Western Cooling Efficiency Center Breakout Session

- WCEC in IoT – Mark Modera
  - WCEC Building Monitoring
  - Building Leakage Diagnosis
- Modeling Efforts – Nelson Dichter
  - ZNE in Commercial Buildings
  - Thermal Energy Storage
  - Hybrid Black Box Model
  - Ground Source Heat Pumps
- Field Evaluations – Curtis Harrington
  - Swimming Pool as a Heat Sink
  - RTU Optimization
  - Aerosol Envelope Sealing

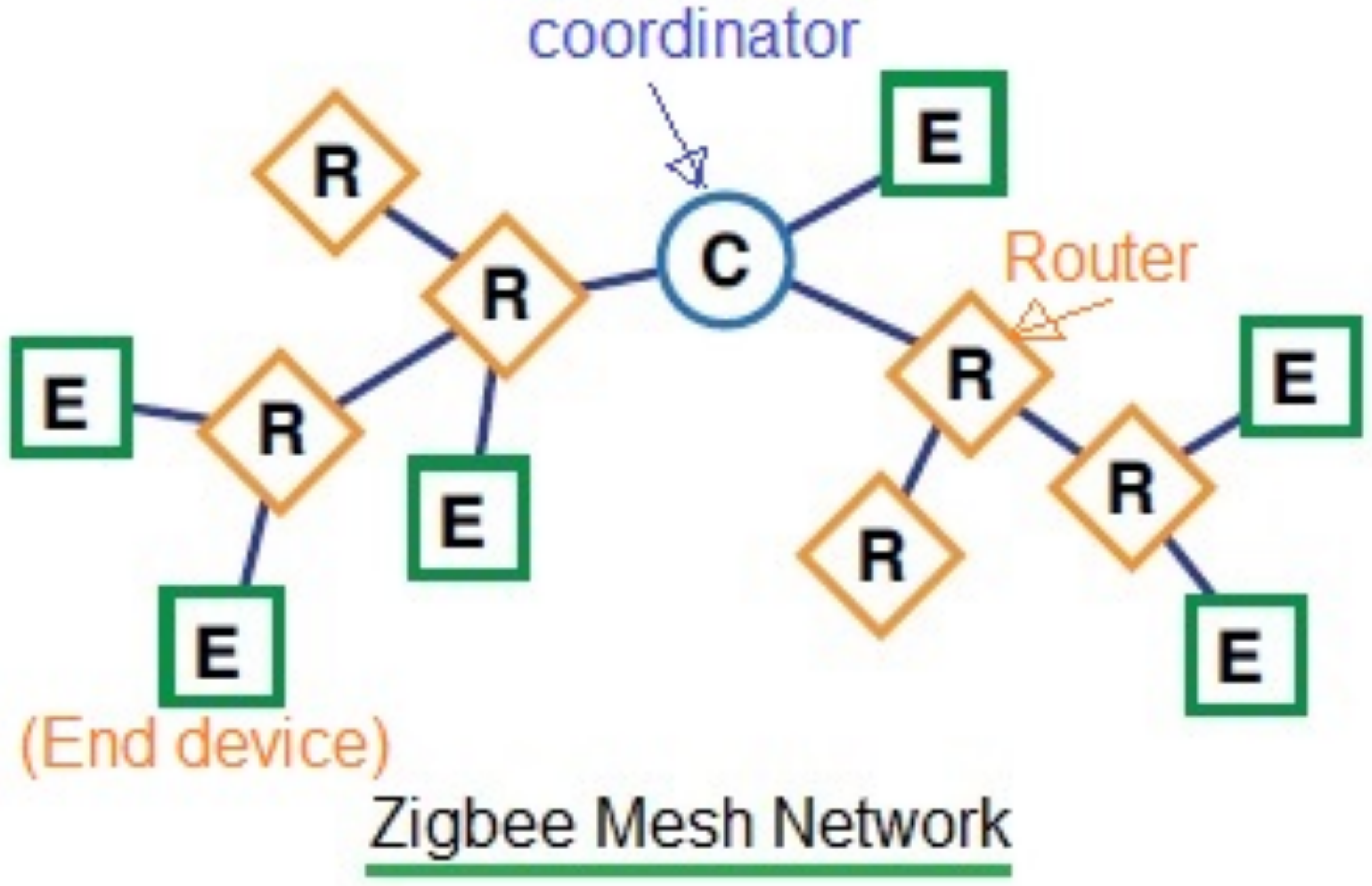
Variable Refrigerant Flow plus Indirect Evap: System Monitoring with IoT Technology

» Building:
- WCEC office space

» System:
- 2 VRF heat pumps
- 13 indoor fan coils

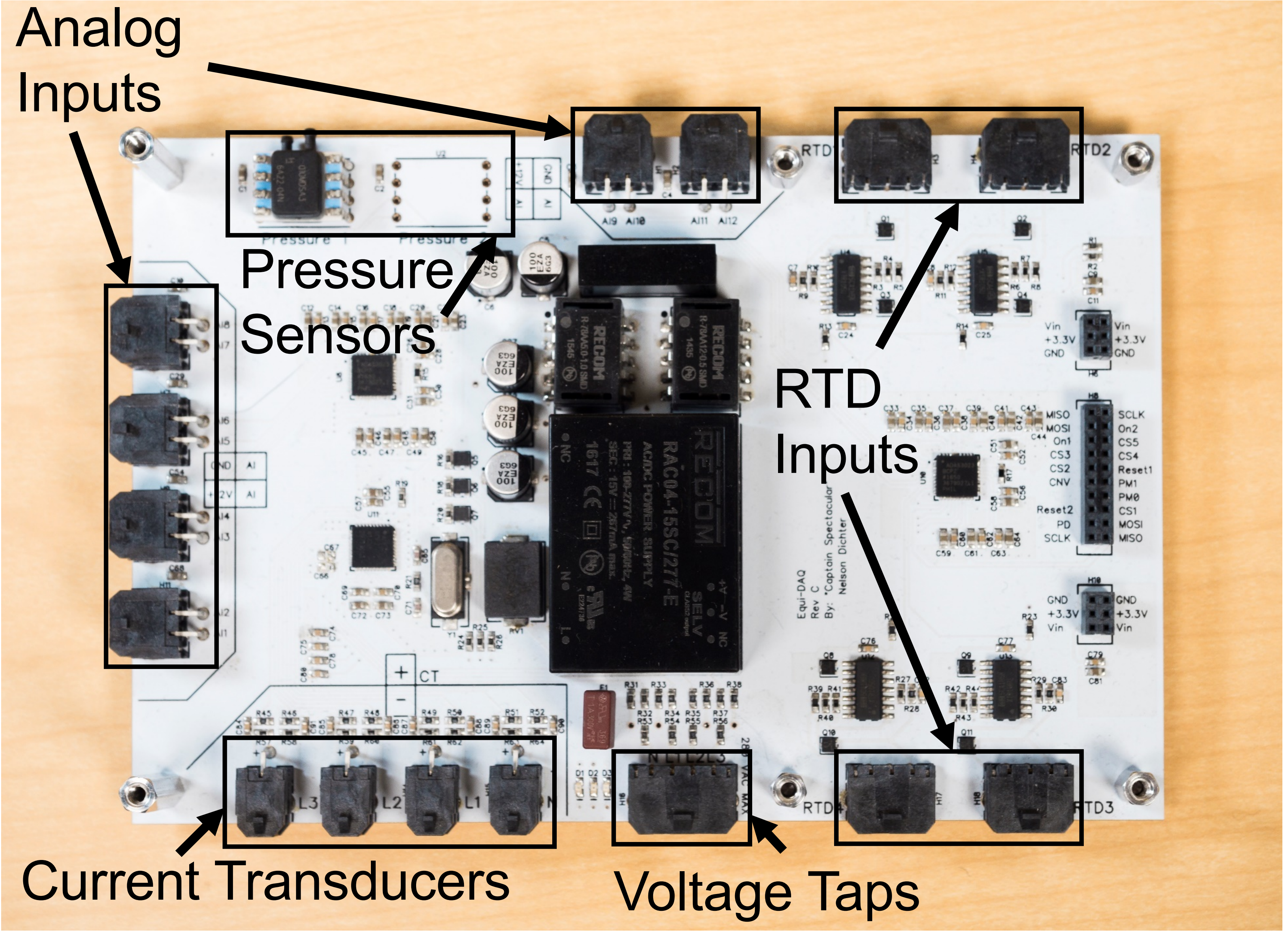
» Challenge:
- Monitoring a distributed system

» Solution:
- Wireless sensors
- Zigbee self healing mesh network



Equipment Monitoring

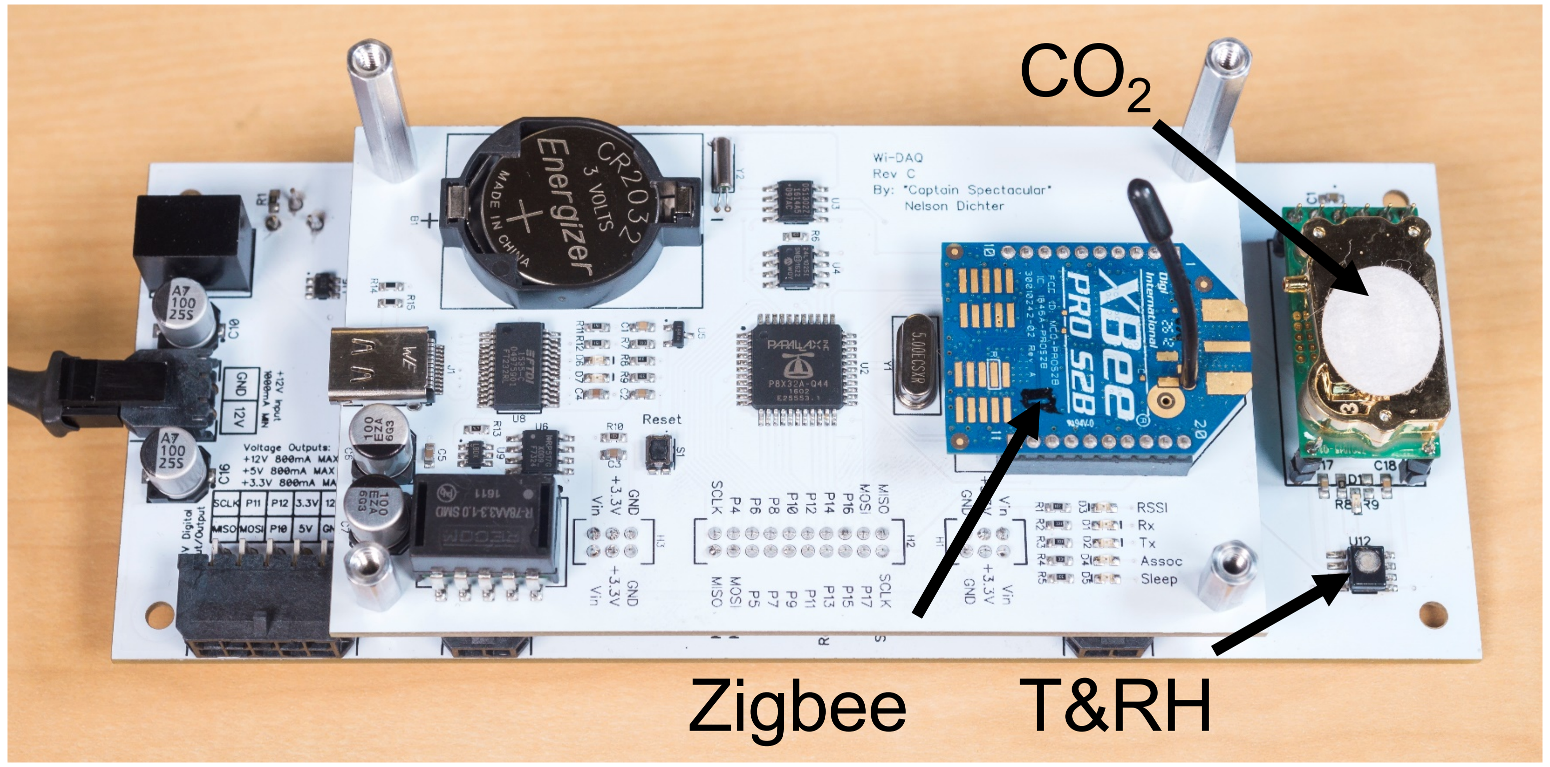
- Features:
  - 3-Phase power meter
  - Analog to digital converters:
    - 16 channels with simultaneous sampling
      - 12 general purpose
      - 4 RTD
    - 16-bit resolution
    - Programable gain amplifier
      - Input voltage 0-1V to 0-10V
    - Differential pressure sensor (14-bit)
    - Absolute pressure sensor (14-bit)



Zone/Ambient Condition Monitoring

» Features:

- Temperature sensor
  - ±0.3 °C
  - 14-bit resolution
- Relative humidity sensor
  - ± 1.7 %
  - 14-bit resolution
- CO_2 sensor
  - 0-5000 ±30 ppm
- Motion Sensor
- LCD screen



Discoveries

» Symptom:

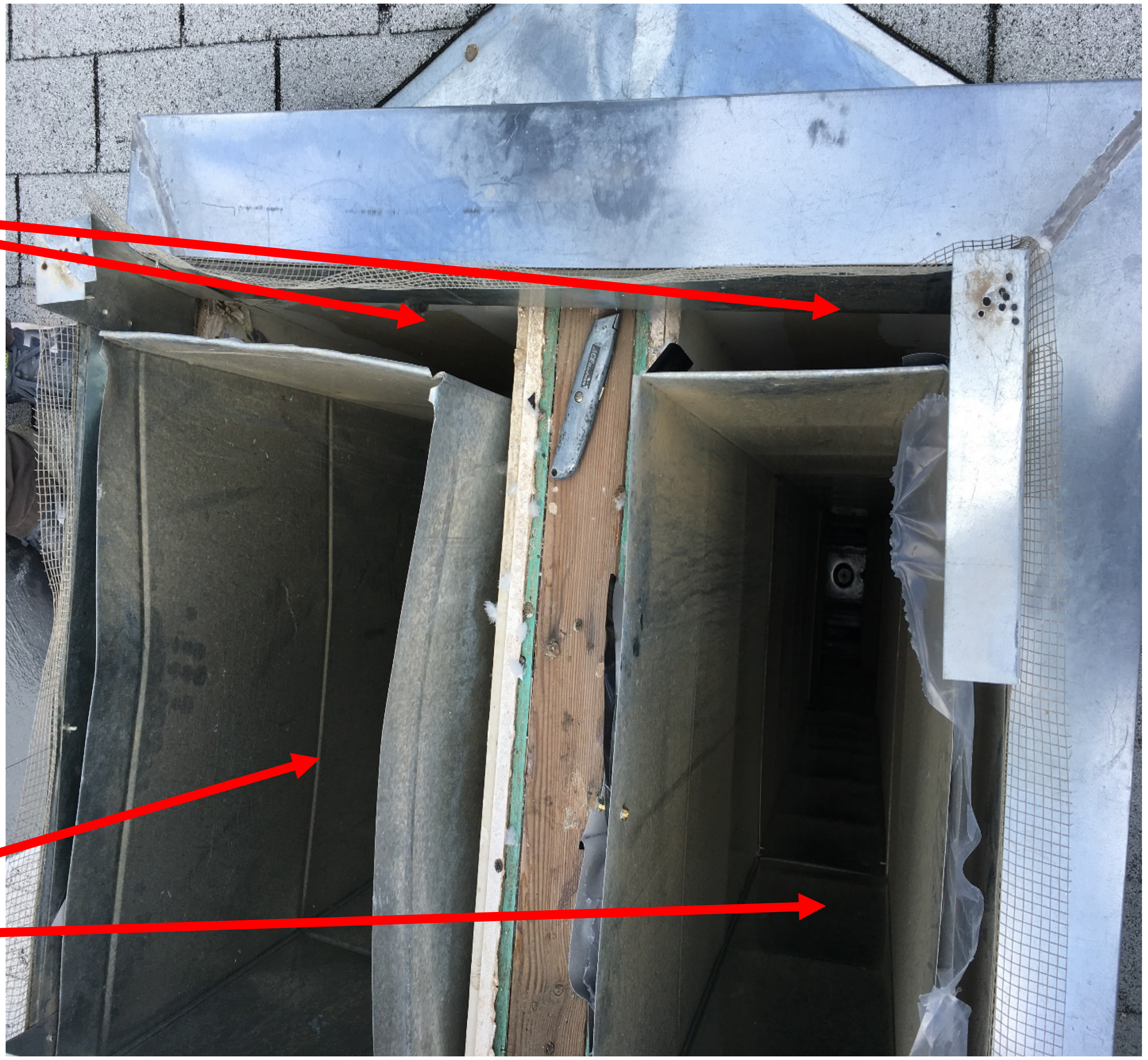
- Ventilation air ~68°F versus 50°F outdoors
- High CO_2 levels

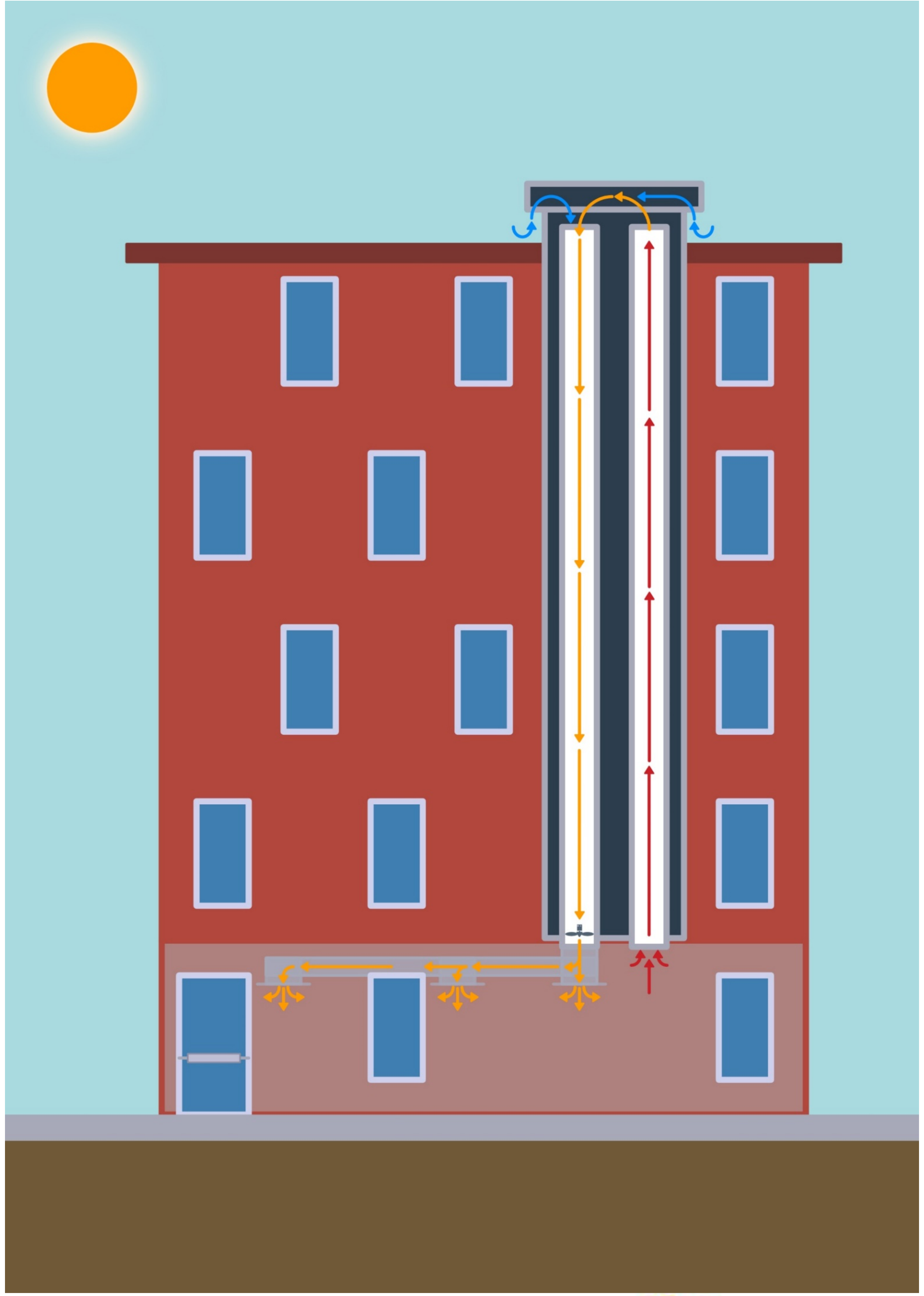
» Causes:

- Short circuit through plumbing chase
- Stack effect

Shaft Openings

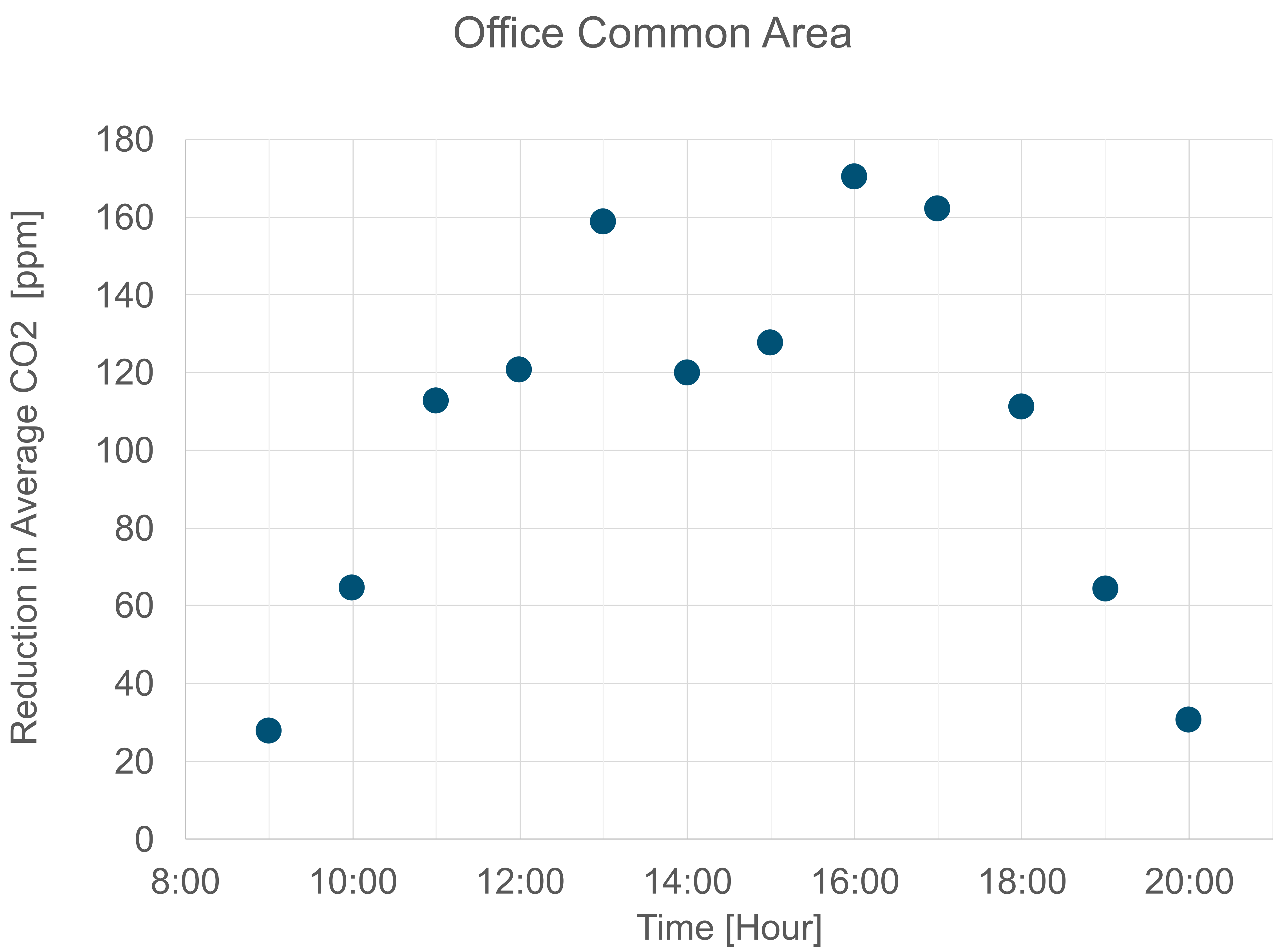
Ventilation Ducts



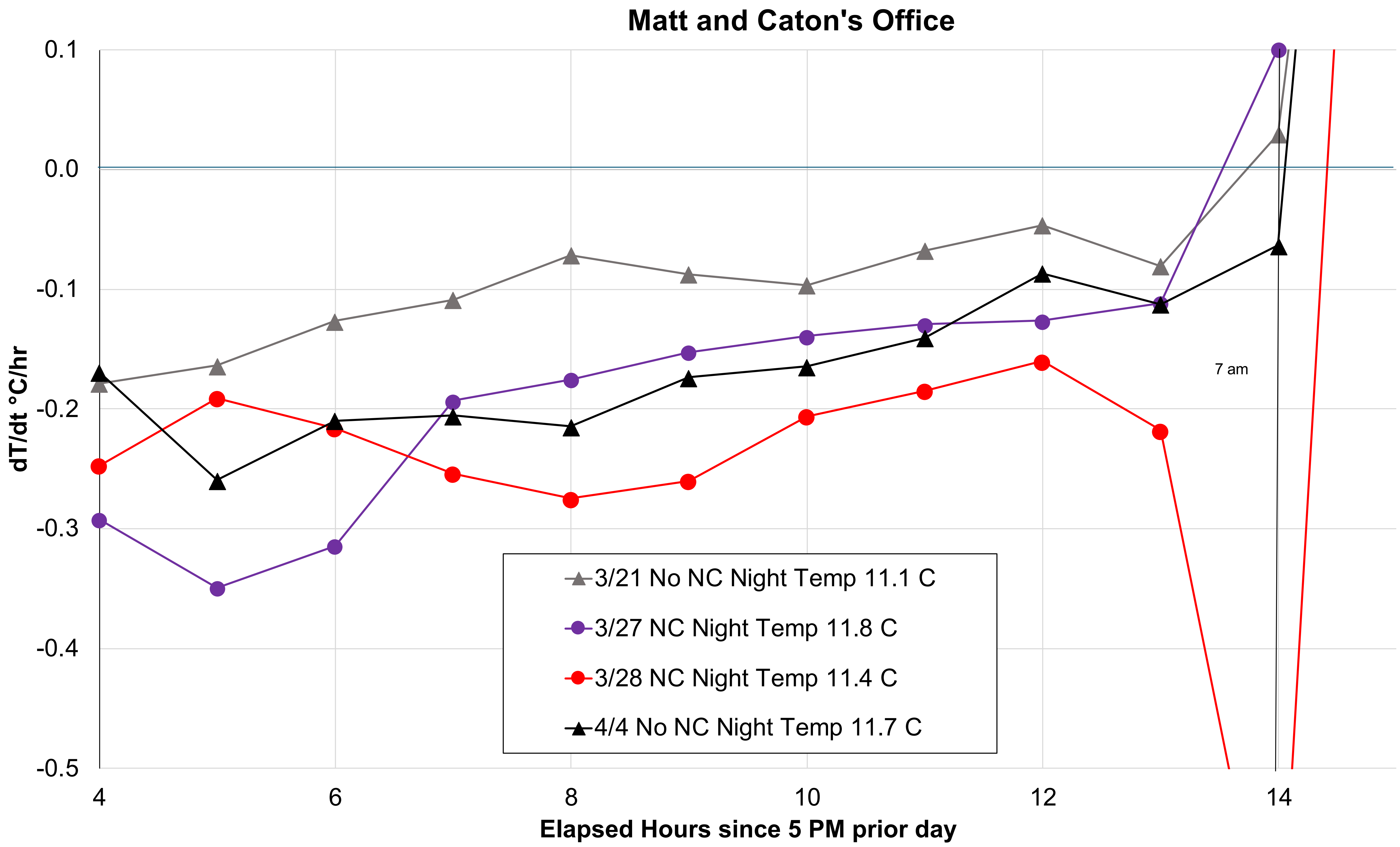


Ventilation Improvements

- **Solution:** sealed the plumbing chase
- **Result:** average CO_2 concentration levels decreased significantly



Zone Temperature Monitoring



- Investigation of impact of night cooling with ventilation on morning space temperatures
- Currently using winter air in lieu of indirect evaporative cooler

IoT Building Leakage Diagnosis: Technology/Methodology Description

- » Small, inexpensive sensors for measuring pressure placed at various points in and around building
- » One-time measurement of outdoor air intake flow
- » Observation of building pressure response to various modes of operation allow leakage to be determined

Methodology

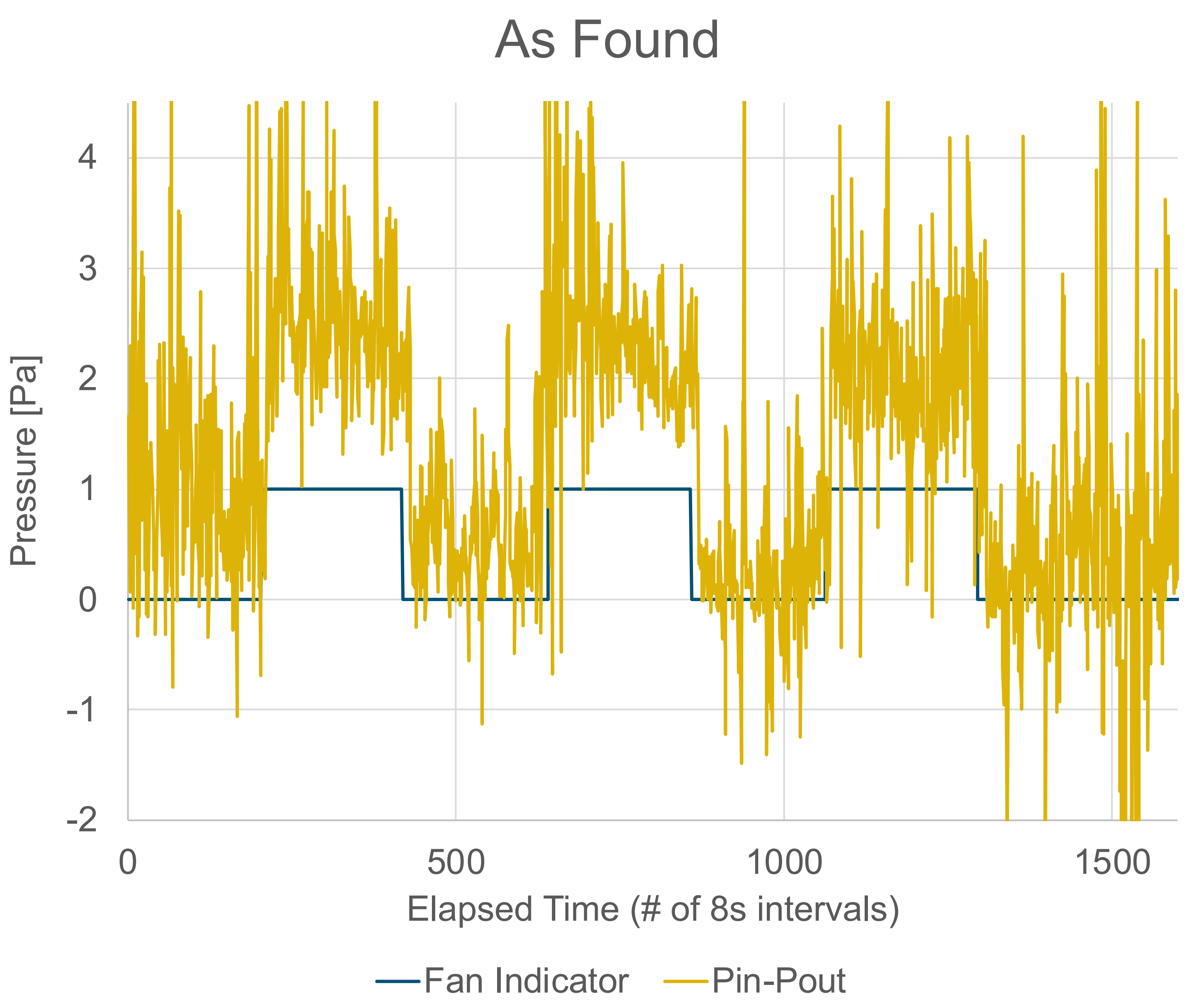
» **SIMPLEST CASE:** Envelope Leakage with Ducts in Conditioned Space

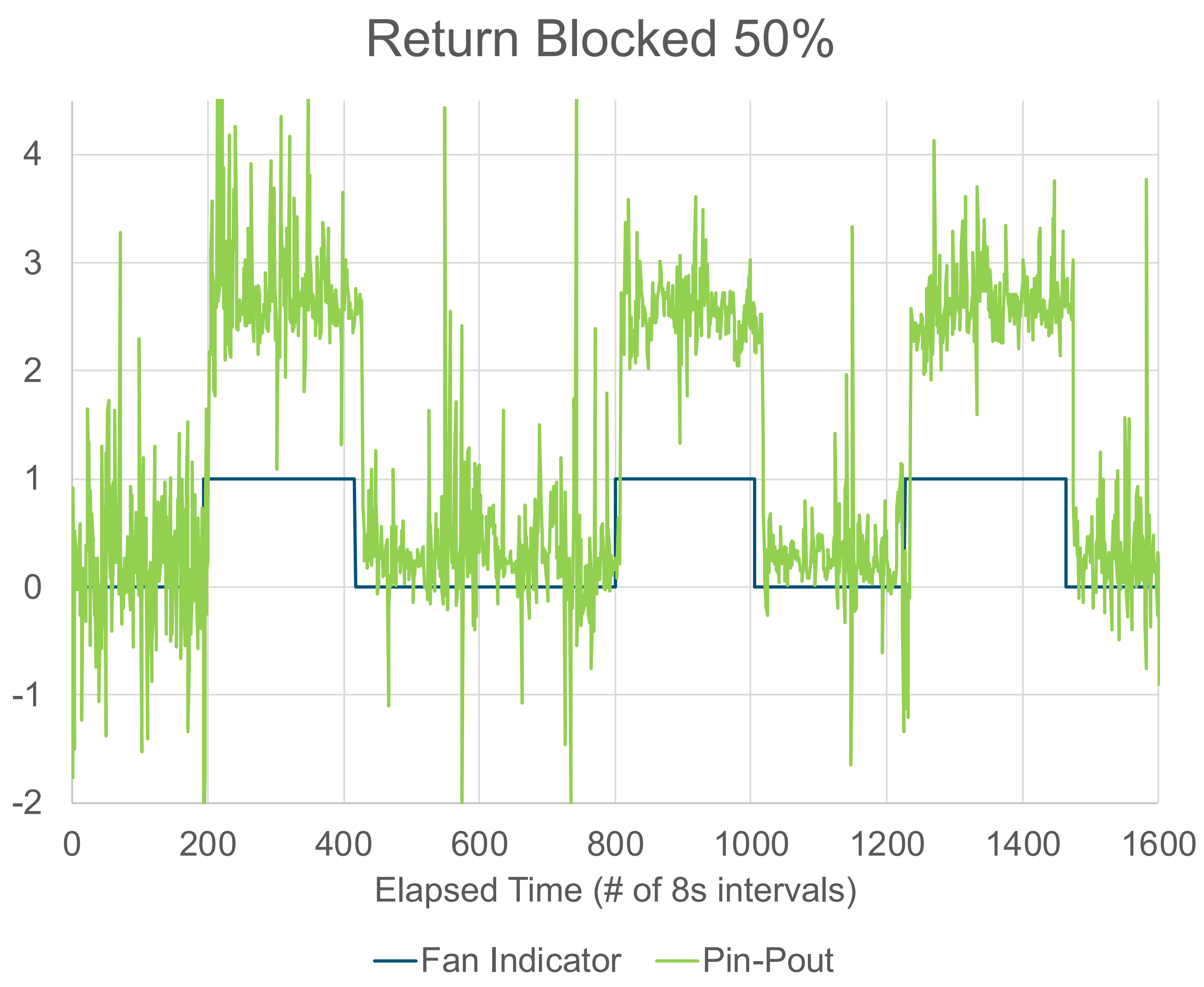
- $\Delta P_{envelope}$ changes with fan operation due to Outdoor Air Intake
- $\Delta P_{envelope}$ plus one-time measurement (or estimate) of OA Intake yields envelope leakage

» **SECOND CASE:** Envelope Leakage with Ducts Leaking Outside Conditioned Space

- $\Delta P_{envelope}$ changes with fan operation due to Outdoor Air Intake and due to duct leakage
- ΔP_{duct} changes are used to obtain additional data used for simultaneous solution for duct/envelope leakage

