Demonstration of Pre-commercial Gas HPWHs for Hot Water & A/C at Full Service Restaurants

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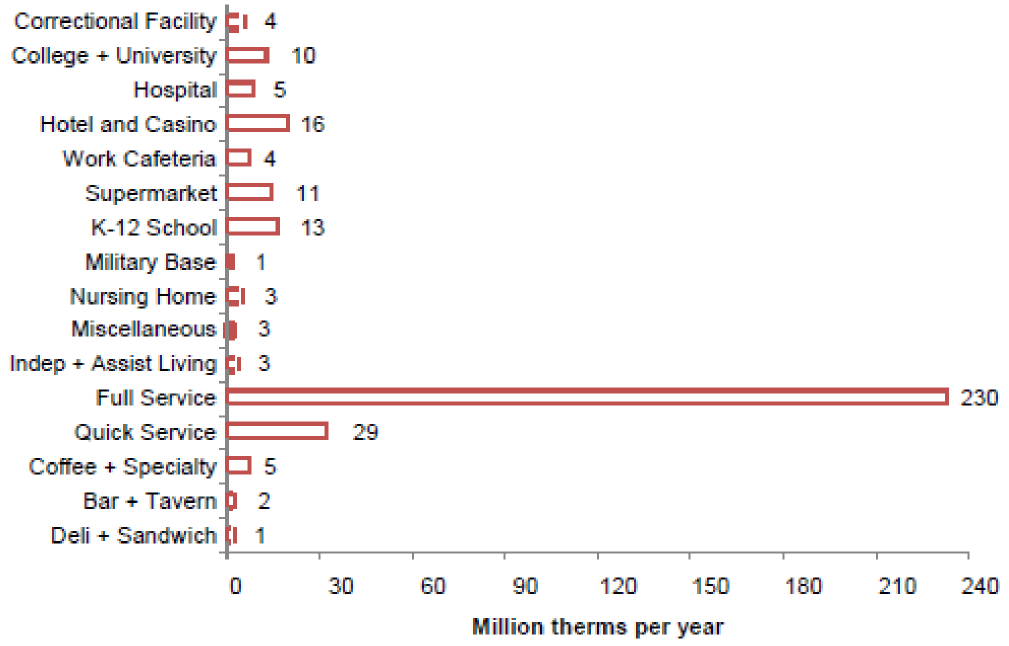
Presentation Outline

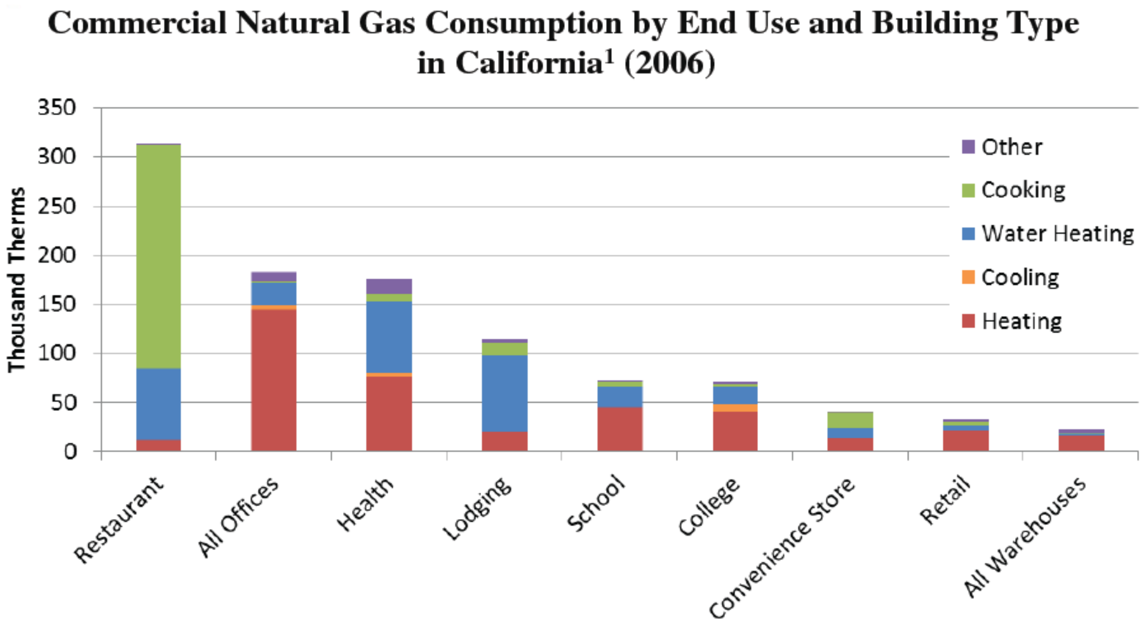
- > Motivation for Commercial Gas HPWH
- > Integrated Commercial GHPWH System Concept
- > Demonstration Sites and Associated Challenges and Opportunities
- > Field Demonstration Research Questions
- > Field Demonstration: Integrated GHP System Design
- > Field Demonstration Measurements
- > Demonstration Sites Baseline Data
- > Next Steps

Motivation – Commercial Water Heating

- Large commercial gas load, big opportunity for savings – particularly **restaurants**
  - Just like rest of USA, California's 88,000 restaurants consume more therms/ft^2 than any other building type



Source: Delagah, A. and Fisher, D. (2013) Energy Efficiency Potential of Gas-Fired Commercial Water Heating Equipment in Foodservice Facilities, Report prepared by FNI for the CEC, CEC-500-2013-050.



Adapted from: DNV Kema, "California Energy Commission Energy Efficient Natural Gas Use in Buildings Roadmap", public presentation (2013).

Motivation – Commercial Water Heating

Basing a Hybrid GHP System for Service Hot Water (SHW) and A/C on a low-cost GAHP has following projected benefits:

- **Efficiency:** With projected 140% AFUE, GAHP system may yield therm savings of up to 45%, with 4:1 modulation for efficient part load operation.
- **Reliability:** GAHP's themselves do not require backup heating, can continue operation without interruption during defrost. Pre-commercial units have gathered 1,000's of hours collectively in multiple states (over multiple size ranges).
- **Emissions/Safety:** AQMD compliant, NOx and GHG emissions are decreased by up to half and all combustion occurs outdoors
- **Climate:** Natural refrigerant/absorbent pairs with 0.0 GWP/ODP
- **Zero Net Energy:** With greater benefit in colder climates, GAHP's can reduce source energy burden in mixed, lower cost ZNE buildings

Motivation – Commercial Gas HPWH

Restaurant applications of GHP’s may be lowest-hanging fruit:

> Hot water-intensive applications, like FSR’s (2,000 gal/day)

> CA mild climate, with high fraction of gas products

> Strong promotion of energy efficiency, new technologies

> Option to utilize ‘free-cooling’ a significant bonus

But GHP’s for commercial hot water already exist, where are they?

> Engine-driven vapor compression products available, though large (400-600 MBH / 117-175 kW) but able to meet NOx with aftertreatment system

> Gas-fired absorption products from overseas, down to 140 MBH / 41 kW

Issue is high equipment cost!

Integrated GHP System Overview

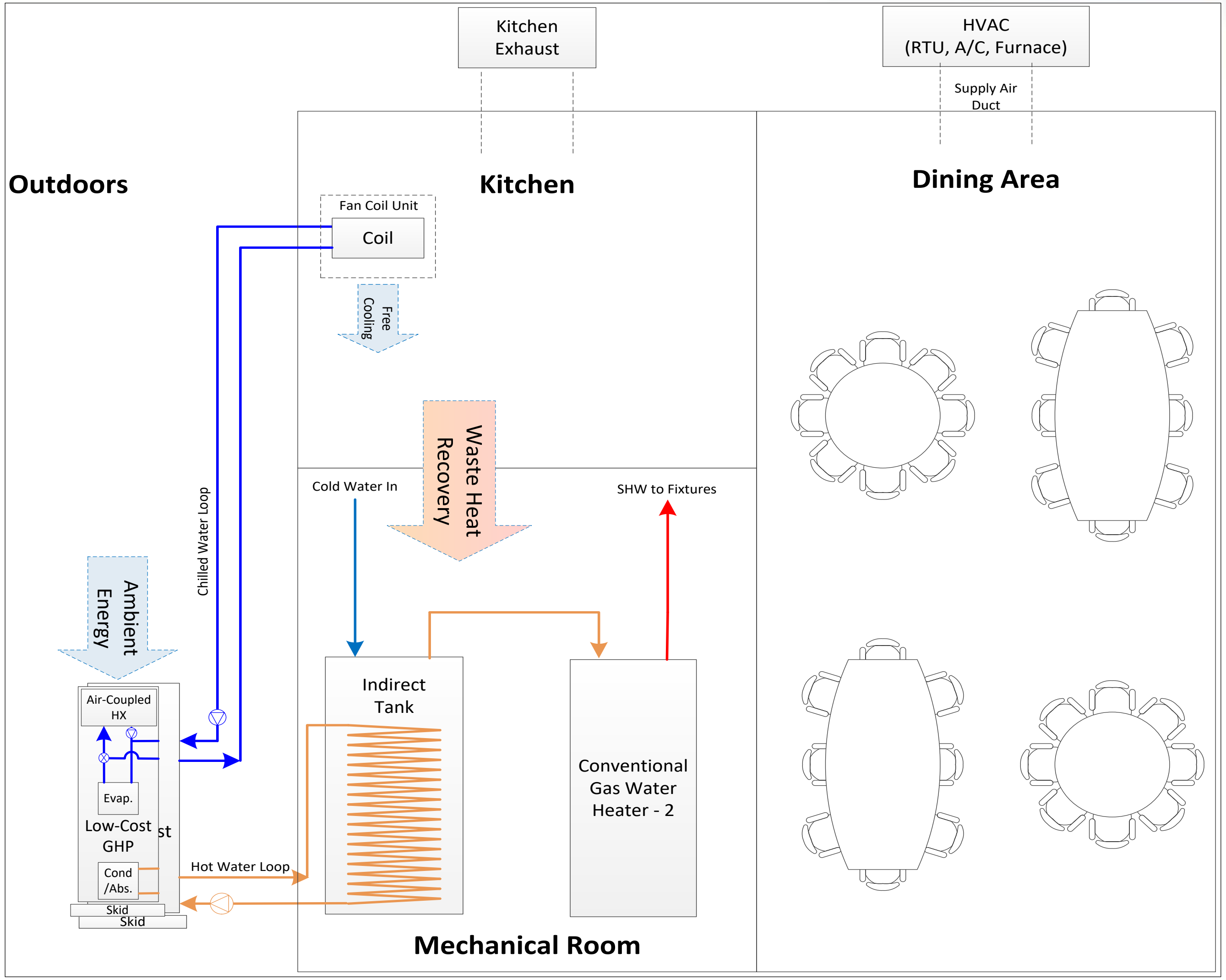
- Direct-fired NH3-H2O single-effect absorption cycle integrated heat recovery.
- Can link with a hydronic air handler for forced-air space heating and indirect-fired storage tank for commercial water heating.

