MONITORING PLAN
FOR THE
PURECELL 400
AT
THE OCTAGON IN NEW YORK, NY

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Submitted to:

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Introduction

This plan describes our approach to monitoring the performance of the fuel cell system installed at The Octagon apartment complex on Roosevelt Island in New York, NY. The UTC Power PureCell® Model 400 fuel cell provides clean and efficient electric power and thermal output to the complex. This fuel cell is expected to supply some of the apartment's electricity requirements in addition to standby power in the event of a power grid failure. The complex will also recover heat from the fuel cell to use for space and Domestic Hot Water (DHW) heating.

System Description

The PureCell® Model 400 is installed in front of the apartment complex. 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 is used to provide space conditioning and water heating for the building. The low temperature loop supplies 140ºF water to meet space heating and DHW tank loads (see Figure 2 and Figure 3).

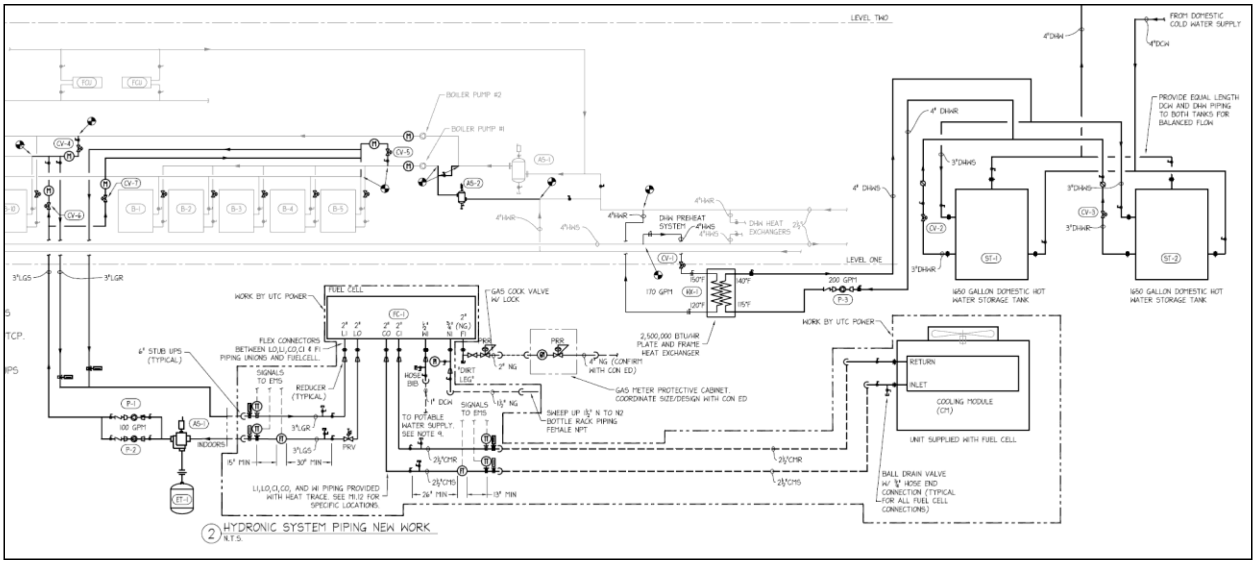

Figure 2. Fuel Cell and DHW Piping Schematic at The Octagon

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 3 shows where the measurements will be made in the thermal loops. Figure 4 and Figure 5 show the locations for the temperature measurements and flow meters in thermal circuits. Flow and temperature sensors are installed for two thermal loops: low temperature and coolant water.

