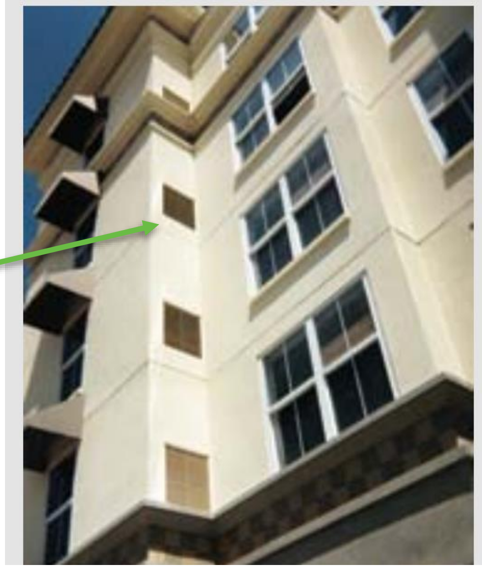
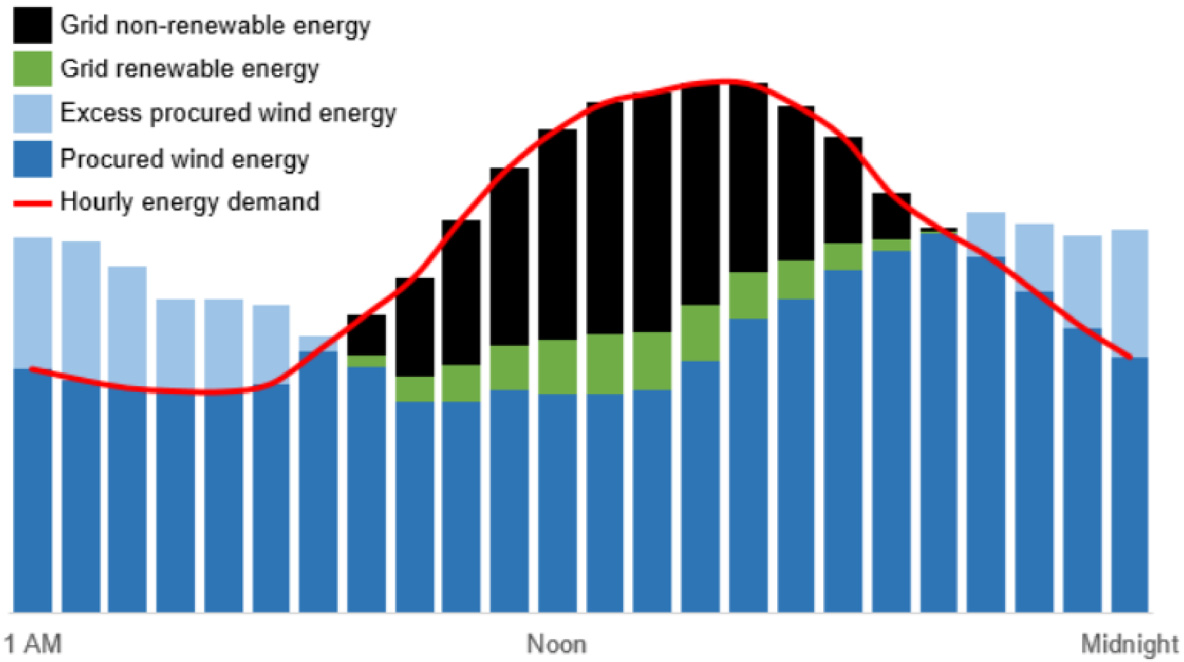
Wall Embedded Multi-Functional Heat Pump with Energy Storage systems For Grid-Responsive and Weather-Transactive Controls





Phase I – Final Presentation
Oak Ridge National Lab
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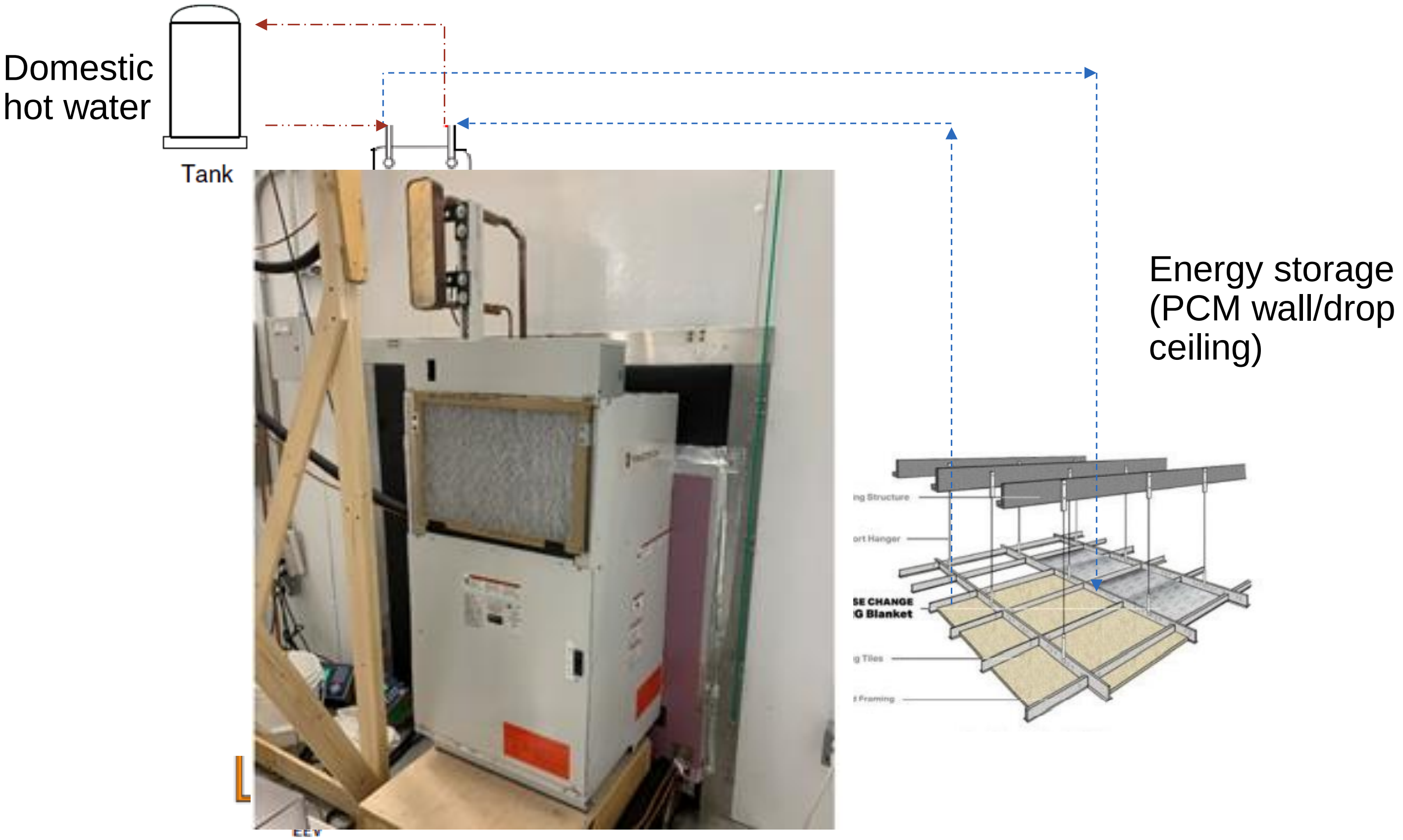
Overview – Innovative Configuration to cover all the functions with a single-set of components

