Ground-Source Integrated Heat Pump System – field measured WH performance

2016 ACEEE Hot Water Forum

Shawn Hern – ClimateMaster, Inc.
Van Baxter, Jeff Munk, and Tony Gehl – Oak Ridge National Laboratory

Portland, OR
February, 22-23, 2016

ORNL is managed by UT-Battelle
for the US Department of Energy

OAK RIDGE National Laboratory

Contents

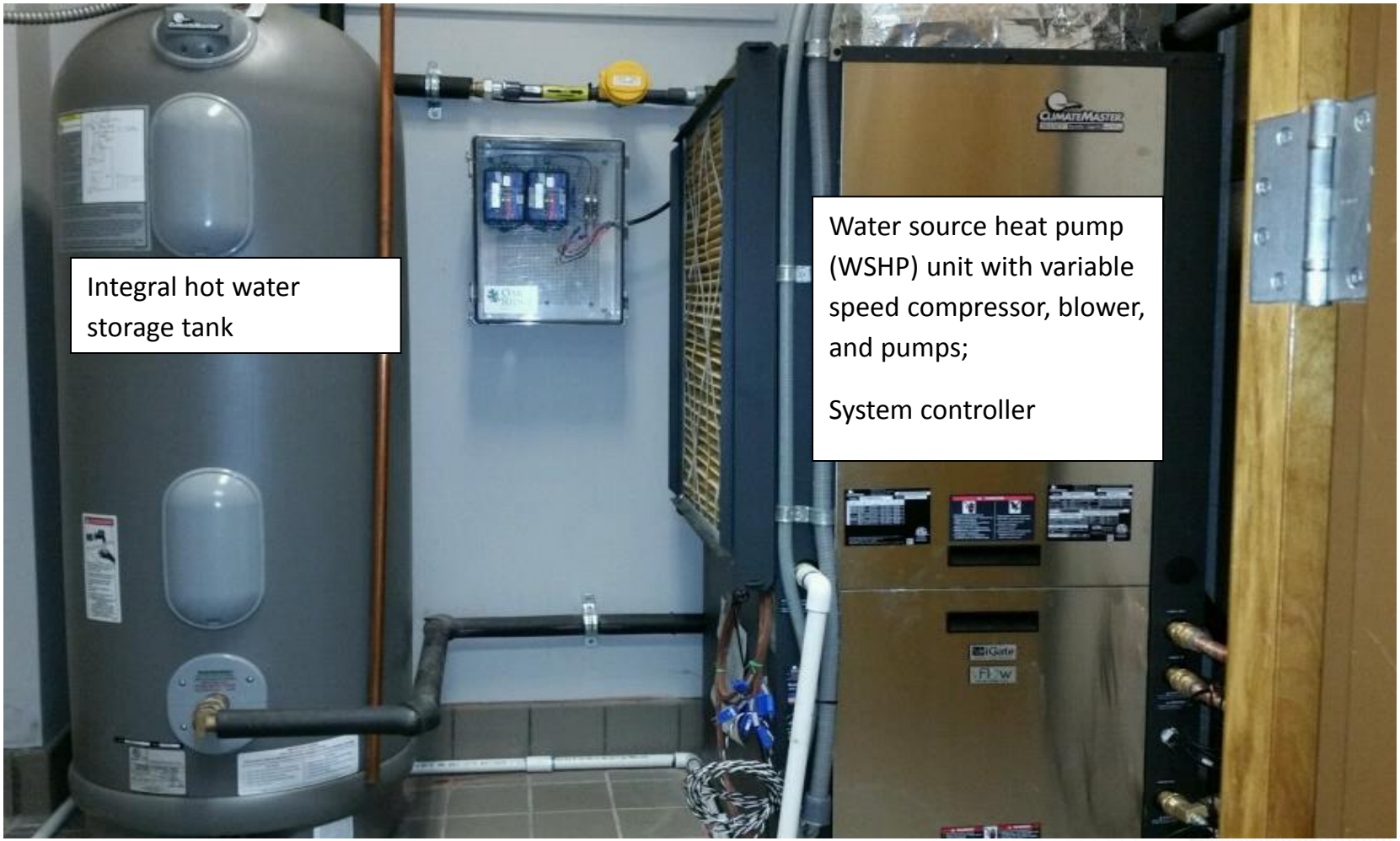
1. GS-IHP system description

2. Field test site and monitoring approach descriptions

3. Test results

4. Concluding observations

GS-IHP System description



Knoxville, TN
Day care center
Test system installation

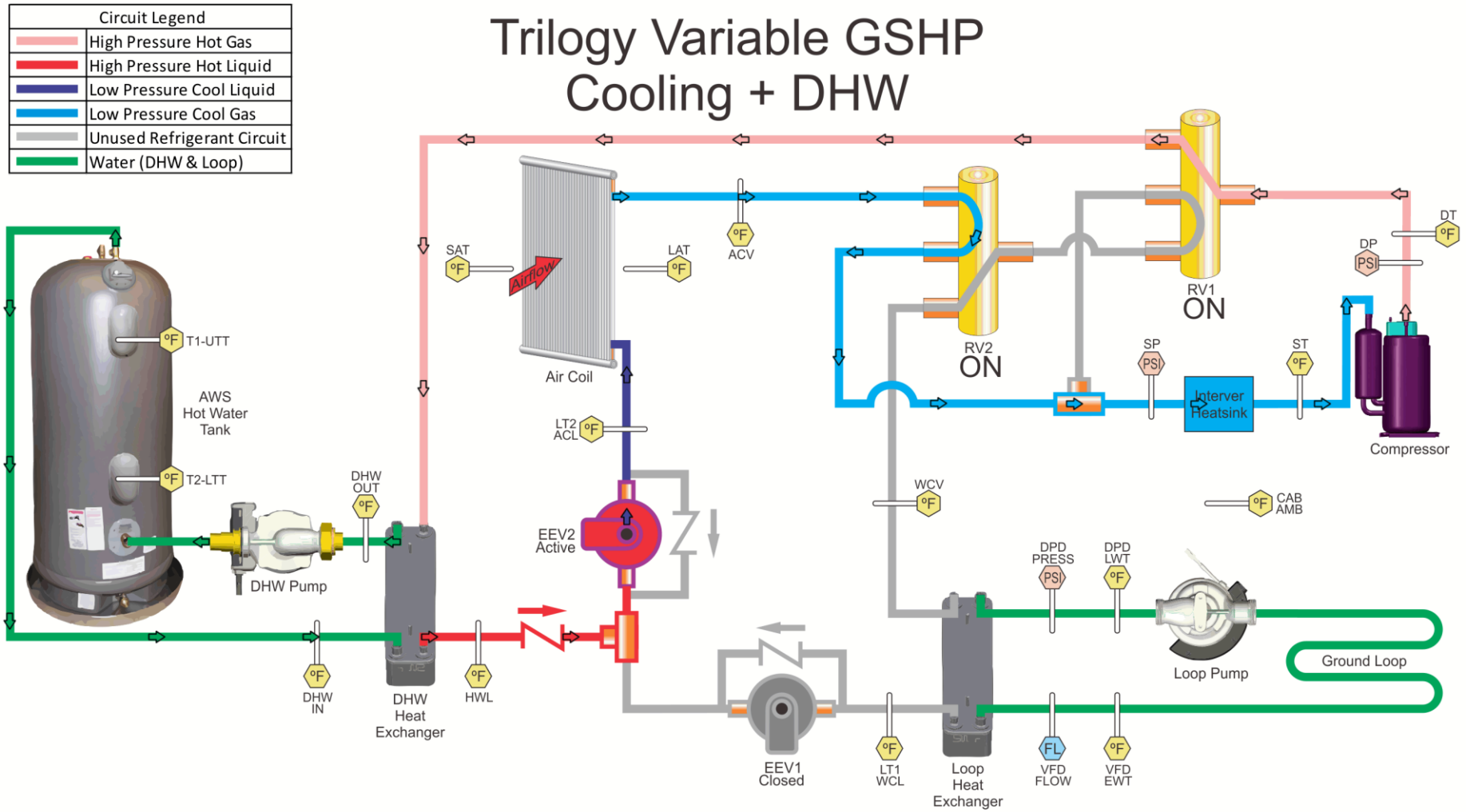
GS-IHP System description

- Variable speed (VS) WSHP utilizing a unique refrigerant circuit to reliably allow 4 modes of operation:
  - Space heating (SH)
  - Space cooling (SC)
  - Space cooling + domestic water heating (SC+WH)
  - Dedicated domestic water heating (WH)
- VS compressor allows 1) constant WH output regardless of ground temp. and 2) a “boost” WH capacity mode when the SH demand is high to decrease the tank recovery time.
  - WH has priority unless space temp. falls below min. limit in winter

