MEASUREMENT AND VERIFICATION PLAN

FOR

CHP SYSTEM AT SEA PARK WEST APARTMENT COMPLEX

Submitted to:

New York State Energy Research and Development Authority
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1. Introduction

This monitoring plan presents the measurement and data collection approach for the CHP system at Sea Park West.

The CHP system at Sea Park West includes two Tecogen 75 kW engine generator units. The two units combined provide 150 kW gross electrical output. The thermal energy output from the units will be used for the domestic water heating and space heating loads. The heat recovery loop includes a DHW heat exchanger (HX) and a dump radiator to heat reject unneeded heat. Each Tecogen unit also includes an exhaust-to-hot water HX that adds heat directly to the boiler drum.

The generators are located next to the boiler room inside the building and the monitoring equipment will be located within the boiler room and maintenance rooms.

2. Instrumentation

The site will supply the instrumentation listed in Table 1. The NYSERDA monitoring contractor will provide the temperature sensors listed in Table 2 and integrate all the sensors into the datalogger.

Table 1. Instrumentation Supplied By Sea Park West, LP

Point	Instrument	Output Type	Sensor Location	Notes
Facility Power (**WT**)	Con Ed Utility Meter	Web	NA	Data will be extracted from Con Edison DMS website (account 69-5302-0326-0001-7)
Generator #1 Power Output (**WE1**)	Wattnode WNB-3Y-208P (CTS-1250-600)	Pulse output 15 Wh/pulse	See figure 3	600 amp CT, x 3
Generator #2 Power Output (**WE2**)	Wattnode WNB-3Y-208P (CTS-1250-600)	Pulse output 15 Wh/pulse	See figure 3	600 amp CT, x 3
Parasitic Power (**WP**)	Wattnode WNB-3Y-208P (CTS-0750-50)	Pulse output 1.25 Wh/pulse	Panel in Engine room	50 amp CT
Natural Gas Fuel Input (**FG**)	Roots B3 Series Model: 2M175-ITPWS	Solid State Pulse 100 cf/pulse	On common gas line serving both engines	Temperature Compensated
Fluid Flow (**FW**)	Onicon F-1110 Flow Meter	4-20 mA output Full Scale: 130gpm	1-1/2" copper piping with 10x diam before and after	± 1% or better at calibrated velocity
Fluid Flow (**FB**)	Onicon F-1110 Flow Meter	4-20 mA output Full Scale: 130gpm	1-1/2" copper piping with 10x diam before and after	± 1% or better at calibrated velocity

Table 2. Temperature Measurements

Hot Water Supply (**THS**)	Veris 10k type 2 Old(Mamac TE211z 1000 ohm RTD)	Resistance Old(4-20 ma 100 – 250 ºF)	Figure 1	Site provides thermowell, ¼" probe, ½ " NPT
Hot Water Return to Radiator (**THR1**)	Veris 10k type 2 Old(Mamac TE211z 1000 ohm RTD)	Resistance Old(4-20 ma 100 – 250 ºF)	Figure 1	Site provides thermowell, ¼" probe, ½ " NPT
Hot Water Return to Engine (**THR2**)	Veris 10k type 2 Old(Mamac TE211z 1000 ohm RTD)	Resistance Old(4-20 ma 100 – 250 ºF)	Figure 1	Site provides thermowell, ¼" probe, ½ " NPT
Hot Water Supply from Exhaust Heat Exchanger (**TBS**)	Veris 10k type 2 Old(Mamac TE211z 1000 ohm RTD)	Resistance Old(4-20 ma 100 – 250 ºF)	Figure 2	Site provides Site provides thermowell, ¼" probe, ½ " NPT
Hot Water Return to Exhaust Heat Exchanger (**TBR**)	Veris 10k type 2 Old(Mamac TE211z 1000 ohm RTD)	Resistance Old(4-20 ma 100 – 250 ºF)	Figure 2	Site provides Site provides thermowell, ¼" probe, ½ " NPT

