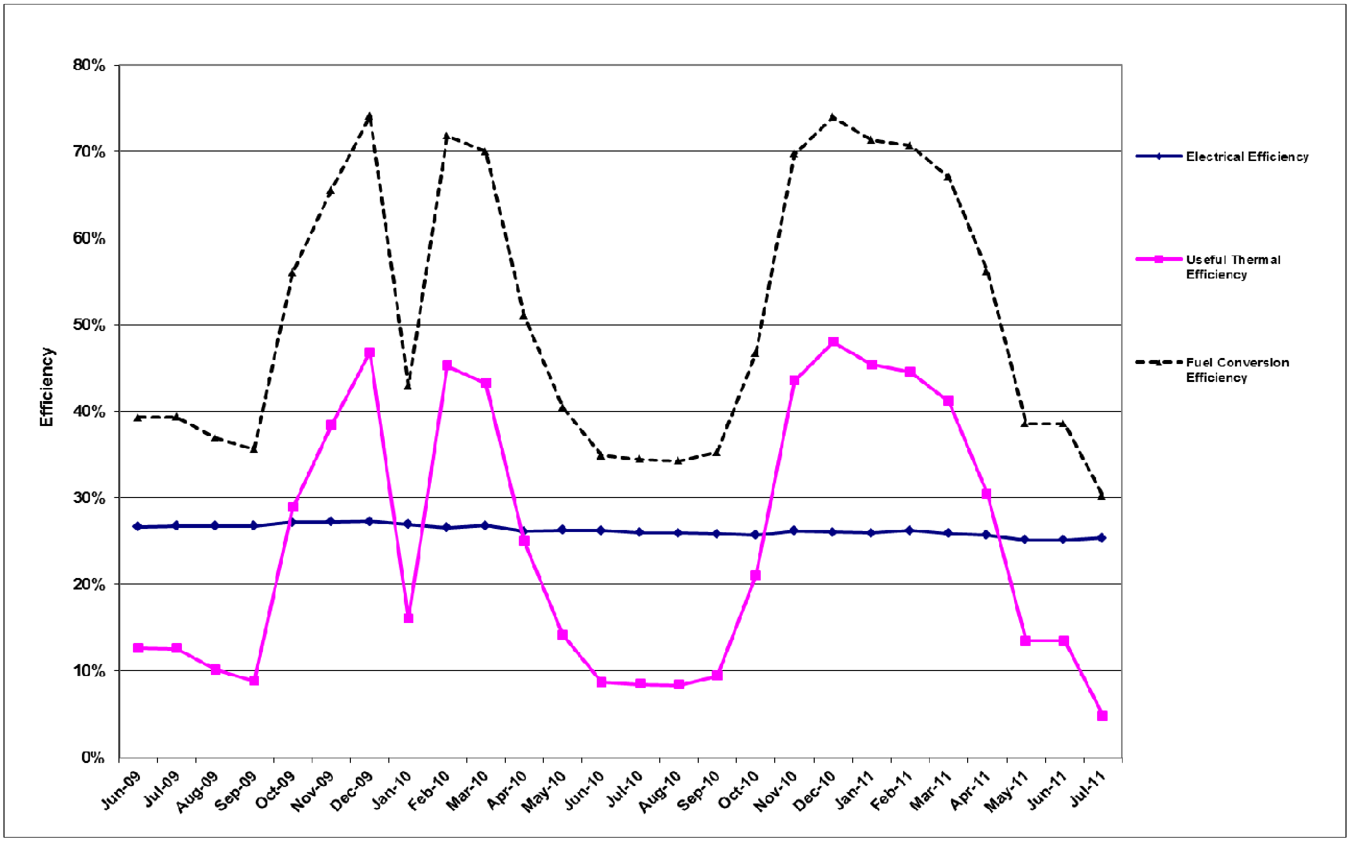

FIGURE 5 2009 CHP SYSTEM EFFICIENCY BY SEASON

POWER GENERATION AND USEFUL THERMAL OUTPUT

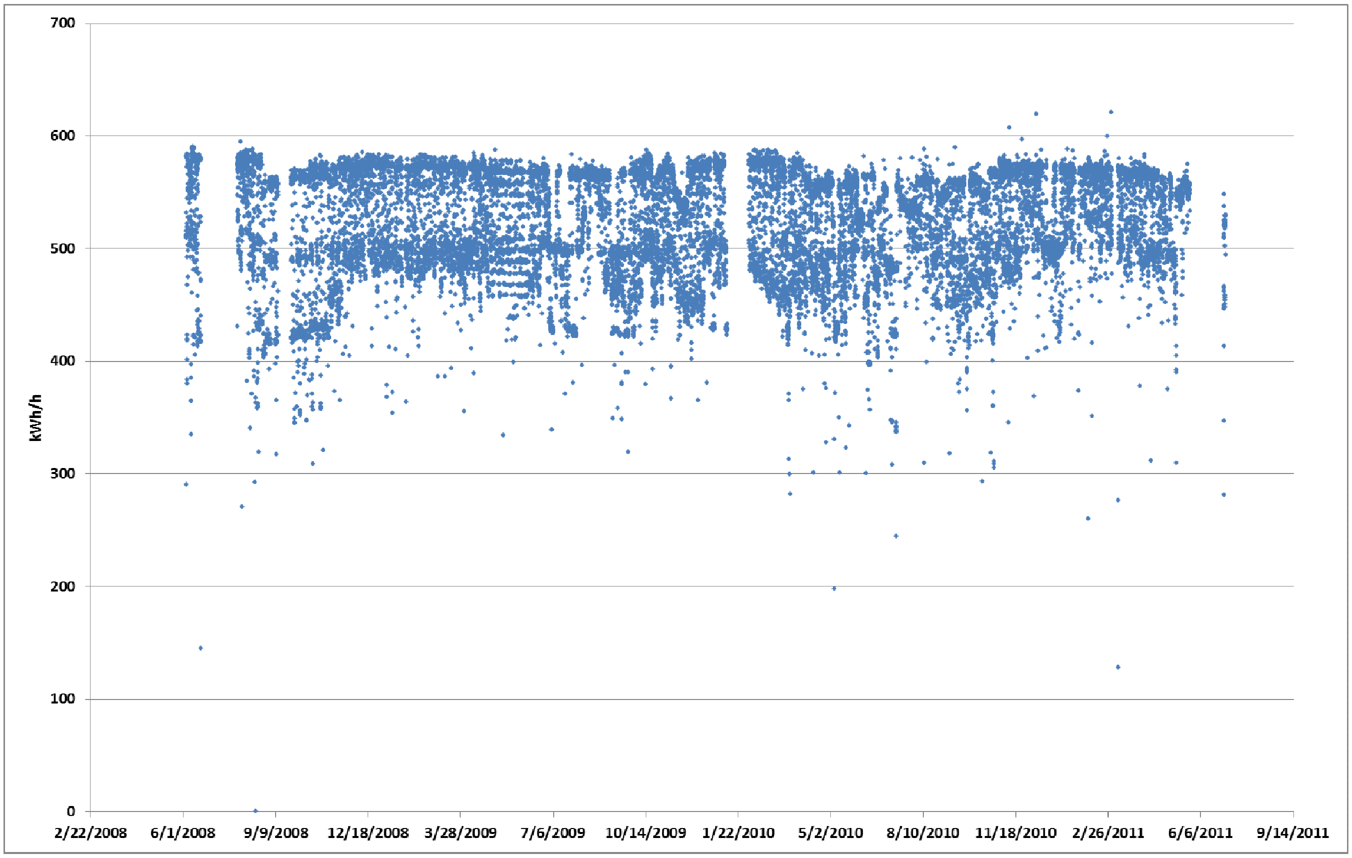

FIGURE 6 CHP POWER OUTPUT VERSUS TIME

Figure 6 provides a general overview of the power production from the CHP plant representing a typical daily electric load following regime ranging from 400 kW up to 580 kW.