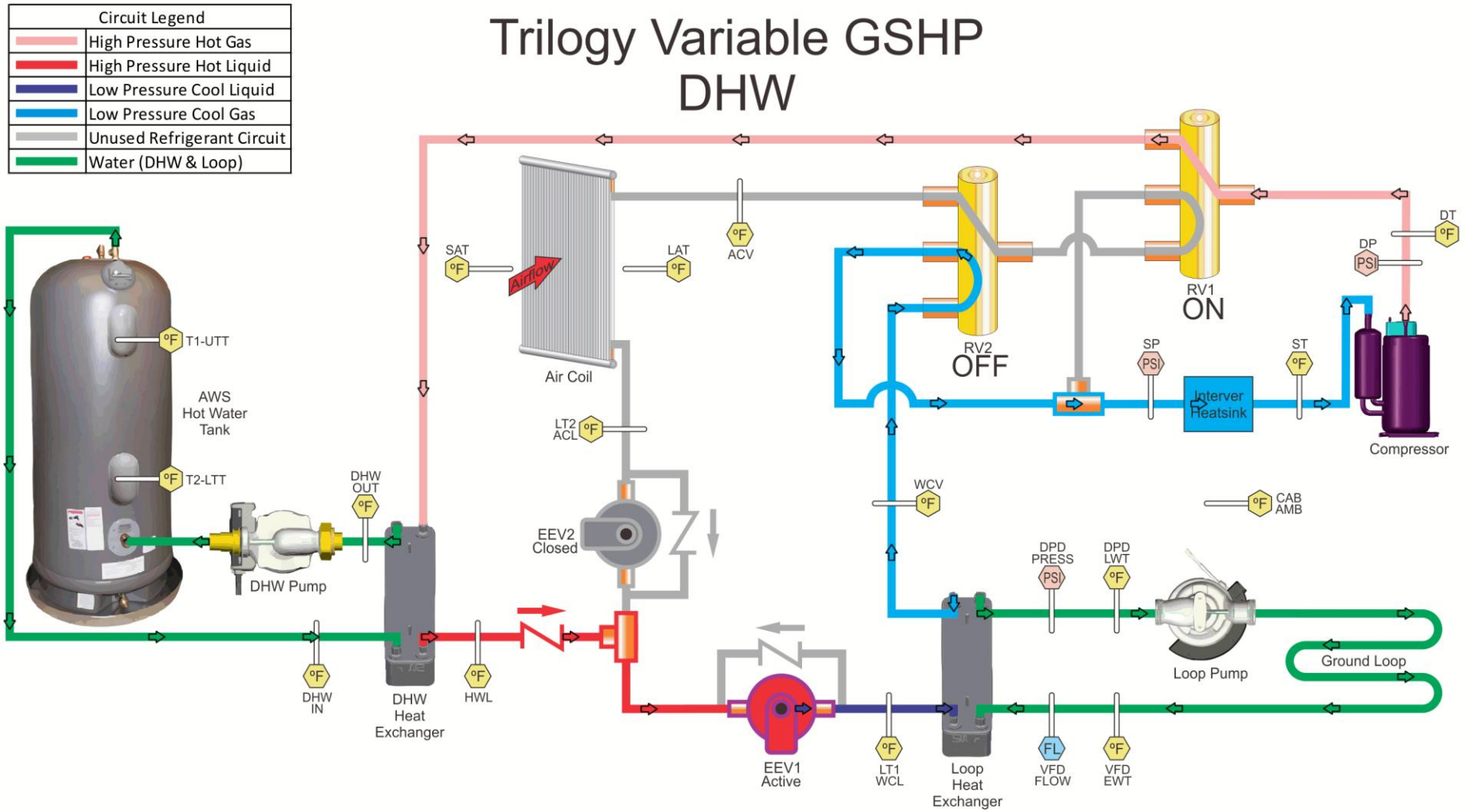
GS-IHP System description

- The packaged system includes a customized version of a commercially available water storage tank and integral system control board
  - electric elements used for backup or emergency WH
- Communications between controller, WSHP, and storage tank
  - monitors set points, space, tank water, and loop temperatures, and operation modes for optimal system and comfort control
    - lower tank temperature controls heat pump WH operation
    - upper tank temperature controls upper element backup operation
- Large 1-1/4” hot water injection port below lower element reduces tank mixing to acceptable levels.

