MEASUREMENT AND VERIFICATION PLAN

FOR

DG/CHP SYSTEM AT
SAINTS JOACHIM & ANNE NURSING AND REHABILITATION CENTER
2720 SURF AVE
BROOKLYN, NY

draft
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Submitted to:

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Submitted by:

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1. Introduction

St. Joachim and Anne is a nursing home and rehabilitation center located in on Coney Island. The CHP system includes three (3) 100-kW InVerde Engine Units from Tecogen that use permanent magnet generators with 480 VAC inverters to provide power output. The engines are capable of providing 125 kW peak and 100 kW continuous. The inverters, oil coolers, and associated electronics have their own small cooling loop and dry cooler (FLC/CT-1, 2, 3). A heat rejection loop from the engine jacket and exhaust heat exchanger is the primary source of thermal output.

The engines are piped in parallel with integrated hot water loop (Figure 2). Heat recovered from the engine jacket and the exhaust gas heat exchanger is injected into hot water loop that serves the various thermal loads (Figure 3). The system has been designed to accept 1 additional engine. The engine loop also includes a dump radiator (FLC-5) that is activated if water returning to the engine is too warm. For this system it is only expected to operate if the power requirements are temporarily larger than thermal loads.

Figure 1. Photo of Engines installed in Roof-top Mechanical Room

The hot water from the engines is used to meet various thermal loads in this printing facility:

- Provide heating to the boiler loop via HX-1 for service water heating loads

- three 30-ton, hot-water driven Yazaki chillers that provide seasonal space cooling in the facility

The hot water flow through the 3 engines is about 90 gpm with a total output of 2,196 MBtu/h. The hot water flow in the main cogen loop is about 140 gpm. The cogen loop flow rate is controlled by a VSD that maintains the required differential pressure in the loop.

At full load the three generators will consume approximately 3,900 std cf/h of natural gas (1300 cf/h each).

The power output from the three engines feeds into one new electrical panel (CGDP) before being fed into the existing main facility distribution panel (MDP), as shown in Figure 4. The main parasitic loads on the CHP system are all fed from MCC, which is separately sub-metered. These parasitic loads include the dump radiators (FLC-5) and the electronics coolers (FLC-1 to FLC-3), the cogen loop pumps (CGP-5 and CGP-6), the engine loop pumps (CGP-1 to CGP-3), the boiler hot water pumps (HWP-1 and HWP-2). The MCC panel also includes parasitic loads for the absorption chiller such as the chilled water pumps (CWP-1 to CWP-4), and the condenser water pumps (CDP-1 and CDP2).

