National Conference on Building Commissioning

Whitepaper on: **Commissioning of Combined Heat and Power Systems**

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ABSTRACT

This paper explores recent commissioning practices of Combined Heat and Power (CHP) systems applied within the built environment. CHP systems are more complex involving increased attention to atmospheric emissions and electric grid interconnection and sophisticated control logic. This study focuses on four specific buildings: a San Francisco hotel retrofitted with a "packaged" microturbine generator/double-effect chiller plant; a Los Angeles casino retrofitted with an advanced reciprocating engine, hot water heat recovery and a single-effect absorption chiller; a Brooklyn laundry retrofitted with two reciprocating engine generators and a hot water heat recovery system; and finally a state-of-the-art hospital in Austin, TX with a combustion turbine, heat recovery steam generator, absorption and electric chillers and thermal storage. These case studies provide design insight, identify commissioning issues and lessons learned from the initial operation. The author's takeaway from this brief study is that there is a need to establish a set of commissioning best practices for CHP systems.

INTRODUCTION

Commissioning CHP systems in commercial and institutional buildings requires broad experience covering small power plant systems (less than 25 MW), heat recovery, thermally activated technologies, electric switchgear, grid interconnection operation and safety, sound and vibration, emissions control as well as building, mechanical and electrical systems integration. While CHP systems are common throughout industrial sites accounting for about 84 GW of electric capacity in America, less than 1 GW of power is currently operating in the built environment. The use of CHP systems in buildings is likely to increase as the need to reduce carbon emissions grows and public policy moves to monetize carbon emissions.

What is really different about CHP systems? Let's break it down first by major components and then examine the integrated system.

1. Continuous duty drivers – The current span of CHP power systems consist of reciprocating engines generally under 10 MW, microturbines between 65 and 250 kW and combustion turbines between 1 and 15 MW. Fuel cells are also in use between 5 kW and 1.5 MW, but are generally quite expensive at this time.
2. Emissions – Onsite combustion requires a firm understanding of the federal, state and local air permit requirements. It is important to know that air permits are indeed essential before any construction is commenced. Generally speaking all these power technologies are capable of being sited anywhere in the USA, with perhaps a few counties in California currently limiting the use of current state-of-the-art reciprocating engines even with after-treatment. The principle question for emissions is generally a matter of cost and not feasibility.
3. Generators – There are two principle classes of generators: induction and synchronous. Induction generators produce electrical power when their shaft is rotated faster than the synchronous frequency of the equivalent induction motor. Induction generators are not self-exciting, meaning they require an external supply to produce a rotating magnetic flux. The external supply can be supplied from the electrical grid or from the generator itself, once it starts producing power. A synchronous generator is a machine that generates an alternating voltage when its armature or field is rotated by an engine, or other means. The output frequency is exactly proportional to the speed at which the generator is driven. The functional purpose and interconnection issues will determine the generator design.
4. Interconnection – Grid interconnection requirements have certain common characteristics with respect to operations and safety, like compliance with IEEE Standard 1547, however, state and local utility requirements and grid characteristics (radial or network) will vary dramatically. This is an area where minimum commissioning is usually dictated by the utility and site commissioning issues are sometimes missed.

5. Waste heat recovery schemes – This covers the wide variety of means to recover waste heat from generators and/or processes for delivery to thermally activated technologies. The range of systems covers ducting and reclaiming heat from hot air sources (process, engine, turbine, microturbine exhausts) and recovering heat in the form of hot liquids (engine jacket water, oil cooling and exhaust, process streams, etc.).
6. Thermal technologies – The most common technologies are heat recovery heat exchangers, heat recovery steam generators, absorption chillers, desiccant dehumidifiers and organic Rankine cycle (ORC) generators. Turning waste heat into hot water or steam is generally the simplest and most cost effective. Absorption chillers can convert the waste heat to chilled water but add another level of complexity and cost to the project. Absorbers are either provided as low-temperature single or high-temperature two stage machines. Desiccant dehumidifiers can be coupled to hot air streams in the 250F range or hot water in the 190 F range. ORC can absorb 400 – 600 F heat and provide electricity at 10 to 15% cycle efficiency.
7. CHP integration – CHP integration focuses on successfully integrating the power generation with the thermal heat recovery and thermally activated technologies. The effectiveness of this effort varies widely depending on the degree of pre-engineering and packaging. Retrofit systems require more flexibility and ability to balance the system in the field.
8. Building system integration – Integrating a CHP system to building loads and systems is critical and requires knowledge of the buildings operation (retrofits) or design intent (new building). Here too, flexibility and ability to balance systems is also essential.

There are clearly more elements that need to be considered in applying and commissioning today's CHP in buildings. Understanding the components, their integration requirements and having the flexibility and means to balance systems is essential. Finally having a commissioning plan that tests the system's capabilities is essential.

COMMISSIONING A MICROTURBINE/CHILLER CHP PLANT AT A SAN FRANCISCO HOTEL

The CHP System was installed at a deluxe 336 room hotel in downtown San Francisco. The hotel is owned by a real estate investment trust whose portfolio includes over 100 properties in 26 states including large holdings in California, Florida, Georgia, Boston, New York, and Washington DC.

CHP System Design

The CHP system is a predesigned standard product that contains four microturbines each rated at 60 kW of electrical power at a 59ºF (15ºC) sea level condition. Rated NOx emissions are less than 9 ppm at 15% exhaust oxygen, which met local emission requirements in force at the time of the installation. The exhaust from each microturbine is manifolded together to deliver input energy to a double-effect absorption chiller (Figure 1). The lithium bromide/water chiller consists of an evaporator, absorber, condenser, high temperature and low-temperature generators, solution heat exchangers, refrigerant and solution pumps, purge, controls and auxiliaries. The chiller is an adaptation of a direct-fired chiller that increases the heat transfer area of the first stage generator to compensate for the lower temperature inlet energy (microturbine exhaust gas). Because it is a double-effect device, the chiller effectively converts the input thermal energy to chilled water and achieves a coefficient of performance (COP) of approximately 1.3. The double-effect feature also permits a manual change-over of the chiller to operate as either a chiller or heater. Thus, the CHP system can provide either space chilling or space heating. The control system includes a diverter valve in the duct between the microturbines and the chiller. If the chilling demand is zero, this valve diverts the microturbine exhaust to atmosphere. If a chilling demand exists, the diverter is positioned to deliver the energy required for the chiller to meet the demand. The ability to isolate the chiller under no load situations is important to avoid excessive concentrations within the chiller and possible solution crystallization.

Also shown in the figure are the fuel gas boosters (FGB) that elevate the pressure of the natural gas fuel supplied by the gas utility to the level required by the microturbine. Each CHP System uses one FGB for a pair of microturbines. The FGB is powered by the DC power produced within one of the microturbine pair and therefore that microturbine experiences a parasitic electrical load that diminishes its AC output.

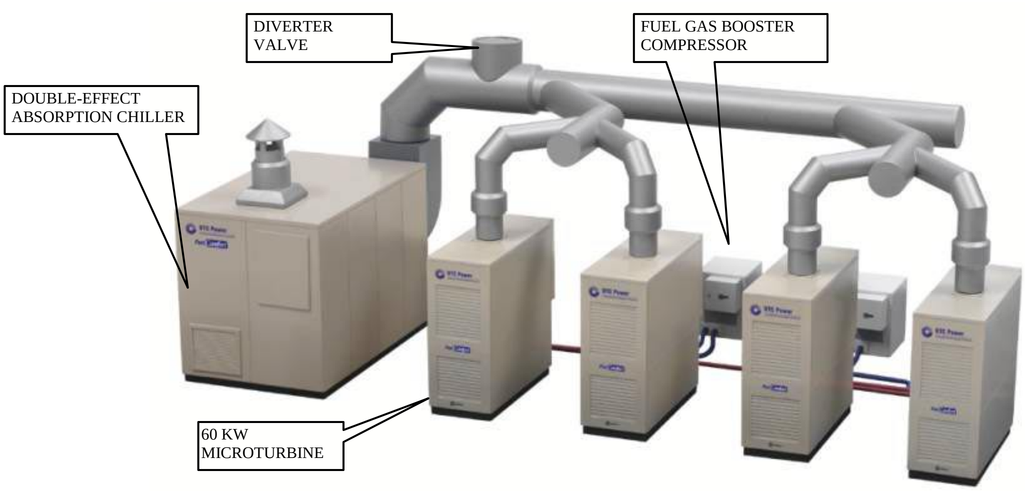


Figure 1 CHP System Schematic

Figure 2 Before and After CHP System Retrofit

Figure 2 shows before (left) and after (right) the CHP system retrofit. It should be noted that the lower right garden serves as a highly coveted entertainment spot for this Mobil five diamond property. The site configuration required modification from the standard design field assembly.

