



Vapor Intrusion (VI) Indicators, Tracers, and Temporal Variability of cVOCs in Industrial Buildings

DoD Virginia Site A – Climate Zone 4



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Agenda

- Objectives
- Site Background
- Field Activities / Sampling Zones
- Results and Observations
 - Indoor, outdoor, utility penetration, and subslab concentrations
 - Comparisons with radon, differential pressures, outdoor barometric pressures, and differential temperatures
- Questions

Funded under Navy Environmental Sustainability
Development to Integration (NESDI) Project 554

Select Objectives

- Measure temporal variability of cVOCs and indicators/tracers in an industrial building with vapor intrusion (VI)
 - Collect high-frequency (~4 hr intervals) indoor, outdoor, utility penetration, and subslab cVOC data for one year
 - Collect corresponding high-frequency VI indicator/tracer data
- Conduct data evaluation to:
 - Provide context for conditions of observed temporal variability
 - Facilitate mechanistic understanding of VI driving forces
 - Provide insight into sampling conditions for estimating RME concentrations

RME Concentrations = Reasonable Maximum Exposure Concentrations
cVOCs = Chlorinated Volatile Organic Compounds

Site Background



- Site located in Mid-Atlantic region
 - Mostly concrete/asphalt-paved industrialized area
 - cVOCs released from damaged industrial wastewater lines
- Medium-to-coarse grain sands in vadose zone
- Depth-to-groundwater: 3 to 8 ft bgs
- Remediation Activities