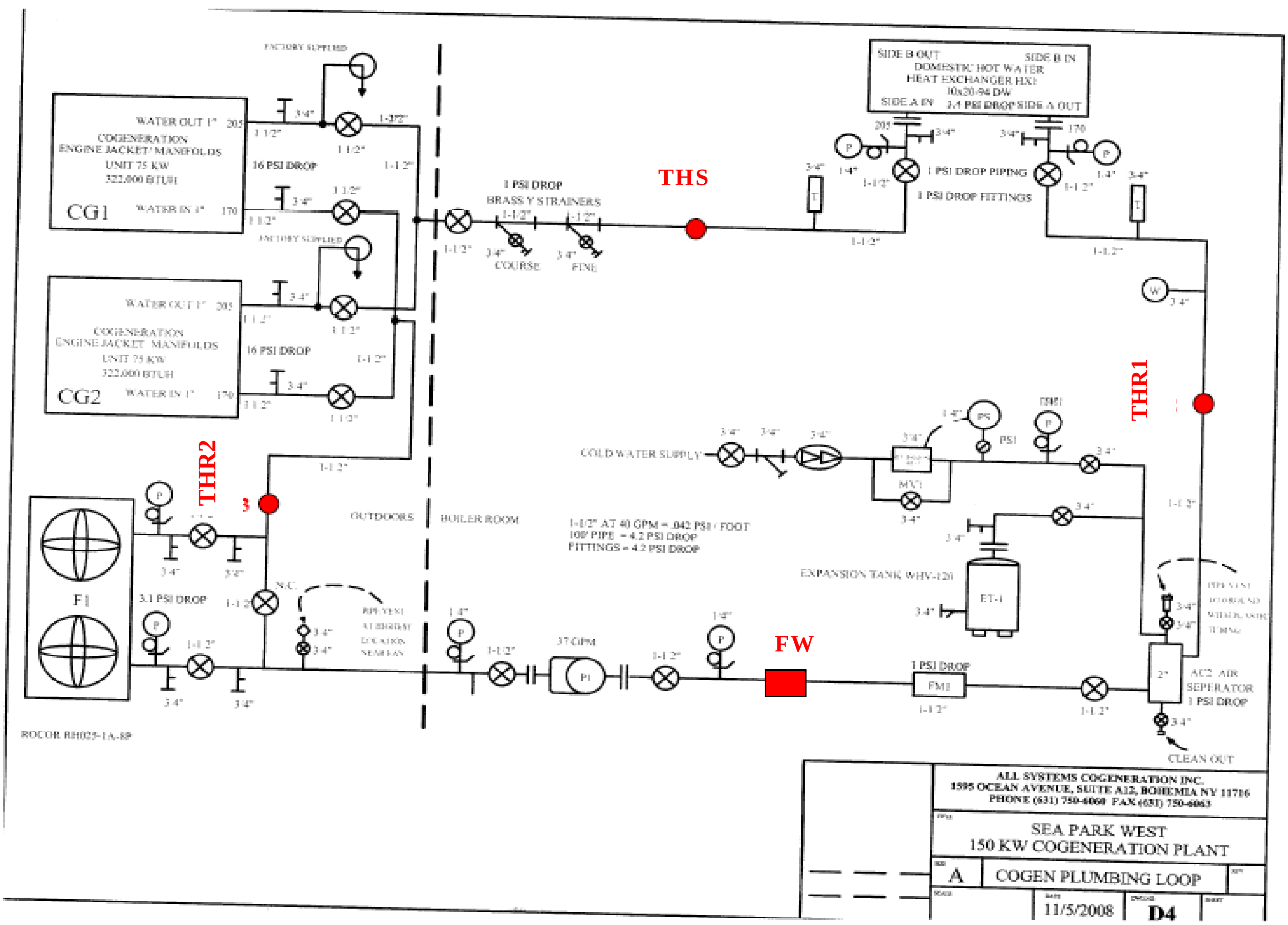


Figure 1. Schematic Drawing (D4) Showing the Location of Temperature Sensors and Flow Meters