Initial Results

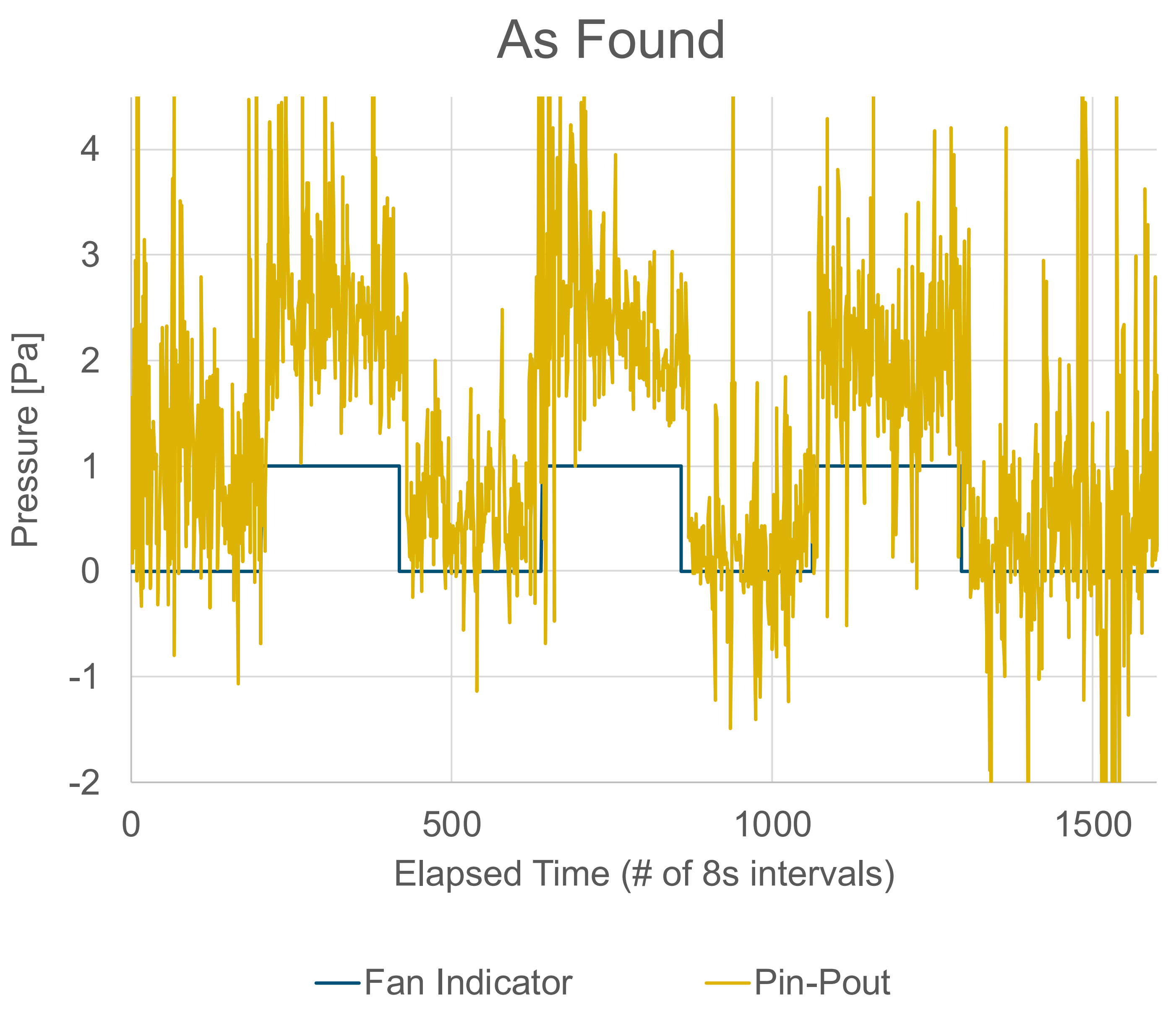


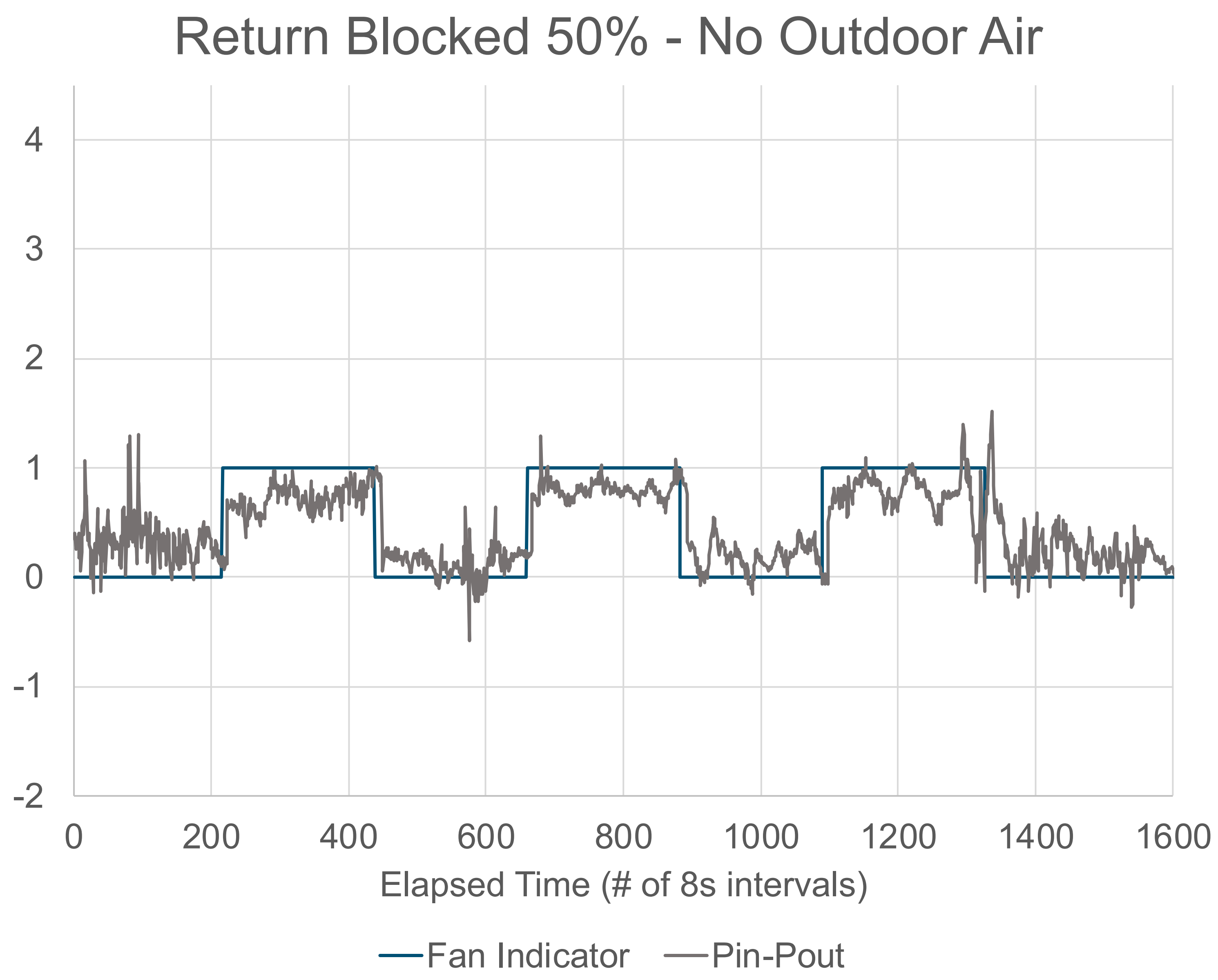


NOTE: Increased Building Pressure Changes when Return Grille is Blocked

More Flow Through OA Intake

Initial Results





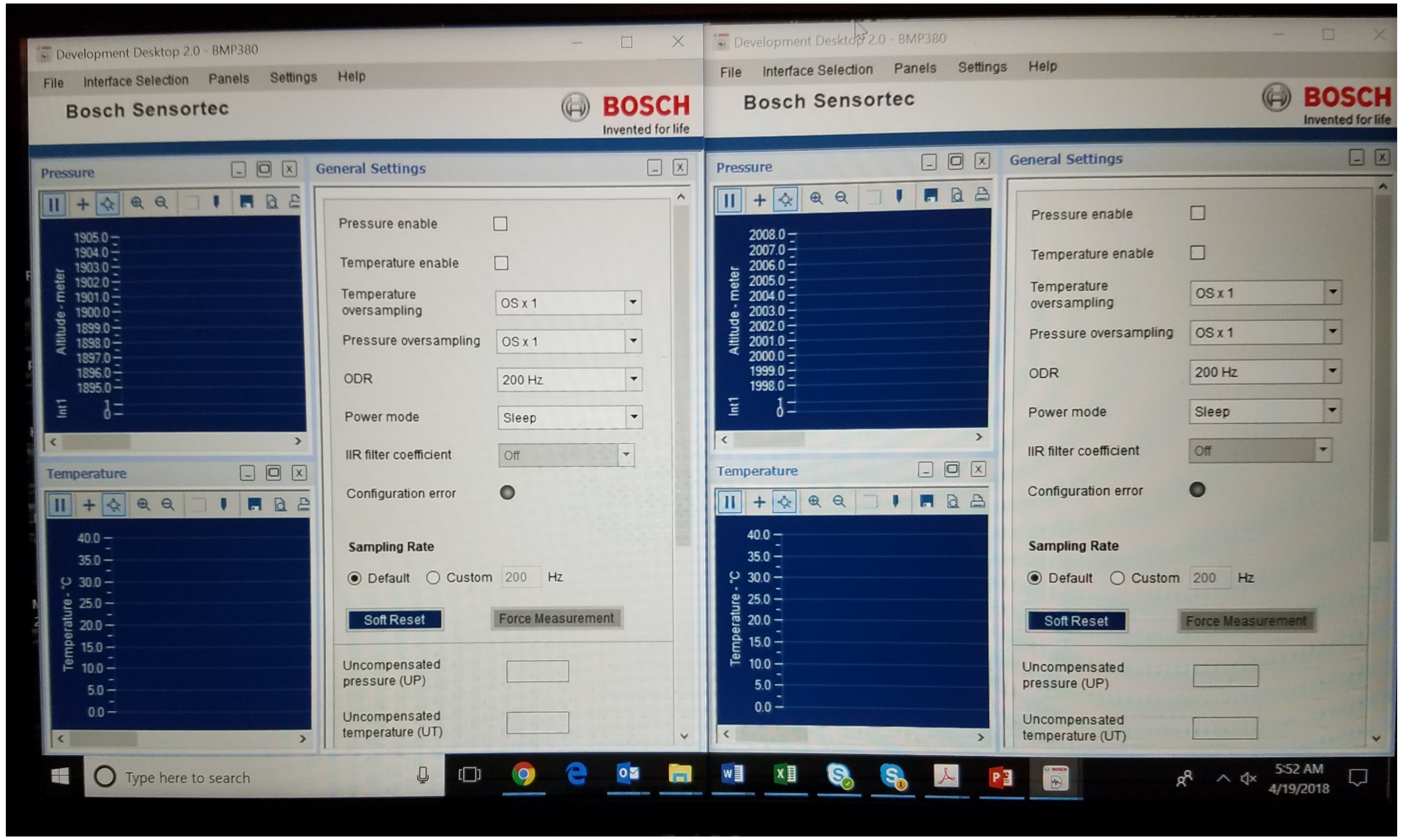
NOTE: Building Pressure Changes due to Fan Operation with No OA Intake

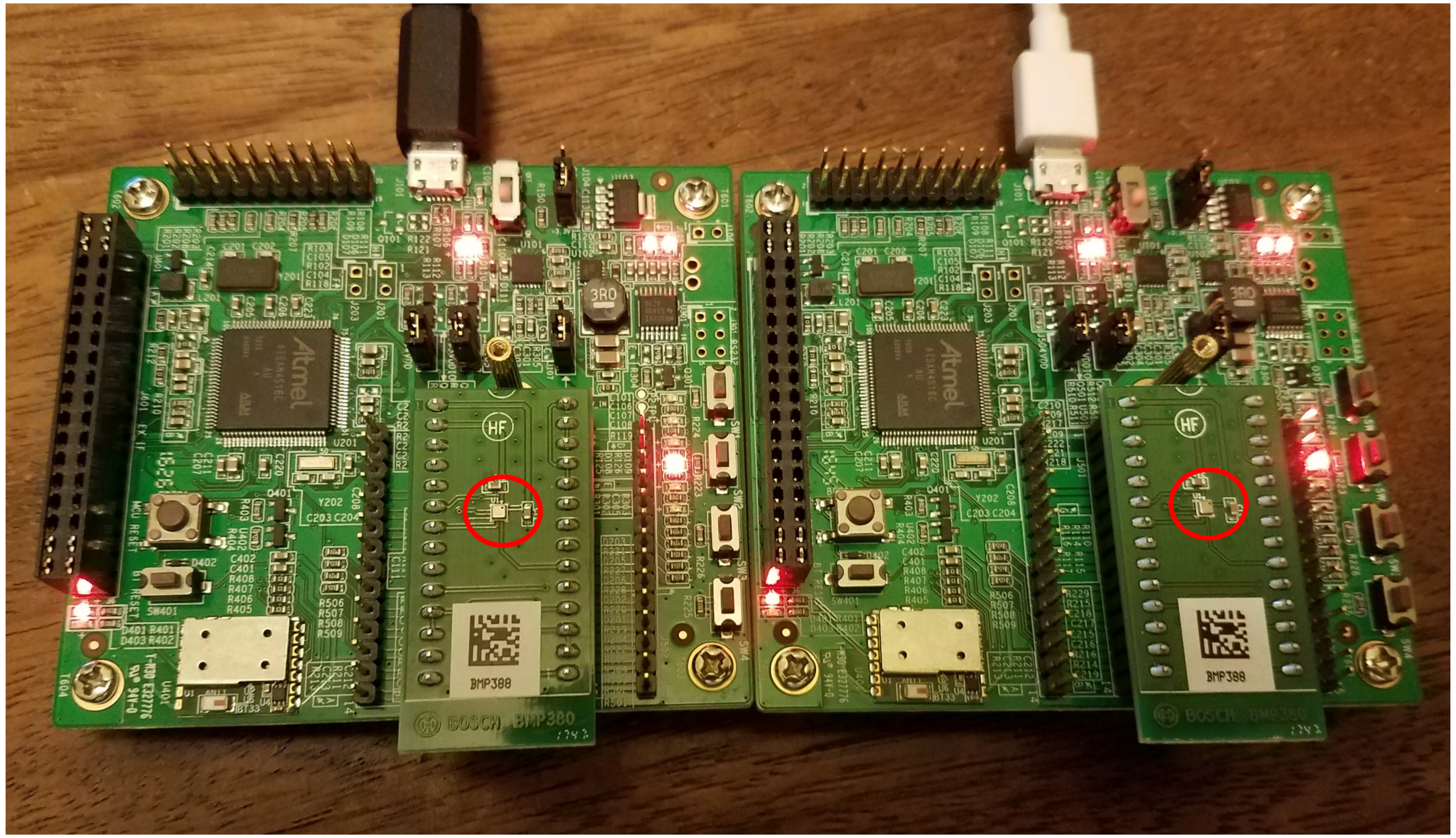
⇨ Net Duct Leakage to/from Outside (more return in this case)

Technical Objectives (NIST Project)

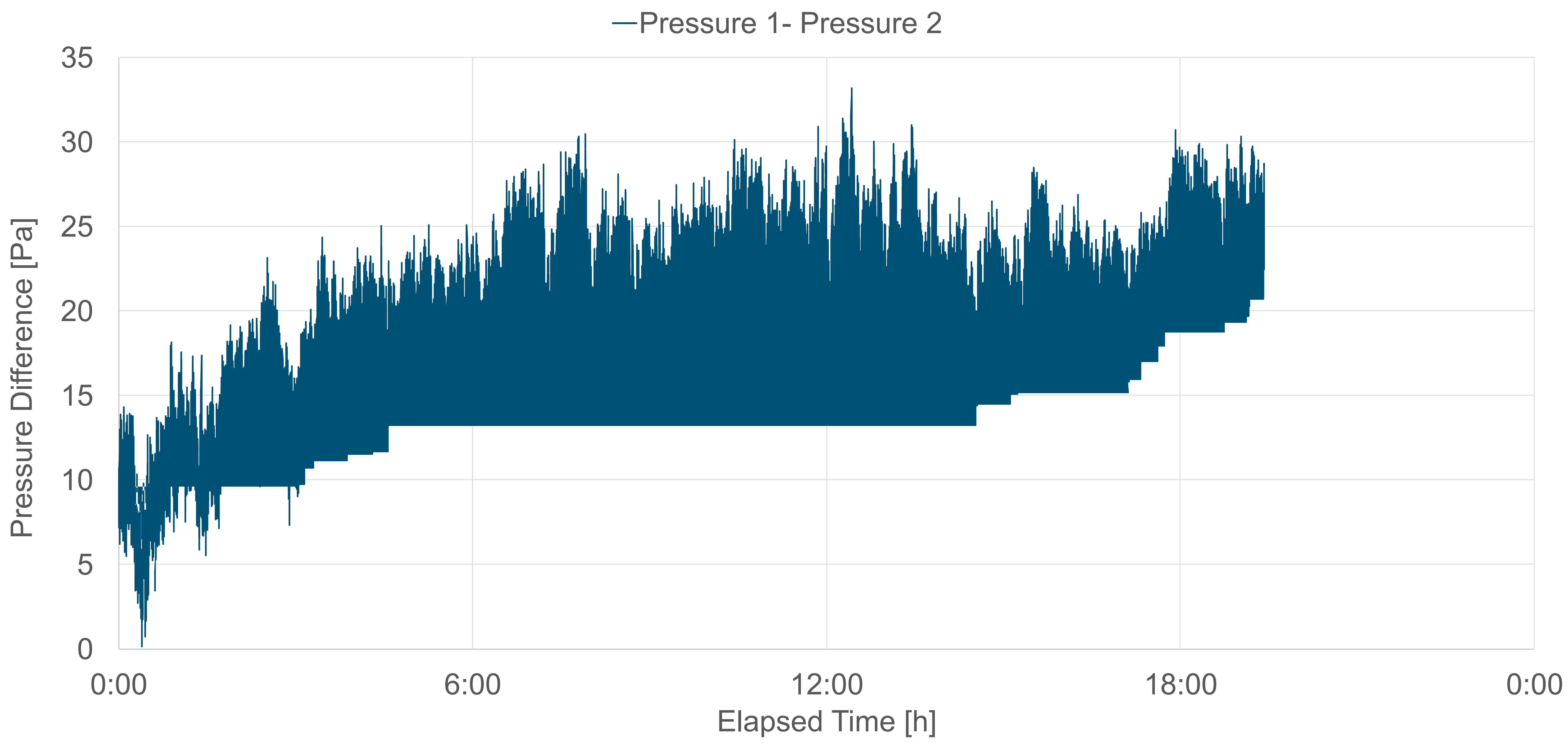
» Carefully examine alternative hardware for pressure measurement

» Test hardware, sensor placement, and analysis protocols in different buildings

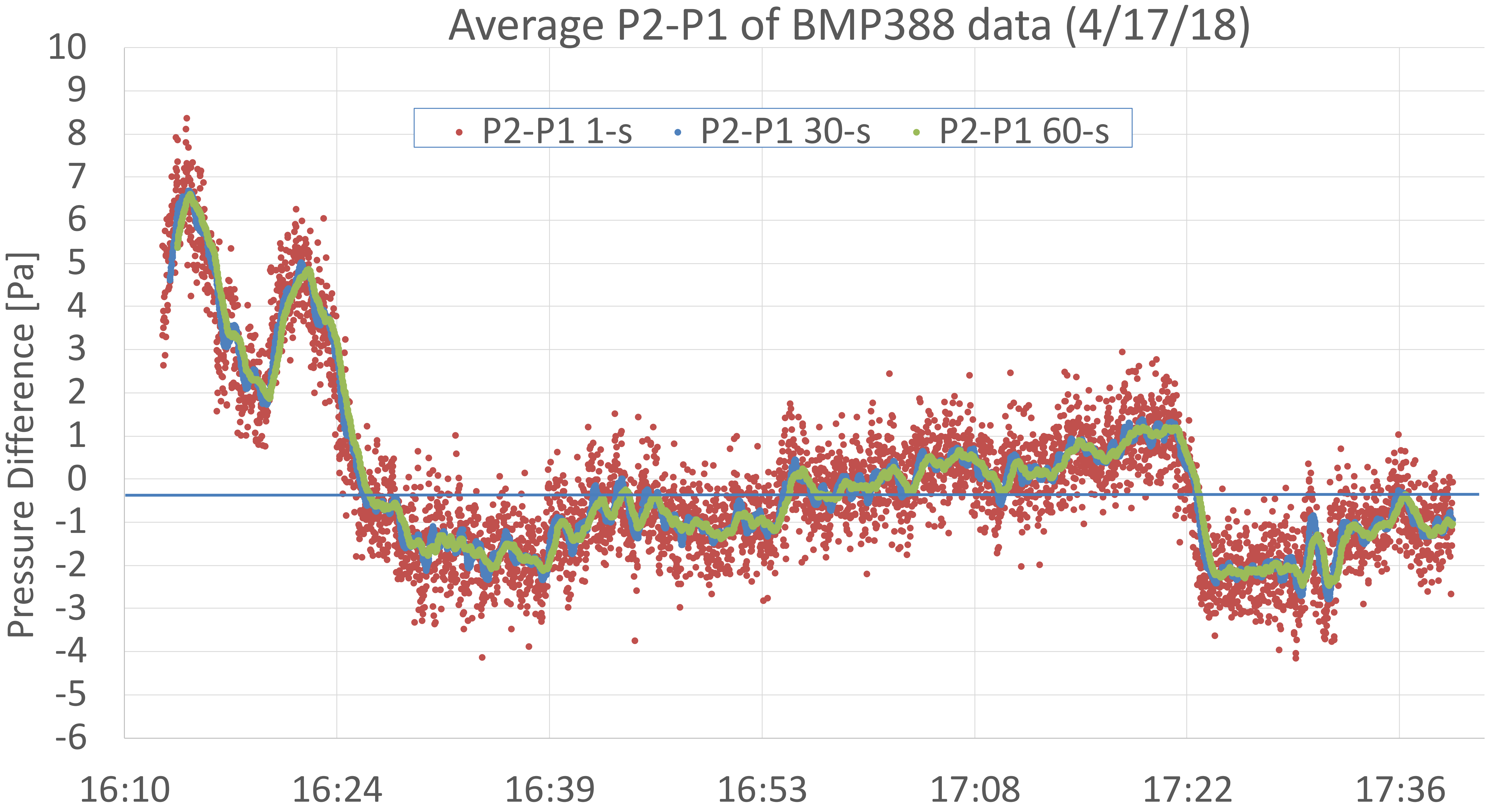




Comparison of Absolute Pressure Sensors

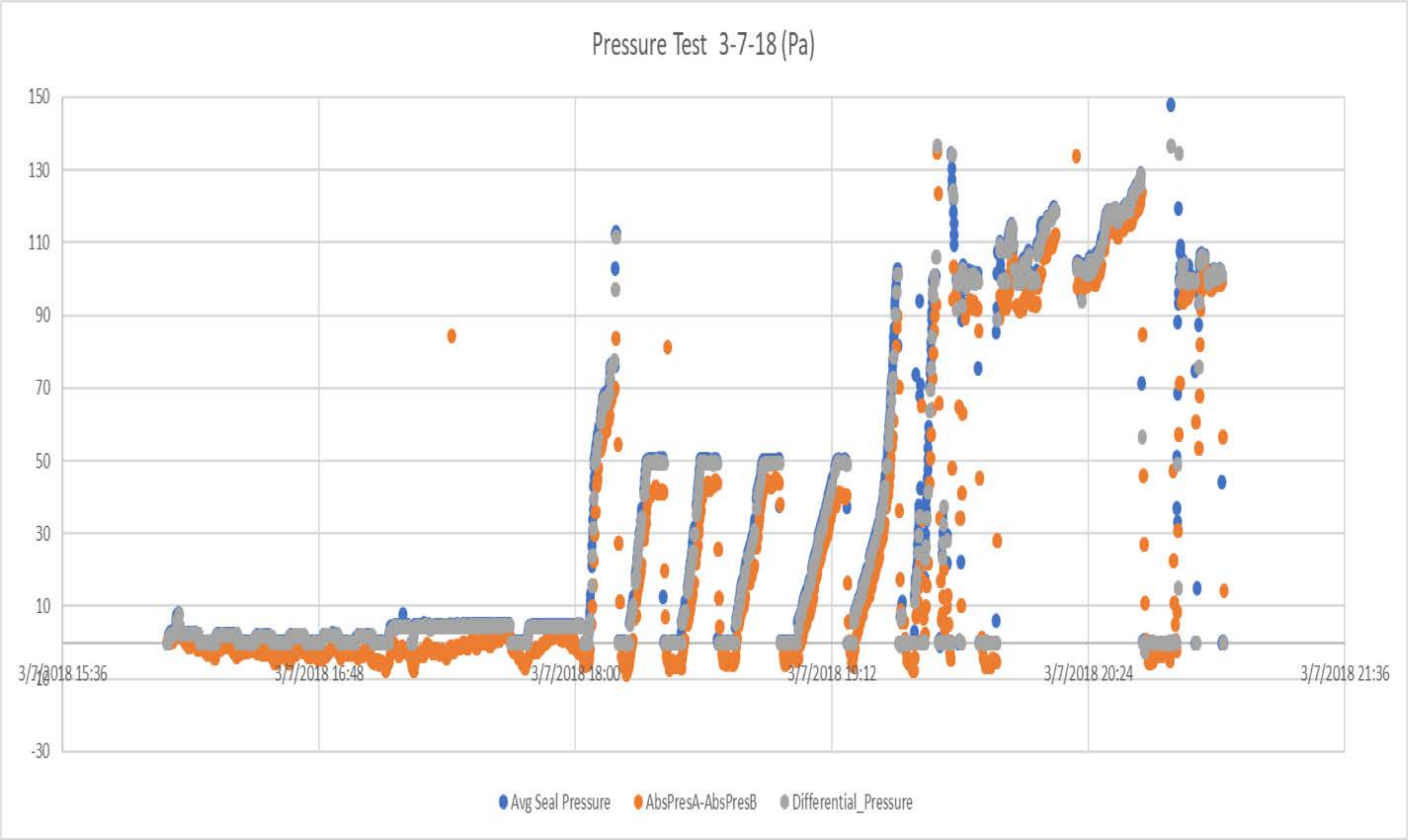


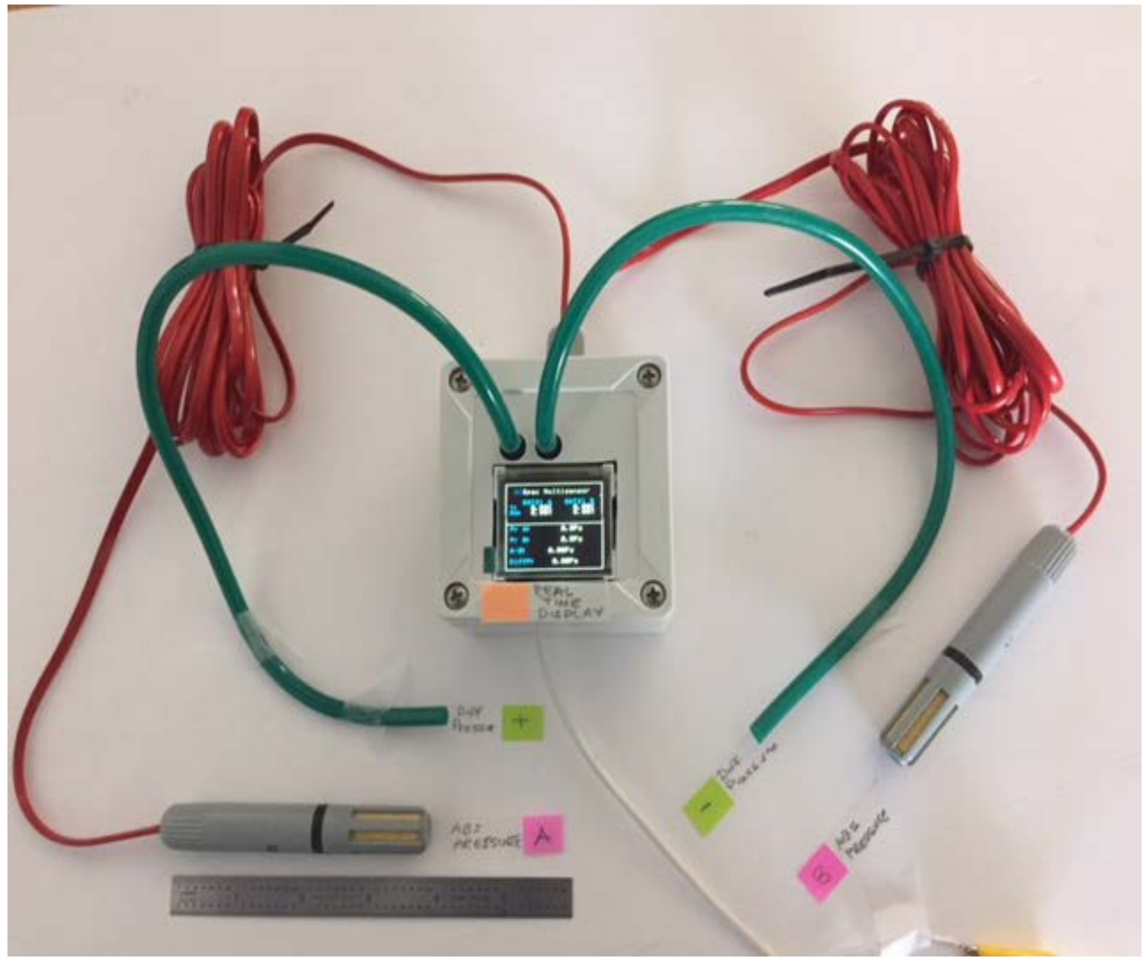
Absolute Pressure Sensors (Round 2)

