MONITORING PLAN
FOR THE
PURECELL 400
AT
1211 AVENUE OF THE AMERICAS IN MANHATTAN, NY

Draft

December 6, 2011

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Introduction

This plan describes our approach to monitoring the performance of the fuel cell system installed at 1211 Avenue of the Americas in Manhattan, NY. The UTC Power PureCell™ Model 400 fuel cell provides clean and efficient electric power and thermal output to the building. This fuel cell is expected to supply a portion of the facility's electricity requirements in addition to partial standby power in the event of a power grid failure. The facility will also recover heat from the fuel cell to use for Domestic Hot Water (DHW) heating and other purposes.

System Description

The PureCell 400 fuel cell is installed near the top of the building. The fuel cell (FC) has separate electrical feeds for parallel operation with the utility or to provide backup power when isolated from the grid. The fuel cell is able to provide 400 kW of electrical power and up to 1.7 million Btu/h of heat. If fully utilized, the fuel cell can obtain a thermal efficiency near 90%.

Power Output:	400 kW 480V, 3ph
Heat Output:	1.71 MMBtu/h (low temp)
	0.79 MMBtu/h (high temp)

Figure 1. PureCell 400 Unit

Most of the thermal output from the FC will be channeled into existing systems by means of a series of heat exchanger units. The high temperature loop supplies 220°F water to meet these existing loads. The low temperature loop supplies 140ºF water to meet the DHW tank loads.