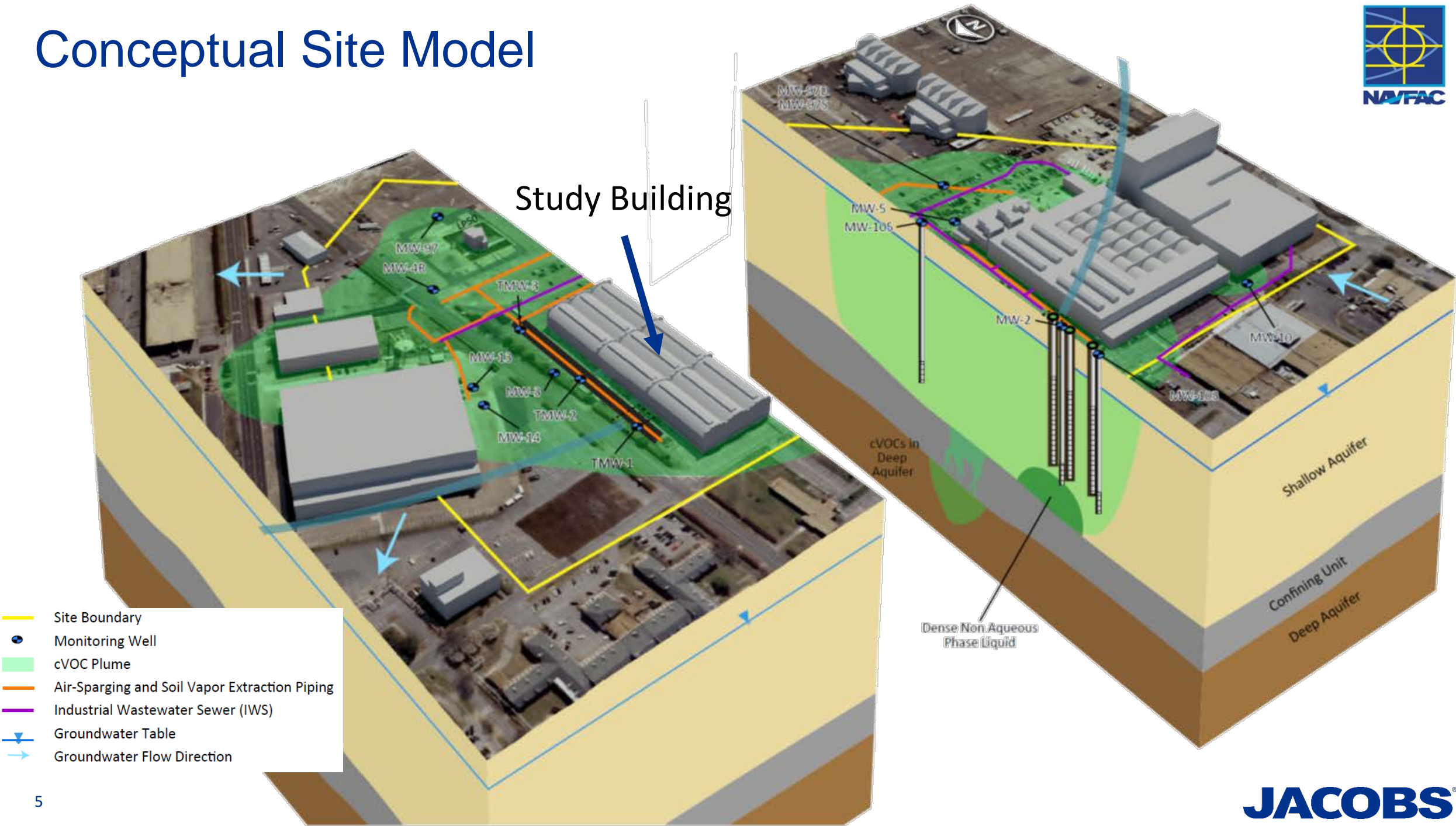


GW cVOCs Beneath/Near Study Building

cVOCs	Max Concs (2014-16) (µg/L)
1,1-DCE	644
1,2-dichloroethane	7.4
Cis-1,2-DCE	474,000
Trans-1,2-DCE	67,700
TCE	898,000
VC	639,000

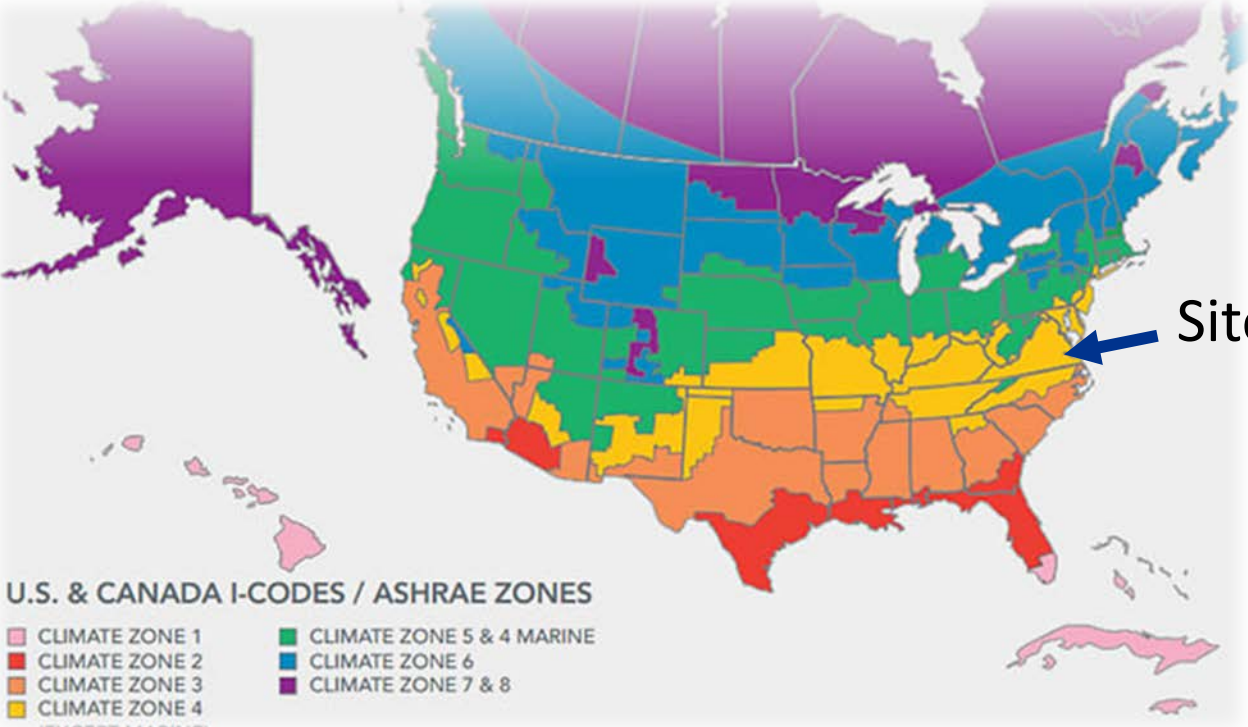
- GW extraction and AS/SVE
- Discontinued in 2012/13 due to limited effectiveness

Conceptual Site Model



- Site Boundary
- Monitoring Well
- cVOC Plume
- Air-Sparging and Soil Vapor Extraction Piping
- Industrial Wastewater Sewer (IWS)
- Groundwater Table
- Groundwater Flow Direction