Data are extracted from the Power Plant Controller (PPC) via MODBUS TCP. 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	43	
Main-2	TLR	Low Temp Return Temp (to FC)	10k Thermistor, Type 2	ohm	°F	42	
Main-3	TCWS	Cooling Water Supply Temp (from FC)	10k Thermistor, Type 2	ohm	°F	35	
Main-4	TCWR	Cooling Water Return Temp (to FC)	10k Thermistor, Type 2	ohm	°F	36	
Main-5	FL	Low Temp Water Flow	Onicon F1100	4-20 mA	gpm	44, 45	3 inch, sched 40 steel, 100 gpm
Main-6	FCW	Cooling Water Flow	Onicon F1100	4-20 mA	gpm	37, 38	2 inch, sched 40 copper, 60 gpm
Modbus TCP	FG	Instantaneous Fuel Flow	PPC	7173	kg/h	Float	page 12 of FCFR
Modbus TCP	FGcum	Cumulative Fuel Consumption	PPC	7191	m³	Float	page 12 of FCFR
Modbus TCP	WFC	Instantaneous Power Output	PPC	10535	kW	Float	page 12 of FCFR
Modbus TCP	WFCcum	Cumulative Power Produced	PPC	7217	MWh	Float	page 12 of FCFR
Modbus TCP	EFF_ELEC	Instantaneous electrical efficiency (LHV)	PPC	7505	%	Float	page 12 of FCFR
Modbus TCP	FC_STATE	Fuel Cell Mode/State Number	PPC	5	Number	Unsigned Int	page 12 of FCFR
Modbus TCP	RTIME	Cumulative "Load" Time	PPC	7205	hrs	Float	page 12 of FCFR
Modbus TCP	NALARM	Total number of alarms	PPC	21	Number	Unsigned Int	page 12 of FCFR
Modbus TCP	SWV	Make-up water tank fill valve status	PPC	763	On/Off	Boolean/Int	page 12 of FCFR
Modbus TCP	SGI	Grid independent status	PPC	60	On/Off	Boolean/Int	page 12 of FCFR
Modbus TCP	SGC	Grid connect status	PPC	59	On/Off	Boolean/Int	page 12 of FCFR

Note: EXP = Obvius expansion board, device 003
Main = Obvius main board, device 250