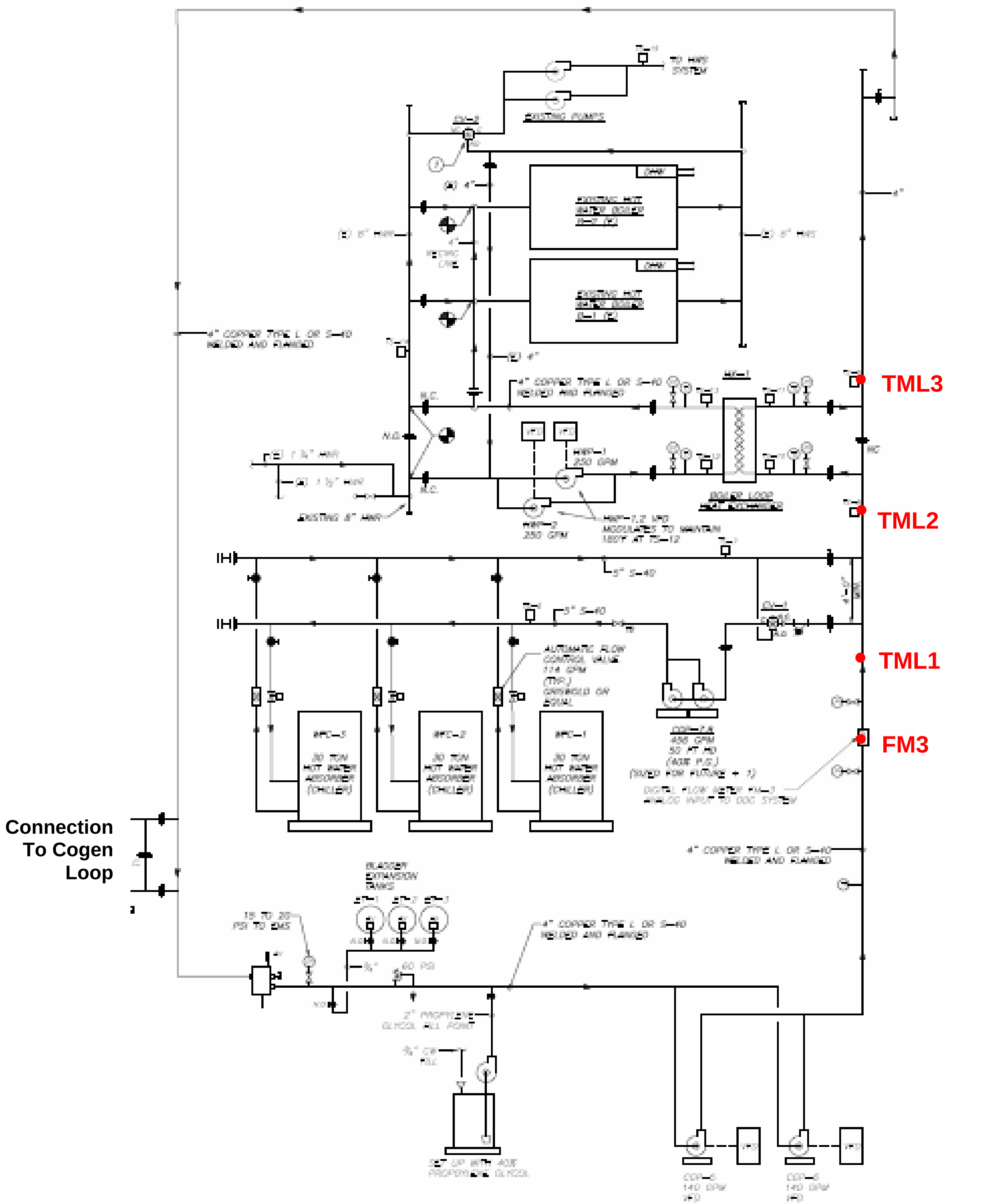


Figure 2. Schematic of Main Cogen Loop (from Drawing M-3.01)