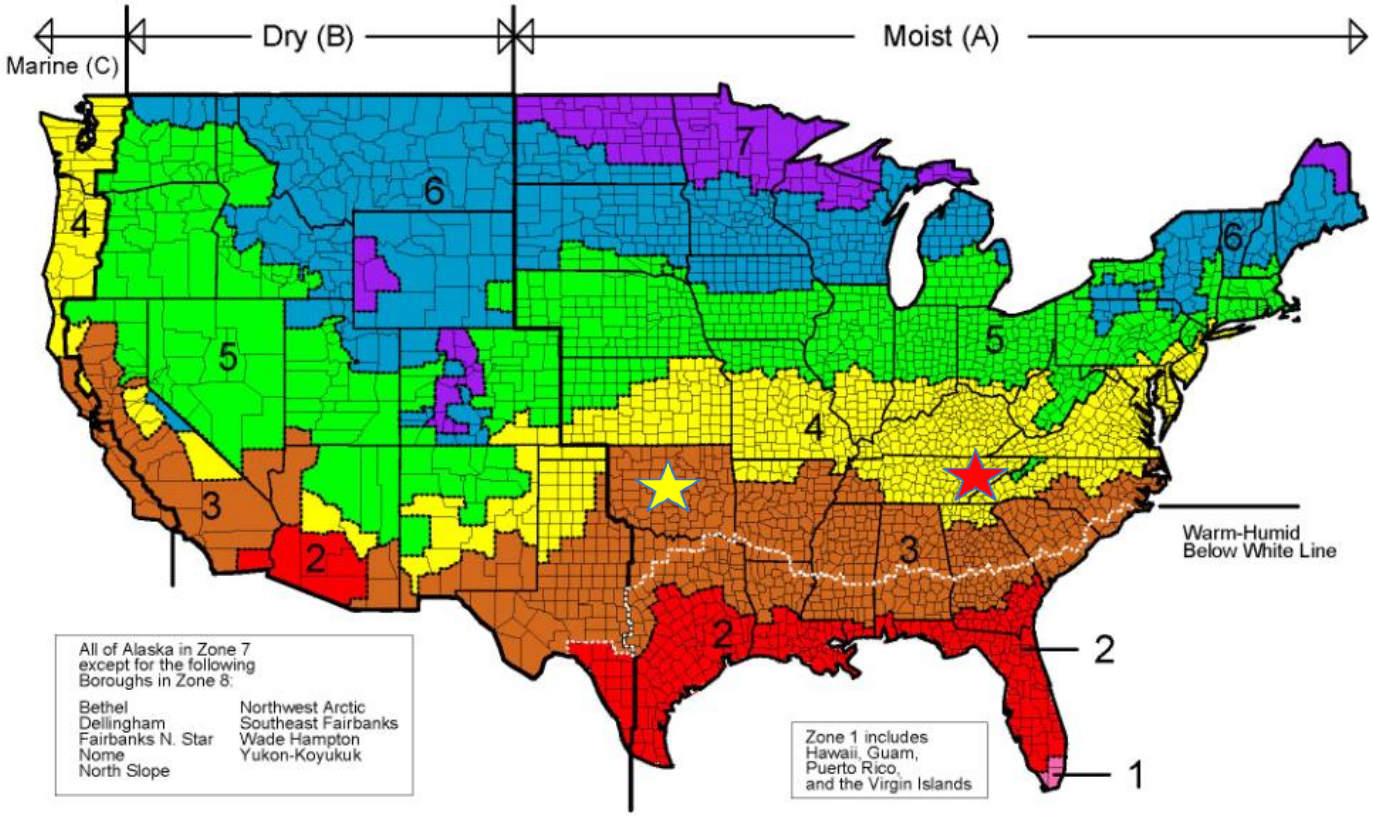
GS-IHP Schematic: SC+WH mode



GS-IHP Schematic: WH only mode



Field Test Sites



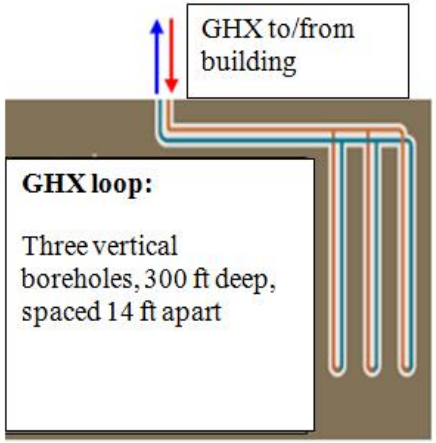
Knoxville, TN
Day care center
Kitchen

Oklahoma City, OK
Homeless shelter
dormitory

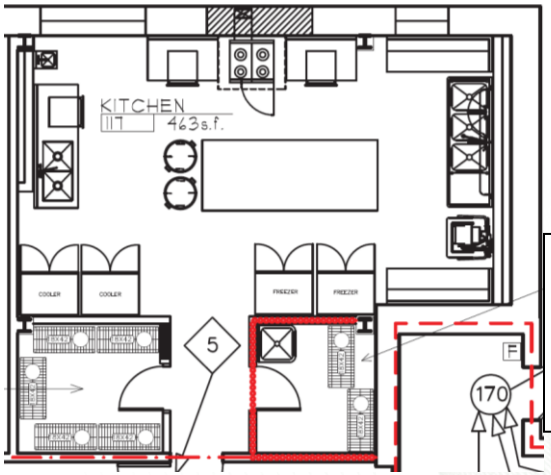
OAK RIDGE National Laboratory

Field Test Sites

Knoxville, TN
Day care center
Kitchen
Aerial view
(Photo courtesy
Google Maps)