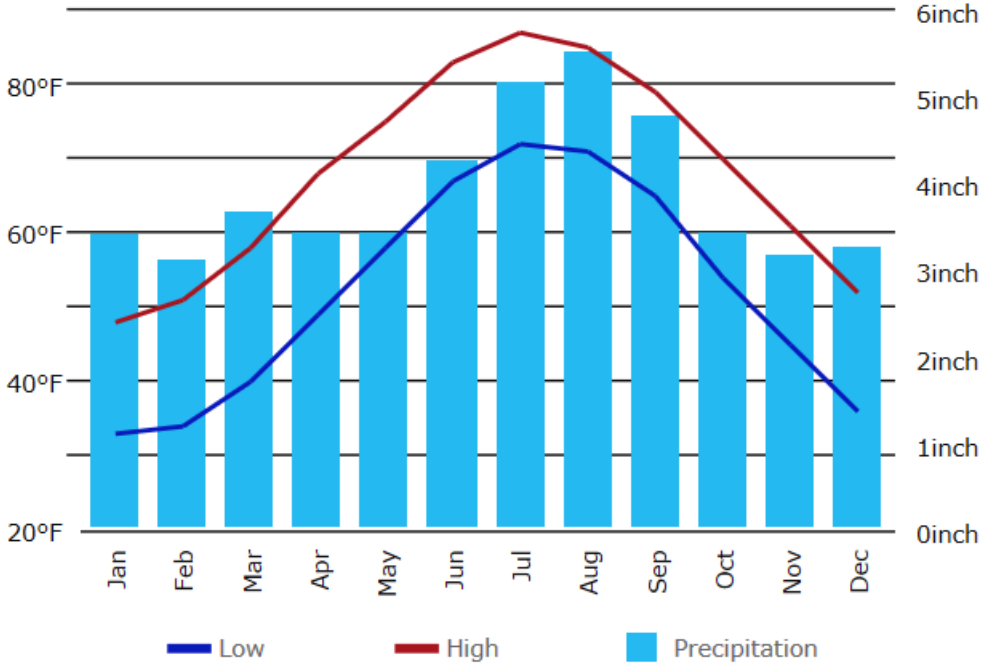
Climate – Zone 4



www.greenbuildingadvisor.com/article/climate-zone-map-including-canada

International Energy Conservation Code (IECC)
 Zone 4; Koppen Cfa humid subtropical

Annual high temperature:	68.1°F
Annual low temperature:	52°F
Average temperature:	60.05°F
Average annual precipitation - rainfall:	46.55 inch



Field Activities

- Detailed Building Survey and Diagnostic Testing

- HVAC evaluation (e.g., type, zones, makeup air, operational settings)
- Tracer gas testing to evaluate air exchange rates

- Building Pressure Control Studies (Near Worst-Case VI)

- Pressure data, measure flow rates, HAPSITE VOC data, discharge rates
- Evaluate leakage, entry points, background, flux

- ***Year-Long VOC and Indicator/Tracer Studies***

- Four sampling zones within industrial building
- High frequency indoor, subslab, and outdoor air cVOCs
- IA/OA (continuous) and subslab (monthly) radon
- Continuous pressure and temperature differential data
- Meteorological data near building

- ***Presenting 4 months of data (May-Sep, 2019)***

- More data collection/analyses underway, which will also include wind and precipitation analyses

RadonEye (IA/OA)



<http://radonftlab.com/radon-sensor-product/rd200/>



dP and Temp



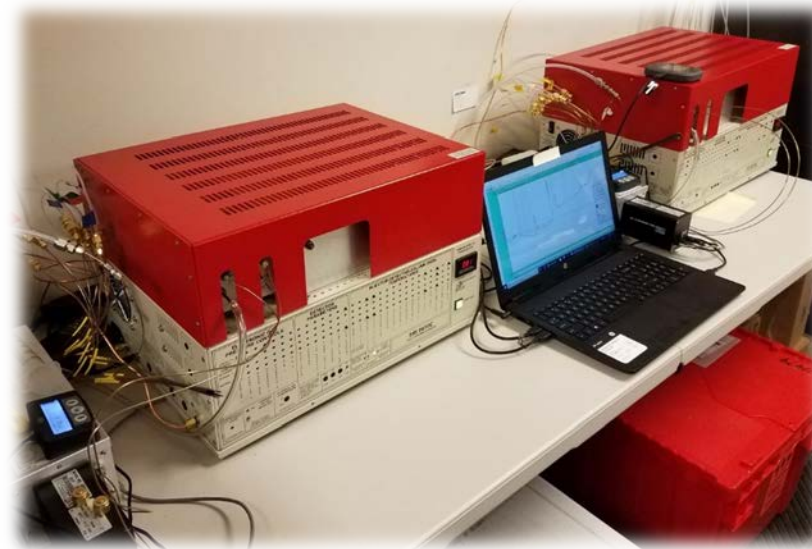
https://www.omegaeng.cz/ppts_t_eng/OM-CP-PRTC110.html

RAD7 (subslab RN)



