# “Metrology” and Measuring Thermal Performance

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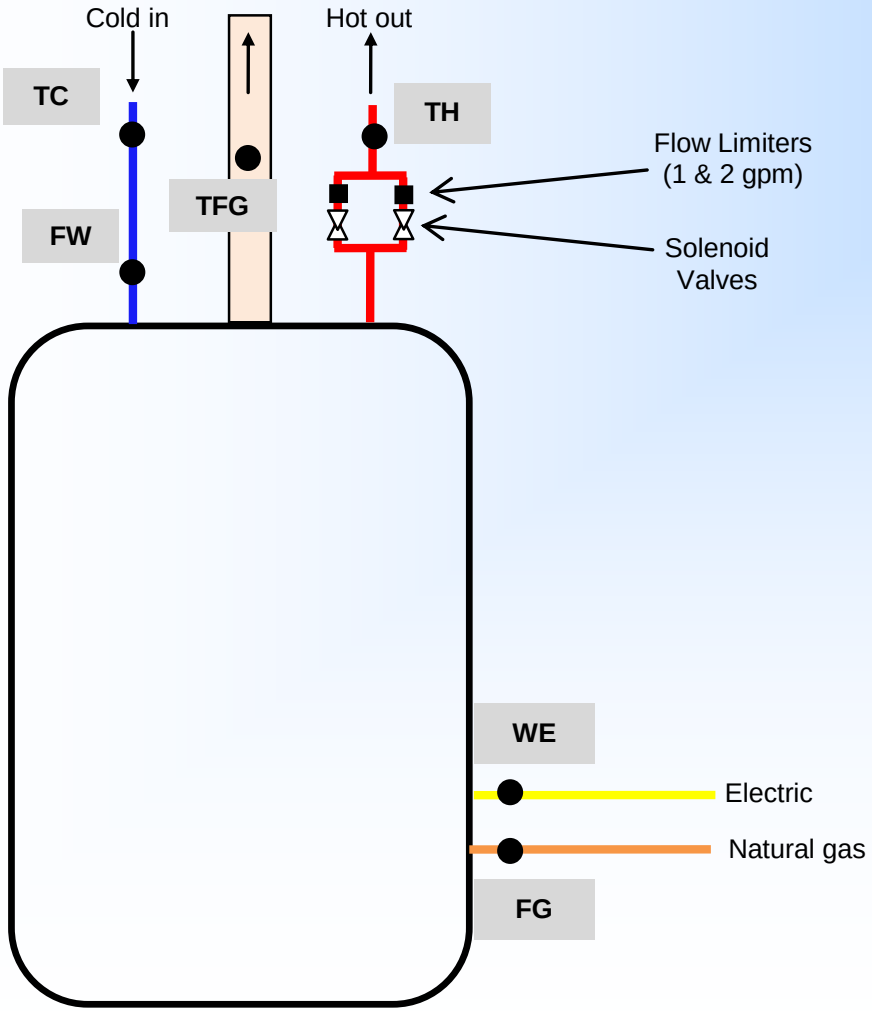
# Overview

- What do you need to Measure?
  - Apply the 1st Law / energy flows
  - Goal:  product development or verify savings
- How to Measure it
  - What instruments, meters, data loggers
  - When do I use what instruments
- Examples
  - Different systems different approaches