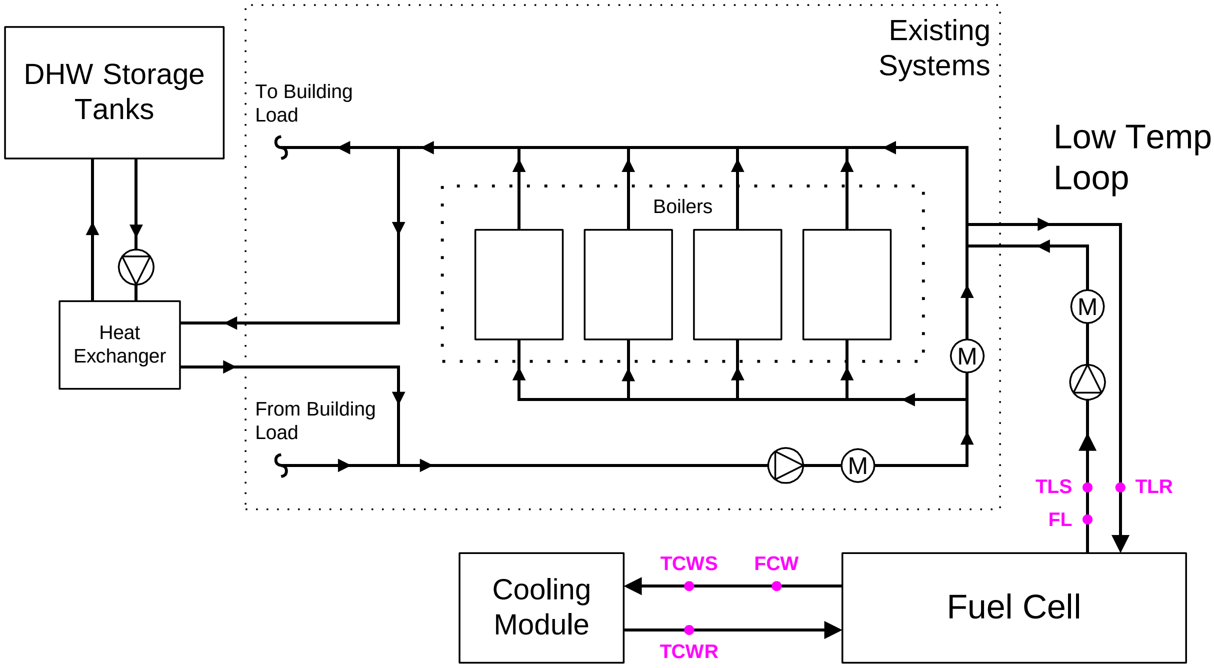

Figure 3. Schematic of Heat Transfer Loops in Fuel Cell System

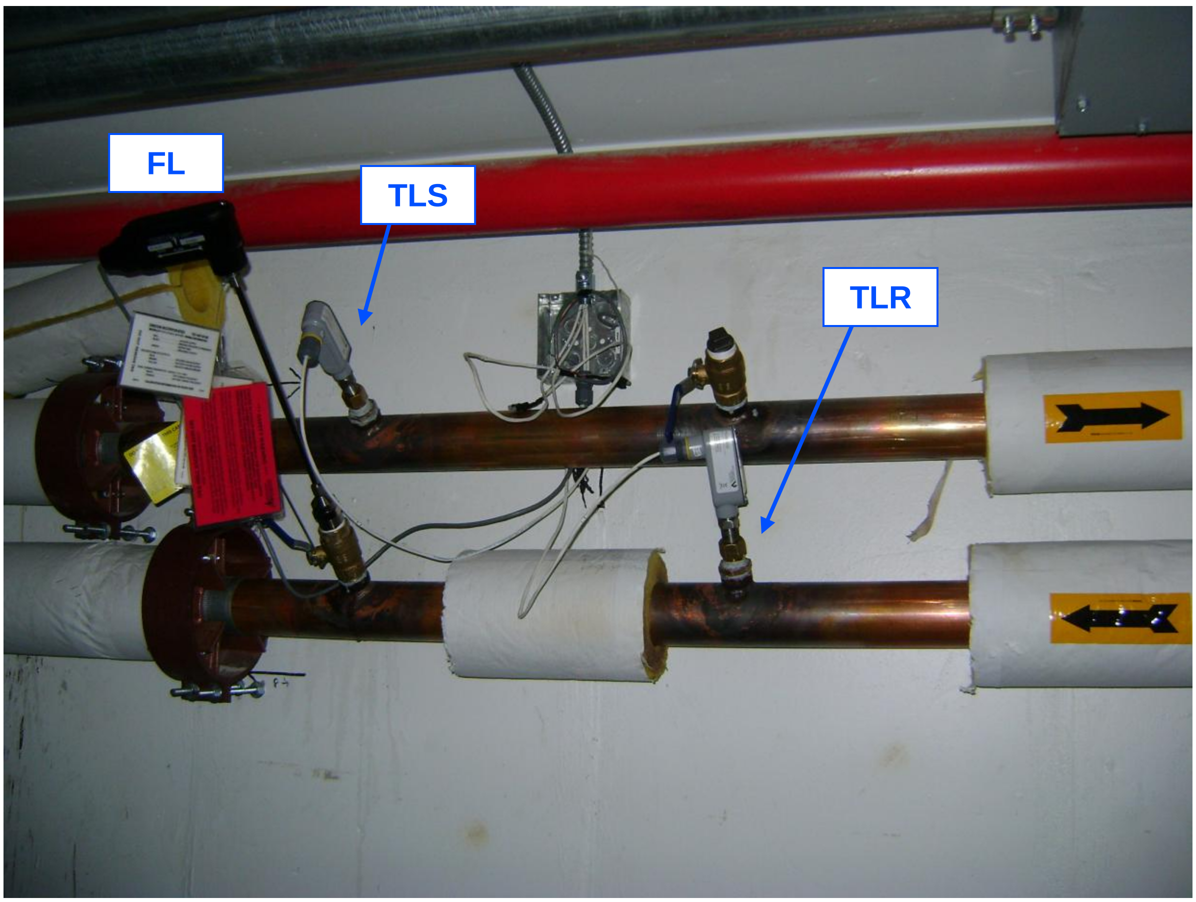

Figure 4. Locations of Temperature Sensors and Flow Meters Inside the Garage Area