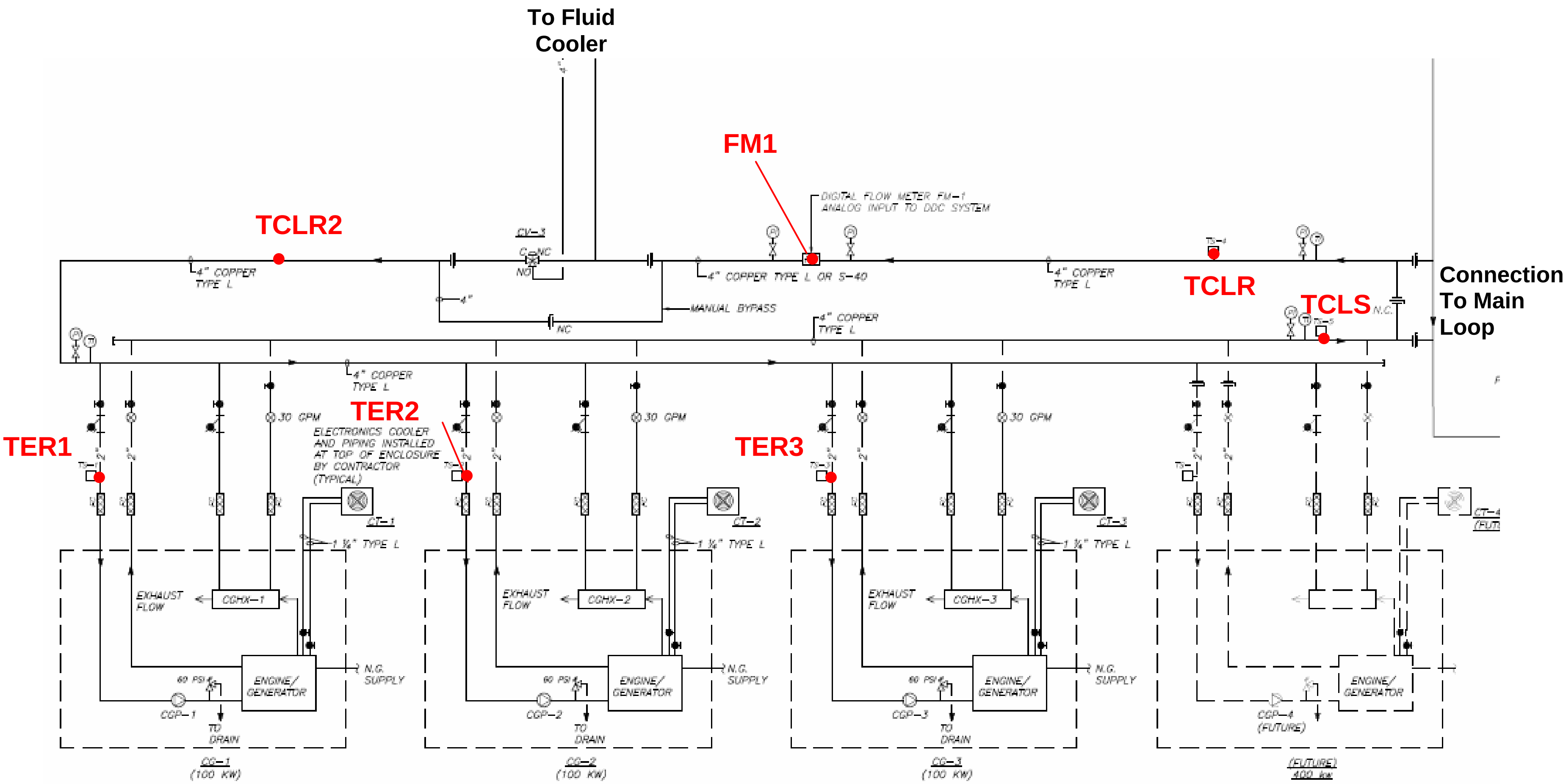


Figure 3. Schematic of Engine Loop (from Drawing M-3.01)

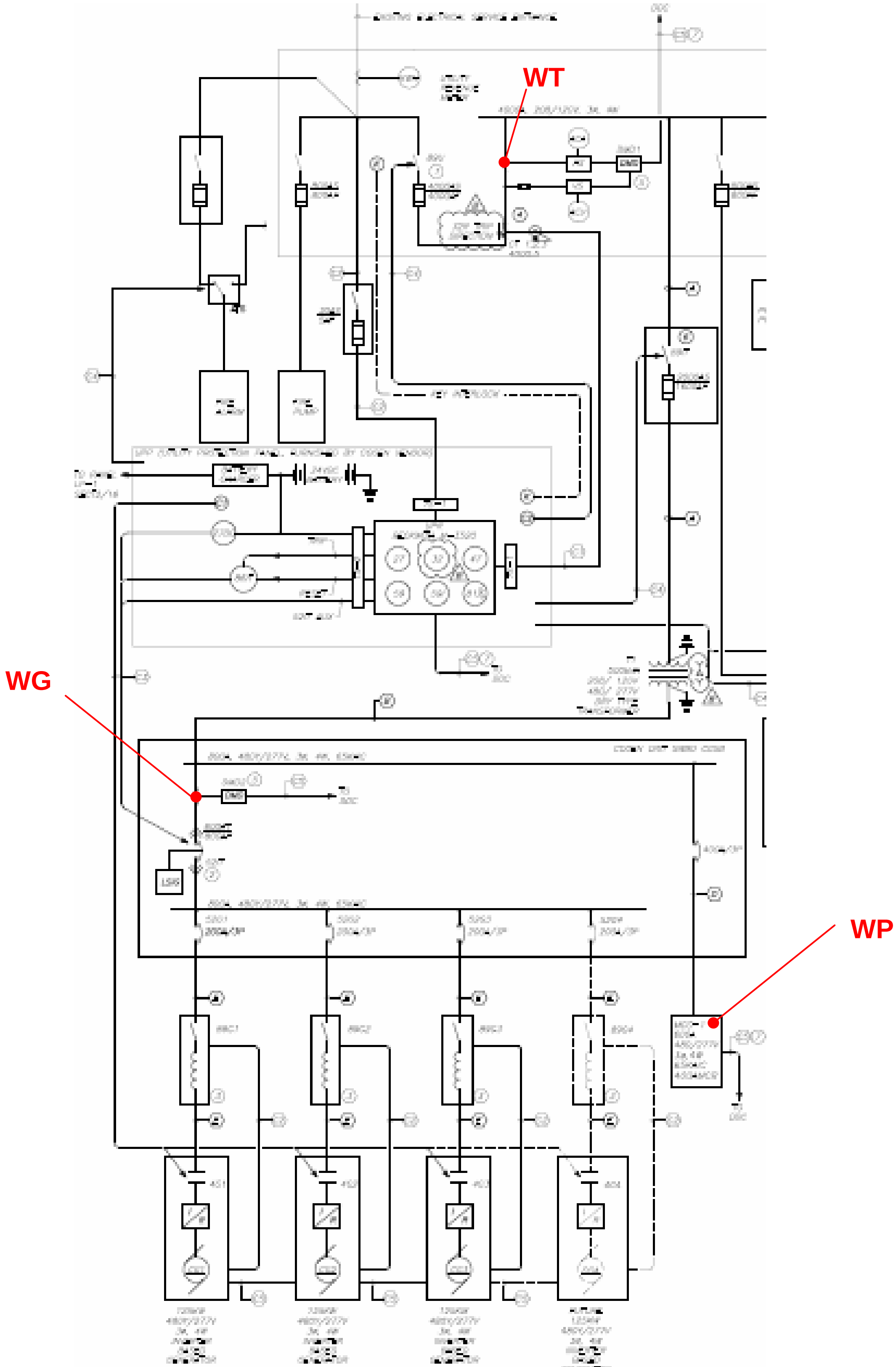


Figure 4. One-Line Schematic of Electrical Interconnection (from Drawing E-3.01)

2. Monitoring Points

The ALC control system at the site will be used for data collection. Table 1 lists the monitored points that will be used to characterize the performance of the CHP system. The table lists the original drawing information as well as the identifying information from the ALC control system. Specifications on the sensor/transducer, the expected engineering units, and the CDH point name (will be used in the data analysis section) are also given.