Figure 7 is divided into two distinct thermal performance regions that require explanation. Figures 13-16 provide insight into the CHP system thermal performance and Figure 17 provides the CHP system power performance explanation with respect to Figure 7.

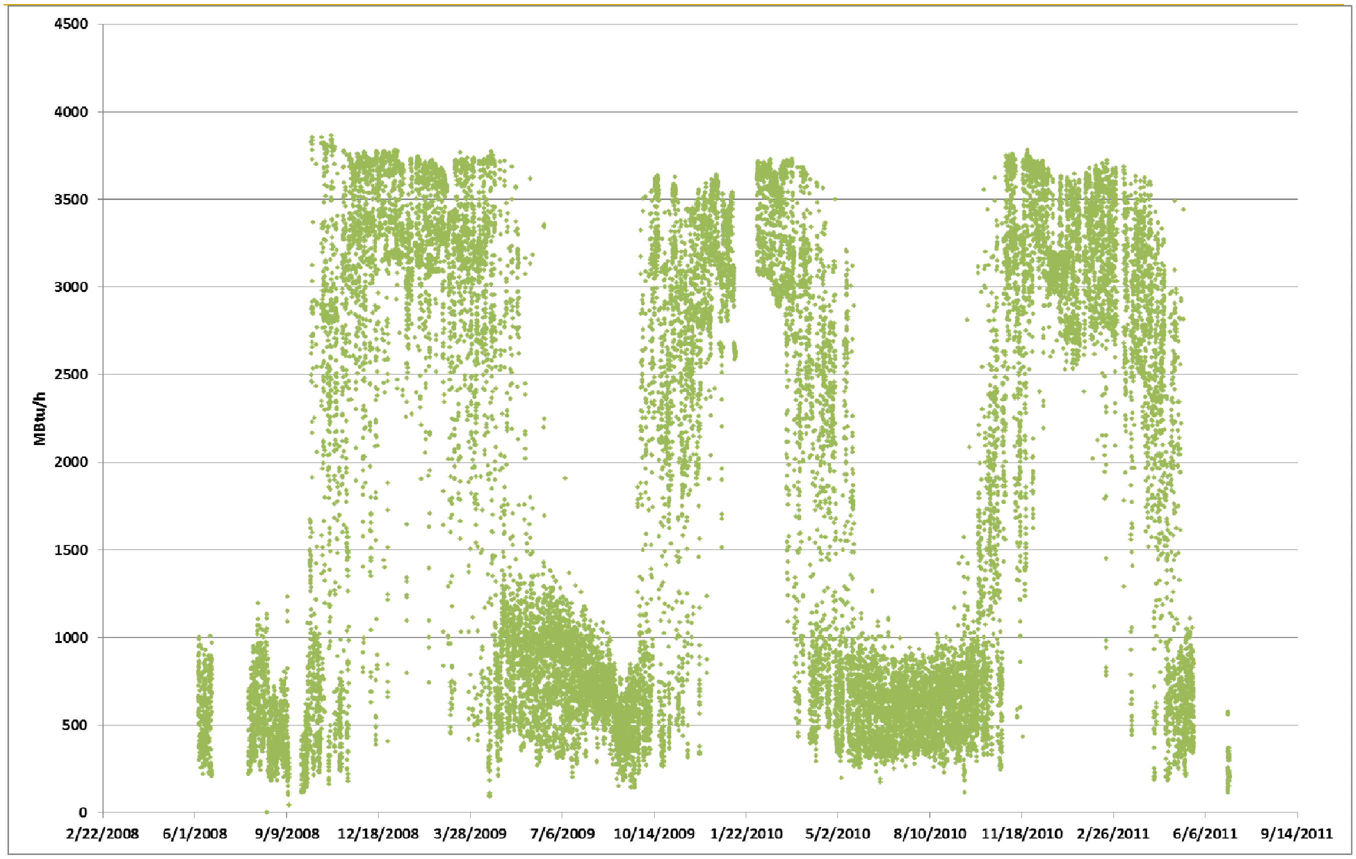

FIGURE 7 CHP USEFUL THERMAL OUTPUT VERSUS TIME

The Figure 7 CHP Useful Thermal Output versus Time pattern is typical of thermal loads providing heating in the wintertime and domestic hot water year round. This site also adds terminal reheat in the summer to add comfort while controlling humidity. Clearly, this cyclical thermal load impacts FCE and operating economics of this system. Adding summertime thermal loads (e.g. cooling and/or dehumidification) would improve system performance. However, economic calculation would be required to determine if this is economically viable.

Note that on the following weekly graphs, weekend days are highlighted as dashed lines to quickly distinguish their operating characteristics.

