# MONITORING PLAN
## FOR THE
## PURECELL 200 FUEL CELL
## AT
## PRICE CHOPPER IN GLENVILLE, NY

Draft

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*Submitted to:*


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## Introduction

This plan describes our approach to monitoring the performance of the fuel cell systems installed at the Price Chopper supermarket in Glenville, NY. The UTC Power PureCell™ Model 200 fuel cell provides clean and efficient electric power and thermal output to the facility. This fuel cell is expected to supply electricity in addition to standby power in the event of a power grid failure. The facility will also recover heat from the fuel cells to use for space and Domestic Hot Water (DHW) heating.

## System Description

The PureCell® Model 200 unit is installed behind the facility. 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 200 kW of electrical power and up to 900,000 Btu/h of heat. If fully utilized, the fuel cell can obtain a thermal efficiency near 90%.


Power Output: 200 kW
480V, 3ph

**Figure 1. PureCell 200 Unit**

Most of the thermal output from the FC is used to provide space conditioning and water heating for the facility. The low temperature hot water loop supplies 130ºF water to meet space heating loads including hot water coils and radiant floor heating circuits (see Figure 2).

## 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 shows where the measurements will be made in the thermal loops. Figure 3 and Figure 4 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 cooling water.

Data are extracted from the Shark Power Meter via MODBUS RTU. 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 | FG | Instantaneous Fuel Flow | Roots Series B3 Gas Meter | Pulse | lb/h | | Temperature Compensated |
| Main-2 | FL | Low Temp Water Flow | Onicon Flow Meter | 4-20 mA | gpm | 6 | 2" Type L Copper |
| Main-3 | FCW | Cooling Water Flow | Onicon Flow Meter | 4-20 mA | gpm | 5 | 2" Type L Copper |
| Main-4 | TLS | Low Temp Supply Temp (from FC) | 10k Thermistor, Type 2 | ohm | °F | 3 | |
| Main-5 | TLR | Low Temp Return Temp (to FC) | 10k Thermistor, Type 2 | ohm | °F | 4 | |
| Main-6 | TCWS | Cooling Water Supply Temp (from FC) | 10k Thermistor, Type 2 | ohm | °F | 1 | |
| Main-7 | TCWR | Cooling Water Return Temp (to FC) | 10k Thermistor, Type 2 | ohm | °F | 2 | |
| | | | | | | | |
| Modbus Dev 1 | WREC_pos | Energy Imported (RECs meter) | Shark 100 | Double | kWh | RS-485 | |
| Modbus Dev 1 | WREC_neg | Energy Produced (RECs meter) | Shark 100 | Double | -kWh | RS-485 | |
| Modbus Dev 1 | WDREC | Power through RECs meter | Shark 100 | Float | Watts | RS-485 | |

