Enabling Electrification of Domestic Hot Water and Space Conditioning with Multi-Function Heat Pumps (MFHP)

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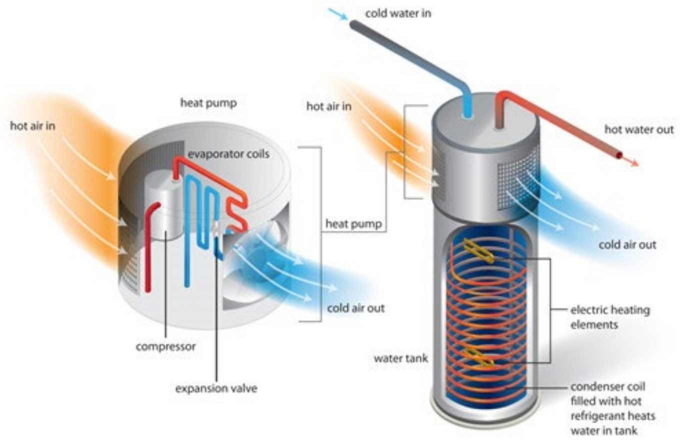
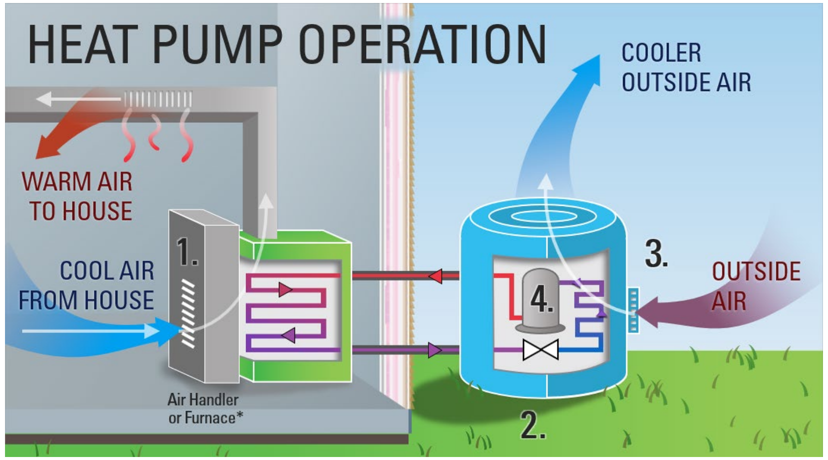
Motivation

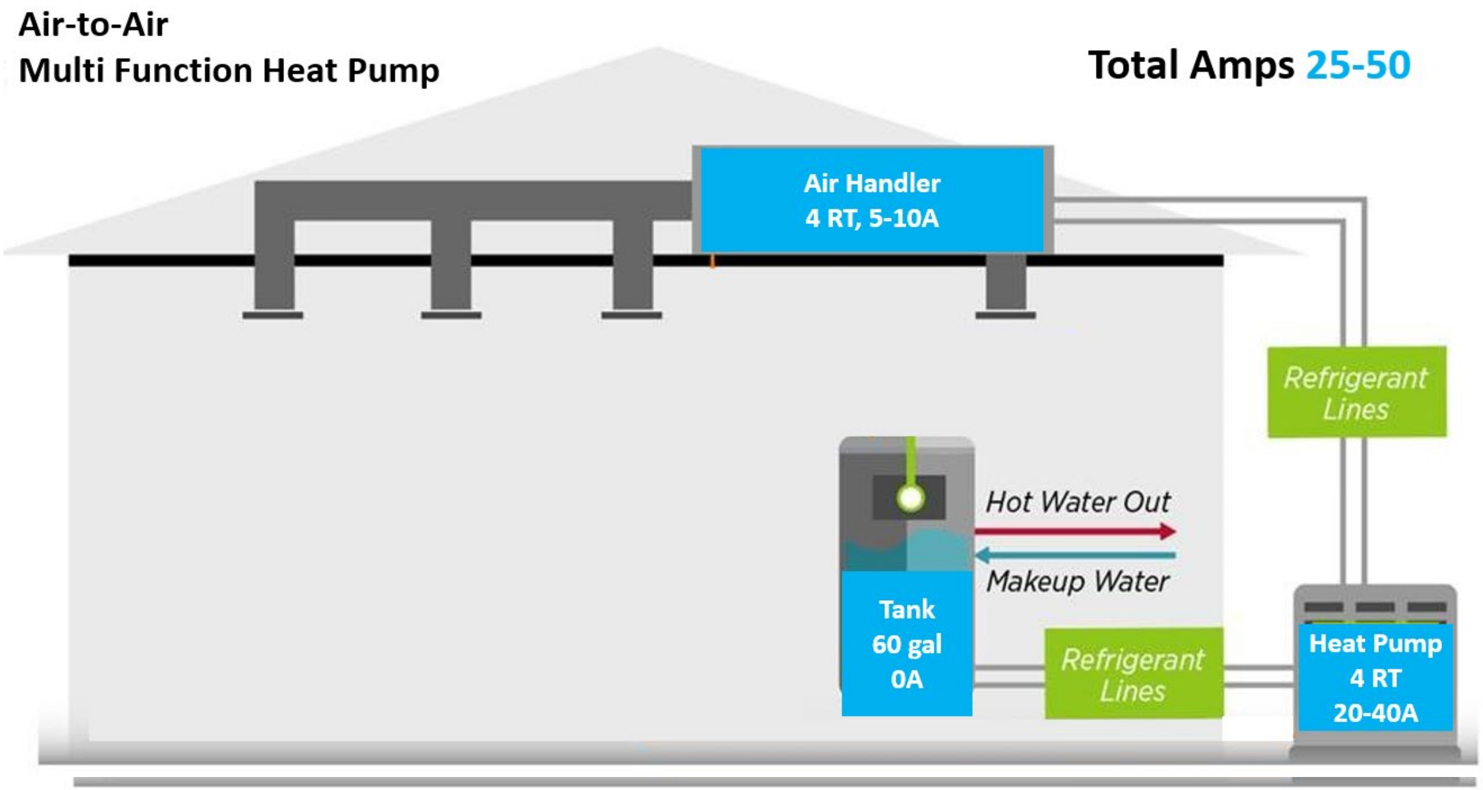
- Onsite GHG emissions from U.S residential buildings 323 Mmt/yr (Source: EIA)
- Electrification of space heating and domestic hot water (DHW) is necessary
- Heat pump water heaters
  - Small compressors
  - Electrical resistance for DHW demand
  - Dedicated electric circuit of 30A
  - Requires air exhaust connections
- Heat pumps for space conditioning
  - Electrical resistance is required for defrosting
  - Dedicated 35 to 45 Amp circuit for air handler