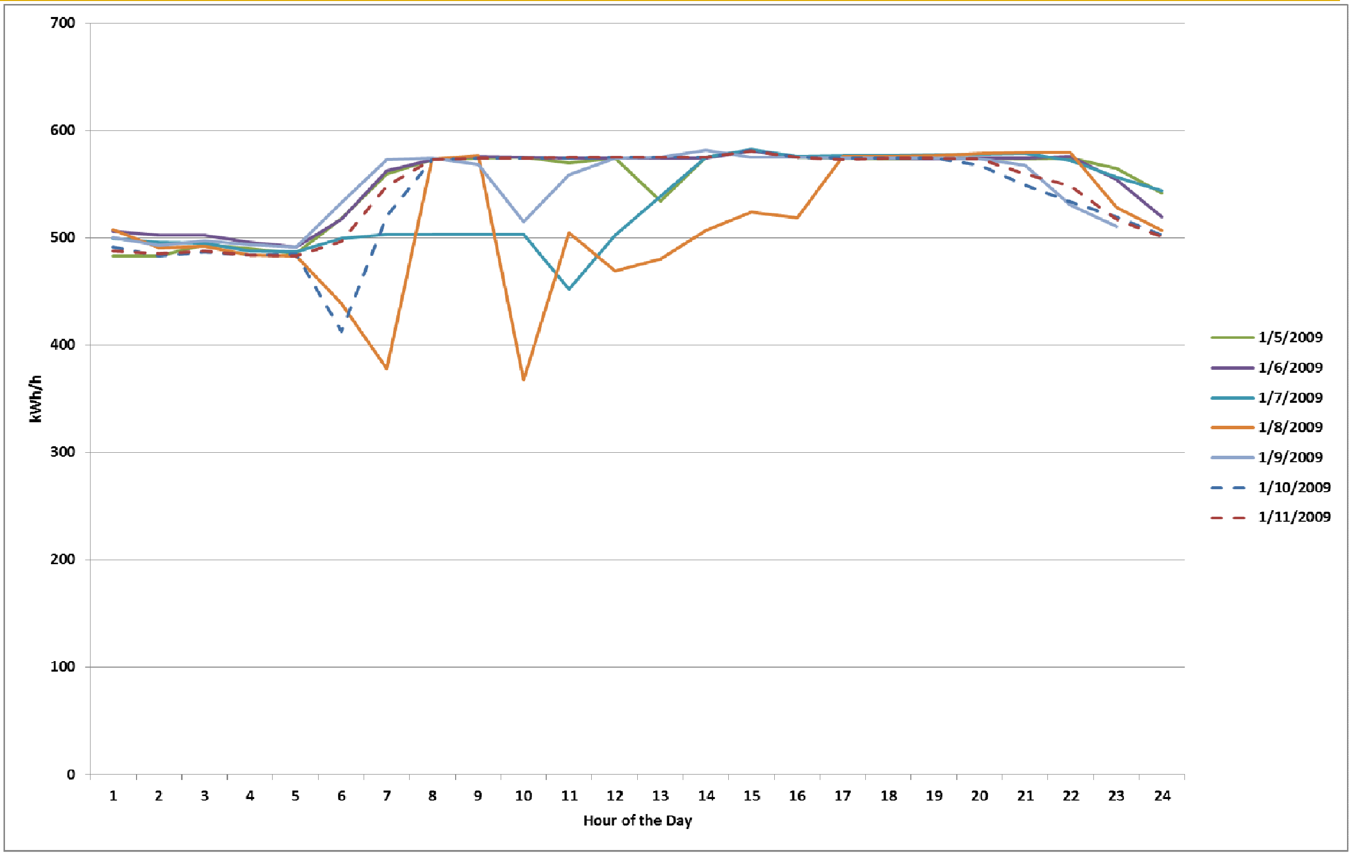

FIGURE 8 CHP POWER OUTPUT VERSUS TIME

Figure 8 covers the time period from January 5 - 11, 2009 providing CHP system power output by hour of the day pattern for the time period. January 5 is a Monday and January 8 & 9 (Wed & Thurs) likely represent engine operating issues that were quickly remedied. Figure 8 shows that all days are showing similar usage patterns suggesting electric load following.

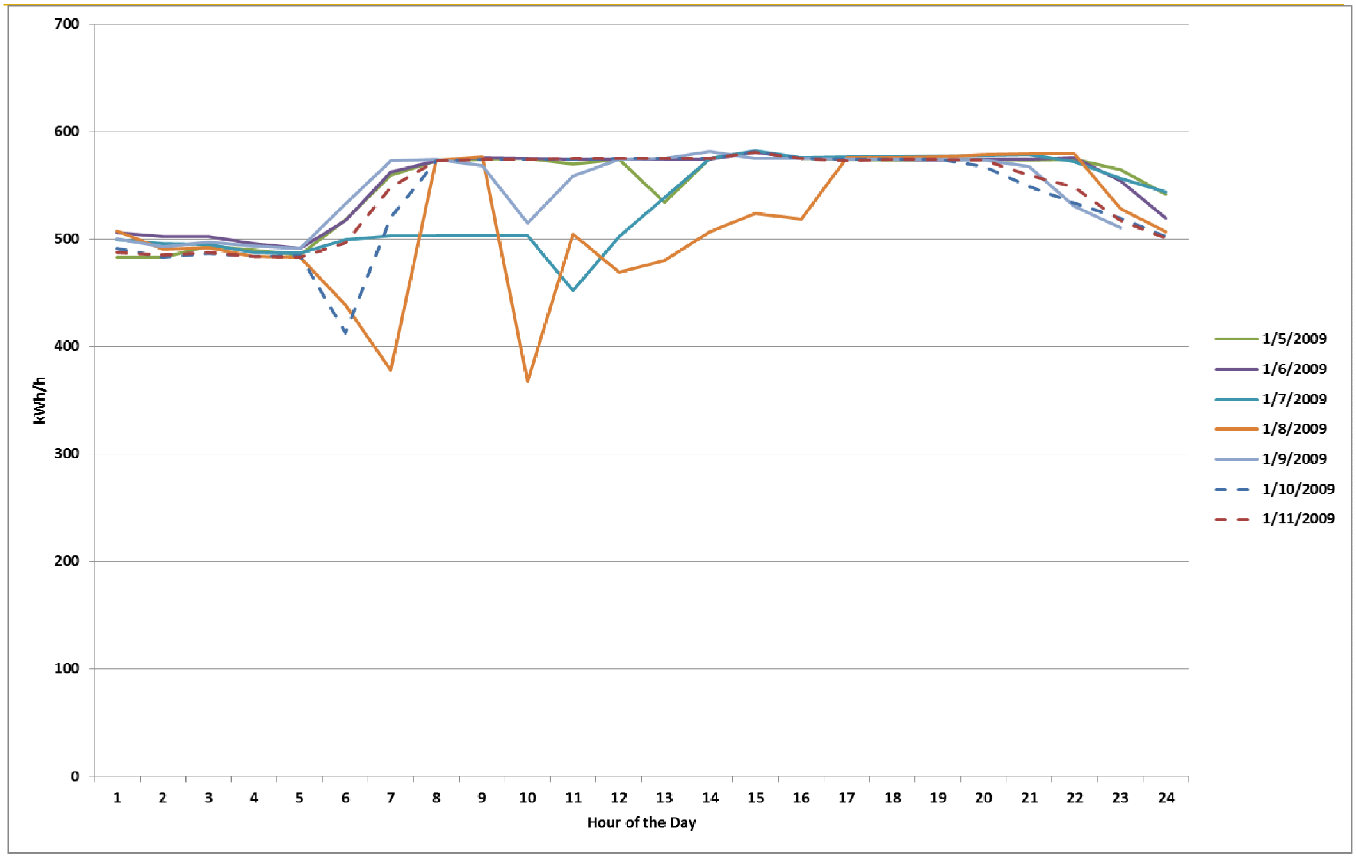

FIGURE 9 CHP USEFUL THERMAL OUTPUT VERSUS TIME

The 24 hour useful CHP recovered heat thermal load profiles from January 5 – 11, 2009 (Figure 9) show a baseline heating load and domestic hot water load starting around 5 am.   Examining this useful thermal pattern shows that the system is not being controlled in thermal load following mode during this time (see Figure 9). The only time the useful thermal energy follows engine performance is when one or two of the engines goes off line between 6 am and 4 pm on January 7 & 8.

