Demonstration of Gas Heat Pump Water Heating/ Cooling in Commercial Food Service

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Presented at 2018 ACEEE Hot Water Forum
Portland, OR
March 21st, 2018

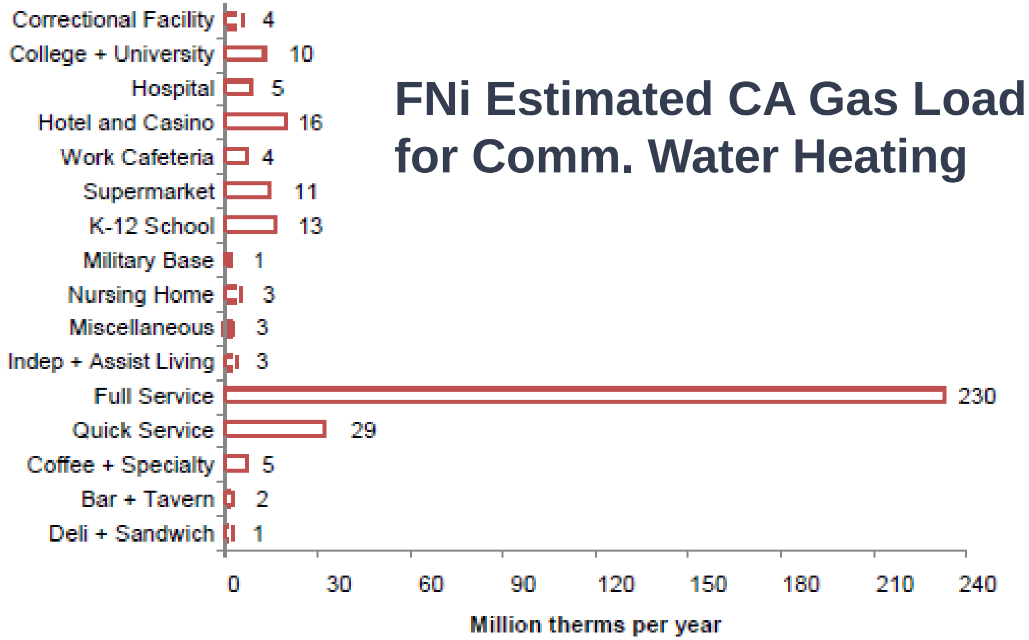
Presentation Outline

- >EE Potential in Commercial Gas WH
- >Motivation for Commercial Gas HPWH
- >Integrated Commercial GHPWH System Concept
- >Low-Cost GAHP Performance Results
- >Demonstration Plans and Next Steps

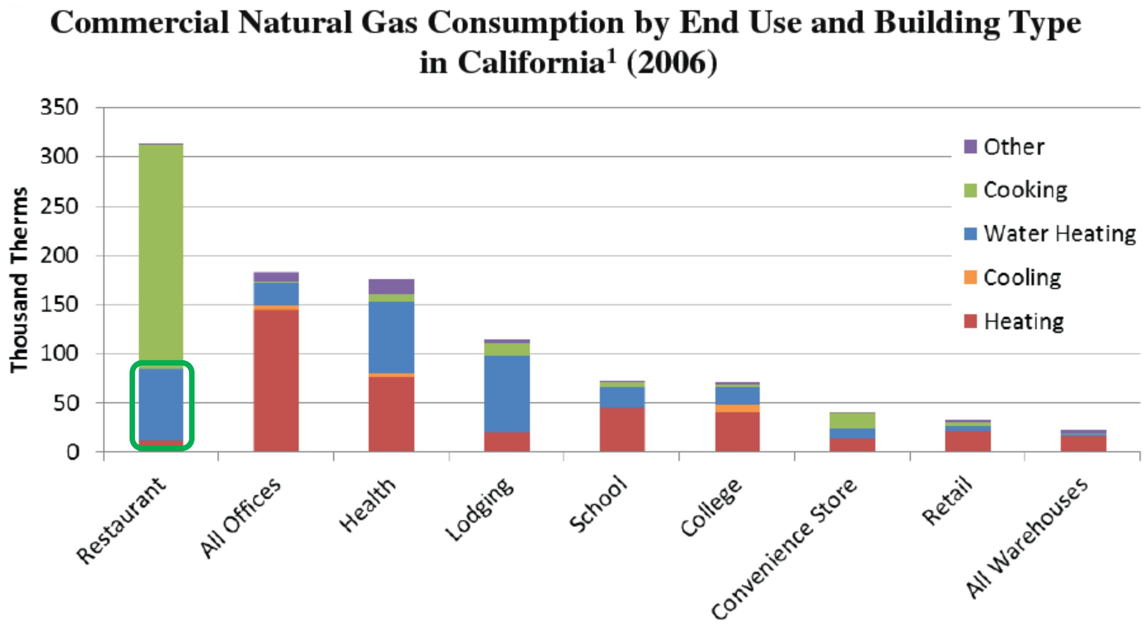
Motivation – Commercial Water Heating

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

> Unlike residential water heating, market already moving towards "condensing" (Thermal Efficiency > 90%), AHRI estimates > 40% of shipments are gas

> Proposed rule requires all gas products to go to condensing efficiency, 95% from 80% for storage, prompts entry of cost-effective gas heat pump products

In California*:

> 90% of FSR/QSRs have gas-fired water heating

> ~85% are storage GWHs, majority are non-condensing (80% TE)

> Entire foodservice industry has ~123,000 units in service (90% storage GWH, 5% tankless, 5% boiler)

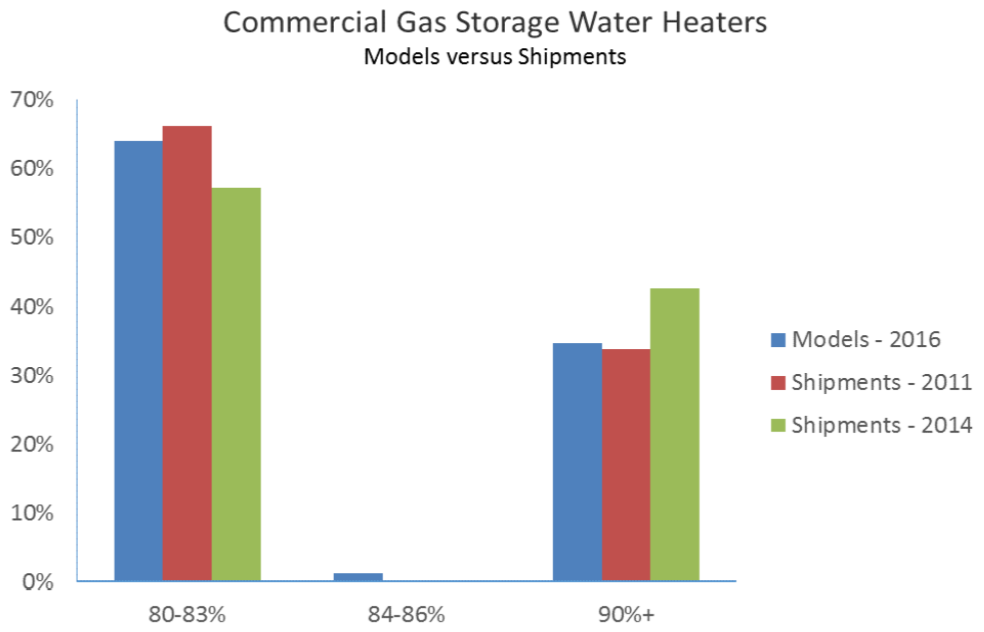


Chart Source: AHRI Response to DOE Comm. WH NOPR, August 30, 2016

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*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.

