ET Summit 2024

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Demonstrating an Integrated Thermal Heat Pump System for Hot Water and Air-Conditioning at Full-Service Restaurants

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Potential for Energy and Emissions Savings

- Service hot water (SHW) remains an important efficiency target in multifamily (MF) and restaurants*
  - 1st gas load in MF (50%), 2nd in restaurants (23%)
  - In CA, restaurants use > 340 million therms/yr**
- Typically boiler + Indirect Storage Tank (IST) (dedicated/zone) or storage-type
  - Racked tankless products evaluated in parallel GTI demos

*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.

**Data Source: EIA RECS (2015), DNV Kema, "California Energy Commission Energy Efficient Natural Gas Use in Buildings Roadmap", public presentation (2013).

Potential for Energy and Emissions Savings

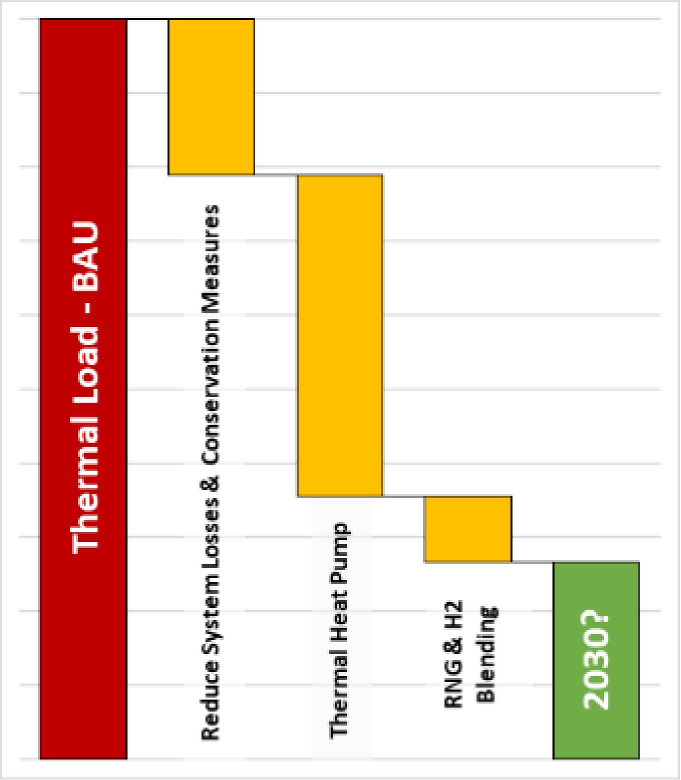
- Industry push to >90% eff., >2X over ’09-’19 to ~50%***
- Must go beyond condensing, leverage innovations in thermal heat pumps Air/water-to-water THPs available, more under development****
  - Retrofit-ready, raise net eff. > 100% of SHW system
  - Optional ‘free cooling’

***Data Source: AO Smith (2020) / ****GTI & Brio Gas Heat Pump Technology and Market Roadmap (2019)

Thermal Heat Pumps

- Primary advantage of THPs is >40% reduction in gas consumption over baseline
  - Studies indicate >1.20 UEF, >140% AFUE feasible*
  - Better retain capacity, efficiency in cold climates**
- Add'l benefits include, typically:
  - Combustion outdoors or sealed, no IAQ concern
  - Climate-friendly natural refrigerants (NH_3, CO_2)
  - Multi-function appliance w/ heat recovery

Reducing GHG Impact



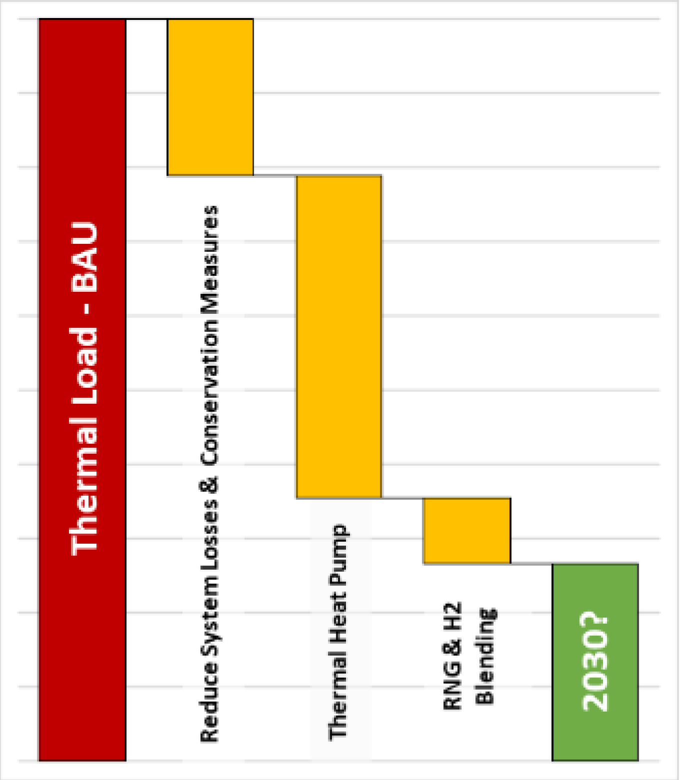
*Glanville, P. et al. *Integrated Gas-fired Heat Pump Water Heaters for Homes: Results of Field Demonstrations and System Modeling,* ASHRAE Transactions . 2020, Vol. 126 Issue 1, p325-332