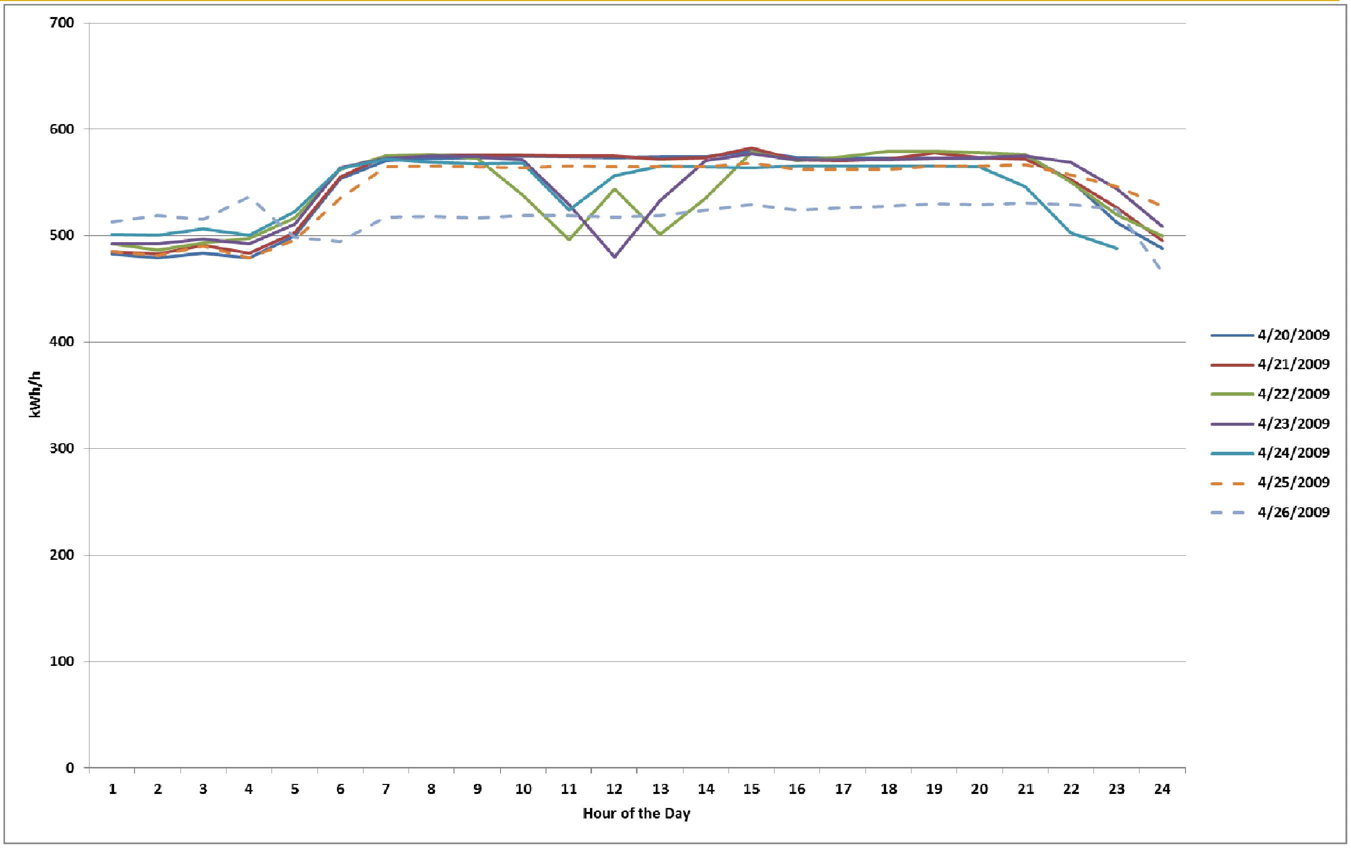

FIGURE 10 CHP POWER OUTPUT VERSUS TIME

Figure 10 covers the time period from April 20 - 26, 2010 providing CHP system power output by hour of the day pattern for the time period. April 22 - 24, Wednesday - Friday, shows reduced power consumption 10 am – 3 pm and Sunday April 26 (showing reduced load characteristics) while the remaining days exhibit full capacity performance 24 x 7. Examining the useful thermal pattern for the same week shows no linkage with thermal load profiles (see Figure 11).

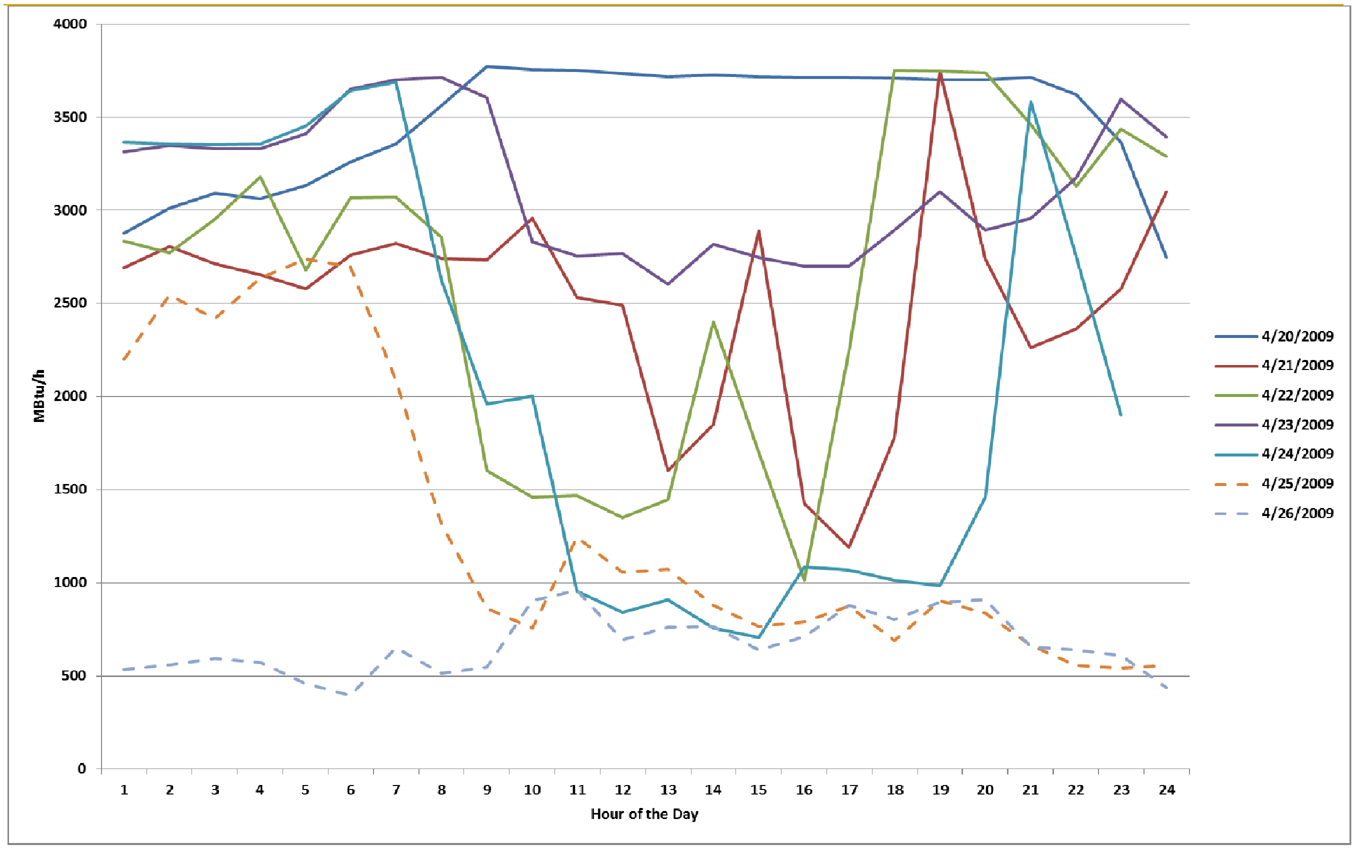

FIGURE 11 SELECTED DAY CHP USEFUL THERMAL OUTPUT VERSUS TIME

The 24 hour useful CHP recovered heat thermal load profiles from April 20 – 26, 2009 (Figure 11) show a very inconsistent thermal load pattern which correlates with typical spring weather patterns and varying heating loads.