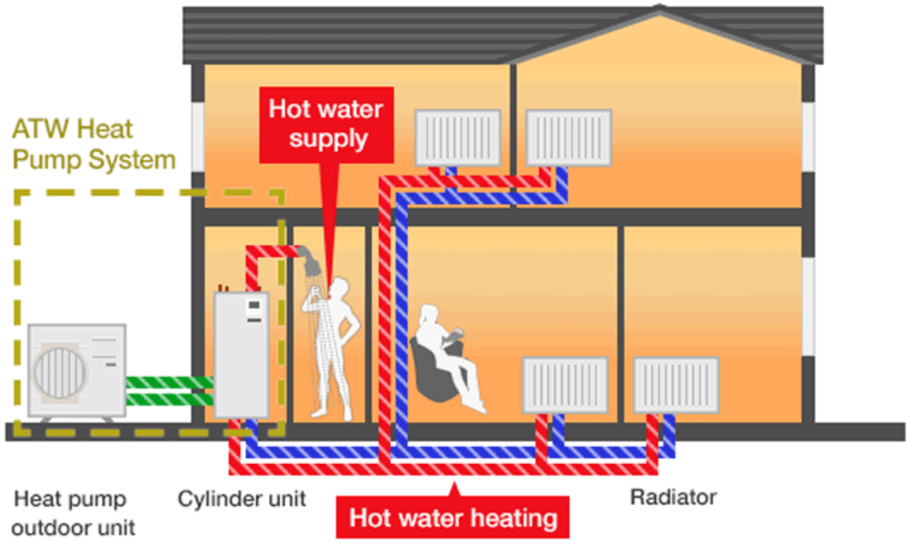


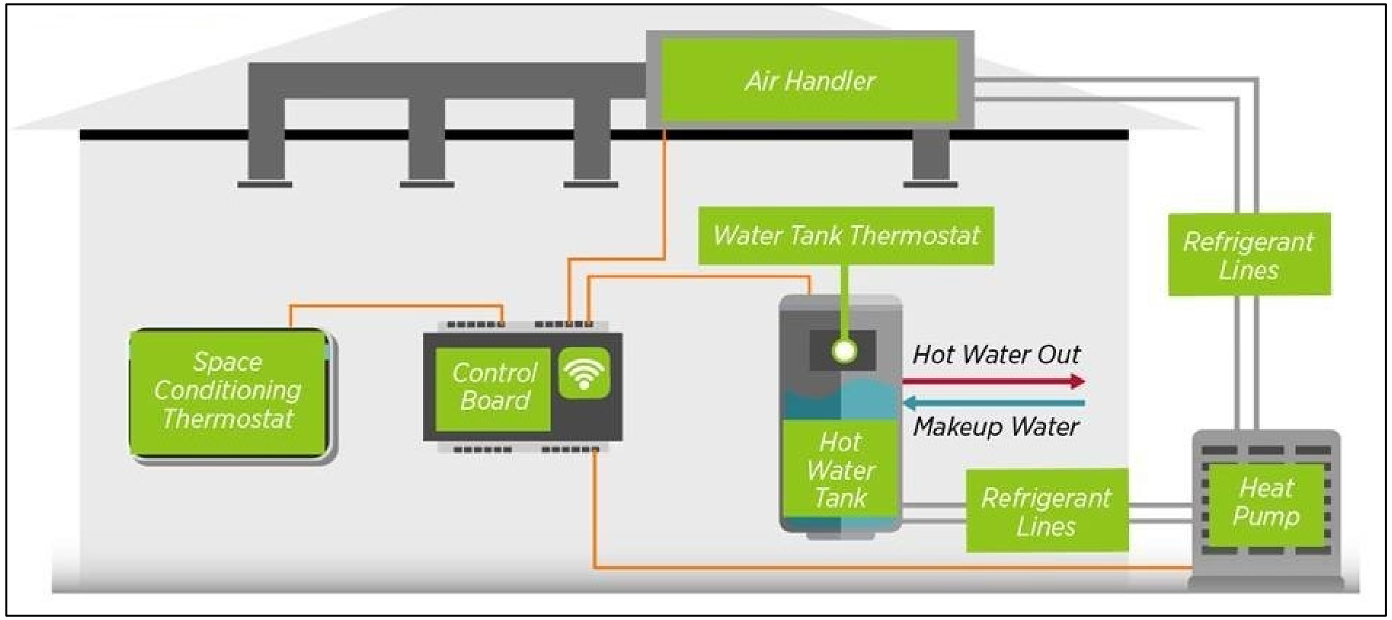
MFHP as Retrofit

- Separate heat pumps for space conditioning and water heating
  - Higher electrical panel capacity requirement
  - Higher installation cost
  - Severe delays and increased cost with service upgrade
- 50% of U.S homes would need electric panel upgrades
- MFHP system eliminates electric resistances
  - Large compressor for DHW
  - Defrost uses water tank heat



Other Heat Pumps





Air to Water Heat Pumps

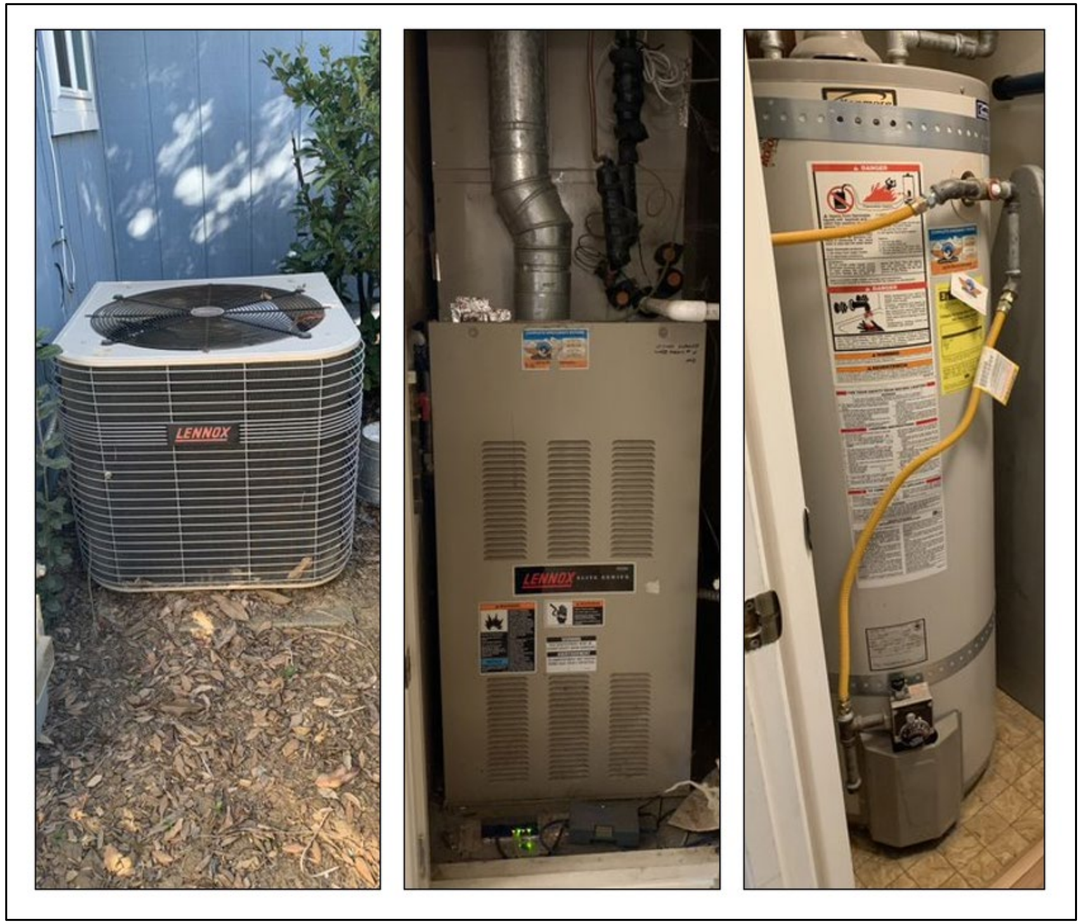
- Hydronic heating and cooling
- CO2 based HPs lack efficient cooling operation
- Separate storage for hot and cold water
- Not ideal for retrofit in ducted households