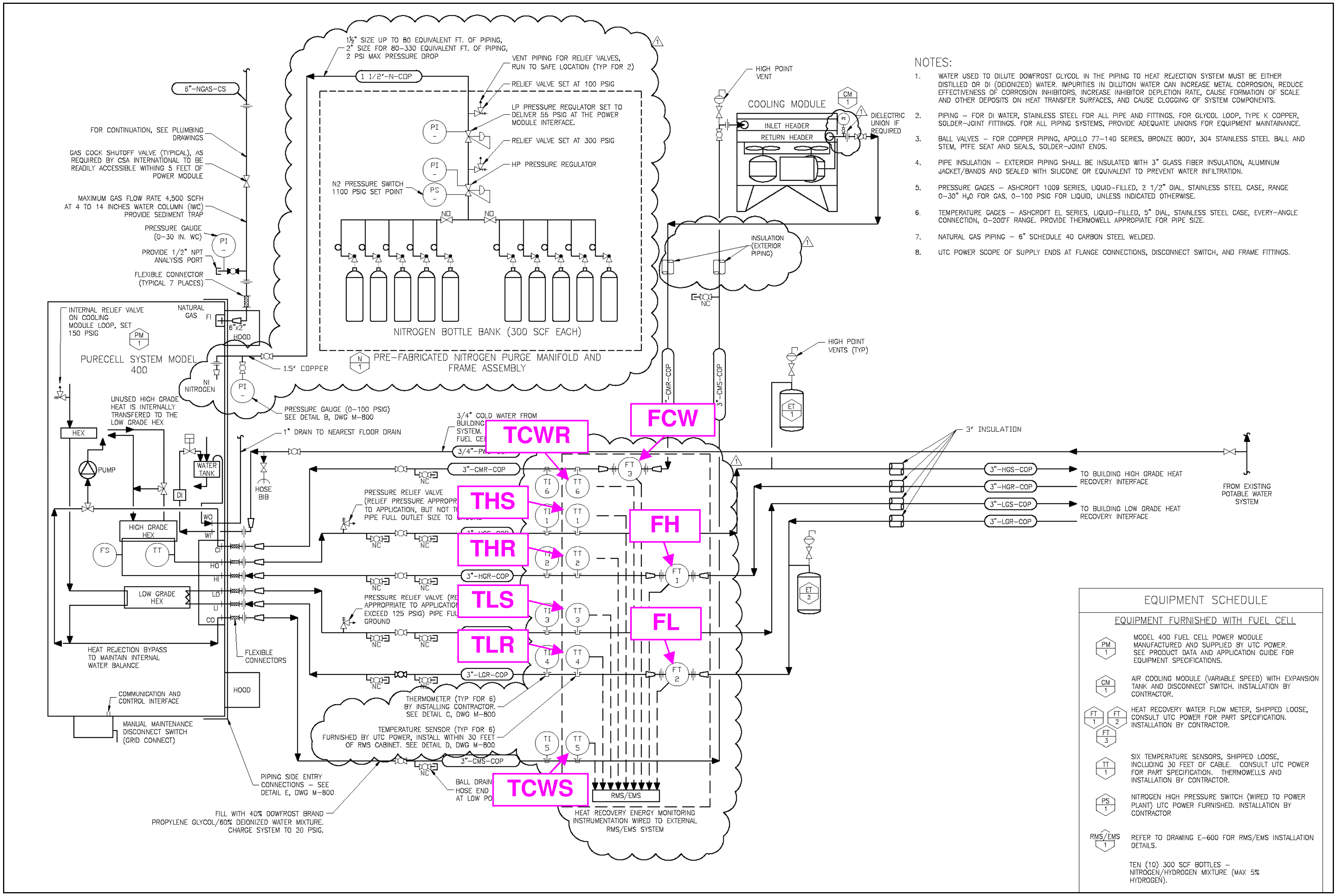


Figure 2. Fuel Cell Piping and Instrumentation Diagram

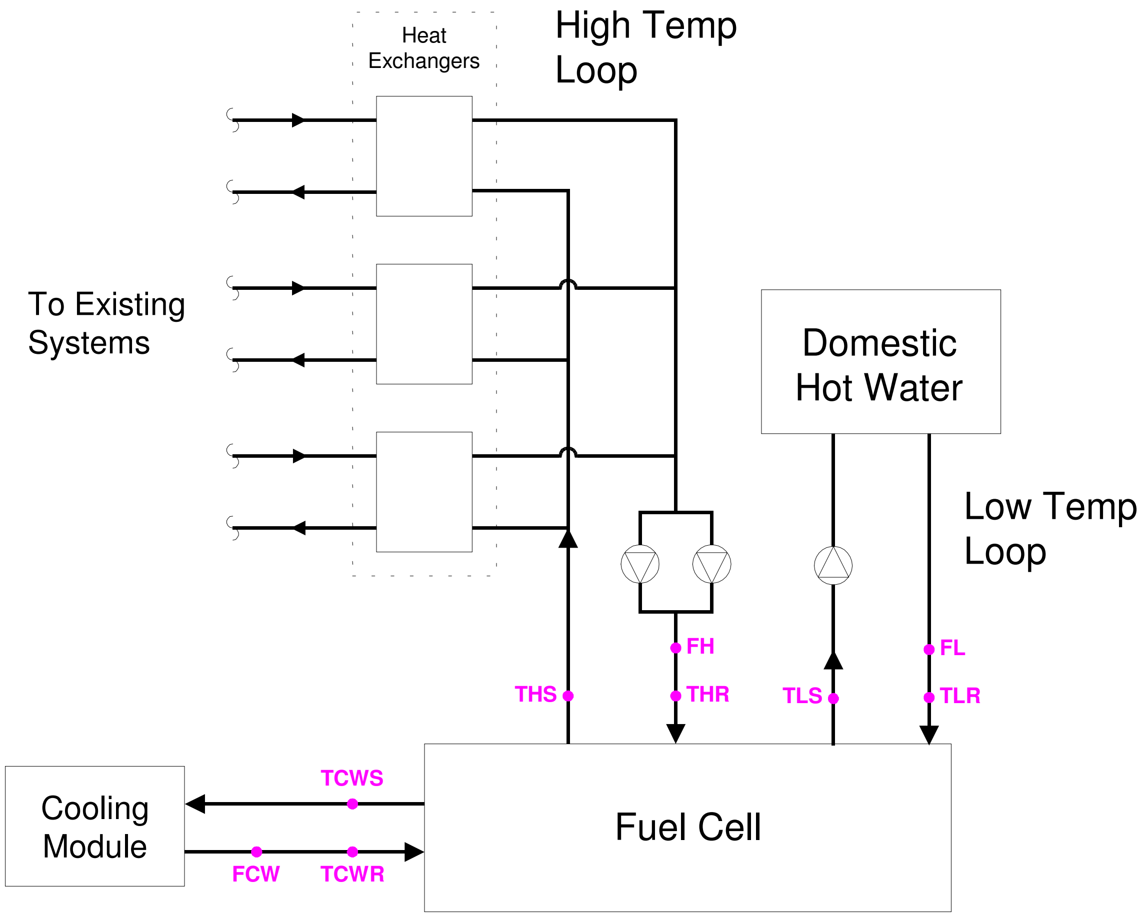


Figure 3. Schematic of Heat Transfer Loops in Fuel Cell System

Heat Recovery Monitoring System

The heat recovery monitoring system (HRM) has been designed to capture the electrical and thermal performance of the system. Table 1 summarizes the measurements that will be captured at the site.

Figure 2 above shows the design schematics for the fuel cell installation, illustrating the layout of piping and sensor instrumentation. Figure 3 above shows where the measurements will be taken in the thermal loops. Flow and temperature sensors are installed for three thermal loops: low temperature, high temperature, and cooling water.

Data are extracted from the Power Plant Controller (PPC) via MODBUS TCP and from the two Shark Power Meters via MODBUS 485/serial connections. The Obvius AcquiSuite datalogger logs the required data.

Table 1. Summary of Measured and Collected Data at the Site

Channel / Source	Data Pt	Description	Instrument / Meter	Signal / Register	Eng Units	Wire	Notes
Main-1	TLS	Low Temp Supply Temp (from FC)	10k Thermistor, Type 2	ohm	°F	8	
Main-2	TLR	Low Temp Return Temp (to FC)	10k Thermistor, Type 2	ohm	°F	7	
Main-3	THS	High Temp Supply Temp (from FC)	10k Thermistor, Type 2	ohm	°F	4	
Main-4	THR	High Temp Return Temp (to FC)	10k Thermistor, Type 2	ohm	°F	5	
Main-5	TCWS	Cooling Water Supply Temp (from FC)	10k Thermistor, Type 2	ohm	°F	1	
Main-6	TCWR	Cooling Water Return Temp (from FC)	10k Thermistor, Type 2	ohm	°F	2	
EXP-1	FL	High Temp Water Flow	Onicon F-1111	4-20 mA	gpm	9	2" Type K Copper, 85 gpm
EXP-2	FH	Low Temp Water Flow	Onicon F-1111	4-20 mA	gpm	6	3" Type K Copper, 115 gpm
EXP-3	FCW	Cooling Water Flow	Onicon F-1111	4-20 mA	gpm	3	3" Type K Copper, 60 gpm
EXP-4	FGCUM2	Cumulative Fuel Consumption - Facility Meter	Cogen Gas Meter	pulse	cf		10 cf / pulse
Modbus Dev 2	WREC_pos	Energy Output through Grid Independent Loop	Shark 100	1100	kWh		
Modbus Dev 2	WREC_neg	Energy Input through Grid Independent Loop	Shark 100	1102	kWh		
Modbus Dev 2	WDREC	Power through Grid Independent Loop	Shark 100	900	Watts		
Modbus TCP	FG	Instantaneous Fuel Flow	PPC	7173	kg/h	Float	
Modbus TCP	FGcum	Cumulative Fuel Consumption	PPC	7191	m^3	Float	
Modbus TCP	WFC	Instantaneous Power Output	PPC	10535	kW	Float	
Modbus TCP	WFCcum	Cumulative Power Produced	PPC	7217	MWh	Float	
Modbus TCP	EFF_ELEC	Instantaneous electrical efficiency (LHV)	PPC	7505	%	Float	
Modbus TCP	FC_STATE	Fuel Cell Mode/State Number	PPC	5	Number	Unsigned Int	
Modbus TCP	RTIME	Cumulative "Load" Time	PPC	7205	hrs	Float	
Modbus TCP	NALARM	Total number of alarms	PPC	21	Number	Unsigned Int	
Modbus TCP	SWV	Make-up water tank fill valve status	PPC	763	On/Off	Boolean/Int	
Modbus TCP	SGI	Grid independent status	PPC	60	On/Off	Boolean/Int	
Modbus TCP	SGC	Grid connect status	PPC	59	On/Off	Boolean/Int	