Table 1 details the performance specifications of the CHP system at 95ºF (35ºC) and at 59ºF (15ºC). The net power levels include power for the two FGB. As indicated, the combined electrical and chilling capability results in CHP efficiency greater than 80%. To achieve this level in an application, the full system output capacity must by used productively by the building.

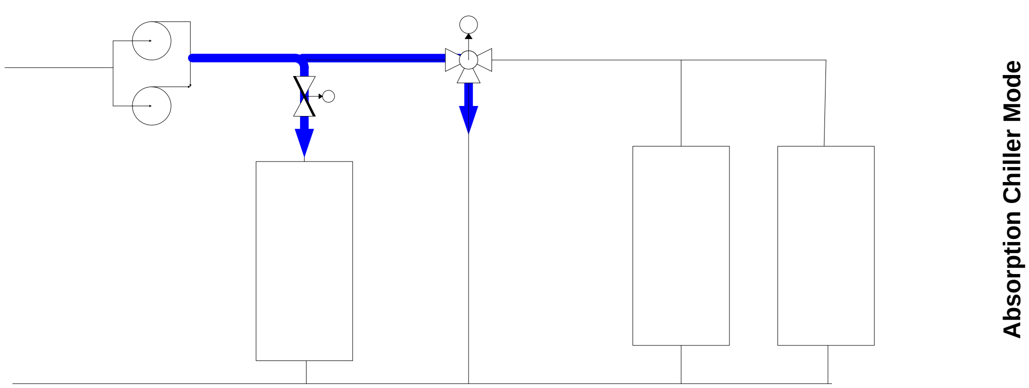
TABLE 1 CHP System Performance Specifications

Rated Performance at 95ºF (35ºC)		
Net Power	kW	193
Cooling	RT	124
CHP Efficiency	%	80
Rated Performance at 59ºF (15ºC)		
Net Power	kW	227
Cooling	RT	142
CHP Efficiency	%	91

Site and Thermal Integration

Based on historical data and analyses, the hotel energy demand averages 670 kW of electrical power and 1,200 kW of combined thermal energy use and power. The electrical demand during the year rarely dropped below 500 kW. Because of the hotel's significant and persistent air conditioning demand throughout the year, the CHP System was integrated only with the chilled water loop (Figure 3). The absorption chiller operates in parallel with two existing 300 RT electric chillers (a primary unit and a spare). However, the design chilled water flow rate was much higher for the electric chiller than for the absorption chiller. To accommodate the different flow rates and pressure drops, a by-pass loop with motorized isolation valves was required to balance flow rates during different operating modes.

The "Absorption Chiller" mode (Figure 3a) required that the motorized valves were positioned to allow returning chilled water to flow only through the absorber and the bypass loop. The chilled water flow rate set-point through the absorber was 270 gpm measured by a flow meter at the absorber exit. The bypass loop had a similar flow rate. The "Simultaneous Chiller" mode (Figure 3b) required the valve settings to allow flow through both chillers but not through the bypass. When this occurred, the lower flow resistance of the electric chiller reduced the chilled water flow through the absorber to 170 gpm. The "Electric Chiller" mode (Figure 3c) required the valve positions to isolate the absorption chiller and bypass loop. The chilled water flow rate through the active electric chiller was roughly 500 gpm.



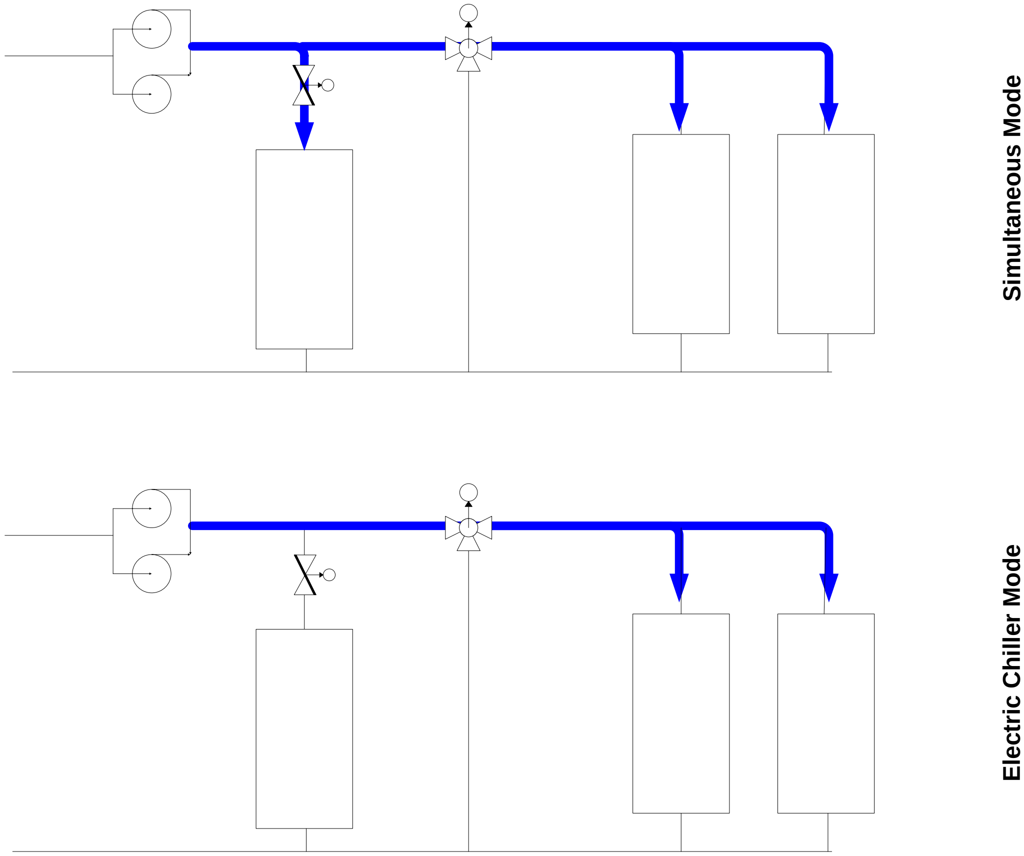


Figure 3 Chiller Plant Operating Modes

Grid Interconnection

The hotel connects to PG&E's San Francisco "network" through multiple feeders to the site. The multiple supplies provide redundancy in the electricity supply, enhancing power reliability. However, they also require "network protectors" on each utility feeder on the customer side of the transformer. A network protector is a combination of a breaker and a reverse current protection relay to prevent the reverse flow of current onto a feeder that experiences a fault. Their purpose is to prevent the flow of electrical energy from one feeder back onto another feeder. The protectors are set to instantaneously detect the reversal and open the contactor, but that opening takes 5-25 seconds and requires a manual reset.

When onsite power generation is installed at a site with a network supply, it may be possible for the site load to momentarily drop below the generator output, resulting in an export of electricity unless other preventive devices are used. This possibility is minimized by requiring a buffer between the generator and the normal load. However, this measure does not guarantee that an export will never occur. If an export does occur, the network protector senses a reverse current and instantaneously begins to open. PG&E expressed concern that all network detectors might sense the reversal and begin to open, rendering the site without any grid-supplied electrical power and requiring time and cost to reset them. To avoid this situation, significant interconnection upgrades were required on this site (Figure 4).

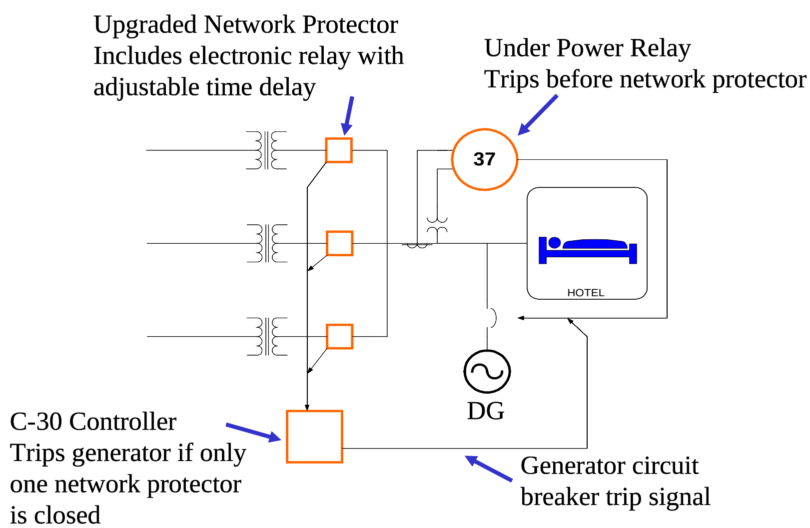


Figure 4 Additional Equipment for Network Interconnection

The network protectors were upgraded with an adjustable time delay to avoid the instantaneous response and an under-power relay that opens if the net demand for grid electricity drops below a threshold of 25 kW. Additionally, a controller isolates the onsite generator if it senses that any one network protector has opened – either because of a feeder fault or power export - adding redundant protection to prevent reverse electricity flow to any feeder. The cost of the interconnect upgrades required by the utility totaled approximately $140,000.