Motivation – Commercial Water Heating

- In total, gas-fired water heating in the California food service industry consumes 340 million therms/year*:
  - Equal to **total** gas consumption of ~1MM CA homes/year
- Using a Gas Heat Pump (GHP) allows for simultaneous use of “free cooling” with producing hot water
  - Advantageous for food service application, with large internal heat loads
- With assumed 100% deployment of gas heat pumps in restaurant applications**:
  - 2.0 MMTCO2e/year in GHG emissions per year
  - 2.7 billion gallons avoided from displaced electricity production

*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.
** Torcellini, P. et al. (2003) Consumptive Water Use for U.S. Power Production, Technical Report prepared by the National Renewable Energy Laboratory under Contract NREL/TP-550-33905.

Motivation – Commercial Gas HPWH

Restaurant applications of GHPs may be lowest low-hanging fruit:

> Hot water-intensive applications, like FSRs (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’ sweetens the deal

But GHPs 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!

GAHPs commercially available in EU for home heating, in 2016 an 18 kW (61 MBH) output released by Italian mfr. Unit costs are prohibitive for US, > $11,000 (excl. shipment)

Image source: Promelle, J., “A Gas Absorption Heat Pump for existing residential buildings: HEAT4U preliminary achievements”, Proceedings of the 2014 Int’l Gas Research Conference, Copenhagen, Denmark.

Motivation – Commercial Gas HPWH

To have an attractive value proposition, even as low-hanging fruit, GHP commercial water heater must be low-cost.

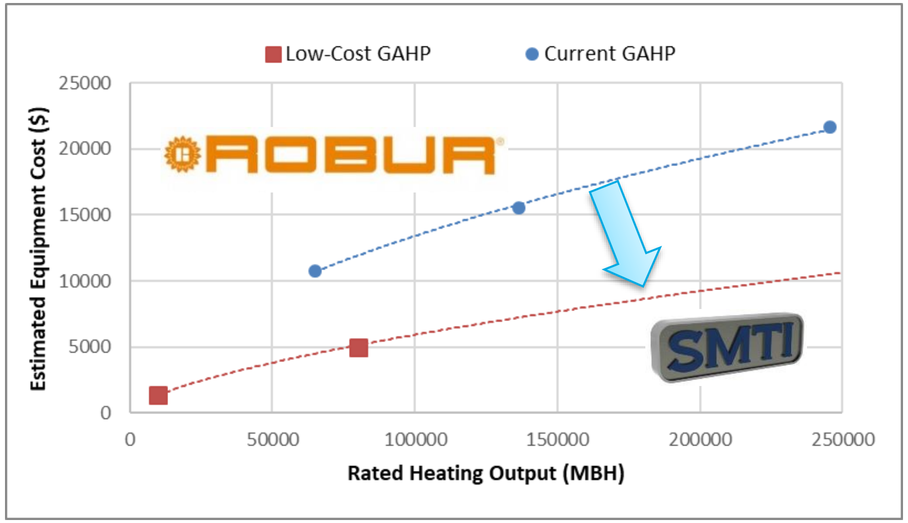
> Builds on effort to develop low-cost gas-fired absorption heat pump for building space heating

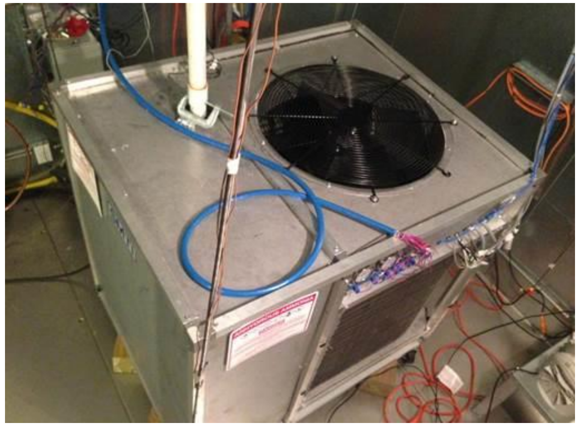
> Target unit cost competitive with condensing boilers/GWHs

Effort to shift cost curve for gas-fired absorption heat pump to be competitive in U.S. market

> Shifts curve against incumbent GAHP manufacturer

> Also favorable against engine-driven example, ~$430/kW for larger-scale system (w/o emission control)





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Motivation – Commercial Gas HPWH

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:** GAHPs themselves do not require backup heating, can continue operation without interruption during defrost. Pre-commercial units have gathered 1,000s of hours collectively in multiple states (over multiple size ranges).

> **Emissions/Safety:** Projected AQMD compliance, 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

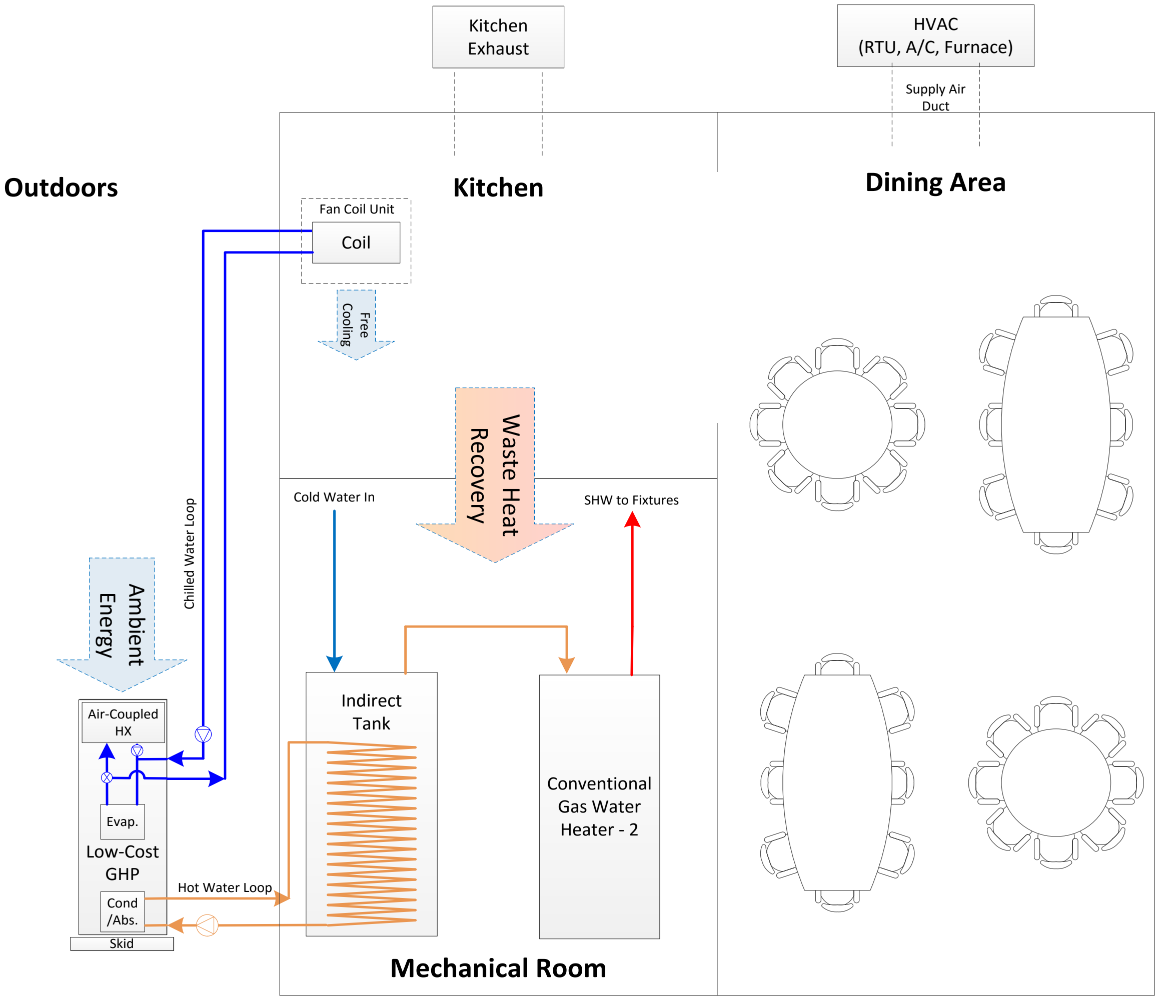
> **Zero Net Energy:** With greater benefit in colder climates, GAHPs can reduce source energy burden in mixed, lower cost ZNE buildings*