Air-to-Air MFHP

- Uses the same circuit as the air-conditioner
- Ideal for retrofit in existing ducted U.S homes
- Unique higher efficiency mode for simultaneous space cooling (AC) and water heating (WH)

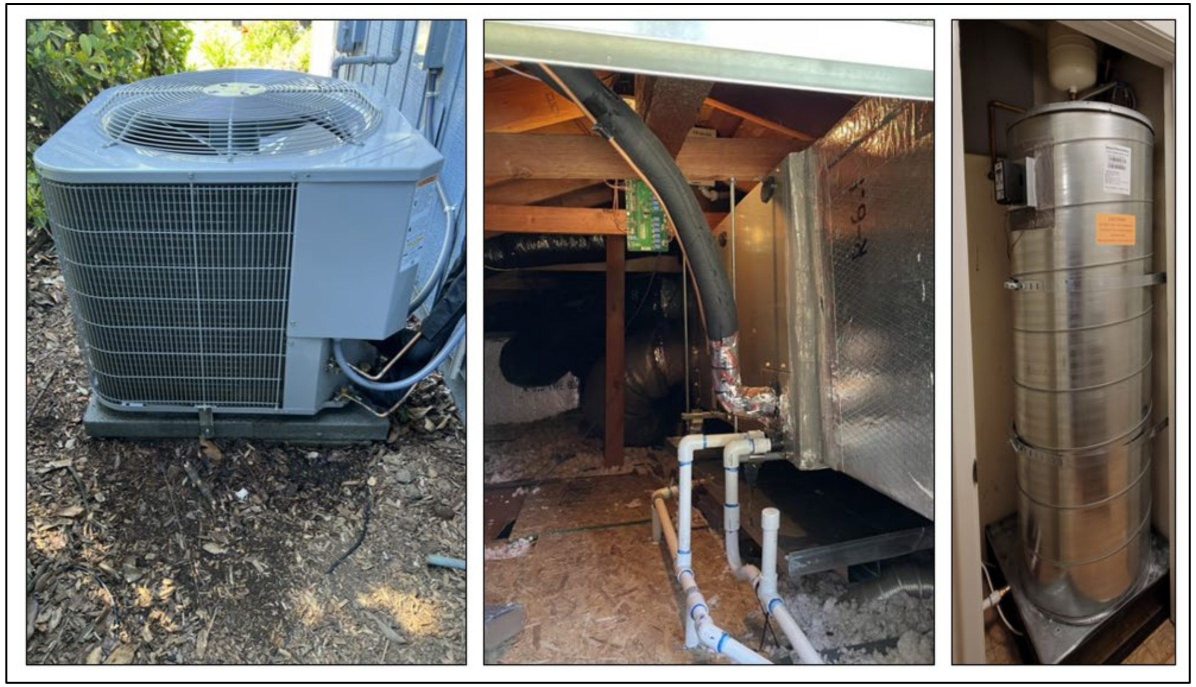
Pre-retrofit

- 2000 sq. ft single family home in Davis, CA
- AC of 12.3kW (3.5 RT)
- Natural gas furnace 29.3kW (100 MBH/hr)
- Natural gas boiler of 11.7 kW (40 MBH/hr)
  - 189-liter (50 gallon) tank
- Electrical panel limited to 100 amp
- Line to the utility transformer limited to 125 amp