# DHW Instrumentation

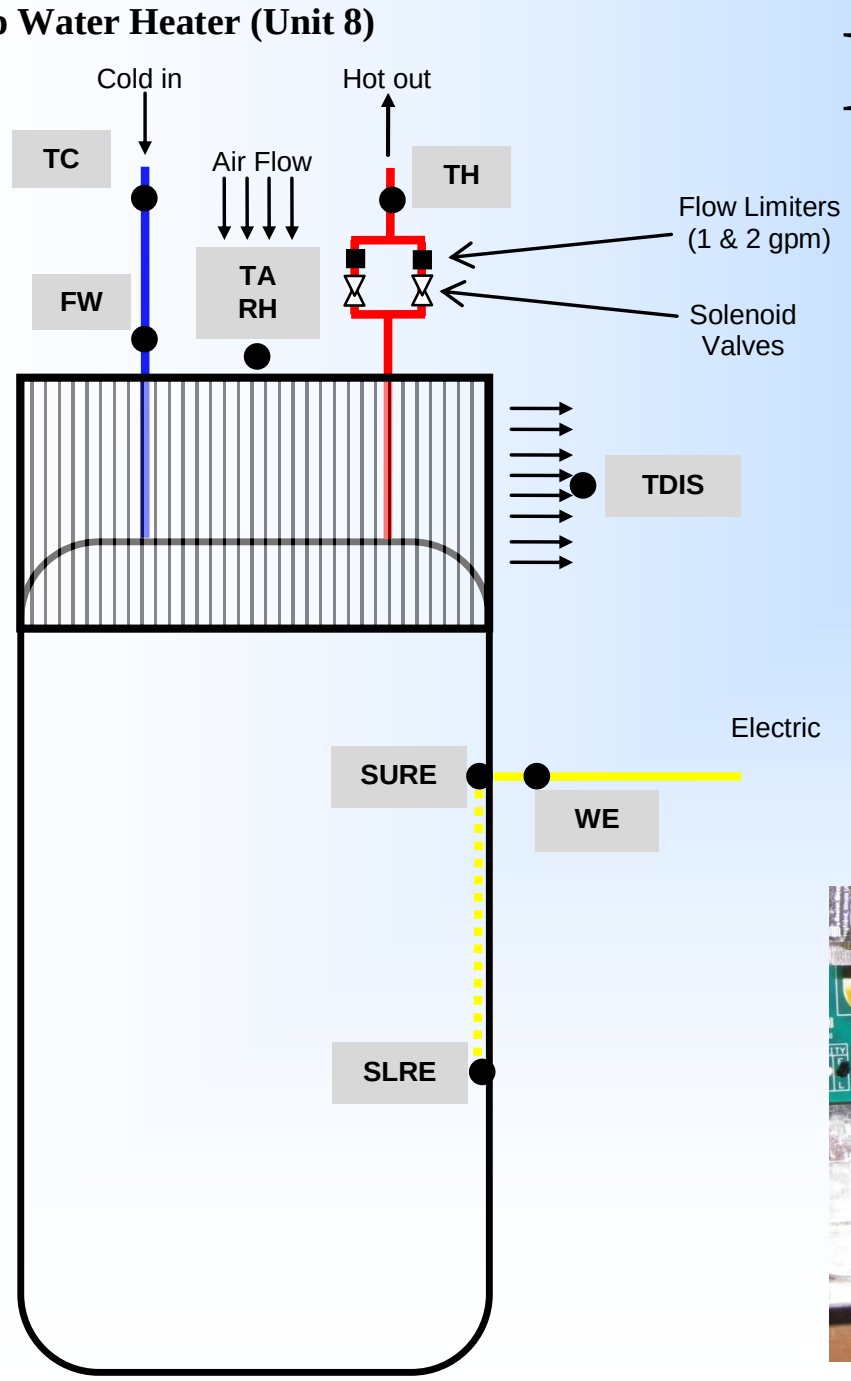
**Gas Storage and Tankless Water Heaters (Units 1, 2, 5, 6, & 7)**