*Glanville, P., Kerr, R., Keinath, C., and Garrabrant, M., (2016), *The Role of Gas Heat Pumps in Zero Net Energy Buildings*, Proceedings of the ACEEE Summer Study on Energy Efficiency in Buildings, Asilomar, CA.

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
- Installed as hybrid system



Integrated GHP System Overview: Low-Cost GAHP

Gas Absorption Heat Pump (GAHP) Component

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. Development team includes SMTI and manufacturing partners. Initial development was **air-source**, this new effort will introduce **hybrid for A/C delivery**.

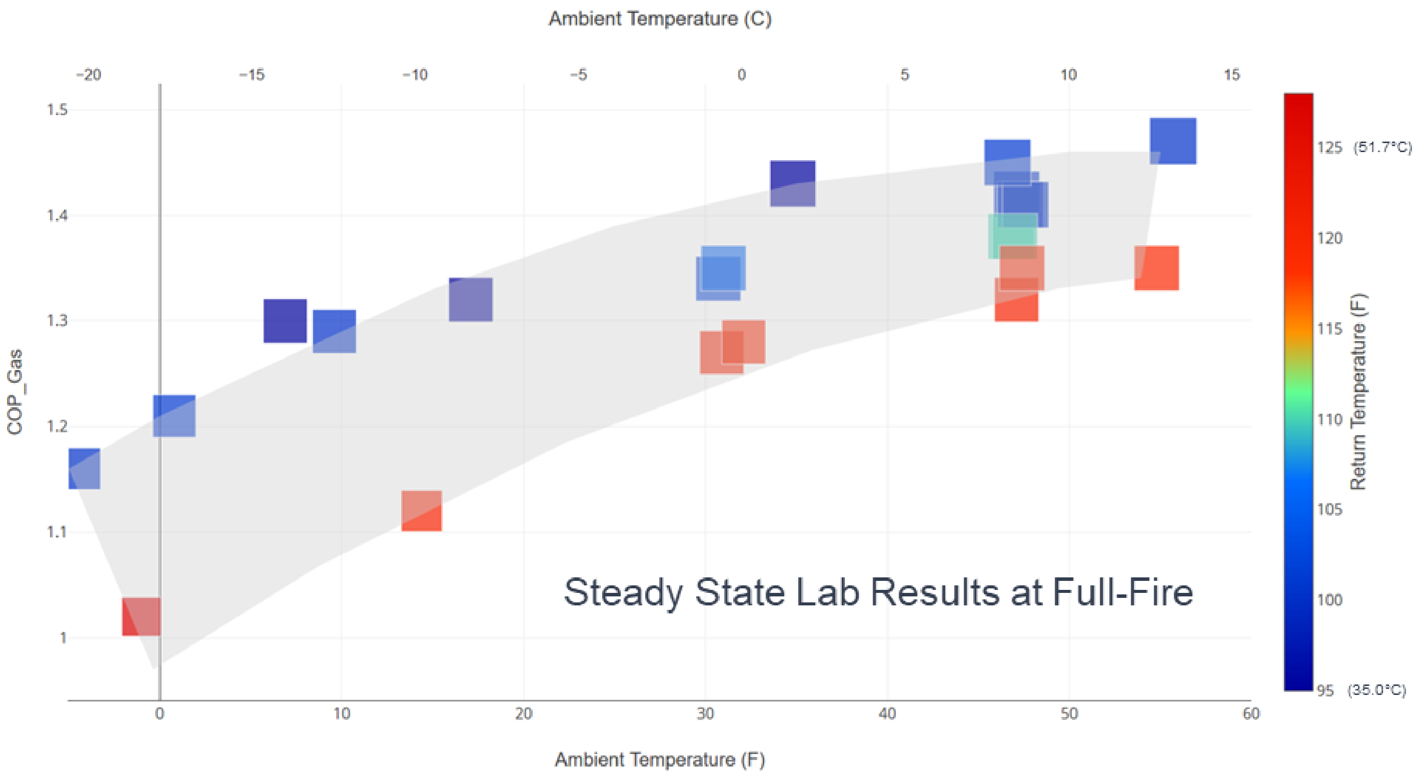
	GAHP	Units/Notes
Heat Pump Output	80,000	Btu/hr with 4:1 modulation
Firing Rate	54,000	Btu/hr
Target Efficiency	COP > 1.4 at 47°F 140% AFUE	Based on GTI lab testing, pending certification
Emissions (projected)	< 14 ng NO_x/J	
Installation	Outdoors	Like boiler, integration with space heating feasible 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	

Summary of Development: Garrabrant, M. and Keinath, C., “Low-Cost Gas Heat Pump for Building Space Heating”, Report DOE-SMTI-0006116-1, prepared under contract EE0006116, 2015.

Low-Cost GAHP Component: Performance

Efficiency: Evaluated in ***heating-only mode*** as a combined space/water heating system*, team demonstrated GAHP performance in laboratory testing:

- Up to 45% energy savings projected over baseline, with projected 140% AFUE (Region IV)*, estimated simple payback of 3-5 years and best-in-class source energy efficiency (details in appendix).
- Nominal 80 kBtu/h (23 kW) output with 4:1 output modulation, no need for aux./backup heat, total power 300-550 W per modulation point.



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*More information: Garrabrant, M., Stout., R., Keinath, C., and Glanville, P. "Experimental Evaluation of Low-Cost Gas Heat Pump Prototypes for Building Space Heating", Proceedings of the 16th Int'l Refrigeration and Air Conditioning Conference at Purdue University, 2016 ***AND*** Glanville, P., Keinath, C., and Garrabrant, M. 2017. "Development and Evaluation of a Low-Cost Gas Absorption Heat Pump", proceedings of the 2017 ASHRAE Winter Conference, Las Vegas, NV.

Low-Cost GAHP Component: Performance

Reliability: Prior generation heating-only GAHP units operating in field since 2016 in Tennessee* and Wisconsin, multiple generations evaluated.