Kitchen area layout

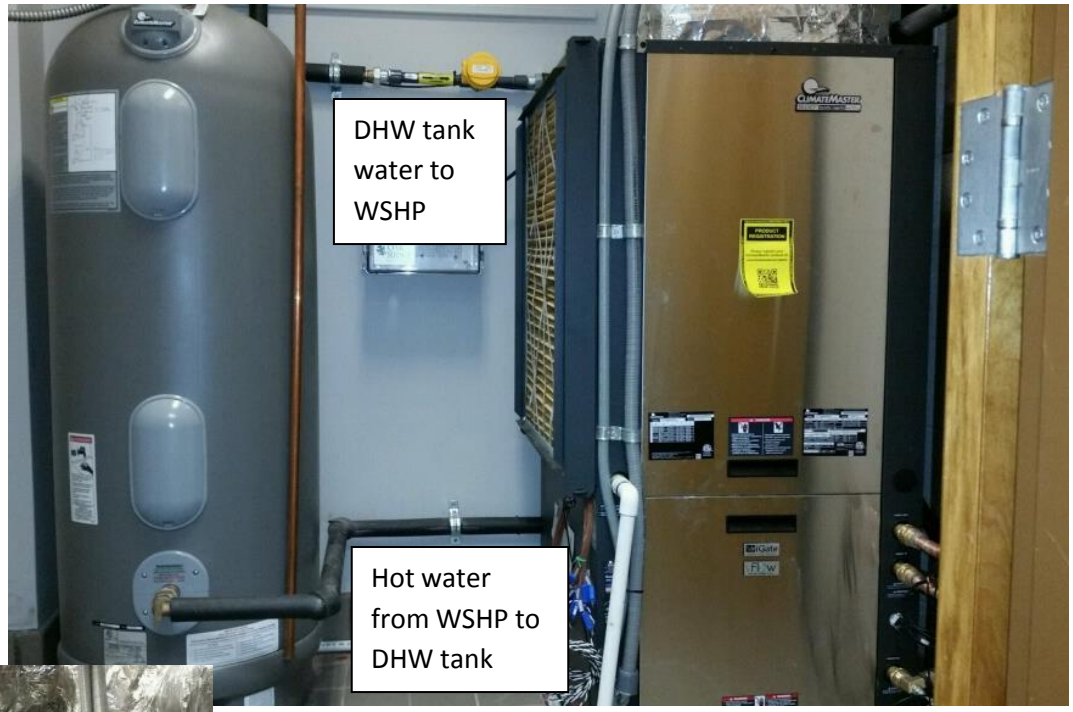


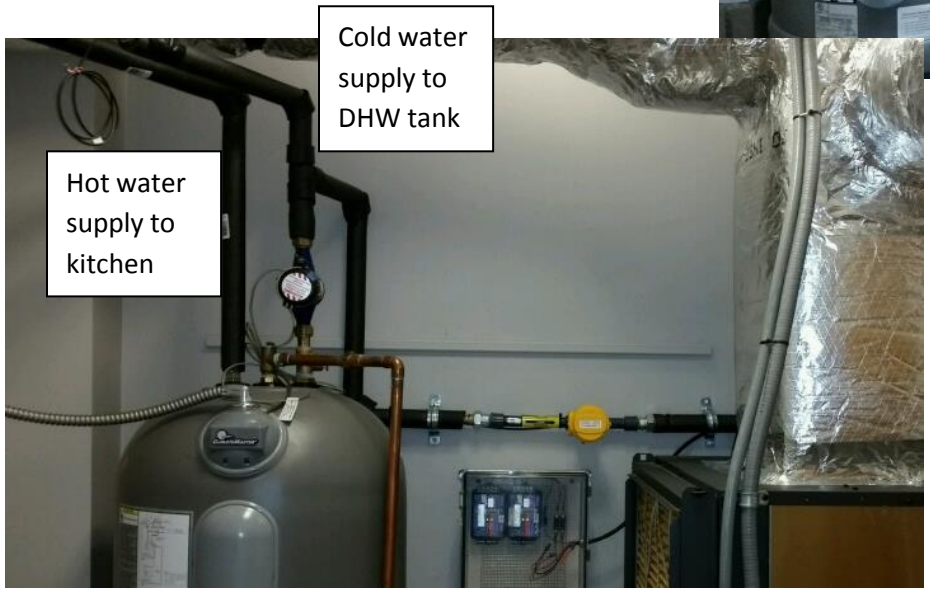
WSHP and
WH tank
location

OAK RIDGE National Laboratory

Field Test Sites

Knoxville, TN
Day care center
Test system installation

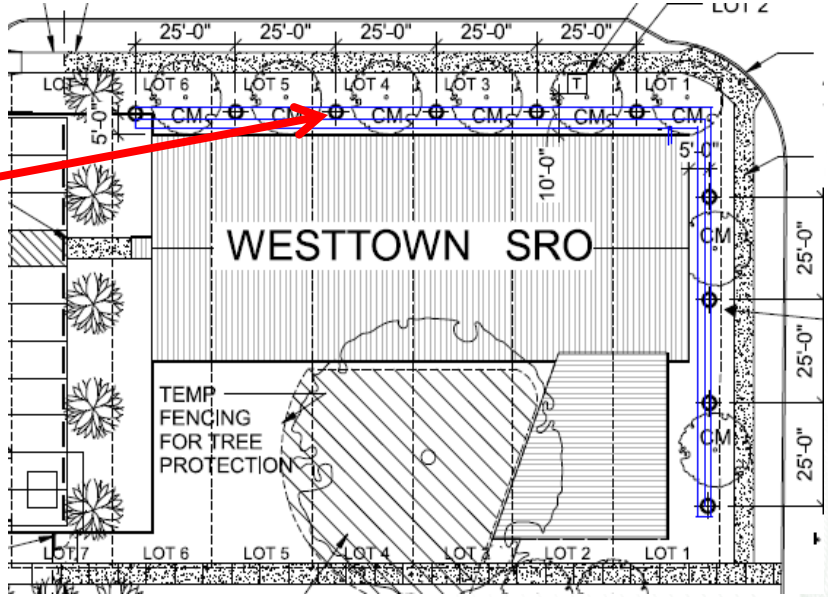