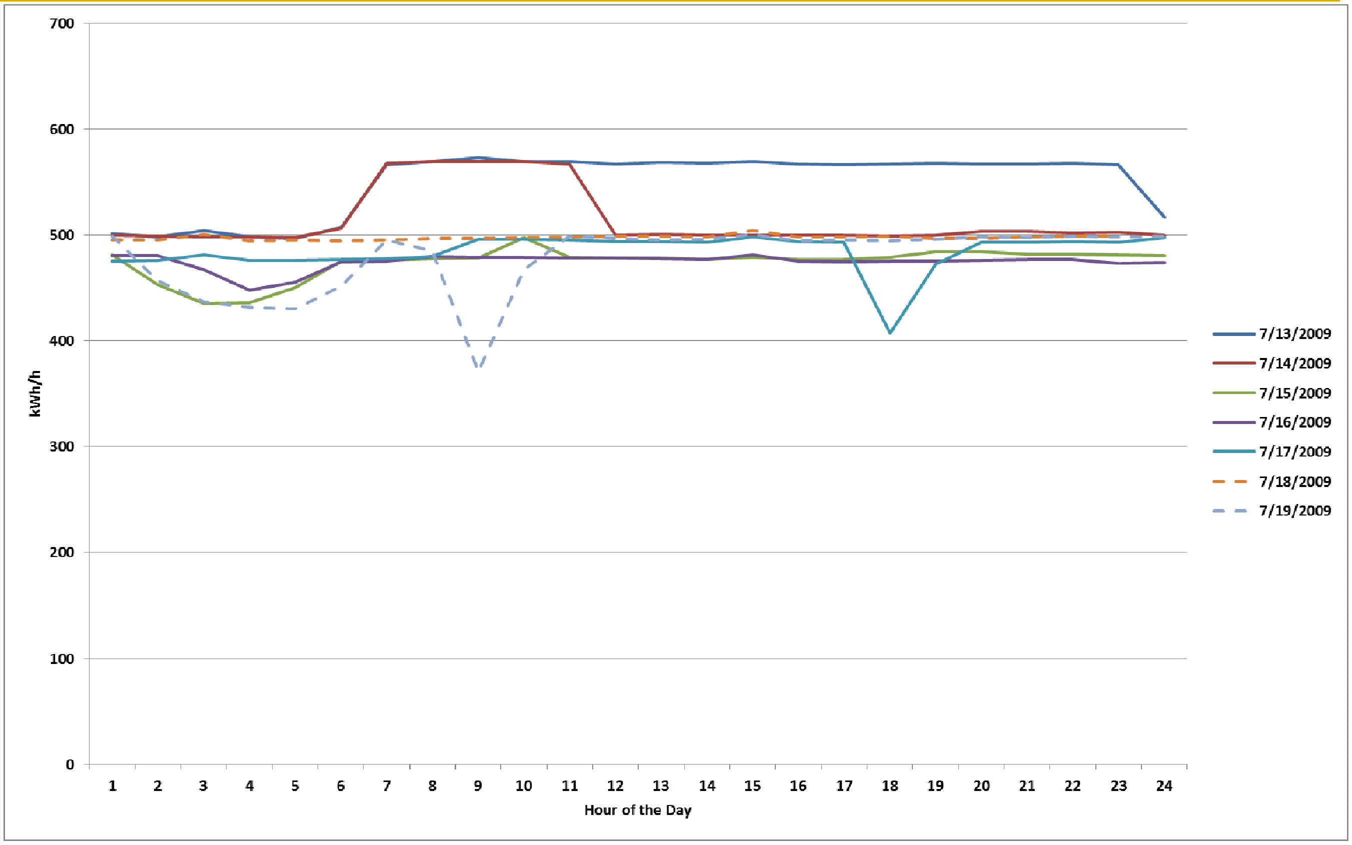

FIGURE 12 CHP POWER OUTPUT VERSUS TIME

Figure 12 indicates a generally consistent power output most of the week at 500 kW, indicating one engine coming offline around 11 am on Tuesday and remaining off the remainder of the week.

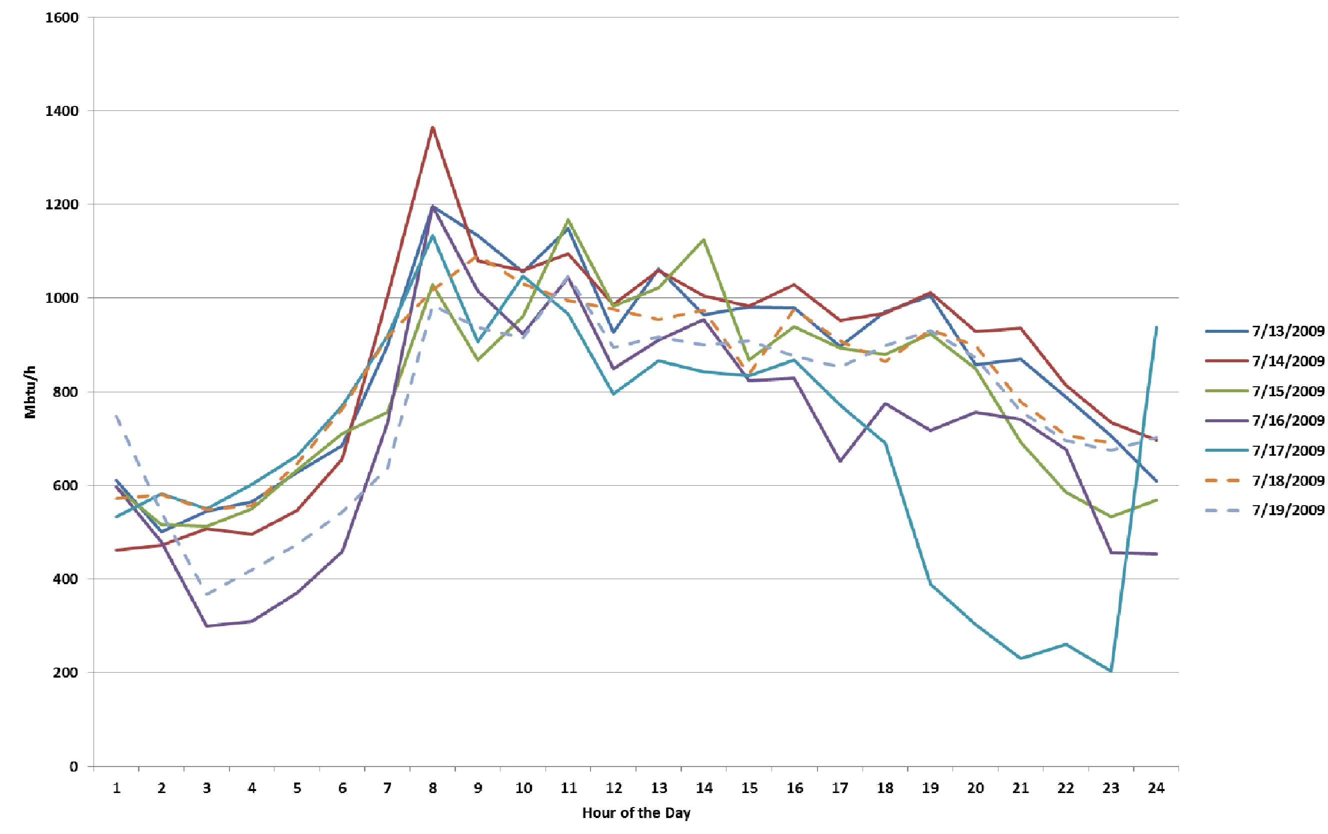

FIGURE 13 SELECTED DAY CHP USEFUL THERMAL OUTPUT VERSUS TIME

The 24 hour useful CHP recovered heat thermal load profiles from July 13 – 19, 2009 (Figure 13) show a consistent thermal load pattern which correlates with domestic hot water load and workday laundry patterns.