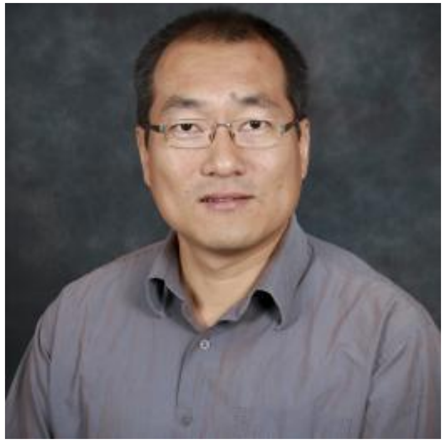
The proposed project will develop an innovative wall embedded air-source integrated heat pump (WAS-IHP) solution capable of space cooling, space heating, water heating (WH), ventilation, and dehumidification. Coupled with enhanced thermal storage elements—a water tank and phase change material (PCM) panels—the unit will respond to grid signals to shift peak load, with a two-level controller for weather-forecast transactive control.



Five Modes:
- Space cooling
- Space heating
- Cooling energy storage
- Water heating with outdoor air source
- Water heating with indoor air source

High efficiency, multi-functional terminal unit to satisfy all home comfort needs and grid-responsive energy storage.

Team



Dr. Bo Shen (PI)

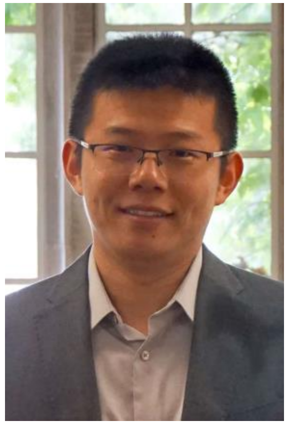
- System design
- Building energy simulation

Dr. Zhenning Li

- Model and optimization
- Laboratory investigation

Drew Welch
Senior Lead HVAC Systems Engineer

- Develop 3-stage compressors for multi-family buildings
- Liquid desiccant latent storage

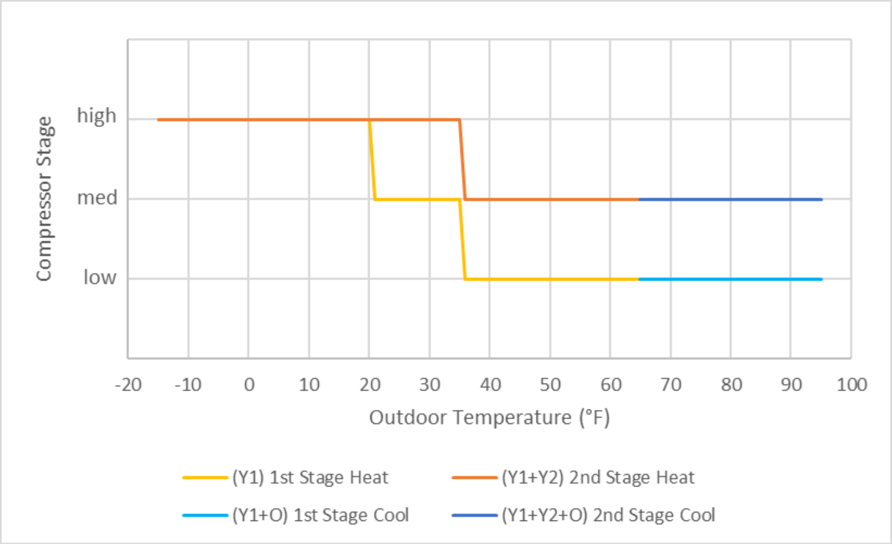


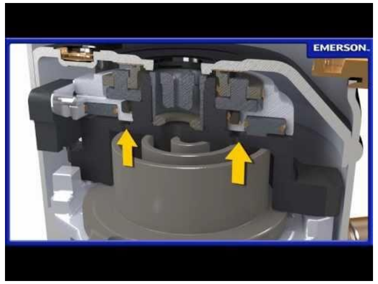
Dr. Jie Cai
Assistant professor at University of Alabama