Field Test Sites

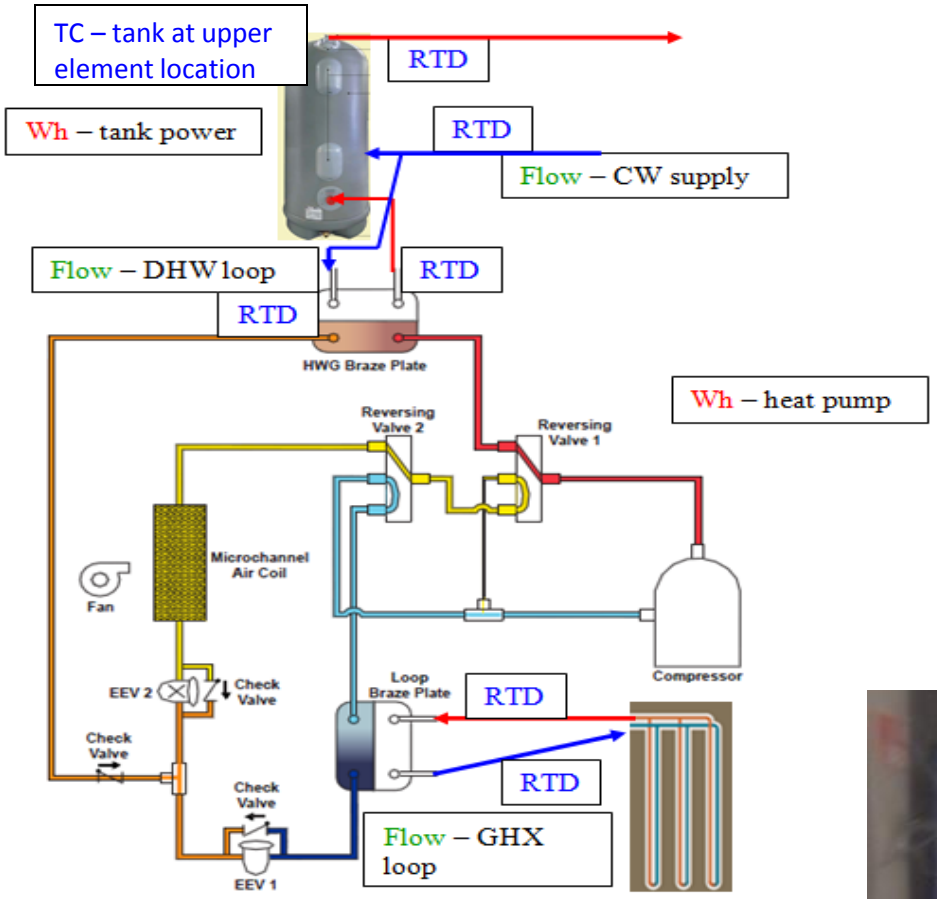
Oklahoma City, OK
Homeless shelter dormitory
Two GS-IHP units each serving 10 dormitory units of 250 ft^2 each
Two other non-integrated GSHPs serving building common areas and offices