Commissioning

Commissioning of the CHP system was completed by Carrier under contract to UTC Power. The commissioning was performed according to a written protocol that provided guidelines for startup of both the microtur~~bines and the~~ absorption chiller. Following the protocol, a safety inspection, site evaluation, mechanical inspection, electrical inspection, and communications inspection were completed prior to startup. The effectiveness of the grid protection circuitry was confirmed. The microturbines were started and performance was verified. The chiller was evacuated of the nitrogen blanket that had been applied for shipping. The chiller was then started and the charge level was verified. Once commissioning was completed the system was put into service. It should be noted that there was not a formal report generated with respected to the exact extent of the commissioning process.

Overall, the CHP System achieved an extremely high level of utility with minimal outages. The CHP System producing at least 60 kW of net electrical power for 8,231 hours, or 94% of the year. Table 2 presents the monthly breakdown of operating, non-operating, and data gap hours. For the year, data gaps represented 2.8% of the available run hours.

TABLE 2 Monthly CHP System Operating Profile

	Max	Operating		Non-Operating		Data Gap	
	Hr	Hr	%	Hr	%	Hr	%
January	744	718	96.5%	26	3.5%	0	0.0%
February	672	633	94.3%	25	3.8%	11	1.7%
March	744	601	80.8%	113	15.2%	30	4.0%
April	720	510	70.8%	109	15.1%	101	14.1%
May	744	648	87.0%	0	0.0%	92	12.3%
June	720	717	99.6%	0	0.0%	3	0.4%
July	744	742	99.7%	0	0.1%	1	0.1%
August	744	744	100.0%	0	0.0%	0	0.0%
September	720	717	99.6%	3	0.4%	0	0.0%
October	744	741	99.6%	0	0.0%	3	0.4%
November	720	718	99.7%	2	0.2%	0	0.0%
December	744	742	99.8%	0	0.0%	2	0.2%
Total	8760	8231	94.0%	277	3.2%	243	2.8%

The CHP System was installed with the chiller in the hotel chilled water loop and parallel to existing electric chillers as described previously and shown in Figure 6. It was observed that the output from the absorption chiller was very interactive with the electric chiller, particularly from May through mid November. This interaction resulted in a shift between the CHP cooling only mode (Figure 3a) and the Simultaneous cooling mode (Figure 3b) for approximately half of the days during this period, as evidenced by a high absorber chilled water flow rate for CHP cooling only mode and a lower flow rate for Simultaneous mode. This binary situation is shown in Figure 5 for July, with a reduced flow rate once every day from July 6 through July 18.

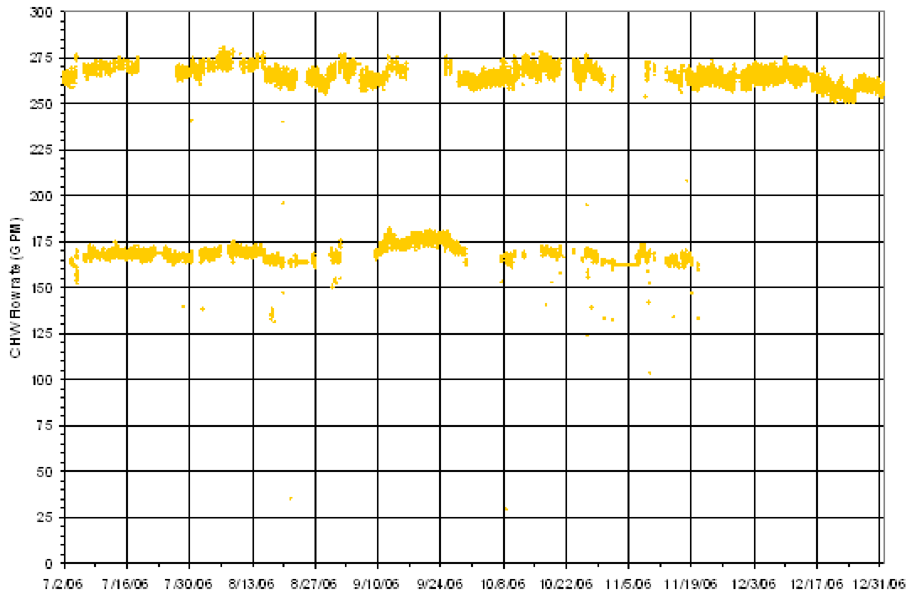


Figure 5 CHP System Chilled Water Flow Rate in July

The switch from CHP cooling only mode to Simultaneous cooling mode occurred whenever the absorber output alone could not satisfy the hotel demand for chilling. In this case, the absorber capacity could not suppress the chilled water temperature returning from the hotel ("returning temperature") to the desired set point for the chilled water temperature required to cool the hotel. The chilled water temperature leaving the absorber ("leaving temperature") could be used for mode control if a parallel chiller was not present. However, with the electric chiller, the returning temperature was a proper indicator that the absorber was not keeping up with the demand and that Simultaneous Mode should be initiated.

The general sequence when switching from CHP Mode to Simultaneous Mode was:

1. The absorption chiller output satisfied the hotel demand as indicated by stable and acceptably low returning temperature.
2. As the hotel demand grew, the diverter valve closed to deliver increasing energy to the absorber and try to maintain absorber leaving temperature. However both return and leaving temperatures increased.
3. When the returning temperature exceeded a "high" set point, the motorized valves of Figure 3 activated and the electric chiller started to achieve the Simultaneous Mode.
4. The absorber chilled water flow rate dropped suddenly by 100 GPM. The lower demand on the absorber required the diverter valve to open to maintain the absorber leaving temperature set point even though the return temperature was high.
5. The hotel demand was not satisfied until the electric chiller output and the reduced absorber output stabilized the return temperature.
6. CHP cooling only mode was re-established only after the hotel demand reduced sufficiently to allow the returning temperature to drop below a "low" set point (5F lower than the "high" set point to reduce mode cycling).

Emissions

Each microturbine uses advanced natural gas combustion technology to constrain NOx emissions < 9 ppm @ 15% exhaust oxygen; it is CARB 2003 certified. The exhaust from each microturbine is manifolded together and delivered as the input energy to a double-effect absorption chiller. On

November 15, 2001, the Air Resources Board (ARB or Board) adopted a regulation that established a distributed generation (DG) certification program as required by Senate Bill 1298 (chaptered September 2000). The DG certification program requires manufacturers of electrical generation technologies that are exempt from district permit requirements to certify their technologies to specific emission standards before they can be sold in California.

Observations

The commissioning process for this cooling and power system took place in the wintertime, which precluded meaningful interaction between the CHP absorption chiller and the hotel's existing electric chillers as the cooling load was low. Thus two critical design deficiencies were not uncovered.

1. The anticipated chilling level was based on both predictions and experience, and concluded that high levels of chilling were required every hour of the year. While electrical load was easily determined from utility electricity bills, it was not as easy to determine thermal loads, particularly chilling loads. Perhaps this design flaw suggests the need for a new assessment approach to measuring thermal system performance prior to building retrofits.
2. The second design flaw stems from the integration of the absorption chiller into the existing chilled water circuit which led to a 100 gpm absorption chilled water drop when the electric chillers were engaged. This untimely reduction in flow dramatically reduces the CHP performance. This critical design/operating flaw provides an important planning lesson, that if timing and/or weather precludes certain testing, then allowance must be made to perform critical testing when the timing/weather is right.