	GAHP	Units/Notes
Heat Pump Output	80,000	Btu/hr with 4:1 modulation
Firing Rate	54,000	Btu/hr
Target Efficiency	COP > 1.4 at 47°F 140% AFUE	Based on GTI lab testing
Emissions	< 14 ng NO_x/J	SCAQMD Rule 1146.2 Certified
Installation	Outdoors	Like boiler, integration with space heating feasible too
Venting	N/A	Outdoors
Gas Piping	3/4”	
Refrigerant Charge	< 0.2	kg/kW heating
	0.0 ODP, 0.0 GWP	
Estimated Unit Cost	Competitive with condensing boilers, $5,000	

Integrated GHP System Overview

System Concept:

- Restaurants commonly have large service hot water (SHW) loads, 1,500 gal/day or greater
- With large internal loads from cooking/equipment, A/C load is also significant, year-round
- GHP split of heating output and "free" cooling, 2-2.5:1, can mesh nicely with restaurant loads



Field Demonstration: Integrated GHP System Design

<u>“Skidding” the GHP System</u>

- Factory assembled, plumbed
- 80 kBtu/hr GAHP
- 113 gallon indirect storage tank
- Skid dimensions:

  48” x 96” x 74” (W x L x H)
- Outdoor installation, ease of installation/removal

Field Demonstration: Integrated GHP System Design

Elements of System Design

- Key components: GHP, storage tank, hydronic cooling coil, conventional backup gas heater, and controls
- With knowledge of site constraints, estimated loads, and prior testing of GHP prototypes, team:
  - Completed design of GHP
  - Finalizing selection of tanks/coils for each site
  - Developed specification for system controls

Field Demonstration: Integrated GHP System Design

System is *Hot Water-Led*, activation of indoor cooling coil depends on SHW loads

Preliminary Control Strategy is:

1. **Chilled Water Circulator control**
    - The circulator pump will be controlled by the GHP PLC via a relay (24V)
    - The relay will open/close the circuit that powers the circulator pump
2. **Fan Coil Unit Fan Control**
    - 24V thermostat wire via DAS relay will control FCU's fan.
3. **If there is a call for cooling and GHP is cycling on,**
    - Unit PLC turns on ChW pump
        - Based on chilled water inlet to FCU set points the DAS turns on and off the fan
    - If thermostat signal from DAS stops cooling in the middle of GHP cycle
      Then GHP switches over to outdoor HX
4. **If there is no call for cooling while the GHP is cycling on**
    - Flow is directed from hydronically-coupled evaporator to air-coupled HX

Field Demonstration: Site #1, 24 Hour Diner

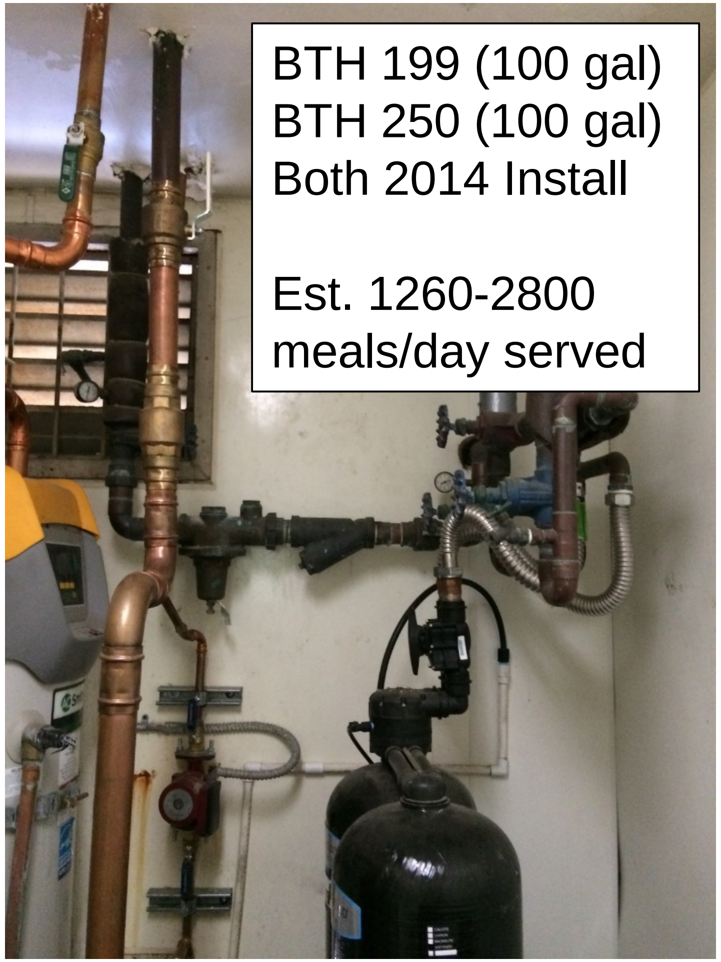
Existing Equipment:

- Water Heating: Two BW Storage GWHs; 100 gal/270 kBtu/hr input each; 82% TE and atm. venting
  - Both set to 140 F, 180 F booster at dishmachine

Estimate of SHW Load

- Mgr estimates 1400 meals/day (Sa/Su), 900 meals/day (M-Th), and 1200 meals/day (F) – all above 600.
  - Peak servers are 9 at one time, 190 max guests