<https://durrige.com/products/rad7-radon-detector/>

GC/ECD (cVOCs)

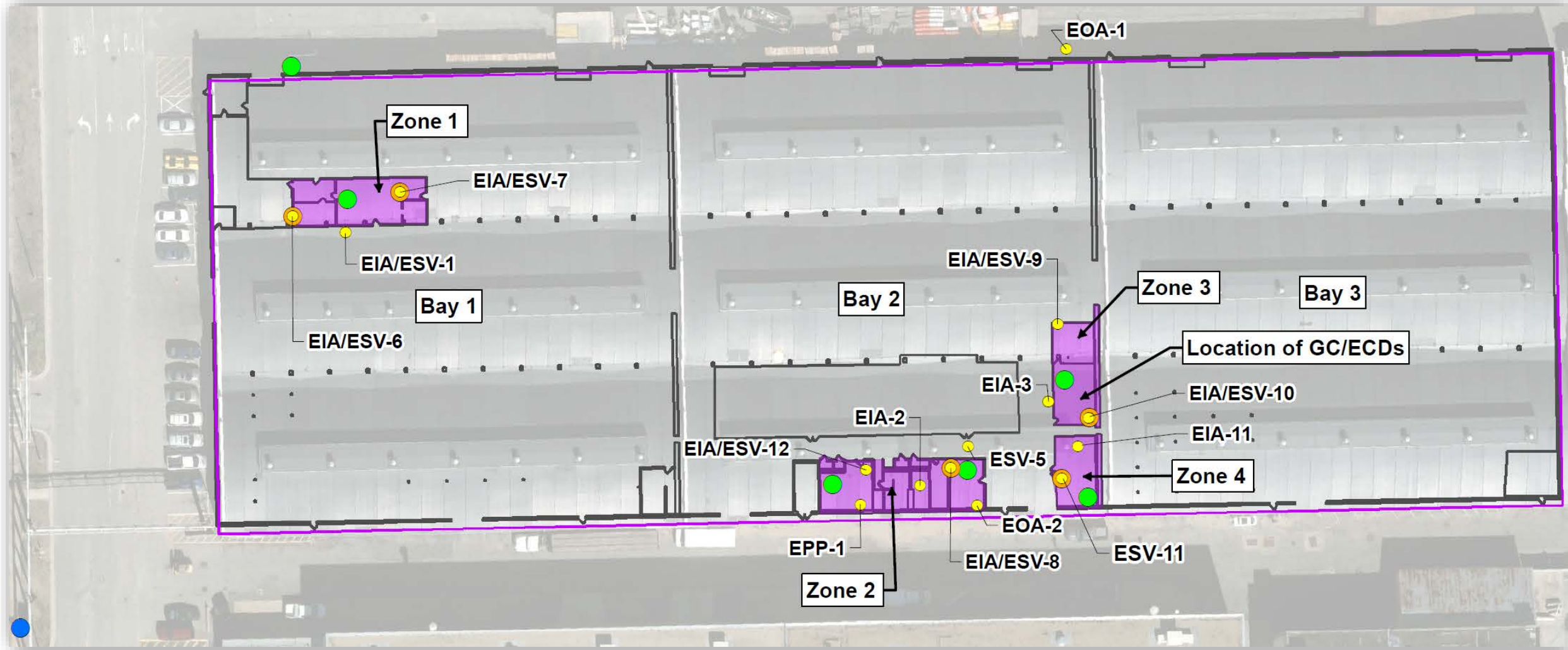


Weather Station



<https://www.davisinstruments.com/solution/vantage-vue/>

Zones Within Larger Building, Sampling Locations, and Types of Data



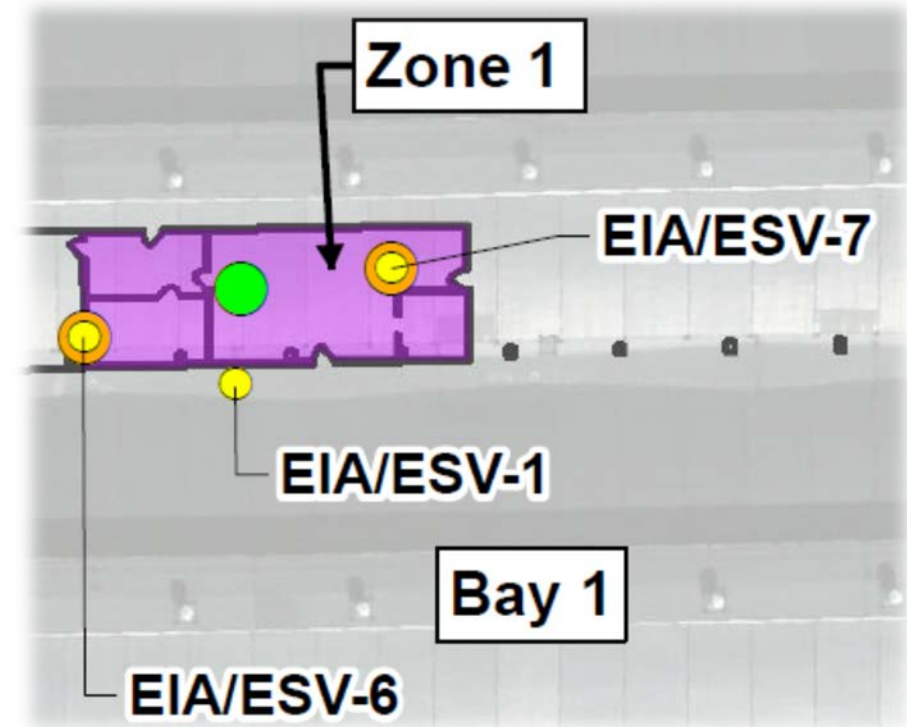
- GC/ECD cVOC Sampling Locations
- Differential Pressure & Temp Locations
- Indoor Radon Sampling Locations
- Outdoor Weather Station

EIA-# = Indoor Air ID for cVOCs & Radon
 ESV-# = Subslab ID for cVOCs & Radon

- Building Details
- Zones
- Building Footprint