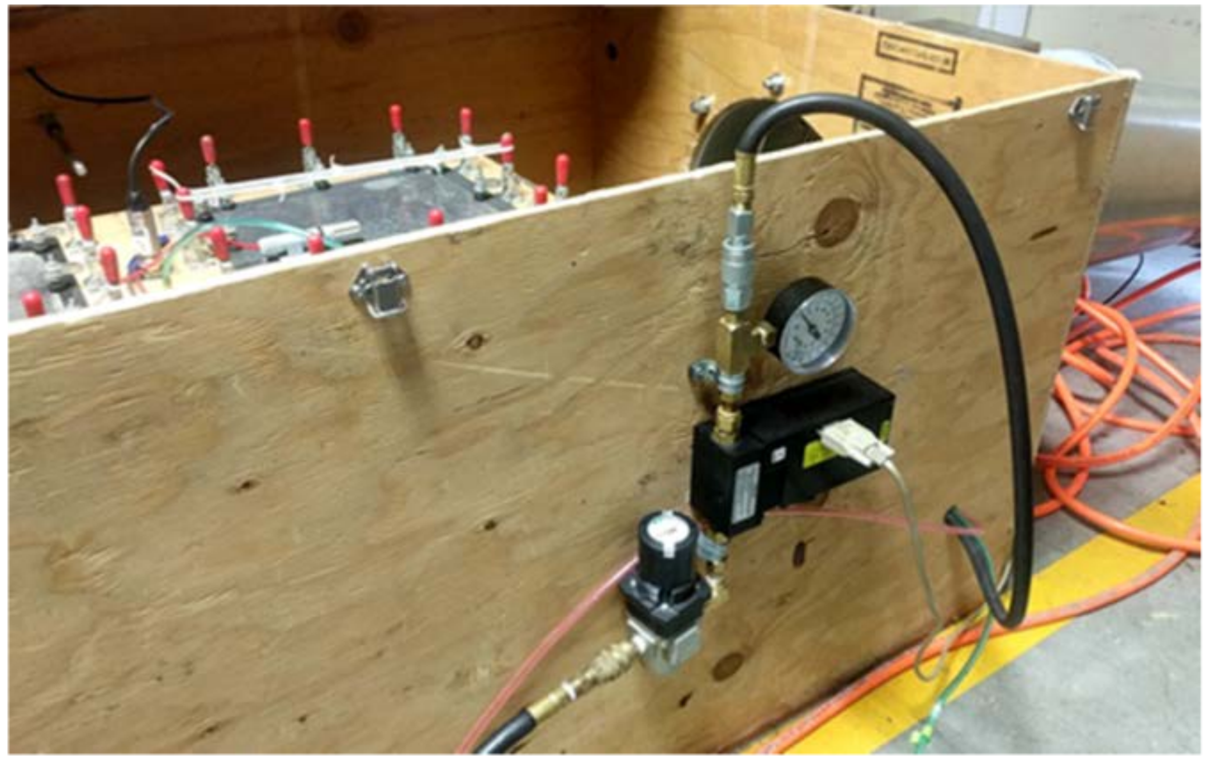


Lab Testing of Sensors (NIST Project)

» Alternative hardware for pressure measurement







DoD Leakage Diagnosis Project

- Demonstrate simplified leakage detection tool on multiple building types/sizes
- Increase adoption of air-sealing efforts within UESC programs
- Determine cost effectiveness of leakage detection tool relative to state-of-the-art

WCEC Modeling

Nelson Dichter

» Valuation of Thermal Energy Storage for Utility Grid Operators

» Low Cost, Large Diameter, Shallow Ground Loops for Ground Coupled Heat Pumps

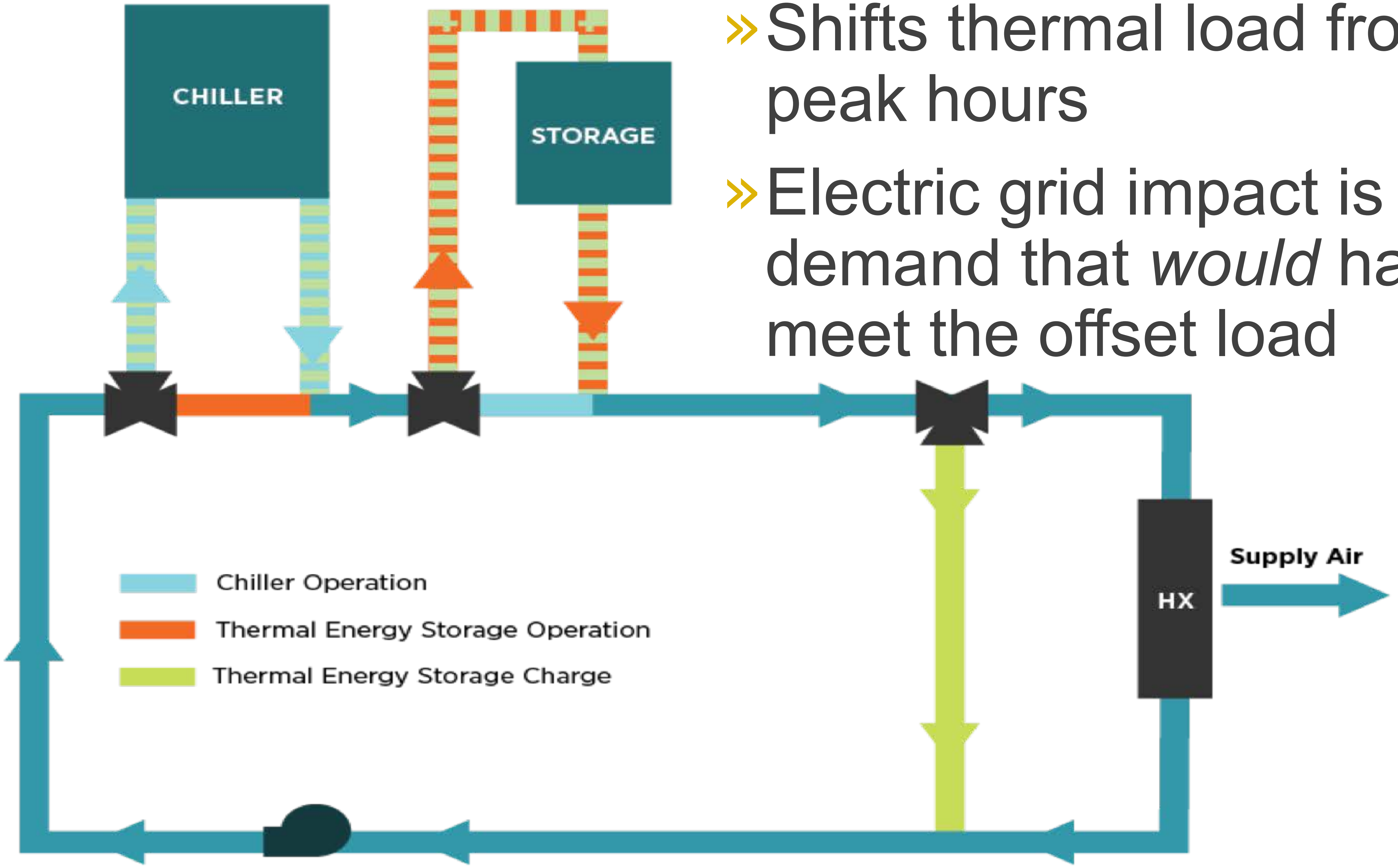
» Hybrid Black Box Model

» Cost Effective Zero Net Energy

Valuation of Thermal Energy Storage for Utility Grid Operators

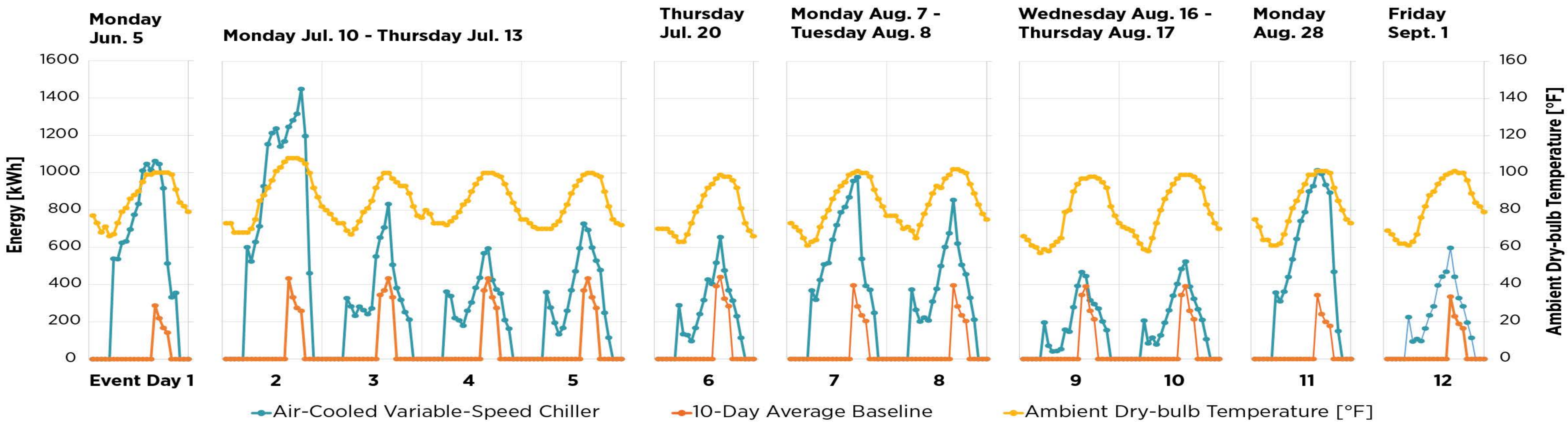
Sponsor: Trane

Thermal Energy Storage



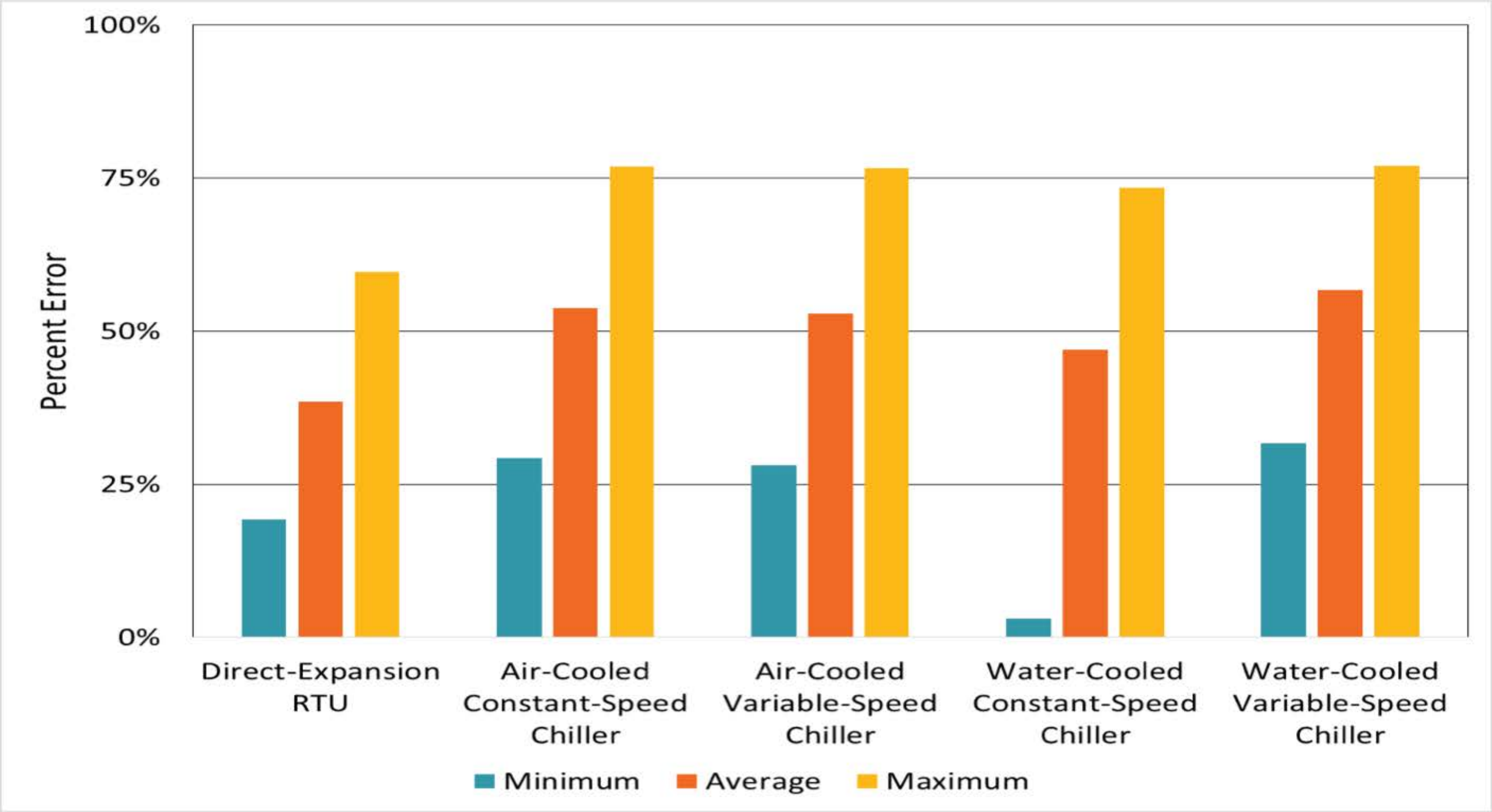
- Shifts thermal load from peak hours to off-peak hours
- Electric grid impact is the peak electric demand that *would* have been required to meet the offset load

Modeled Energy Use vs 10-Day Average Baseline Prediction



10-Day average baseline and actual electricity use for the 10-story office building in Sacramento with direct expansion RTUs on four consecutive event days in July

Model Comparison by Equipment Type



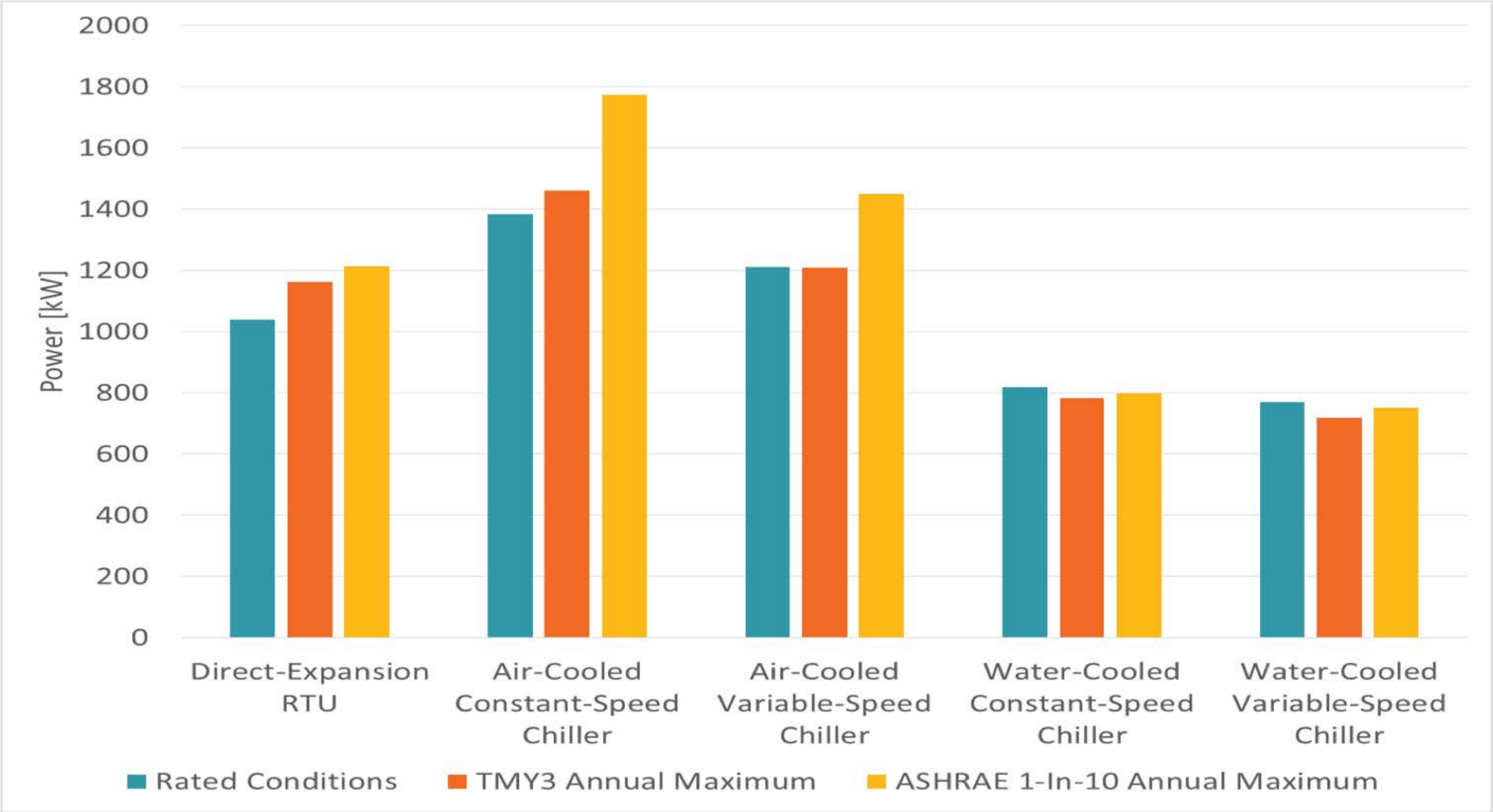
The minimum, average and maximum under-prediction of the 10-day average baseline relative to the actual electrical demand impact for a 10-story office building in Sacramento, for each type of cooling system

Disparities in Weather Data Sources

» Choice of weather data source can have a large impact on predicted value of the thermal energy storage system

Annual Maximum Dry-bulb Temperature and Coincident Wet-bulb Temperature					
		TMY3	CZRV2	CZ2010	ASHRAE 10-Year
Burbank	Dry-Bulb [°F]	100.4	102.0	106.9	109.0
	Wet-Bulb [°F]	76.1	77.2	78.6	79.7
Riverside	Dry-Bulb [°F]	110.1	103.7	109.4	111.0
	Wet-Bulb [°F]	70.8	72.7	74.0	77.0
Sacramento	Dry-Bulb [°F]	107.6	103.1	107.8	109.8
	Wet-Bulb [°F]	76.1	74.6	75.5	78.8

Modeled Annual Peak Demand



Annual maximum electricity offset using TES systems for the 10-story office building in Riverside

Future Work

» Investigate and test alternative methods for:
  - Measuring the electric grid impact of thermal energy storage
  - Determining the value of thermal energy storage

Low Cost, Large Diameter, Shallow Ground Loops for Ground Coupled Heat Pumps

Sponsor: CEC

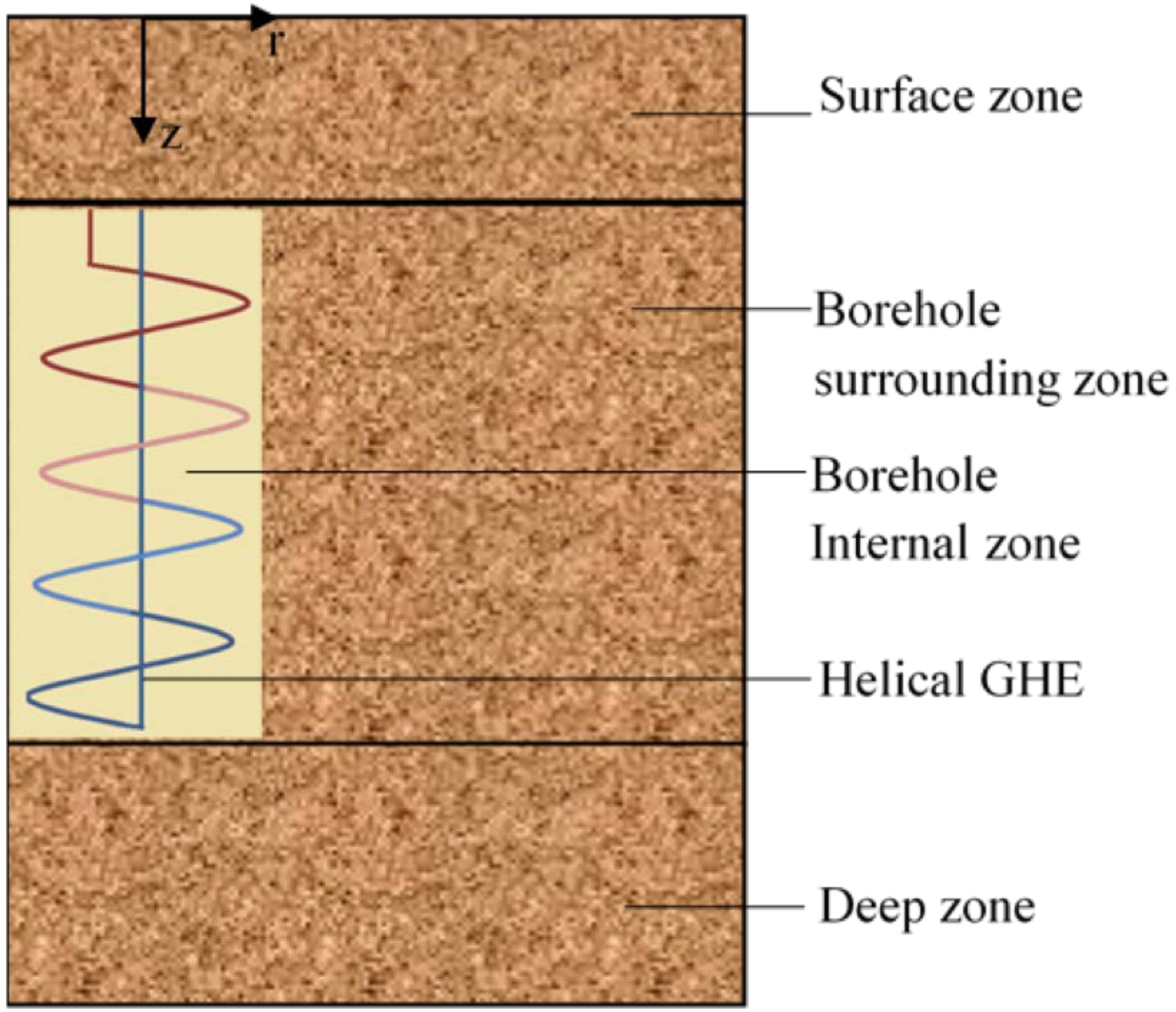
Overall Project Objectives

- Development of tools and information to facilitate market acceptance of low-cost ground heat exchangers for ground-coupled heat pump systems through:
  - HE design guidelines
  - Installation best practices
  - Modeling tools