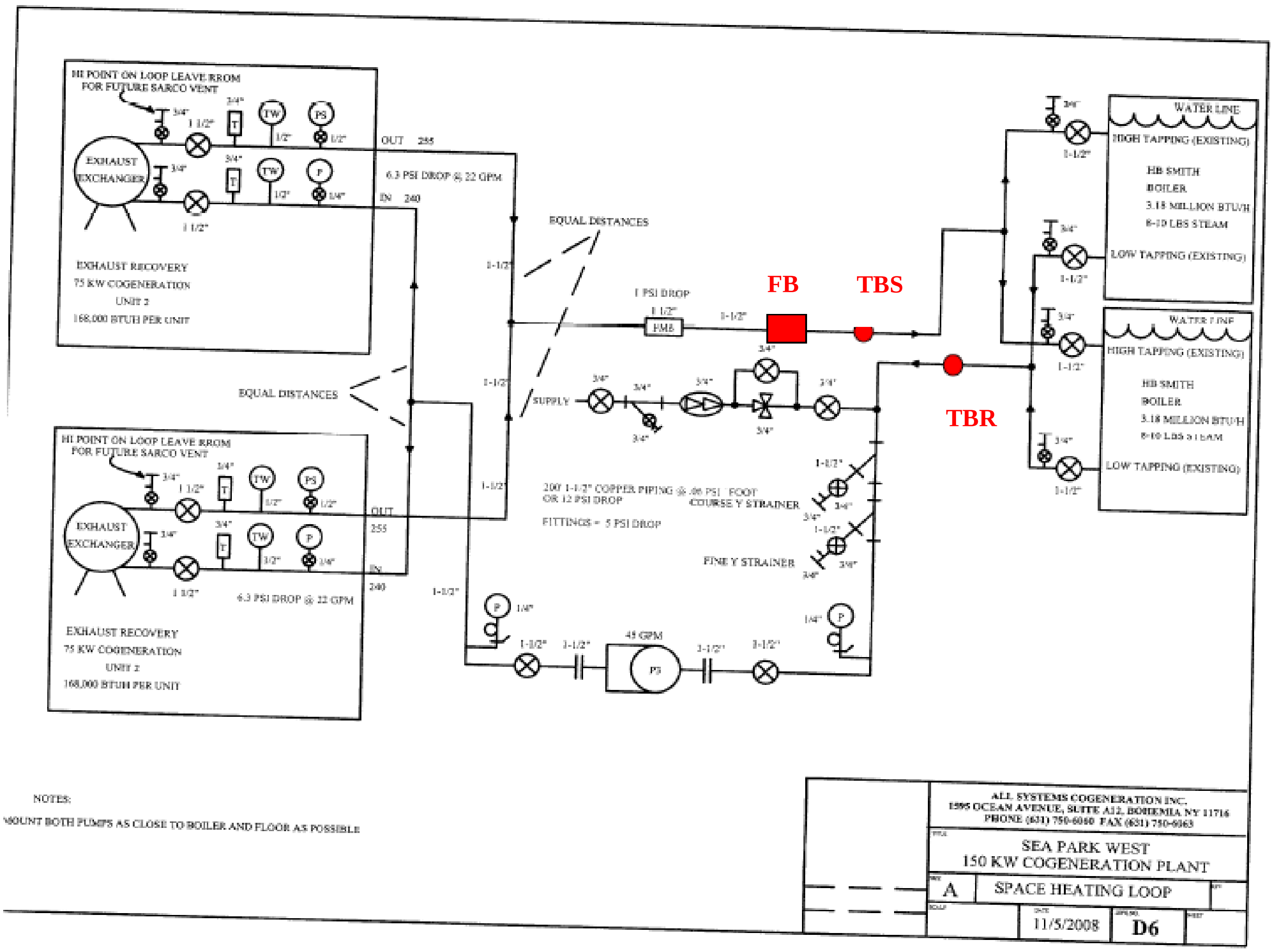


Figure 2. Schematic Drawing (D6) Showing Space Heating Loop Recovery

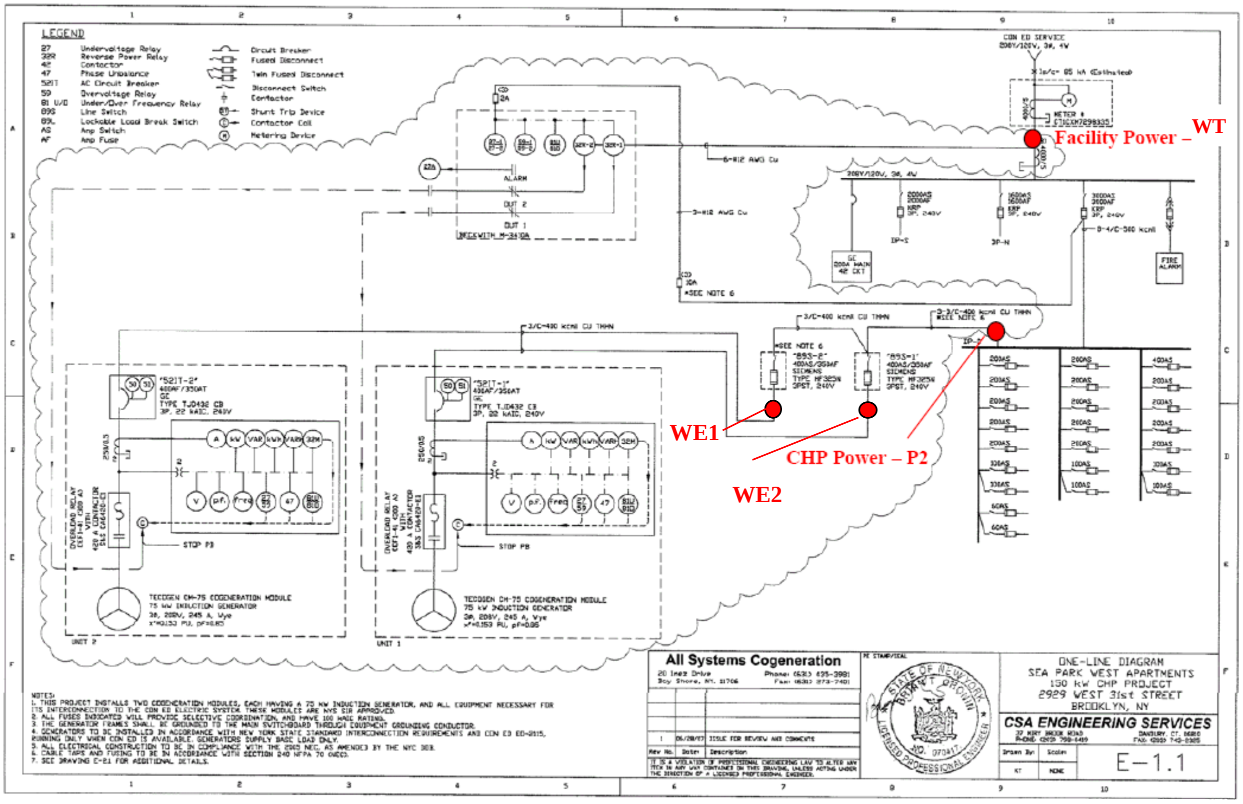


Figure 3. One Line Electrical Drawing (E-1.2) Showing Locations of Power Measurement

Datalogger

An Obvius Acquisuite 8812 datalogger will be installed to record the required data. The sensors will be sampled or scanned at 1-second intervals. All readings will be averaged, summed or calculated for each 1-minute interval. The datalogger will be able to hold more than 100 days of recorded data if communications are lost. The datalogger will continue to log data for a few hours in the event of a power outage at the site. The data will be downloaded from the datalogger at least once a day by a phone-modem connection and loaded into a database. The data will be checked for validity and posted on the NYSERDA web site.

Onsite Installation

CDH Energy will install a datalogger panel at a location in the engine near the generator, see Figure 4. The monitoring system panel will be approximately 1.5 ft x 1.5 ft x 0.75 ft. Power for the panel will be taken from a nearby electrical panel.

Communications

The datalogger will use a phone mux to share a dedicated phone line with one of the Tecogen units.

Figure 4. Datalogger Location

On Site Support

Our role as the MA will be to maintain the data logger over the two-year monitoring period. We will periodically check the CHP web site to ensure the system is operating properly and also respond to issues identified by the Data Integrator or others. We will first work with the QC contractor and NYSERDA to determine if the problem is a CHP system issue or a data collection issue. In the event of a data logger issue, we will be on-site within 48 hours. If the problem is with the instrumentation supplied by the site, we will work with them to help correct the problem in a timely manner.