- Develop grid-responsive, weather-transactive supervisory control

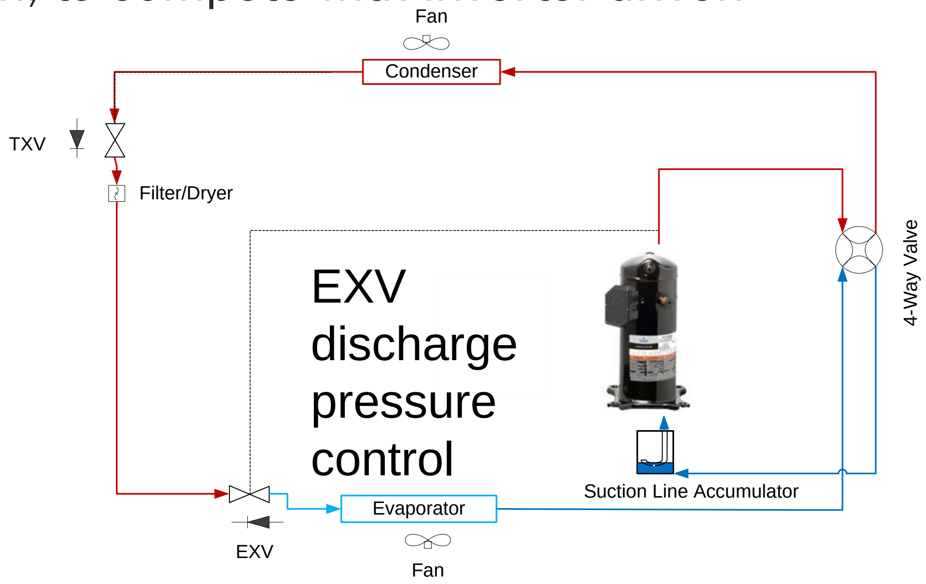
Approach: Low-Cost Capacity Modulation Technique: Emerson 3-stage compressor sample having 2-ton capacity at the top speed + Discharge Pressure Control

- Single, 3-stage, scroll compressor
  - Preliminary capacity levels of 100%, 67%, 45%
    - 67% is used for rated capacity of cooling mode, 100% capacity for enhanced heating at low ambient temperatures.
    - Compatible with 2-stage thermostat
  - 30% reduction in compressor cost per rated cooling ton, to compete with inverter-driven variable-speed compressors





Mechanical capacity modulation



In the AC/HP market having capacity < 2-ton, scroll compressors don't have cost advantage; lower cost capacity modulation will make scroll compressors win over inverter-driven rotary compressors.

Overall predictive control architecture

Control algorithm

- Mixed-integer linear programming routine

PCM model:

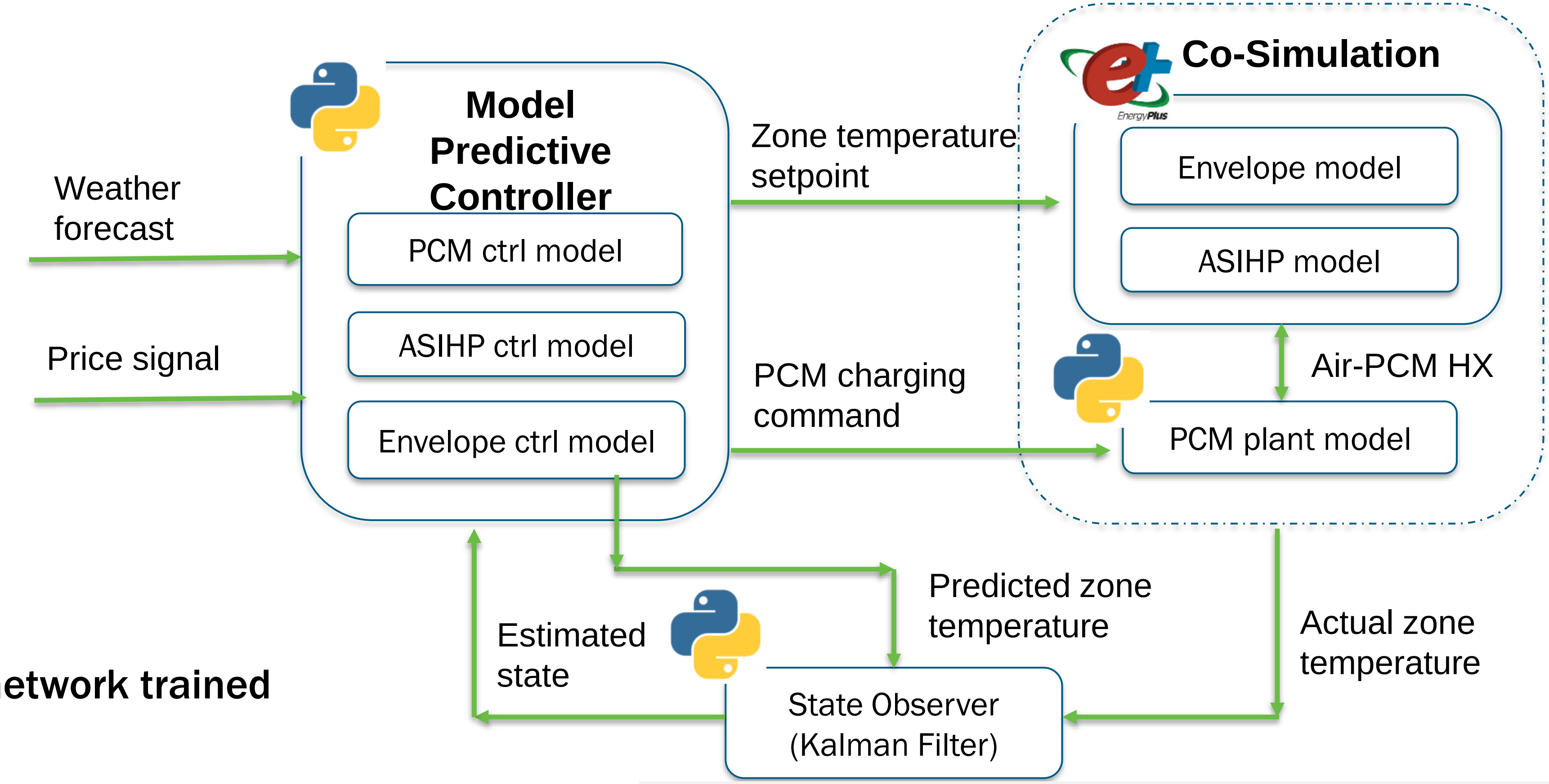
- Multi-node enthalpy method
- Piece-wise linear map between enthalpy and temperature
- Identical control and plant models

Envelope control model:

- Resistance/capacitance network trained with E+ data

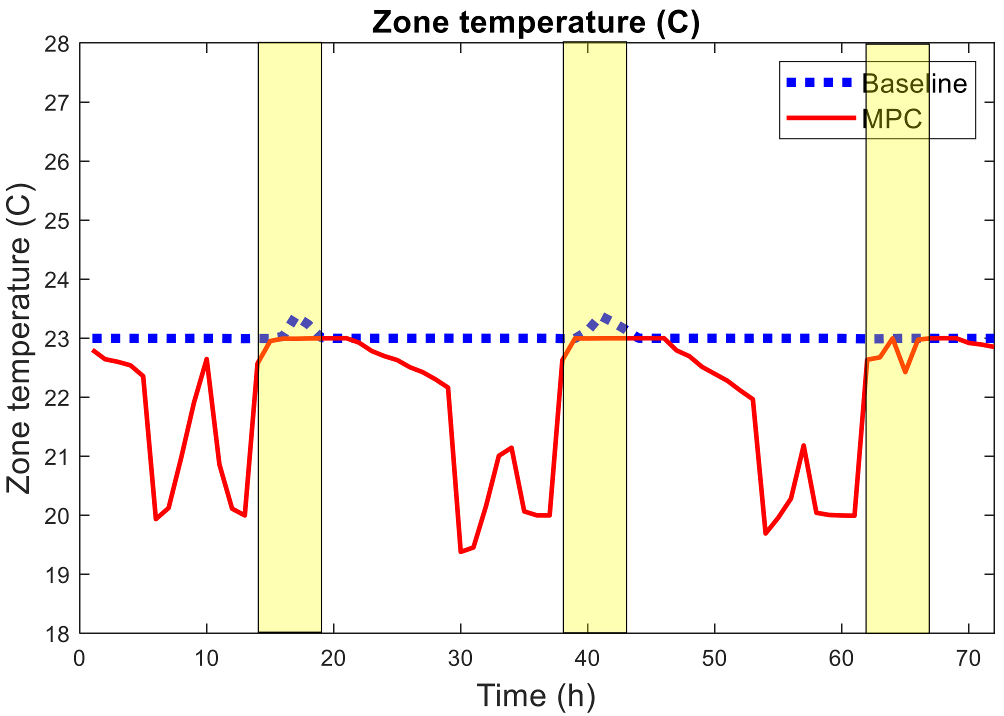
ASIHP control model:

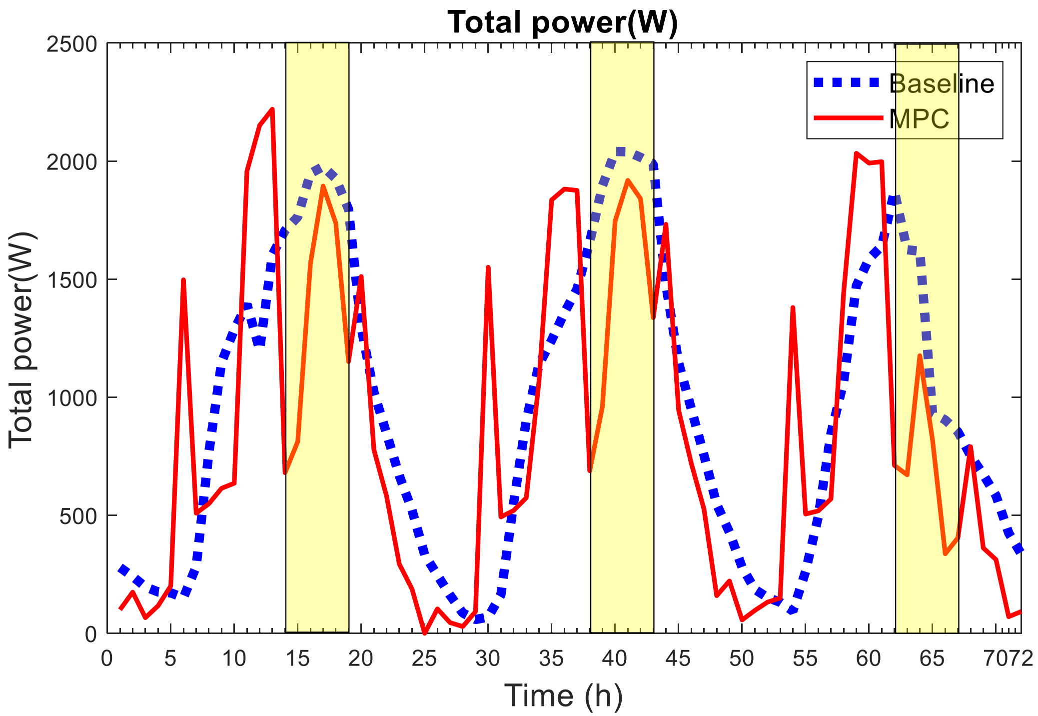
- Performance curves with simplifying assumptions to ensure solvability



Predictor/corrector to estimate values for all state variables (all nodal temperatures in the thermal network). These estimated states are updated every hour and are used as initial states for predictive optimization of the 24-hr look-ahead time horizon.