Note: Main = Obvius main board, device 250

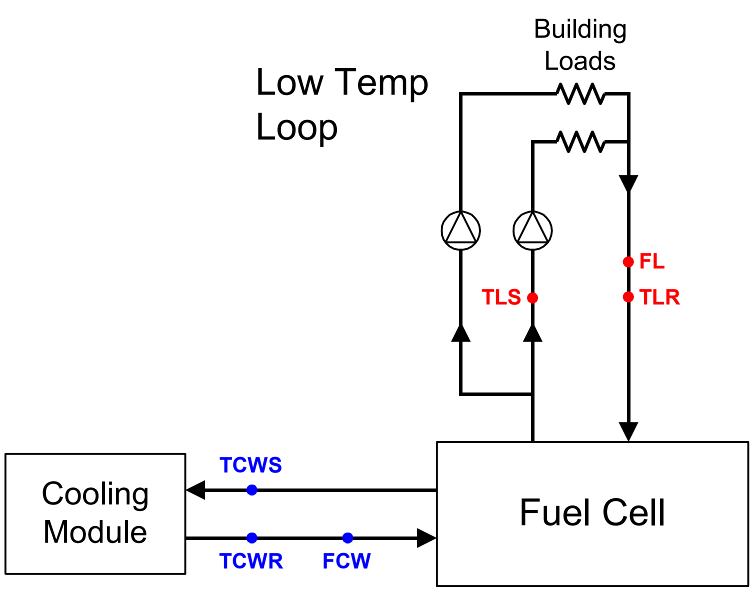


**Figure 2. Schematic of Heat Transfer Loops in Fuel Cell System**

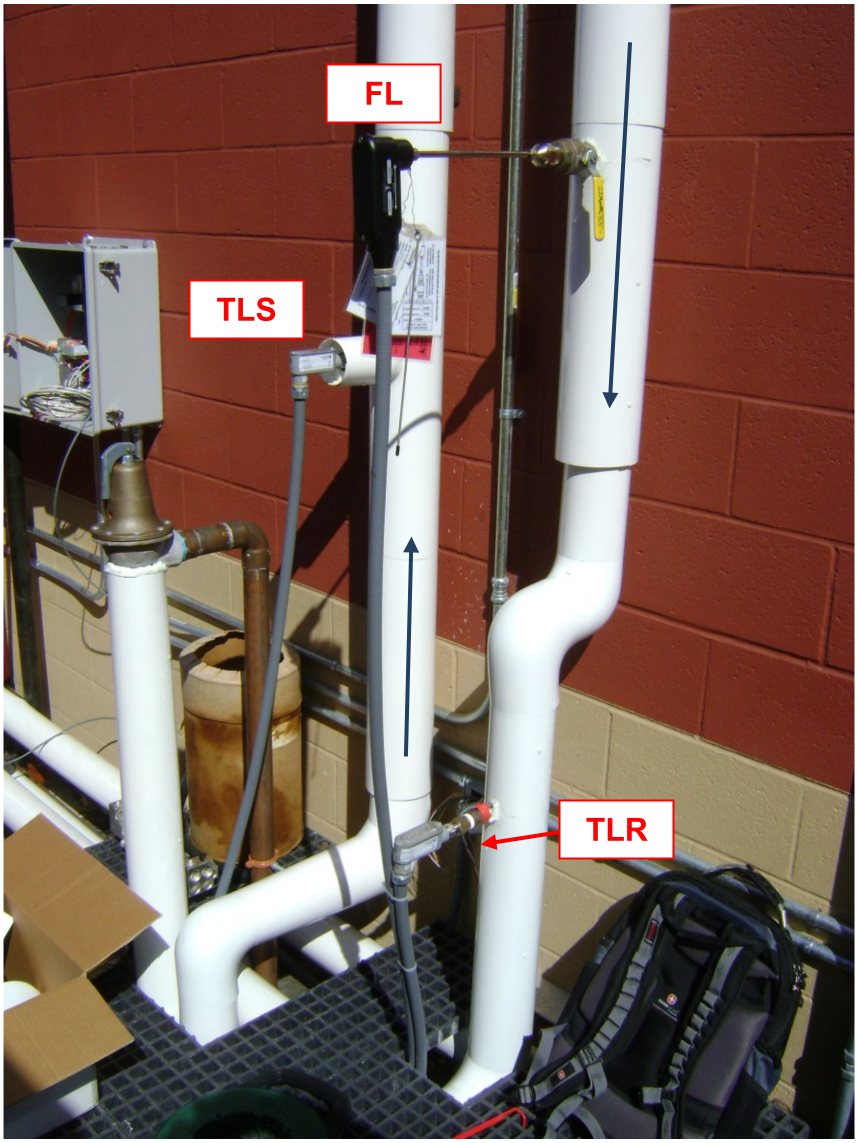


**Figure 3. Locations of Low Grade Loop Temperature