Field Demonstration: Site #2, Casual Chain Restaurant

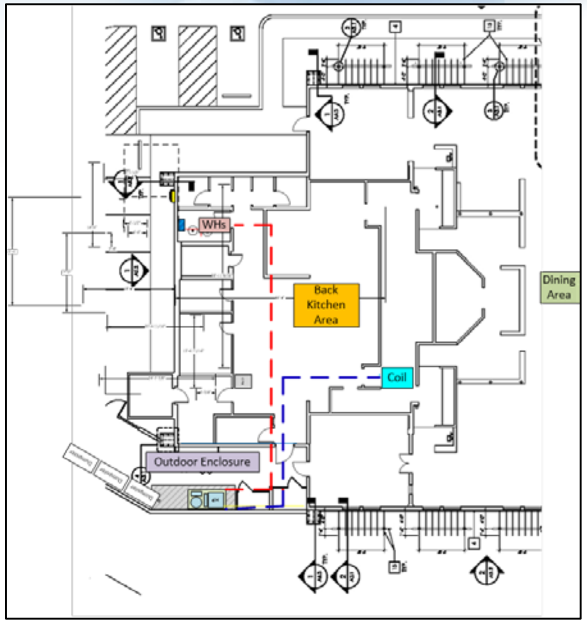


BTH 199 (100 gal)
BTH 250 (100 gal)
Both 2014 Install

Est. 1260-2800 meals/day served

Challenges in Installation

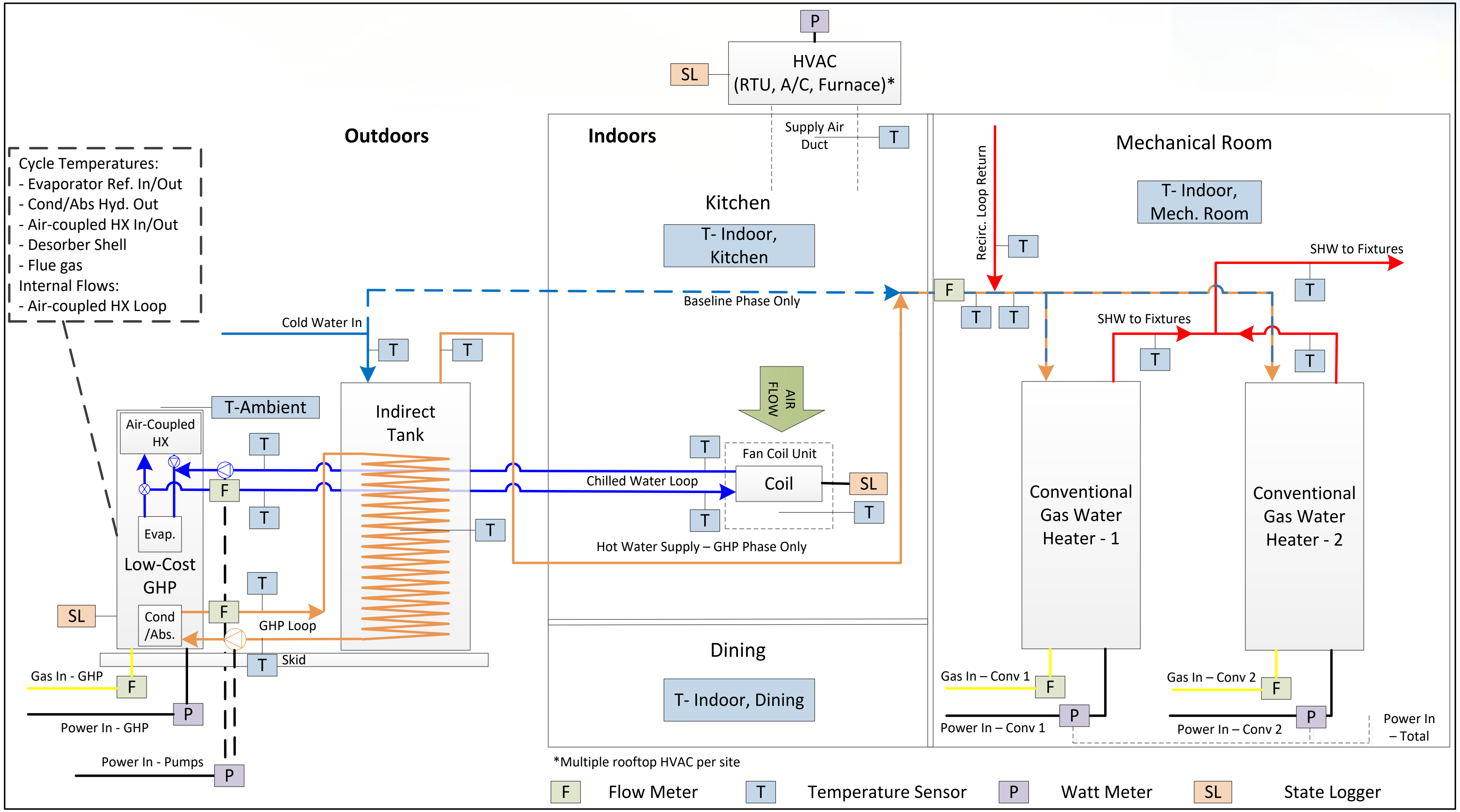
- Limited hours for installation
- Location limitations for skid:
  - Through traffic and loading/unloading of supplies
  - GHP access requirement for maintenance, emergency disconnect
  - Location for GHP not suitable in parking lot
    - would require additional permits
    - would block unloading area
- Crowded and limited roof-space
- Long pipe run requirements – introduces potential leaks, material and labor expenses.
- Anti-theft skid requirements and cost
- Fan Coil unit:
  - Expensive
  - Not readily available



Field Demonstration: Research Questions

- Key metrics measured and estimated are:
  - Heat Pump/System Coefficient of Performance
  - Heat Pump Capacity and other cycle properties
  - Evaporator Superheat and Desorber Shell Temperatures over cycles
- Under installed conditions in the Los Angeles Basin, how do the low-cost GHP delivered efficiencies and system COP's vary with hot water usage patterns, A/C loading, operating conditions, and installation type?
- What therm savings can California IOUs anticipate from this new technology?
- How do these compare to competing gas/electric commercial water heating technologies, with and without supplemental cooling?
- What retrofit installation issues present barriers to market adoption
- What are the benefits over existing high-efficiency gas-fired water and HVAC equipment?

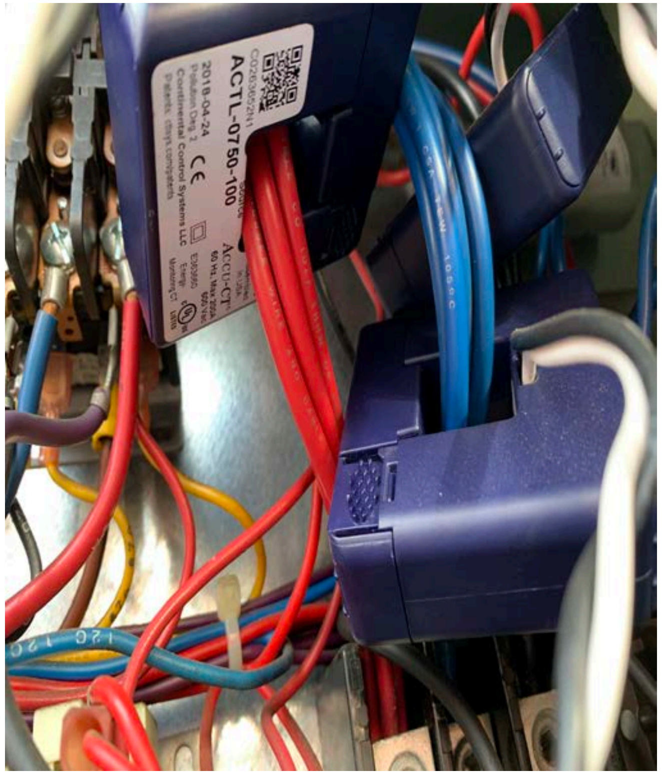
Field Demonstration: Continuous Measurements

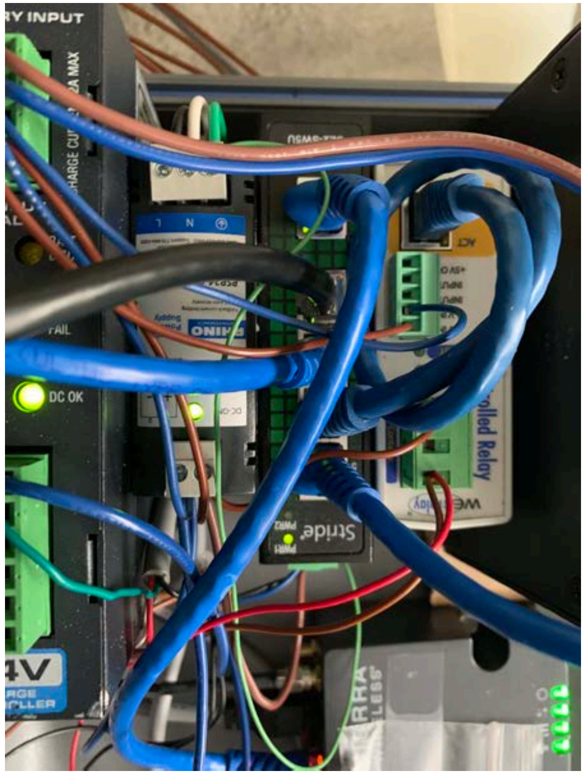


Continuous Measurement Points – Overview

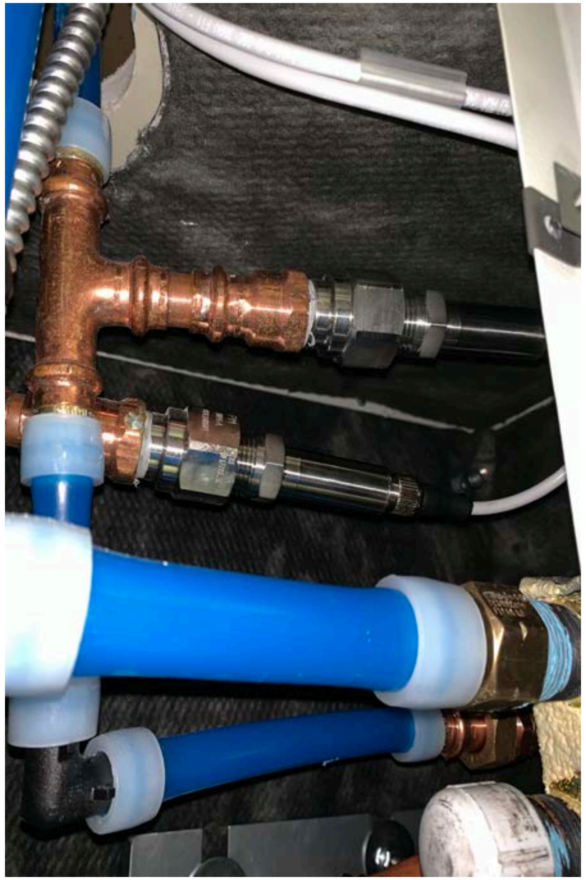
Measurement	Method	Accuracy	Measurement Point - Baseline*	Measurement Point – Int. GHP System
Natural Gas Input	Positive displacement diaphragm meter with integrated pulser	±1%, Temperature Compensated	- Conv. Gas Water Heater(s)	- Conv. Gas Water Heater(s) - GHP
Electricity Input	True RMS power transducer with split core current transformers (CT)	±0.5% (Meter), ±0.75% (CT)	- Conv. Gas Water Heater(s) - Existing HVAC	- Conv. Gas Water Heater(s) - Existing HVAC - GHP Skid/Pump
Water Flow	In-line turbine flow meter with pulse output	Resolution of 0.025 gallons	- SHW Output	- SHW Output
Recirculating Loop Flow	Vortex-shedding flow meter, magnetic-inductive flow meter, or in-line turbine flow meter	±2% of range or better, effectively ±0.5 GPM or better	N/A	- ChW Loop - GHP Loop
Water Temperature (Hot/Cold)	Thermocouple Type T	±0.9 °F	- Inlet/Outlet to Conv. Gas Water Heater(s)	- Inlet/Outlet to Conv. Gas Water Heater(s) and Indirect Tank - Chilled Water Loop Supply/Return @ Indoor Cooling Coil
Water Temperature (Hot/Cold)	RTD sensor	± 0.81 °F	N/A	- GHP Loop Supply/Return, two per loop - Chilled Water Loop Supply/Return @ GHP
Air Temperature	Thermocouple Type T	±1.5°F	- Indoors – Kitchen, Mechanical Room - HVAC Supply	- Indoors - Kitchen, Mechanical Room - HVAC Supply - Indoor Cooling Coil Supply - Ambient at GHP
Ambient Weather Condition	Publicly Accessible Weather Station	N/A	- Outdoors	- Outdoors
Equipment Runtime	Dry contact	N/A	- Existing HVAC	- Existing HVAC - Indoor Cooling Coil - GHP