## Measure

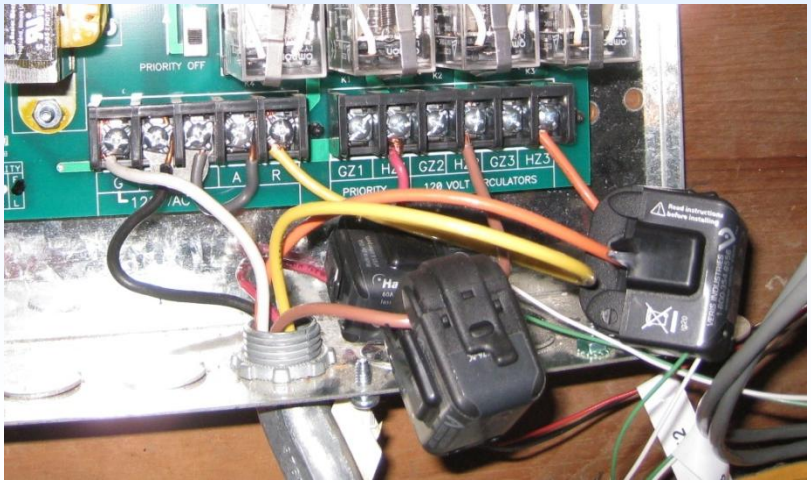
- Flow, ΔT & Q out
- Fuel input
- Power Input

# Instrumentation HPWH




## Additional Measurements

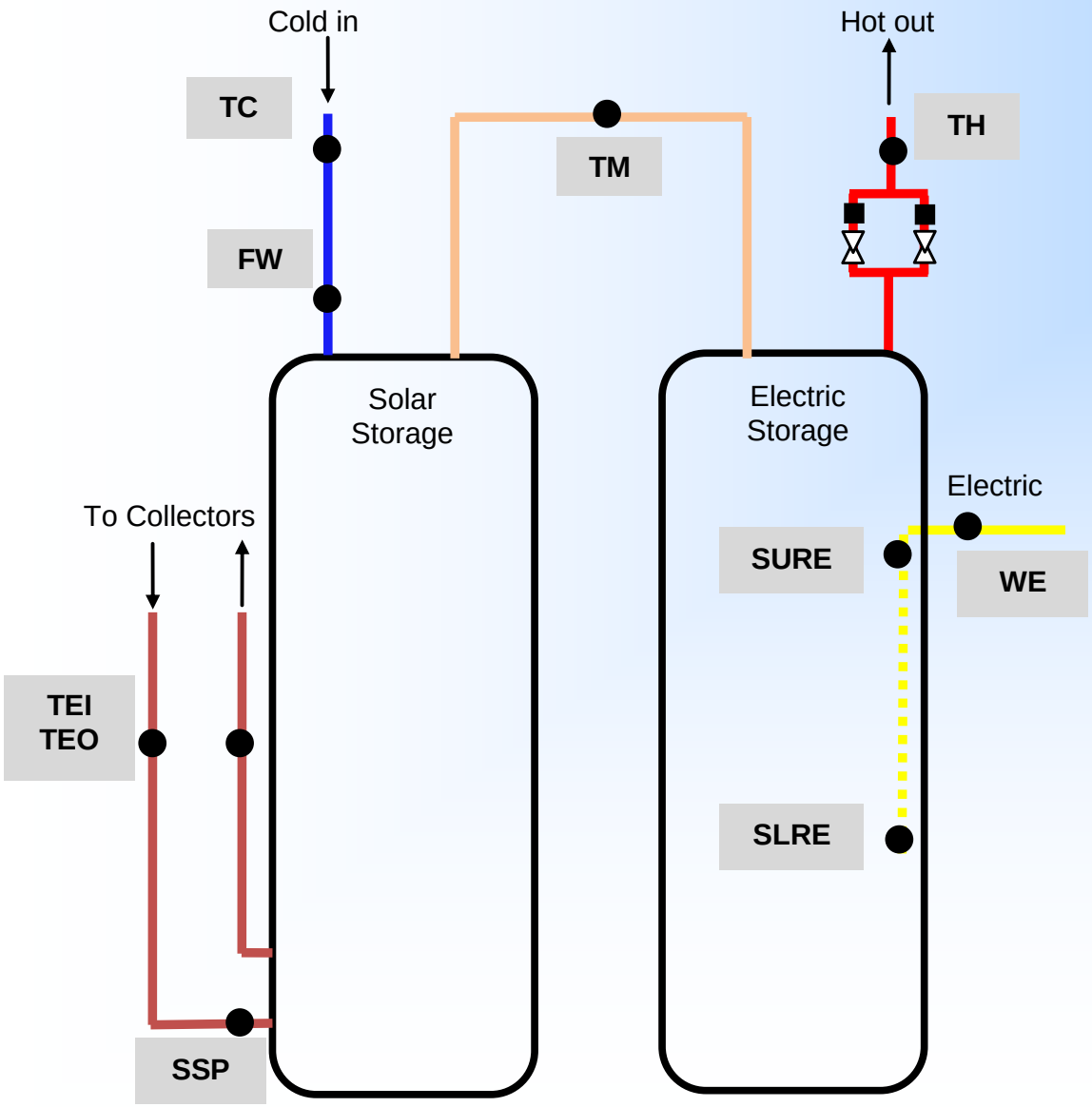
- Space Conditions (T/RH)
- Discharge Air
- Status of Elements