Around the 12th and 24th month of the monitoring period, we will come on site to verify and check the instrumentation and sensors. Temperature sensors will be compared to readings with handheld instruments; power transducer readings will also be compared to handheld power readings. Where feasible, we will check flow readings with ultrasonic flow meters. Based on these measurements we will prepare a verification summary report documenting the findings from each visit. The verification/calibration reports will also be posted on the CHP web site.

3. Data Analysis

The collected data will be used to determine the net power output of the system as well as the fuel conversion efficiency (FCE).

Table 3. Summary of Monitored Data Points

No.	Data Point	Description	Engineering Unit
1	WT	Facility Power Consumed (Imported)	kWh/int
2	WE1	Generator #1 Power Output	kWh/int
3	WE2	Generator #2 Power Output	kWh/int
3	WP	Parasitic Power Consumption	kWh/int
4	FG	Engine Fuel Consumption (both engines)	cf/int
5	FW	Flow between Engine and Heat Exchanger	gpm
6	FB	Flow between Exhaust Exchanger and Boiler	gpm
7	THS	Engine Supply Temperature	◦F
8	THR1	Heat Exchanger Return Temperature	◦F
9	THR2	Engine Return Temperature	◦F
10	TBS	Boiler Supply Temperature	◦F
11	TBR	Boiler Return Temperature	◦F

Peak Demand or Peak kW

The peak electric output or demand for each power reading will be taken as the average kW in a 1-minute interval, or

$$\text{kW} = \frac{\text{kWh}}{\Delta t} = \frac{\text{kWh per interval}}{(1/60)\ \text{h}}$$

<u>Heat Recovery Rates</u>

The heat recovery rates will be calculated at each 1-minute recording interval.