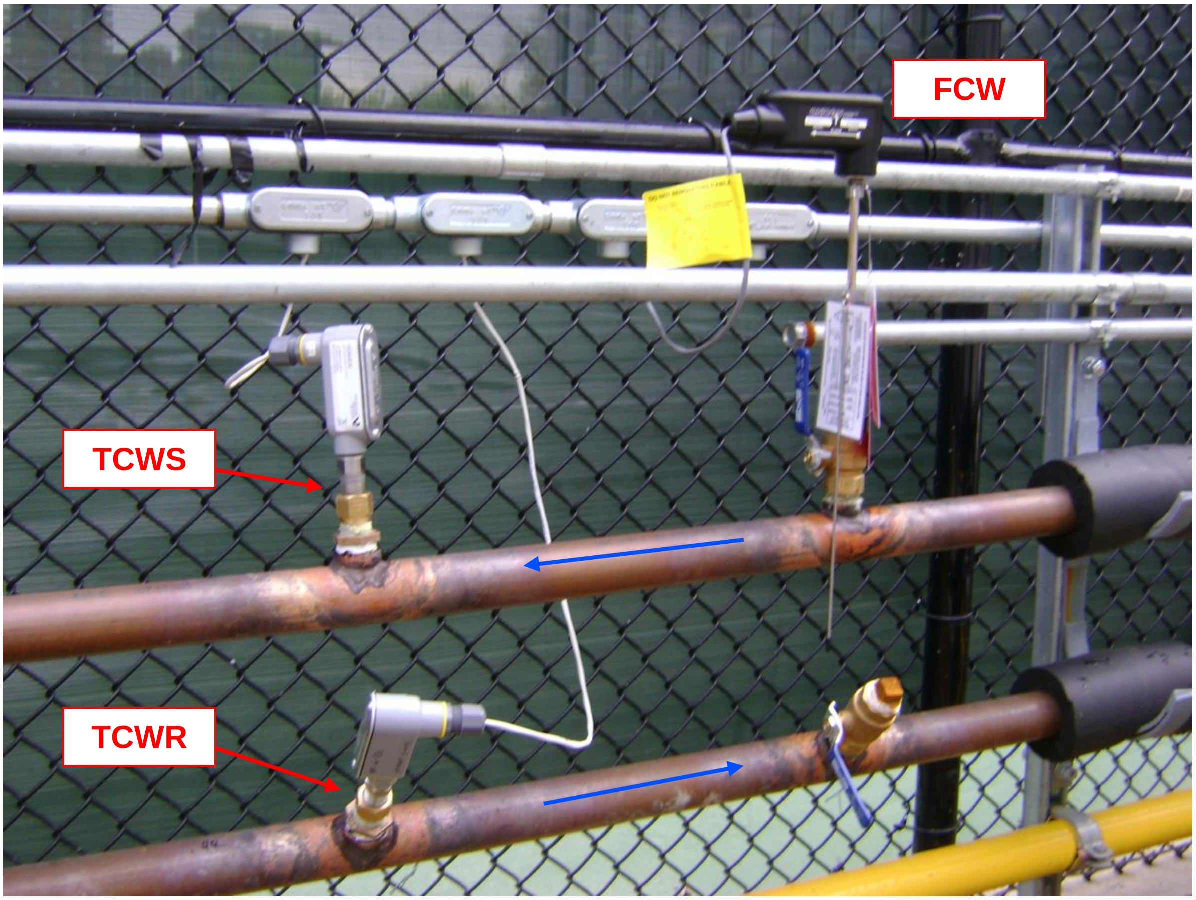

Figure 5. Locations of Temperature Sensors and Flow Meters for Cooling Loop

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 6. A Babel Buster gateway device reads MODBUS data from the PPC and makes that data available to the Obvius data logger. The Babel Buster also makes PPC and sensor data available as MODBUS TCP data for the Trane Building Monitoring System (BMS) at the apartment.