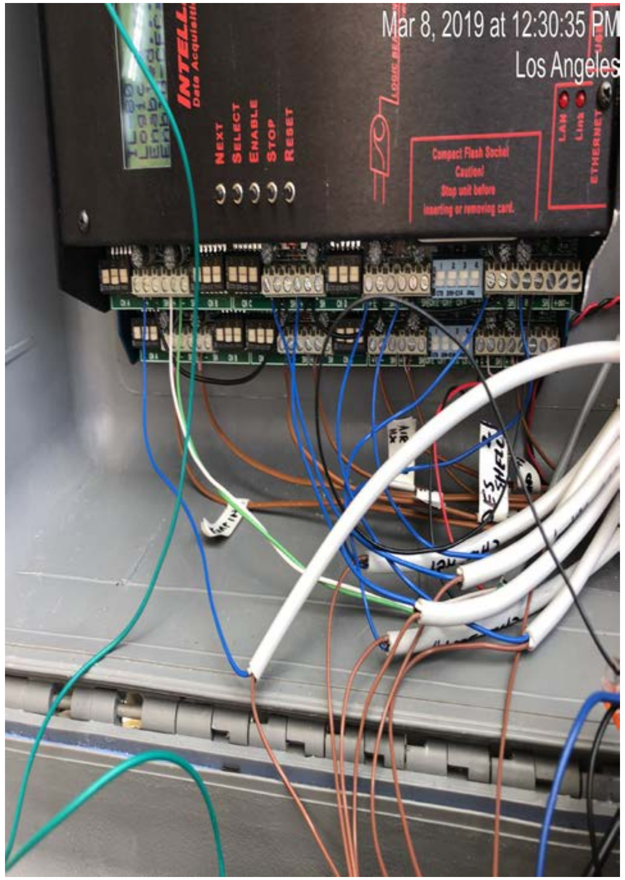
Continuous Measurement Points – Overview





Continuous Measurement Points – Overview





Continuous Measurement Points – Overview

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Current Probe Point Values

START automatic refresh of values every 10 seconds.

STOP automatic refresh of values.

Probe Point Name	Value	Units	Date and Time Measured
DI_A GAHP Gas	1.575	CF	03/04/2019 15:50:40
Gas Min	1.2	CF	03/04/2019 15:50:16
Gas Max	1.425	CF	03/04/2019 15:50:16
GAHP Gas Rate	13.499994	CF	03/04/2019 15:50:16
Firing Rate	18702.003906	CFH	03/04/2019 15:50:16
Hydronic Pump Power	142.5	W	03/04/2019 15:50:16
CHW Pump Power	0	W	03/04/2019 15:50:16
1G_Gas Valve Runtime	1		03/04/2019 15:50:40
0A_Skid SHW Out	110.178078	F	03/04/2019 15:50:40
DI_C GAHP Hyd Pump	16	wh	03/04/2019 15:50:40
DI_B GAHP Total Pwr	51	wh	03/04/2019 15:50:40
DI_D GAHP CHW Pump	0	wh	03/04/2019 15:50:40
AI_B CHW Flow Rate	-0.007168	gpm	03/04/2019 15:50:40
AI_A Hyd Flow Rate	8.323036	gpm	03/04/2019 15:50:40
1H_Flue Gas	210.365601	'F	03/04/2019 15:50:40
1F_Outdoor Evap	63.23159	'F	03/04/2019 15:50:40
1D_GAHP RHX In	107.749832	'F	03/04/2019 15:50:40
1E_GAHP RHX Out	67.00975	'F	03/04/2019 15:50:40
1C_Desorber Shell	201.324921	'F	03/04/2019 15:50:40
1B_Evap Out	58.104088	'F	03/04/2019 15:50:40
0B_Mid Tank	116.601654	F	03/04/2019 15:50:40
0C_Hyd Sup 1	117.615547	F	03/04/2019 15:50:40
0D_Hyd Ret 1	110.590927	F	03/04/2019 15:50:40
0E_Hyd Sup 2	117.490425	F	03/04/2019 15:50:40
0F_Hyd Ret 2	110.672363	F	03/04/2019 15:50:40
0G_Skid CHW Supply	63.432236	F	03/04/2019 15:50:40
0H_Skid CHW Return	61.531265	F	03/04/2019 15:50:40
1G_Voltage	2.552472	V	03/04/2019 15:50:40
1A_Evap In	55.450378	'F	03/04/2019 15:50:40

Home/Status | Current Values & Control | Logge

Current Probe Point Values

START automatic refresh of values every 10 seconds.

STOP automatic refresh of values.

Probe Point Name	Value	Units	Date and Time Measured
AI_B FCU CHW Supply	68.109795	F	03/04/2019 15:52:54
0H_SHW_Tank_Out_2	67.437492	F	03/04/2019 15:52:54
AI_A FCU Supply Air	70.428093	'F	03/04/2019 15:52:54
AI_C FCU CHW Return	67.519958	F	03/04/2019 15:52:54
N-OUT-AMB-T_Temp	66.380005	F	03/04/2019 15:52:54
N-IN-FCU-TRH_Temp	70.141998	F	03/04/2019 15:52:54
N-IN-FCU-TRH_RH	49.599998	%RH	03/04/2019 15:52:54
DI_A GWH 1 Gas	10773.799805	CF	03/04/2019 15:52:54
DI_B GWH 2 Gas	45.599998	CF	03/04/2019 15:52:54
DI_C CWS Water Flow	12269.348633	Gallons	03/04/2019 15:52:54
DI_D GWH1&2 PWR	9546.5	wh	03/04/2019 15:52:54
ILIM-7_0E_MechRoom	80.140182	'F	03/04/2019 15:52:54
ILIM-7_0F_Recirc	124.906334	'F	03/04/2019 15:52:54
ILIM-7_0G_RecircMix	122.78936	'F	03/04/2019 15:52:54
0A_CWS In Temp	120.089035	F	03/04/2019 15:52:54
0B_GWH 1 SHW Temp	135.30188	F	03/04/2019 15:52:54
0C_GWH 2 SHW Temp	93.338867	F	03/04/2019 15:52:54
0D_SHW (GWH1&2) Temp	135.726395	F	03/04/2019 15:52:54
N-OUT-AMB-T_RSSI	-41	db	03/04/2019 15:52:54
N-IN-FCU-TRH_RSSI	-62	db	03/04/2019 15:52:54
N-OUT-HP1-PLS_RSSI	-35	db	03/04/2019 15:51:54
N-OUT-HP2-PLS_RSSI	-23	db	03/04/2019 15:52:54
N-OUT-HP3-PLS_RSSI	-41	db	03/04/2019 15:52:54
N-OUT-HP4-PLS_RSSI	0	db	03/04/2019 15:52:54
N-OUT-HP5-PLS_RSSI	-66	db	03/04/2019 15:52:54
N-OUT-RTU-PLS_RSSI	-40	db	03/04/2019 15:52:54
N-OUT-HP1-DRY_rssi	-36	db	03/04/2019 15:52:54
N-OUT-HP2-DRY_rssi	-27	db	03/04/2019 15:52:54
N-OUT-HP3-DRY_rssi	-63	db	03/04/2019 15:52:54
N-OUT-HP4-DRY_rssi	-71	db	03/04/2019 15:52:54
N-OUT-HP5-DRY_rssi	-76	db	03/04/2019 15:52:54
N-OUT-RTU-DRY1_rssi	-51	db	03/04/2019 15:52:54
N-OUT-AMB-T_Age	394	s	03/04/2019 15:52:54
N-IN-FCU-TRH_Age	393	s	03/04/2019 15:52:54
N-OUT-HP1-PLS_Age	470	s	03/04/2019 15:52:54
N-OUT-HP2-PLS_Age	484	s	03/04/2019 15:52:54
N-OUT-HP3-PLS_Age	152	s	03/04/2019 15:52:54
N-OUT-HP4-PLS_Age	0	s	03/04/2019 15:52:54
N-OUT-HP5-PLS_Age	134	s	03/04/2019 15:52:54
N-OUT-RTU-PLS_Age	296	s	03/04/2019 15:52:54
N-OUT-HP1-DRY_Age	1961	s	03/04/2019 15:52:54
N-OUT-HP2-DRY_Age	3396	s	03/04/2019 15:52:54
N-OUT-HP3-DRY_Age	1840	s	03/04/2019 15:52:54
N-OUT-HP4-DRY_Age	2454	s	03/04/2019 15:52:54
N-OUT-HP5-DRY_Age	11010	s	03/04/2019 15:52:54
N-OUT-RTU-DRY1_Age	3460	s	03/04/2019 15:52:54
N-OUT-HP1-PLS_data	48835	wh	03/04/2019 15:52:54
N-OUT-HP2-PLS_data	72740	wh	03/04/2019 15:52:54
N-OUT-HP3-PLS_data	16290	wh	03/04/2019 15:52:54
N-OUT-HP4-PLS_data	0	wh	03/04/2019 15:52:54
N-OUT-HP5-PLS_data	46907.5	p	03/04/2019 15:52:54
N-OUT-RTU-PLS_data	11585	wh	03/04/2019 15:52:54
N-OUT-HP1-DRY_dat	1	state	03/04/2019 15:52:54
N-OUT-HP2-DRY_dat	1	state	03/04/2019 15:52:54
N-OUT-HP3-DRY_dat	1	state	03/04/2019 15:52:54
N-OUT-HP4-DRY_dat	1	state	03/04/2019 15:52:54
N-OUT-HP5-DRY_dat	0	state	03/04/2019 15:52:54
N-OUT-RTU-DRY1_dat	0	state	03/04/2019 15:52:54
N-OUT-AMB-T_Batt	3.68	V	03/04/2019 15:52:54
N-IN-FCU-TRH_Batt	3.7	V	03/04/2019 15:52:54
N-OUT-HP1-PLS_batt	3.71	V	03/04/2019 15:52:54
N-OUT-HP2-PLS_batt	3.66	V	03/04/2019 15:52:54
N-OUT-HP3-PLS_batt	3.71	V	03/04/2019 15:52:54
N-OUT-HP4-PLS_batt	0	V	03/04/2019 15:52:54
N-OUT-HP5-PLS_batt	3.7	V	03/04/2019 15:52:54
N-OUT-RTU-PLS_batt	3.74	V	03/04/2019 15:52:54
N-OUT-HP1-DRY_bat	3.66	V	03/04/2019 15:52:54
N-OUT-HP2-DRY_bat	3.73	V	03/04/2019 15:52:54
N-OUT-HP3-DRY_bat	3.7	V	03/04/2019 15:52:54
N-OUT-HP4-DRY_bat	3.65	V	03/04/2019 15:52:54
N-OUT-HP5-DRY_bat	3.69		03/04/2019 15:52:54
N-OUT-RTU-DRY1_bat	3.64	V	03/04/2019 15:52:54
N-GTWY_ID	929061		03/04/2019 15:52:54
Temp-ID	390375		03/04/2019 15:52:54
TRH-ID	390368		03/04/2019 15:52:54
N-OUT-HP1-DRY-ID	390366		03/04/2019 15:52:54
N-OUT-HP2-DRY-ID	390352		03/04/2019 15:52:54