** Glanville, P. et al. *Demonstration and Simulation of Gas Heat Pump-Driven Residential Combination Space and Water Heating System Performance,* ASHRAE Transactions . 2019, Vol. 125 Issue 1, p264-272

Thermal Heat Pumps

- Key piece in thermal load decarbonization puzzle
  - Address low-hanging fruit with system losses, conservation (e.g. demand recirculation)
  - THP partial/full retrofit
  - Further reductions with low-carbon fuels (25% blend shown, higher is feasible)

Reducing GHG Impact



Integrated System Design

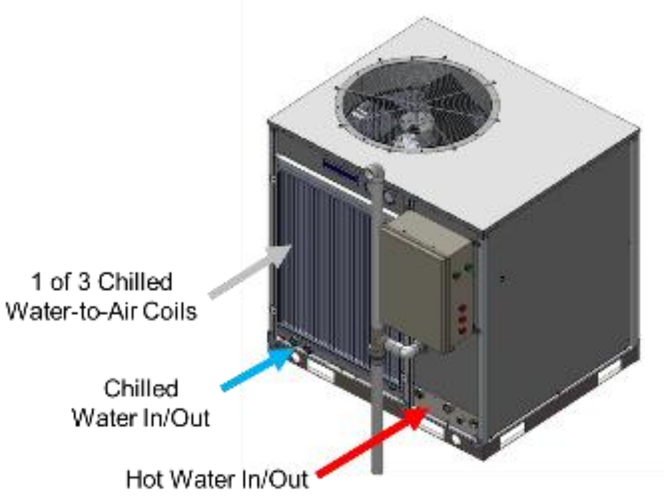
<u>"Skidding" the THP System</u>

- Factory assembled, plumbed
- 80 kBtu/hr THP with chilled water-to-air coils replacing refrigerant-to-air evaporator coil
- 113 gallon (428 L) IST
- Skid dimensions:

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

<u>Indoors/Balance of System</u>

- Chilled Water Fan Coil, conv. gas-fired water heaters, controls



Test Sites & Existing Equipment

Site #1: 24-Hour Diner

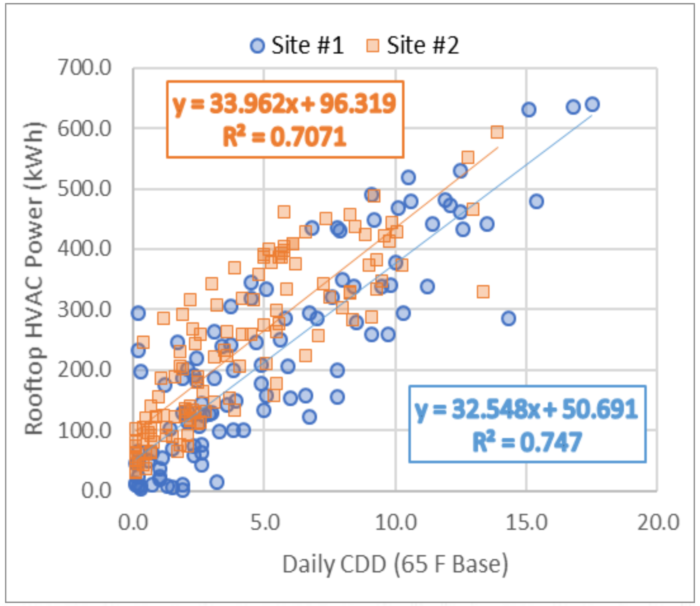
- Mgr estimated 1400 meals/day (Sa/Su), 900 meals/day (M-Th), and 1200 meals/day (Fri); ~3,500 gal/day
- Water Heating: Two Storage GWHs; 100 gal/270 kBtu/hr input each; 82% TE and atm. venting
  - Both set to 140°F, 180°F booster at dish machine, 24/7 recirculation
- HVAC: 1 RTU, 5 HPs