COMMISSIONING A RECIPROCATING ENGINE/CHILLER CHP PLANT AT A GARDENA, CA CASINO

This casino or 'Card Club' concept exists under grandfathered regulations in the state of California. It is open 24/7/365 and has needs for electric power, cooling and domestic hot water heating year round. It is located in the city of Gardena which is approximately 8 miles inland and 10 miles south of Los Angles. Electricity is supplied from the local electric utility. Existing chillers include a 4-compressor 80 ton reciprocating chiller and a 120 ton centrifugal chiller. Space heating needs are minimal and domestic hot water is provided by two boilers with integrated storage tank.

CHP System Design

The generator module (Figure 6) contained a 255 kW net electric output natural gas reciprocating engine generator set with automatic grid paralleling electrical system and jacket heat recovery. The generator module also contained advanced emissions controls and remote communications and dispatch capabilities.

Figure 6 Generator Module

Figure 7 shows the exhaust heat recovery module comprised of an exhaust-to-water heat exchanger and circulating pump used to recover exhaust heat after the catalyst and EGR.

Figure 7 Exhaust Gas Heat Recovery Module

The Thermal System Module (Figure 8) consists of a 75 RT single-effect hot-water fired absorber, heating load heat exchanger, cooling tower pump, condenser pump, pipe, valves & fittings, outdoor enclosure and thermal system controller. The cooling tower was matched to the Thermal Module and a customer provided chemical treatment skid was added.

Figure 8 Thermal System Module

Finally there is a Dump Heat Exchanger (Figure 9) to remove the engine heat in the event that the Thermal Module is not in use. The Dump Heat Exchanger uses 3.5 kW at full dump equivalent to 1.5 % of generator output if no thermal load.

Figure 9 Dump Heat Exchanger

The CHP system schematic is shown in Figure 10.

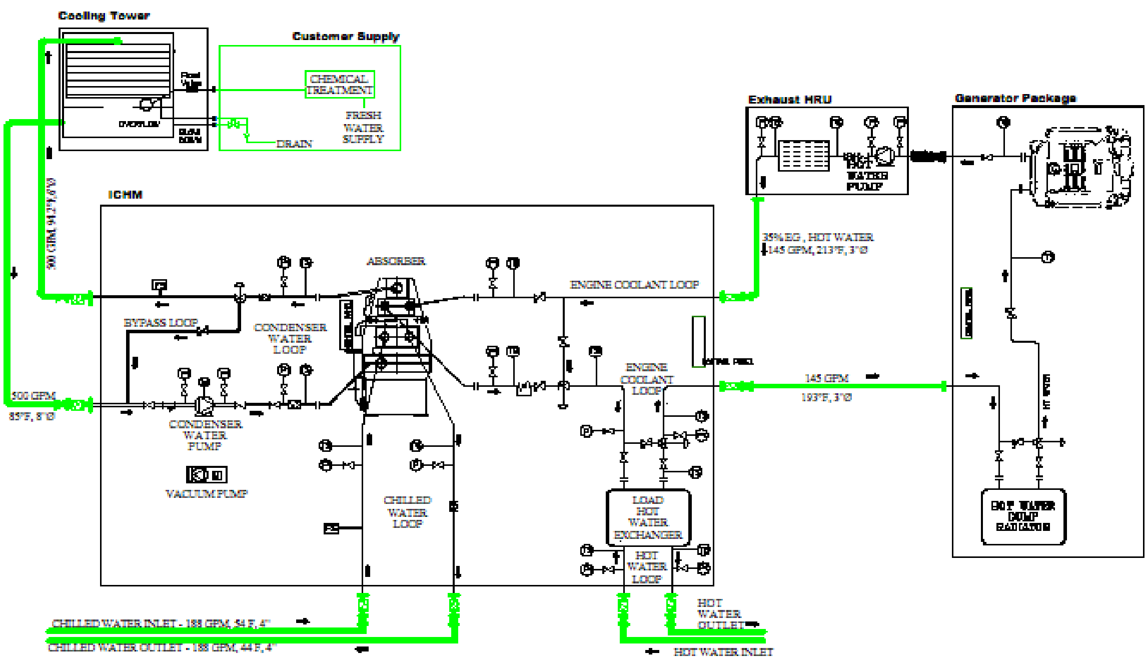


Figure 10 CHP System Schematic

Site and Thermal Integration

The Thermal Module design provides simultaneous chilled and hot water for maximum load factor. At this location the hot water is to be used to heat domestic hot water using a double-walled heat exchanger. Existing chillers are designed to be staged by the building energy management system to allow CHP chiller take base load. (Figure 11)

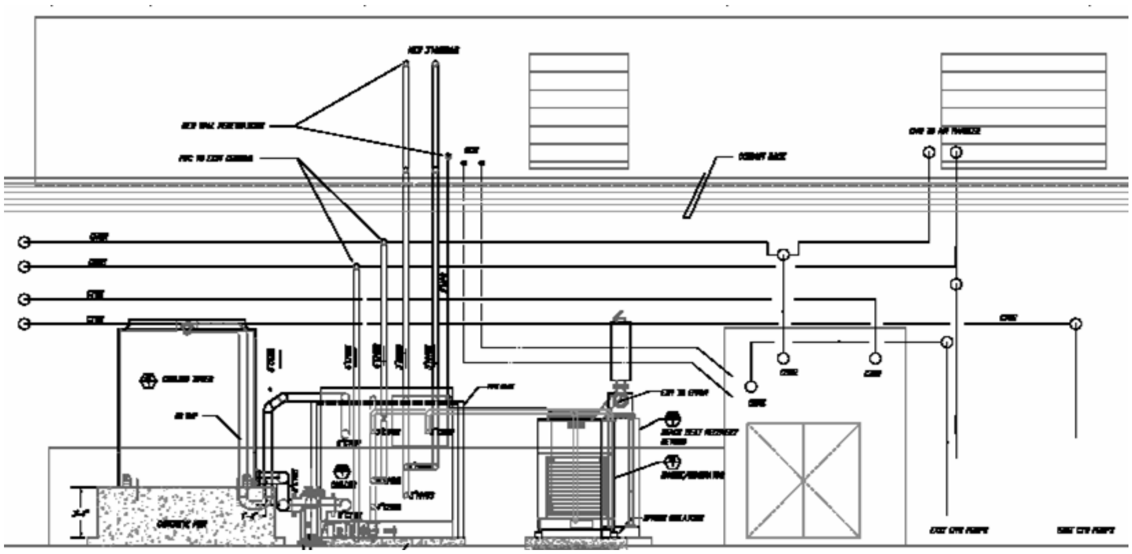


Figure 11 Thermal Building Connections

Grid Interconnection

The generator is configured to parallel with electric grid with a ‘non-export’ protective relay. Generator design operation targets baseload operation and is expected to run at full load most of the time.

Commissioning

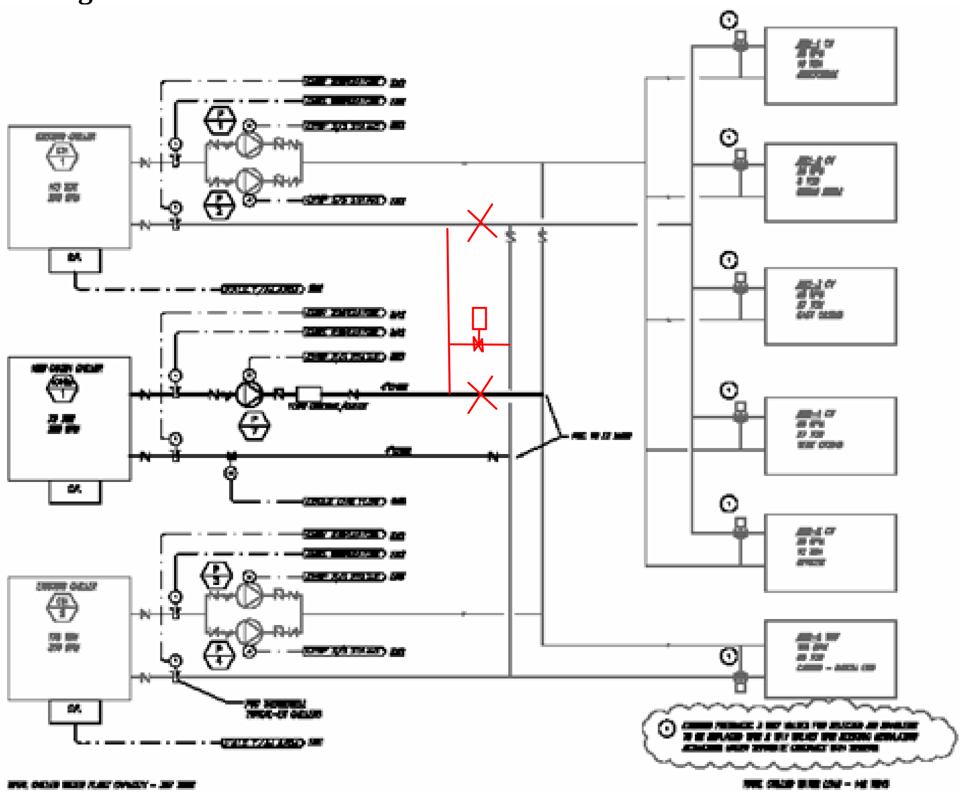


Figure 12 Chilled Water Schematic

The CHP chiller was tied into a common header with the existing two chillers and each chiller had its own pump. Flow balancing problems were immense and the design provided no way to baseload the thermal chiller. The changes in red were suggested to assist in balancing the chilled water supply. Also note that the three way valves supplying the six air handlers had been replaced with two way valves eliminating the ability to bypass causing low flow alarms on both the reciprocating compressor chiller and absorber.