and Flow Sensors in Rear of the Facility**

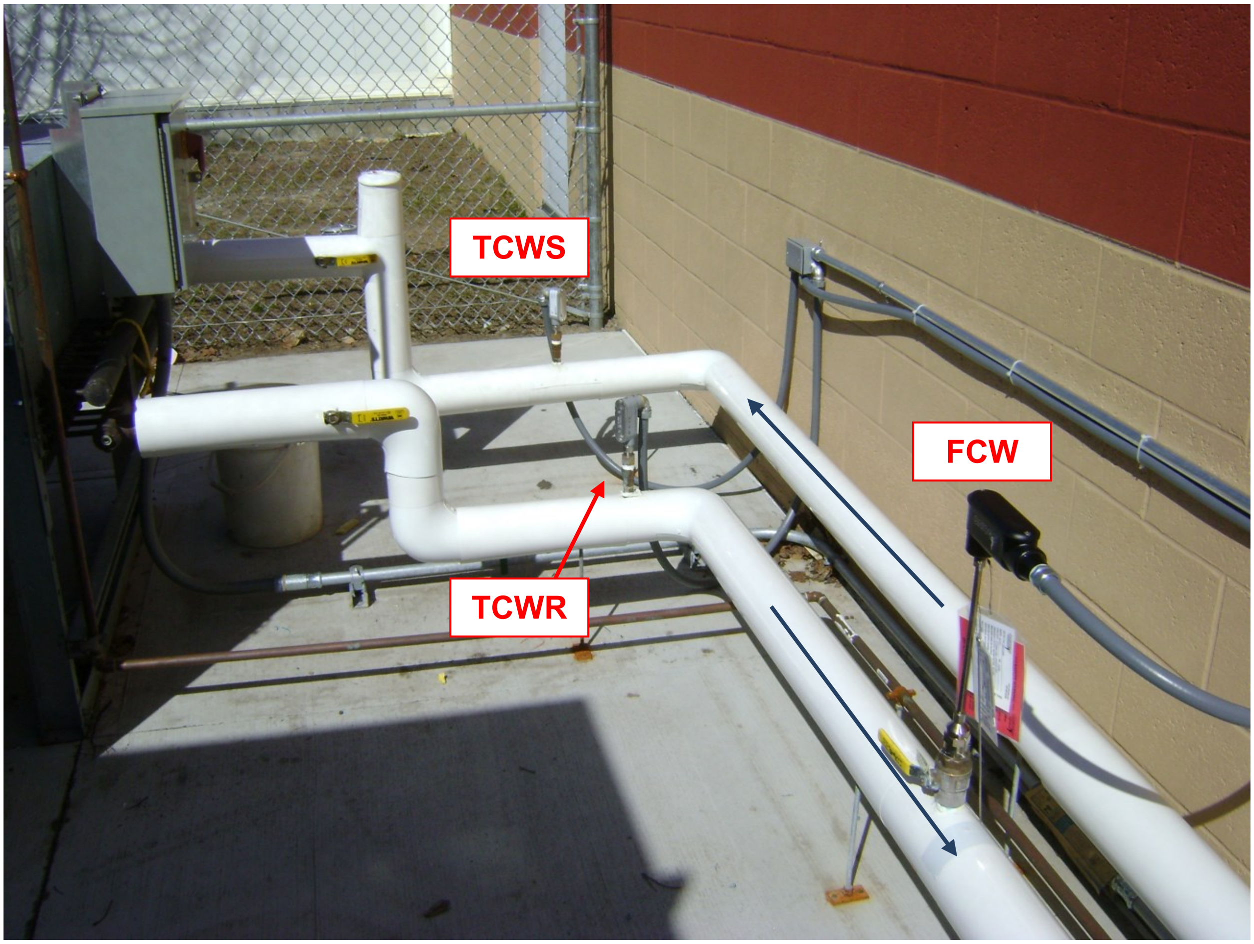


**Figure 4. Locations of Cooling Module Loop Temperature and Flow Sensors in Rear of the Facility**

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.