Table 1. List of Monitored Data Points to be Collected

No.	Drawing Tag Name (see pics)	ALC Point Name	Manufacturer / Model #	Description	CDH Point Name	Eng Units
1	DMD-2	CGDP Power Meter - Real Power (kW)	Siemens 9330	Generator Power Output	WG_kw	kW
2	DMD-2	CGDP Power Meter - Energy Forward (kWH)	Siemens 9330	Generator Energy Output	WG	kWh (cum)
3	DMD-1	MDP Power Meter - Real Power (kW)	Siemens 9330	Facility Import	WT_kw	kW
4	DMD-1	MDP Power Meter - Energy Forward (kWH)	Siemens 9330	Facility Import	WT	kWh (cum)
5	DMD-3	MCC Power Meter - Real Power (kW)	Siemens 9330	Misc Cogen Loads	WM_kw	kW
6	DMD-3	MCC Power Meter - Energy Forward (kWH)	Siemens 9330	Misc Cogen Loads	WM	kWh (cum)
7		(not installed yet)	Bryan Dankin RMG-32A (5600 CF/h)	Generator Gas Input	FG	CF
8	FM-1	Flow Rate	Onicon F-1110 (0-375 gpm)	Engine Loop Flow Rate	FM1	gpm
9	TS-4	CGHWS	ALC Thermistor	Engine Loop Supply Temp	TCLS	F
10	TS-5	CGHWR	ALC Thermistor	Engine Loop Return Temp	TCLR	F
11		(not labeled)	ALC Thermistor	Engine Loop Return (after FLC)	TCLR2	F
12	TS-1	Cogen 1	ALC Thermistor	Engine Return Temp 1	TER1	F
13	TS-2	Cogen 2	ALC Thermistor	Engine Return Temp 2	TER2	F
14	TS-3	Cogen 3	ALC Thermistor	Engine Return Temp 3	TER3	F
15	FM-3	Main Flow Rate	Onicon F-1110 (0-375 gpm)	Main Loop Flow Rate	FM3	gpm
16		installed??	ALC Thermistor	Main Loop Supply Temp	TM1	F
17	TS-8	TS-8	ALC Thermistor	Main Loop Temp After Chiller	TM2	F
18		Return Temp	ALC Thermistor	Main Loop Return	TM3	F
19		Boiler Water Supply	ALC Thermistor	Boiler Supply Temp	TBS	F
20		Boiler Water Return	ALC Thermistor	Boiler Return Temp	TBR	F
21				Status of CGP-5 (Main)	SP5	0 or 1
22				Status of CGP-6 (Main)	SP6	0 or 1
23				Status of CGP-7 (Chiller HW)	SP7	0 or 1
24				Status of CGP-8 (Chiller HW)	SP8	0 or 1
25		Fan1 Status		Status of Dry Cooler Fan 1	SF1	0 or 1
26		Fan2 Status		Status of Dry Cooler Fan 2	SF2	0 or 1
27		Fan3 Status		Status of Dry Cooler Fan 3	SF3	0 or 1
28		Fan4 Status		Status of Dry Cooler Fan 4	SF4	0 or 1
29		Fan5 Status		Status of Dry Cooler Fan 5	SF5	0 or 1

Temperature Sensors

The temperature sensors are BAPI thermistor probes installed in thermowells.

Fluid Flowmeters (FM-1, FM-3)

The hot water flowmeters are Onicon model F-1110 single-turbine insertion meters. Each flowmeter is inserted into the 4-inch (or a 5 inch) line through a 1-inch ball valve. Both were calibrated for a range of 0 to 375 gpm. The typical flow (used for calibration) was 200 gpm. Since the flow through the engine loop is expected to range from 30 to 90 gpm (with 1 to 3 engines), the accuracy for the engine loop is not expected to be as good as for the main cogen loop, where expected flow is closer to 140 gpm.

Engine-Generator Power Output (WG, WT, WP)

The power output of the 3 engine-generator units is consolidated into one feed in panel CGDP (see Figure 4). A Siemens power transducer (DMD-2) measures the gross power produced by the 3 engine units. The parasitic power consumption of the CHP system is measured by Siemens meter (DMD-3) installed in the MCC panel in the rooftop mechanical room. A Siemens meter is also used to measure facility power import from the utility.

CGDP Electric Panel
Rooftop Mechanical Room

Siemens 9330 Power Meter (DMD-2)

Figure 5. Power Meters for Generator Output and Total Facility Power

Engine-Generator Gas Input (FG)

There is one rotary gas meter measuring the combined gas use of the CHP system. The meter has been installed but it has not been connected to the ALC system yet. This Model 5.6 meter has a max rating of 5,600 CF/h.