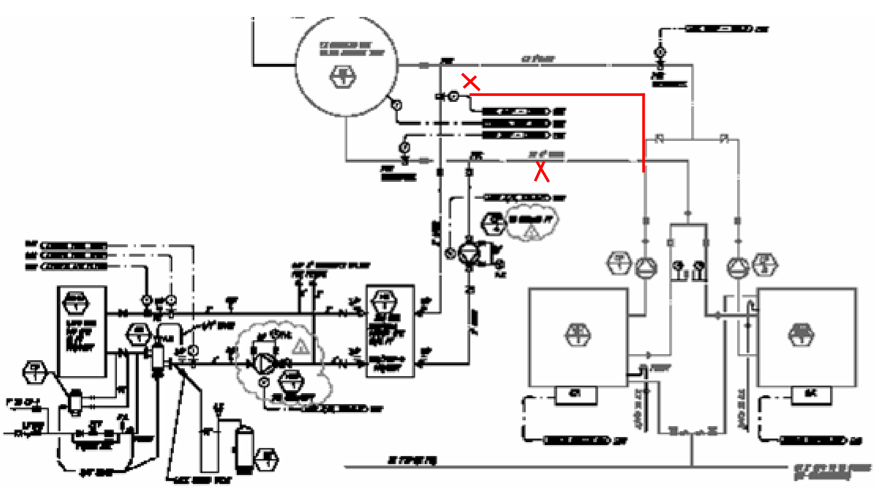


Figure 13 Hot Water System Piping

The designed parallel hot water piping feature allows the CHP system to be turned on or off but it caused conflict with existing boiler pumps and prevented baseloading the CHP thermal heating. The bypass and cuts in red (Figure 13) were suggested to permit series flow and eliminated the pump and flow conflicts.

During the field test, the Thermal Module was run by itself with the electric chillers manually locked out. The system was started up in the morning and allowed to stabilize. The engine generator was ramped up to 260 kW and the engine jacket return temperature was increased to 195 F. Load was gradually applied to the system but the chilled water supply temperature was unstable. After some observation, both the coolant water flow rate and chilled water flow rate were adjusted. At these new settings the chilled water temperature was steadily pulled down until it reached set point of 44 F. Data was taken after the system stabilized and showed the chiller was holding the load at between 60 to 70 tons during three hours and the chilled water supply temperature remained at set point showing the system was not overloaded. The Thermal Module chiller load peaked at 72 tons at 2:12 PM. However, there was no more load available and after 4 PM ambient conditions further reduced the load. The chiller held set point throughout the remainder of the day. The following graph shows a plot of chilled water supply temperature and load from 9 AM through 11:59 PM on the test day. The yellow band represents the chilled water supply temperature set point of 44 F +/- 1F.

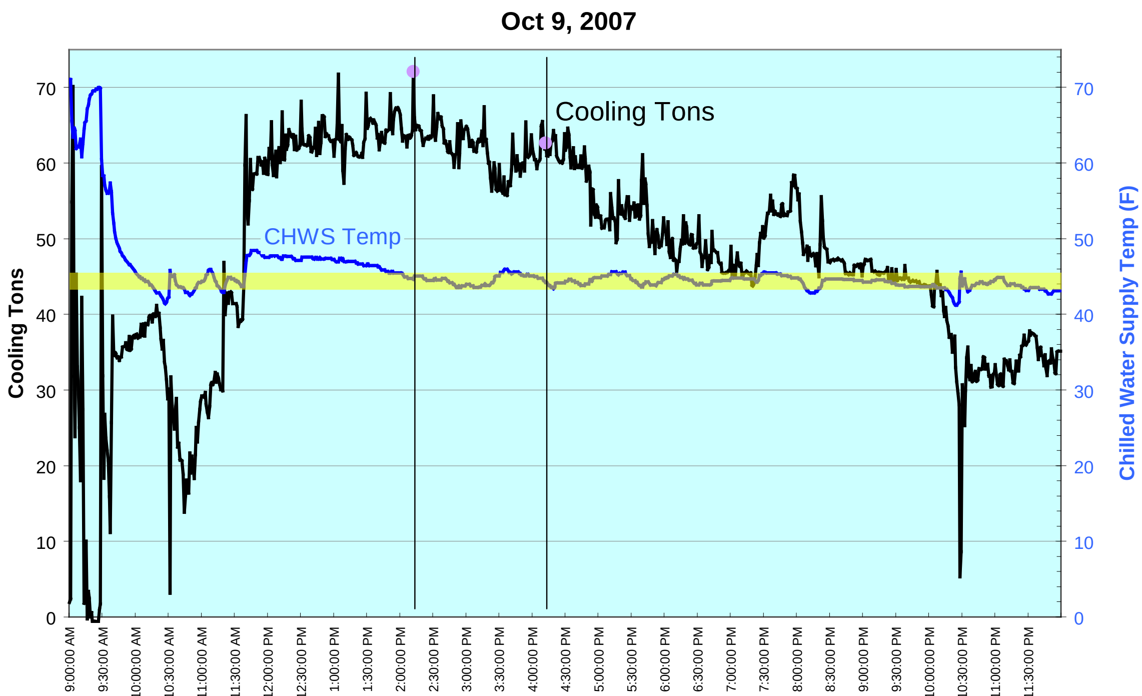


Figure 14 Chilled Water Supply Temperature and Load

Emissions

The 260 kW lean burn, gaseous-fueled engine incorporates an exhaust gas recirculation (EGR) system and a 3-way catalyst to deliver emissions levels as low as 0.6 ppm NOx, 1.5 ppm NMHC and 42.8 ppm CO at 15% oxygen.

Observations

1. Factory test proved performance +/- 5% at design hot water temperatures. Site test at commissioning did not allow for full load but did prove system operation. Weather during commissioning is a large factor in generating heating or cooling load. Construction sequences often do not coincide with weather leaving system commissioning, in this case, where there was little cooling load. If this situation can be anticipated, then contingency should be added to recommission the chiller for performance.
2. Site engineering is a vital ingredient particularly for retrofit CHP installations “as built” drawings of complete building systems are often inaccurate or incomplete.
3. Series flow should be used on all CHP thermal loops to balance flow and eliminate pumping problems especially in retrofit situations.
4. Miscellaneous problems: packing caps not removed from piping, field lines not flushed, pressure reducing valves not set, expansion tanks not charged and filters not included on pumps.

COMMISSIONING A RECIPROCATING ENGINE/WATER HEATING CHP PLANT AT A BROOKLYN, NY LAUNDRY

Arrow Linen provides laundry service for restaurants in Brooklyn, New York. They launder uniforms and linen for over 2,300 customers ranging from “mom and pop” pizza stores to large catering halls. Arrow Linen operates six days a week from about 4 am until about 4 pm, and uses a significant amount of electric power and steam in their operations. Electricity is used for lighting, general power, laundry cleaning and processing operations. Medium-pressure steam (115 psig) is used for washing and pressing the linens processed within the facility, as well as for heating the plant’s hot water load. The peak electric demand typically ranges from 350 kW to 370 kW depending on the month, while the average demand during operating hours is approximately 260 kW.

CHP System Design

Arrow Linen installed a combined heat and power (CHP) system in June of 2004 to manage rising energy costs. The CHP system is comprised of two reciprocating engine packages with a maximum aggregated output of 300 kW. Arrow Linen’s requirements for the CHP system were that it had to be efficient, clean and easily integrated into their operations. The system was sized to meet the average electrical load for the plant. This ensured that all power generated by the system could be utilized internally at the facility. The system recovers waste energy from the engines’ cooling water and hot exhaust to supply most of the hot water needs at plant. The system has operated exceptionally well since its installation, supplying 70% of the plant’s power needs and 14% of its thermal needs with an overall efficiency of 76%.