- Facilitate market acceptance of GHEs
- Provide T24 compliance tools

Capacitance Resistance Model (CaRM)

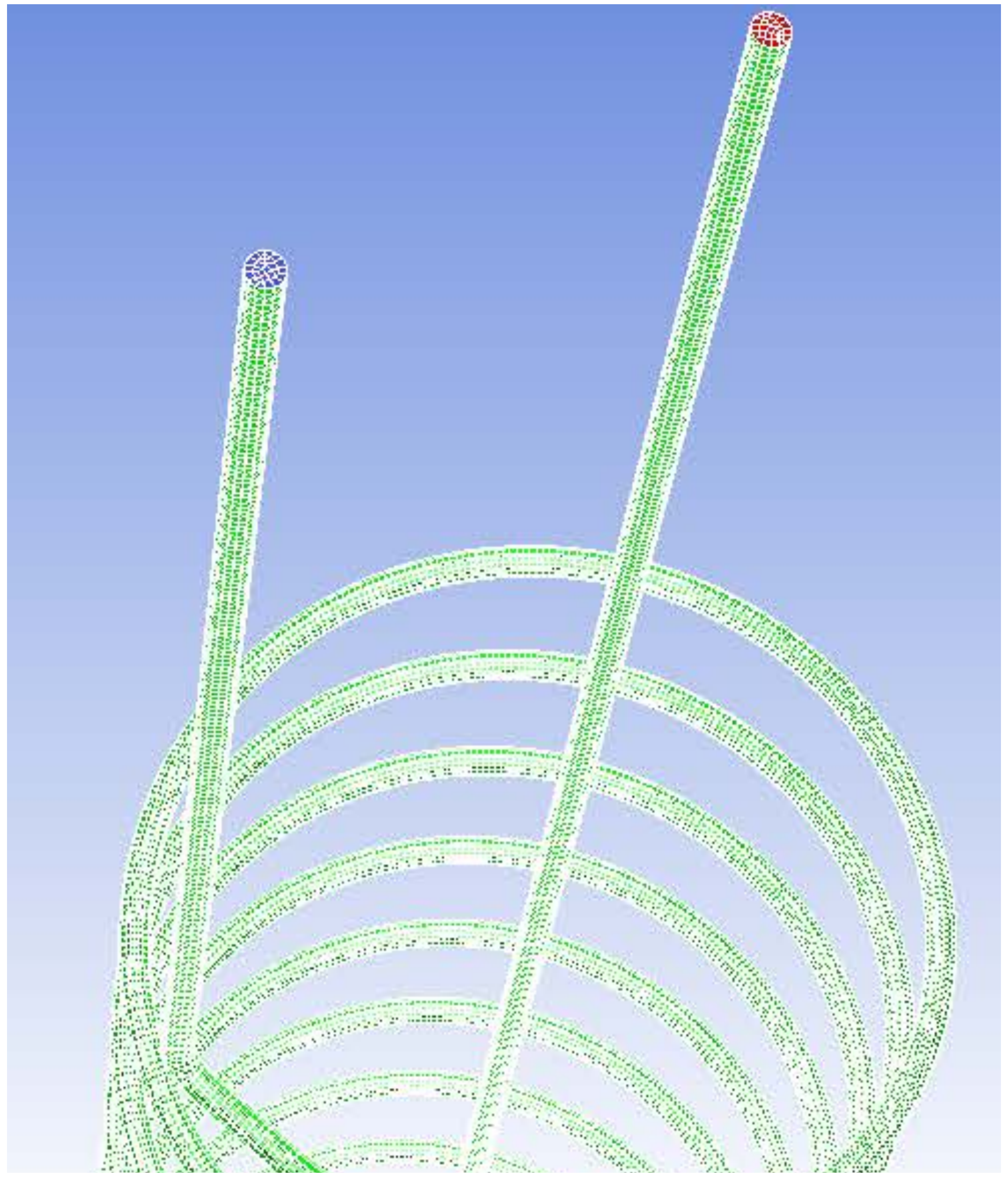
- Collaboration with Prof. Zarrella, University of Padova, Italy
- Models heat transfer as current, temperature differences as voltage
- Incorporates heat transfer in axial and radial directions
- Model assumptions:
    - Isothermal B.C. at bottom and radial boundary of bore
    - Axial symmetry
    - Heat transfer from GHE piping in surface zone neglected
    - Isotropic soil properties, uniform in each layer

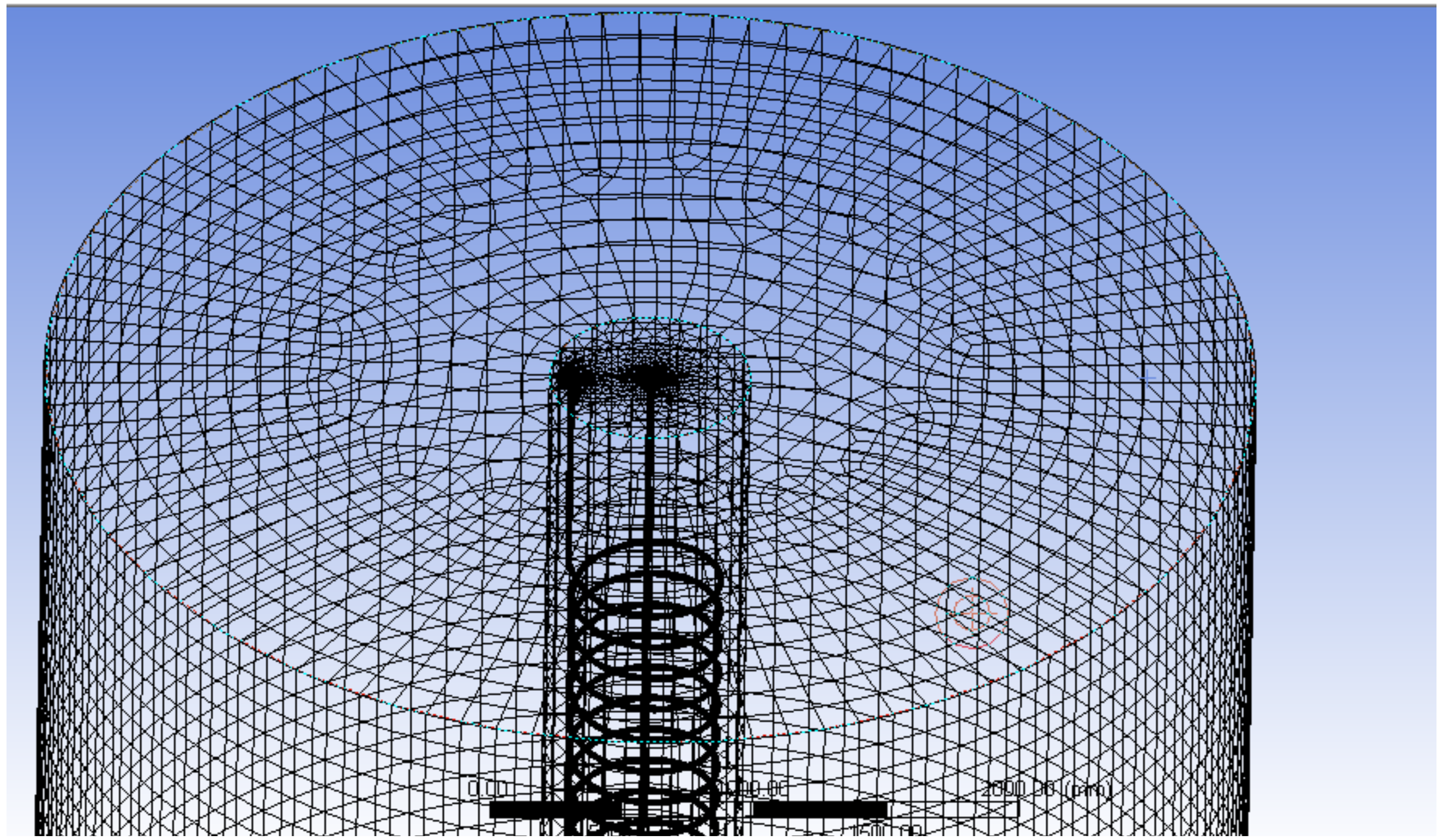


Zones defined in CaRM

Computational Fluid Dynamics (CFD) model

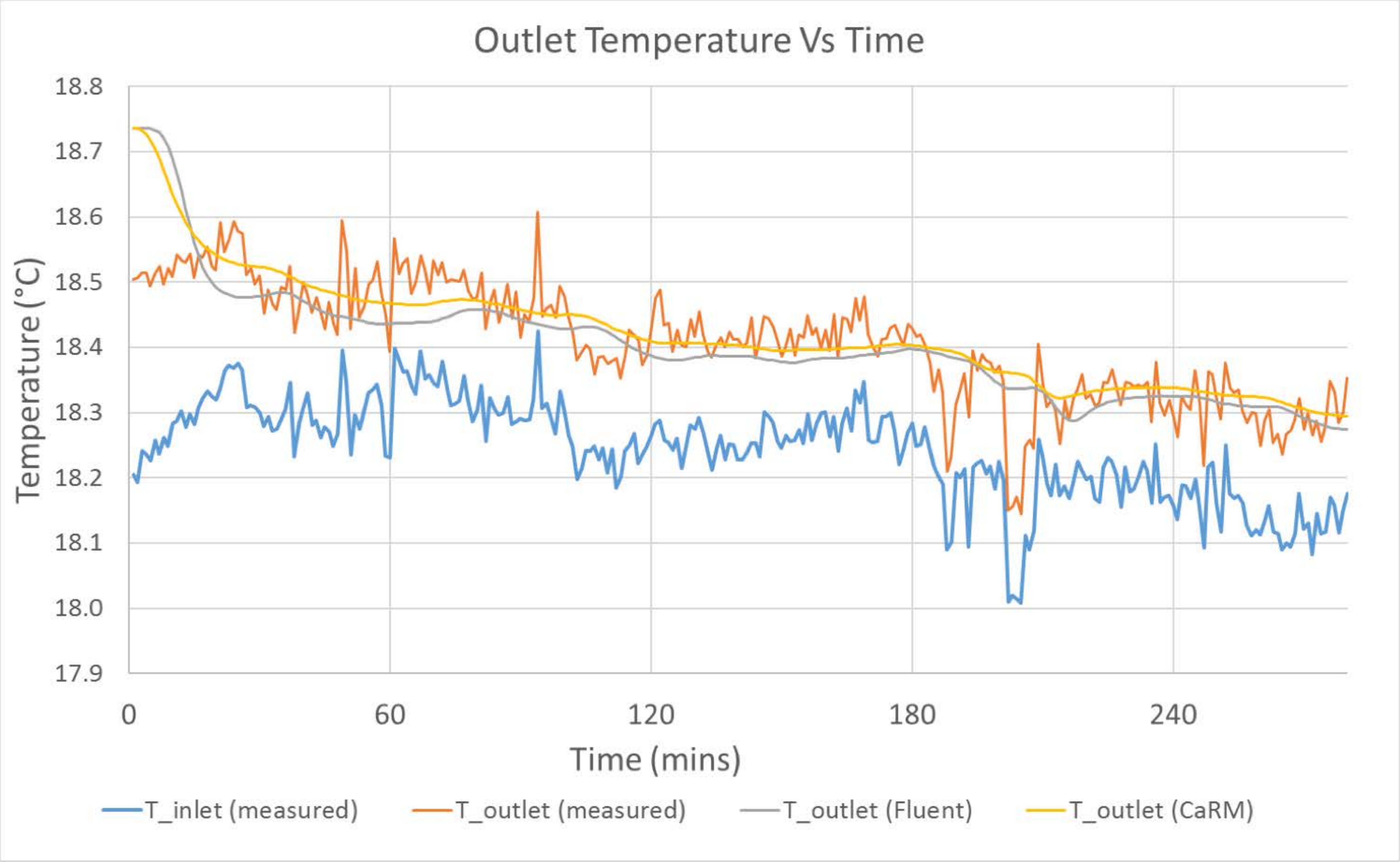
- Validate CaRM Results
- Incorporate complex heat transfer phenomenon (soil porosity, irrigated soil)





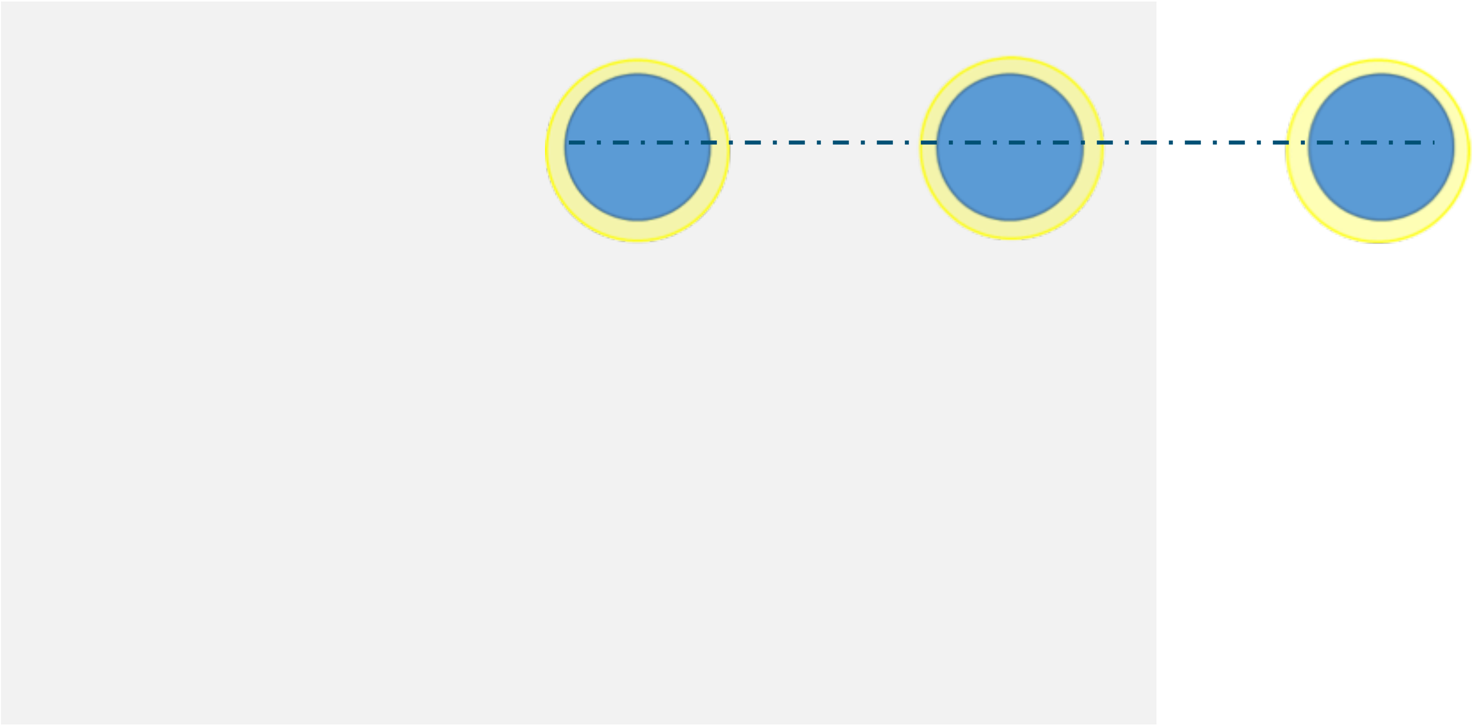
Helical GHE model mesh

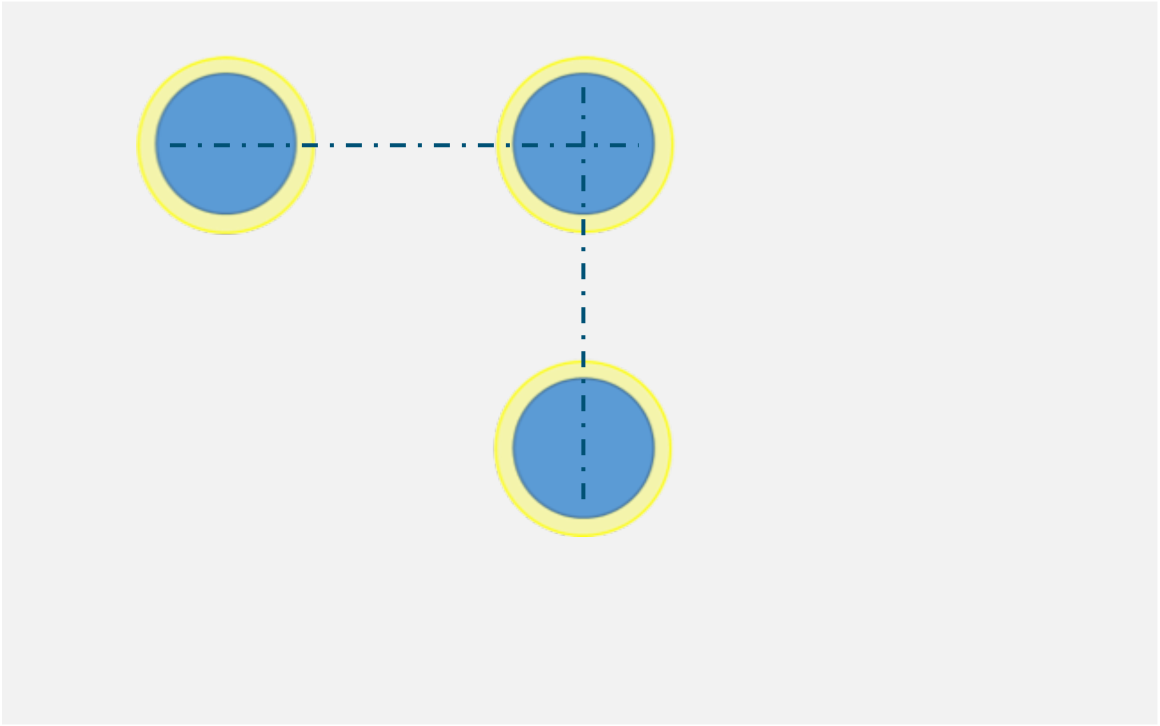
CFD Model vs CaRM: Global Comparison



Path Forward

- Perform controlled lab test in the field to further calibrate the model
- Investigate the interactive effects of adjacent heat exchangers
- Model will be used to develop algorithm for EnergyPlus