The piping arrangement at this site allows for multiple heat rates to be determined with five temperature sensors and two flow reading using the following equations:

Useful heat recovery (**QU**) = K· [FW·(THS-THR1) + FB·(TBS-TBR)]

Rejected (unused) heat recovery (**QR**) = K· FW·(THR1-THR2)]

The loop fluid is expected to be water. The factor K is based on the properties of the loop fluid. (K ~ 500 Btu/h-gpm-°F for pure water; ~480 for 30% glycol).

<u>Calculated Quantities</u>

For this site, the <u>net</u> power output from the engines is determined as:

WG = WE1 + WE2 – WP

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

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

where:	QU	-	Useful heat recovery (Btu/h)
	WG	-	Generator output (kWh)
	FG	-	Generator gas consumption (Std CF)
	Δt	-	1/60 hour for 1-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:

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

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

4. Environmental Monitoring

CDH Energy will also complete the emissions testing required for the NYSERDA CHP Program. We will use a Testo XL350 to measure NOx and CO from each unit. The program calls for engine generator units have emissions less than:

NOx: 1.6 lb per MWh
CO: 6.3 lb per MWh

These limits translate to the following concentrations assuming a 275°F exhaust and the rated engine efficiency:

NOx: 100 ppmv in exhaust
CO: 600 ppmv in exhaust)

To measure these values we will rent a Testo XL350 with the option to measure NO and NO_2. Figure 5 shows the instrument and measurement ranges. This instrument corresponds to the EPA Conditional Test Method (CTM-030). We will rent a unit from Clean Air Engineering (www.cleanair.com) with standard measurement ranges. The instrument automatically calculates the NOx from the measured NO and NO_2 concentrations.

	O_2	CO	~~CO-low~~	NO	~~NO-low~~	NO_2	SO_2	H_2S	C_XH_Y
Range	0-25%vol	0-10,000 H2 comp	~~0-500ppm H2 comp~~	0-3000 ppm	~~0-300ppm~~	0-500 ppm	0-5000 ppm	0-300 ppm	0-4%
Accuracy	<0.8% of f.v	<5ppm 0-99 ppm <5% of m.v. 100-2000 ppm <10% of m.v. 2001-10000 ppm	~~<2 ppm 0-39.9 ppm <5% of m.v. 40-500 ppm~~	<5 ppm 0-99 ppm <5% of m.v. 100-2000 ppm <10% of m.v. 2001-3000 ppm	~~<2 ppm 0-39.9ppm <5% of m.v. 300 ppm~~	<5 ppm 0-99 ppm <5% of m.v. 500 ppm	<5 ppm 0-99 ppm <5% of m.v. 100-2000 ppm <10% of m.v. 2001-5000 ppm	<2 ppm 0-39.9 ppm <5% of m.v. 40-300 ppm	<0.04% vol. 0-0.4% vol. <10% of m.v. 0.41 - 4% vol.
Resolution	0.1% vol	1 ppm	~~0.1 ppm~~	1 ppm	~~0.1 ppm~~	0.1 ppm	1 ppm	0.1 ppm	0.01 vol%
Resp. Time	20s (t95)	40s (t90)	~~40s (t90)~~	30s (t90)	~~30s (t90)~~	40s (t90)	30s (t90)	35s (t90)	40s (t90)

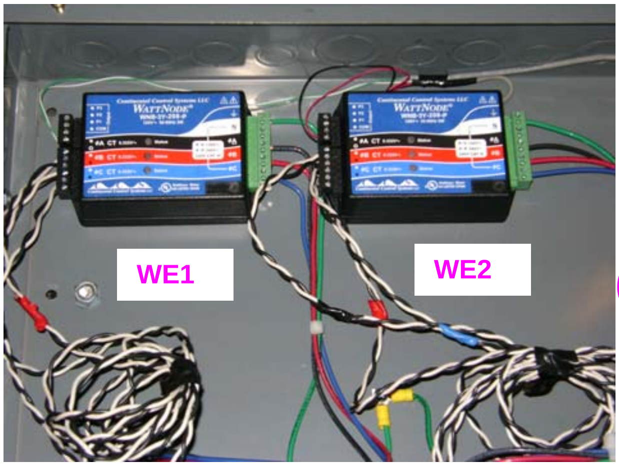
Figure 5. Testo XL350 Handheld Emissions Tester with Specs (Std Measurement Ranges)