Results for hot summer days – Atlanta, no temp relax



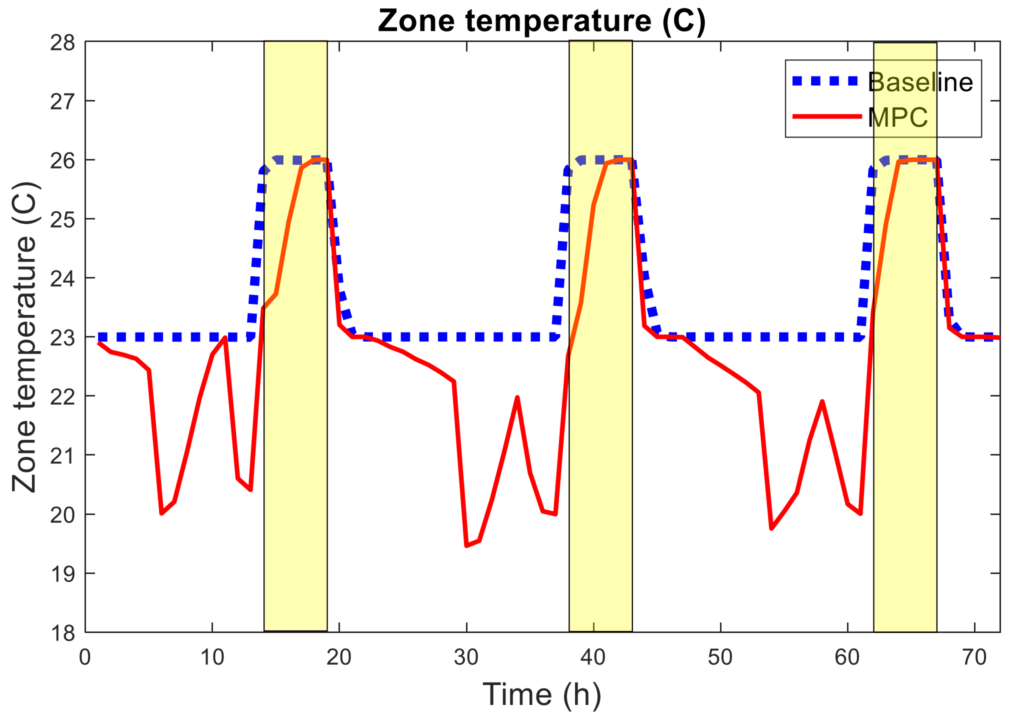


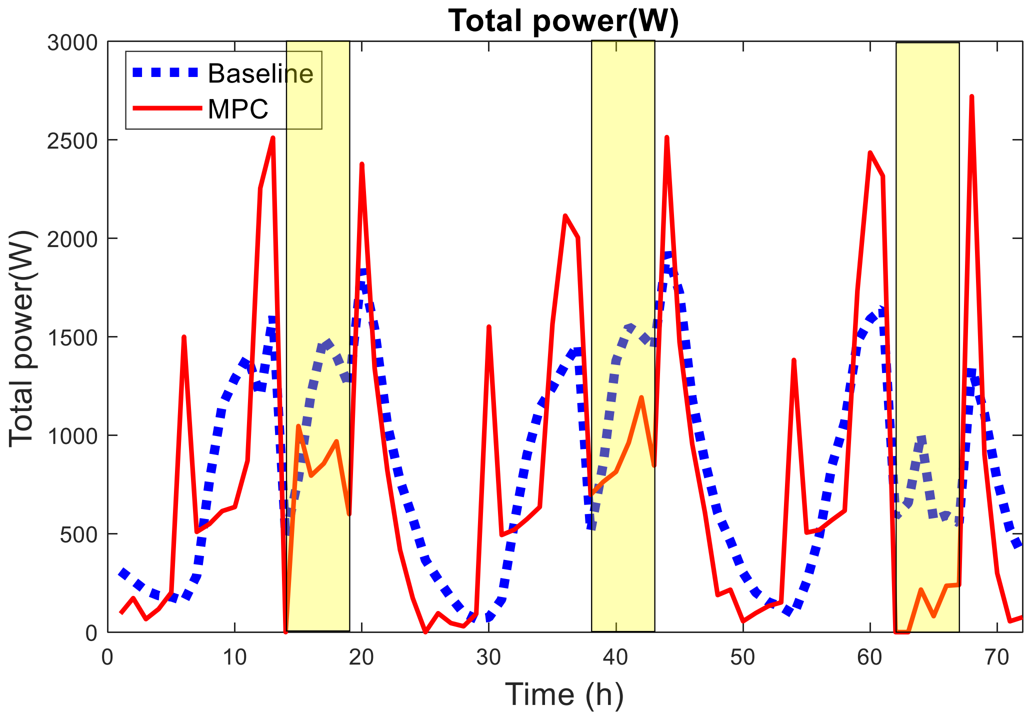
- ❑ Zone temperature setpoint: 23C
- ❑ Temperature lower limit for precooling: 20C
- ❑ PCM melting temp = 19.7C
- ❑ Peak hour = 2:00pm-7:00pm (summer)
- ❑ Electricity price: peak hour = 0.2$/KWh
  off-peak hour = 0.05$/KWh

Reference: Georgia Power TOU-REO-12

- ❖ **Three-day electricity cost:**
  - ❑ MPC control:
    Electricity bill = $6.1406 (23.01% cost savings)
  - ❑ Baseline control:
    Electricity bill = $7.9763

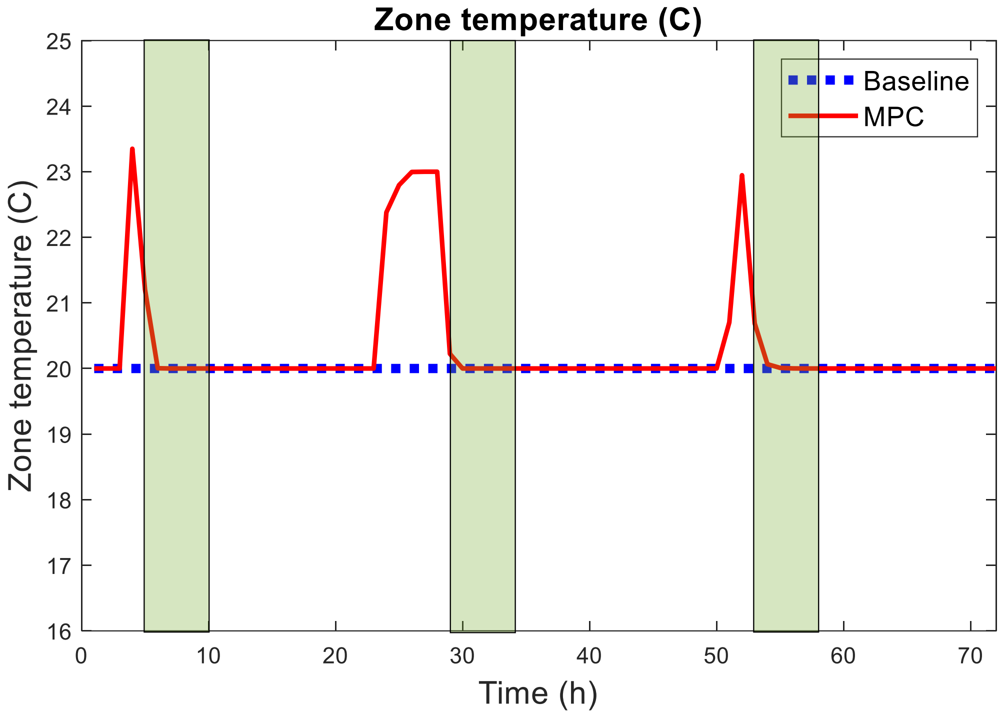
Results for hot summer days – Atlanta, with temp relax