Data Logging Equipment

The ALC control system will transfer 15-minute data to CDH each night by email. The ALC system will be setup to email the data listed in Table 1 at a regular time each night or morning as a time-stamped CSV file. The file should include the 96 records for the previous days' data.

Verification

Once the data collection process is established, CDH Energy staff will come on-site and use our hand held meters to confirm proper readings are being collected.

3. Data Analysis

Heat Recovery

The amount of useful heat recovery for this system can be calculated 2 different ways: 1) using the flow-delta T for the engine loop, or 2) using the flow delta-T for the main cogeneration loop. Both methods are summarized below.

Useful heat recovery	**QUe** =	**K·FM1·(TCLS-TCLR)**	engine loop
	QUm =	**K·FM3·(TM1-TM3)**	main cogen loop

The flow meter **FM3** is expected to operate more frequently near its calibration point, therefore we will use **QUm** as primary measurement of useful heat recovery. The measurement **QUe** will be used as a check. The factor K will be determined based on the fluid in the loops, which is expected to be a glycol-water mix (K ~ 490 Btu/h-gpm-°F for pure water at 180°F; approximately 480 for 30% glycol). CDH will use a Hygrometer to estimate the glycol concentration if required.

The non-useful or rejected heat recovery will be determined using the following calculation:

Non-Useful or Rejected heat recovery **QR** = **K·FM1·(TCLR-TCLR2)**

Calculated Quantities

For this site, the gross power output from the engine generators will be measured by the power transducer in the CGDP panel, so

WNET = **WG – WP_o**

Where **WP_o** includes only a subset of the parasitic loads in Panel MCC measured by **WP**. The chilled water and condenser water pumps will be excluded from the panel power by looking at the seasonal variations in power use. The table below lists parasitics that will be included in the variable **WP_o**.

Table 2. Summary of Included Parasitics

MCC Panel

Load	Size (HP)	Included Parasitic	Description
CGP-5	7.5	Yes	Cogen Loop
CGP-6	7.5	Yes	
CGP-7	7.5	Yes	Cogen Chiller HW
CGP-8	7.5	Yes	
CDP-1	20		Condenser Pumps
CDP-2	20		
CWP-1	7.5		CHW Pri Pumps
CWP-2	7.5		
CWP-3	15		CHW 2nd Pumps
CWP-4	15		
HWP-1	5	Yes	Boiler Pumps
HWP-2	5	Yes	
FLC-1	3	Yes	Electronics (each engine)
FLC-2	3	Yes	
FLC-3	3	Yes	
FLC-5	15	Yes	Fluid Cooler
CTH-1	15	Yes	
CTF-1	7.5	Yes	
	86.5	HP for Included Parasitics	

The fuel conversion efficiency of the CHP system, based on the lower heating value of the fuel, will be defined as:

$$FCE = \frac{QU \cdot \Delta t + 3{,}412 \cdot (WNET)}{LHV_{gas} \cdot FG}$$

where:
- QU - Useful heat recovery (Btu/h)
- WG - Generator output (kWh)
- FG - Generator gas consumption (Std CF)
- Δt - 1/12 hour for 5-minute data
- LHV_{gas} - Lower heating value for natural gas (~905 Btu per CF)

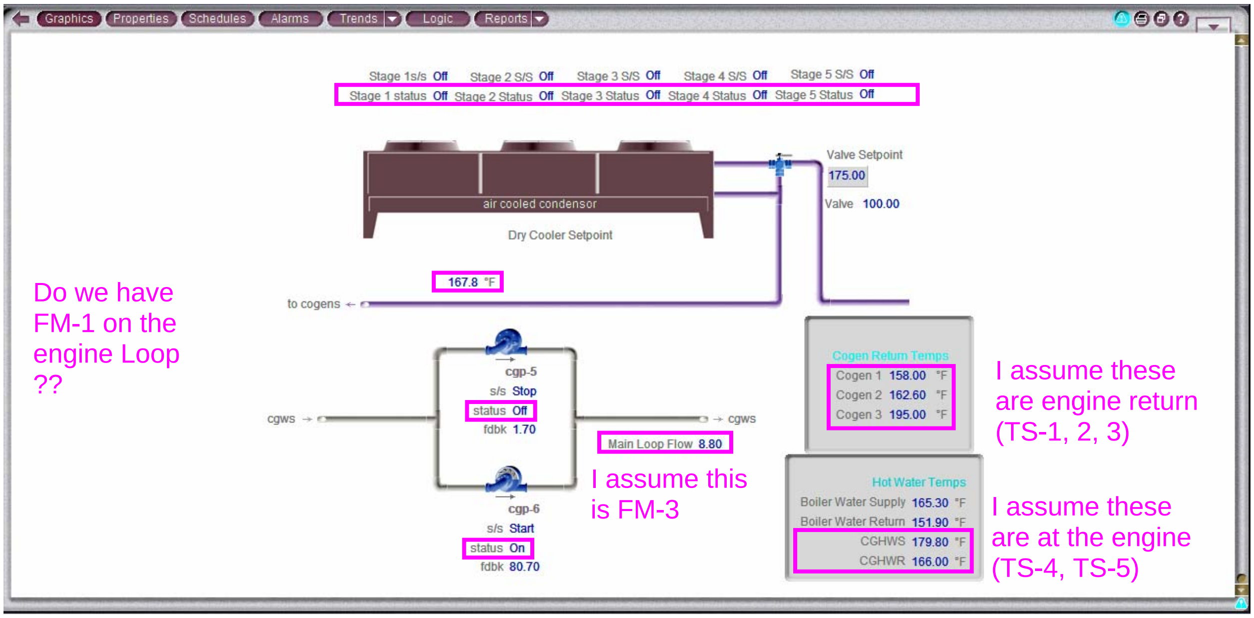
The FCE can be calculated for any time interval. When converting to daily, monthly, or annual values, each value is summed and then the formula is applied:

$$FCE = \frac{\sum^{N} QU \cdot \Delta t + 3412 \cdot \sum^{N} (WNET)}{LHV_{gas} \cdot \sum^{N} FG}$$

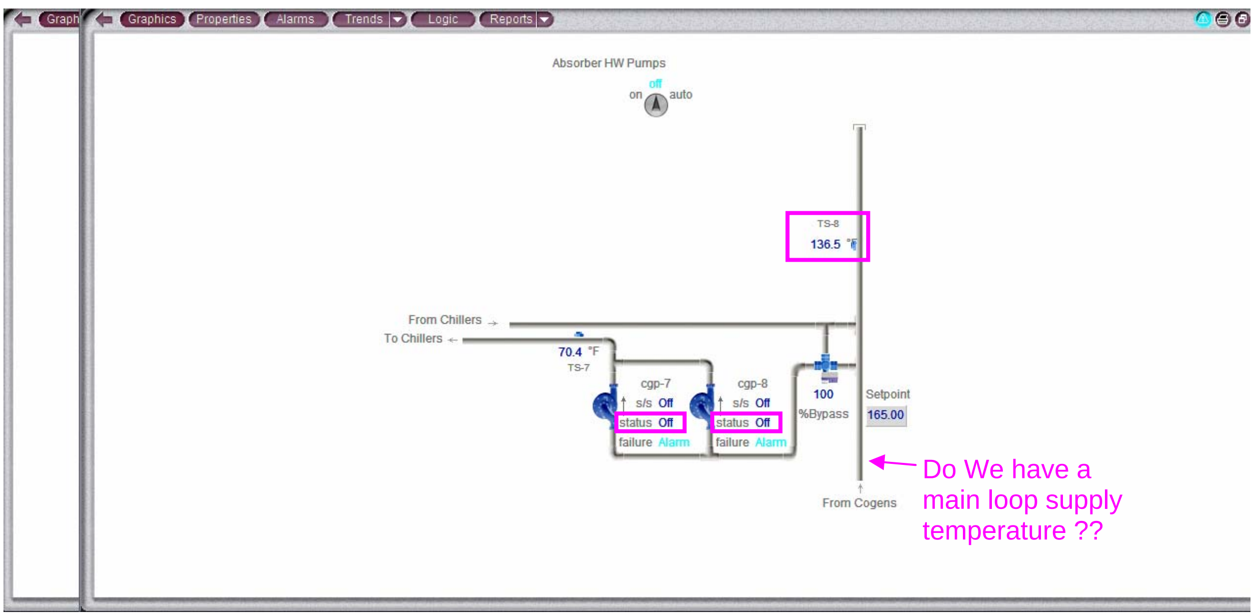
Where N is equal to the number of intervals in the period of interest.