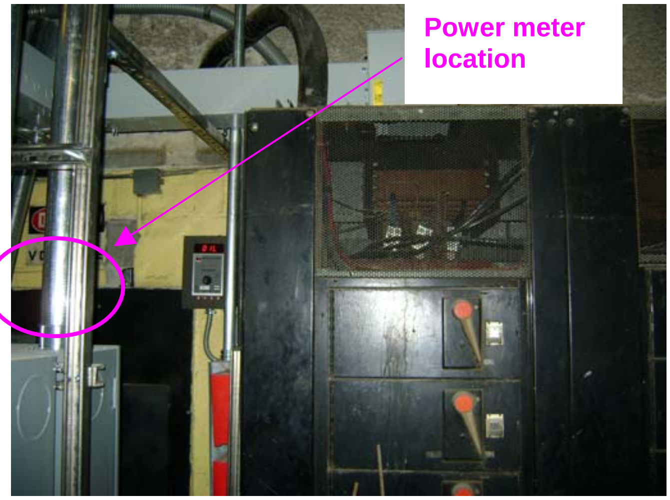
Measurements will be taken in the exhaust stack above each Tecogen Unit (we will drill a ¼ inch port if not available). Emissions will be measured for 30 minutes. The average for the 30-minute period must be below the upper limits given above.

Once the applicant has confirmed the engine-generator units will meet the requirements, CDH will come onsite to complete the testing. In the event that units do not pass, CDH will remain on site for up to 8 hours while units are adjusted or tuned. In the event that the units do not pass, CDH will reschedule and return to site for only one additional day for retesting.

Appendix:

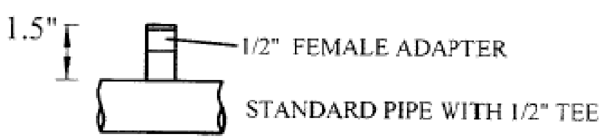
The locations of the T1 (THS) and T2 (THR1) thermowells





The location of the Generator Power Transducer

THERMISTOR WELL DETAILS



TEMPERATURE WELL 1/2"
McMASTER PART NO. 3957K64

Appendix B

Seapark West

Flowmeter

FB (flow between exhaust heat exchanger and boiler) couldn't be verified since the system wasn't running in heating mode, but the sensor was manually spun to ensure that it provided pulse outputs to the Obvius. FW on the other hand (flow between engine and heat exchanger) was reading 45 gpm, with the expected flow being 37 gpm.

Generator Power

	Generators #1 & #2				Parasitic	
	Manual (A)	Manual (V)	Manual (kW)	Obvius (kW)	Manual (kW)	Obvius (kW)
Trial 1	450,456, 460	216	142	141.4	3.11	*values were off due to sig. fig's on multiplyer, power readings changed to w/h to avoid problem
Trial 2	450, 450, 455	215	142	141.5	2.94	
Trial 3	450, 453, 453	214.66	141	141	3.16	

There was no power output from Generators #1 and #2 initially due to the ground being wired instead of the neutral. This was corrected.

For the parasitic power measurement, the CT's were facing the load instead of the line, which gave a negative power output. Since there wasn't much room to work with the CT's the signal output was switched from P1 to P2, causing the power to be positive.

Gas Meter

	Obvius		
	Pulses	cf	cf/h
10:30	14674	1467400	
10:40	14677	1467700	1800
10:57	14682	1468200	1765
11:00	14683	1468300	2000

Meter: 3M175 - 3000 cf/h
cf/pulse = 100

We received one pulse in 3:03, which works out to approx 20 pulses per hr. This would yield 2,000 cf/h. With a LHV of 900 btu/cf and an estimated engine efficiency of 25% this amount of natural gas flow would be capable of producing 131.84 kW. This is very close to the combined generator output, and the difference is accounted for by a higher turbine efficiency than estimated.

Temperature Sensors

	THS / Sensor #1		THR1 / Sensor #2			THR2 / Sensor # 3	
	Fluke (F)	Obvius (F)	Fluke (F)	Obvius (F)	Gauge (F)	Fluke (F)	Obvius (F)
10:13	187.3	196	141.5	151	153		
10:20						140	158
10:26	192.8	208	136	158	152		
10:28						139	145.4
10:45		197.4		150.7	154		

The best verification was for sensor #2 since there was a gauge near the temp sensor, because measurements with the fluke were always low, since we could only use the surface probe to measure the temperature of pipe. Temp sensors #4 and #5 could not be verified since they are on the loop that wasn't running. The water temperature is below the sensors minimum range, so the Obvius is recording 110 ° plus or minus for these two sensors (their lowest mA output).