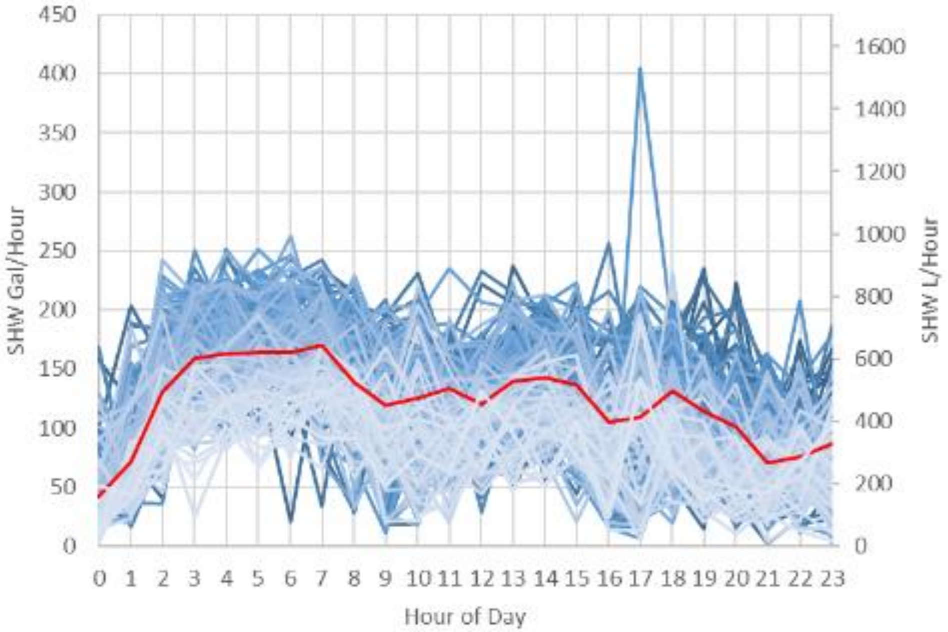
Site #2: Full-Service Restaurant (FSR)

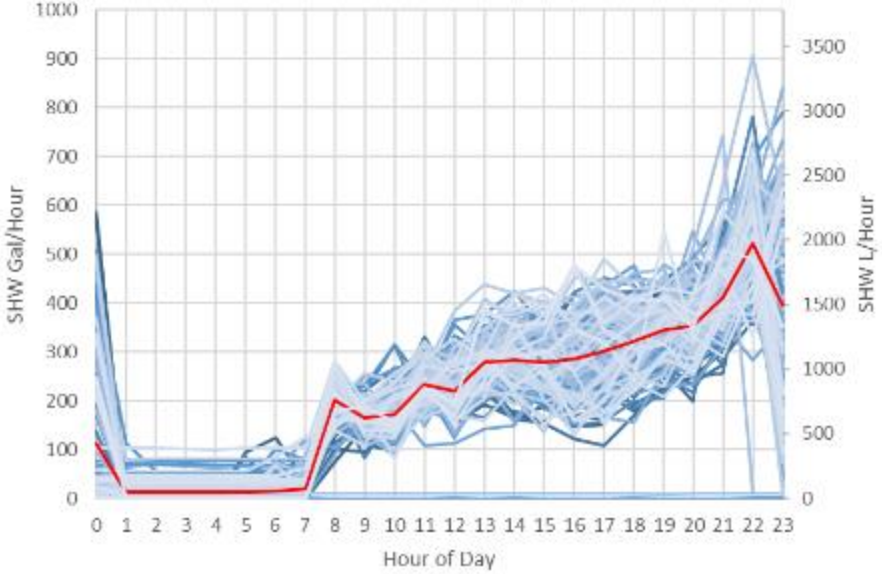
- Mgr estimated 1,260-2,800 meals/day, ~6,000 gal/day
- Water Heating: Two Storage GWHs; 100 gal each, BTH 199 and BTH 250; 97% TE
  - Also set to 140°F, 180°F booster at dishmachine, 24/7 recirculation
- HVAC: 5 RTUs

Baseline Data Collection – 7 mo.