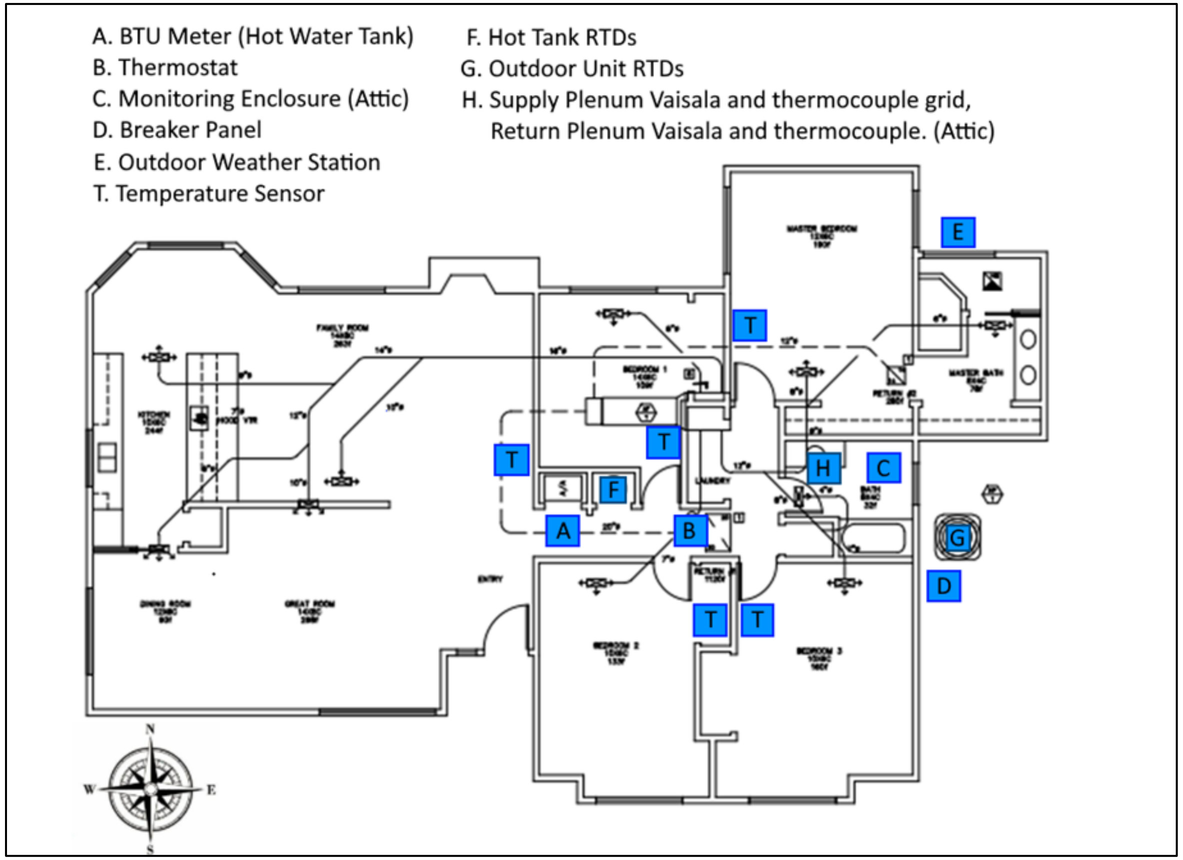
Post-retrofit with MFHP

- Air-to-air single speed R410A MFHP
- Outdoor unit cooling capacity of 14kW (4 RT)
- Modified from 16 SEER Heat pump
- Air handler unit (AHU) 2480 m^3/hr (1460 CFM)
- 227 liter tank (60 gallons)
- Water Tank placed in the same closet as pre-retrofit DHW boiler
- No resistance heat installed in tank or AHU
- MFHP modes:
  - AC
  - DHW
  - AC and DHW
  - Space heating
  - Defrost mode



Instrumentation

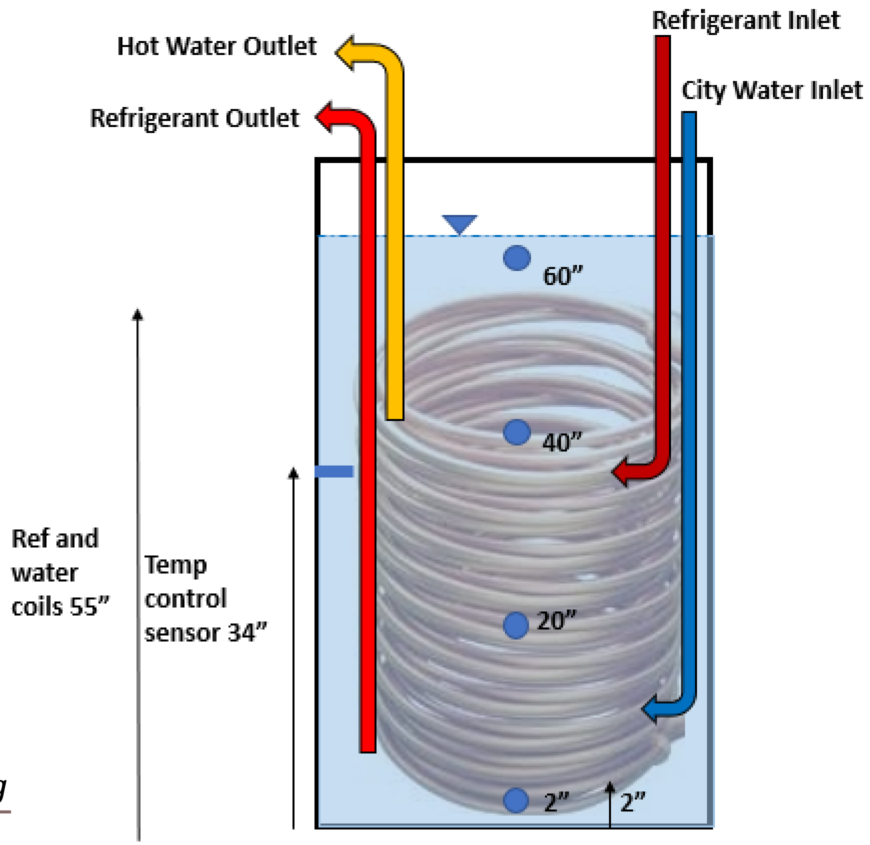
Type	Locations	Manufacturer/Model
Temperature/RH	Supply and Return Plenum	Vaisala HMD62
Temperature/RH	Outside	Vaisala HMS100
Temperature	Supply duct and return plenum	Type T Thermocouple
Temperature	Outdoor unit and Hot Water Tank	Omega PR-10L RTD
Digital I/O State module	MFHP Controller	ICP DAS M-7059D
Power meters	Outdoor unit and Air Handler	Wattnode WND-WR-MB
BTU meter	Hot Water Tank outlet	Onicon System 40