Seapark West Addendum

Site Events

Date	Event
9/25/2009	Data Collection Begins
10/8/2009	The RTD sensor for TBS is no longer working properly. Boiler heat recovery is currently being set to zero until this issue is resolved. Heat recovered through domestic hot water is unaffected.
11/24/2009	Added 24VDC supply, moved FB to exp board. Exp board is now separately powered with its own power supply.
4/5/2010	Switched the datalogger to send 1 minute data instead of 5 minute data. This was done to aide in the debugging of several issues.
4/7/2010	Pulse counts from the fuel meter were not being counted properly, adjusted the closed resistance threshold for pulse readings on the data logger from 1000 to 2500. Switched the RTD sensors to thermistors.
6/16/2010	Installed new veris 10k type 2 Curve on the obvius datalogger.
9/28/2010	Updated documentation. Changed the date that thermistor offsets were being applied to temperatures too 4/7/2010 (was 7/4/2010). Modified range checks to account for 1 min data. Fixed the calculation of dumped heat recovery to use FW (HX flow rate) instead of FB (boiler flow rate).

Data Logger Setup

Logger Chan	Chan Type	Data Point	Wire	Logger Mult	Notes
250-In1	Pulse	WG1	5 – Red/Blk	0.015 kWh/p	
250-In2	Pulse	WG2	5 – Grn/Wht	0.015 kWh/p	
250-In3	Pulse	WP	0	0.001 kWh/p	Mult by: 1.25/1.00
250-In4	4-20ma		6		Was FW2 before 11/24/09
250-In5	Resistance	T3/THR2	7	100-250F	Was 4-20ma before 4/7/2010
250-In6	Resistance	T4/TBS	9	100-250F	Was 4-20ma before 4/7/2010
250-In7	Resistance	T5/TBR	8	100-250F	Was 4-20ma before 4/7/2010
250-In8			Unused		
001-In1	4-20ma	FW1	Red/Blk/Blue	0-130 gpm	
001-In2	Resistance	T1/THS	3	100-250F	Was 4-20ma before 4/7/2010
001-In3	Resistance	T2/THR1	4	100-250F	Was 4-20ma before 4/7/2010
001-In4	Pulse	FG	5	100 cf/p	
001-In5	4-20ma	FW2	Red/Gr/Blk	0-130 gpm	

Notes: 250 = main board, 001 = expansion board

Database Setup

```
Chan Name Device    column
WE1_ACC,  mb-250,  0
WE2_ACC,  mb-250,  5
WP_ACC,   mb-250,  10
FG_ACC,   mb-001,  15
THR2,     mb-250,  21
TBS,      mb-250,  26
TBR,      mb-250,  31
FW,       mb-001,  0
THS,      mb-001,  6
THR1,     mb-001,  11
FB,       mb-250,  15   →   mb-001, 20  (changed 11/24/09 10 am)
```

Temperature Sensor Calibration before 4/7/2010 2 pm

Data Point	Sensor ID	Multiplier	Offset
THS	#1	1.0617	-5.3032
THR1	#2	0.9783	+0.8494
THR2	#3	0.9711	+1.5024
TBS	#4	0.9922	-0.6696
TBR	#5	0.9916	+2.9896

Temperature Sensor Calibration After 4/7/2010 2 pm

Data Point	Sensor ID	Multiplier	Offset
THS	#23	1	-2.6
THR1	#24	1	-2.9
THR2	#25	1	-3.2
TBS	#26	1	-2.5
TBR	#27	1	-2.3

[Actual T] = [measured T] x mult + offset

WattNode Multiplier Table

CT Size (amps)	Pulses Per kilowatt-hour (PpKWH)				Watt-hours per pulse (WHpP)			
	3Y-208 3D-240	3Y-400 3D-400	3Y-480 3D-480	3Y-600	3Y-208 3D-240	3Y-400 3D-400	3Y-480 3D-480	3Y-600
5	8000.00	4173.91	3465.70	2766.57	0.125	0.2396	0.2885	0.3615
15	2666.67	1391.30	1155.24	922.190	0.375	0.7188	0.8656	1.0844
30	1333.33	695.652	577.617	461.095	0.750	1.4375	1.7313	2.1688
50	800.000	417.391	346.570	276.657	$\boxed{1.250}$	2.3958	2.8854	3.6146
60	666.667	347.826	288.809	230.548	1.500	2.8750	3.4625	4.3375
70	571.429	298.137	247.550	197.612	1.750	3.3542	4.0396	5.0604
100	400.000	208.696	173.285	138.329	2.500	4.7917	5.7708	7.2292
150	266.667	139.130	115.523	92.219	3.750	7.1875	8.6563	10.844
200	200.000	104.348	86.643	69.164	5.000	9.5833	11.542	14.458
250	160.000	83.478	69.314	55.331	6.250	11.979	14.427	18.073
300	133.333	69.565	57.762	46.110	7.500	14.375	17.313	21.688
400	100.000	52.174	43.321	34.582	10.000	19.167	23.083	28.917
600	66.667	34.783	28.881	23.055	$\boxed{15.000}$	28.750	34.625	43.375
800	50.000	26.087	21.661	17.291	20.000	38.333	46.167	57.833
1000	40.000	20.870	17.329	13.833	25.000	47.917	57.708	72.292
1200	33.333	17.391	14.440	11.527	30.000	57.500	69.250	86.750
1500	26.667	13.913	11.552	9.2219	37.500	71.875	86.563	108.44
2000	20.000	10.435	8.6643	6.9164	50.000	95.833	115.42	144.58
3000	13.333	6.9565	5.7762	4.6110	75.000	143.75	173.13	216.88
any	$\frac{40.000}{CTsize}$	$\frac{20.870}{CTsize}$	$\frac{17.329}{CTsize}$	$\frac{13.833}{CTsize}$	$\frac{CTsize}{40}$	$\frac{CTsize}{20.87}$	$\frac{CTsize}{17.329}$	$\frac{CTsize}{13.833}$