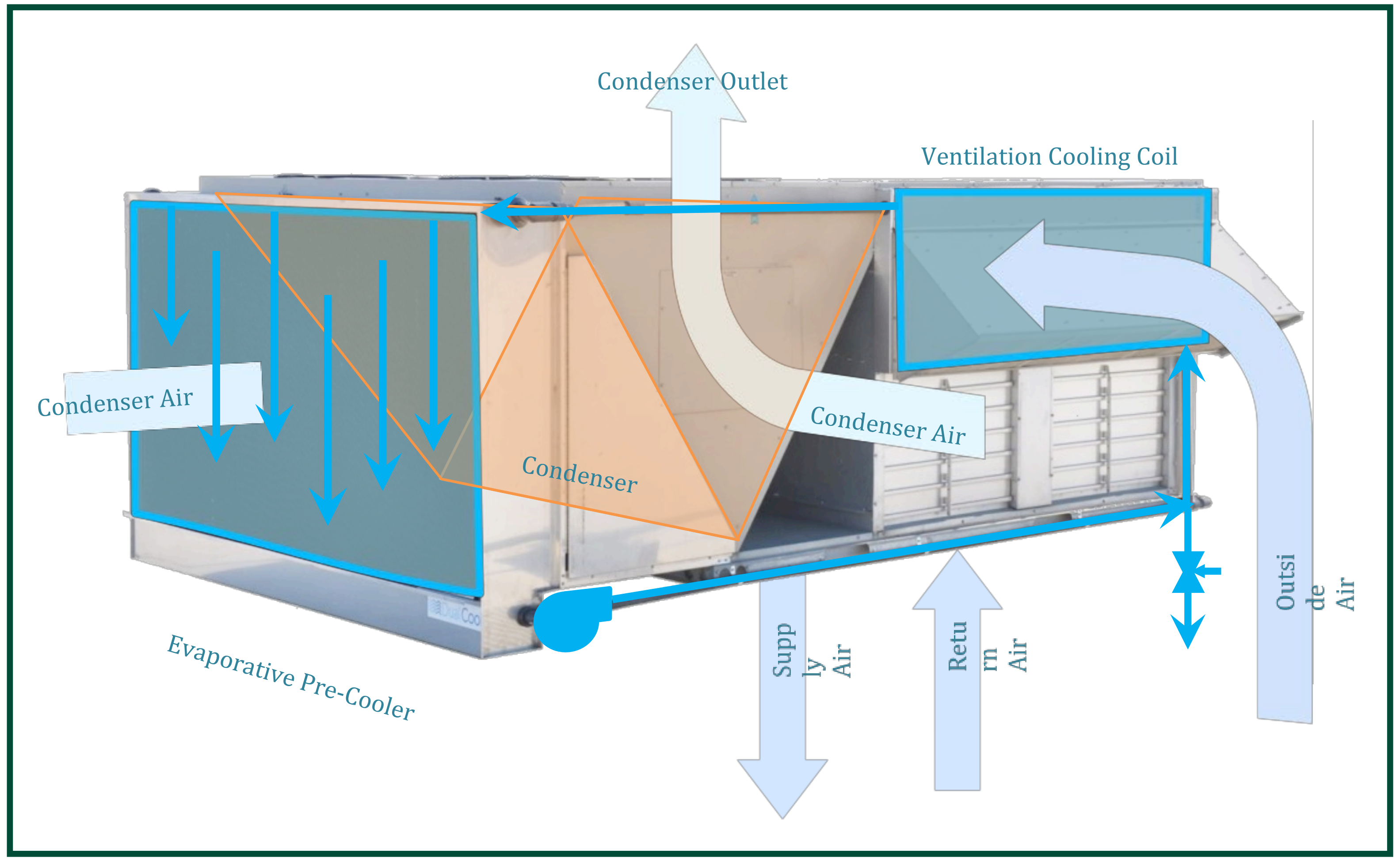


Hybrid Black Box Model

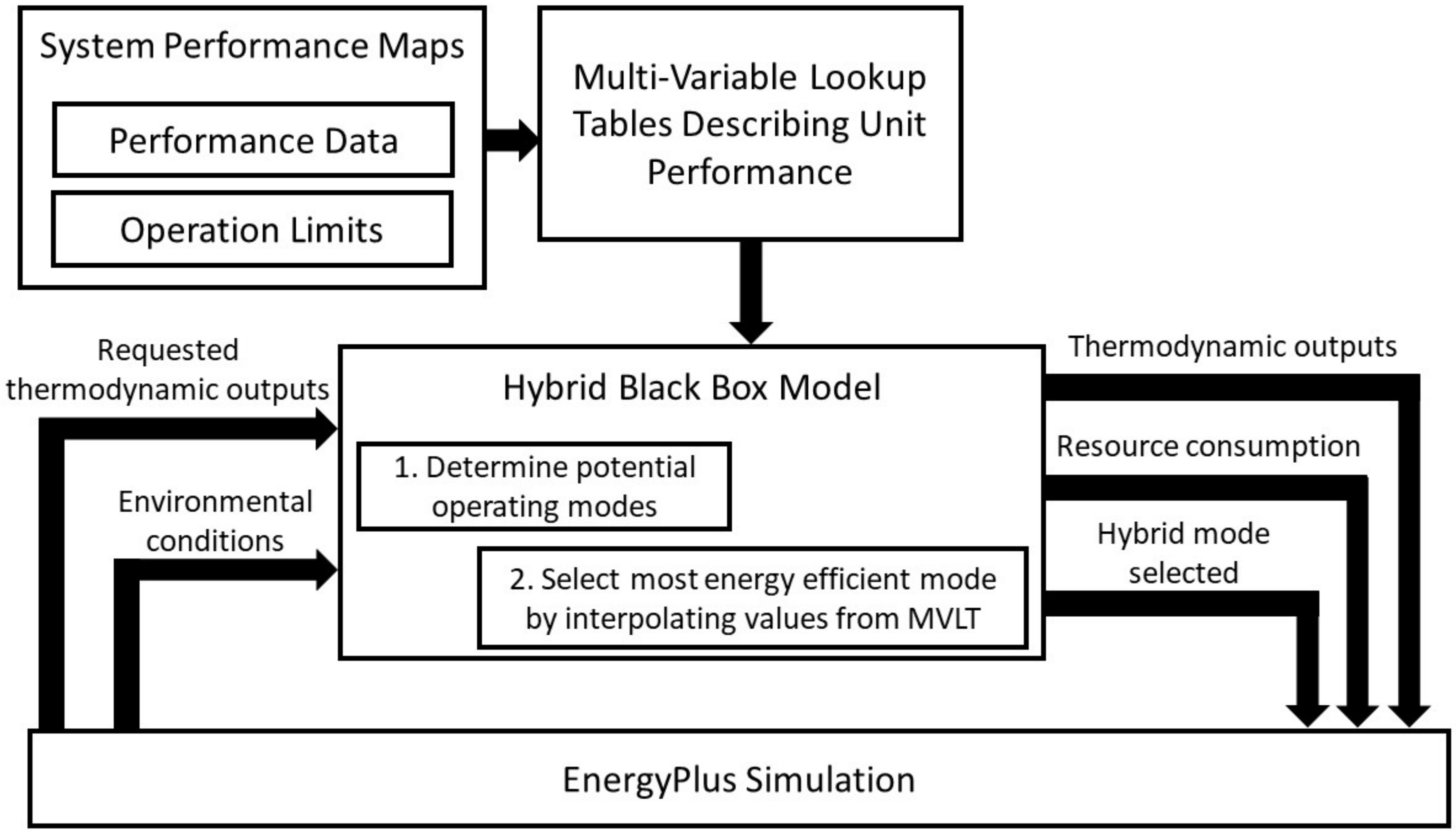
Sponsor: SCE, DOE

Hybrid Black Box Model

- 30% of electricity consumption in CA commercial buildings is for cooling and ventilation
- Hybrid air conditioners can reduce electricity consumption
- Current simulation tools make modeling hybrid air conditioners difficult
- In order to address this issue a black box model was created

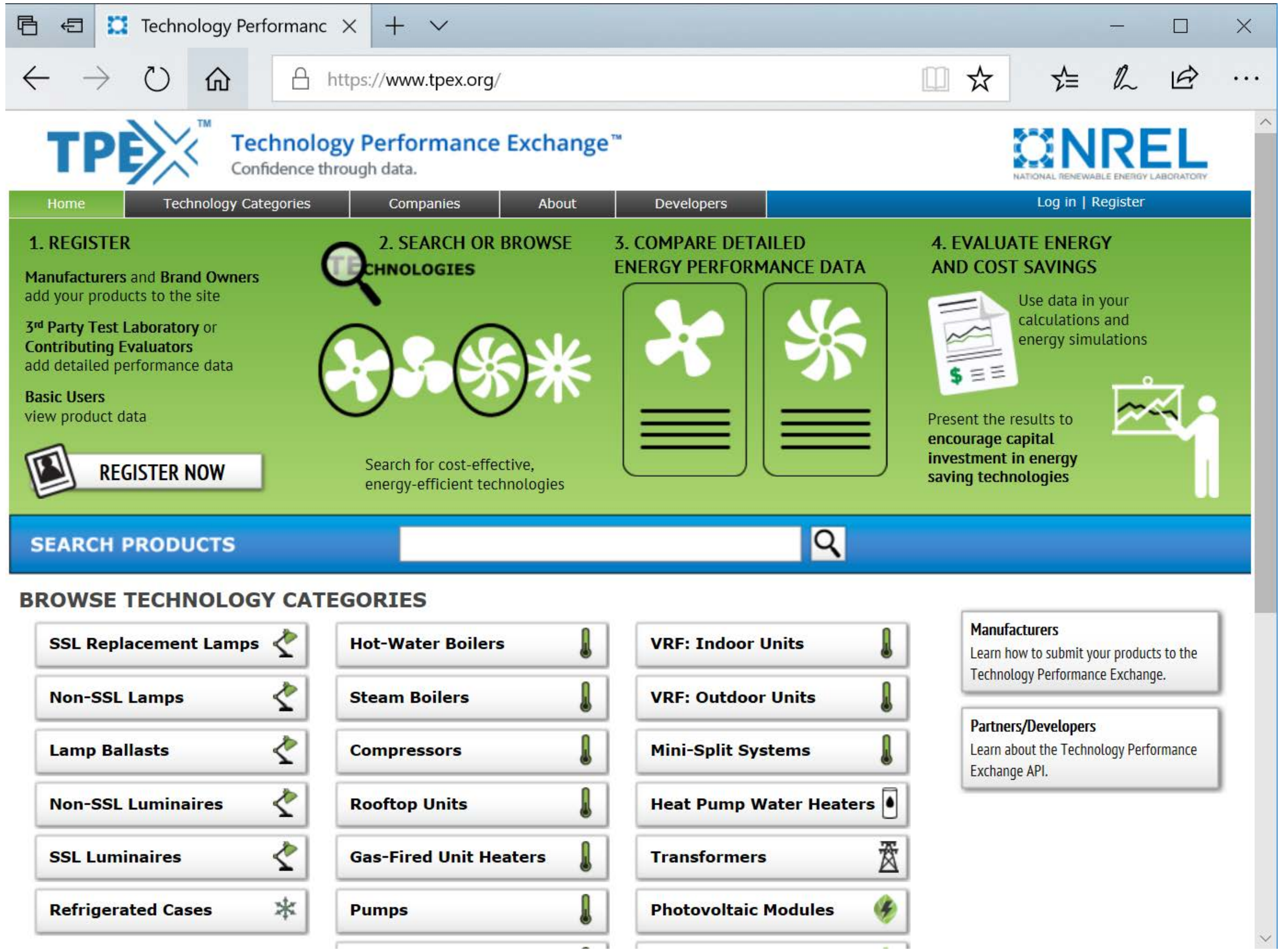


Model Architecture



Technology Performance Exchange (TPEX)

- » TPEX created to connect manufacturer data with building modelers
- » Any manufacturer can share their data
- » Provides database for modelers to help facilitate simulations of hybrid systems



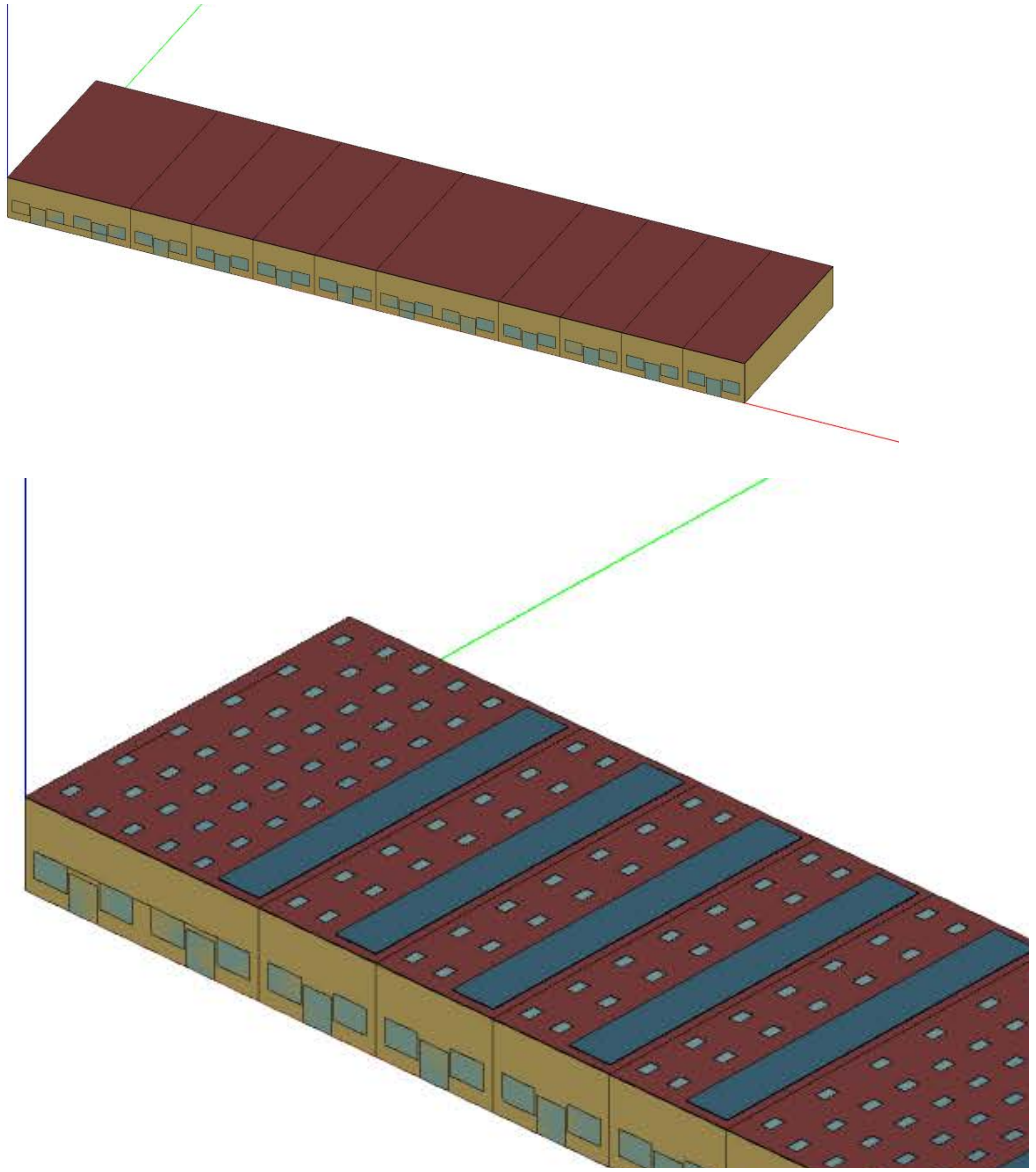
Cost Effective Zero Net Energy

Sponsor: CEC

Project Overview

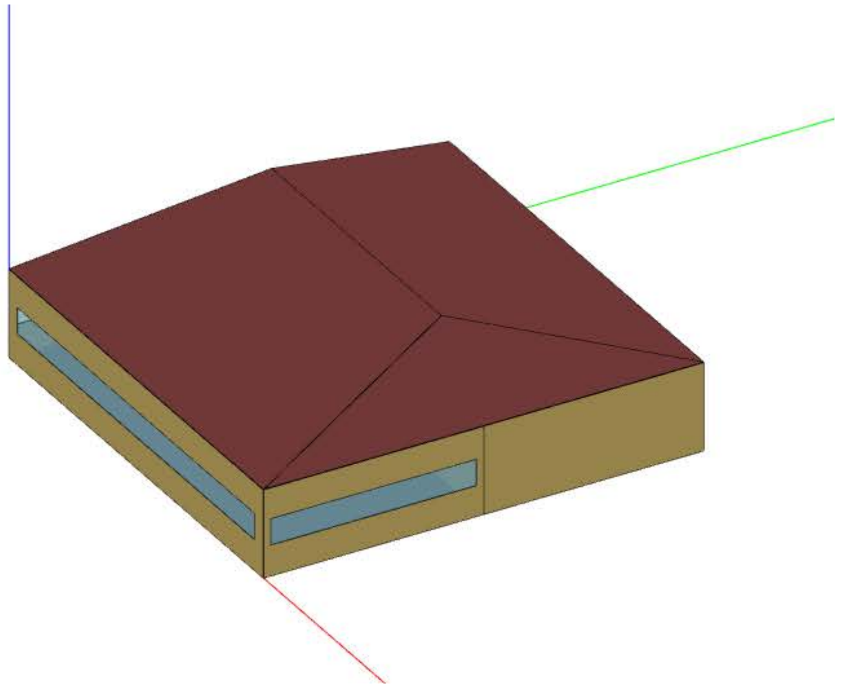
- Project Goal
  - To create packages of energy saving strategies and technologies that will allow commercial and multifamily residential buildings in California to reach zero-net-energy (ZNE) cost-effectively
- Approach: Parametric Analyses
  - 11 Building Types
  - California's 16 Climate Zones
  - More than 30 measures

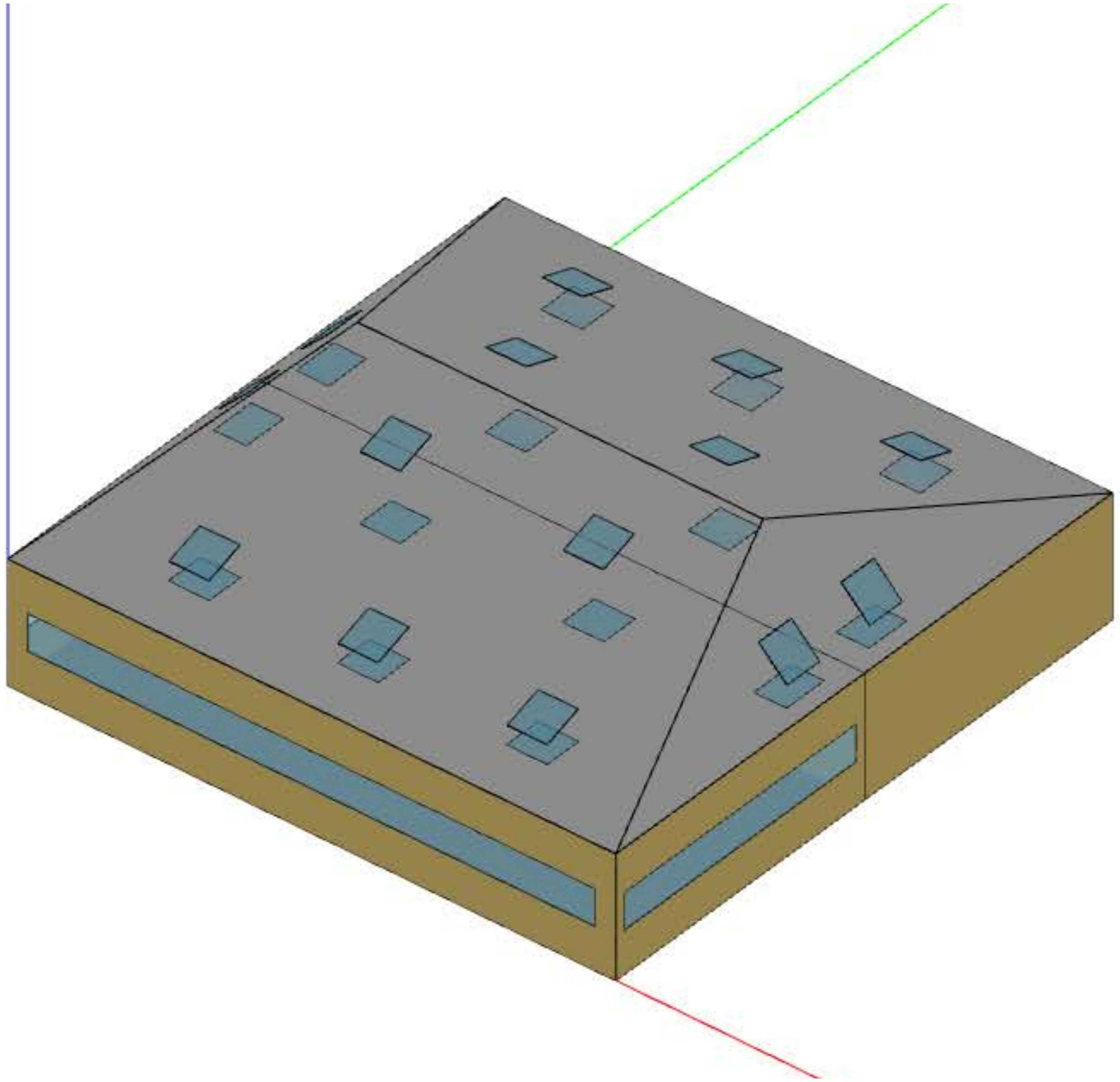
Skylight, Light tube, PV measure



- User specifies percentage of roof used for skylights/light tubes and for PV panels.
- The PV panels are placed first
- Skylights and light tubes are placed in the remaining space

Skylight, Light tube, PV measure





» Light tubes are added to roof surfaces on unconditioned zones that are above occupied zones

WCEC Field Testing

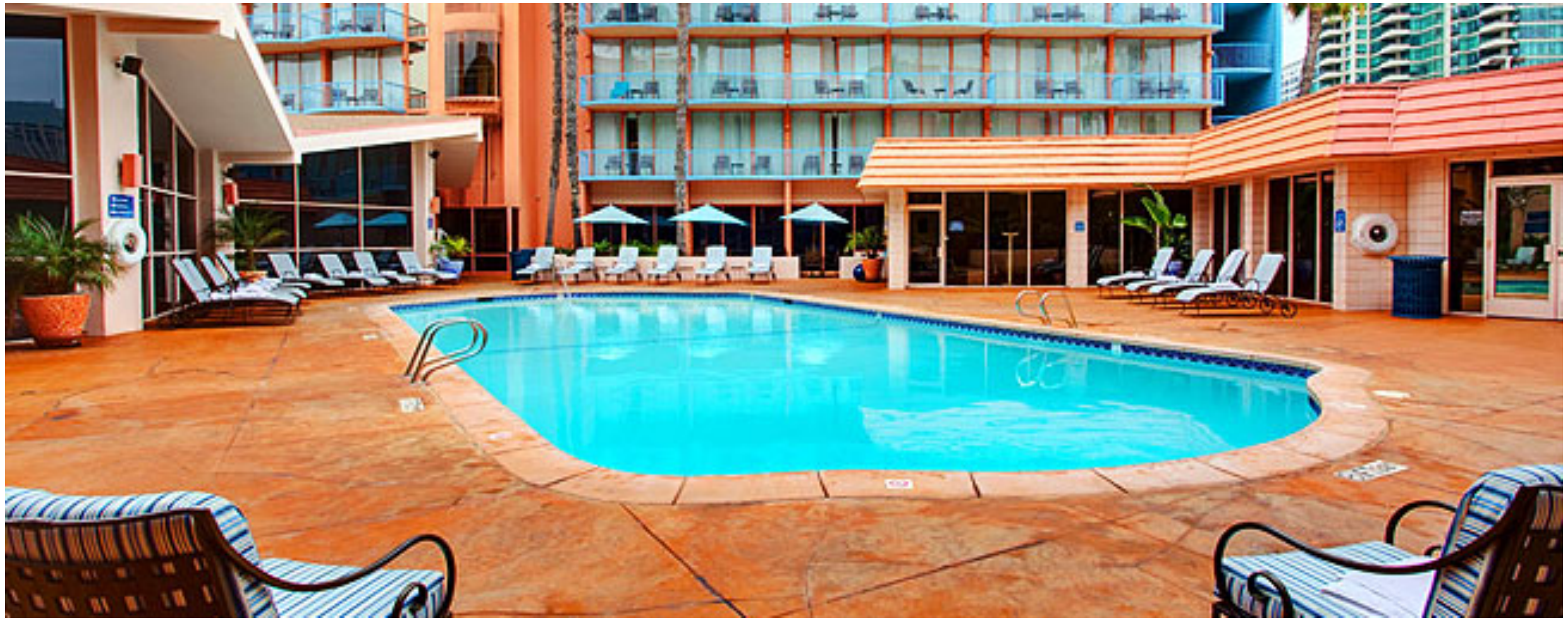
Curtis Harrington, Senior Engineer

Project Highlights

» Swimming Pools As Heat Sinks
» RTU Optimization
» Aerosol Envelope Sealing

Swimming Pools as Heat Sinks

» Sponsored by San Diego Gas and Electric



Opportunity

» Air conditioners reject heat to outdoor air
  - Efficiency of HVAC system is lowest at peak times