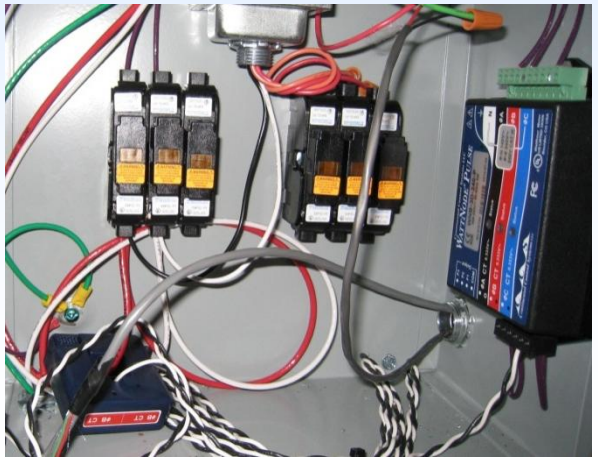
# Instrumentation SOLAR

# Instrumentation - SOLAR DRAIN

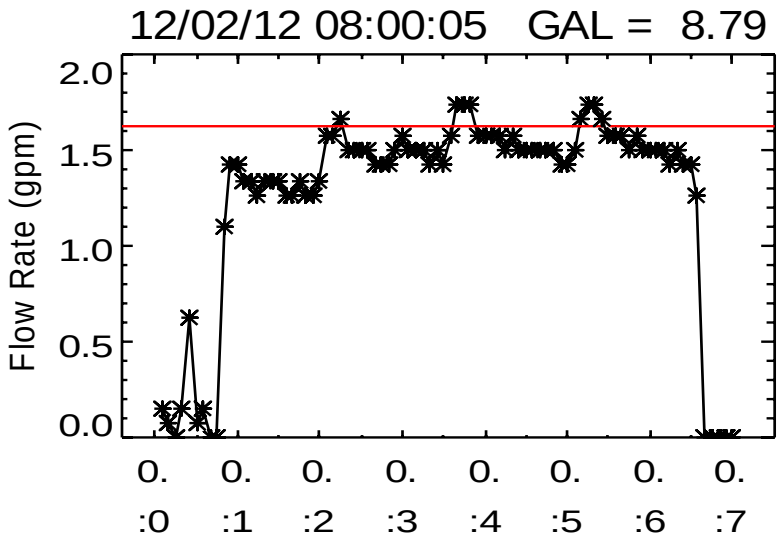
**Solar Thermal with Separate Electric Storage (Unit 4)**