Table 5: Scale Factors - Bidirectional Outputs

Sensor Verification

Power

There was no power output from Generators #1 and #2 initially due to the neutral wire not being connected. This was corrected by connecting neutral to enclosure ground.

For the parasitic power measurement, the CT's were facing the load instead of the line, which gave a negative power output. Since the CT could not be easily reversed, the signal output was switched to use the P2 output instead of P1.

	Generator #1 & #2 Combined						Parasitic	
	Fluke 39 (Volts)	Fluke 39 (A)	(kVA)	Implied PF	Fluke 39 (kW)	Obvius (kW)	Fluke 39 (kW)	Obvius (kW)
Trial 1	450,456, 460	216	170.4	0.83	142	141.4	3.11	
Trial 2	450, 450, 455	215	168.2	0.84	142	141.5	2.94	3.275
Trial 3	450, 453, 453	214.66	167.7	0.84	141	141	3.16	

Notes: Parasitic power was multiplied by 1.25 to correct for trucation of 0.00125

Gas Meter (September 2009)

The meter provides one pulse in 183 seconds, which works out to approx 18-20 pulses per hr. This would yield 1,800 cf/h with 100 cf/pulse. The results in the table below confirm that the gas consumption by the engines was about 1800 cf/hr. With a LHV of 900 btu/cf and power use of 141 kW this translates to estimated engine efficiency of about 29%.

	Obvius		
	Pulses	cf	cf/hr
10:30	14,674	1,467,400	
10:40	14,677	1,467,700	1800
10:57	14,682	1,468,200	1778
11:00	14,683	1,468,300	1800

Meter: 3M175 - 3000 cf/h max
cf/pulse = 100

After changing the resistance threshold on 4/7/2010

Timestamp	Gas Meter	Obvious
1:08	90912.2	17977900
1:30	90918.9	17978600
1:51	90925.1	17979200
2:32	90937.1	17980400
84 minutes	24.9=2490cf	2500cf
Cf/hour =	1778	1785

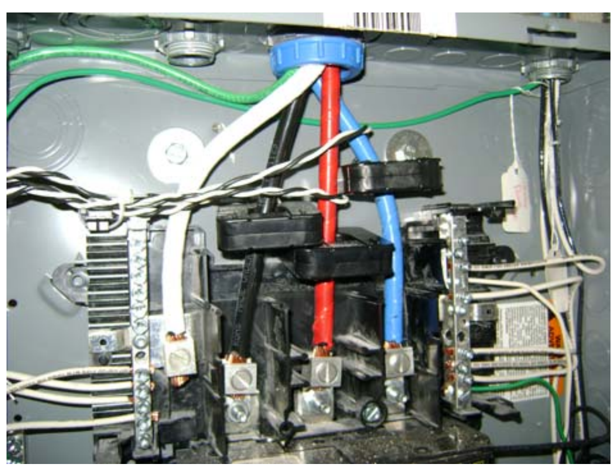
THR2 – Behind boilers, bottom left corner of wall.

TBR – Behind boilers, bottom right corner of wall.

FB – Behind boilers just to the left of TBR sensor

TBS – Behind boilers, right side of wall, above TBR

WE1 and WE2 – in front of boilers, in small box mounted above head height.



WP – In the generator room, same wall to the left of Obvius panel.

THS – on HX wall, left most and lower of the THR1 temp sensor.

FW – on HX wall below expansion board box (grey in upper left corner of pic)

FG – in narrow side room, off of large boiler room, against right wall

THR1 – on HX wall, right most and top most temp sensor.

Obvius Datalogger Box – Mounted on the right wall when looking in generator room from outside.

Obvius Expansion Board Box – Mounted on HX wall.

Gas Meter with new Head Installed