Appendix A

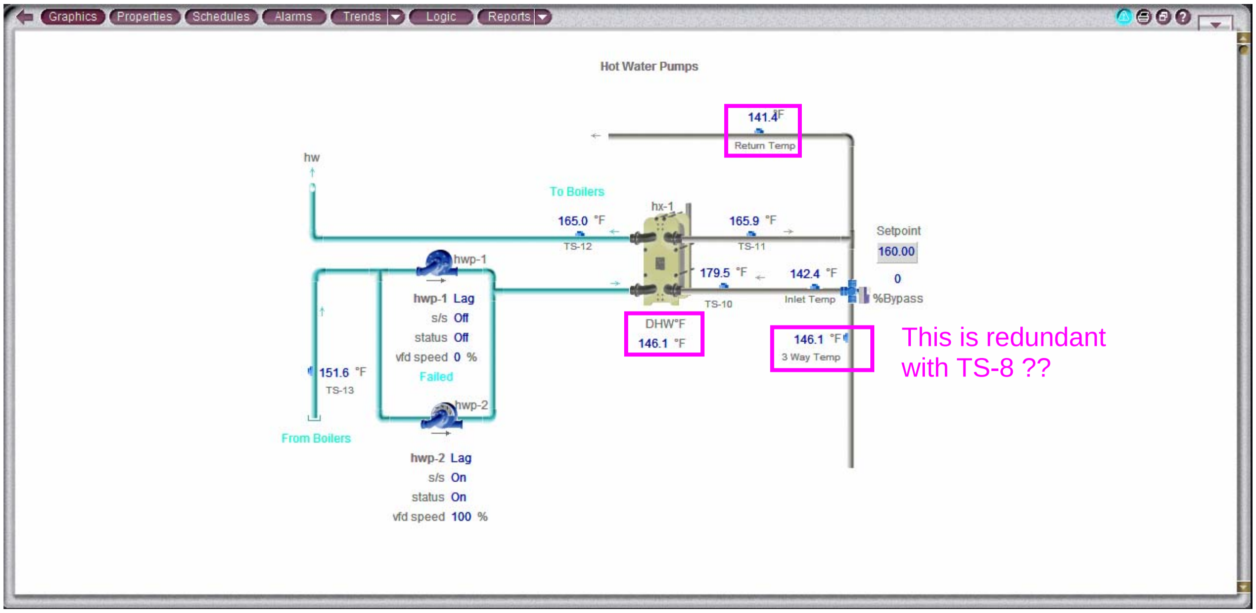
ALC Screen Shots



Graphics
Properties
Schedules
Alarms
Trends
Logic
Reports
Stage 1s/s Off
Stage 2 S/S Off
Stage 3 S/S Off
Stage 4 S/S Off
Stage 5 S/S Off
Stage 1 status Off
Stage 2 Status Off
Stage 3 Status Off
Stage 4 Status Off
Stage 5 Status Off
air cooled condensor
Valve Setpoint
175.00
Valve 100.00
Dry Cooler Setpoint
167.8 °F
to cogens
Do we have FM-1 on the engine Loop ??
cgp-5
s/s Stop
status Off
fdbk 1.70
cgws
cgws
Main Loop Flow 8.80
I assume this is FM-3
cgp-6
s/s Start
status On
fdbk 80.70
Cogen Return Temps
Cogen 1 158.00 °F
Cogen 2 162.60 °F
Cogen 3 195.00 °F
I assume these are engine return (TS-1, 2, 3)
Hot Water Temps
Boiler Water Supply 165.30 °F
Boiler Water Return 151.90 °F
CGHWS 179.80 °F
CGHWR 166.00 °F
I assume these are at the engine (TS-4, TS-5)



Graphics
Properties
Alarms
Trends
Logic
Reports
Absorber HW Pumps
off
on
auto
TS-8
136.5 °F
From Chillers
To Chillers
70.4 °F
TS-7
cgp-7
s/s Off
status Off
failure Alarm
cgp-8
s/s Off
status Off
failure Alarm
100
%Bypass
Setpoint
165.00
From Cogens
Do We have a main loop supply temperature ??


Graphics
Properties
Schedules
Alarms
Trends
Logic
Reports
Hot Water Pumps
141.4 °F
Return Temp
hw
To Boilers
hx-1
165.0 °F
TS-12
165.9 °F
TS-11
Setpoint
160.00
hwp-1
179.5 °F
142.4 °F
Inlet Temp
0
%Bypass
TS-10
hwp-1 Lag
s/s Off
status Off
vfd speed 0 %
Failed
DHW°F
146.1 °F
146.1 °F
3 Way Temp
This is redundant
with TS-8 ??
151.6 °F
TS-13
hwp-2
From Boilers
hwp-2 Lag
s/s On
status On
vfd speed 100 %

Addendum - Joachim

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Site Contact:
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- Website data begins June 29th, 2011
- CDH on site to verify meters and readings June 29th 2011

Verification – June 29th

Summary:

1. The headers in the data file for Utility Import and Generator Power are reversed. This will be corrected within the CDH Database.

2. The power reading at the meter for Generator Power is off by a factor of two. CDH will apply a multiplier of 2 on the collected data. Once the meter is fixed, CDH will be notified and will only apply the multiplier to the historic data.

3. The ALC system did not have a correct pulse multiplier for the gas readings. The multiplier has been confirmed as 10 cf per pulse. The data file now contains two channels for gas, cubic feet per minute and cubic feet per hour. These channels support the generated power after the power has been adjusted.

4. On the main loop, the temperature sensors TM2 (TS 8) and TM3 (TS 11) are on the returns for the chiller loop and hot water loop respectively. The flow meter for the main loop is positioned on a bypass line between the chiller supply and return. This prevents the flow meter from measuring the total water flowing in the main loop, as hot water going to the chiller will bypass the flow meter. Currently, we will not use the main loop to measure heat recovery in the system unless the flow meter and temperature sensors are moved. We can use the measurements from the cogen loop.