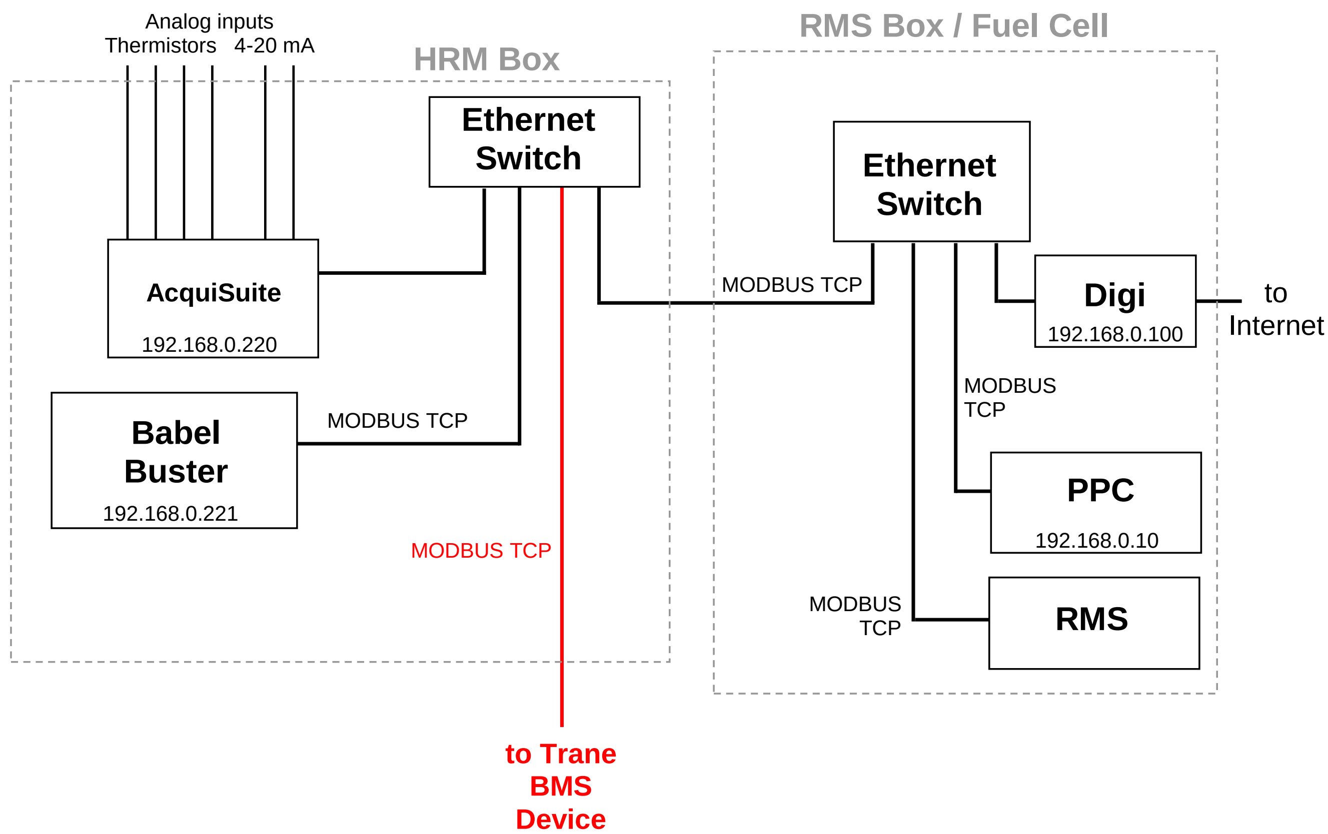

Figure 6. Layout of HRM, RMS and PPC Network

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 1-minute recording interval. The calculations listed below will be completed before the data are displayed on the web site:

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

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

where: Q_{xx} - Delivered heat recovery for loop *xx* (Btu/h)
(*xx* :: *lo* = low temp, *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 ethylene glycol (e.g., DowFrost). The factor *k* is equal to:

Low Temp Loop: k_{lo} = 489.9 Btu/h·gpm·°F for 0% glycol at 160ºF
Cooling Water: k_{cw} = 456.6 Btu/h·gpm·°F for 40% glycol at 130ºF

The Useful and and Unused heat recoveries will be:

$$Q_{useful} = Q_{lo}$$

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

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:

$$\mathrm{kW_{avg}} = \frac{\mathrm{kWh}}{\Delta t}$$

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 is 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:

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

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

where: *QL* - Useful heat recovery – low temperature loop (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

To 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 2 lists the emissions factors we will use for the displaced emissions.

Table 2. 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 The Octagon 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 The Octagon

Internet address: 166.143.143.154

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. The **AcquiSuite** can also create a file every few minutes that is used to generate the real-time screen.
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**.