	Average SHW: Gal/day	Peak SHW: Gal/day	Peak SHW: GPM	SHW Inputs: Therms/kWh	Delivered Est. SHW Efficiency	Annual HVAC A/C Demand: MWh
Site #1: 24-hr Diner	2,722	3,736	11.9	8,300 / 716	70.0%	79.0
Site #2: FSR	4,821	6,995	19.7	13,100 / 966	79.1%	71.0







Integrated THP System - Operation

Near constant THP operation over 12 months

- Continuation of SHW demand at both sites during THP period
- Calls for cooling observed year-round

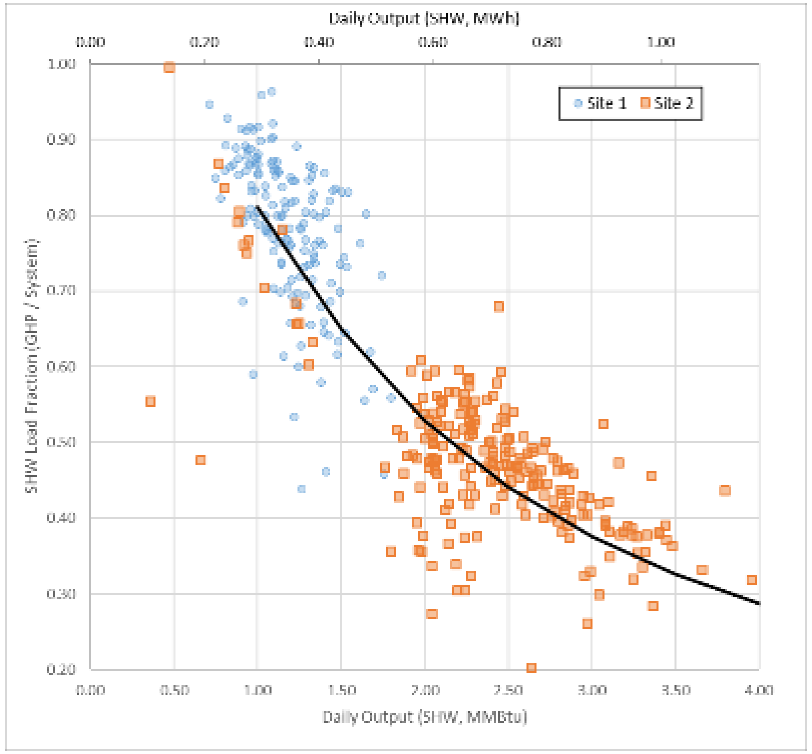
Wide range of conditions observed

- Outdoors 35ºF-111ºF
- THP return 100°F-125°F

	Site #1 24 h Diner	Site #2 FSR
THP Cycles	1157	597
THP Hours	4792	4224
Average COP_{Gas} SHW (SHW + A/C)	1.10 – 1.30 (1.30 – 1.70)	1.25 – 1.45 (1.40 – 1.90)
Average SHW Gal/day	2,226	4,396
Avg. T Rise °F	66.1	70.7
Average THP Load Fraction	73.7%	43.2%

THP @ Site #1 serves a smaller demand, thus is "load-following", leading to:

- Greater THP utilization, BUT
- Greater fluctuations in THP operation
- Lower overall efficiencies