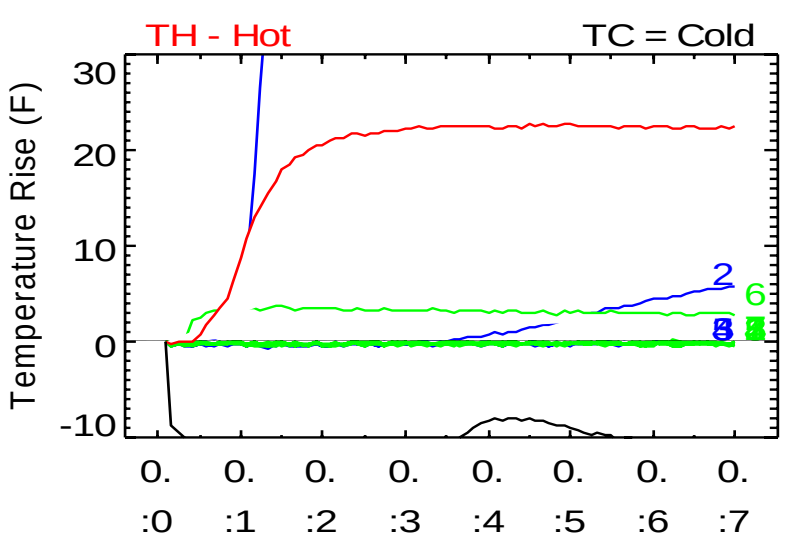


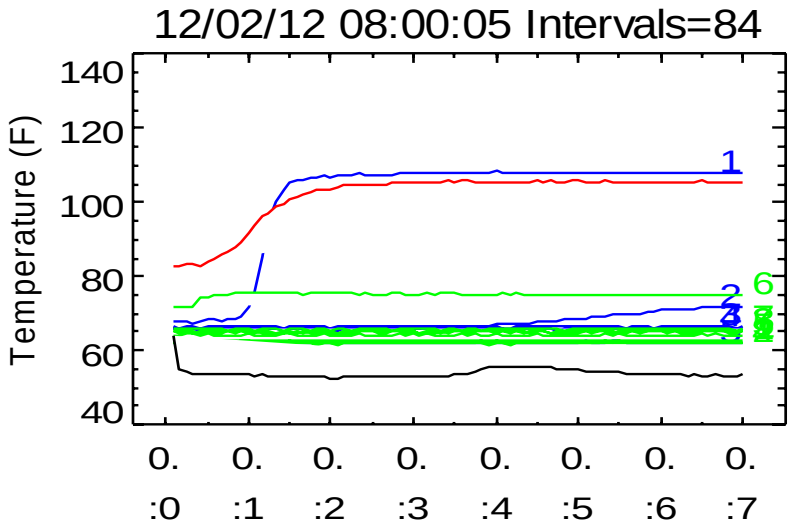




# Residential DHW is Complicated!




TT1: Trunk Temp - Master Bathroom: Rise= 40.7
TT2: Trunk Temp - Bathroom 2: Rise= 5.8

## Master Shower

Useful GAL = 8.03 (TT > 100. )

TF6: Fixture Temp 6 - Master Bath Sink: Rise= 3.8
TF7: Fixture Temp 7 - Bathroom 2 Sink: Rise= 0.3

# Different Instruments

- Temperatures
  - thermocouples good for $\Delta T$; low mass
  - Thermistors lower cost; self-calibration helps
- Water Flow
  - DHW is intermittent (positive displacement)
  - Larger systems more steady state
  - Resolution and accuracy
- Fuel
  - resolution
- Power
  - Different systems different approaches