GHX – ten vertical boreholes, each 500 ft. deep and 25 ft. apart

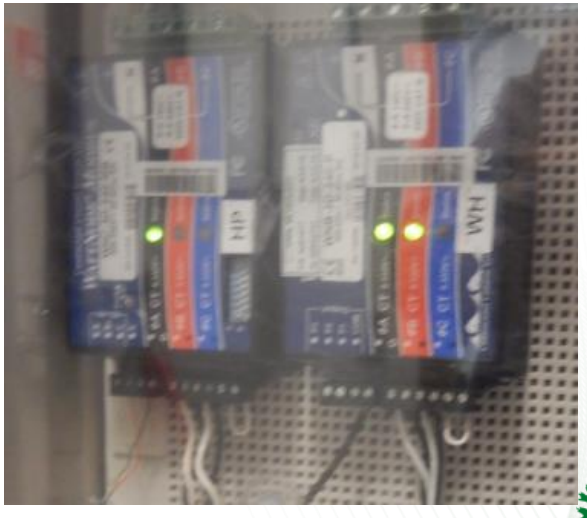


OAK RIDGE National Laboratory

Field Test Monitoring Approach



Data logger @ Knoxville site



WH meters @ Knoxville site

Sensor locations
- Monitoring start August 2015 at Knoxville
- Monitoring start late January 2016 at OKCity

Field Test Data Analysis Approach

Space cooling delivered (SC Mode)

$$Q_{SC} = V_{GroundLoop}\rho_{GroundLoop}c_{GroundLoop}(LWT - EWT) - W_{IHP}$$

Space cooling delivered (SC +WH Mode)

$$Q_{SC} = Q_{WH,IHP} - W_{IHP}$$

Space heating delivered

$$Q_{SH} = V_{GroundLoop}\rho_{GroundLoop}c_{GroundLoop}(EWT - LWT) + W_{IHP}$$

Water heating delivered by IHP

$$Q_{WH,IHP} = V_{DHWLoop}\rho_{DHWLoop}c_{DHWLoop}(LDHWT - EDHWT)$$

Water heating delivered to building

$$Q_{WH} = V_{Hot}\rho_{Hot}c_{Hot}(T_{Hot}{}^{1} - T_{Cold})$$

[1] Due to the numerous small volume hot water draws and the response time of the hot water temperature sensor, T_{Hot} was taken to be the tank temperature measured at the upper element.