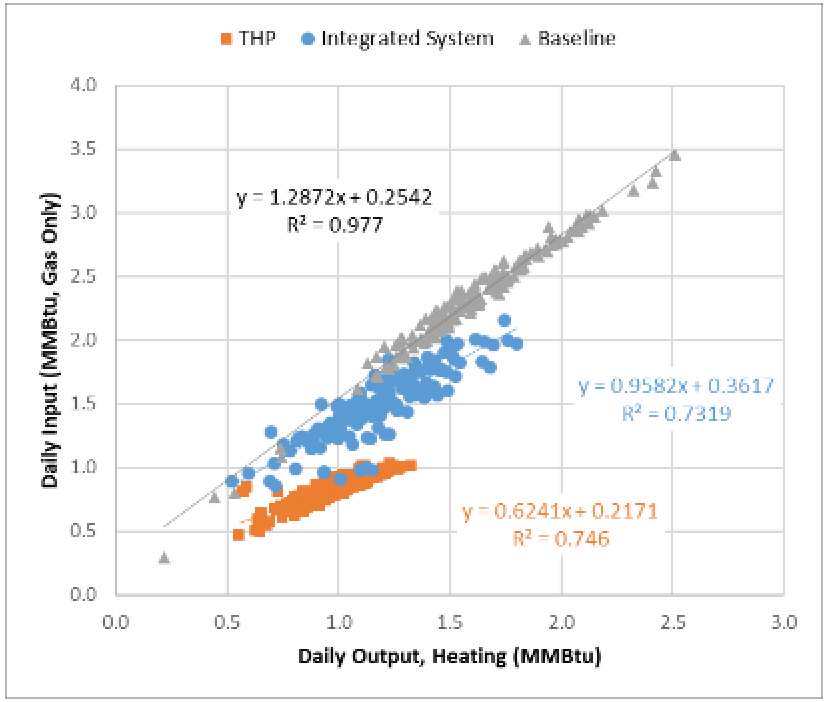


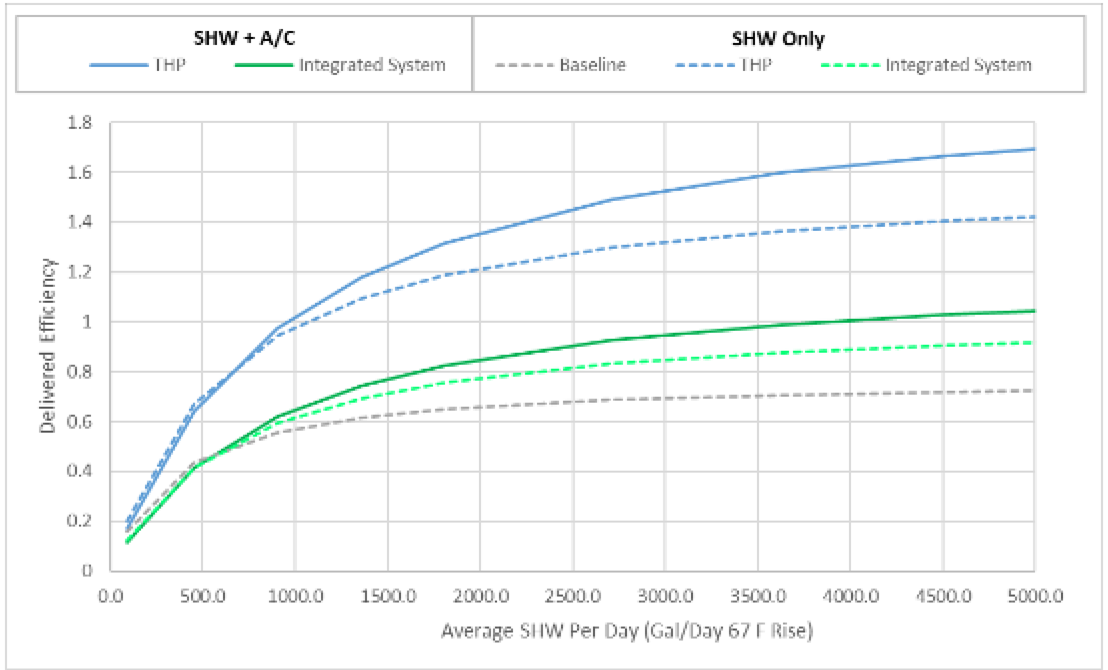
Integrated THP System - Efficiency

$$Input = m \cdot Output + b;$$

$$\frac{Output}{Input} = DEF = \left(m + \frac{b}{Output}\right)^{-1}$$

- "Input/Output" approach used (Site #1 Highlighted)
  - Site #1 therm savings = 16% (system); 52% (GHP only)
  - Site #2 therm savings = 26% (system); 53% (GHP only)
- For Site #2, typical demand translates to COP of 1.65 (THP), 1.10 (Overall System), and 0.75 (Baseline)