> At two sites, units operated with combined > 1,800 operating cycles and > 2,200 hours, currently operational. When servicing required, improvements made in subsequent generation

> Year-round (DHW and Combi mode), all-weather operation, down to 0 F. With recent version, cycle-averaged efficiencies range from 1.25-1.65 for outdoor temperatures 15 F to 65 F*

Source: SMTI

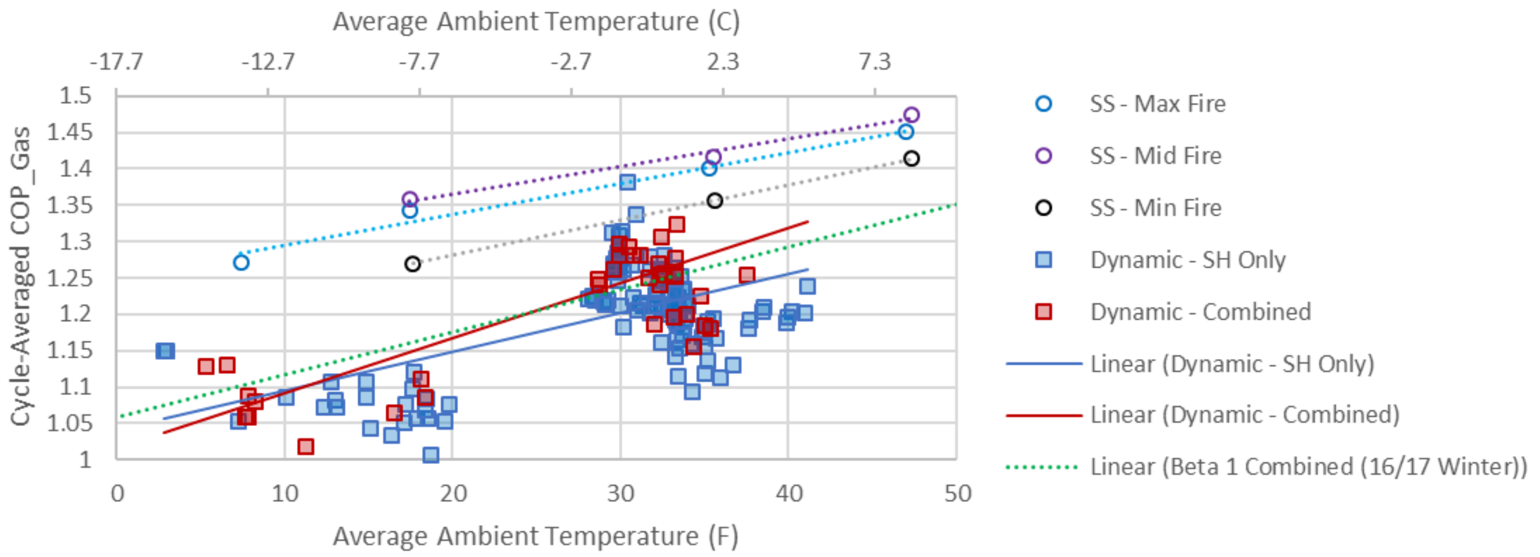
Source: AC Docs

*Glanville, P., Suchorabski, D., Keinath, C., and Garrabrant, M. 2018. “Laboratory and Field Evaluation of a Gas Heat Pump-Driven Residential Combination Space and Water Heating System ”, proceedings of the 2018 ASHRAE Winter Conference, Chicago, IL.

Low-Cost GAHP Component: Performance

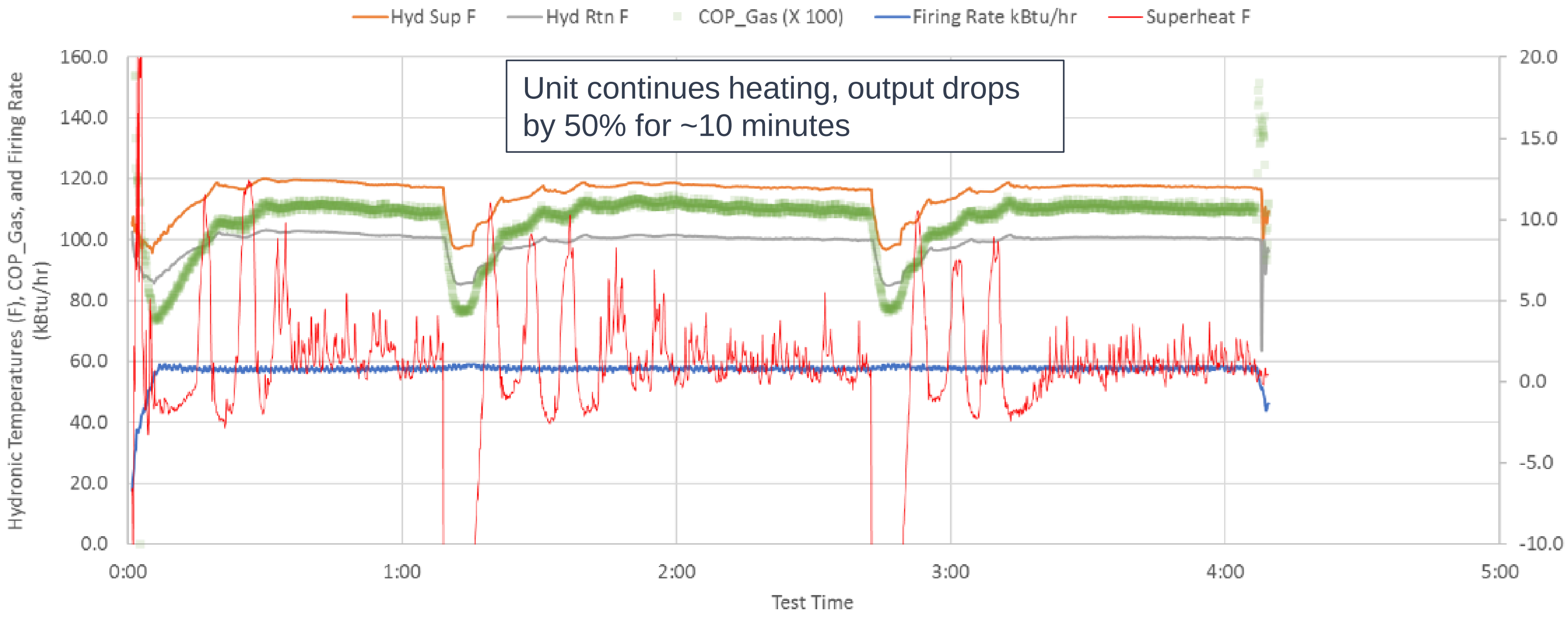
Dynamic Response: Performance of laboratory-controlled GAHP combi system with 24/48 hour simulated use patterns to compare to early field-trial, define cycling losses

- Developed protocol to impose combined SH/DHW loads dynamically with variations in simulated weather conditions (appendix)
- 2nd Gen. prototype in steady-state lab testing had COP_{Gas} of 1.44 at 34 F (1 C) while field unit ranged from 1.0-1.45, with cycling losses between 8-15% depending on many factors. As with field trial, DHW priority enforced.



Low-Cost GAHP Component: Performance

Dynamic Response: Active method supplies hot refrigerant vapor to the evaporator coil, bringing its temperature above 32°F (0°C) and melting/removing the frost build-up. Method allows the unit to continue operation (at a reduced COP). Unit continues to provide heat to the conditioned space during defrost period