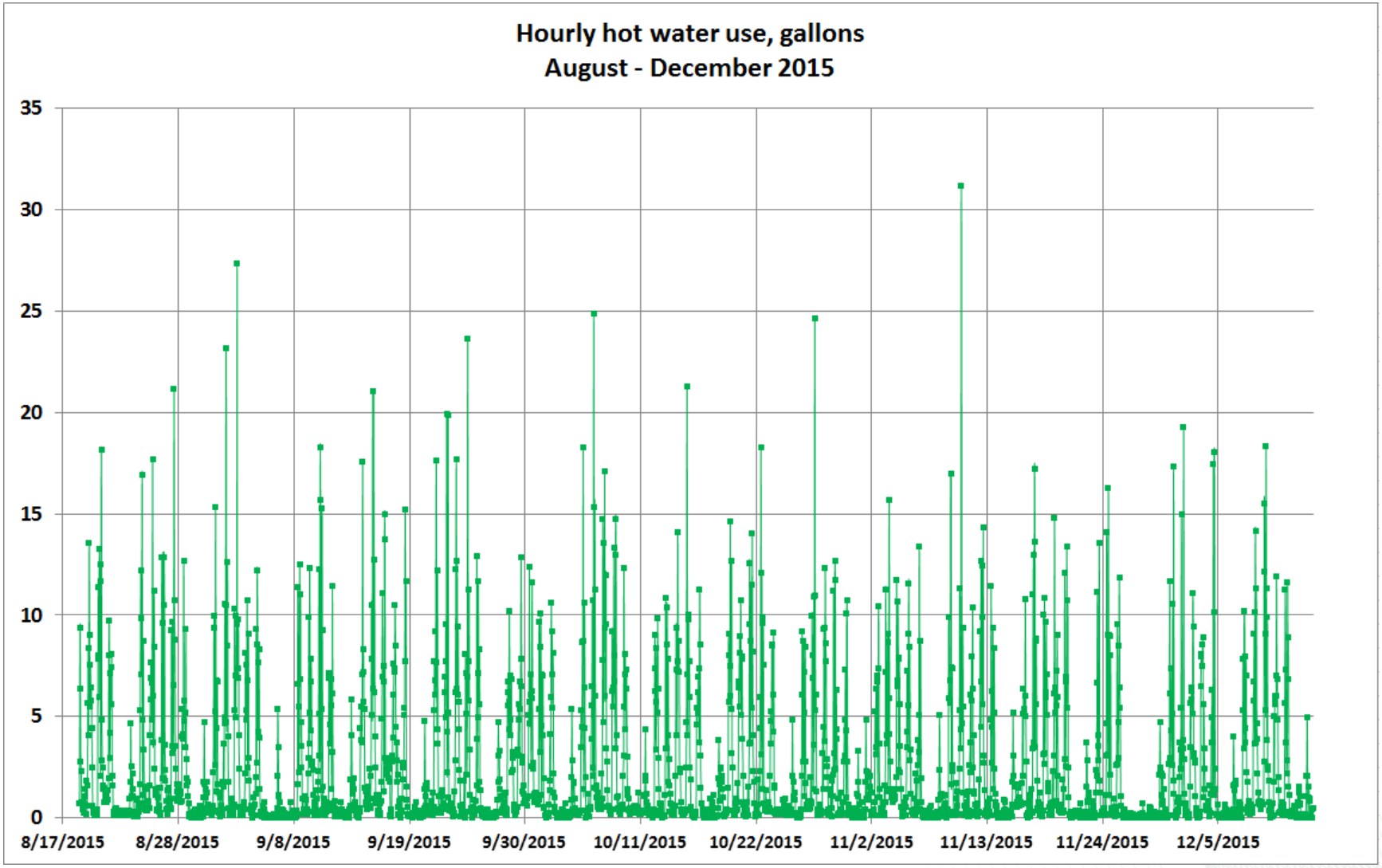
NOTE --
Simulated performance of baseline RTU/heat pump + electric storage WH system operating under same delivered loads and indoor/outdoor conditions as GS-IHP for energy savings estimation

GS-IHP Field Test Unit vs. Baseline
performance ratings

Parameters	GS-IHP	Baseline RTU/WH
Cooling capacity (Btu/h)	18,000 (min speed, 68F EWT)[a] 48,000 (max speed, 77F EWT)[a]	48,000 @ 95F[b]
Cooling EER	45.1 (min speed, 68F EWT)[a] 21.6 (max speed, 77F EWT)[a]	11.4 @ 95F[b]
Cooling SEER	na	13.0[b]
Heating capacity (Btu/h)	24,000 (min speed, 41F EWT)[a] 60,000 (max speed, 32F EWT)[a]	45,000 @ 47F[b] 28,000 @ 17F[b]
Heating COP	5.1 (min speed, 41F EWT)[a] 3.3 (max speed, 32F EWT)[a]	3.05 @ 47F[b] 2.26 @ 17F[b]
WH capacity (kW)	~8.2-11.7 for 110F HW entering & 35-80F EWT	4.5
WH COP (or EF)	~2.5-5.0	1.00 (0.94 EF)
SC+WH combined EER	Up to 30 (min speed) Up to 19 (max speed) 110 F entering HW	na