# Laboratory Testing – Solar/HPWH

Unit 3
SOLAR

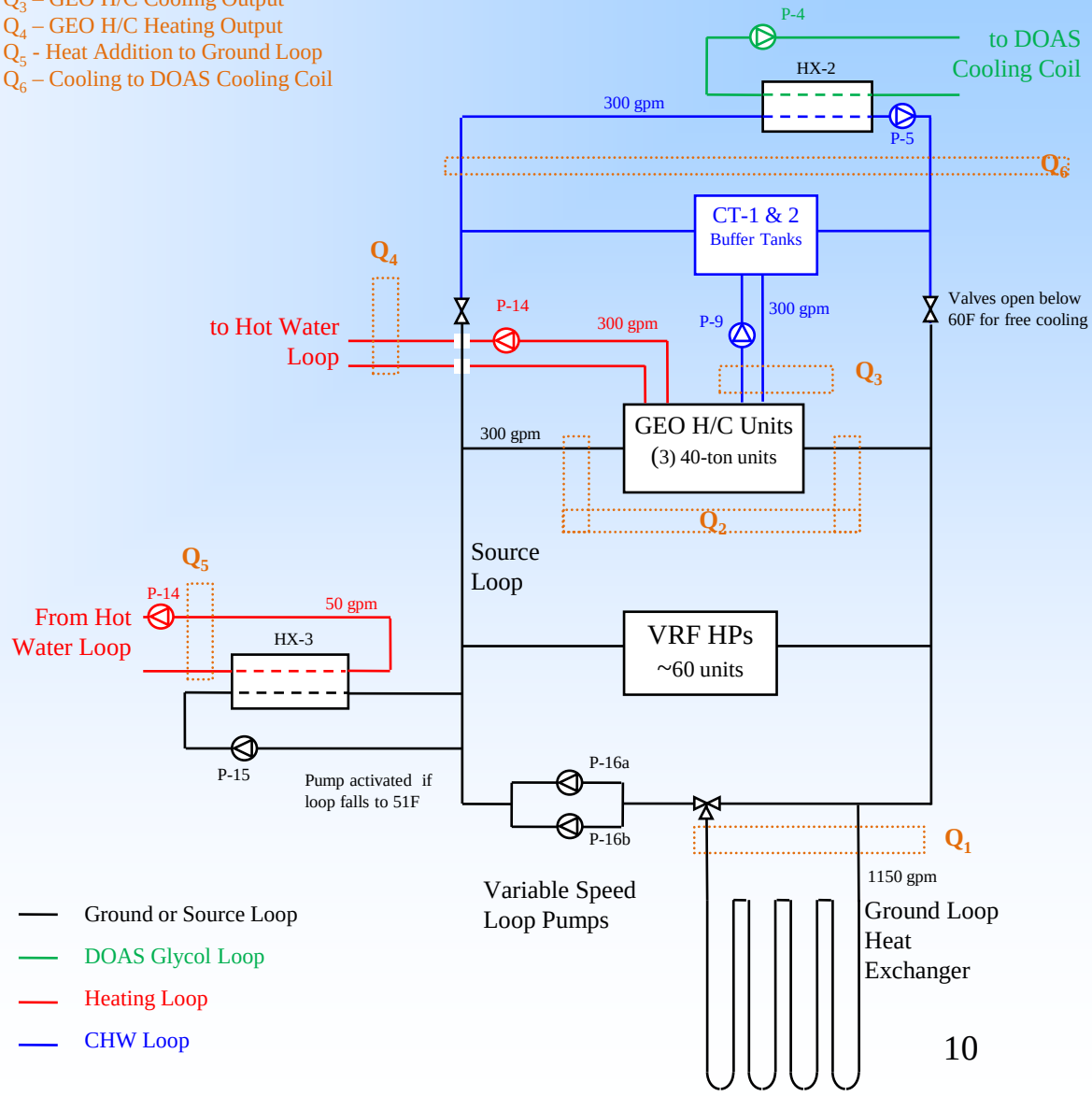
Unit 4
SOLAR DRAIN

Unit 8
HPWH
(EF=2.4)