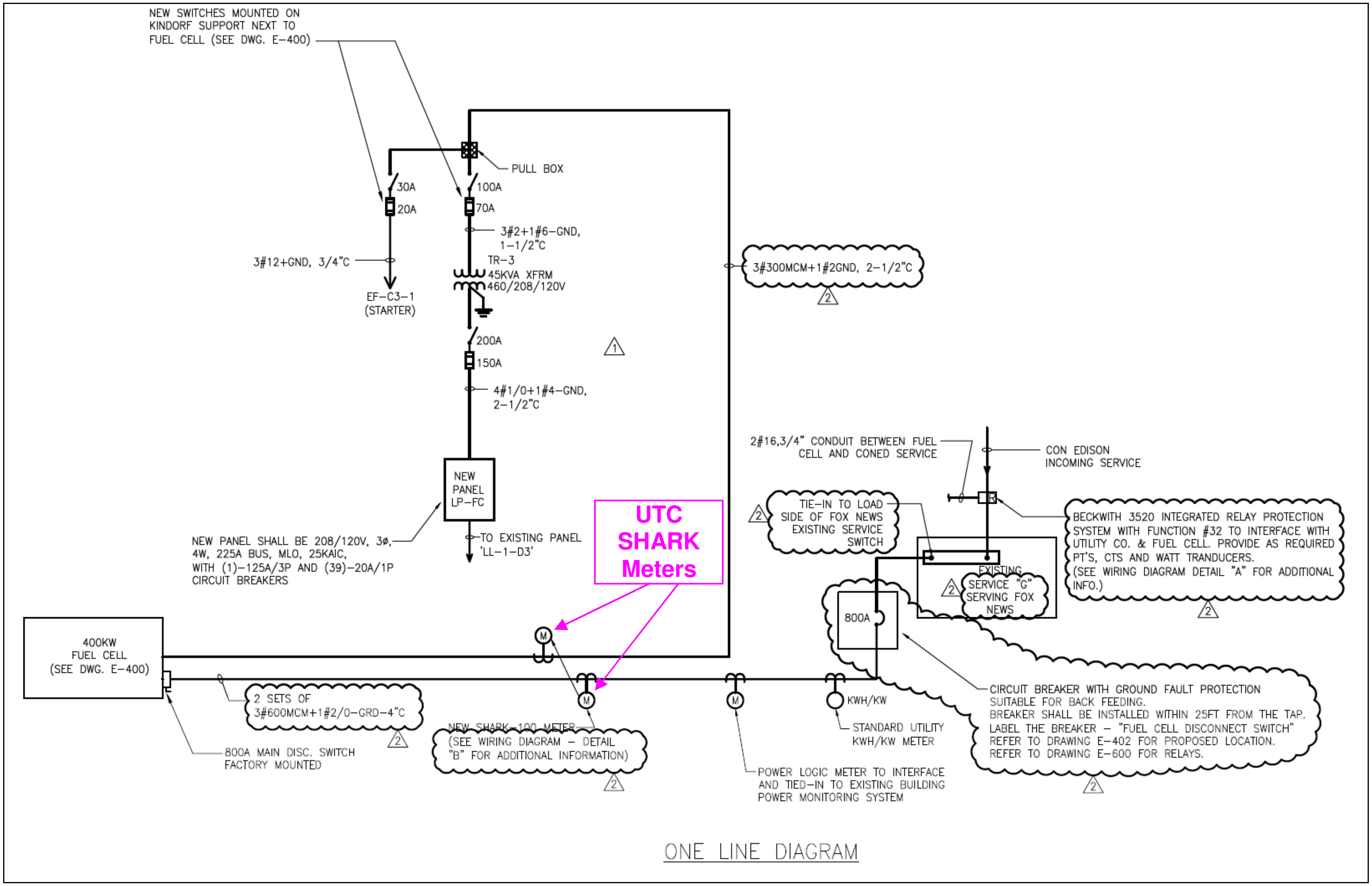
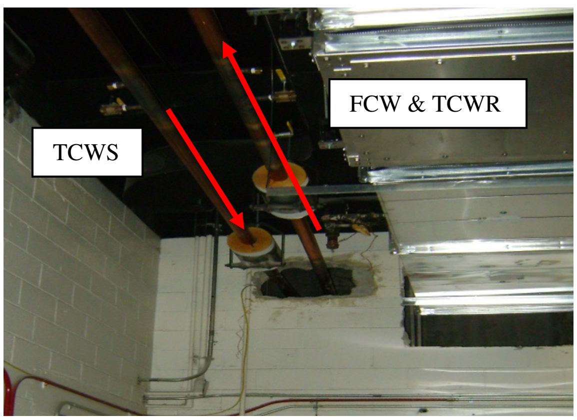