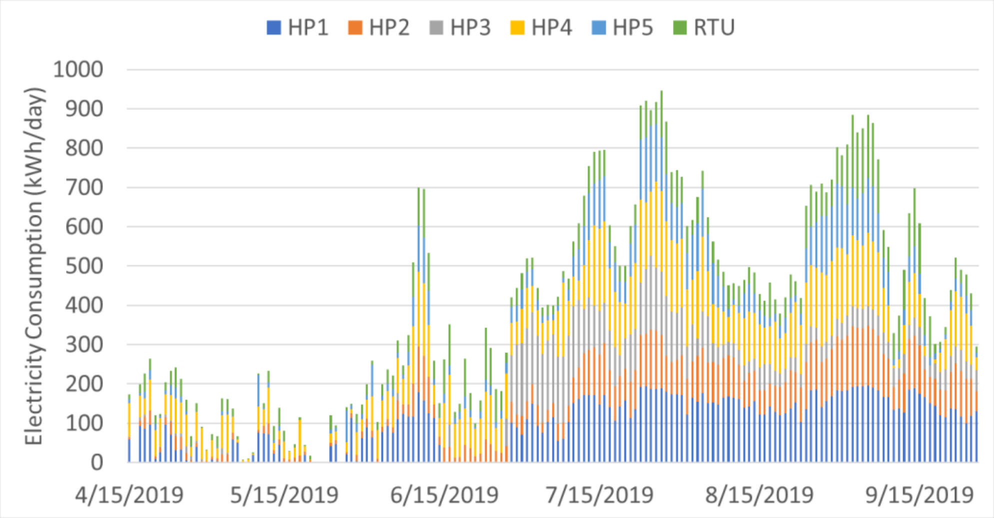


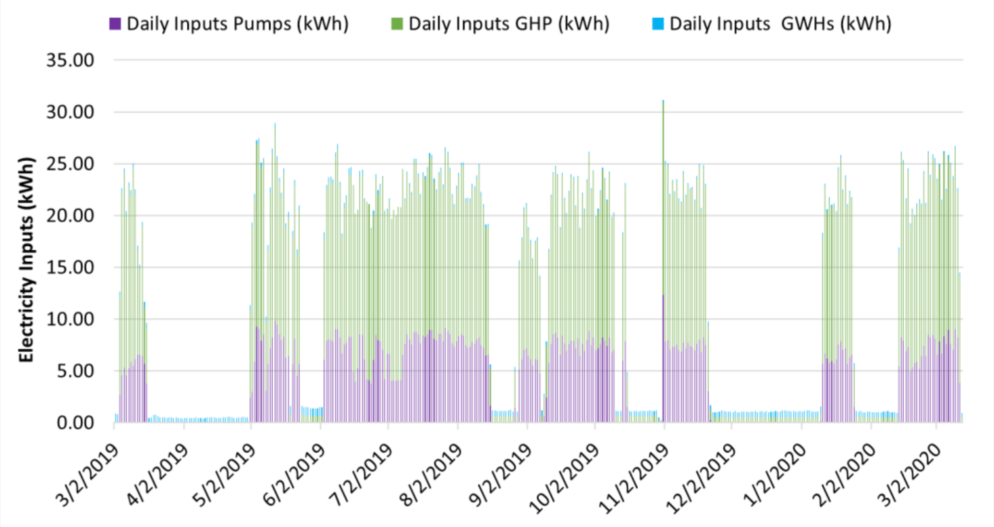


Integrated THP System – Power Demand

Power Consumption:

- THP power 10-15 kWh/day
- Gas water heaters (small contribution)
- Circulation pumps important (≈ 50% GAHP*), FCU ≈ 550 W
  - Higher ΔP led to low flow (lower A/C perf.) and higher power draw
- For supplemental A/C, ~5,500 ton-hrs delivered across sites (at coil)
- Weather-adjusted reduction in annualized monitored HVAC
  - Savings at Site #1 = 10,820 kWh; Site #2 = 9,660 kWh
  - 13.7% and 13.6% respectively





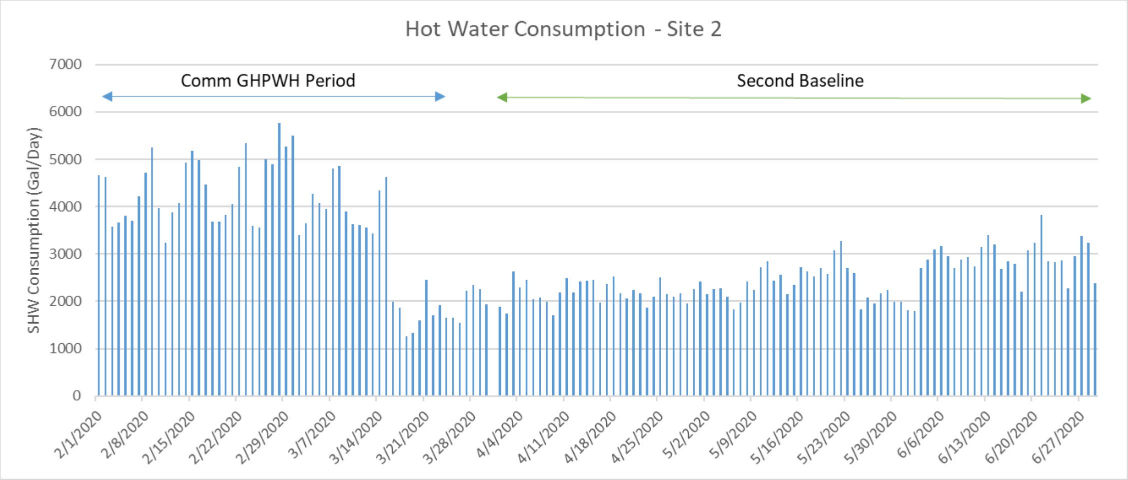
Integrated THP System – Economics

Large impact of THP sizing

- As-is, payback is attractive for high-usage Site #2
- Modeling suggests sizing THP to meet 30%-60% of peak load is "sweet spot"