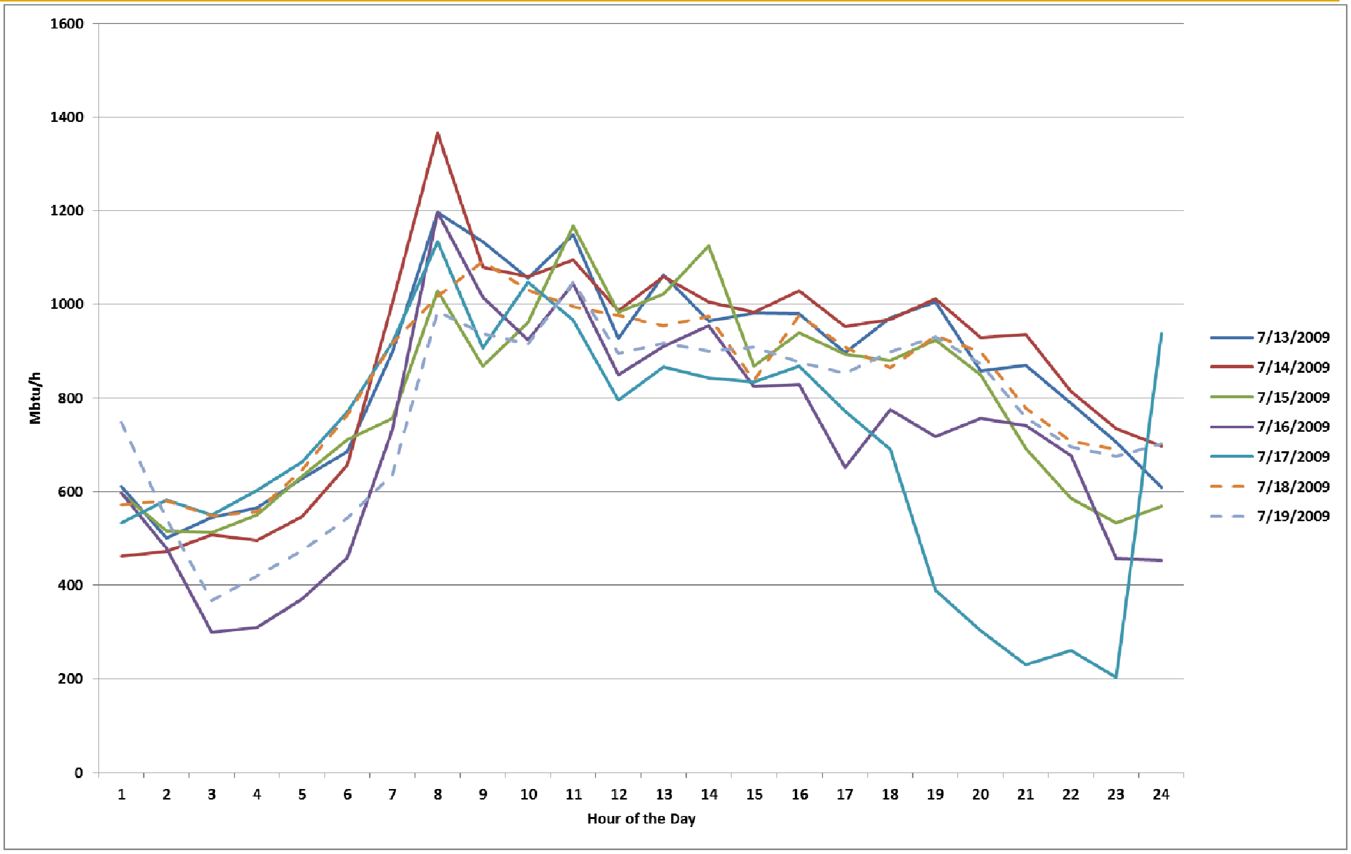

FIGURE 14 CHP POWER OUTPUT VERSUS TIME

Figure 14 and Figure 12 indicate that two engine/generators went offline at 7 am on Wednesday October 14, one came back on line the next hour and the other was back on line by 4 pm.