Data Analysis

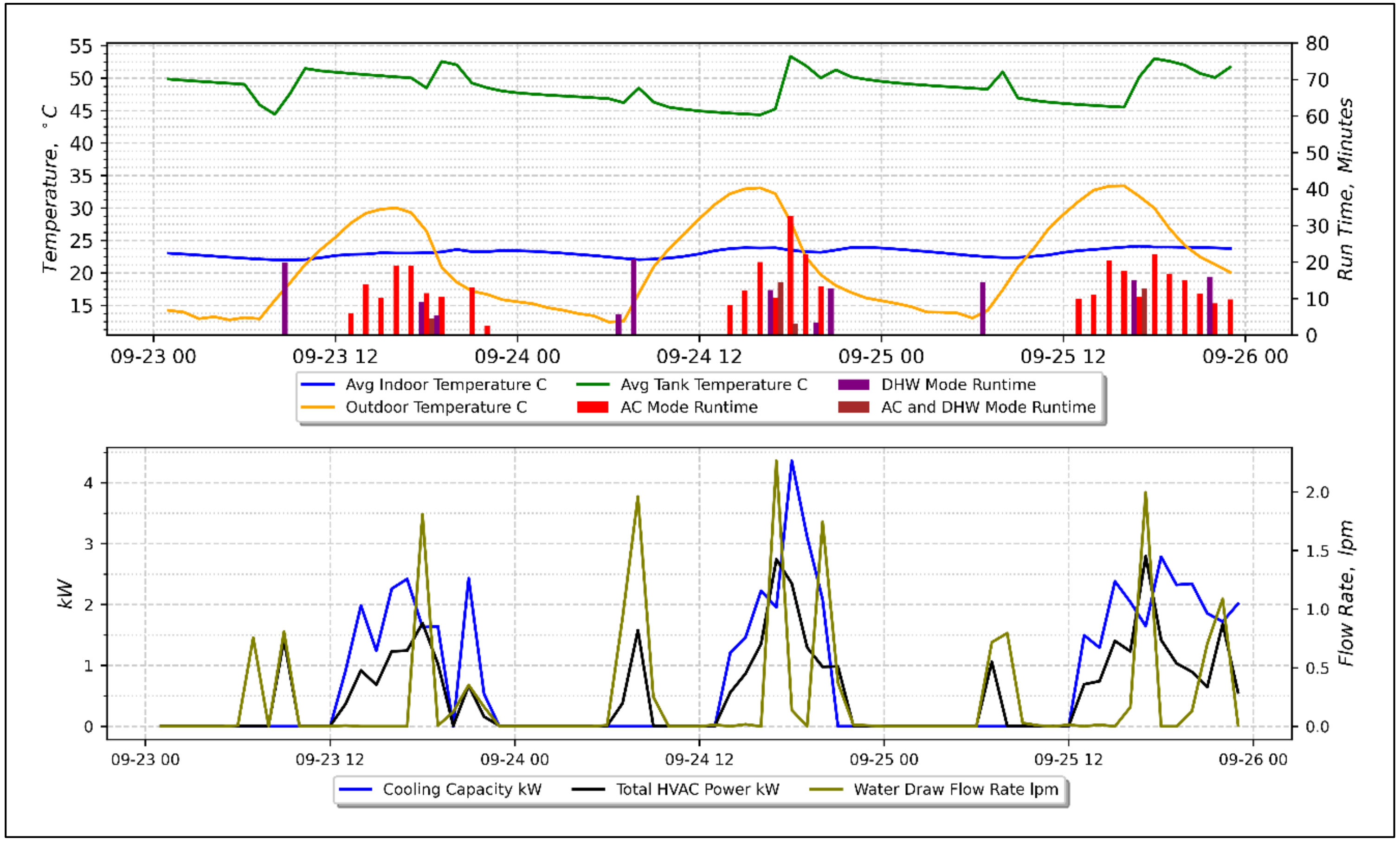
- Heat rate in DHW draws $$Q_{Water} = c_{p_{water}} \rho_{water} \dot{V}_{water} \Delta T$$
- Heat rate of Thermal Energy Storage (TES) charge $$Q_{TES} = m_{TES} c_{p_{water}} \frac{\Delta T_{avg,Tank}}{\Delta t}$$
- Total heat rate of the condenser during DHW mode $$Q_{DHW} = Q_{TES} + Q_{Water}$$
- Cooling capacity $$Q_{cooling} = \rho_{air} \cdot \dot{V}_{air} \cdot (H_{return} - H_{supply})$$
- Coefficient performance

$$COP_{\mathrm{AC}} = \frac{Q_{cooling}}{P_{total}} \qquad COP_{\mathrm{DHW}} = \frac{Q_{DHW}}{P_{total}} \qquad COP_{AC+DHW} = \frac{Q_{DHW} + Q_{cooling}}{P_{total}}$$



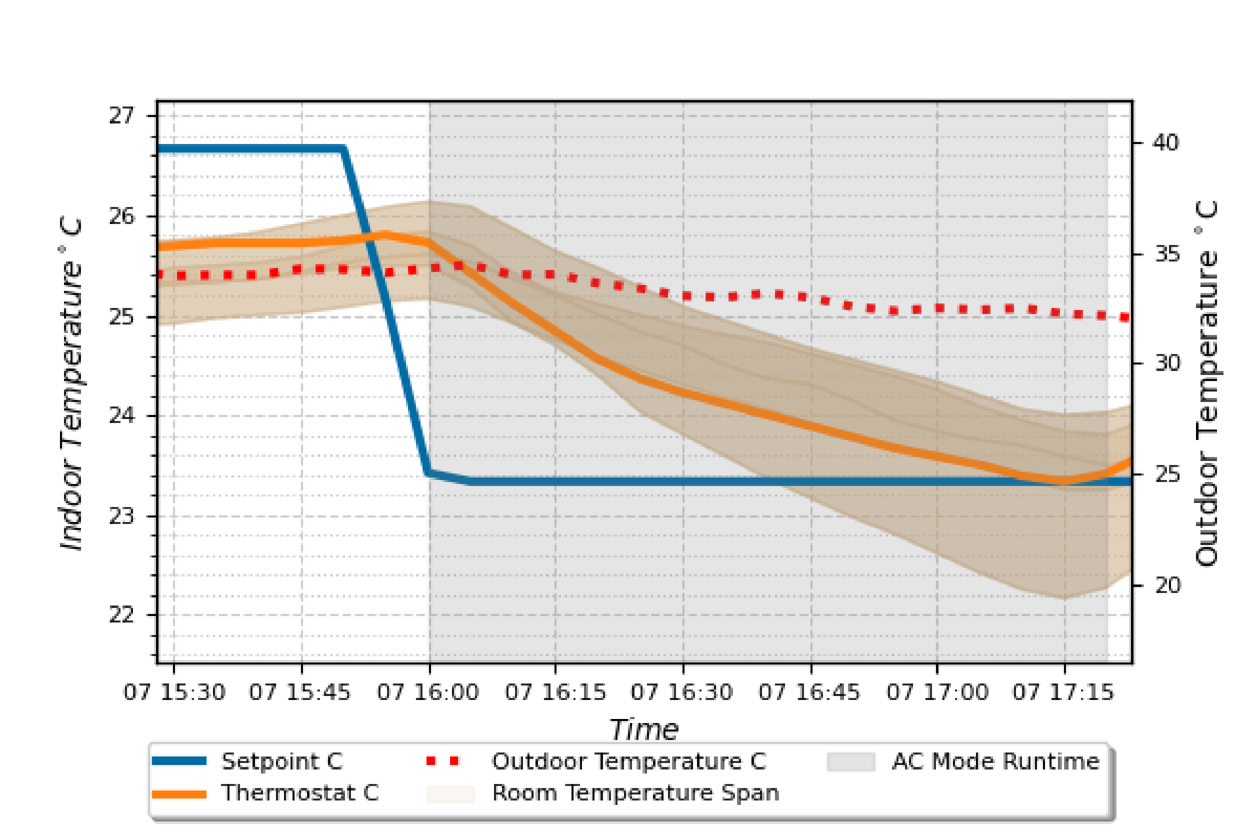
Results - Hourly

- MFHP kept indoor temperature constant while outdoor fluctuated
- DHW mode brings the tank average temperature above 50° C
- Runtime of the MFHP modes shown
  - Short AC cycling times
  - Infrequent and short simultaneous AC and DHW mode
- Cooling capacity larger than power draw -> average COP > 1