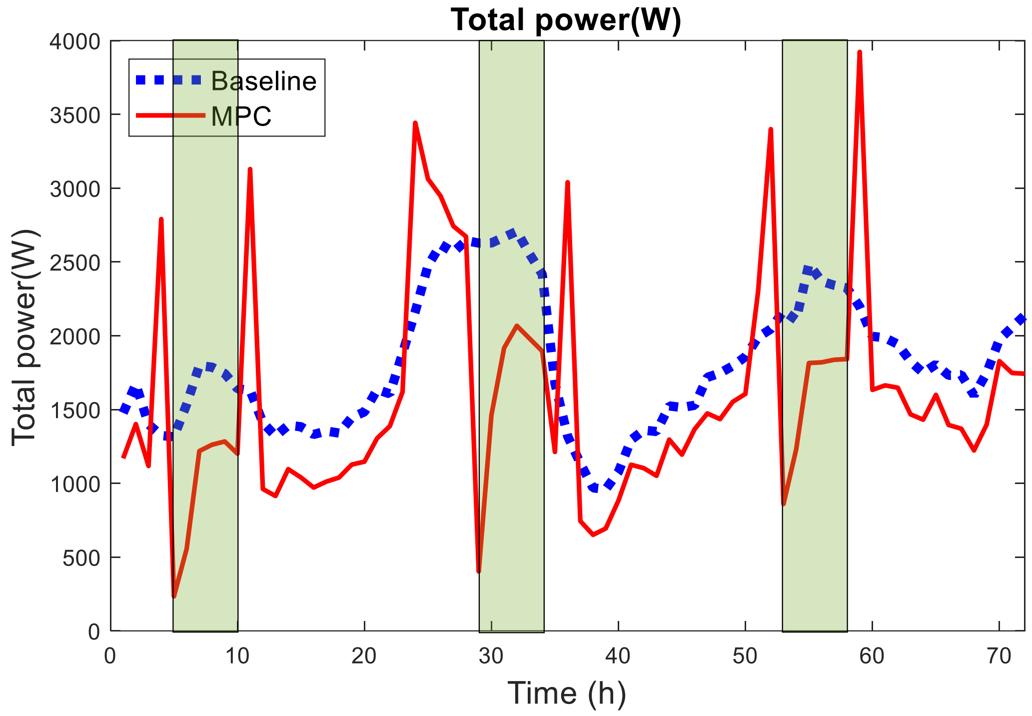




- Zone temperature setpoint: 23C (off peak), 26C (on peak)
- **Three-day electricity cost:**
  - MPC control:
    Electricity bill = $4.3373 (50% cost savings versus baseline DX coil with no temp relax)
  - Baseline control:
    Electricity bill = $5.6590

Results for winter days - Indianapolis, no temp relax





- ❑ Zone temperature setpoint: 20C
- ❑ Upper limit of preheating temperature: 23C
- ❑ PCM melting temp = 24C
- ❑ Peak hour = 5:00am-10:00am (Winter)
- ❑ Electricity price: peak hour = 0.2$/KWh
  off-peak hour = 0.05$/KWh

-Assumed TOU, same as cooling season

- ❖ **Three-day electricity cost:**
  - ❑ MPC control with PCM ceiling:
    Electricity bill = $9.3908 (24.19% cost savings)
  - ❑ Baseline control:
    Electricity bill = $12.3878

Laboratory Prototype – Delivered all the functions !