Figure 4. One Line Electrical Diagram

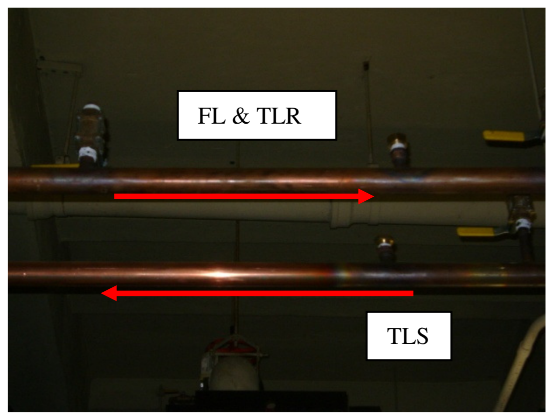
Table 2. Photos

Front of fuel cell, from basement parking lot

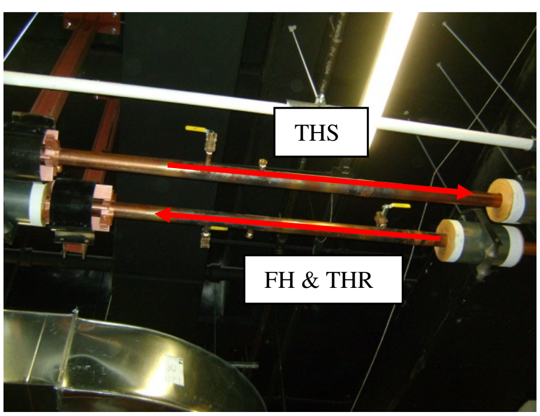

Piping from back of fuel cell: high temp water, low temp water, and cooling water loops



Cooling water loop and sensor locations – supply (left) and return (right)



Low temperature loop and sensor locations – supply (bottom) and return (top)



High temperature loop and sensor locations – supply (top) and return (bottom)

The monitoring system is based around the Obvius AcquiSuite data logger. The layout of the HRM and the connections with other network components of the Fuel Cell system are shown in Figure 5. A Babel Buster gateway device reads MODBUS data from the PPC and makes that data available to the Obvius data logger.

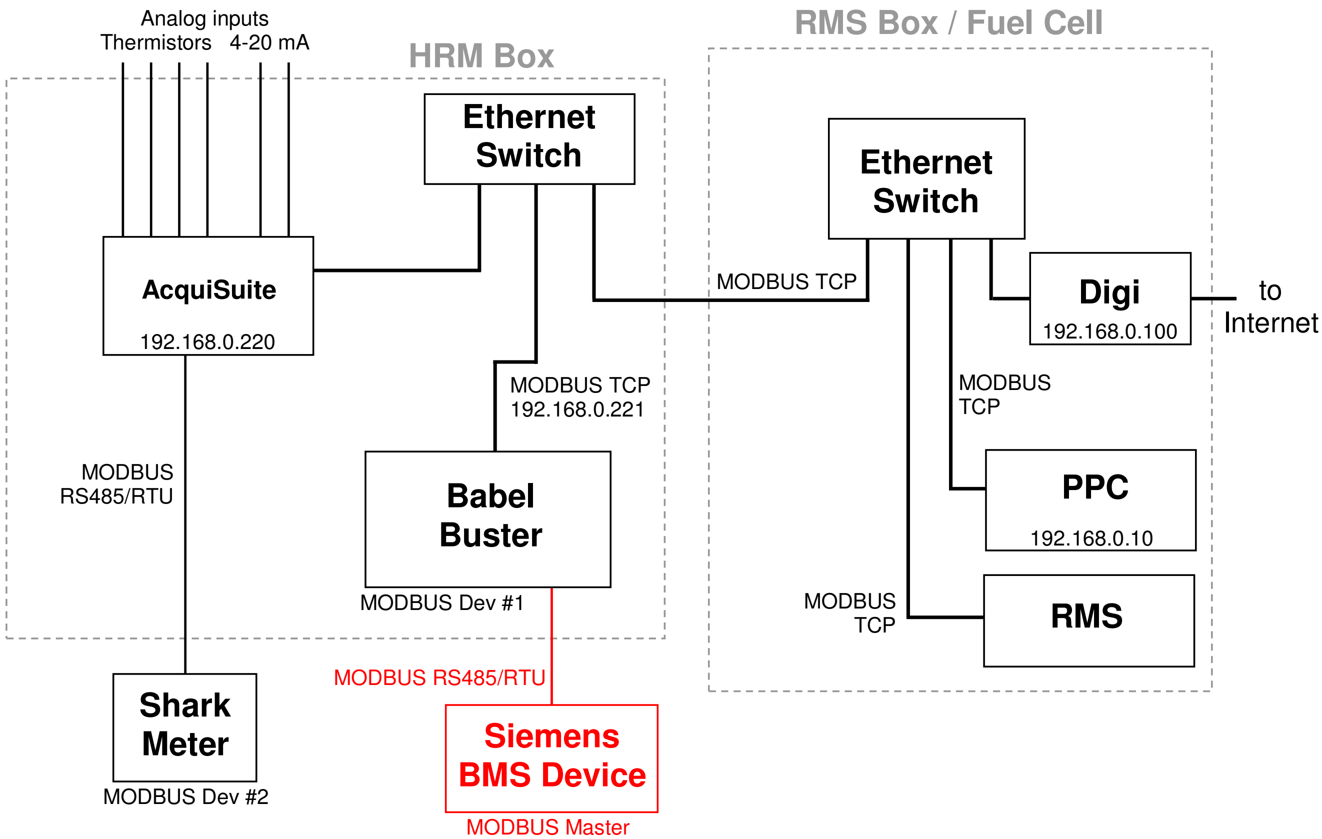


Figure 5. Layout of HRM, RMS and PPC Network

Calculated Quantities

Heat Recovery Rates

The data to determine the delivered heat recovery energy and the delivered cooling will be collected by the datalogger at each scan interval and then averaged for each 15-minute recording interval. The calculations listed below will be completed before the data are displayed on the web site:

$$Q_{lo} = \frac{1}{n}\sum_{i=1}^{n} k_{lo} \cdot FL_i \cdot (TLS_i - TLR_i)$$

$$Q_{hi} = \frac{1}{n}\sum_{i=1}^{n} k_{hi} \cdot FH_i \cdot (THS_i - THR_i)$$

$$Q_{cw} = \frac{1}{n}\sum_{i=1}^{n} k_{cw} \cdot FCW_i \cdot (TCWS_i - TCWR_i)$$

where:	Q_{xx}	-	Delivered heat recovery for loop *xx* (Btu/h) (*xx* :: *lo*=low temp, *hi*=high temp, *cw*=cooling water)
	k_{xx}	-	density specific heat product constant for fluid in loop *xx*
	i	-	i^{th} scan (or read)
	n	-	number of scans in the averaging period

The loop fluid is expected to be water with propylene glycol (e.g., DowFrost). The factor *k* is equal to:

Low Temp Loop: k_{lo} = 466.0 Btu/h·gpm·°F for 30% glycol at 130ºF
High Temp Loop: k_{hi} = 466.6 Btu/h·gpm·°F for 30% glycol at 180ºF
Cooling Water: k_{cw} = 466.6 Btu/h·gpm·°F for 30% glycol at 180ºF

Assuming the loops all use 30% glycol.

The Useful and and Unused heat recoveries will be:

$$Q_{useful} = Q_{lo} + Q_{hi}$$

$$Q_{unused} = Q_{cw}$$

Power and Energy

Generally power meters can provide a host of data points, many of them redundant. Our approach, where possible, is to grab the register value associated with energy (kWh) and from that value determine the average power for each 15-minute interval. This average power value is defined as:

$$\text{kW}_{\text{avg}} = \frac{\text{kWh}}{\Delta t}$$

This average Power over a short time interval (15 minutes) is usually indistinguishable from the "demand" or instantaneous power data reported by most meters (most utilities use a sliding 15-minute interval). The fuel cell PPC and the Shark meter are both given as instantaneous kW. Cumulative reads are in kWh.

Efficiency Calculations

The electrical and total efficiency of the Fuel Cell, based on the lower heating value of the fuel, will be calculated using:

$$\eta_{electrical} = \frac{WFC}{LHV \times FG \times \frac{1}{3600}}$$

$$\eta_{total} = \frac{WFC + (QL + QH) \times \frac{1}{3412.8}}{LHV \times FG \times \frac{1}{3600}}$$

where:

QL, QH	-	Useful heat recovery – low, high temperature loops (Btu/h)
WFC	-	Power output (kW)
FG	-	Generator gas input (kg/h)
LHV	-	Lower heating value for natural gas (~48,667 kJ/kg)

Greenhouse Gas Calculations

The determine the reductions in greenhouse gas emissions for the fuel cell system, we need to measure or estimate the emissions from the fuel cell itself and then also estimate the emissions that would have occurred without the fuel cell meeting these loads. The displaced emissions include the CO_2 not emitted at the utility power plant because of lower electrical consumption and the CO_2 not emitted by an on-site furnace or boiler to meet the thermal output. Table 3 lists the emissions factors we will use for the displaced emissions.

Table 3. Displaced Emissions Factors

	Natural Gas	**Electricity from Power Plant**	
CO_2 emissions	12.06 lb per CCF	1.28 lb per kWh	Massachusetts
		0.98 lb per kWh	Connecticut
		0.86 lb per kWh	New York
NOx emissions	0.1 lb per CCF	2.45 lb per MWh	Massachusetts
		2.45 lb per MWh	Connecticut
		2.45 lb per MWh	New York

Notes: CCF ~ 100 MBtu
CO_2 data from EIA state-by-state summary, 1998-2000.
NOx data based on NY State.

The equations to calculate actual and displaced emissions are listed below:

$$\text{Displaced emissions} = (\text{kWh produced}) \times (\text{lb/kWh}) + \frac{(\text{thermal output, MBtu}) \times (\text{lb/CCF}) / 100}{0.80}$$

$$\text{Actual emissions} = (\text{Natural gas input, therms}) \times (\text{lb/CCF})$$

$$\text{Reduced Emissions} = (\text{Displaced emissions, lbs}) - (\text{Actual Emissions, lbs})$$

Project Web Site

CDH will create a web site for 1211 AOA that provides access to all the historic data collected at the site. The website will provide custom, detailed plots and tables of the collected data from the site that will be updated once a day.