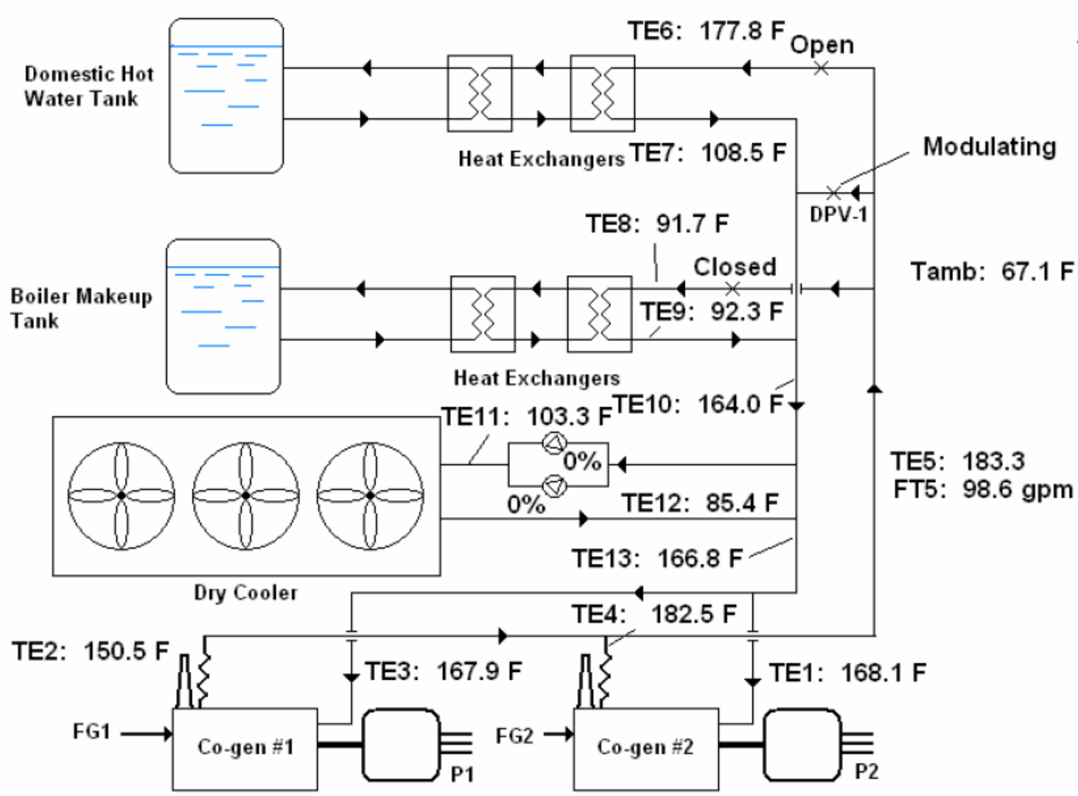


Figure 15 CHP System Schematic

Figure 16 Engine Generator

Site and Thermal Integration
There are two thermal loads served by the CHP system. The primary load that is always met first is process hot water needs. The domestic hot water tank (3300 gal) is heated by the CHP system through a secondary heat exchanger loop that runs at constant volume. Energy is supplied to this heat loop through an intermediate loop that is heated in the first heat exchanger with energy recovered from the engines. If hot water demand falls below the energy available from the engines, the excess heat is used to preheat boiler make-up water through a second intermediate heat exchanger loop similar to the domestic hot water loop. The intermediate heat exchanger loops in both instances are to ensure that both domestic hot water and steam are absolutely clean for laundry operations.

As shown in Figure 15, the engine coolant is routed through the engine blocks to cool the engines and then through heat exchangers in the engines' exhaust to recover additional heat. If the thermal demand for hot water or boiler makeup falls below the energy recovered from the engines, then excess energy is dumped from the engine coolant in the dry cooler.

Grid Interconnection
1. Some of the provisions and requirements in the Inter-connect requirement (EO-2115-206) were vague and open for interpretation. Trying to make an arrangement with the utility for Pre-operational test was a major task. There were many parties required to witness the test; such as the technician who will be conducting the test, the electrical engineer who designed the system, the contractor who installed the relay, an engineer from the utility, a project manager from the utility. To make the situation worse, trying to get everyone at the same place at the same time occurred during heavy vacation season causing more delays in scheduling for the test. During the test, the utility engineer insisted on varying some of the test methods. Changing the test methods did not have any bearing on confirming the integrity of the protective relay, but made it very difficult to carry out the test.
2. The utility engineer also had an issue with the type of utility disconnect switch used and the location where the switch was installed. The switch was a circuit breaker type instead of a knife type with fuses and the switch was not installed in the basement as specified in the Inter-connect manual. The EO-2115-206 provides an electrical specification and lock-out ability (lockable in both open and close position) of the switch and its intended use. The switch was installed at the most accessible location from the street without violating the New York City Electrical Code.
3. Another issue was the tariff and the future protective relay testing method/procedure. The utility company required the future tests to be conducted during normal business hours and required that the test had to be witnessed by the utility engineer and if the test was to be conducted during non-normal business hours, the utility might have the right to impose a fee. All of the issues were resolved.
4. Automatic Load-following Control (ALC) did not function as designed therefore the CHP system was operating at a fixed kW output thus limiting operating hours. The original ALC consisted of a Programmable Logic Controller (PLC) to send analog signals to the individual generator control to vary kW output to maintain a set importing kW from the utility. The problem occurred when there was a sudden drop in a facility's electrical load and the generator could not react fast enough thus causing the Inter-tie Breaker to open on Reverse Power. The problem was resolved by replacing the PLC with a wattmeter to retransmit an actual importing kW to a generator control. As the importing kW from the utility got closer to the set point, kW output from the generators defaulted to a minimum output instead of trying to maintain a set importing kW. This caused an increase in electrical demand from the utility. If the utility did not require the reverse power relay and the generator's ramping capability was faster, then, this would not have been an issue.

Commissioning

1. The generators shut down on Voltage and Frequency faults. The generators were out of commission until the root cause of the problem was determined. The cause of the problem was due to a faulty feeder cable to Generator #2. The feeder cable insulation failed due to a vibration thus causing a shifting of voltage and frequency. To prevent this from occurring again, all the entrance and exit connectors at the terminating boxes/enclosures were replaced with internally insulated fittings and the insulating bushings were also upgraded. Additionally, where possible, the feeder cable entrance and exit points were relocated so that the wires were not straining against the fittings or any part of the enclosure. Ascertaining the root cause of the problem was extremely difficult. The faults were frequent but without any pattern. Sometimes, when the fault occurred, only the generator would lock out and sometimes, Inter-tie Breaker would trip thus disabling both generators. Resolving this problem was most difficult and took a long time due to a fall out between the distributor/contractor and the generator manufacturer.
2. The dump heat exchanger was short cycling and available heat generated by the generators was not being utilized. Some of available heat was being dumped into the atmosphere. Water flow through the heat exchangers was not balanced and the balancing valves were not installed. To correct this problem, the missing valve was installed and the flow through the heat exchanger was balanced.
3. As winter approached, the heat exchangers were extracting more heat then available thus causing the loop temperature to fall below the minimum threshold point. When the return water temperature to generators fell below the threshold point, the DDC controller would bypass the heat exchangers to prevent condensation from occurring inside the engines. This caused the heat exchanger valves to short cycle and some of the available heat was lost. To resolve this problem, a limit provision was added in the DDC's thermal recovery program taking into consideration the outside air temperature and the number of generators that are online de-rating the heat exchangers capacity accordingly to maximize heat recovery.

Emissions

Arrow Linen is required by the New York State Department of Environmental Conservation to install catalytic converters as reasonably available control technology. NYS DEC 227 subpart 227-2.4 requires NOX emissions to be controlled to 2 grams per horsepower-hour. The catalytic converters (the black cylinders) can be seen in Figure 17.

Figure 17 Engine Exhaust Systems

Table 3 Emission Requirements

	NOx	CO	VOC
Major Source Threshold (MST)	25	100	25
50% of MST	12.5	50	12.5
Potential to Emit	10.42	5.17	1.13
Actual Emissions	5.42	3.78	0.86

Arrow Linen is required to obtain an Air Facility Registration through the life of the project. They are also expected to monitor their emissions to be certain that they stay below 50% of the MST shown in Table 3.