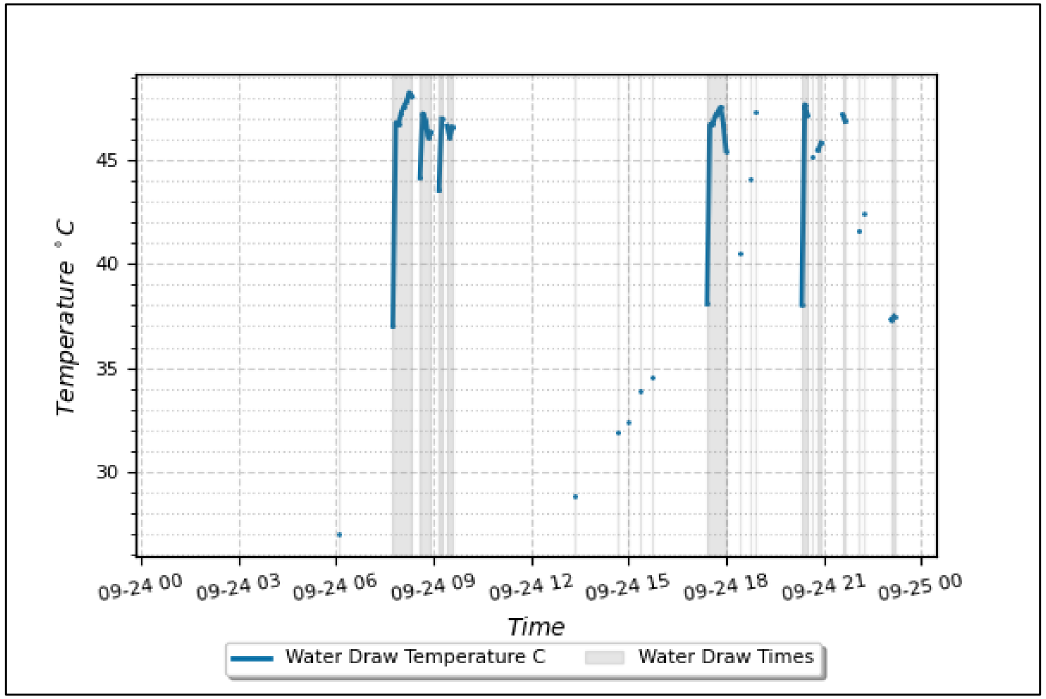
Results – House Cooling

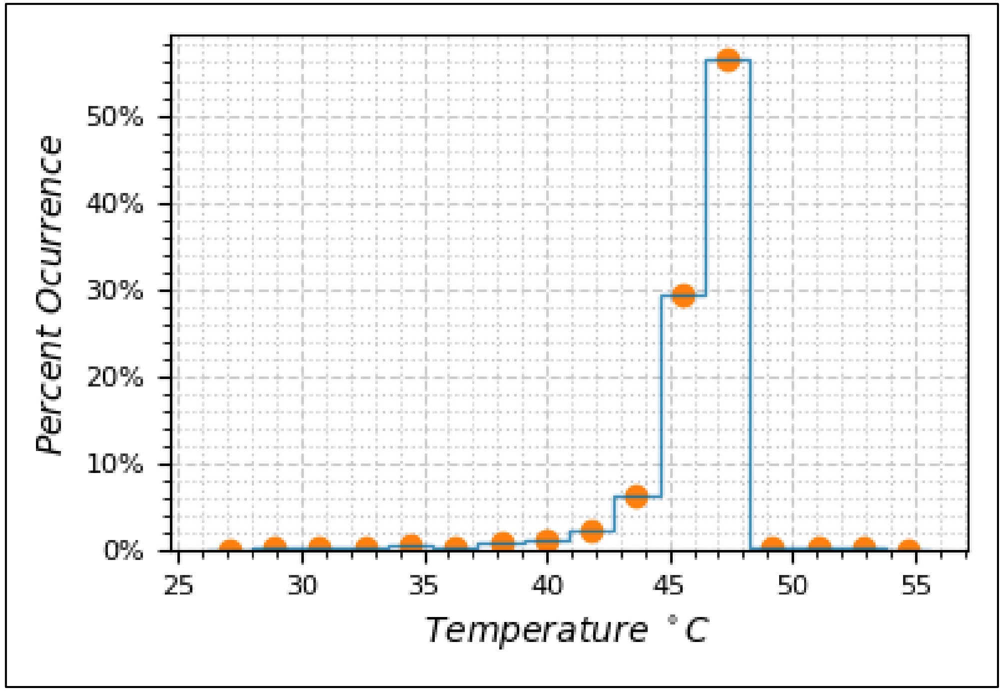
- Ecobee remote sensors are placed in each room
- Tracked the ability of the MFHP to effectively cool
- Observed temperature response for step input



- Ecobee set point changed from 26.7°C to 23.3°C
- Thermostat showed a drop of 1.5°C first 30mins
- Span of room temperatures increase as solar gains effect temperature of particular rooms