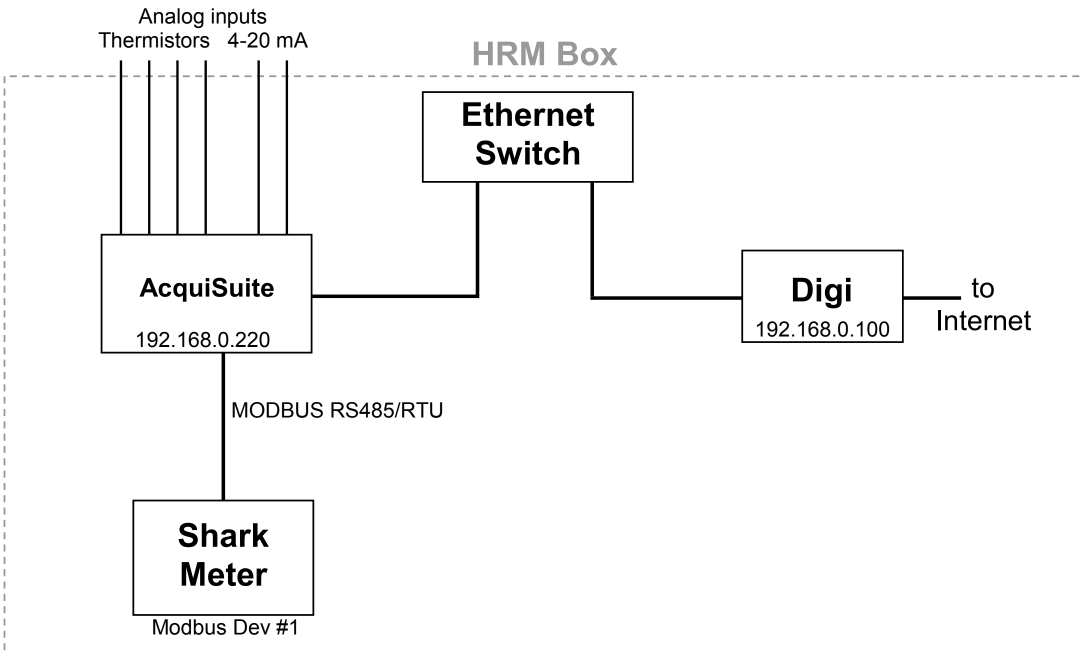


**Figure 5. Layout of HRM Network**

# 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:

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

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

| | | | |
|---|---|---|---|
| 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: $k_{lo}$ = 456.6 Btu/h·gpm·°F for 40% glycol at 130ºF
Cooling Water: $k_{cw}$ = 459.3 Btu/h·gpm·°F for 40% glycol at 180ºF

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<br>0.98 lb per kWh<br>0.86 lb per kWh | Massachusetts<br>Connecticut<br>New York |
| NOx emissions | 0.1 lb per CCF | 2.45 lb per MWh<br>2.45 lb per MWh<br>2.45 lb per MWh | Massachusetts<br>Connecticut<br>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 Price Chopper 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 Price Chopper, Glenville

Internet address: 166.141.147.129

**Table 3. Summary of Major HRM Components**

| | |
|---|---|
| Obvius **AcquiSuite** A8812 | This datalogger includes thermistors and flow meters to measure thermal loads. 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. |

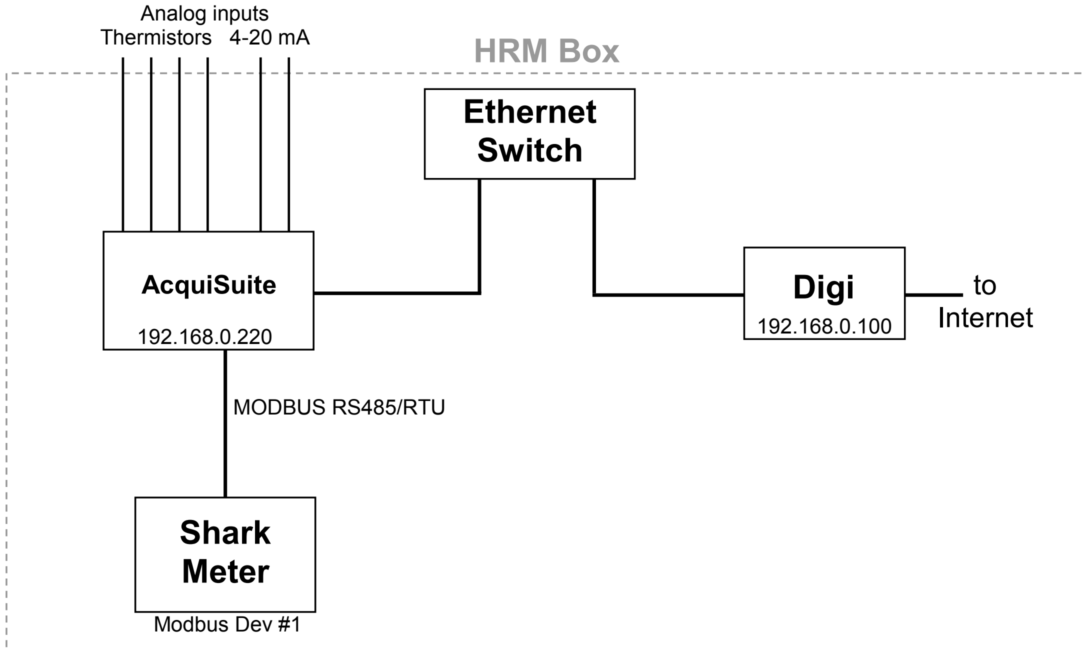


**Figure 6. Layout of HRM Network**

The AcquiSuite performs all communications with devices on the network. It reads data from the temperature and flow sensors and from the Shark power meter, and then logs all the data.