Remote Control

Note: Remote control settings and values change upon press of *Update Logger* button below.

Remote Switches	HIGH	LOW
Force FTP Transfer	○	●
Force Daily Email	○	●
Force Sync HP4 NEW P	○	●
GHPWH Alarms	●	○
Switch	●	○
Force Network Reform	○	●
Force Sync TRH	○	●
Force Sync AMB-T	○	●
Remote Tstat Contol	○	●
Reform Network	○	●

Remote Constants Programming

Remote Constant	Value
Kitchen Tstat	75
FCU CHW Thermostat	65

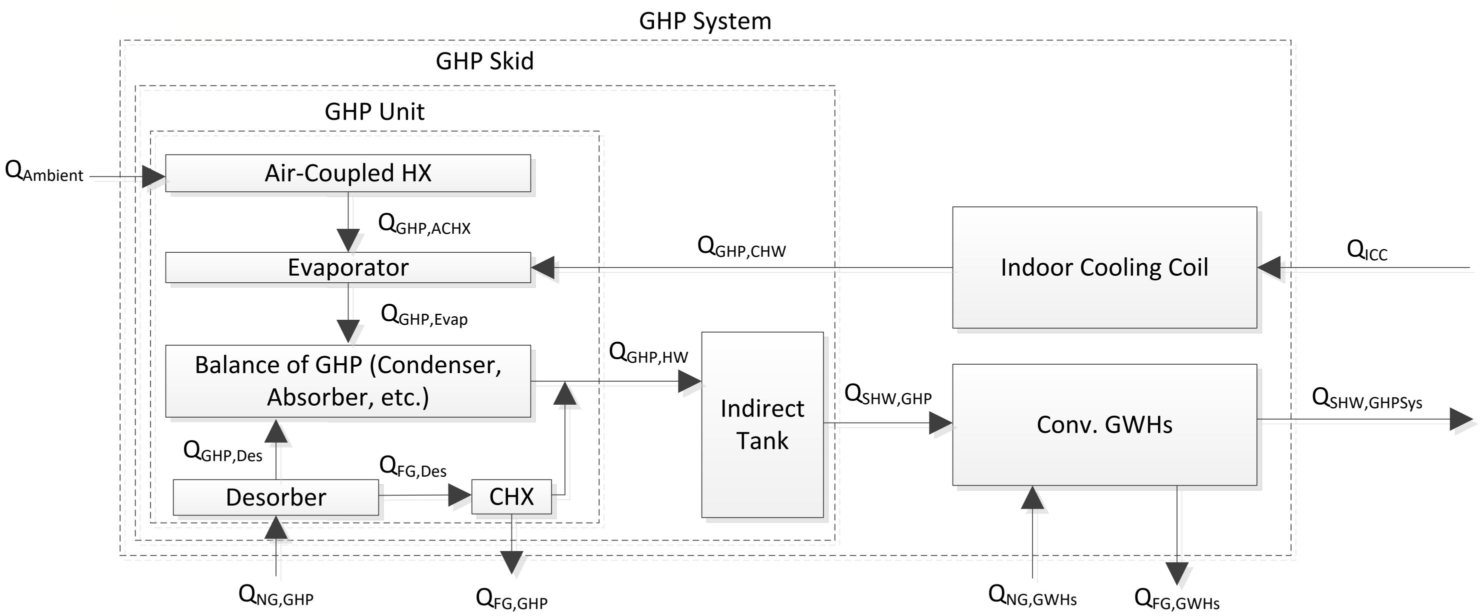
Update Logger with new settings

Cancel

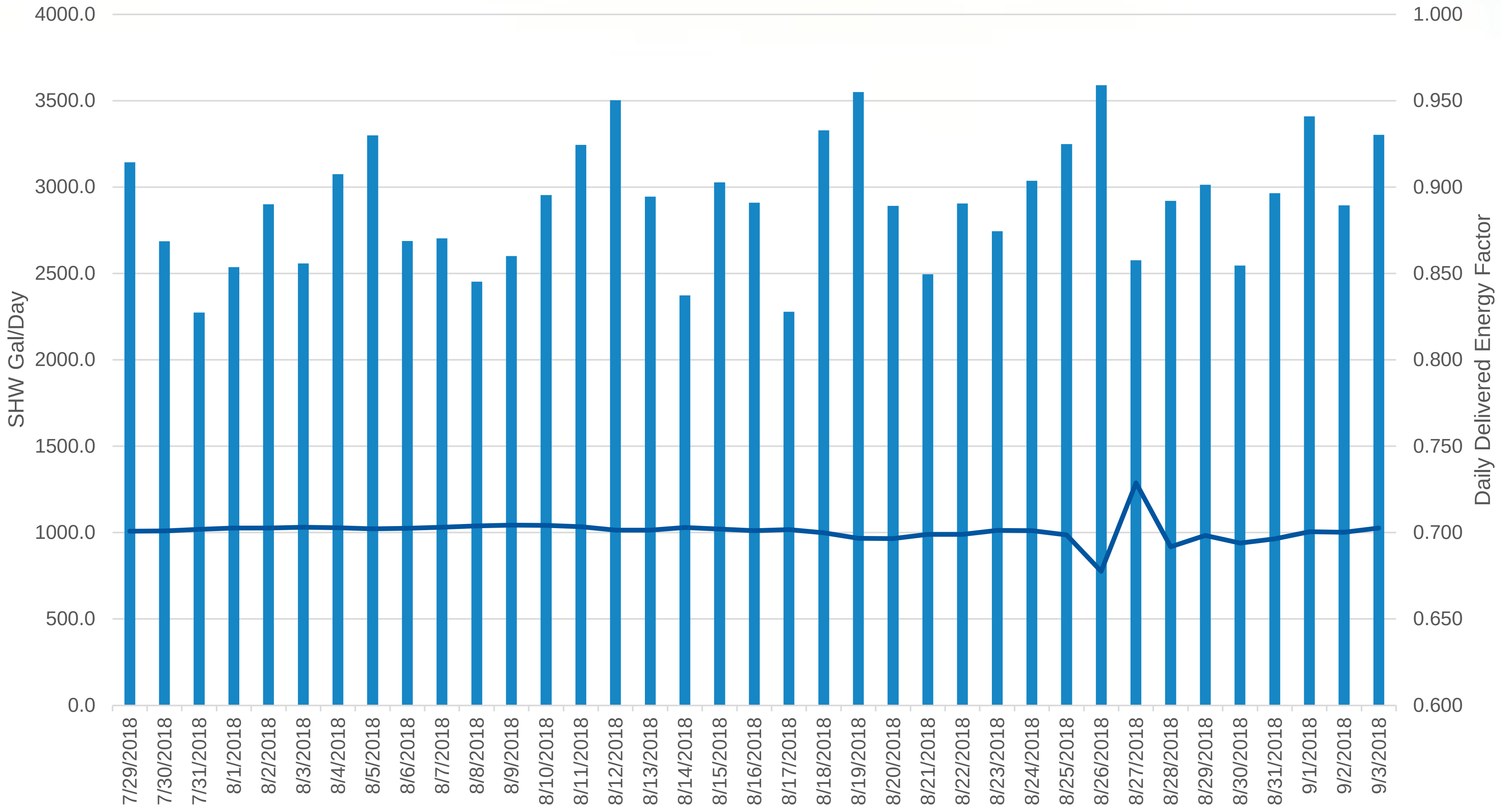
Field Demonstration: Key Efficiency Metrics