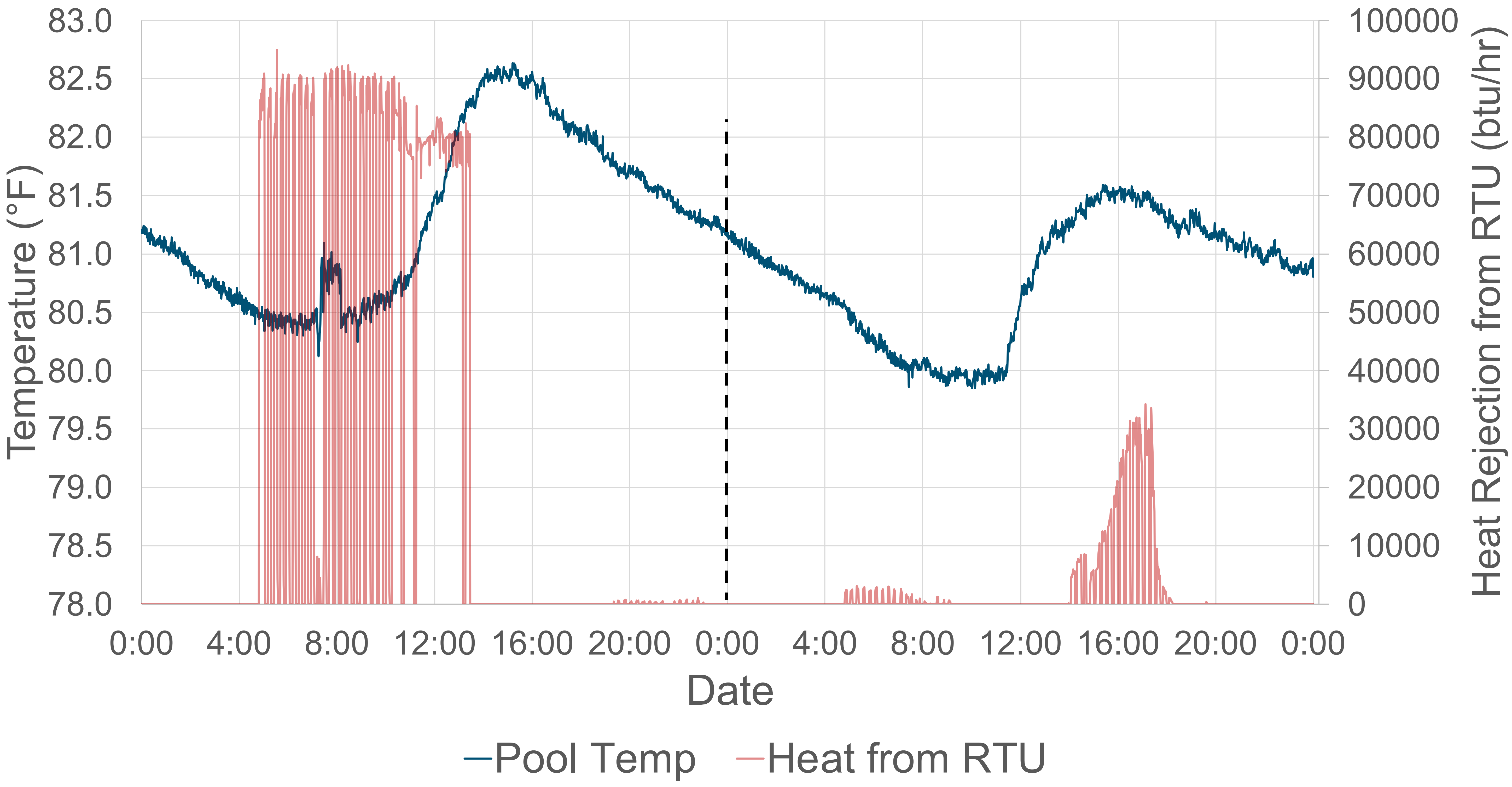
» Heated pools burn gas to maintain pool temperatures

» Rejecting A/C heat to pool could:
  - Reduce gas used for pool heating
  - Improve A/C efficiency
  - Reduce air conditioner peak energy use

Experimental Design

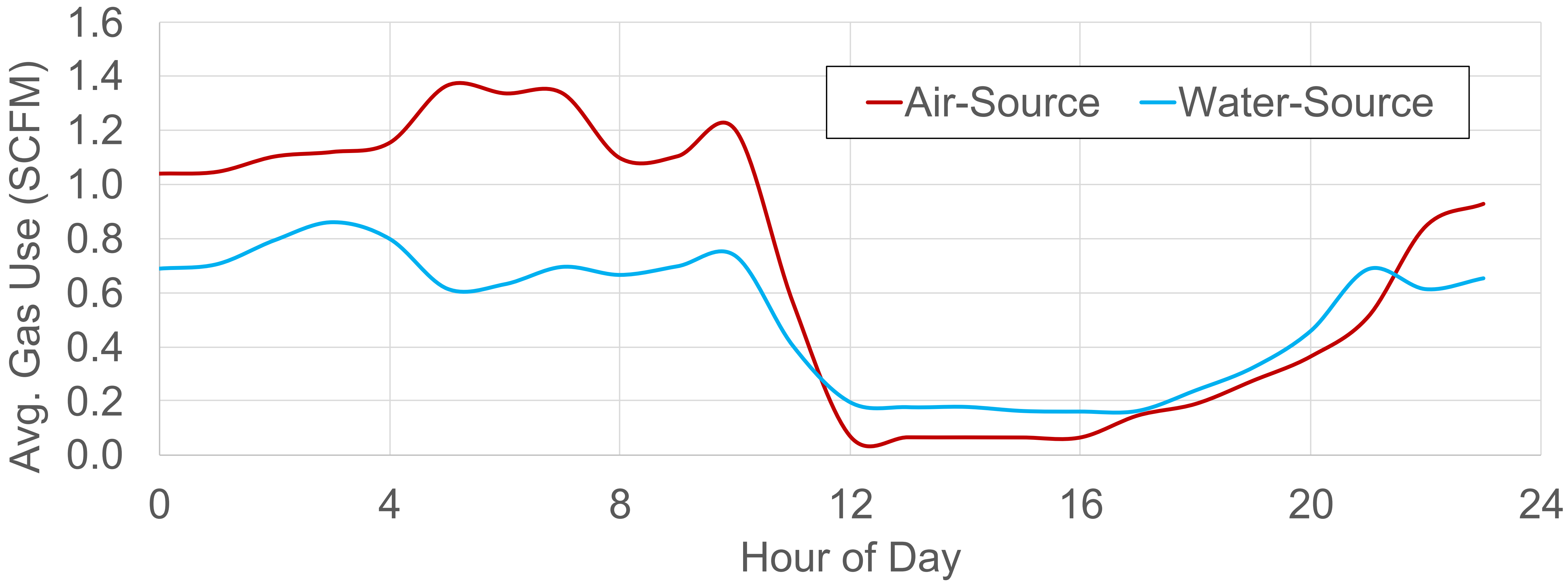
- Install unit for rejecting A/C heat to pool
  - Maintain air-source rejection capability (baseline)
- Monitor HVAC energy use under both modes
  - Air-source heat rejection
  - Pool-source heat rejection
- Monitor cooling efficiency
- Monitor pool heater gas use

Sample Pool Temp Profile



Pool Heater Gas Use

- 29% reduction in NG used for pool heating
  - Expect more savings with larger and more consistent A/C loads
- Reduction of 3 therms/day for the hotel
  - Represents $100/mo. savings during cooling season
- A/C use generally occurs out of phase with pool heating



Pool Air Conditioner Energy Use

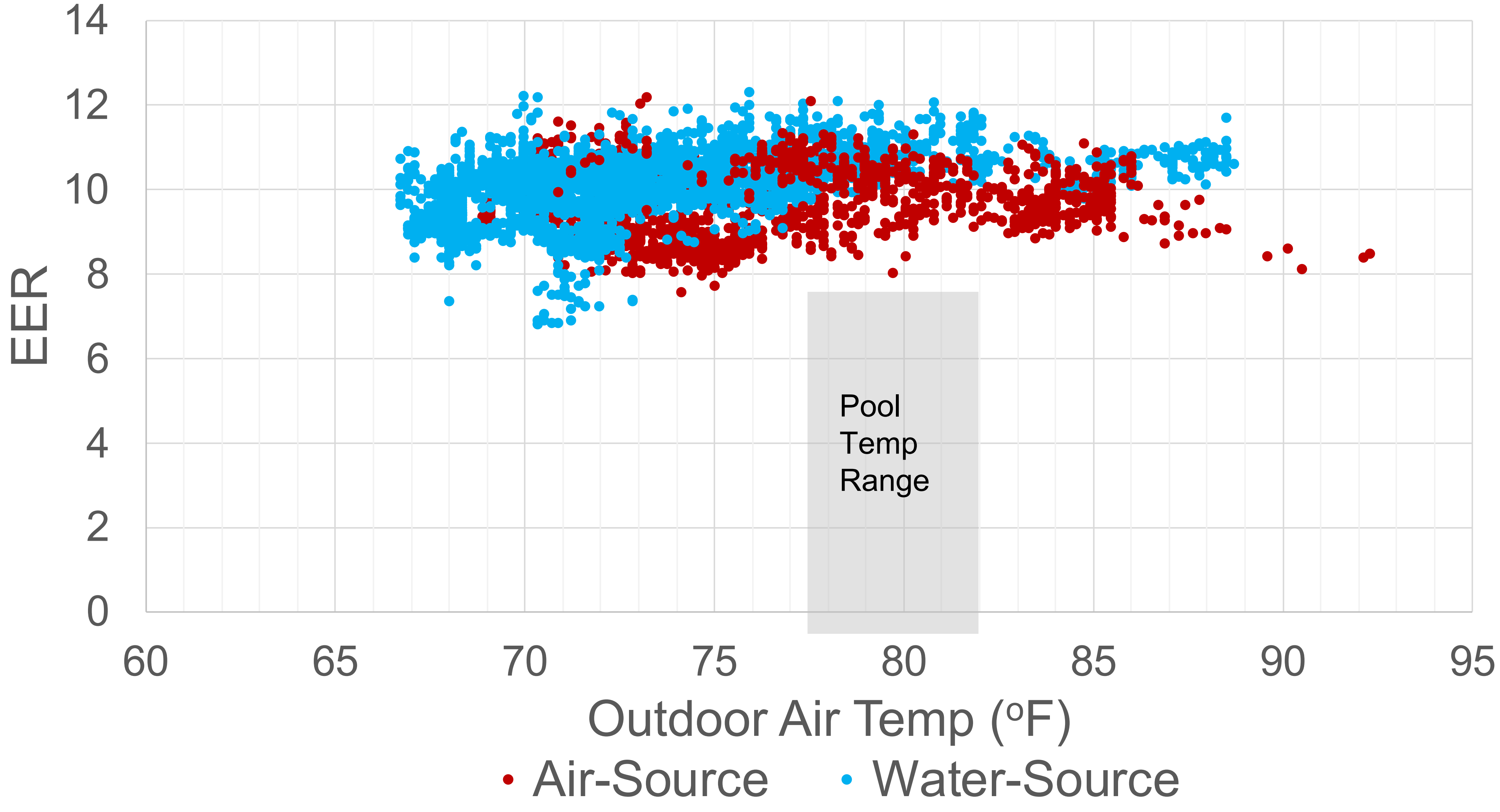
» Unit may be oversized (cycling)
  - 5-Ton unit on 720 sq.ft. fitness center
  - Difficult to establish steady-state

» **5%** reduction in cooling power use
  - Low due to mild weather
  - Expect more savings inland

» Higher rejection temperature for pool-coupled system
  - 79°F for water-side vs. 71.5°F for air-side

Pool Air Conditioner Energy Use

- Efficiency was lower than expected in both modes
- Slight improvement for retrofit at hotter temperatures

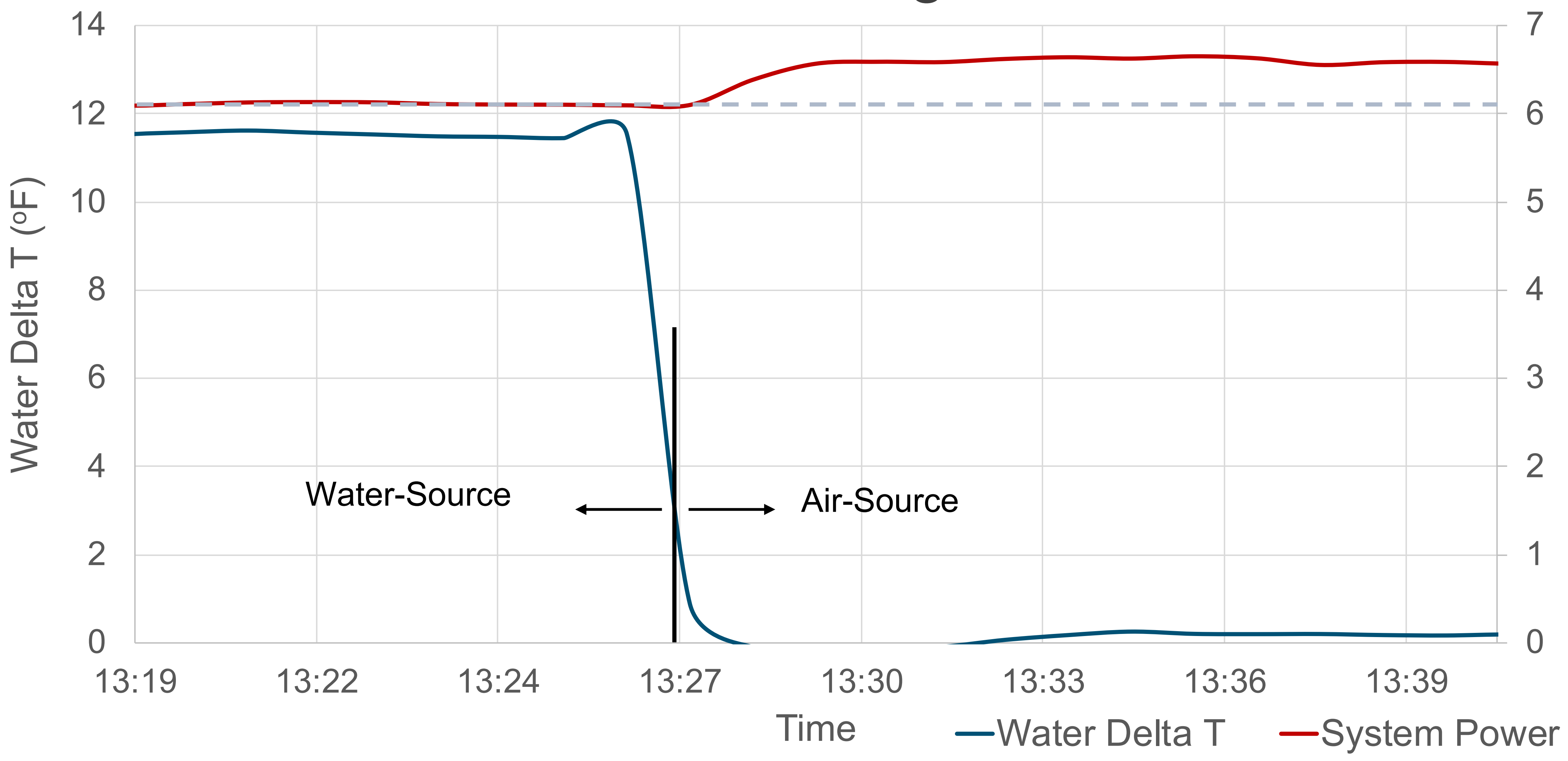


Peak Demand Savings

» 12% reduction in max power draw during observation period

Example (Sep. 1st)

» 8% increase in demand after switching to air-source



Considerations for Implementation

» One A/C unit impacts a large pool
  - Consistent A/C loads are expected to increase gas savings

» Expected tradeoffs based on climate:
  - Mild climates: more gas savings, less electricity savings
  - Hot climates: less gas savings, more electricity savings

» Suggest modeling impact in different climates

RTU Optimization Package

» Sponsored by Southern California Edison

Objective: Demonstrate potential of combining a condenser-air pre-cooler with compressor speed reduction

Project Approach

- Testing simplified approach:
  - Compressor speed reduction (80% capacity)
  - Condenser air pre-cooler
- Reduces energy use and peak demand while maintaining capacity at peak
- Laboratory testing on 4-ton RTU and field testing on 10-ton RTU (2 stages)

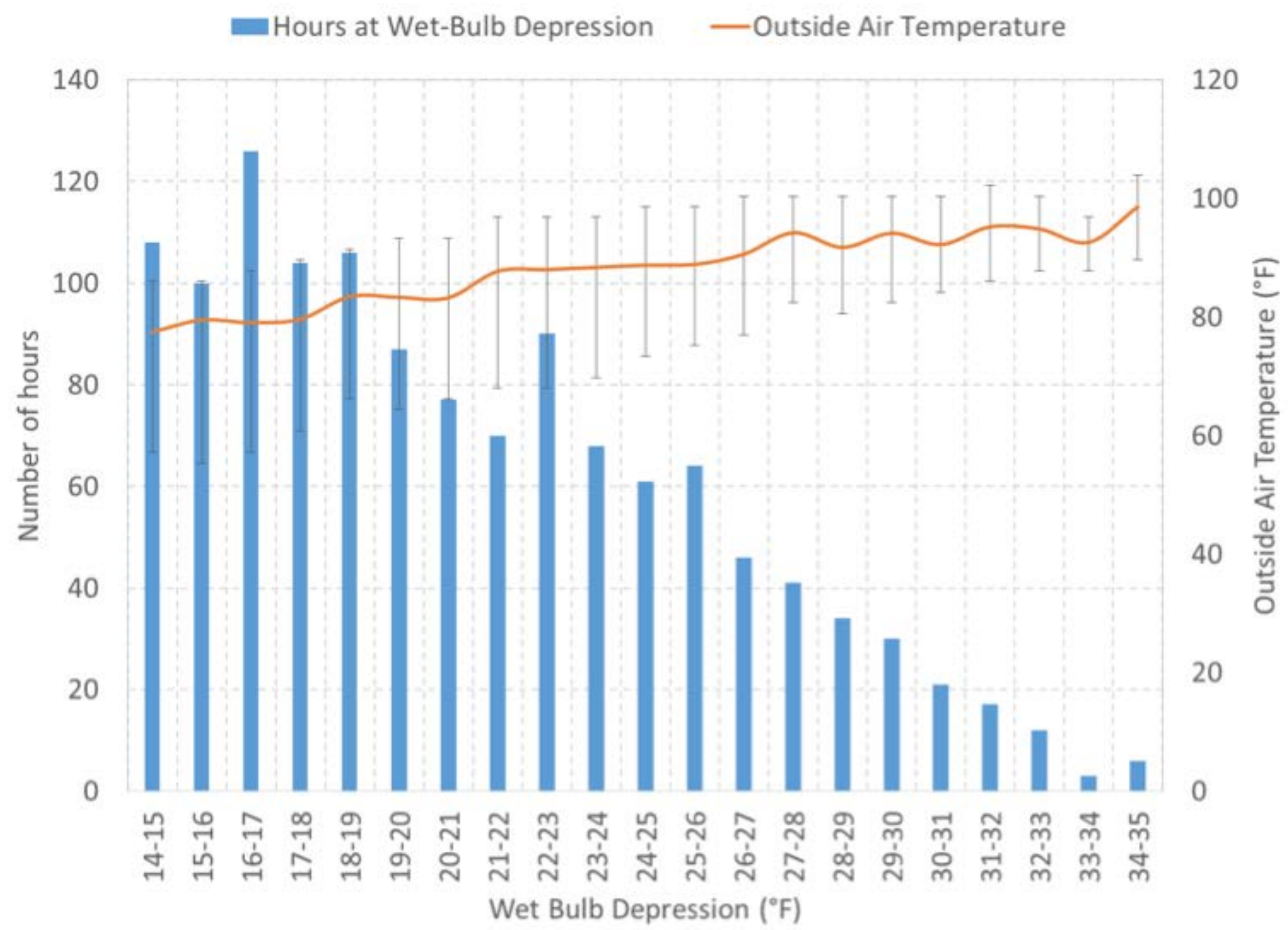
Field Testing

» Field site identified by hours where wet-bulb depression was > 15°F between 7am – 9pm from May – October (TMY3 data)

» Short term monitoring used to identify unit with consistent runtime to study impacts on compressor cycling

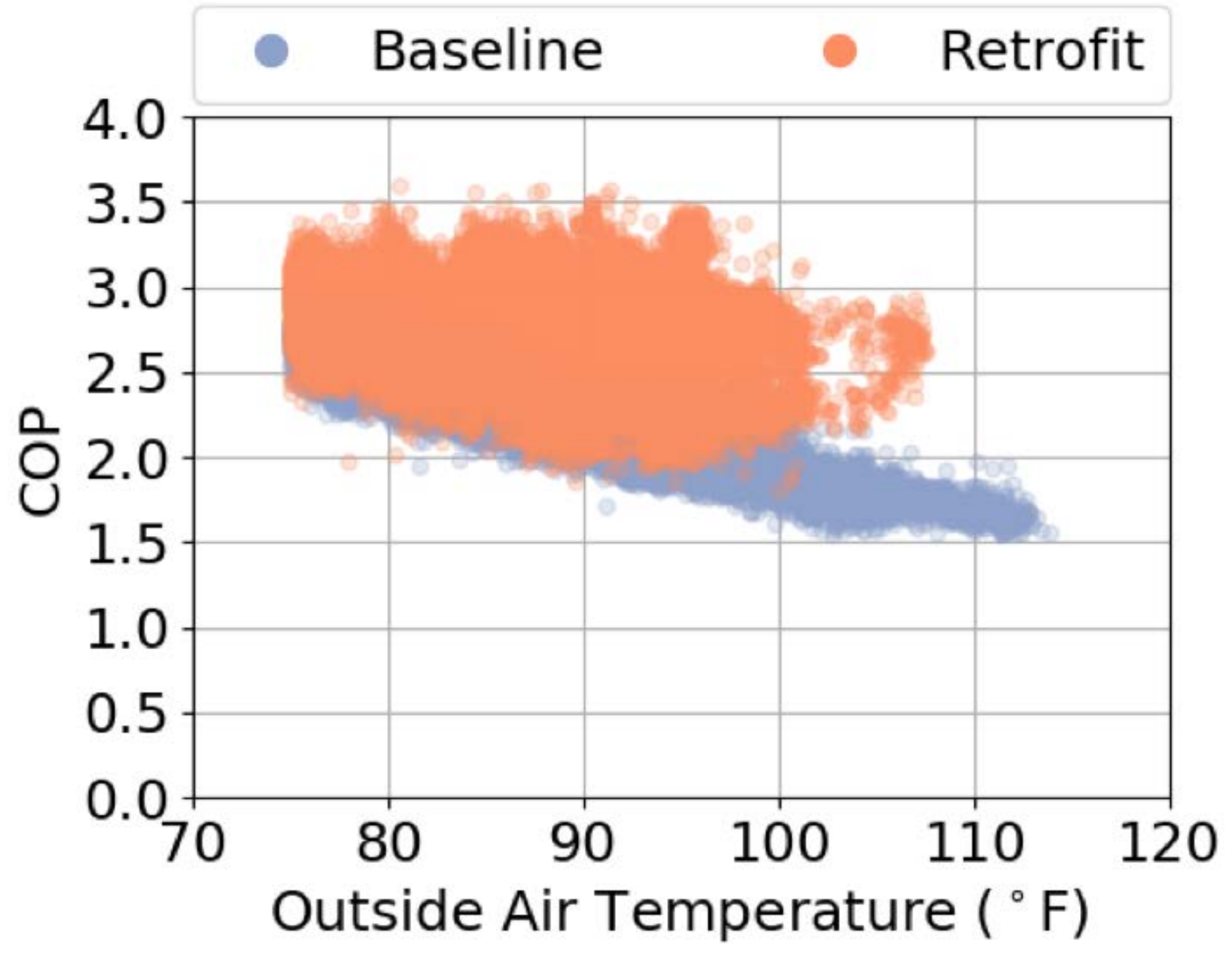
» 10-ton RTU was retrofitted with VFDs for each compressor and condenser-air pre-cooler