Zone 1 – Administrative Office 103

- Compartments
 - Two rooms (104 and 105) regularly occupied
 - Server room in SE corner
 - Hallway
- 3-Ton split-HVAC system
 - Direct expansion air-source heat pump and air handling unit
 - Ducted to outdoor for ventilation air
 - Thermostat in office “on” unless occupants turn off
- Baseline air exchange tracer test
 - 0.8 air exchanges per hour (ACH)

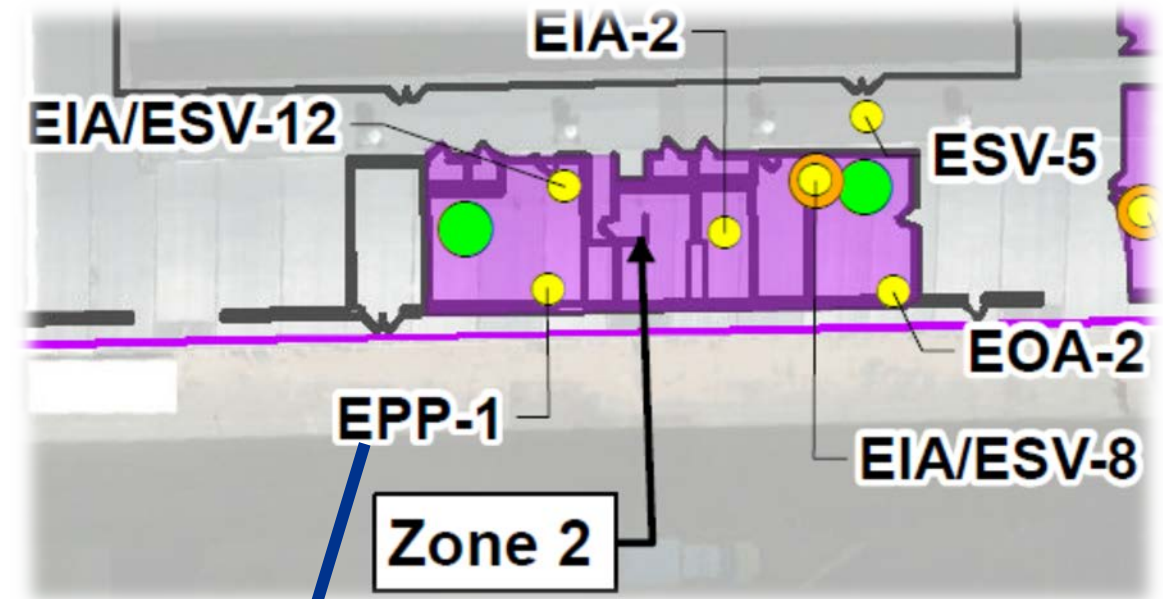


- GC/ECD cVOC Sampling Locations
- Differential Pressure & Temp Locations
- Indoor Radon Sampling Locations
- Outdoor Weather Station