- **Utilization:** GHP SHW output as fraction of total system output
- **Heat Pump COP** – Efficiency of absorption heat pump based only on heat from combustion.
- **GHP Heating/Cooling COP** – Steady state efficiency of GHP on gas-basis only (COP_{Gas}), reported on time-averaged and cycle-averaged basis.
- **Delivered Energy Factor** – Daily/weekly transient output/input efficiency metric includes gas/electric inputs and tank heat loss and mixing effects.

$$COP_{HP} \geq COP_{Gas} \geq DEF$$

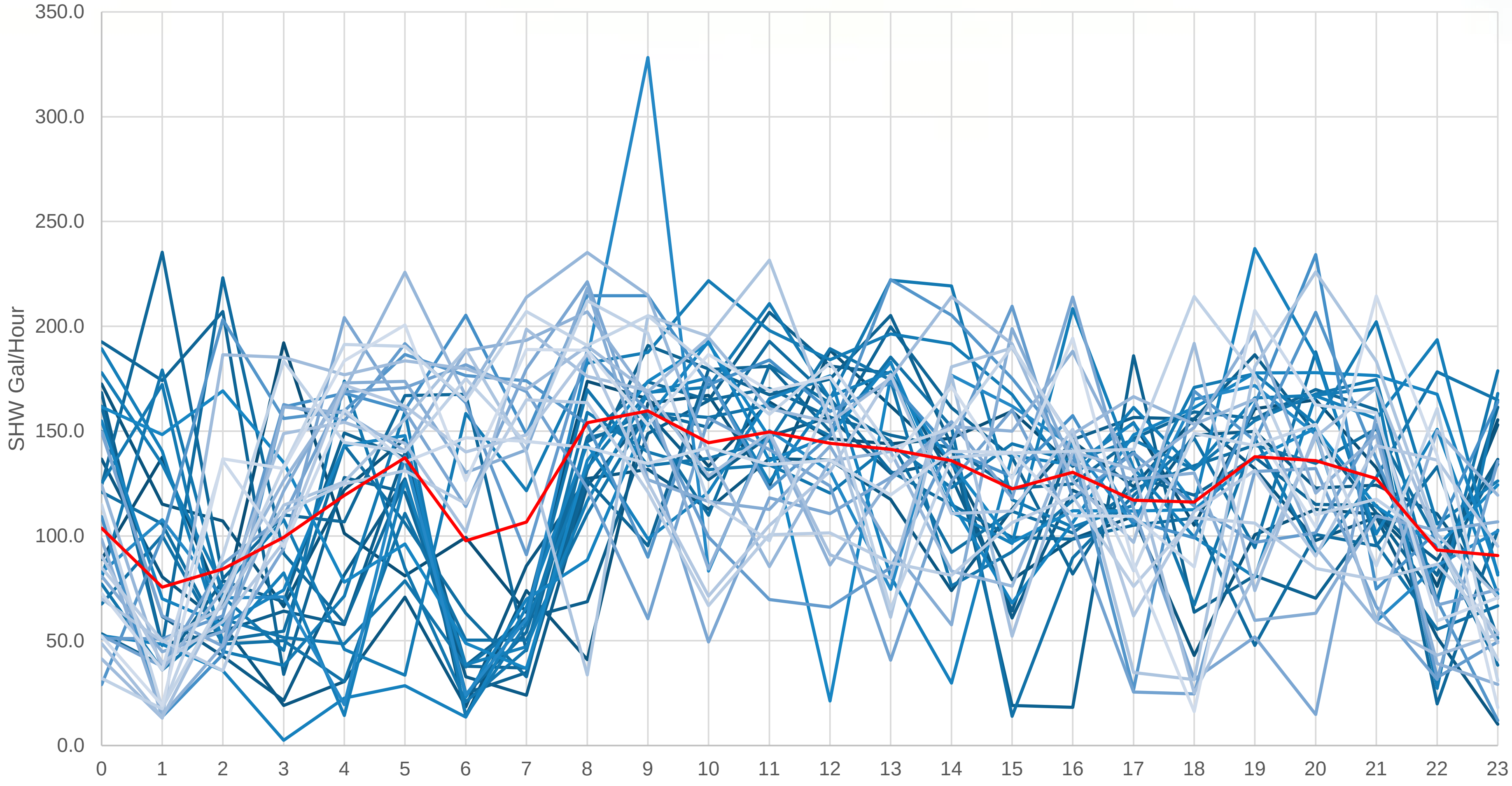


Site #1 Data – 24 Hour Diner Baseline Data



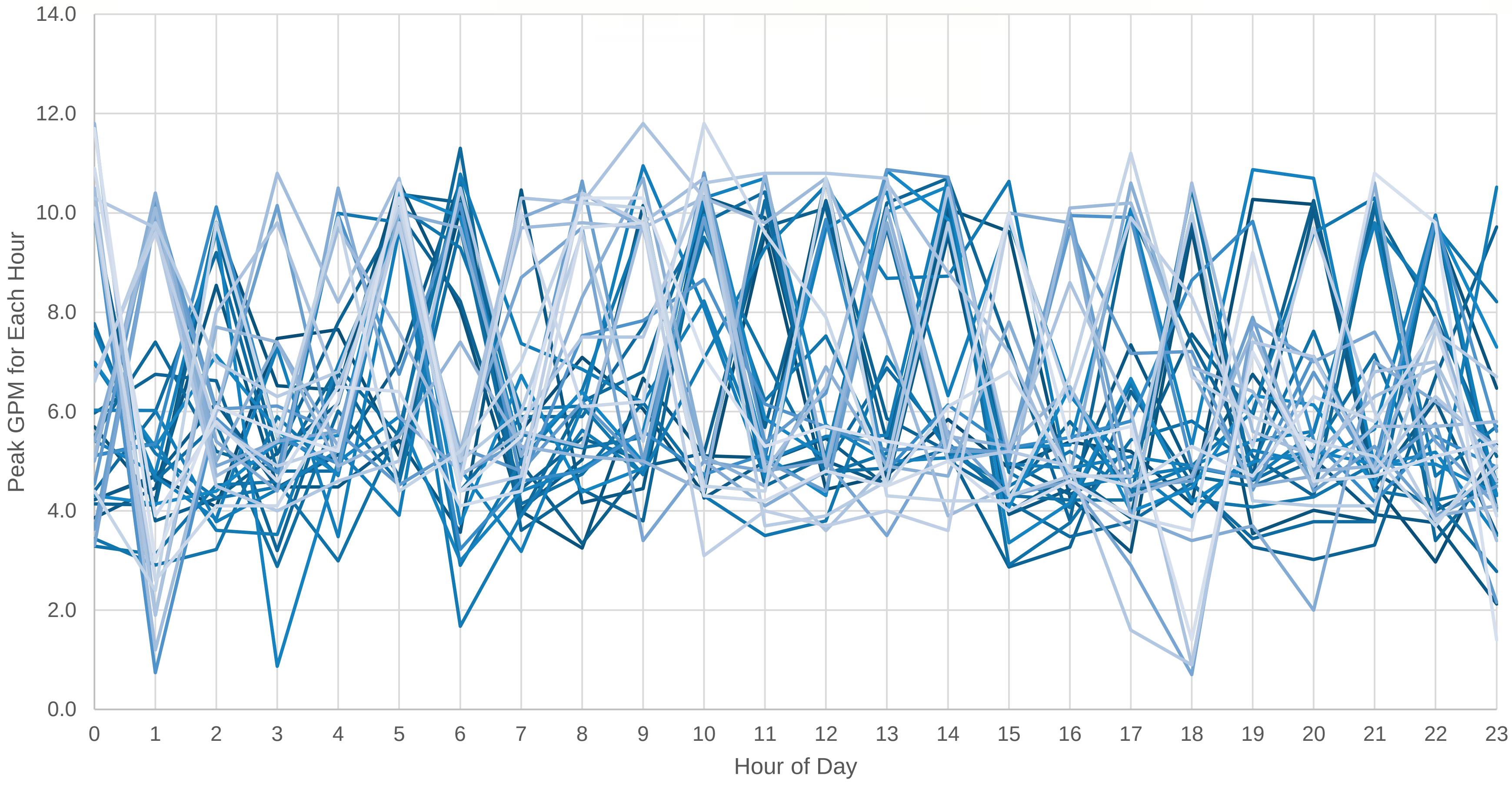
- Very close to original estimate of 3,500 gal/day
- Peak usage on Sundays typically
- Steady output at ~143 F, DEF ~70%