Appendix A - Fuel Cell HRM at 1211 Avenue of the Americas

Internet address: 166.141.147.128

Table 1. Summary of Major HRM Components

Obvius **AcquiSuite** A8812	This datalogger includes thermistors and flow meters to measure thermal loads. It also reads MODBUS registers from the **Babel Buster**. All data are stored in the **AcquiSuite** memory and transferred to the CDH Energy servers from this device.
Control Solutions **Babel Buster** BB2-7010-01	This gateway device reads data from the **PPC** (via MODBUS TCP) and makes it available as MODBUS data to the **AcquiSuite**.
Power Plant Controller **PPC**	This fuel cell controller provides data as MODBUS registers to the **Babel Buster**.

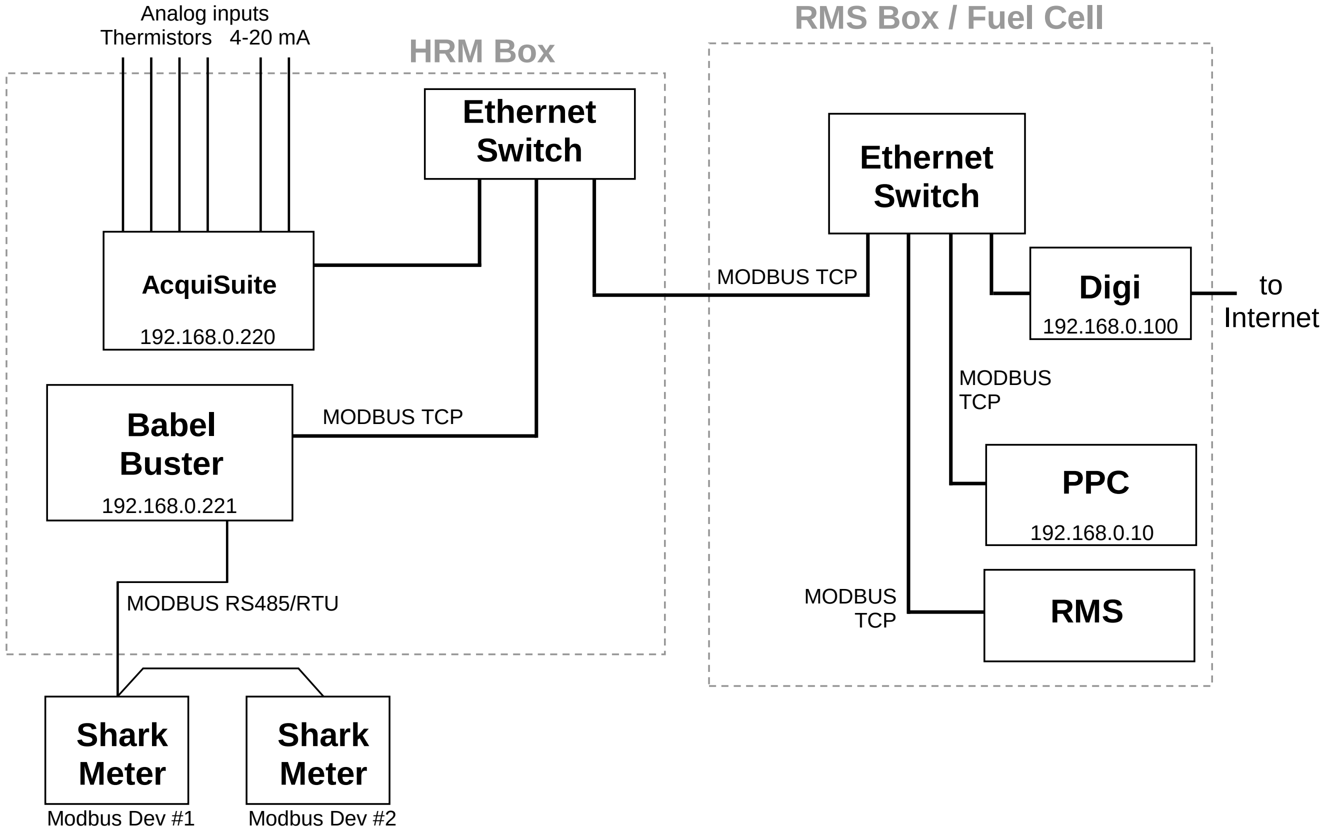


Figure 1. Layout of HRM and RMS Network

The Babel Buster provides all the communications (i.e., reads) between the devices on the network. It reads data from the PPC device and makes the data available for the Obvius AcquiSuite datalogger to read. The AcquiSuite logs all the data.

Table 2. Network Devices and Addresses

Network Layout

Label	Device	Protocol	IP Address	MODBUS RTU Mode	MODBUS RTU Address
AcquiSuite	Obvius AcquiSuite	Modbus TCP	192.168.0.220		
Babel Buster	CSI Babel Buster 2 Multi-network Interface	Modbus TCP	192.168.0.221		
		Modbus RTU		Master	n/a
		BACnet	192.168.0.221		
PPC	UTC Power Power Plant Controller (PPC)	Modbus TCP	192.168.0.10		
Shark	Shark 100 - GI Power Transducer	Modbus RTU		Slave	1
Shark	Shark 100 - CG Power Transducer	Modbus RTU		Slave	2