Water-to-refrigerant heat exchanger

Multifunctional Packaged Heat Pump

3-stage compressor controller

Labview DAQ

Outdoor side

Air Capacity Measurement

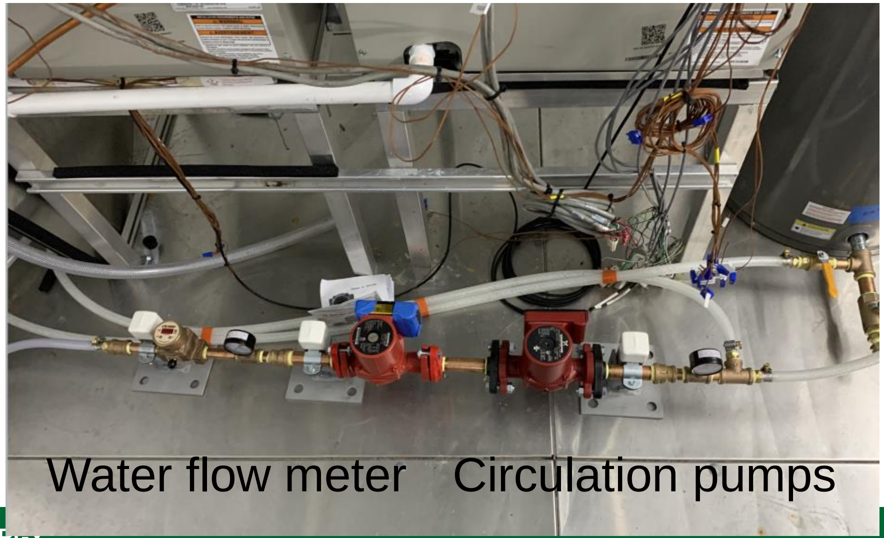
Code tester to measure air flow rate

Chilled mirror humidity sensor to measure supply air dew point

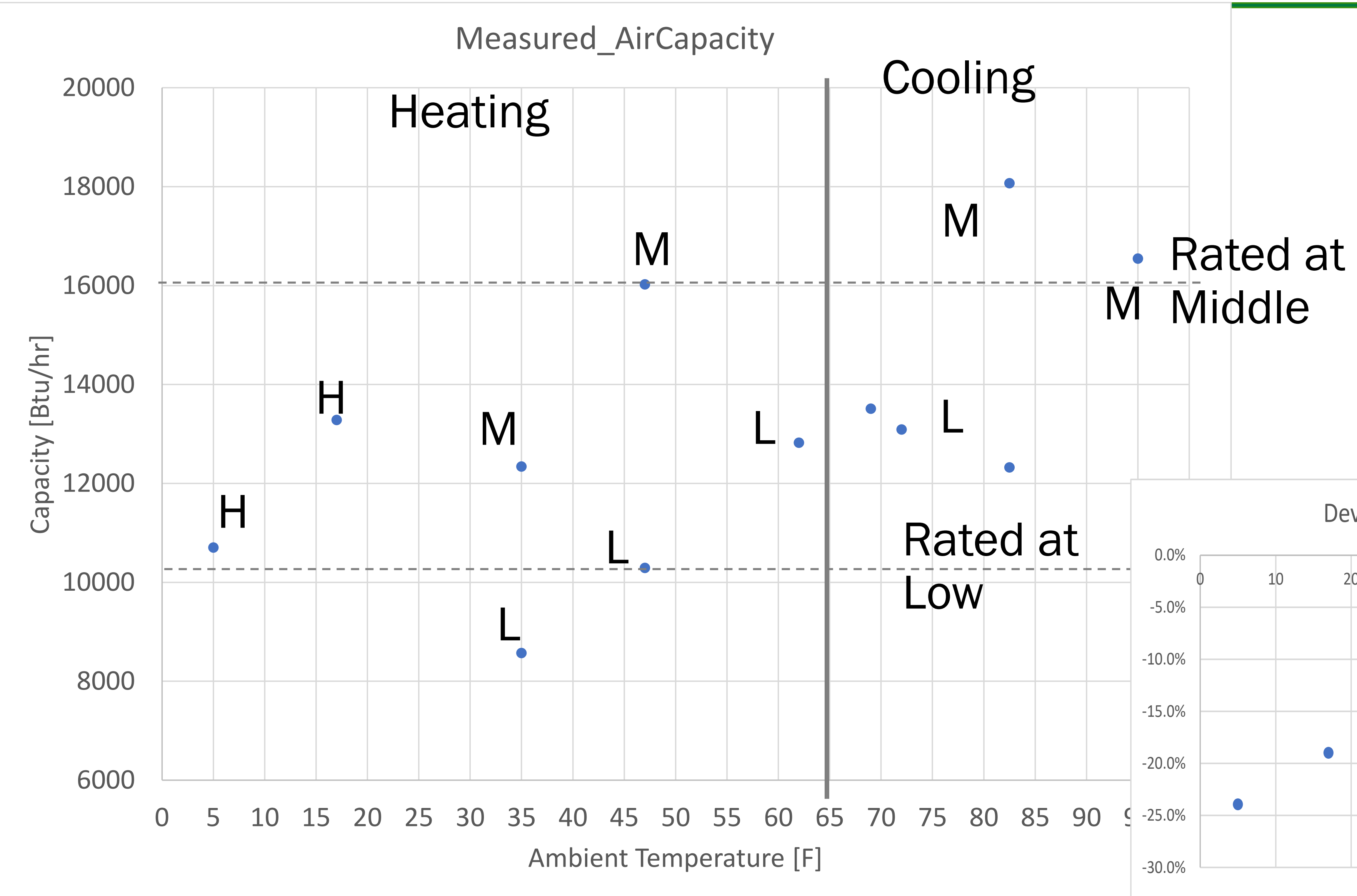
Water Loop

Phase change panel

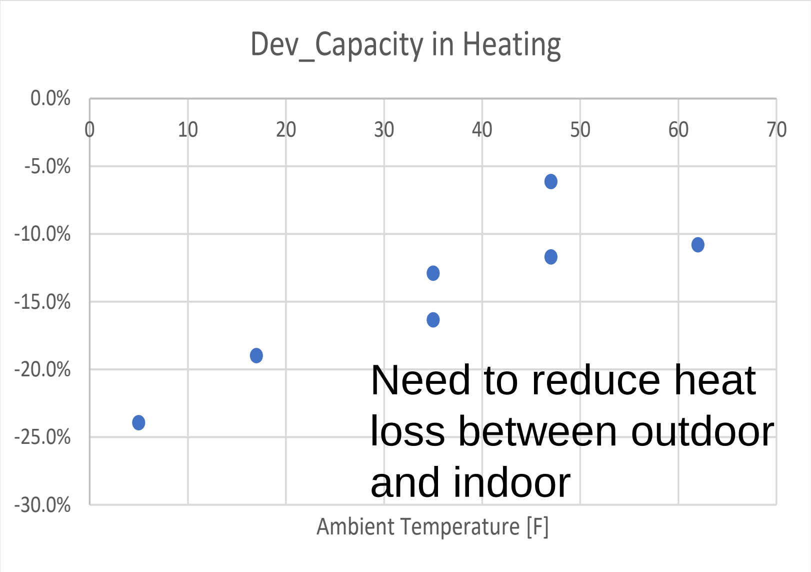
Hot water tank



Laboratory Measured Air Side Capacity

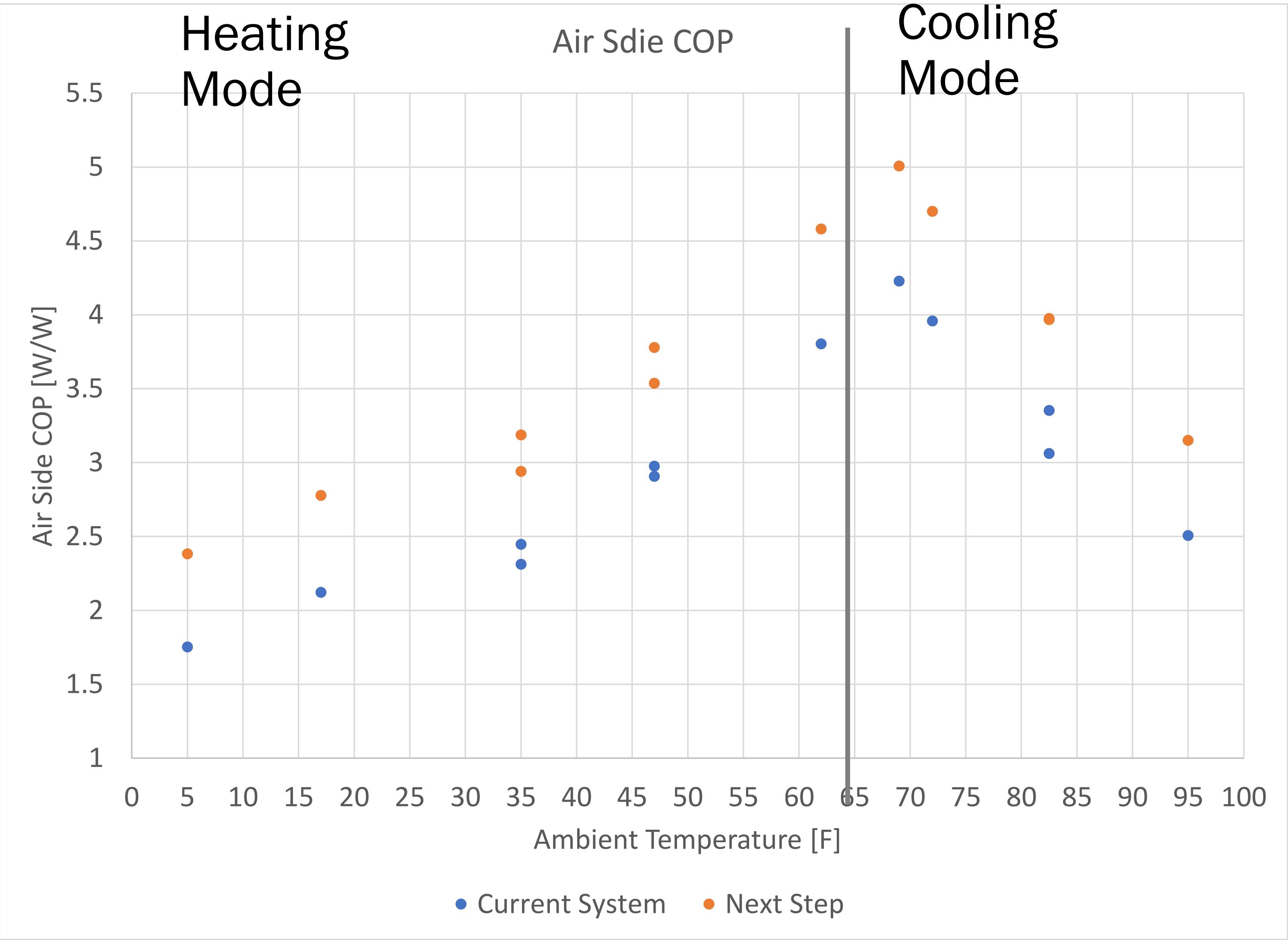


Worked down to 5 F, maintained > 70% rated capacity if rated at middle compressor stage; maintained 100% capacity if rated at compressor low stage