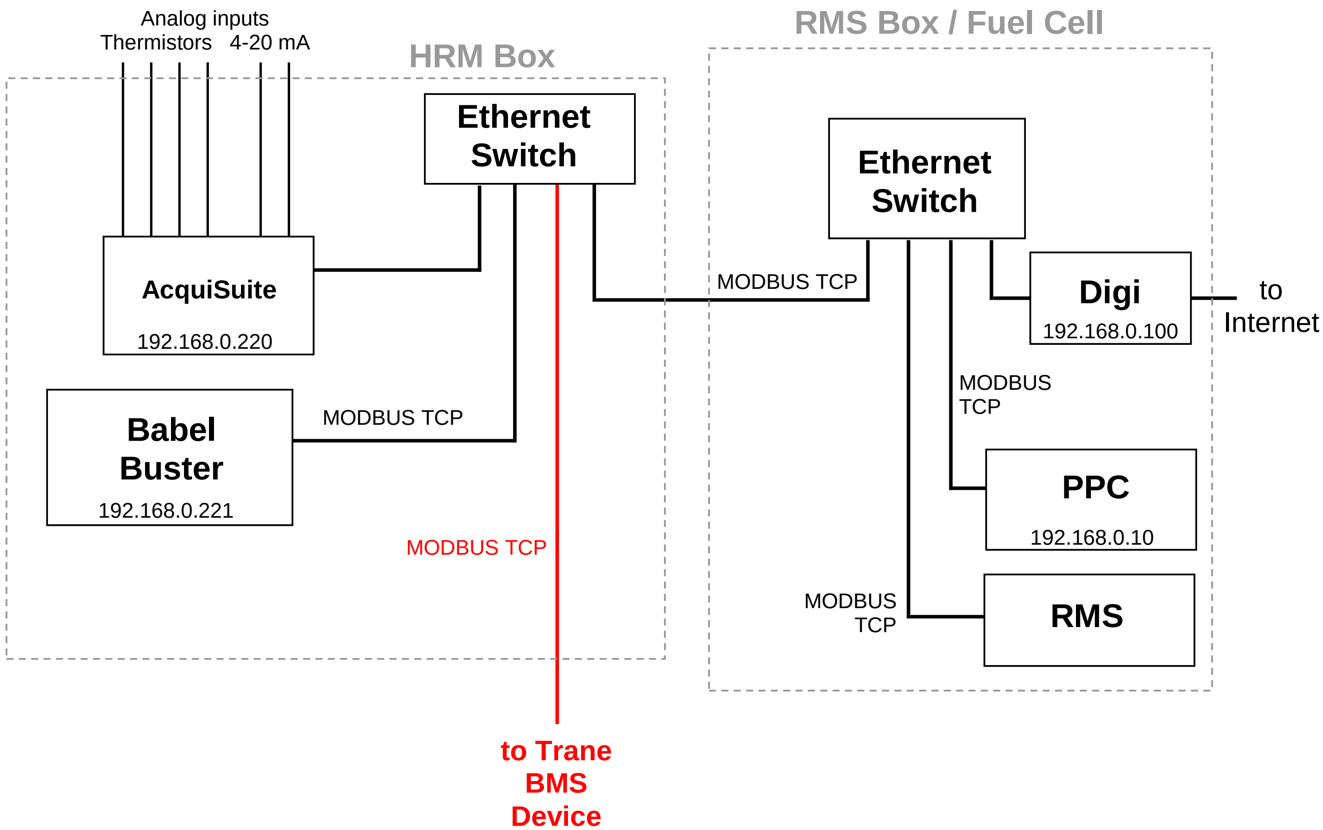

Figure 1. Layout of HRM and RMS Network

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
AcquiSuite	Obvius AcquiSuite	Modbus TCP	192.168.0.220
Babel Buster	CSI Babel Buster 2 Multi-network Interface	Modbus TCP	192.168.0.221
		BACnet	192.168.0.221
PPC	UTC Power Power Plant Controller (PPC)	Modbus TCP	192.168.0.10