Table 3. Listing of Data Points Collected from all Devices

Babel Buster Variable	Source	CDH Name	UTC / Obvius Variable Name	Description	Native Units	Babel Buster MODBUS Address	Source Data Address	Source Data Type	Notes	Babel Buster Data Type	Eng Units
AI-1	PPC	FG	FUEL	Fuel flow rate	kg/h	1	7173	Float		Float	kg/h
AI-2	PPC	FGcum	CUMFUEL	Cumulative fuel consumed at standard temperature	m³	3	7191	Float		Float	m³
AI-3	PPC	WFC	KW	Electrical power output	kW	5	10535	Float		Float	kW
AI-4	PPC	WFCcum	MWH	Cumulative electrical power output	MWh	7	7217	Float		Float	MWh
BI-1	PPC	SWV	WTRVLV	Make-up water tank fill valve status	On/Off	3001	763	Boolean/Int		Boolean	On/Off
AI-5	PPC	EFF_ELEC	EFFELEC	Instantaneous electrical efficiency	%	9	7505	Float		Float	%
AI-6	PPC	FC_STATE	STATE	Fuel cell state Number	Number	11	5	Unsigned Int		Float	Number
BI-2	PPC	SGI	GISTATUS	Grid independent status	On/Off	3002	60	Boolean/Int		Boolean	On/Off
BI-3	PPC	SGC	CGSTATUS	Grid connect status	On/Off	3003	59	Boolean/Int		Boolean	On/Off
AI-7	PPC	RTIME	LOAD	Cumulative load time hr	hrs	13	7205	Float		Float	hrs
AI-8	PPC	NALARM	NUMALARMS	Total number of alarms	Number	15	21	Unsigned Int		Float	Number
AI-12	PPC	ISTATE	ISTATE	Fuel Cell Inverter State	Number	23	13	Float		Float	Number
AI-9	SHARK	GI_WREC_pos	GI_MWHREC_pos	Energy Output through Grid Independent Loop	kWh	17	1100	Double		Float	kWh
AI-10	SHARK	GI_WREC_neg	GI_MWHREC_neg	Energy Input through Grid Independent Loop	kWh	19	1102	Double		Float	kWh
AI-11	SHARK	GI_WDREC	GI_KWREC	Power through Grid Independent Loop	Watts	21	900	Float		Float	Watts
AI-14	SHARK	CG_WREC_pos	CG_MWHREC_pos	Energy Output through Grid Connected Loop	kWh	27	1100	Double		Float	kWh
AI-15	SHARK	CG_WREC_neg	CG_MWHREC_neg	Energy Input through Grid Connected Loop	kWh	29	1102	Double		Float	kWh
AI-16	SHARK	CG_WDREC	CG_KWREC	Power through Grid Connected Loop	Watts	31	900	Float		Float	Watts
	EXP-1	FL	FLOWLG	Flow rate – low grade heat	gpm	51	4-20 mA (0-115)		Onicon F-1111	Float	mA x 1000
	EXP-2	FH	FLOWHG	Flow rate – high grade heat	gpm	53	4-20 mA (0-150)		Onicon F-1111	Float	mA x 1000
	EXP-3	FCW	FLOWCW	Flow rate – coolant water	gpm	55	4-20 mA (0-80)		Onicon F-1111	Float	mA x 1000
	Main-1	TLS	TEMPLGIN	Temperature – low grade heat return	°F	39	ohm		10k, Type 2	Float	Ohms
	Main-2	TLR	TEMPLGOUT	Temperature – low grade heat supply	°F	41	ohm		10k, Type 2	Float	Ohms
	Main-3	THS	TEMPHGIN	Temperature – high grade heat return	°F	43	ohm		10k, Type 2	Float	Ohms
	Main-4	THR	TEMPHGOUT	Temperature – high grade heat supply	°F	45	ohm		10k, Type 2	Float	Ohms
	Main-5	TCWS	TEMPCWIN	Temperature – coolant water return	°F	47	ohm		10k, Type 2	Float	Ohms
	Main-6	TCWR	TEMPCWOUT	Temperature – coolant water supply	°F	49	ohm		10k, Type 2	Float	Ohms

= Data from Shark Meter via MODBUS RTU

= Data provided or received from PPC via MODBUS TCP

= Data from sensors on Obvius AcquiSuite

Babel Buster XML File


```
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<!-- Babel Buster BB2-7010 v2.10 configuration file -->
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   <rule localreg="6"    remtype="hold_reg" remreg="5"     remfmt="uint"   dev="1" scale="0.000000" offset="0.000000" poll="1.00" name="STATE"/>
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   <rule localreg="21"   remtype="hold_reg" remreg="3"     remfmt="double" dev="2" scale="0.000000" offset="0.000000" poll="1.00" name="Acquisuite TLR"/>
   <rule localreg="22"   remtype="hold_reg" remreg="5"     remfmt="double" dev="2" scale="0.000000" offset="0.000000" poll="1.00" name="Acquisuite THS"/>
   <rule localreg="23"   remtype="hold_reg" remreg="7"     remfmt="double" dev="2" scale="0.000000" offset="0.000000" poll="1.00" name="Acquisuite THR"/>
   <rule localreg="26"   remtype="hold_reg" remreg="9"     remfmt="double" dev="2" scale="0.000000" offset="0.000000" poll="1.00" name="Acquisuite TCWS"/>
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</bipclient_read>

<bipclient_write>
</bipclient_write>

</configuration>
```