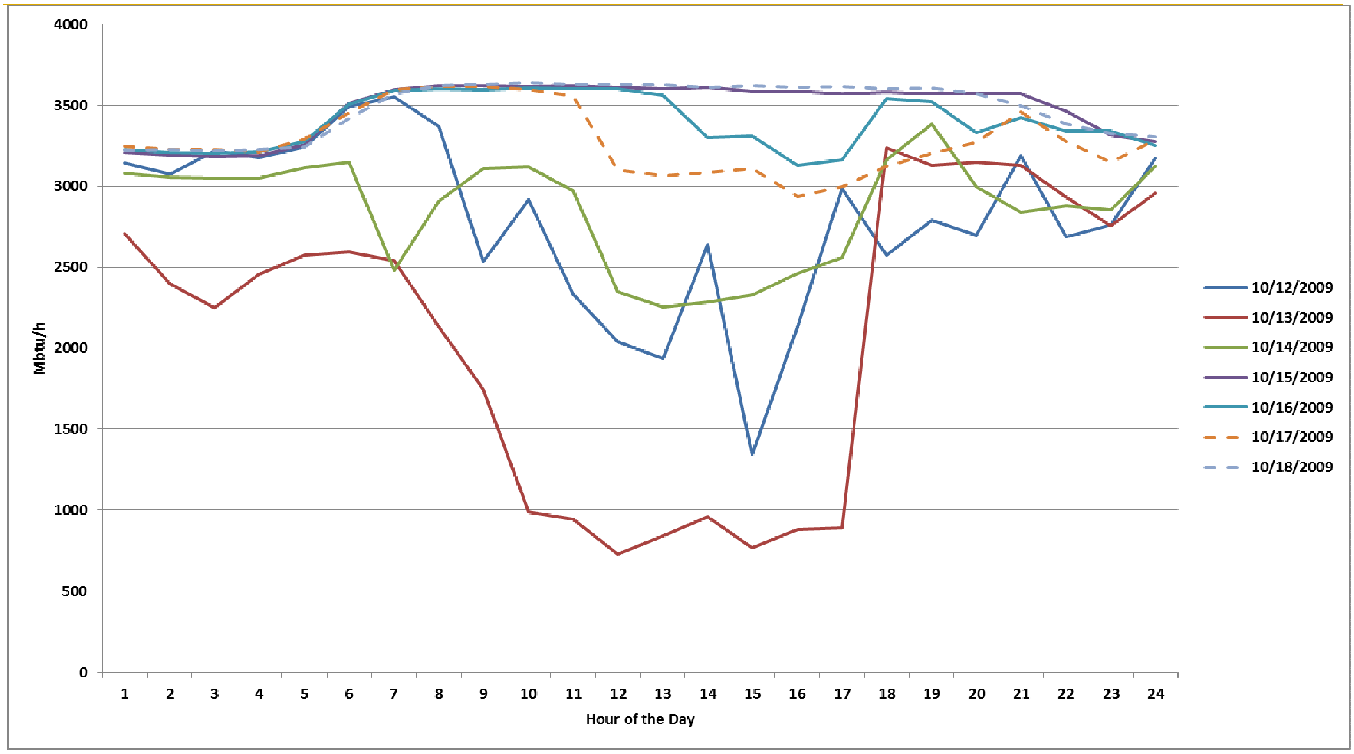

FIGURE 15 SELECTED DAY CHP USEFUL THERMAL OUTPUT VERSUS TIME

The 24 hour useful CHP recovered heat thermal load profiles from October 12 - 18, 2009 (Figure 15) show a very inconsistent thermal load pattern which correlates with typical fall weather patterns and varying heating load and also shows consistent thermal load pattern which correlates with domestic hot water load and workday laundry patterns.

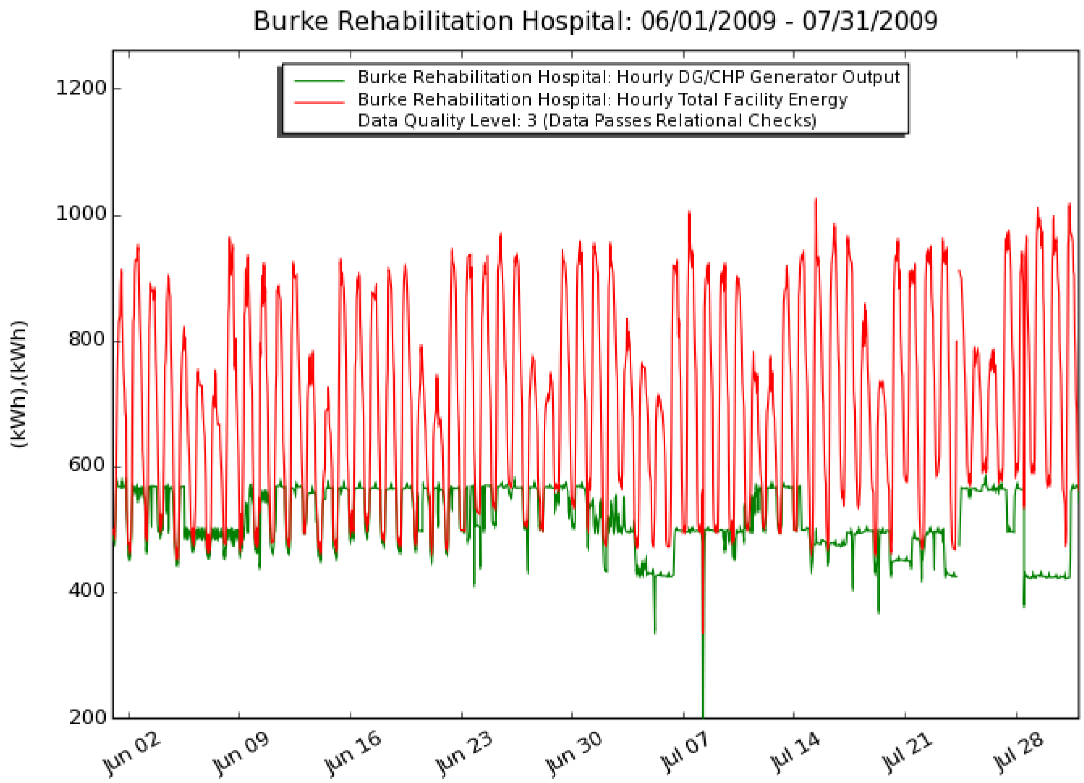

FIGURE 16 SUMMER 2009 ENGINE PERFORMANCE

Figure 16 shows the CHP system operating at maximum available power capacity during the summer except when the building load falls below the system capacity or when one or more engines are down.

PERFORMANCE SUMMARY

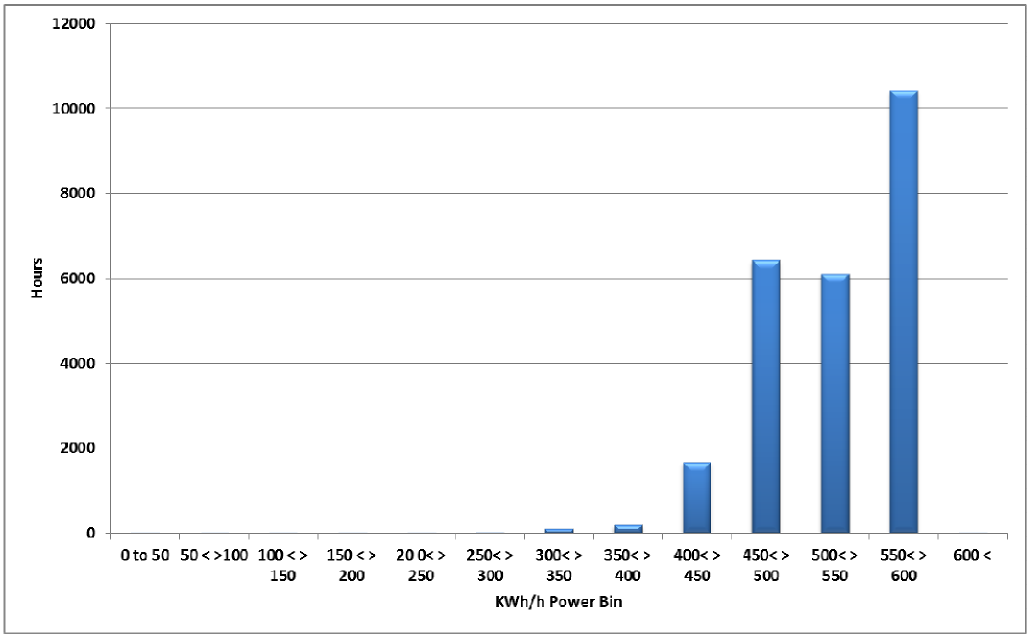

FIGURE 17 PERFORMANCE BY POWER BINS

During the 24,988 hours that met the range and relational checks 98.5% of this time, the CHP system delivered 100 kW and greater (Figure 17).

LESSONS LEARNED

TABLE 2 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
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April-11	710	380,289	4,946	1,536	25.7%	30.4%	56.2%
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Total preceding 12 months	**8,028**	**4,220,403**	**54,772**	**15,109**	**25.8%**	**27.0%**	**52.8%**

The Burke system consisted of eight 75 kW Tecogen units. The 12 month period engine in July 2011 shows an average FCE of 52.8%.

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[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.