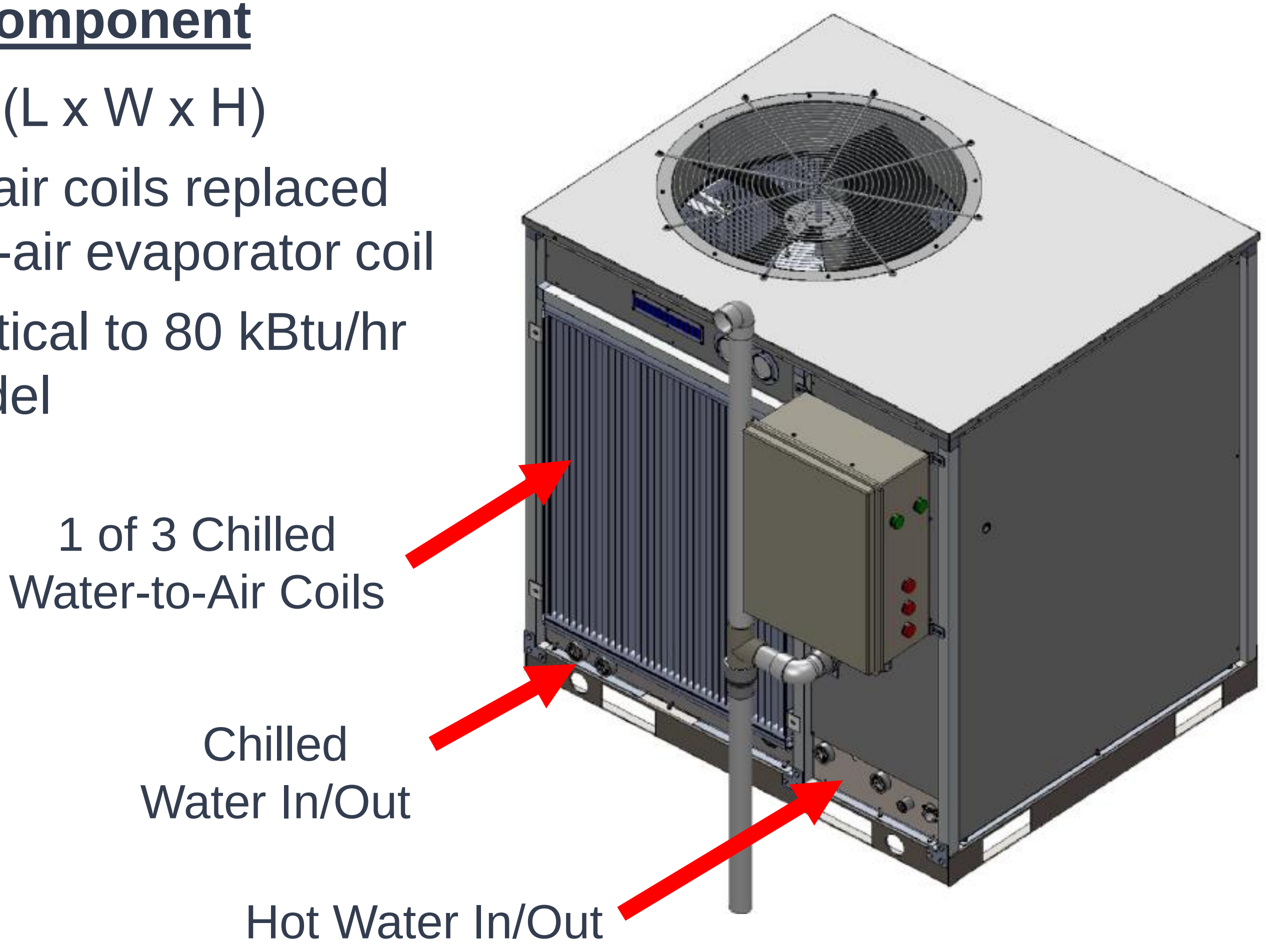
Experimenting with Defrost Control

Source: SMTI

Field Demonstration: Integrated GHP System Design

<u>Low-Cost GAHP Component</u>

- 47” x 38.5” x 46” (L x W x H)
- Chilled water-to-air coils replaced the refrigerant-to-air evaporator coil
- Dimensions identical to 80 kBtu/hr heating-only model



Heating-only 80kBtu/hr unit operating in 2016

Images and information courtesy of SMTI

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 GAHP, now in fabrication/assembly phase
- Tanks/coils selected for each site
- Developing initial specification for system controls based on prior testing/modeling

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Image Source: Lochinvar and Williams

Field Demonstration: Integrated GHP System Design

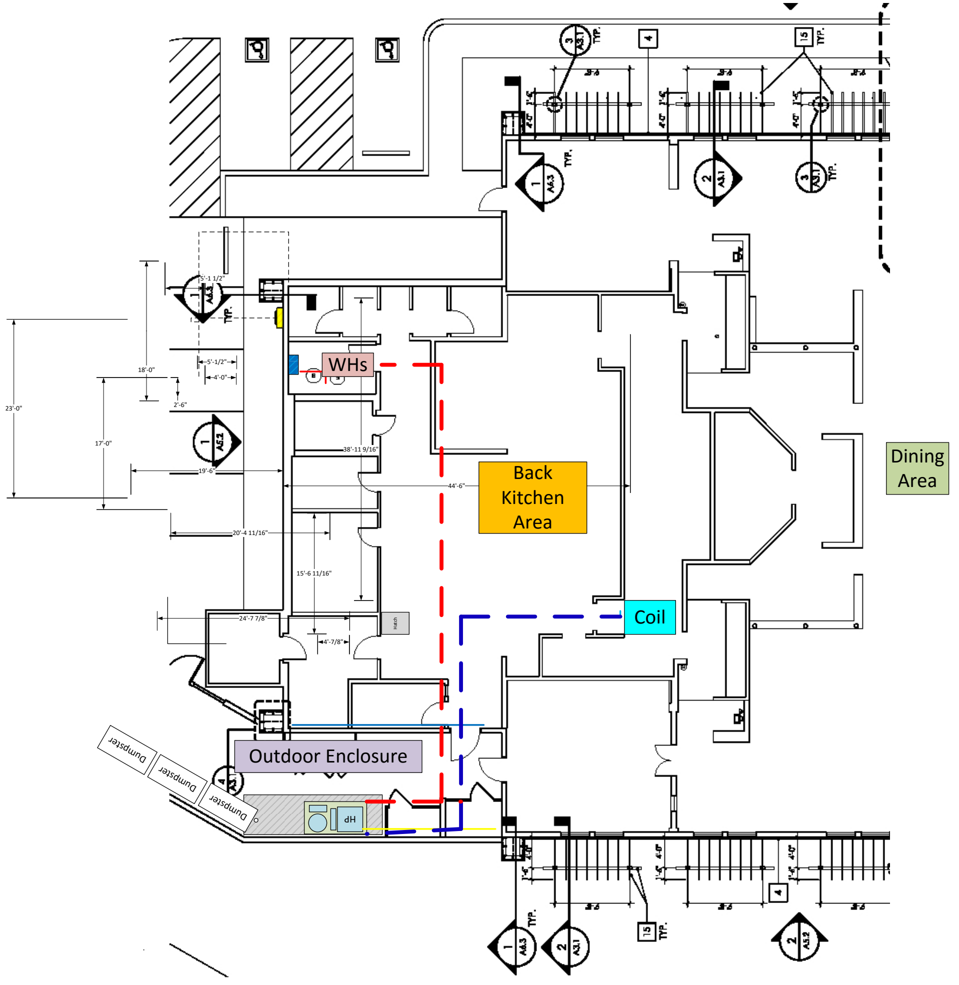
System is *Hot Water-Led*, activation of indoor cooling coil depends on SHW loads. Preliminary Control Strategy is:

1) If there is a call for cooling and GHP is cycling on,
   - Chilled water loop to indoor cooling coil is activated (pump) and air-coupled HX is disabled via 3-way valve
   - Indoor cooling coil fan is activated when supply chilled water temperature drops below the aquastat setting and flow is detected (flow switch)
   - Indoor cooling coil cycles off with GHP, upon SHW cycle completion
2) 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: Restaurant Sites & Next Steps

In Q3-18, integrated GHP systems will be installed at two California full-service restaurants:

- Sites are from local, national chains, one with 24-hr/day operation
  - Existing equipment at sites are non-condensing and condensing, respectively
  - Peak estimated SHW is 3,500 and 7,000 gal/day
  - Delivered water temperature compatible with GAHP (140 F), 180 F at dishwasher through booster
- Sites are in South Coast Air Basin, GAHP unit will undergo AQMD certification
- Baseline monitoring will characterize A/C, SHW I/O through mid-summer



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 late 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

References for More Information

Referenced Materials:

- Garrabrant, M. and Keinath, C., “Low-Cost Gas Heat Pump for Building Space Heating”, Report DOE-SMTI-0006116-1, prepared under contract EE0006116, 2015. https://www.osti.gov/biblio/1328433

- Garrabrant, M., Stout., R., Keinath, C., and Glanville, P. “Experimental Evaluation of Low-Cost Gas Heat Pump Prototypes for Building Space Heating”, Proceedings of the 16th Int’l Refrigeration and Air Conditioning Conference at Purdue University, 2016 . https://docs.lib.purdue.edu/cgi/viewcontent.cgi?referer=&httpsredir=1&article=2572&context=iracc

- Glanville, P., Keinath, C., and Garrabrant, M. 2017. “Development and Evaluation of a Low-Cost Gas Absorption Heat Pump”, proceedings of the 2017 ASHRAE Winter Conference, Las Vegas, NV.

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Questions?

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Technical Appendix

Low-Cost GAHP Component: Performance

Test Data Shown in Table

- Steady state points held for at least 15 minutes
- GAHP loop glycol measured to be 12.3% (vol, by KF).
- GAHP ΔP is 10 psi @ 8gpm

Rating Point	Actual Ambient Temperature (°F, dry bulb)	Actual Ambient Humidity (°F, dew point)	Actual Hydronic Return Temperature (°F)	Firing Rate (Btu/hr)	Output (Btu/hr)	COP_Gas	Measured Power Draw (W)
1	45.1	31.1	95.5	14313	20233	1.41	309.0
2	32.8	30.8	95.2	13728	18609	1.36	315.7
3**	14.7	2.3	94.8	15232	19322	1.27	335.1
4	14.8	12.2	95.3	34317	46601	1.36	438.7
5	33.0	28.3	94.9	55537	77778	1.40	591.9
6	14.4	12.2	94.6	55737	74875	1.34	611.9
7	4.9	3.4	94.4	56871	72339	1.27	604.7
8	44.4	38.2	95.4	55407	80365	1.45	585.8
9	44.7	40.1	95.4	33665	49607	1.47	412.8
10	33.2	29.2	95.2	34721	49208	1.42	425.0
2*	33.5	29.8	95.2	23063	32247	1.40	329.5
3a*	14.6	12.8	94.7	21851	18609	1.36	339.8
3b*	15.0	10.9	95.0	14003	16837	1.20	325.7

* Note that tests 2/3 were repeated as the GAHP was unable to modulate down to the lowest firing rate, 2* and 3* were not used in AFUE calculations but represent valid steady state test points.

** This is the repeated test point from prior reporting, original data is test “3b”

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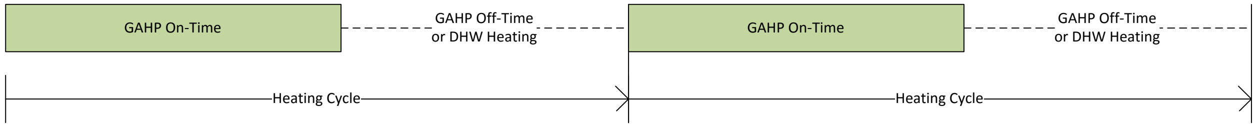
Low-Cost GAHP Component: Performance

Resulting AFUE Calculation – ANSI *Z21.40.4*

Output data for Region IV								Note: G_1<G_v<G_2; Case No. BL(Tj) v.s. Q_1 and Q_2									
j	T(j)	nj/N	BL(Tj)	Q_1	G_1	E_1	Case	G_v	E_v	Q_2	G_2	E_2	HLF	PLF	Output(kBtu)	Gas (kBtu)	Elec (kWh)
1	62	0.132	3.1	20.7	13.9	0.84	I	5.0		86.3	50.6	1.19	0.15	0.79	2121	1804	110
2	57	0.111	8.2	20.5	14.0	0.85	I	7.3		85.0	51.2	1.19	0.40	0.85	4755	3816	231
3	52	0.103	13.3	20.4	14.2	0.85	I	10.0		83.8	51.8	1.18	0.65	0.91	7170	5451	328
4	47	0.093	18.5	20.2	14.3	0.86	I	12.9		82.5	52.3	1.18	0.91	0.98	8964	6482	387
5	42	0.100	23.6	18.3	13.1	0.85	II	16.1	0.87	78.9	55.5	1.13	1.00	1.00	12317	8413	453
6	37	0.109	28.7	18.5	13.6	0.86	II	19.6	0.89	78.1	55.5	1.14	1.00	1.00	16344	11163	506
7	32	0.126	33.9	18.7	14.0	0.87	II	23.4	0.91	77.3	55.6	1.14	1.00	1.00	22266	15397	600
8	27	0.087	39.0	18.9	14.4	0.87	II	27.5	0.94	76.5	55.6	1.15	1.00	1.00	17704	12483	426
9	22	0.055	44.1	19.1	14.8	0.88	II	31.9	0.97	75.7	55.7	1.15	1.00	1.00	12665	9144	277
10	17	0.036	49.3	19.3	15.2	0.88	II	36.5	1.00	74.9	55.7	1.16	1.00	1.00	9254	6859	187
11	12	0.026	54.4	19.2	15.4	0.89	II	41.5	1.03	73.6	56.3	1.15	1.00	1.00	7379	5624	140
12	7	0.013	59.5	19.0	15.5	0.89	II	46.7	1.07	72.3	56.9	1.15	1.00	1.00	4038	3166	72
13	2	0.006	64.7	18.9	15.7	0.89	II	52.2	1.10	71.1	57.4	1.15	1.00	1.00	2024	1634	35
14	-3	0.002	69.81	18.7	15.8	0.90	III	58.0		69.80	58.0	1.14	1.00	1.00	728	605	12
15	-8	0.001	74.9	18.6	16.0	0.90	III	64.1		68.5	58.6	1.14	1.00	1.00	391	306	16
		Cost HSPF	12.34	Gas seasonal COP		1.39			**AFUE**	**139**	**%**		Seasonal total		128121	92346	3780
	Source fuel HSPF		10.77						**ASHEC**	**3780**	**kWh**				SHO	SHGEC	SHEEC

Low-Cost GAHP Component: Performance



Dynamic loads were imposed as follows:

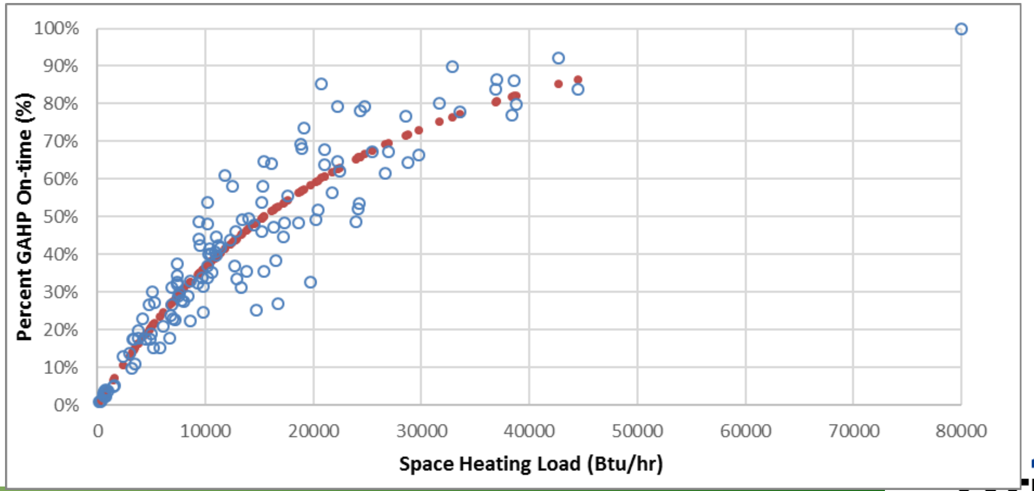
- Controlled DHW loads are delivered via a indirect gal. tank.
- Space heating loads (Btus) are tracked by software, with thermostat calls, but target heating output (Btu/hr) is managed separately.
  - SH loads are shed at a plate heat exchanger (PHX), so separate is needed.
  - Using field site 80k data, a relationship between hourly load and on-time is defined.
  - Data for first heating season has a median heating cycle duration of 64.1 minutes, default to hour-long periods.
  - With load defined, hourly space heating target is also defined, to assure unit cycles on/off.

$$\dot{Q}_{load} = Q_{SH} / (t_{on-time} + t_{off-time})$$

$$[\%\ \text{On-time}] = t_{on-time} / (t_{on-time} + t_{off-time})$$

$$[\%\ \text{On-time}] = \frac{\dot{Q}_{load}}{\left(A + B*(\dot{Q}_{load}) + C*(\dot{Q}_{load})^2\right)};$$

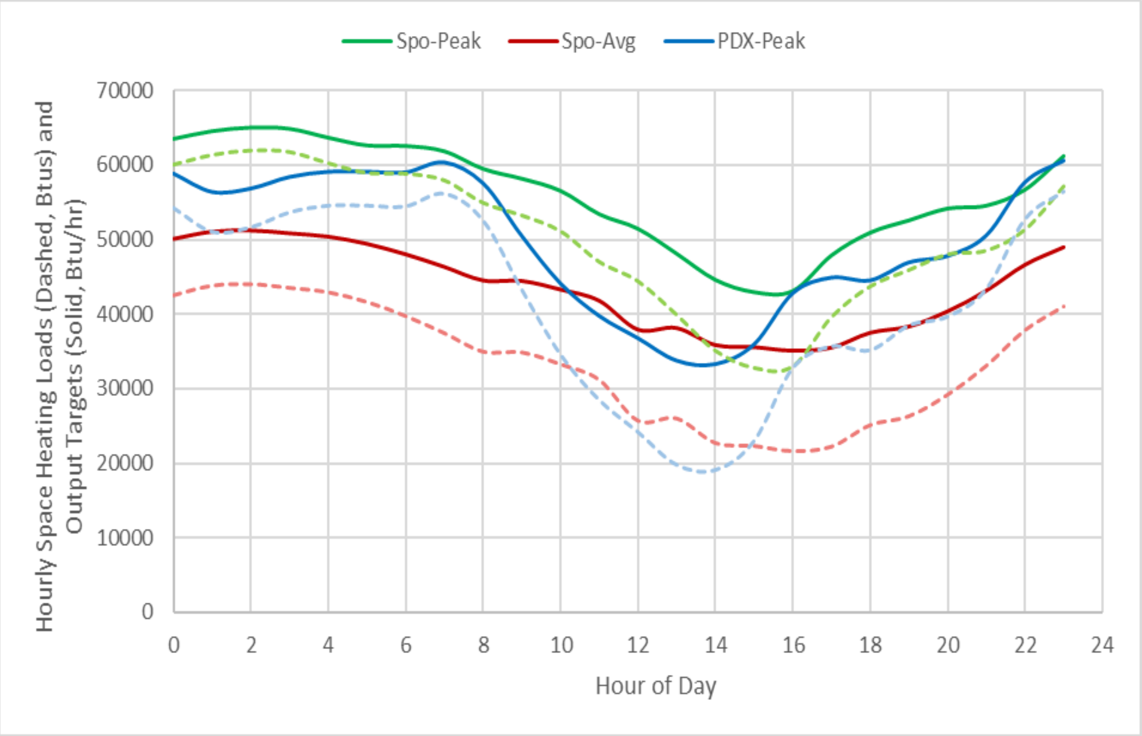
Where A = 2.096E+04, B = 6.199E-01, and C = 1.474E-06.



Low-Cost GAHP Component: Performance

The GAHP sequencing programs:

- At start of each hour, system activates in SH mode and SH control valve opens to meet Space Heating Output target at PHX (continuous adjustment).
- "Call for heat" remains until:
  - If call for DHW interrupts, rig shifts to DHW recovery mode while SH schedule "waits" until completed. Unmet SH load is tracked and added to next SH event.
  - If SH load is satisfied, unit cycles down while loop pump remains for several minute "wind down". All "wind downs" have a Output Target of 28,800 Btu/hr*.
  - If the hour elapses and there is unmet SH load, it is added to the next hour and the SH mode continues
- DHW loading (125 F sp), ambient temperature schedules are overlaid
  - If DHW recovery completes while SH load is met (rare), a DHW "wind down" also occurs for several minutes.