Table 3. Listing of Data Points Collected from all Devices

Babel Buster Variable	Source	CDH Name	UTC / Obvius Variable Name	Description	Native Units	Source Data Address	Source Data Type	Notes	Babel Buster MODBUS Address	Babel Buster Data Type	Eng Units
AI-1	PPC	FG	FUEL	Fuel flow rate	kg/h	7173	Float		1	Float	kg/h
AI-2	PPC	FGcum	CUMFUEL	Cumulative fuel consumed at standard temperature	m^3	7191	Float		3	Float	m^3
AI-3	PPC	WFC	KW	Electrical power output	kW	10535	Float		5	Float	kW
AI-4	PPC	WFCcum	MWH	Cumulative electrical power output	MWh	7217	Float		7	Float	MWh
BI-1	PPC	SWV	WTRVLV	Make-up water tank fill valve status	On/Off	763	Boolean/Int		3001	Bolean	On/Off
AI-5	PPC	EFF_ELEC	EFFELEC	Instantaneous electrical efficiency	%	7505	Float		9	Float	%
AI-6	PPC	FC_STATE	STATE	Fuel cell state Number	Number	5	Unsigned Int		11	Float	Number
BI-2	PPC	SGI	GISTATUS	Grid independent status	On/Off	60	Boolean/Int		3002	Bolean	On/Off
BI-3	PPC	SGC	CGSTATUS	Grid connect status	On/Off	59	Boolean/Int		3003	Bolean	On/Off
AI-7	PPC	RTIME	LOAD	Cumulative load time hr	hrs	7205	Float		13	Float	hrs
AI-8	PPC	NALARM	NUMALARMS	Total number of alarms	Number	21	Unsigned Int		15	Float	Number
	Main-1	TLS	TEMPLGOUT	Temperature – low grade heat supply	°F	ohm		10k, Type 2	39	Float	Ohms
	Main-2	TLR	TEMPLGIN	Temperature – low grade heat return	°F	ohm		10k, Type 2	41	Float	Ohms
	Main-3	TCWS	TEMPCWOUT	Temperature – coolant water supply	°F	ohm		10k, Type 2	51	Float	Ohms
	Main-4	TCWR	TEMPCWIN	Temperature – coolant water return	°F	ohm		10k, Type 2	53	Float	Ohms
	Main-5	FL	FLOWLG	Flow rate – low grade heat	gpm	4-20 mA (0-150)		F-1111	55	Float	mA x 1000
	Main-6	FCW	FLOWCW	Flow rate – coolant water	gpm	4-20 mA (0-100)		F-1111	61	Float	mA x 1000