Zone 2 -- Office 211, Breakroom, and Restroom



- Compartments
 - Regularly occupied office
 - Breakroom and restrooms
 - Supply room and janitor closet
- 4-Ton split-HVAC system
 - Direct expansion air source heat pump unit
 - Ducted to outside with damper closed, but filter enclosure open to warehouse
 - Supply/return vents in office/breakroom/restrooms; exhaust fans in restrooms always on
 - Thermostat in office "on" unless occupants turn it off
- Baseline air exchange tracer test
 - Office 211: 2.7 - 3.0 ACH
 - Breakroom: 2.3 - 3.0 ACH
 - Men's restroom: 3.1 ACH

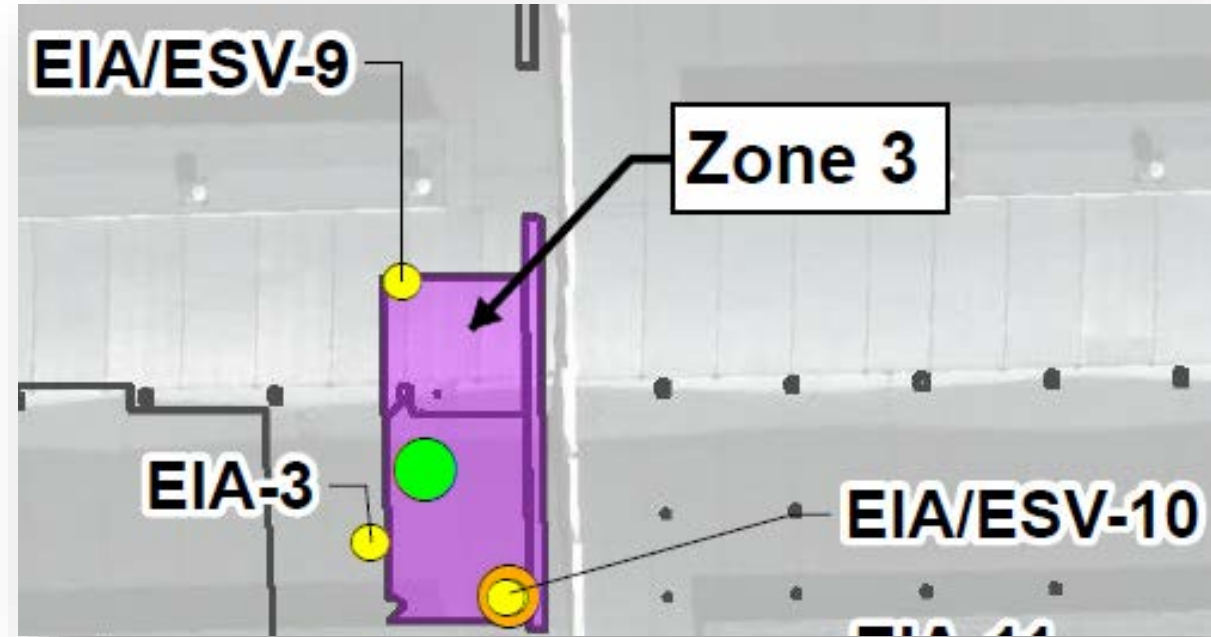


Utility Sampling Location

- GC/ECD cVOC Sampling Locations
- Differential Pressure & Temp Locations
- Indoor Radon Sampling Locations
- Outdoor Weather Station

Zone 3 – Shipping/Receiving Office 209

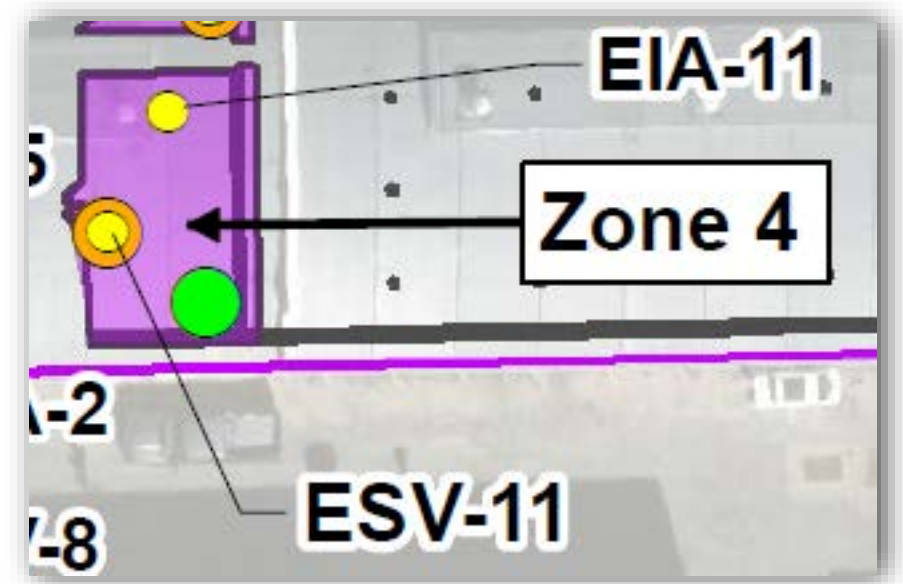
- Compartments (regularly occupied)
 - Cubicles/work areas (southern compartment)
 - Manager office (northern compartment)
- 2-Ton split-HVAC system
 - Direct expansion air-source heat pump
 - No connection to outdoor air
 - Supply/return vents
 - Thermostat in manager office is always on (unless occupant turns it off)
- Baseline air exchange tracer test
 - 0.9 air exchanges per hour