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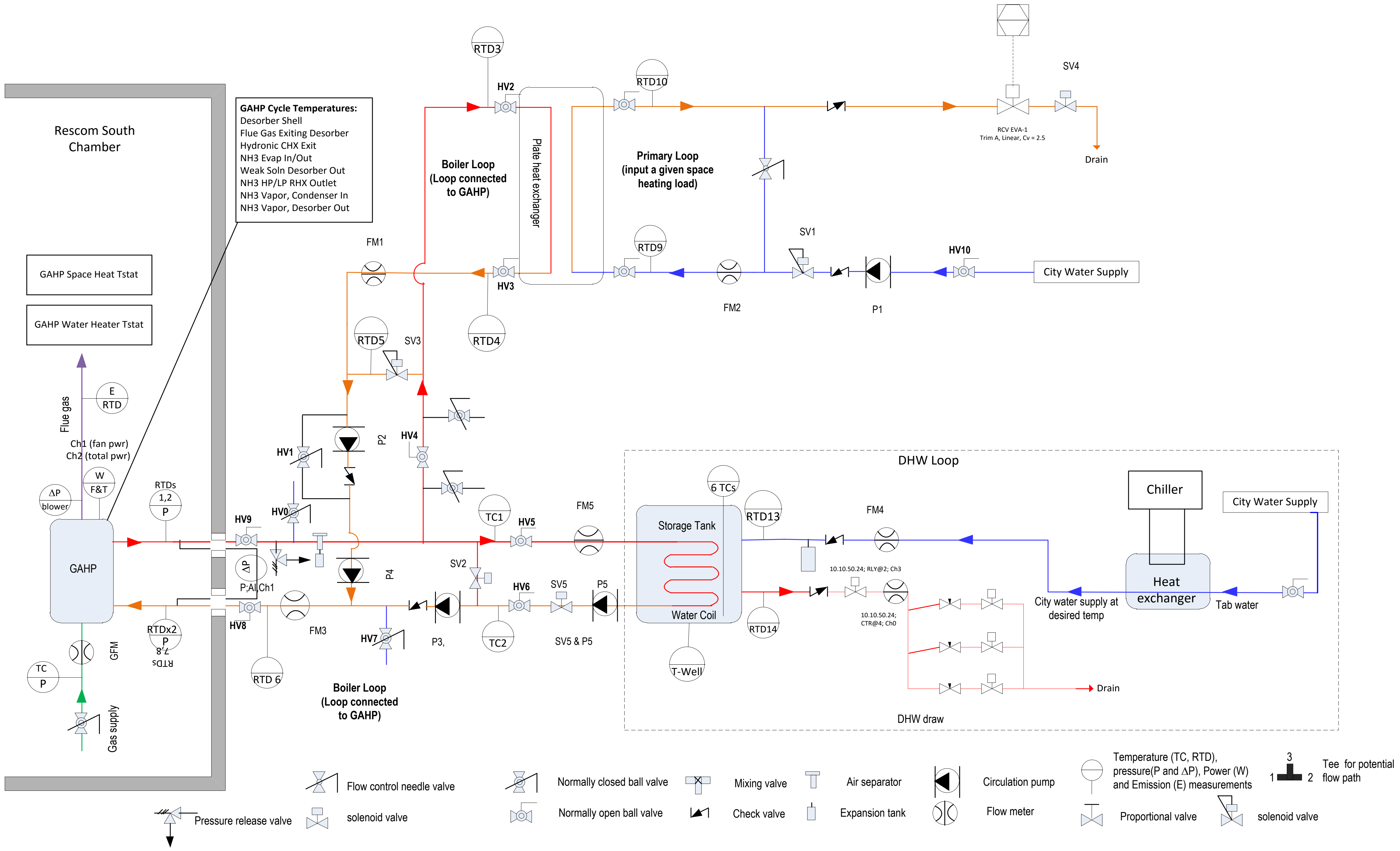
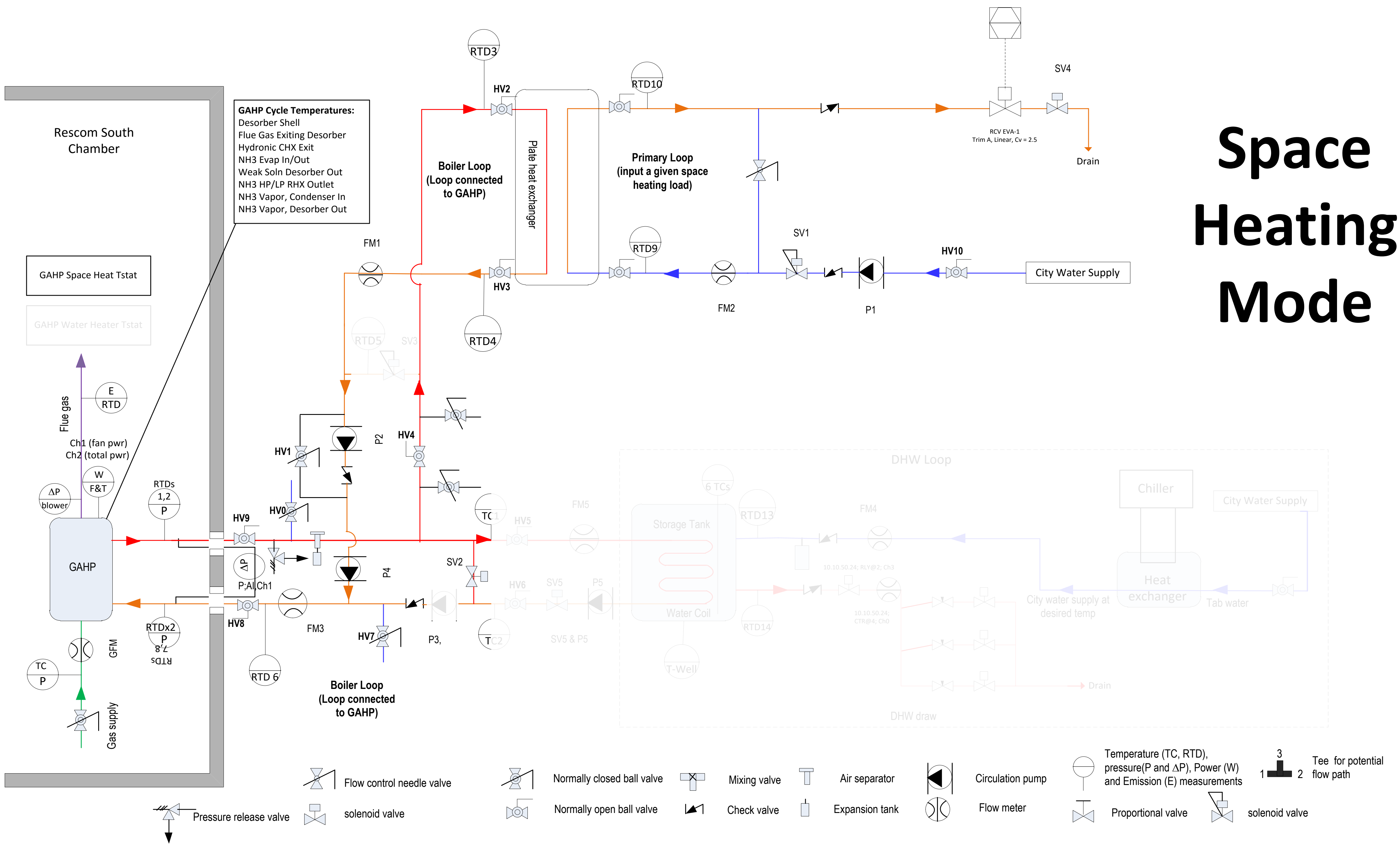
* Wind down output assumes 2400 btus extracted from loop in 5 minute period, for a 10 gallon volume in a loop with 8.0 Btu/gal*F (gly/H2O) dropping 30 F (125 F to 95 F)



Rescom South Chamber
GAHP Cycle Temperatures:
Desorber Shell
Flue Gas Exiting Desorber
Hydronic CHX Exit
NH3 Evap In/Out
Weak Soln Desorber Out
NH3 HP/LP RHX Outlet
NH3 Vapor, Condenser In
NH3 Vapor, Desorber Out
GAHP Space Heat Tstat
GAHP Water Heater Tstat
Flue gas
E RTD
Ch1 (fan pwr)
Ch2 (total pwr)
W F&T
ΔP blower
RTDs 1,2 P
GAHP
HV9
HV8
ΔP
P;AI,Ch1
RTDx2 P
RTDs 7,8
GFM
TC P
Gas supply
RTD 6
FM3
Boiler Loop (Loop connected to GAHP)
RTD3
HV2
HV3
RTD4
FM1
RTD5
SV3
Boiler Loop (Loop connected to GAHP)
Plate heat exchanger
RTD10
Primary Loop (input a given space heating load)
RTD9
FM2
SV1
P1
HV10
City Water Supply
SV4
RCV EVA-1
Trim A, Linear, Cv = 2.5
Drain
HV1
P2
HV4
HV0
P4
HV7
P3,
SV2
TC1
HV5
FM5
HV6
SV5
P5
TC2
SV5 & P5
DHW Loop
6 TCs
Storage Tank
RTD13
Water Coil
RTD14
T-Well
FM4
10.10.50.24; RLY@2; Ch3
10.10.50.24; CTR@4; Ch0
Chiller
City Water Supply
Heat exchanger
City water supply at desired temp
Tab water
Drain
DHW draw
Flow control needle valve
Normally closed ball valve
Mixing valve
Air separator
Circulation pump
Temperature (TC, RTD), pressure(P and ΔP), Power (W) and Emission (E) measurements
3
1
2
Tee for potential flow path
Pressure release valve
solenoid valve
Normally open ball valve
Check valve
Expansion tank
Flow meter
Proportional valve
solenoid valve



Space Heating Mode

DHW Recovery Mode