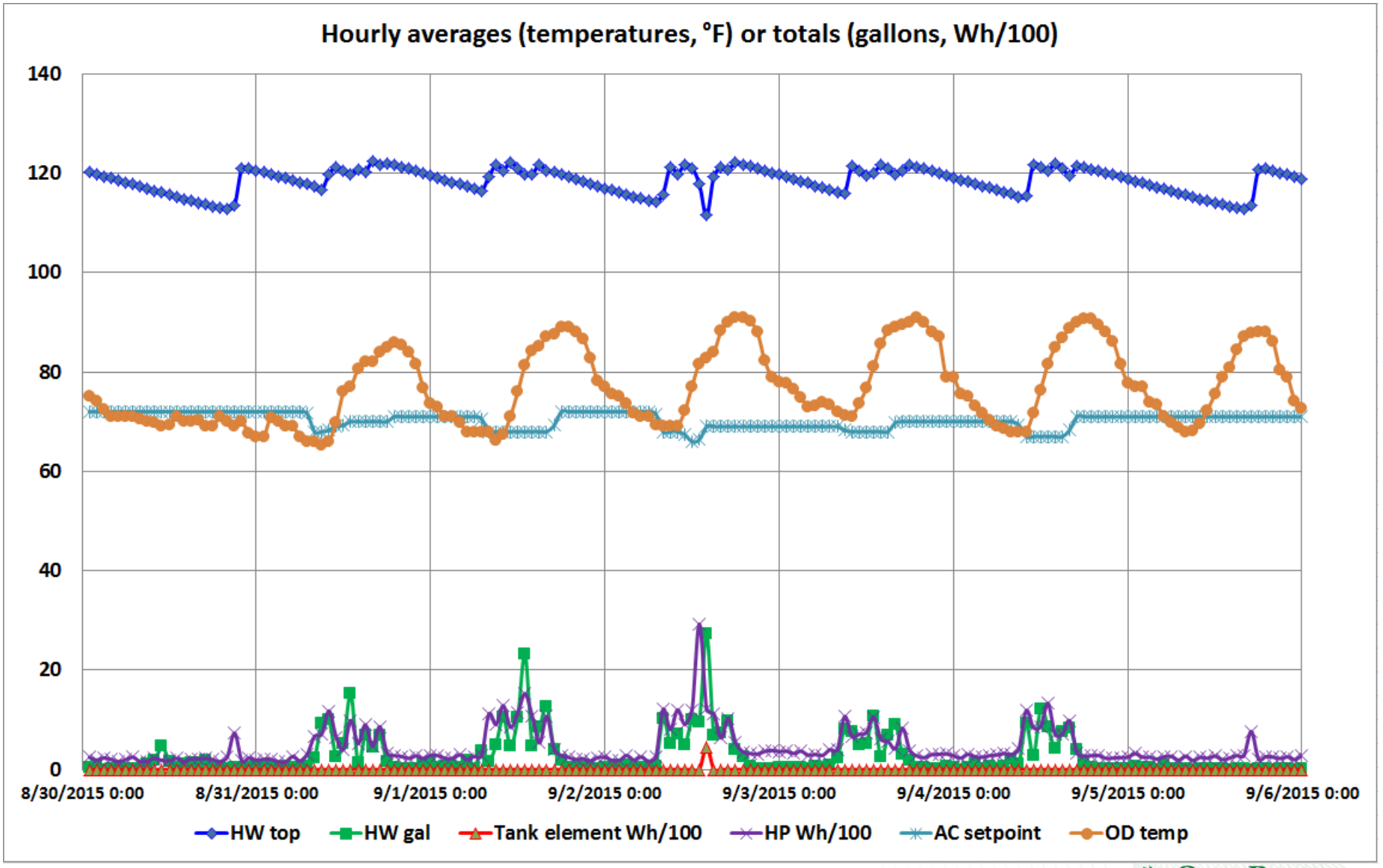
[a]Ratings per ANSI/AHRI/ASHRAE/ISO 13256-1; water source heat pumps;
EWT → entering ground HX fluid temperature
[b]Ratings per ANSI/AHRI 210/240; air source heat pumps

Kitchen WH demand profile



- Full season WH demand profile
  - operating hours: ~7-5, 5 days/week

GS-IHP system energy and HW use for week of 8/30-9/5/2015



GS-IHP Field Test Unit vs. Baseline
August-December field performance, Knoxville

Parameters	GS-IHP (measured)	Baseline RTU/WH (estimated)
Total space cooling (SC) delivered, kWh	5943	5943
SC energy use, KWh (GS-IHP savings vs. baseline)	766 (44.6%)	1382
Average SC COP	7.75[a]	4.30
Total space heating delivered, kWh	0.0	0.0
Water heating (WH)		
WH from heat pump to tank, kWh	863	--
WH del. to kitchen, kWh (gal.)	703 (~6700)	703 (~6700)
GS-IHP tank backup, kWh	0.8	--
Total WH energy use, kWh (GS-IHP savings vs. baseline)	197 (73.7%)	748
Average WH COP or EF	3.57[b]	0.94
Total system energy use (savings %)	1011 (53.6%)	2178 (--)
Carbon eq. emissions (MT)	0.7	1.5

[a]Combined value for SC only and SC+WH modes
[b]Combined value for WH only and SC+WH modes; based on WH delivered to kitchen

GS-IHP Field Test Unit vs. Baseline
August-December monthly avg. hourly peak kW

Month	GS-IHP (% reduction for GS-IHP)	Baseline RTU/HP + WH (estimated)
August 18-31	1.705 (58.9%)	4.153
September 1-30	2.923 (32.9%)	4.357
October 1-31	1.642 (57.4%)	3.851
November 1-30	1.888 (59.0%)	4.609
December 1-14	1.531 (57.5%)	3.606
Total period maximum peak demand	2.923	4.609

Peaks generally occurred in early afternoon
Noon-1pm or 1-2pm

GS-IHP Field Test Unit vs. Baseline

Total energy cost savings for August 18 - December 14 test period (based on local utility rate structure)

	GS-IHP	Baseline RTU/HP + WH
Electricity consumption	$118	$254
Electricity demand	$131	$277
Total costs	$249	$531
Energy cost savings vs. baseline	$282 (53.1%)	--

Summary

- GS-IHP system demonstrated ~54% energy savings vs. simulated RTU/heat pump + electric storage WH baseline system meeting same loads at the Knoxville test location
- up to ~60% monthly hourly peak kW reduction vs. base RTU/WH
- Energy cost savings of ~53% for GS-IHP
  - More than half from demand cost reduction
- Field demonstration to continue through August 2016 with data from both sites
  - Final report will include cost/payback analysis

Questions?

Shawn Hern – shern@climatemaster.com

WSHP website:
http://www.climatemaster.com/residential/climatemaster-trilogy-45-mode-series-heat-pump/

Van Baxter – vdb@ornl.gov