Results – DHW delivery temperature



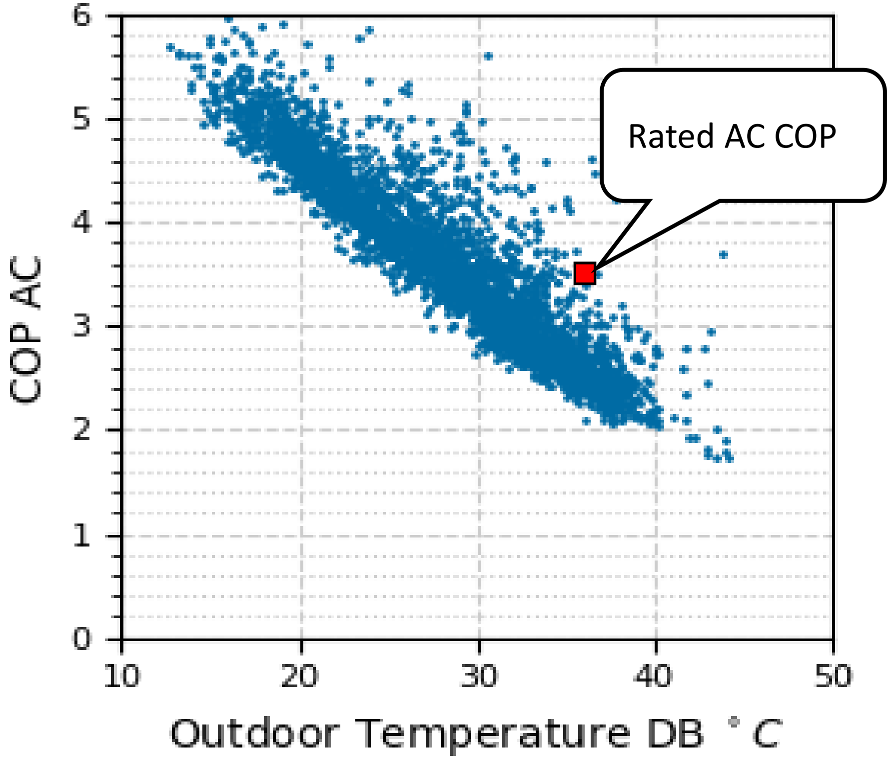


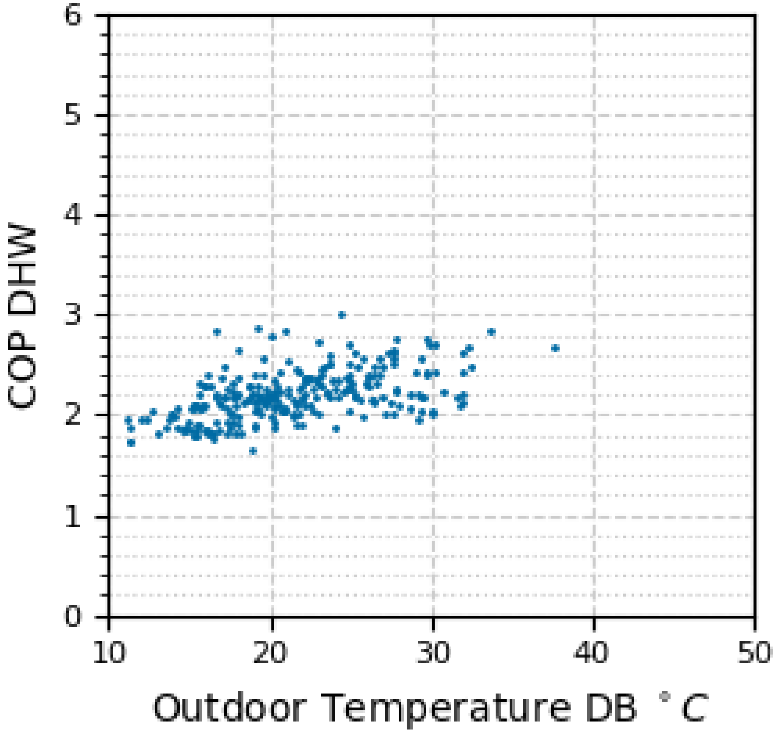
- DHW delivery temperature during water draws
- Starting water draws show lower temperature due to heat capacity of RTD and tubing

- Filtering out first 5 minutes of water draw
- 15% of the total water draw occurrences or 3.2% of the total water draw volume is below 45°C

Results – AC COP and DHW COP

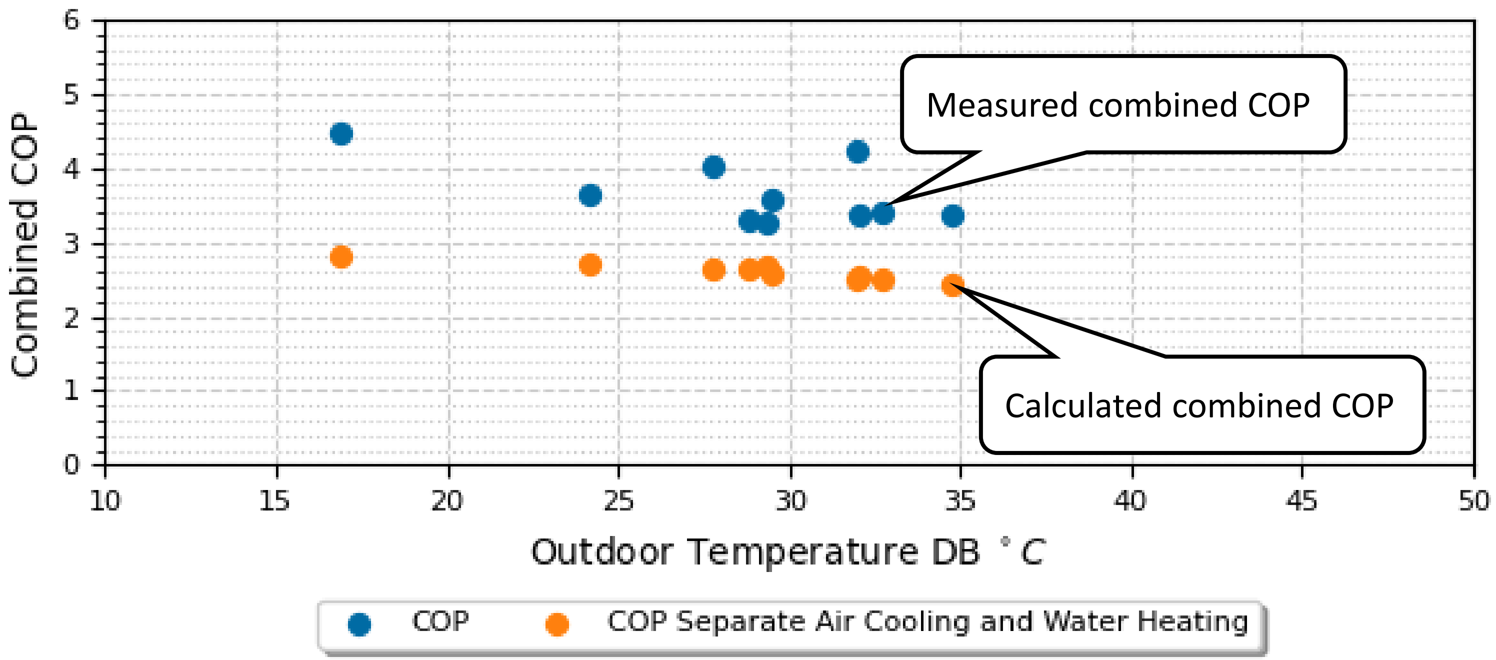
- AC mode COP vs outdoor temperature
  - Varies with indoor conditions and runtime
- Rated AC COP is 3.5 w/o MFHP modifications
  - Field efficiency vary from ratings
  - Different indoor conditions and fan pressure rise
  - Increased refrigerant pressure drop from valves and linesets
  - Suboptimal refrigerant charge in MFHP
- DHW COP varies with tank average temperature