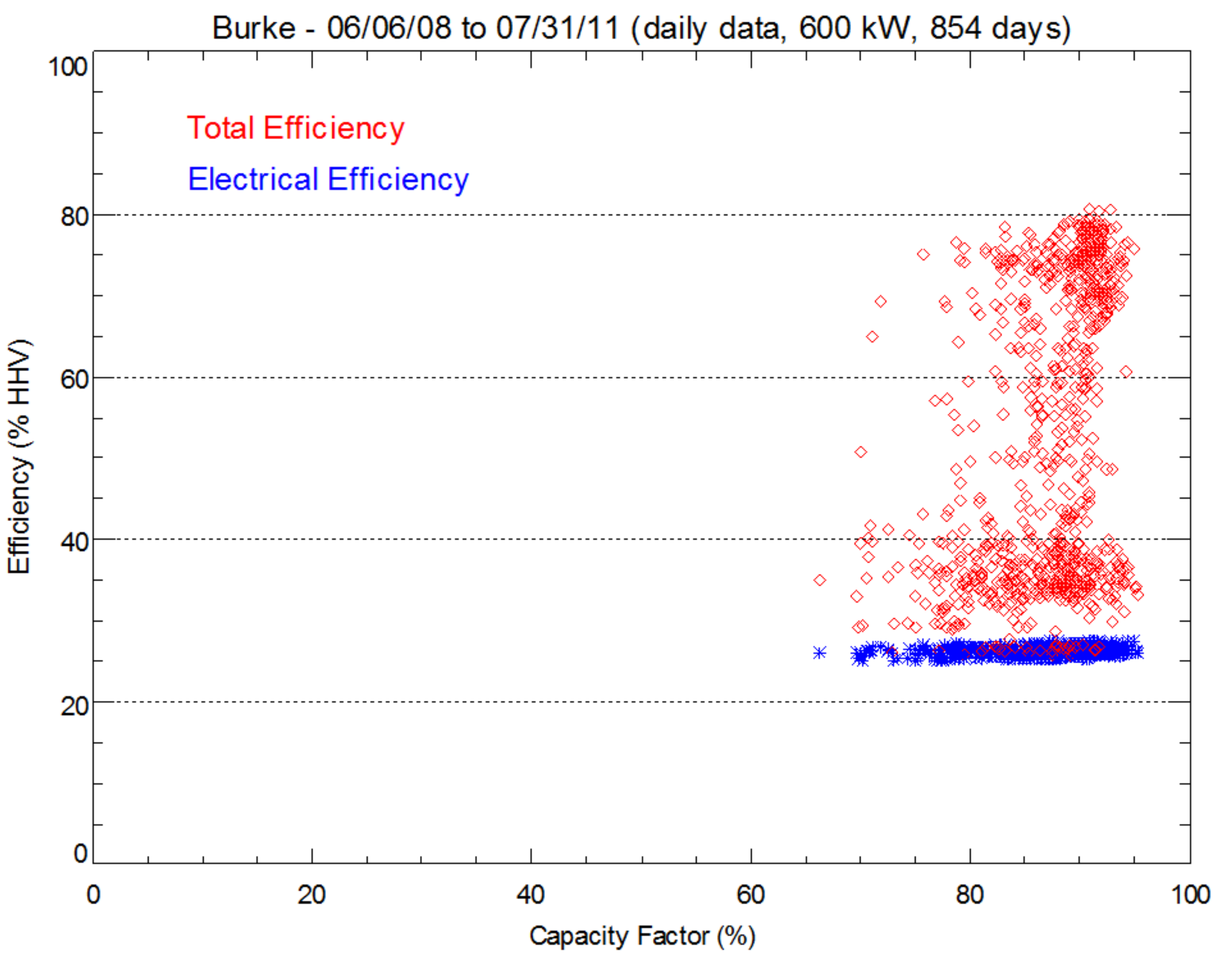

FIGURE 18 CAPACITY FACTOR[4]

Capacity Factor (Figure 18) presents the CHP generated power efficiency over the time period (854 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 generally operated between 70% and 95% of the generating capacity at about 25.8% power efficiency (HHV). The useful thermal energy (heating only) operated at high efficiency during the winter months (upper grouping) and lower during the summer months averaging 27% thermal efficiency (HHV).

This system works reasonably well because the system size was selected considering the seasonal variations in the thermal loads. Thermal loads were much higher in the winter but still substantial in the summer time for this hospital.

[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.

The long term performance data available for this site shows that there is a slight degradation in electrical efficiency over the first few years of operation. It clearly points to the importance of overhauling and tuning these small engines over their life cycle.

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)** Three power transducers are installed on-site to measure the net generator power. One transducer measures the gross power output of the eight engines and the other two measure parasitic loads associated with the power generation. The difference between the gross power and the parasitic power is calculated on a 15-minute interval. This 15-minute data is then summed into hourly data for the online database.
2. **DG/CHP Generator Gas Use (total cubic feet)** Data for this point comes from a utility gas pulse output installed on the meter serving the engines. The 15-minute data is summed into hourly data for the online database. The meter has a resolution of 1000 cu ft making the data coarse on an hourly basis. The data for this channel is best viewed on a daily basis.
3. **Useful Heat Recovery (total MBtu)** The Useful Heat Recovery is calculated from loop temperature and flow averages on a 15-minute interval. The heat recovery rate is calculated by taking the temperature difference between the loop leaving the engines and before the dump radiator (in °F) is then multiplied by the flow rate (in gpm) and the heating content factor for pure water (0.488 Btu/h-F-gpm). The 15-minute heat recovery rate is averaged for the hourly data.

The large seasonal swings in useful thermal energy negatively impact the CHP system efficiency and economics. This system should be studied with respect to adding summer thermal capacity.

Following energy efficiency trends depicted in Table 1 and Figure 5 can provide owner/operators with valuable guidance with respect to operation and maintenance requirements of the CHP system to maintain peak performance.

Data Collection and quality for this site for much of the period is in the high 90th percentile or at 100%. (Table 3) Exceptions are March 2011 for all parameters and May/June 2011 for kWh and Useful Heat in the mid-70th and 80th percentiles.

TABLE 3 PERCENTAGE OF GOOD DATA

Month	Power	Gas Use	Useful Heat
June-09	99.9%	100.0%	99.9%
July-09	99.6%	99.7%	100.0%
August-09	100.0%	99.9%	99.9%
September-09	98.3%	98.2%	96.7%
October-09	99.9%	99.7%	99.9%
November-09	99.3%	99.7%	100.0%
December-09	98.5%	99.2%	100.0%
January-10	93.3%	99.7%	37.8%
February-10	99.0%	99.7%	91.4%
March-10	99.9%	98.3%	100.0%
April-10	97.5%	98.3%	98.5%
May-10	95.8%	96.8%	96.8%
June-10	99.2%	100.0%	99.9%
July-10	98.4%	99.9%	99.9%
August-10	98.8%	100.0%	99.9%

September-10	100.0%	100.0%	99.9%
October-10	99.1%	100.0%	100.0%
November-10	99.0%	100.0%	100.0%
December-10	97.7%	100.0%	100.0%
January-11	86.8%	96.5%	96.7%
February-11	98.8%	100.0%	100.0%
March-11	77.0%	78.2%	78.5%
April-11	98.6%	100.0%	100.0%
May-11	76.1%	99.9%	83.7%
June-11	76.1%	99.9%	83.7%
July-11	98.1%	99.9%	98.9%