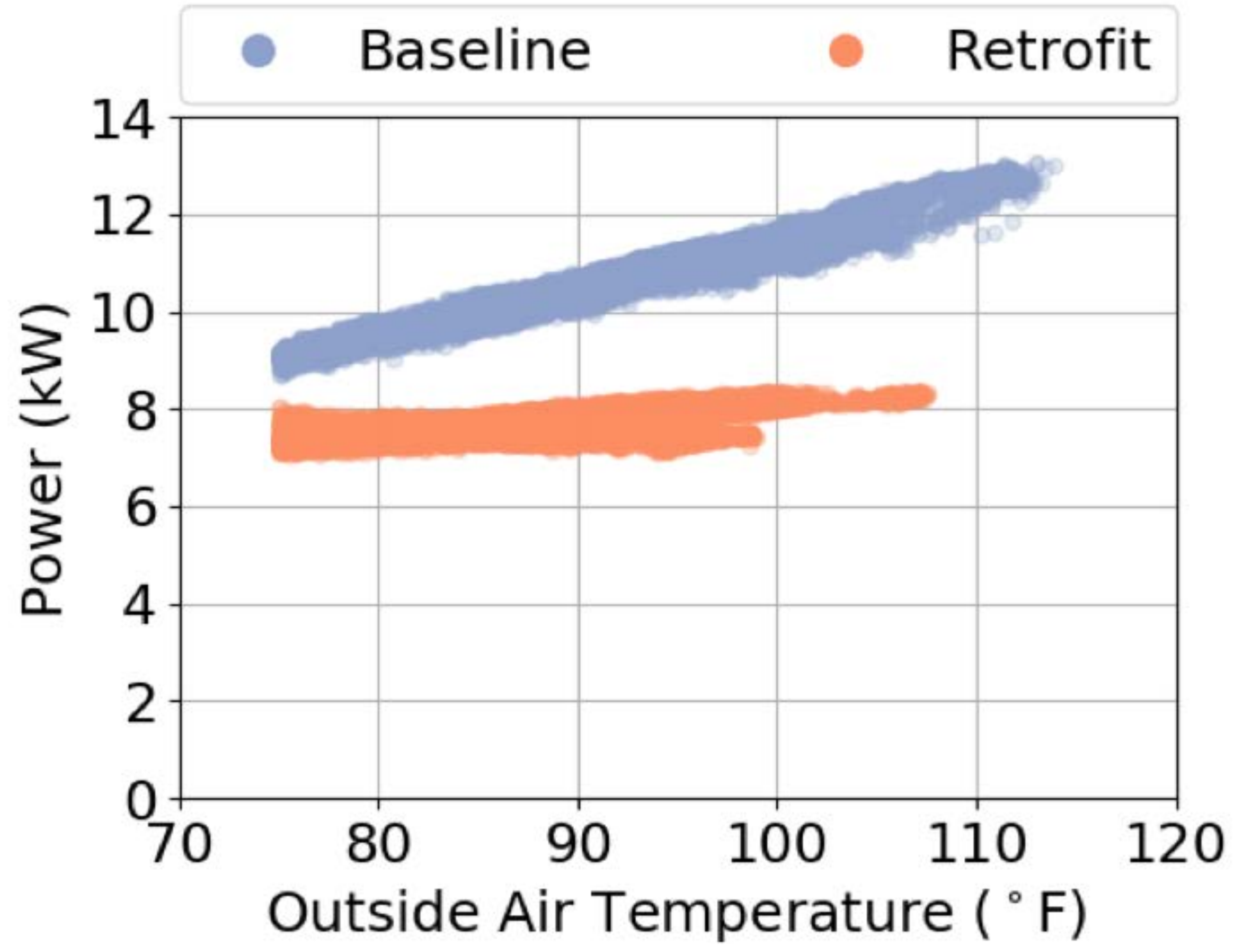
» Selected RTU did not provide ventilation



Field Testing

- Similar to the laboratory testing, the field test demonstrated *flattening* trends as outside air temperature increased
- Averaged over all operating conditions (stage 2):
  - COP: +23%
  - Net capacity: -9%
  - Power: -26%
  - SHR +3%

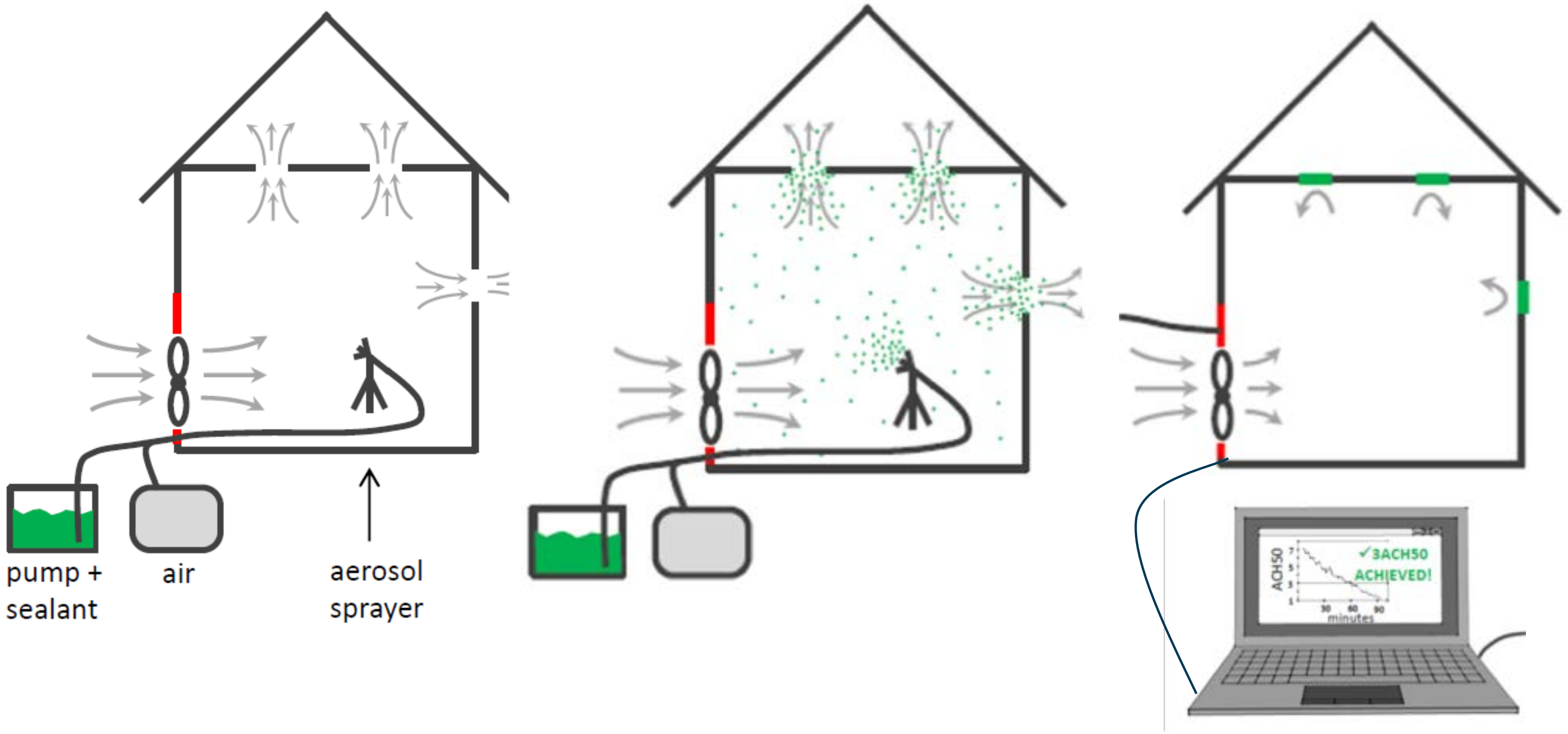




Aerosol Sealing in New Construction

» Sponsored by Department of Energy Building America

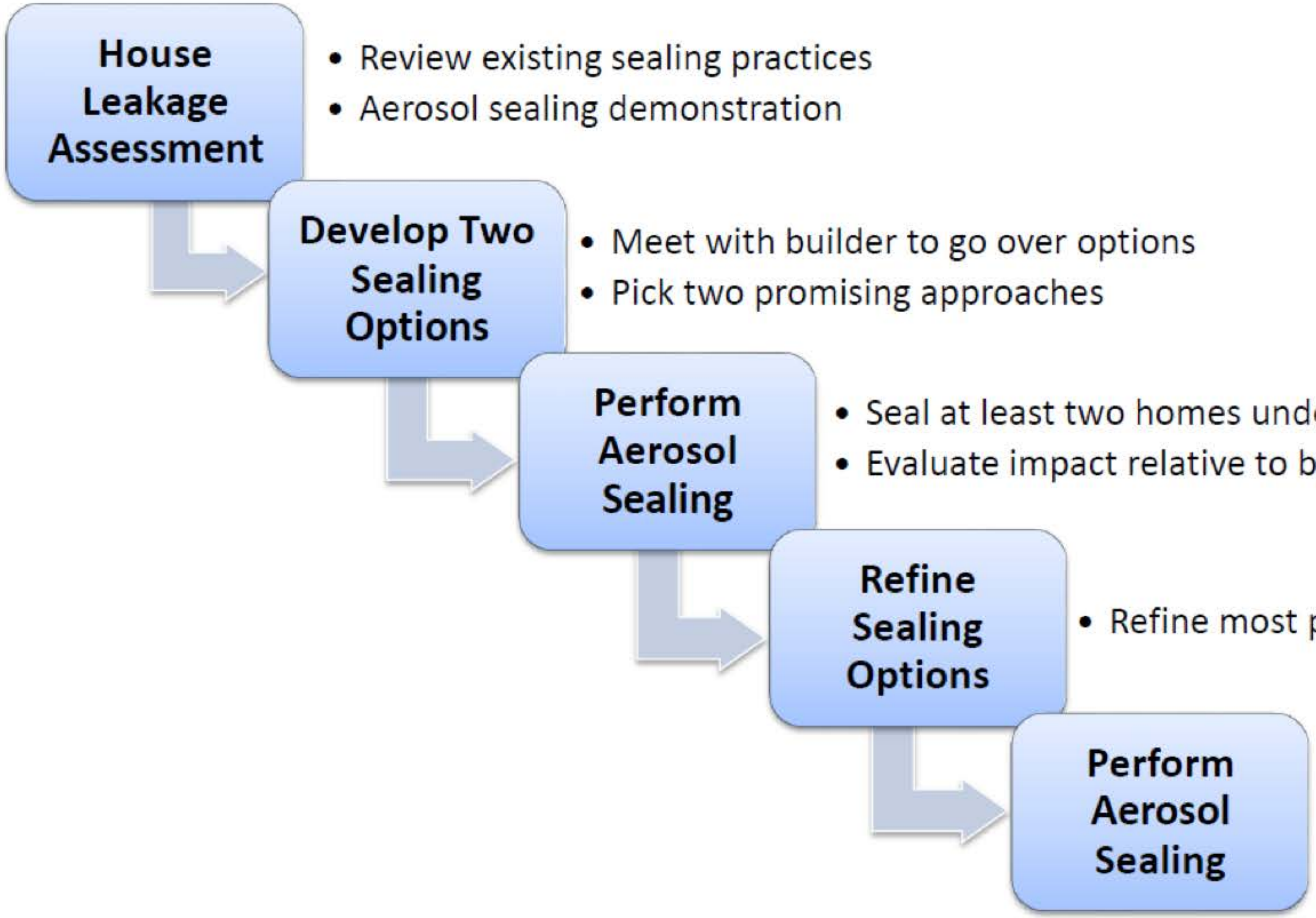
Basic Concept



Building America Project Goals

» Integrate aerosol envelope sealing into home building process
  - Determine appropriate stage for application
  - Measure performance relative to conventional methods
  - Determine existing sealing efforts that could be avoided
  - Determine cost-effectiveness

Project Approach



House Leakage Assessment
- Review existing sealing practices
- Aerosol sealing demonstration

Develop Two Sealing Options
- Meet with builder to go over options
- Pick two promising approaches

Perform Aerosol Sealing
- Seal at least two homes under each option
- Evaluate impact relative to baseline

Refine Sealing Options
- Refine most promising option

Perform Aerosol Sealing
- Seal 3-4 homes under refined option

CA Builder #1

- California Builder #1
- Homes designed with sealed attics
- Using open-cell spray foam
  - Under roof deck
  - At rim joist and other mechanical penetrations
- Fiberglass/mineral wool in wall cavity
- HRV integrated into central air handler
- Target leakage of 800 CFM50 (2.1-2.4 ACH50)

Conventional Sealing

Category	Component	Who does sealing?	Material used for sealing?	Can AeroBarrier Replace?	Quality of seal work
Ceiling/Attic	Attic access panels		Gasketed Door	No	Excellent
	Drop down stairs	N/A			N/A
	Whole-house fans	N/A			N/A
	Recessed lighting fixtures	N/A	Gasketed fixture	Yes	Excellent
	Drop ceiling/soffit	Insulation Contractor	Closed Cell Spray Foam	Yes	Excellent
Walls	Exterior Walls	Insulation Contractor	Gasket/OSB	N/A	Excellent
	Sill Plate	Carpentry Contractor	Gasket/OSB	Yes	Acceptable
	Top Plate	Insulation Contracor	Gasket	Yes	Acceptable
	Drywall to top plate	Insulation Contracor	Gasket	Yes	Excellent
	Interior partition wall to exterior wall	Carpentry Contractor/Insulation Contractor	Solid Blocking/Can Foam	Yes	Excellent
	Knee walls	Carpentry Contractor	OSB		Excellent
Windows, skylights and doors	Rough openings	Window Installation Contractor	Can Foam	Yes	Excellent
Rim joists		Insulation Contractor	Open Cell Spray Foam	Yes	Excellent
Shafts, penetrations to unconditioned spaces	Ducts	Insulation Contractor	Can Foam/Open Cell Spray Foam	No	Excellent
	Flues	Insulation Contractor	Can Foam/Open Cell Spray Foam	No	Excellent
	Shafts	Insulation Contractor	Can Foam/Open Cell Spray Foam	No	Excellent
	Plumbing	Insulation Contractor	Can Foam/Open Cell Spray Foam	Yes	Excellent
	Piping	Insulation Contractor	Can Foam/Open Cell Spray Foam	Yes	Excellent
	Wiring	Insulation Contractor	Can Foam/Open Cell Spray Foam	Yes	Excellent
	Exhaust fans	Insulation Contractor	Can Foam/Open Cell Spray Foam	Yes	Excellent
	Other				N/A
Garage separation walls	Floor cavities aligned with garage separation walls	Carpentry Contractor/Insulation Contractor	Blocking/Open Cell Spray Foam	No	Excellent
Other	Shower/tub on exterior wall	Carpentry Contractor/Insulation Contractor	OSB/Open Cell Spray Foam	Yes	Excellent
	Stair stringer on exterior wall		None	Yes	N/A
	Fireplace on exterior wall	N/A	N/A	N/A	N/A
	Electrial/low voltage boxes on exterior walls		None	Yes	N/A
	HVAC register boots that penetrate building thermal envelope	N/A		Yes	N/A

ENERGY STAR Rater Field Checklist

Can foam at seams where wood is joined

Can foam and gasket at sill plate

Foam gasket to seal drywall to top plate

Sealing Options – Before Drywall

- Advantage of sealing before drywall
  - Addresses outer wall surface
  - Seals less prone to damage in wall cavity
  - Easier aerosol distribution
- Sealing options
  - Option 1: Seal home after spray foam insulation
  - Option 2: Seal home before spray foam insulation
    - Does aerosol sealing seal as well as spray foam?

CA Builder #1 Results Summary

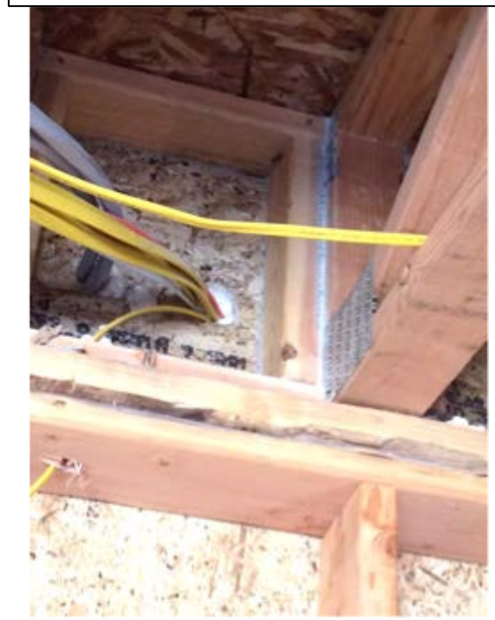
Option 1

Option 2

Seals formed under trusses

Seal formed at corner of wall assembly

Seal formed at rim joist



Seals electrical box

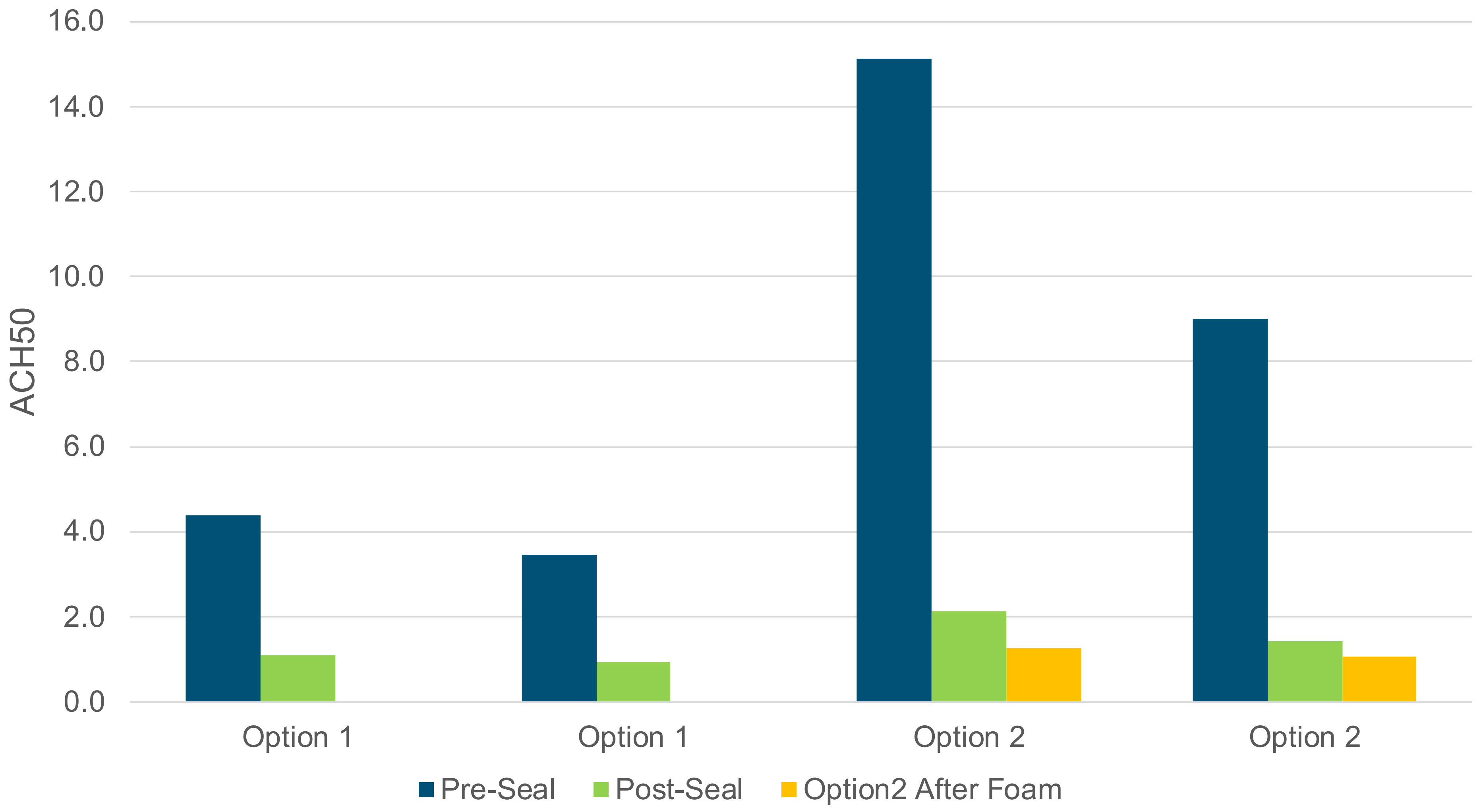
Seal between studs

CA Builder #1 Results Summary

79% Average leakage reduction

73% Tighter than baseline homes

56% Greater building tightness using Aerosols versus open-cell spray foam



CASE STUDIES | PRESS ARTICLES | NEWS | HVAC PRESENTATIONS | NEWSLETTER | REPORTS | PUBLICATIONS | INTERVIEWS | RESEARCH | EDUCATION | DEMONSTRATION BRIEFS | OVERVIEW | OUTREACH | MISSION | CONTACT | TECHNICAL SERVICE AGREEMENTS |

wcec.ucdavis.edu

TECHNOLOGY TOPICS | SECTOR RESEARCH | BEHAVIORAL RESEARCH | SYSTEMS INTEGRATION | CONTROLS | DEMAND SIDE MANAGEMENT | EVAPORATIVE TECHNOLOGIES | RADIANT COOLING | TITLE 24 | VIDEO PRODUCTION | MARKET TRANSFORMATION |