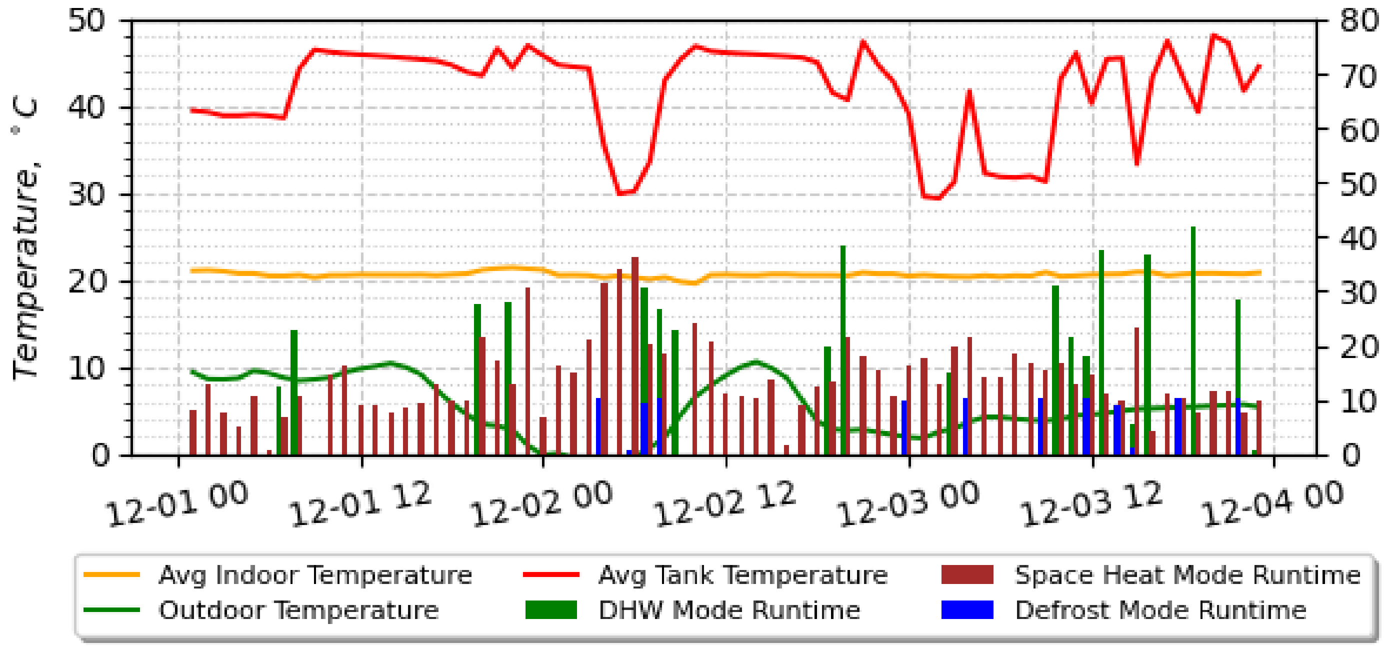


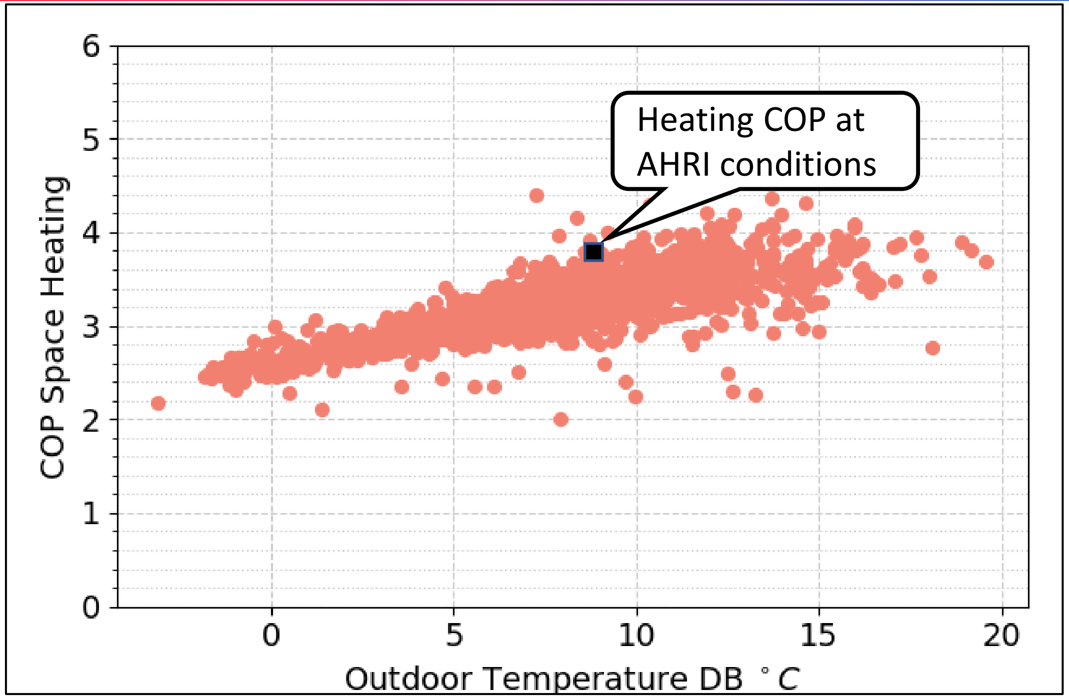
Results AC+DHW mode

- Simultaneous AC and DHW mode was infrequent
- Compressor lift is higher in the simultaneous mode – higher power draw than each mode
- Higher combined COP than separate AC and DHW modes
- The measured combined performance was 36% higher on average



Results- Winter





- Average tank temperature fluctuates more in winter due to defrost cycles
- No simultaneous space heating and DHW - DHW mode was prioritized instead of switching back and forth
- Heating COP was slightly below the unit rated COP (3.8) at AHRI conditions w/o MFHP modifications

Conclusions

- Retrofit electrification of space and water heating currently needs separate air-source heat pumps each with electrical resistance elements
- Electric panel and service upgrades are a major barrier to heat pump adoption
- Air-to-air MFHP system capable of proving space conditioning and water heating without panel upgrade is investigated as a retrofit for single family home
- System is monitored over the summer and reported average AC COP of 2.8 (at 35°C Outdoor dry bulb) while adequately meeting cooling and hot water needs
- The simultaneous AC and DHW mode demonstrated an average 36% better performance
- Continued monitoring showed space heating COP of 3.3 (at 8.3°C Outdoor dry bulb)
- Lab evaluation is required to understand the MFHP operation and suggest improvements

MFHP Next Steps

- Improve performance of individual modes
  - Detailed laboratory experimentation to understand reliability and inefficiencies
  - Refrigerant charge optimization across all MFHP modes
  - Water tank heat exchanger model development and design improvement
- Develop advanced controls
  - Load flexibility controls to store DHW energy during low price times
  - Predictive algorithm to increase simultaneous mode runtime
- Continue study with more sites
  - Demonstrate installation and commissioning in various building types
  - Characterize performance in other sizes of the heat pumps
  - Determine performance and sizing variation in various climates

Acknowledgements

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Questions

- Questions / Comments??
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