Table 4. Sensor and Wiring Details for AcquiSuite

Channel / Source	Data Pt	Description	Instrument / Meter	Signal / Register	Eng Units	Wire	Notes
Main-1	TLS	Low Temp Supply Temp (from FC)	10k Thermistor, Type 2	ohm	°F	8	
Main-2	TLR	Low Temp Return Temp (to FC)	10k Thermistor, Type 2	ohm	°F	7	
Main-3	THS	High Temp Supply Temp (from FC)	10k Thermistor, Type 2	ohm	°F	4	
Main-4	THR	High Temp Return Temp (to FC)	10k Thermistor, Type 2	ohm	°F	5	
Main-5	TCWS	Cooling Water Supply Temp (from FC)	10k Thermistor, Type 2	ohm	°F	1	
Main-6	TCWR	Cooling Water Return Temp (from FC)	10k Thermistor, Type 2	ohm	°F	2	
EXP-1	FL	High Temp Water Flow	Onicon F-1111	4-20 mA	gpm	9	85 gpm
EXP-2	FH	Low Temp Water Flow	Onicon F-1111	4-20 mA	gpm	6	3 inch, 115 gpm
EXP-3	FCW	Cooling Water Flow	Onicon F-1111	4-20 mA	gpm	3	3 inch, 60 gpm
Modbus Dev 1	GI_WREC_pos	Energy Output through Grid Independent Loop	Shark 100	1100	kWh		
Modbus Dev 1	GI_WREC_neg	Energy Input through Grid Independent Loop	Shark 100	1102	kWh		
Modbus Dev 1	GI_WDREC	Power through Grid Independent Loop	Shark 100	900	Watts		
Modbus Dev 2	CG_WREC_pos	Energy Output through Grid Connected Loop	Shark 100	1100	kWh		
Modbus Dev 2	CG_WREC_neg	Energy Input through Grid Connected Loop	Shark 100	1102	kWh		
Modbus Dev 2	CG_WDREC	Power through Grid Connected Loop	Shark 100	900	Watts		
Modbus TCP	FG	Instantaneous Fuel Flow	PPC	7173	kg/h	Float	
Modbus TCP	FGcum	Cumulative Fuel Consumption	PPC	7191	m^3	Float	
Modbus TCP	WFC	Instantaneous Power Output	PPC	10535	kW	Float	
Modbus TCP	WFCcum	Cumulative Power Produced	PPC	7217	MWh	Float	
Modbus TCP	EFF_ELEC	Instantaneous electrical efficiency (LHV)	PPC	7505	%	Float	
Modbus TCP	FC_STATE	Fuel Cell Mode/State Number	PPC	5	Number	Unsigned Int	
Modbus TCP	RTIME	Cumulative "Load" Time	PPC	7205	hrs	Float	
Modbus TCP	NALARM	Total number of alarms	PPC	21	Number	Unsigned Int	
Modbus TCP	SWV	Make-up water tank fill valve status	PPC	763	On/Off	Boolean/Int	
Modbus TCP	SGI	Grid independent status	PPC	60	On/Off	Boolean/Int	
Modbus TCP	SGC	Grid connect status	PPC	59	On/Off	Boolean/Int	

Table 5. Forwarded Addresses on Digi Modem

Forward TCP/UDP/FTP connections from external networks to the following internal devices:

Enable	Protocol	External Port	Forward To Internal IP Address	Forward To Internal Port
☑	UDP	47808	192.168.0.51	47808
☑	TCP	3389	192.168.0.199	3389
☑	TCP	8081	192.168.0.220	80
☑	TCP	8082	192.168.0.221	80
☑	FTP	8083	192.168.0.220	21
☑	TCP	8084	192.168.0.220	23
☑	FTP	0	0.0.0.0	0

Obvius AcquiSuite

The AcquiSuite data logger produces a separate file of 1-minute data for each device. The read map for the data logger is given below.

Chan Name	Device	Column
FG,	mb-001,	0
FGCUM,	mb-001,	1
WFC,	mb-001,	2
WFCCUM,	mb-001,	3
SWV,	mb-001,	4
EFF_ELEC,	mb-001,	5
FC_STATE,	mb-001,	6
SGI,	mb-001,	7
SGC,	mb-001,	8
RTIME,	mb-001,	9
NALARM,	mb-001,	10
ISTATE,	mb-001,	16
FL,	mb-003,	1
FH,	mb-003,	6
FCW,	mb-003,	11
TLS,	mb-250,	1
TLR,	mb-250,	6
THS,	mb-250,	11
THR,	mb-250,	16
TCWS,	mb-250,	21
TCWR,	mb-250,	26

Notes: mb-001 – MODBUS Reads
mb-003 - AcquiSuite Expansion Board
mb-250 – AcquiSuite Main Board

Sensor Calibrations:

Thermistor #	Name	Wire	Input Channel	Mult	Offset
4-19	TLS	8	Main-1	0.99506	0.02
4-21	TLR	7	Main-2	0.99401	-0.20
4-33	THS	4	Main-3	0.99058	0.50
4-42	THR	5	Main-4	0.98909	1.55
6-34	TCWS	1	Main-5	0.98353	0.86
6-37	TCWR	2	Main-6	0.98450	0.32

Flow Meter Calibrations

The flow meter for the low grade loop was factory-calibrated for a 3" pipe, but the installed pipe was later discovered to have a 2" diameter. Using the inner diameters for 2" and 3" pipes, we applied a factor of 0.4541 to the Onicon readings ($1.959^2 / 2.907^2$) and then compared against an ultrasonic flow meter for verification. At the same time, similar readings were taken at the cooling module loop. The high grade loop was skipped because no flow was being reported at the time.

	Ultrasonic	Onicon	Factor	Adjusted Value k = 0.946
FL (Water)	24.1	25.60	0.941	24.2
	24.5	25.72	0.953	24.3
	24.4	25.61	0.953	24.2
	24.3	25.63	0.948	24.3
	24.1	25.63	0.940	24.3
	24.2	25.66	0.943	24.3
	24.3	**25.64**	**0.946**	**24.3**
				k = 0.881
FCW (Water)	29.1	33.13	0.878	29.2
	26.6	33.14	0.803	29.2
	26.4	31.39	0.841	27.7
	26.1	30.46	0.857	26.8
	30.2	30.35	0.995	26.7
	30.5	33.26	0.917	29.3
	28.2	**31.95**	**0.881**	**28.2**