(green) = Data provided or received from PPC via MODBUS TCP

(orange) = Data from sensors on Obvius AcquiSuite

Babel Buster XML File


```xml
<?xml version="1.0" encoding="ISO-8859-1"?>
<!-- Babel Buster BB2-7010 v2.10 configuration file -->
<configuration>

<modbus_devices>
   <dev id="1" ipaddr="192.168.0.10"  unit="1"   rate="1.000000" name="UTC PPC"  swapped="1"/>
   <dev id="2" ipaddr="192.168.0.220" unit="250" rate="1.000000" name="Acquisuite Main Board"/>
</modbus_devices>

<client_read>
   <rule localreg="1"    remtype="hold_reg" remreg="7173"  remfmt="float"  dev="1" scale="0.000000" offset="0.000000" poll="1.00" name="FUEL"/>
   <rule localreg="2"    remtype="hold_reg" remreg="7191"  remfmt="float"  dev="1" scale="0.000000" offset="0.000000" poll="1.00" name="CUMFUEL"/>
   <rule localreg="3"    remtype="hold_reg" remreg="10535" remfmt="float"  dev="1" scale="0.000000" offset="0.000000" poll="1.00" name="KW"/>
   <rule localreg="4"    remtype="hold_reg" remreg="7217"  remfmt="float"  dev="1" scale="0.000000" offset="0.000000" poll="1.00" name="MWH"/>
   <rule localreg="3001" remtype="coil"     remreg="763"   remfmt="int"    dev="1" scale="0.000000" offset="0.000000" poll="1.00" name="WTRVLV"/>
   <rule localreg="5"    remtype="hold_reg" remreg="7505"  remfmt="float"  dev="1" scale="0.000000" offset="0.000000" poll="1.00" name="EFFELEC"/>
   <rule localreg="6"    remtype="hold_reg" remreg="5"     remfmt="uint"   dev="1" scale="0.000000" offset="0.000000" poll="1.00" name="STATE"/>
   <rule localreg="3002" remtype="coil"     remreg="60"    remfmt="int"    dev="1" scale="0.000000" offset="0.000000" poll="1.00" name="GISTATUS"/>
   <rule localreg="3003" remtype="coil"     remreg="59"    remfmt="int"    dev="1" scale="0.000000" offset="0.000000" poll="1.00" name="CGSTATUS"/>
   <rule localreg="7"    remtype="hold_reg" remreg="7205"  remfmt="float"  dev="1" scale="0.000000" offset="0.000000" poll="1.00" name="LOAD"/>
   <rule localreg="8"    remtype="hold_reg" remreg="21"    remfmt="uint"   dev="1" scale="0.000000" offset="0.000000" poll="1.00" name="NUMALARMS"/>
   <rule localreg="12"   remtype="hold_reg" remreg="13"    remfmt="uint"   dev="1" scale="0.000000" offset="0.000000" poll="1.00" name="ISTATE"/>

   <rule localreg="20"   remtype="hold_reg" remreg="1"     remfmt="double" dev="2" scale="0.000000" offset="0.000000" poll="1.00" name="Acquisuite TLS"/>
   <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="26"   remtype="hold_reg" remreg="5"     remfmt="double" dev="2" scale="0.000000" offset="0.000000" poll="1.00" name="Acquisuite TCWS"/>
   <rule localreg="27"   remtype="hold_reg" remreg="7"     remfmt="double" dev="2" scale="0.000000" offset="0.000000" poll="1.00" name="Acquisuite TCWR"/>

   <rule localreg="28"   remtype="hold_reg" remreg="9"     remfmt="double" dev="2" scale="0.000000" offset="0.000000" poll="1.00" name="Acquisuite FL"/>
   <rule localreg="31"   remtype="hold_reg" remreg="11"    remfmt="double" dev="2" scale="0.000000" offset="0.000000" poll="1.00" name="Acquisuite FCW"/>
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   <rule localreg="10" remtype="hold_reg" remreg="1102" remfmt="double" unit="1" scale="0.000000" offset="0.000000" poll="0.00" name="MWHREC_neg"/>
   <rule localreg="11" remtype="hold_reg" remreg="900"  remfmt="float"  unit="1" scale="0.000000" offset="0.000000" poll="0.00" name="KWREC"/>
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<rtu_write>
</rtu_write>

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</rtu_device>

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</bip_devices>

<bipclient_read>
</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	43	
Main-2	TLR	Low Temp Return Temp (to FC)	10k Thermistor, Type 2	ohm	°F	42	
Main-3	TCWS	Cooling Water Supply Temp (from FC)	10k Thermistor, Type 2	ohm	°F	35	
Main-4	TCWR	Cooling Water Return Temp (to FC)	10k Thermistor, Type 2	ohm	°F	36	
Main-5	FL	Low Temp Water Flow	Onicon F1100	4-20 mA	gpm	44, 45	3 inch, sched 40 steel, 100 gpm
Main-6	FCW	Cooling Water Flow	Onicon F1100	4-20 mA	gpm	37, 38	2 inch, sched 40 copper, 60 gpm
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Modbus TCP	FGcum	Cumulative Fuel Consumption	PPC	7191	m³	Float	page 12 of FCFR
Modbus TCP	WFC	Instantaneous Power Output	PPC	10535	kW	Float	page 12 of FCFR
Modbus TCP	WFCcum	Cumulative Power Produced	PPC	7217	MWh	Float	page 12 of FCFR
Modbus TCP	EFF_ELEC	Instantaneous electrical efficiency (LHV)	PPC	7505	%	Float	page 12 of FCFR
Modbus TCP	FC_STATE	Fuel Cell Mode/State Number	PPC	5	Number	Unsigned Int	page 12 of FCFR
Modbus TCP	RTIME	Cumulative "Load" Time	PPC	7205	hrs	Float	page 12 of FCFR
Modbus TCP	NALARM	Total number of alarms	PPC	21	Number	Unsigned Int	page 12 of FCFR
Modbus TCP	SWV	Make-up water tank fill valve status	PPC	763	On/Off	Boolean/Int	page 12 of FCFR
Modbus TCP	SGI	Grid independent status	PPC	60	On/Off	Boolean/Int	page 12 of FCFR
Modbus TCP	SGC	Grid connect status	PPC	59	On/Off	Boolean/Int	page 12 of FCFR

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
TLS,	mb-250,	1
TLR,	mb-250,	6
TCWS,	mb-250,	11
TCWR,	mb-250,	16
FL,	mb-250,	21
FCW,	mb-250,	26

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

Sensor Calibrations:

Thermistor #	Name	Wire	Input Channel	Mult	Offset
32	TLS	43	Main-4	0.98596	-0.19
31	TLR	42	Main-5	0.98722	0.07
6-35	TCWS	35	Main-6	0.98580	-0.20
6-36	TCWR	36	Main-7	0.98643	-0.10