Site #1 Data – 24 Hour Diner Baseline Data



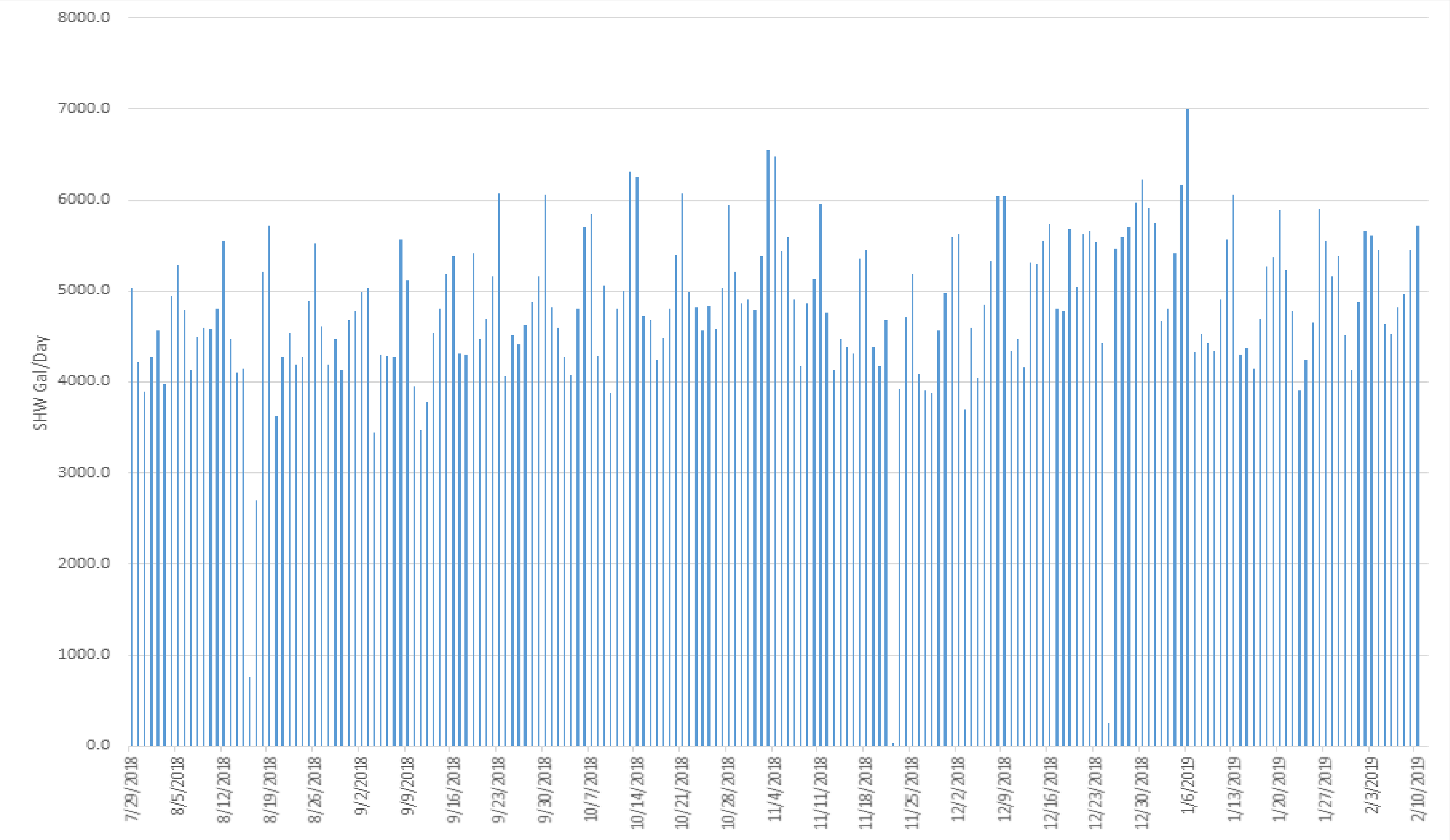
- Throughout the day, usage is spread out/steady
- Avg. 100-150 gal/hr
- Peak up to 250 gal/hr, except for anomalous event > 300 gal/hr

Site #1 Data – 24 Hour Diner Baseline Data



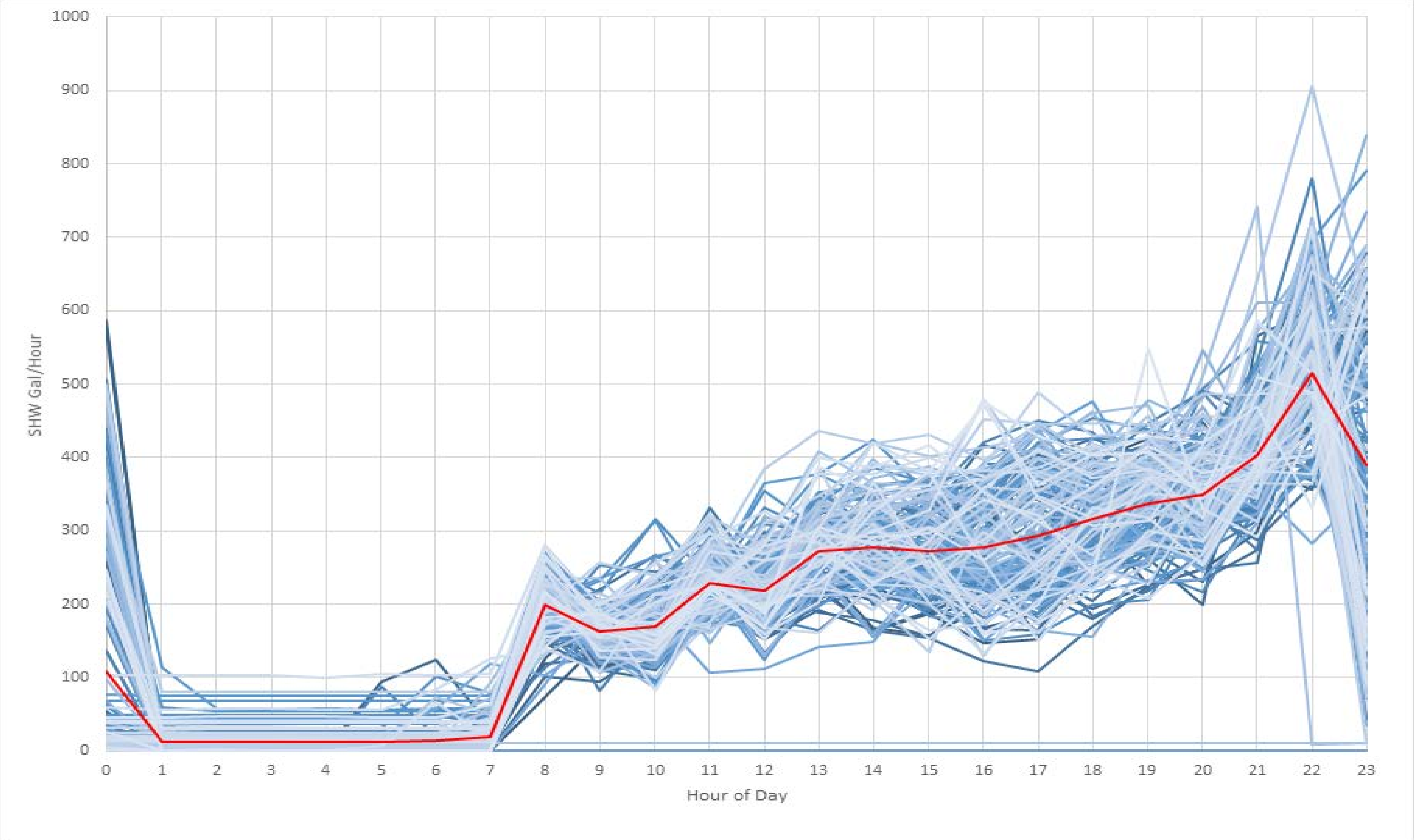
- Peak GPM for each hour shown, maximum between 10-12 GPM
- 4-8 GPM much more common