Need to reduce heat loss between outdoor and indoor

Measured COPs



Efficiencies need improvements

1. The present sample compressor underperformed versus compressor map
2. Replace the indoor blower with a variable-speed brushless DC blower
3. Reduce the heat loss

Next Steps

- Improve the performance with replacing compressor and blower, better thermal insulation.
- Verify Targets: IEER > 17.0; HSPF > 11.0; Annual water heating COP > 4.0; PCM charging COP > 3.2 @95F ambient temperature.
- Integrate liquid desiccant latent storage loop

Thank you

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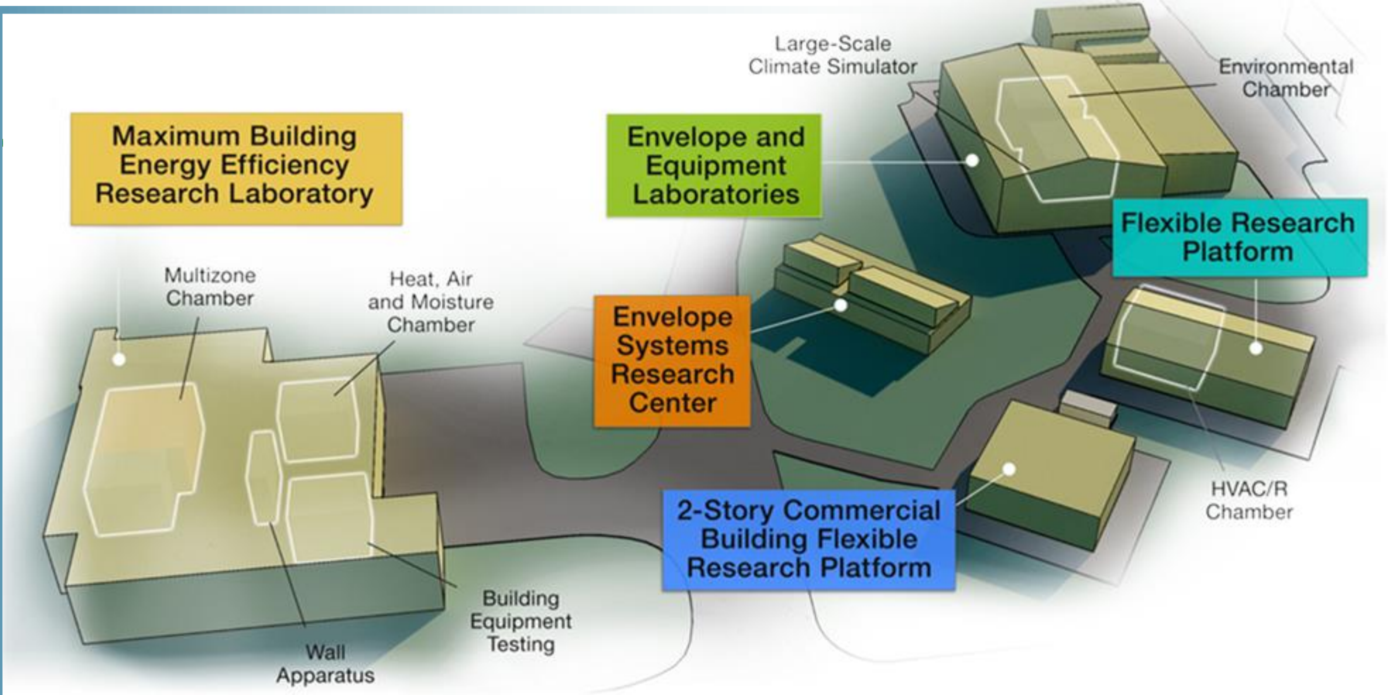

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