- GC/ECD cVOC Sampling Locations
- Differential Pressure & Temp Locations
- Indoor Radon Sampling Locations
- Outdoor Weather Station

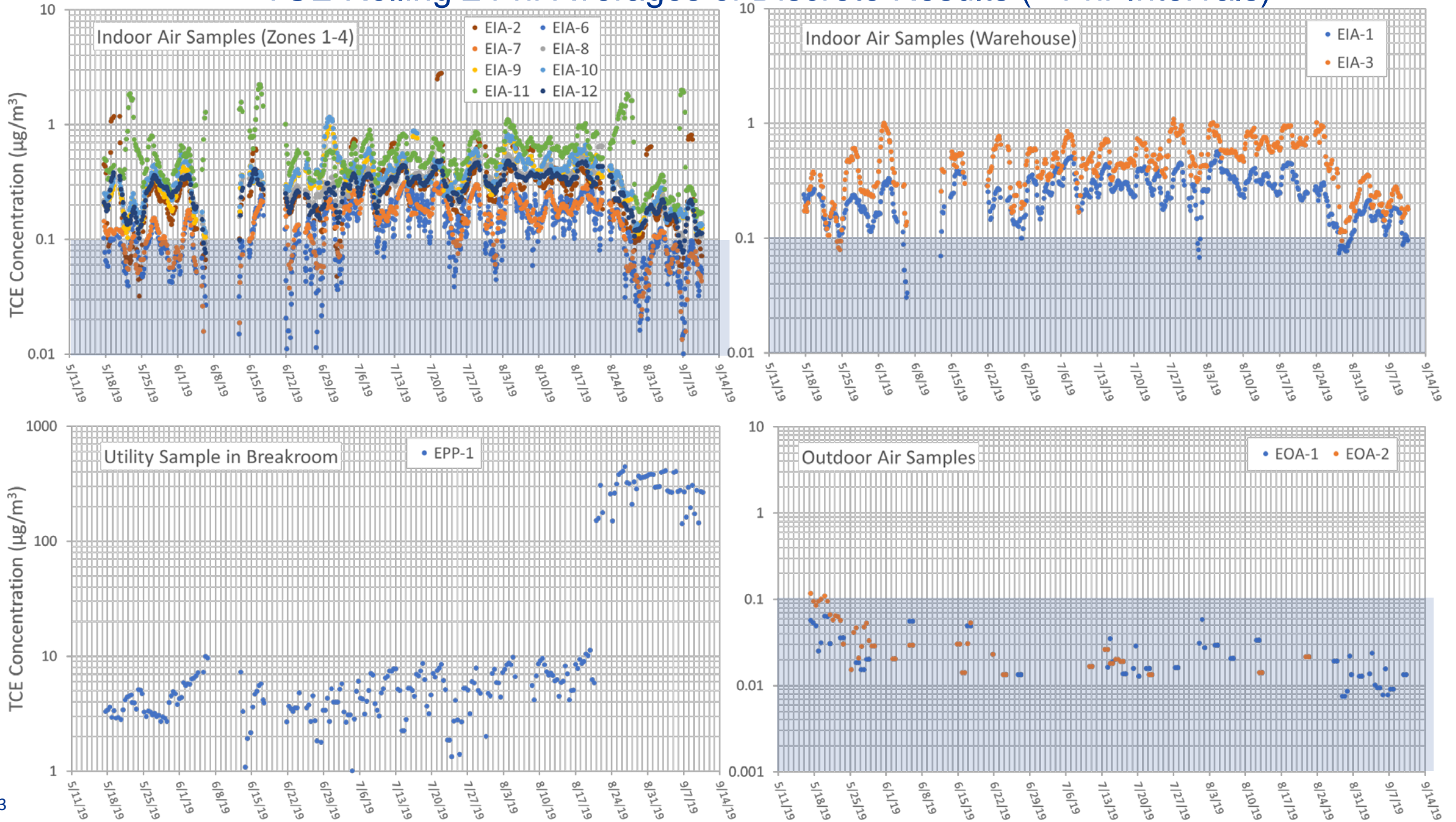
Zone 4 – Supply Storage Room 210

- Compartment
 - Single storage room (510 ft²)
 - Frequently entered, but not occupied full-time
- Air Handling
 - Wall-mounted ductless unit with wireless thermostat (always operating)
 - No connection to outdoor air
 - Return vent, but no supply vent
 - Passive wall vent between storage room and warehouse, blocked with cardboard/duct tape
- Baseline air exchange tracer test
 - 0.2 air exchanges per hour