**Table 4. 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 | | |
| | | Modbus RTU | | Master | |
| Shark | Shark 100 - REC Power Transducer | Modbus RTU | | Slave | 1 |

**Table 5. Listing of Data Points Collected from all Devices**

| Source | CDH Name | UTC / Obvius Variable Name | Description | Native Units | Source Data | | Wire | Notes |
|---|---|---|---|---|---|---|---|---|
| Main-1 | FG | FG Ave | Fuel flow rate | lb/h | Pulse | | | Roots Gas Meter |
| Main-2 | FL | FL Ave | Flow rate – low grade heat | gpm | 4-20 mA (0-??) | | 6 | Onicon Meter |
| Main-3 | FCW | FCW Ave | Flow rate – cooling water | gpm | 4-20 mA (0-85) | | 5 | Onicon Meter |
| Main-4 | TLS | TLS Ave | Temperature – low grade heat supply | °F | ohm | | 3 | 10k, Type 2 |
| Main-5 | TLR | TLR Ave | Temperature – low grade heat return | °F | ohm | | 4 | 10k, Type 2 |
| Main-6 | TCWS | TCWS Ave | Temperature – cooling water supply | °F | ohm | | 1 | 10k, Type 2 |
| Main-7 | TCWR | TCWR Ave | Temperature – cooling water return | °F | ohm | | 2 | 10k, Type 2 |
| | | | | | **Address** | **Type** | | |
| SHARK | WREC_pos | W-hours, Received | Energy Imported (RECs meter) | kWh | 1100 | Double | RS-485 | Modbus RTU |
| SHARK | WREC_neg | W-hours, Delivered | Energy Produced (RECs meter) | -kWh | 1102 | Double | RS-485 | Modbus RTU |
| SHARK | WDREC | Watts, 3-Ph total | Power through RECs meter | Watts | 900 | Float | RS-485 | Modbus RTU |

= Data from sensors on Obvius AcquiSuite    = Data from Shark Meter via MODBUS RTU

**Table 6. Sensor and Wiring Details for AcquiSuite**

| Channel / Source | Data Pt | Description | Instrument / Meter | Signal / Register | Eng Units | Wire | Notes |
|---|---|---|---|---|---|---|---|
| Main-1 | FG | Instantaneous Fuel Flow | Roots Series B3 Gas Meter | Pulse | lb/h | | Temperature Compensated |
| Main-2 | FL | Low Temp Water Flow | Onicon Flow Meter | 4-20 mA | gpm | 6 | 2" Type L Copper |
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| Main-6 | TCWS | Cooling Water Supply Temp (from FC) | 10k Thermistor, Type 2 | ohm | °F | 1 | |
| Main-7 | TCWR | Cooling Water Return Temp (to FC) | 10k Thermistor, Type 2 | ohm | °F | 2 | |
| | | | | | | | |
| Modbus Dev 1 | WREC_pos | Energy Imported (RECs meter) | Shark 100 | Double | kWh | RS-485 | |
| Modbus Dev 1 | WREC_neg | Energy Produced (RECs meter) | Shark 100 | Double | -kWh | RS-485 | |
| Modbus Dev 1 | WDREC | Power through RECs meter | Shark 100 | Float | Watts | RS-485 | |

**Table 7. 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 15-minute data for each device. The read map for the data logger is given below.

Device 001 (SHARK Meter): Column

```
WREC_pos......................16
WREC_neg......................15
WDREC..........................9
```

Device 250 (AcquiSuite Main Board):

```
FG.............................1
FL.............................6
FCW...........................11
TLS...........................16
TLR...........................21
TCWS..........................26
TCWR..........................31
```

## Sensor Calibrations:

| Thermistor # | Name | Wire | Input Channel | Offset |
|---|---|---|---|---|
| 4-26 | TLS | 3 | Main-4 | -2.1 |
| 4-25 | TLR | 4 | Main-5 | -1.7 |
| 4-24 | TCWS | 1 | Main-6 | -1.3 |
| 4-23 | TCWR | 2 | Main-7 | -1.2 |