Site #2 Data – Casual Chain Restaurant Baseline Data



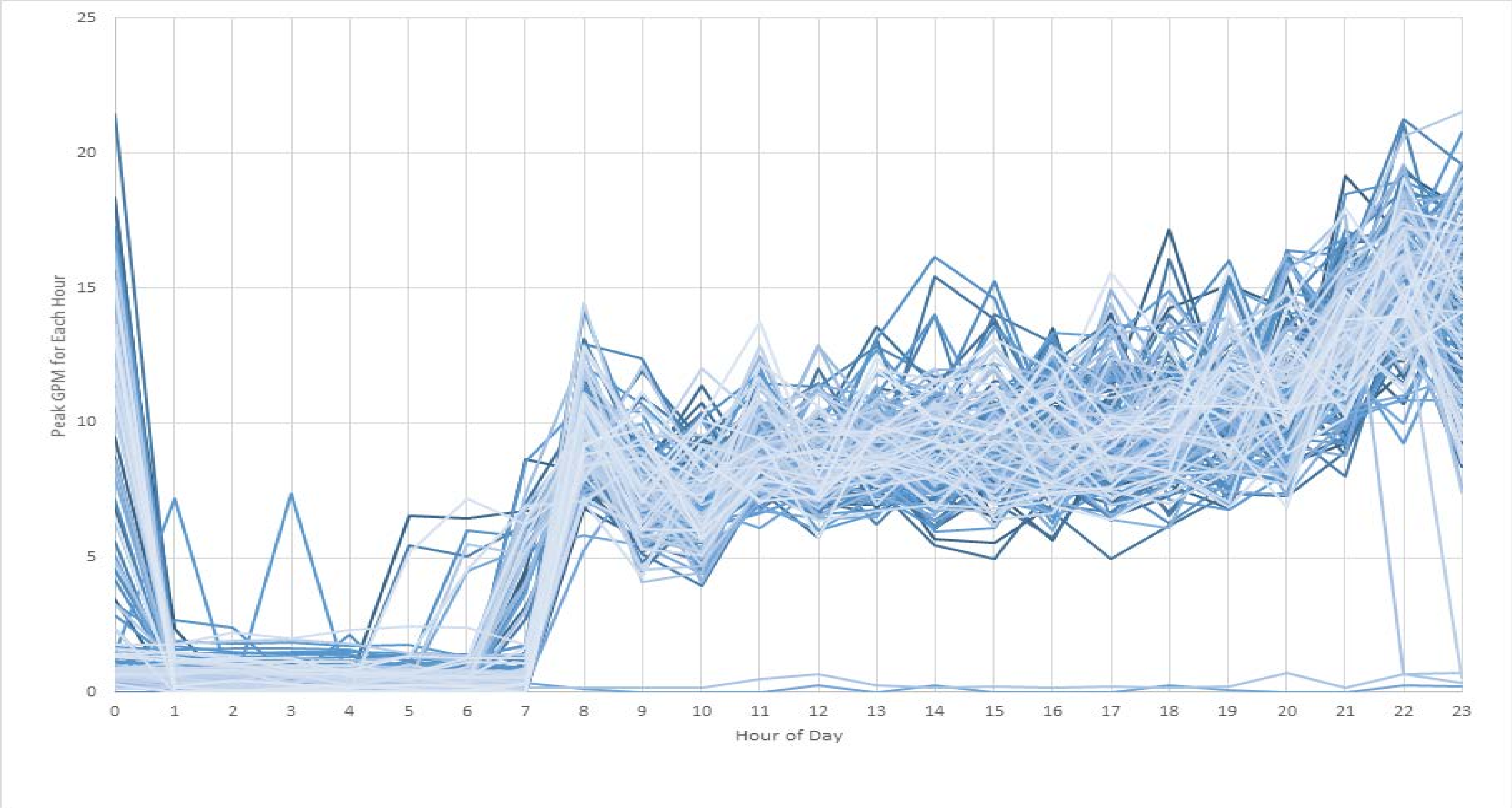
- Less than original estimate of 6,000 gal/day
- Peak usage on Sundays typically

Site #2 Data – Casual Chain Restaurant Baseline Data



- Large variation throughout day and day-to-day
- Avg. ~200-300 gal/hr
- Peak up to 800 gal/hr

Site #2 Data – Casual Chain Restaurant Baseline Data



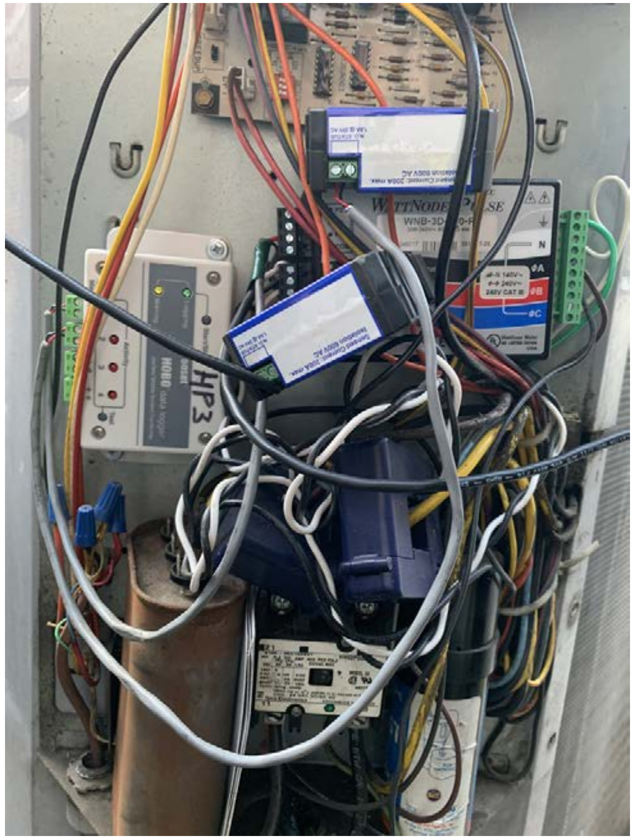
- Peak GPM for each hour shown, max between 15-20 GPM
- 10-15 GPM much more common
- Downtime in morning

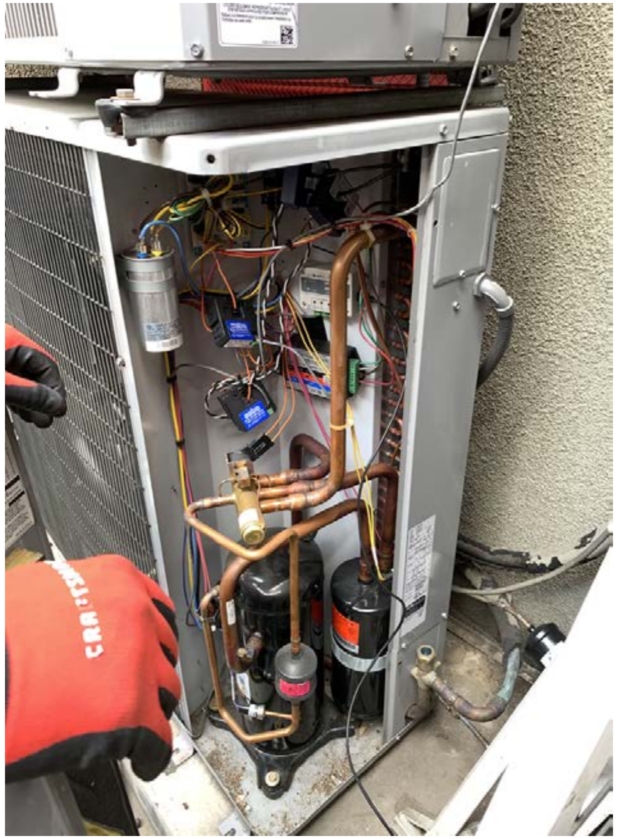
Displaced Cooling Measurement Approach – Rooftops

Displaced A/C Energy: Rooftop DAS will not have thorough characterization of HVAC system operation, however limited rooftop measurements with indoor cooling coil measurements will permit:

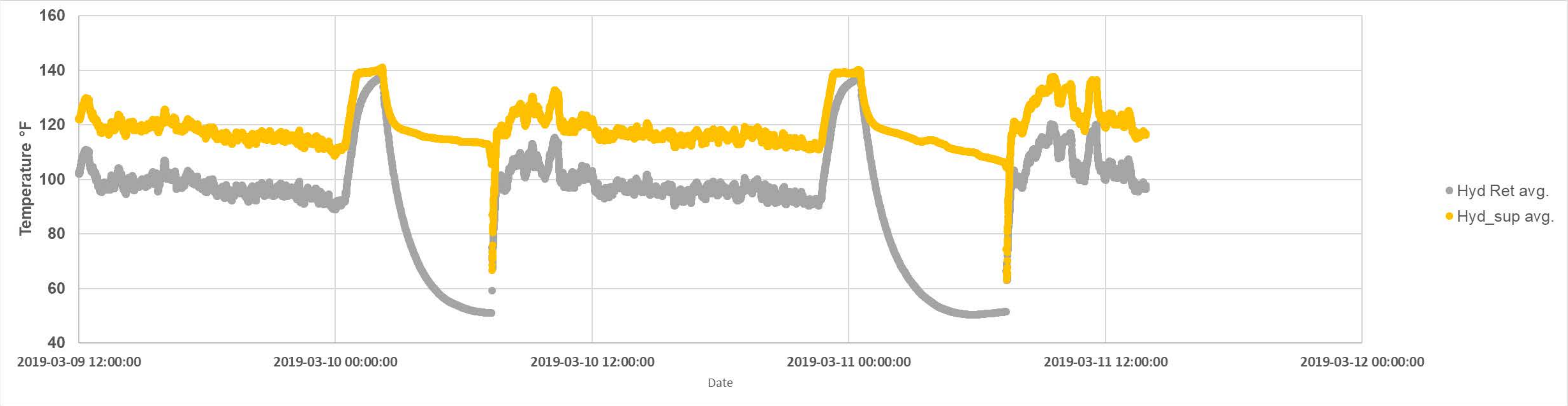
- *<u>Full Credit for GHP System</u>:* using measurements of indoor cooling coil capacity with runtime, GHP system cooling given full credit:
  - This non-conservative approach assumes that all cooling delivered at the ICC is (a) useful and (b) would otherwise be provided by building HVAC equipment.
- *<u>Displacement as-measured</u>:* Actual CDD-normalized HVAC input during GHP System monitoring compared to baseline.
  - Conservative approach which measures total power consumption by building HVAC during baseline and gas heat pump monitoring periods and, when adjusting for weather and other factors, quantifies avoided power consumption for A/C while ICC provides cooling.

Displaced Cooling Measurement Approach – Rooftops





Preliminary Commissioning Data



Field Demonstration: Restaurant Sites & Next Steps

- Goal of demonstration to show 40% or greater therm savings and measurable reduction in displaced A/C (up to 20%)
  - Monitoring through 2019
- In addition to field assessment of Integrated GHP system:
  - Develop sizing tools and design guide
  - Evaluate potential with ZNE Restaurants
  - Market research and outreach events with various stakeholders
- Coordination with parallel GAHP-related efforts in other applications

Questions?

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