Net elec. increase assumes all cooling is useful

- Assumes $0.91/therm; $0.15/kWh; GHG - 1,178.7 lb/MWh elec.; 144.2 lb/MMbtu gas
- Assessment was based on pre-COVID demand



	Site #1 24 h Diner	Site #2 FSR
Average SHW Gal/day	2,226	4,396
Avg. T Rise °F	66.1	70.7
Average THP Load Fraction	73.7%	43.2%
Fuel Savings – System As-Is	16%	26%
Fuel Savings – THP Right-size	52%	53%
Net Electricity Increase (kWh/day)	8.3	6.9
Operating Cost Savings – Gas (Net)	$967 ($617)	$2,775 ($2,527)
Simple Payback – Fuel Basis	2.0 – 6.4	1.1 – 2.2
GHG Reduction – THP Right-size Lbs/yr (%)	44,610 (46%)	82,330 (48%)

Questions / Comments

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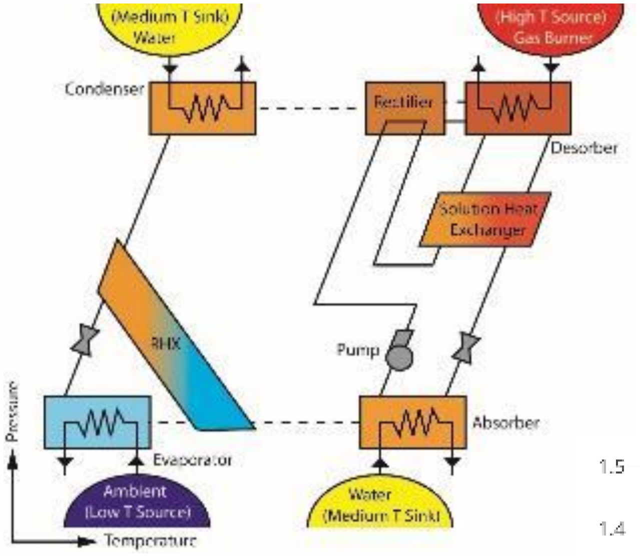
Learning Objectives

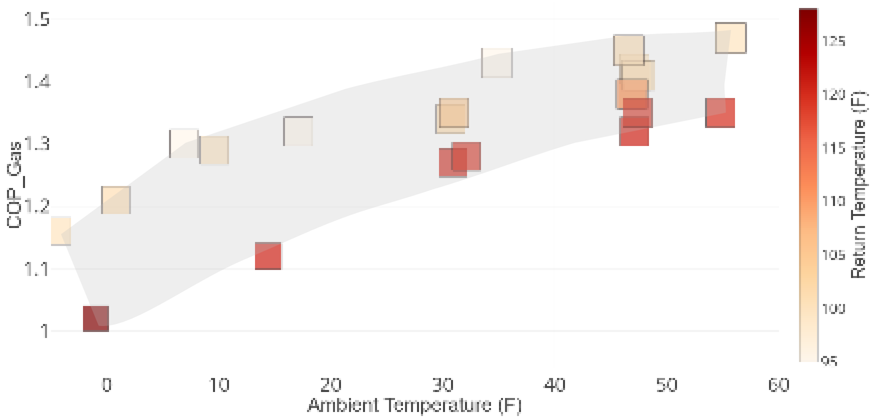
- Define the benefits of thermal heat pumps (THP) as applied to commercial water heating.
- Understand some of the design tradeoffs when sizing the heat pump component in an integrated system.
- Understand the difference between the three zone and the five zone model.
- Apply this five-zone model to commercial heat exchanges
- Measure local heat transfer coefficient in the plate heat exchanger.
- Visualize flow regime in plate heat exchangers.