5. On the cogen loop, the point we were getting for TCLR (TS 4) was after the dump radiator. We are now correctly getting the point TCLR (TS 4) and the temperature measurement after the dump radiator on the cogen loop. We requested the supply temperatures for each engine to compare against the return temperatures.

6. We measured flow using an ultrasonic flow meter and compared the reading to the FM1. The readings taken indicate the reading from FM1 is consistently high. CDH will use the data acquired and apply an offset.

7. The calculation for heat recovered from the system will be based on FM1, TCLR, and TCLS. The calculation for heat dumped from the system will be based on FM1, TCLR2 (after dump temperature), and TCLR.

Site Information:

site information	
Piping	steel
size	4"
diameter	4.5"
wall	.237"
Glycol reading	34%
multiplier	0.464

Multiplier is used in the equations for calculating heat recovered and dumped (k) and is based on the glycol concentration used in the loop.

Flow Meter Multiplier:

Ultrasonic		AMS	
L/s	gpm	gpm	factor
4.2	66.57136	77.6	0.857878
4.34	68.7904	77	0.893382
4.28	67.83938	74.2	0.914277

avg factor = 0.888513

Power:

	Database		Meter		Fluke
	Power (kW)	Para (kW)	Main (kW)	Engine (kW)	Total (kW)
9:00	253.4	9.8	264	264.5	248
9:15	272.2	9.6			
9:30	290.6	9.7	280	279.2	263

Readings were taken while system was increasing load. Database values are averages of 15-minute data ending at the recorded timestamp. The meter reading from the main meter has been multiplied by a factor of 2.

Heat Recovery:

Q	k	FM1	TCLS	TCLR2
1627.422	0.464	78	219	174

Q = k * FM1 * (TCLS – TCLR2)
Q = Total heat generated by system
Data from ALC system

Table 1. List of Received data points

CDH ID	File Header Version 1	File Header Version 2	File Header Version 3
WT_ACC	MDP Energy (kWh)	MDP Energy (kWh)	MDP Energy (kWh)
WT_KW	MDP Power (kW)	MDP Power (kW)	MDP Power (kW)
WG_ACC	CGDP Power (kWh)	CGDP Power (kWh)	CGDP Power (kWh)
WG_KW	CGDP Power (kW)	CGDP Power (kW)	CGDP Power (kW)
WP_ACC	WP_ACC (kWh)	WP_ACC (kWh)	WP_ACC (kWh)
WP_KW	WP_KW Misc Cogen Loads (kW)	WP_KW Misc Cogen Loads (kW)	WP_KW Misc Cogen Loads (kW)
FG	Engines Gas Use	Engines Gas Use	Engines Gas Use
FG_H			Engine Gas Use Per Hour
FM1	Engines Flow (GPM)	Engines Flow (GPM)	Engines Flow (GPM)
TCLS	Engine Supply (CGWS Temp)	Engine Supply (TCLS Temp)	Engine Supply (TCLS Temp)
TCLR	Engine Return (CGWR Temp)	Engine Return (TCLR)	Engine Return (TCLR)
TCLR2			After Dump Temperature
FM3	Main CGP Flow	Main CGP Flow	Main CGP Flow
TM1	Main CGWS Temp	TM1 Main Loop Supply	TM1 Main Loop Supply
TM2		TM2 Main Loop After Chiller	TM2 Main Loop After Chiller
TM3		TM3 Main Loop Return	TM3 Main Loop Return
TAO	OA Temp	OA Temp	OA Temp
SP5	CGP-5 Speed	CGP-5 Speed	CGP-5 Speed
SP6	CGP-6 Hz	CGP-6 Hz	CGP-6 Hz
SF1		Dry Cooler Fan 1 Status	Dry Cooler Fan 1 Status
SF2		Dry Cooler Fan 2 Status	Dry Cooler Fan 2 Status
SF3		Dry Cooler 3 Fan Status	Dry Cooler 3 Fan Status
SF4		Dry Cooler 4 Fan Status	Dry Cooler 4 Fan Status
SF5		Dry Cooler 5 Fan Status	Dry Cooler 5 Fan Status
TER1		CG-1 Inlet Temperature	CG-1 Inlet Temperature
TER2		CG-2 Inlet Temperature	CG-2 Inlet Temperature
TER3		CG-3 Inlet Temperature	CG-3 Inlet Temperature
SP7		CGP-7 Status	CGP-7 Status
SP8		CGP-8 Status	CGP-8 Status
TBS		Boiler Water Supply Temperature	Boiler Water Supply Temperature
TBR		Boiler Water Return Temperature	Boiler Water Return Temperature
TES1			CG-1 Outlet Temperature
TES2			CG-2 Outlet Temperature
TES3			CG-3 Outlet Temperature
SVHW			Hot Water Bypass Valve
SVCH			Chiller Bypass Valve