Observations

Some problems arose due to installation issues, climate changes and the equipment provided did not work as anticipated. It took some time to address all these problems and issues. A major attribution for delaying and addressing some of the problems was due to a fall out between the contractor/Generator Distributor and the Generator Manufacturer.

COMMISSIONING A GAS TURBINE/HYBRID CHILLER CHP PLANT AT AN AUSTIN, TX HOSPITAL

The key design goals for this CHP plant were:

1. Maximum possible energy efficiency
2. Significant reduction in emissions, especially carbon
3. Improved reliability with grid independence option
4. Investment grade financial returns
5. Green Building and become the first LEED® Platinum Hospital

CHP System Design

The CHP plant consisted of a series of modularized, pre-engineered components most of which were skid mounted, piped, pre-wired and pretested. This process reduced field labor and improved the field commissioning process. The primary modules are listed below:

- Chiller water primary and secondary pump module
- Packaged duplex electrical centrifugal chiller plant totaling 1,500 refrigeration tons
- Packaged boilers totaling 22,000 lbs/hr of steam
- Thermal energy storage tank totaling 8000 ton-hours of chilled water
- 1,500 kW black start engine generator
- Fuel gas compressor module
- 4.3 MW combustion turbine
- Turbine exhaust diverter valve and stack
- Steam absorption chiller totaling 1,000 refrigeration tons
- Heat recovery steam generator (HRSG)
- HRSG Exhaust Stack

The CHP system, Figure 18, delivers 4.3 MW of electricity, 930 RT of chilled water and up to 13,500 lbs/hr of steam to the hospital.

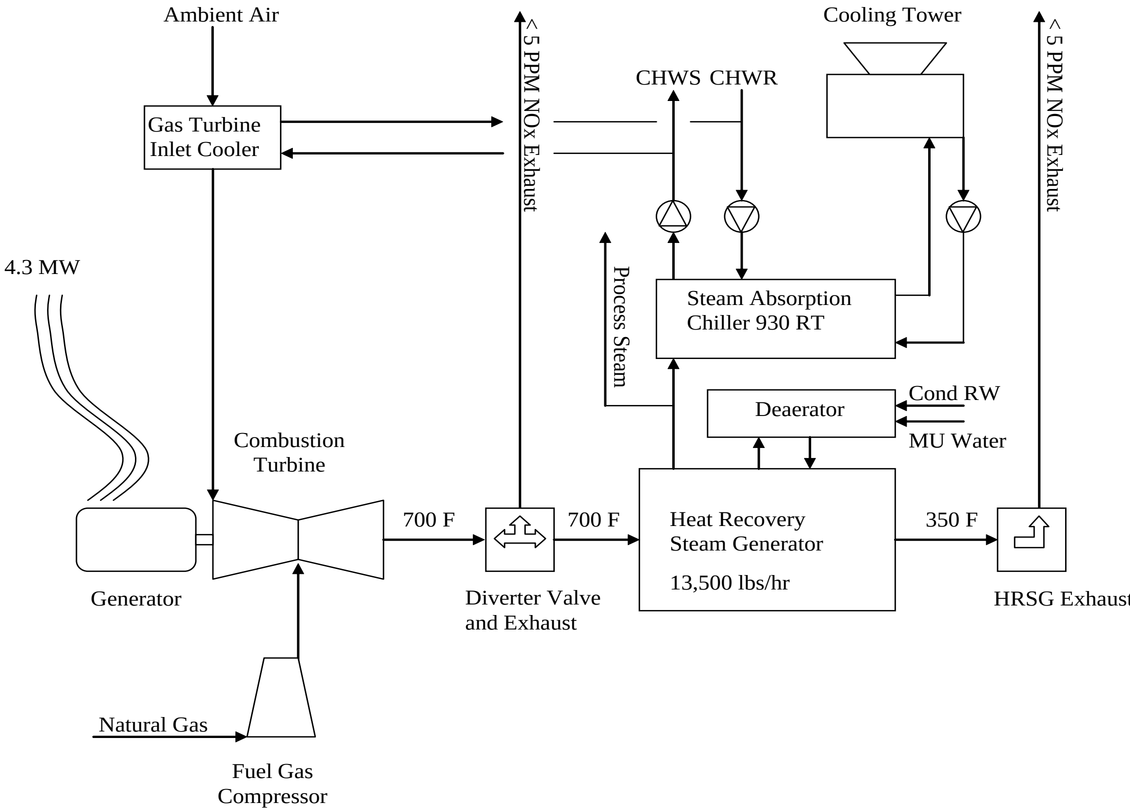


Figure 18 CHP System Schematic

Figure 19 CHP Hybrid Power Plant with Thermal Storage

Figure 19 provides an “as built” look at the utility owned energy center. The CHP plant building is shown in the foreground with bypass and HRSG exhaust stacks above and a thermal storage tank in the background.

Grid Interconnection

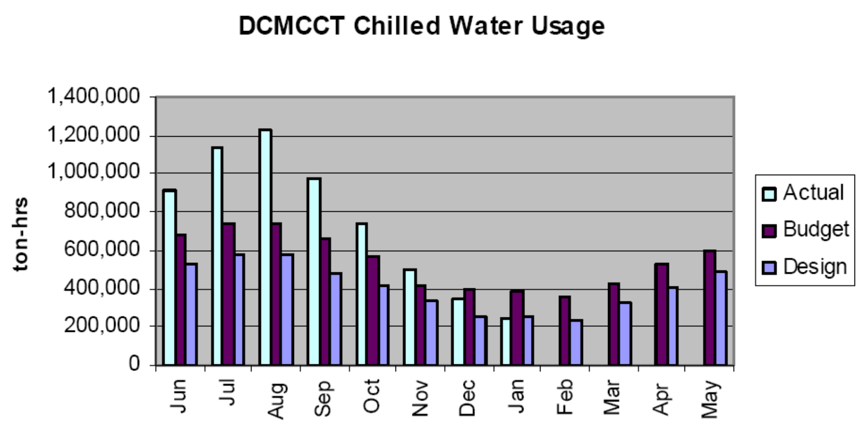
The CHP plant is the primary source of electrical power to the hospital customer. Dual electric utility feeds, each from a separate substation, are brought to the CHP, where appropriate switchgear introduces the CHP generation into the fold. The CHP generation feeds a portion of its output to the hospital, with the balance exported to the utility feeder. Each electric substation feeder is monitored continuously by its respective substation such that any fault on the grid will trip the feeder at the CHP location. The feeder will not be restored to the CHP until a person manually proves that the fault is not within the CHP itself. There is an isolation transformer within the CHP plant to prevent ground faults from or to the electrical distribution system.

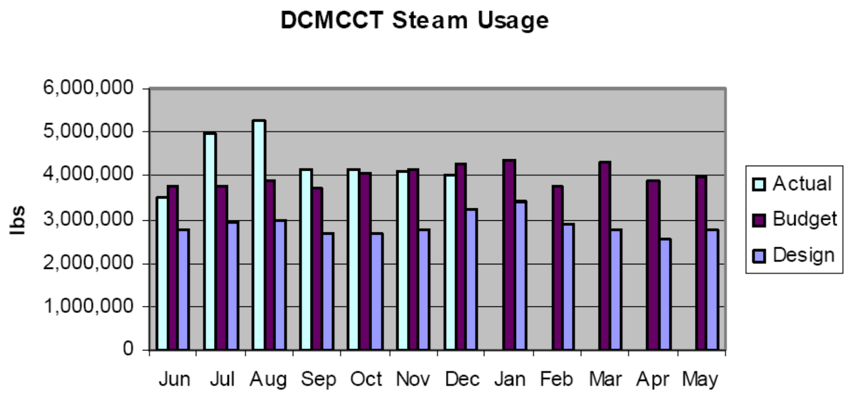
Commissioning

The initial commissioning of the CHP hybrid plant was undertaken prior to June of 2007 by the contractor. In general, electrical power, chilled water and steam were effectively delivered to the Hospital within design parameters but the Hospital building commissioning process was another story. The Hospital opened in June 2007 and was not fully commissioned at time of opening. Commissioning and recommissioning of HVAC equipment and controls and day lighting controls continued after opening until March 2008. The personnel involved in commissioning have discovered several mechanical deficiencies such as ineffective steam coils that had to be retrofit, after hospital occupancy. Additionally, redefinition of HVAC sequence of operation was necessary to minimize the unnecessary treatment of the 30% outside air requirements in areas of the hospital that are partially or totally unoccupied. Excessive time and effort is required to perform such adjustments in a live acute care medical facility.