Project Support: Utilization Technology Development, SoCalGas, and the California Energy Commission (PIR-16-001). Final Report

THP – Absorption Cycle

- HP Component is comprised of:
  - Heat exchangers: Absorber, Condenser, Desorber, Evaporator, Rectifier, RHX, and SHX
  - Solution pump
  - Expansion: EEV & WS Let Down

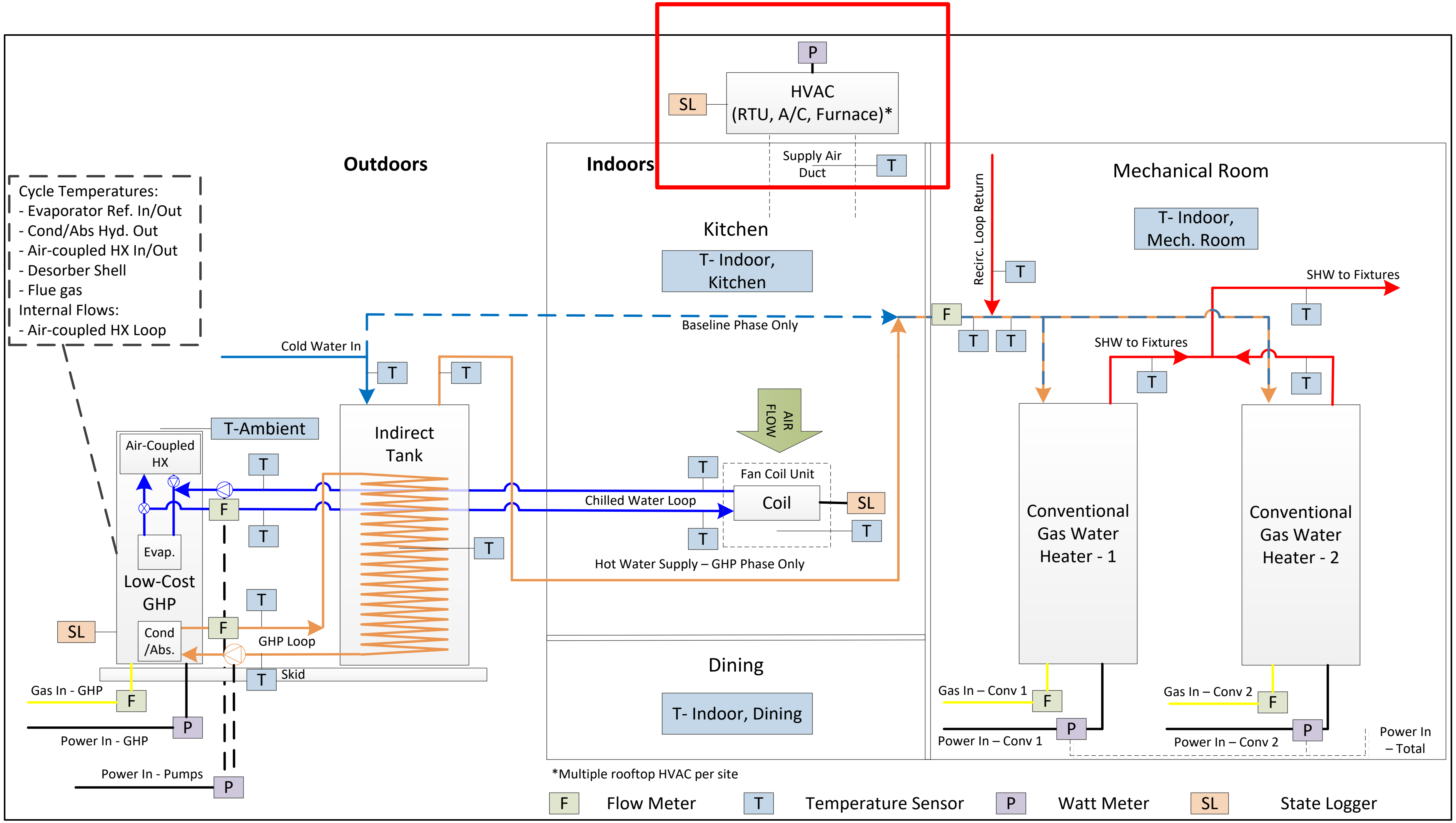




140% AFUE for HVAC Applications per GTI Testing*

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

Monitoring Plan



Integrated THP System - Installation

Siting:

- Neither site met req's on spacing for THP, evaporator coil was closer than recommended to adjacent wall
- Indoor FCU was in suboptimal location at both sites, concerns of existing MEP in drop ceiling dictated placement
  - OTS FCU performance sub-par, high hydronic ΔP, one had internal damage

Closed Loops

- Air removal challenging, particularly ChW loops, after commissioning & servicing.
- ChW pumps undersized for fittings & instrumentation, below target flow rate for both sites – mainly Site #2

Calibration

- Only calibration applied to critical hydronic loop temperatures (sup/rtn X 2)