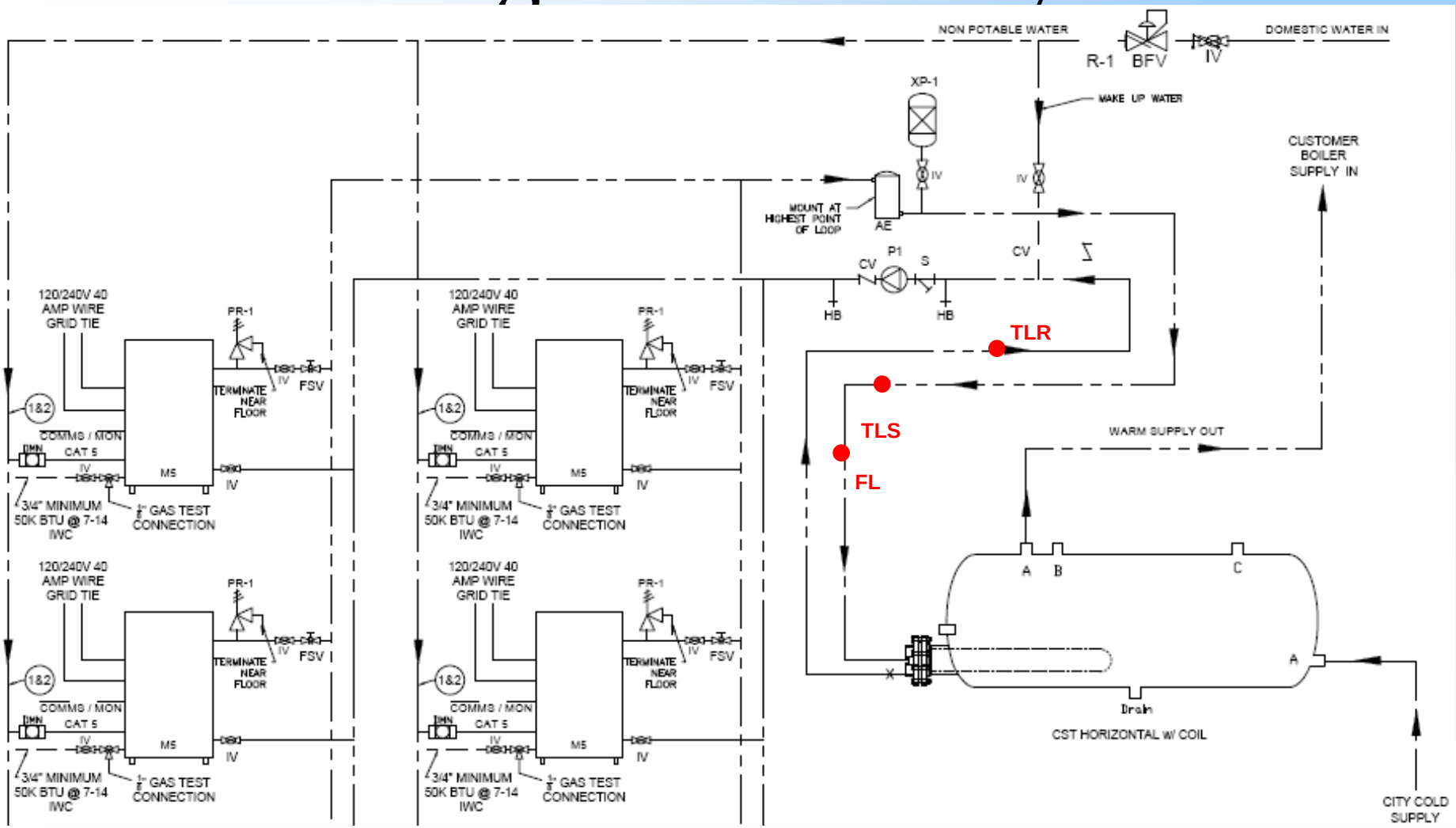
# Geothermal Heat Pumps

Thermal Energy (BTU) Meters

$Q_1$ - Heat extracted from / rejected to Ground Loop
$Q_2$ – Source Heat input / output to GEO H/C
$Q_3$ – GEO H/C Cooling Output
$Q_4$ – GEO H/C Heating Output
$Q_5$ - Heat Addition to Ground Loop
$Q_6$ – Cooling to DOAS Cooling Coil