Table 4 October 2007 through January 2008 Building Requirements

	Chilled Water Million ton-hrs	Steam Mbtuh (through Dec 2007)	Electricity Million kWh
Actual	1.82	12.2	3.75
Budgeted	1.76	12.5	3.53
Design	1.26	8.7	3.35





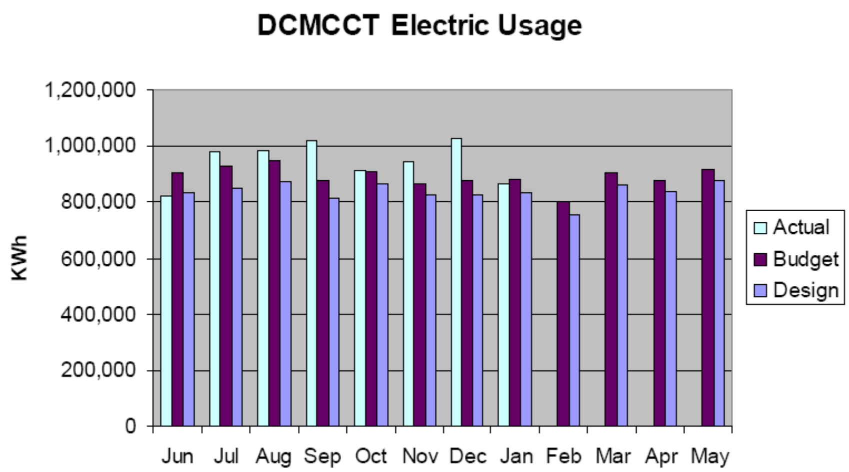


Figure 20 Hospital Chilled Water, Steam and Electricity Monthly Load

Figure 20 provides a clear graphical picture of the hospital load requirements from its opening in June 2007 through January 2008. Projections based on January and February data indicate chilled water peak tonnage will be in the 1,400 –1,500 ton range – close to original "budget" projection, less than the 1,800 peak tons seen at opening, but greater than 1,230-1,260 "design" projection. The March 2008 energy profiles show that thermal energy consumption is actually below design while electrical consumption is slightly above design. The occupancy and demand for the hospital spaces is significantly higher than anticipated which impacts the energy demand.

Emissions

The combustion turbine utilizes an ultra lean premix combustion system resulting in very low NOx emissions, capable of meeting the State of Texas' air quality emission requirements for NOx without the use of selective catalytic reduction systems. The recuperator uses a portion of the waste heat in the turbine exhaust to preheat the air supplied to the turbine, resulting in increased electrical generating efficiency and decreased steam production compared to a conventional non-recuperated turbine.

These extraordinary claims for low emissions were proven to be even better by on-site measurements taken by the environmental engineering group within Austin Energy. In addition to exceeding manufacturer's claims, the emissions rate for energy produced by the CHP system are actually even lower due to the output based emissions methodology approved by Texas Commission on Environmental Quality (the value of thermal energy that is recycled into useful steam is included as energy produced, in addition to the electricity that is produced, so emissions per MWH equivalent are reduced).

Observations

The building performance during 2007 provided many challenges which remind us that buildings are complex projects especially with respect to energy efficiency. This LEED Platinum designed building has had its share of design and implementation issues leading to these important building level observations:

1. An accurate 24/7 energy profile is needed for the CHP design. The profiles should be refined as the design process continues. At least four iterations should be considered: scoping study phase, feasibility phase, preliminary design phase, complete design phase.
2. The HVAC/control system design must comprehensively be able to implement the energy control management strategies used for the energy modeling.
3. Comprehensive submittal review is required to ensure control management strategies meet the design intent.
4. If the schedule allows, complete all commissioning prior to occupancy.
5. Post-commissioning after occupancy will result in greater energy savings as systems are tuned to the actual building operation.
6. Tweak/adjust design after occupancy to optimize energy performance.

The hybrid CHP plant commissioning was relatively uneventful except having to accommodate significantly higher cooling and steam loads that originally anticipated. However, this is not the end of the story. A critical element was left out of the initial design that was essential to system reliability. The initial design called for two independent power feeds from discrete substations and necessary transformers and switchgear. All energy systems were intended to be designed and installed with N+1 redundancy so that failure of any critical component would not jeopardize delivery of reliable electrical and thermal energy.

The plan of operation for the CHP is that the combustion turbine produces power in parallel with the electric grid, using either of two electric grid feeders. Whenever one electrical feeder goes unreliable, the CHP should continue operations in parallel with the redundant electrical feeder. Should both electrical feeders go unreliable, then the CHP should continue operations in an "island" mode. Should the CHP trip off line during any of these scenarios, the back up generators will run, even if in black-start mode, to assure delivery of life safety power to the hospital.

Commissioning of the initial CHP installation was completed and plant operations was demonstrated under various scenarios to the satisfaction of contractor, owner, customer and Texas State Health Service inspectors who must certify such compliance as a requisite to issuing certificate of occupancy for the hospital.

After installation of the initial plant design, and commencement of operations of the CHP, operations staff discovered that a failure of one transformer could render other plant systems unreliable. Therefore a new contractor was engaged to design and install the added transformer and switchgear to assure the N+1 reliability. Another goal of the improvement project was to increase KVA capacity so that another electrically driven chiller could be added.

With the introduction of a second electrical engineer and installation contractor for this new work came new risks associated with plant sequence of operations. The initial plant control sequence was modified to accommodate the new distribution equipment but in so doing, new points of failure were created. With a live CHP plant serving mission critical loads, subsequent commissioning is quite difficult and fraught with risks of inadvertent downtime. Such was the case which has created additional burden on the project provider and the customer. To address the question of CHP plant reliability, Austin Energy has agreed to install a new and second back up generator to provide electrical power to the hospital while the CHP system undergoes yet another commissioning and re-commissioning activity.

During the subsequent re-commissioning of the CHP is an expectation to model the voltage sags that are frequent on a typical utility feeder. Unfortunately for the commissioning process, such sags and other real life issues can not be artificially introduced which represent a risk to designers and operators during real life CHP operations.

CONCLUSIONS

CHP systems applied to the built environment have created a series of new entrants supplying predesigned and engineered energy solutions which are likely to grow in their usage. The CHP plants are more complex and require systematic approaches to commissioning. Current commissioning practices, from this brief review appear to be intuitive and not systematic.

General themes arising out of this review are:

1. A written commissioning report is essential to determine exactly what was tested and how the tests were accomplished.
2. All essential elements must be tested to assure functional performance.
3. If timing and weather precludes performance testing of certain systems, arrangements should be made to perform these tests at a later date.
4. Site engineering is a vital ingredient particularly for retrofit CHP installations because “as built” drawings of complete building systems are often inaccurate or incomplete.
5. In retrofit situations series flow should be used on all CHP thermal loops to balance flow and eliminate pumping problems.
6. Balancing valves are essential to assure flows are correct.

RECOMMENDATIONS

Further Research – This limited dataset of four sites provides a glimpse into the issues surrounding proper design and commissioning of CHP systems. Perhaps more could be learned by broadening the dataset.

Performance Protocols – Adapt an appropriate performance testing protocol. The Association for State Technology Transfer Institutes has provided a framework to generate a cost effective field performance test protocol. http://www.dgdata.org/

Commissioning Protocols – Develop CHP specific commissioning and retrocommissioning protocols that focus on the unique aspects of CHP systems. Commissioning and retrocommissioning methods and tools are necessary to ensure that buildings reach their technical potential and operate energy-efficiently. However, documented commissioning methods are currently only available for some conventional HVAC systems and do not address the advanced systems and system combinations like CHP. The International Energy Agency ANNEX 47 Cost-effective Commissioning for Existing and Low Energy Buildings seeks to enable the cost-effective commissioning of existing and future buildings in order to improve their operating performance. The commissioning techniques developed through this Annex will help transition the industry from the intuitive approach that is currently employed in the operation of buildings to more systematic operation that focuses on achieving significant energy savings. CHP systems should be an integral part of this effort.
http://ctec-varennes.rncan.gc.ca/en/b_b/bi_ib/annex47/index.html

Commissioning Database – Several States and the US government have developed CHP case study databases. However, there has been no attempt to study the commissioning process for CHP systems. A CHP Commissioning Database would be a unique attempt to standardize and centralize CHP commissioning data and make this data easily accessible. Providing lessons learned would be invaluable to designers, practitioners, operators and owners.

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