# Fuel Cells / CHP
# Preheating Multi-Family DHW



# Displaying Results

Week of Mar 02, 2014 Mar 09, 2014 - Mar 15, 2014

**Unit 3 Summary**

| Date | Percent Valid Data (%) | Water Flow (gal) | Delivered Heat (MBtu) | Power (kWh) | Solar Pump Runtime (minutes) | Solar Flux (kWh/m^2) | Avg Supply Temp (F) | Avg Cold Temp (F) | Conversion Efficiency (-) |
|---|---|---|---|---|---|---|---|---|---|
| Mar 09, 2014 | 100.0 | 70.9 | 33.2 | 8.2 | 201.3 | 5.1 | 119.0 | 63.3 | 1.19 |
| Mar 10, 2014 | 100.0 | 70.5 | 34.4 | 9.2 | 5.0 | 1.6 | 119.5 | 61.0 | 1.09 |
| Mar 11, 2014 | 100.0 | 71.8 | 34.6 | 5.9 | 383.5 | 6.3 | 118.3 | 61.2 | 1.72 |
| Mar 12, 2014 | 100.0 | 71.7 | 35.7 | 8.6 | 0.0 | 0.2 | 119.2 | 59.4 | 1.21 |
| Mar 13, 2014 | 100.0 | 71.6 | 36.5 | 11.2 | 9.8 | 3.6 | 119.8 | 58.6 | 0.96 |
| Mar 14, 2014 | 100.0 | 71.1 | 35.7 | 10.0 | 156.4 | 3.7 | 119.5 | 59.7 | 1.04 |
| Mar 15, 2014 | 13.5 | 0.0 | 0.0 | 0.3 | 0.0 | 0.0 | - | - | 0.00 |
| **Total** | **87.6** | **427.5** | **210.0** | **53.4** | **756.0** | **20.3** | **119.2** | **60.5** | **1.15** |

Solar DHW

Week of Mar 02, 2014 Mar 09, 2014 - Mar 15, 2014

**System Summary Fuel Cell 3 (9594)**

| Date | Power Produced (kWh) | Max Power (kW) | Fuel Consumption (MBtu) | Low Grade Heat (MBtu) | High Grade Heat (MBtu) | Electrical Efficiency (%) | Total Efficiency (%) | Total Heat Balance (%) |
|---|---|---|---|---|---|---|---|---|
| Mar 09, 2014 | 9,601.0 | 400.4 | 75,288.3 | 1,044.7 | 19.2 | 43.5 | 44.9 | 89.7 |
| Mar 10, 2014 | 9,601.0 | 400.4 | 74,875.7 | 3,040.0 | 262.2 | 43.8 | 48.2 | 89.2 |
| Mar 11, 2014 | 9,597.0 | 400.6 | 76,036.7 | 1,762.2 | 3.4 | 43.1 | 45.4 | 94.7 |
| Mar 12, 2014 | 9,602.0 | 400.6 | 76,035.0 | 2,542.7 | 123.6 | 43.1 | 46.6 | 94.7 |
| Mar 13, 2014 | 9,601.0 | 400.4 | 76,251.6 | 41.6 | 97.4 | 43.0 | 43.1 | 88.2 |
| Mar 14, 2014 | 9,401.0 | 400.5 | 73,669.5 | 2,942.1 | 122.8 | 43.5 | 47.7 | 83.6 |
| Mar 15, 2014 | - | - | - | - | - | - | - | - |
| **Total** | **57,403.0** | **400.6** | **452,156.7** | **11,373.3** | **628.4** | **43.3** | **46.0** | **90.1** |

Fuel Cell / CHP