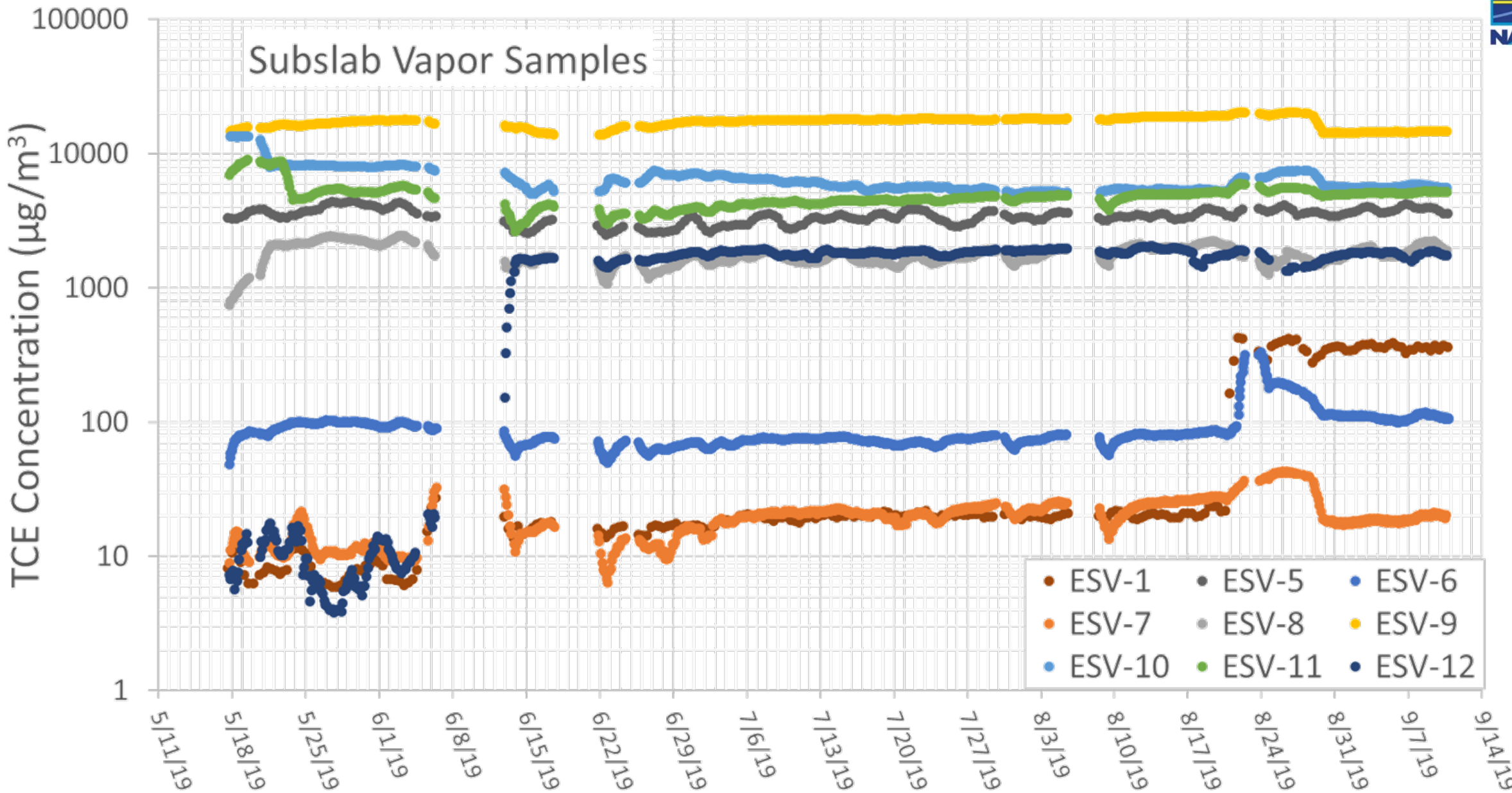


- GC/ECD cVOC Sampling Locations
- Differential Pressure & Temp Locations
- Indoor Radon Sampling Locations
- Outdoor Weather Station

TCE Rolling 24-hr Averages of Discrete Results (~4-hr Intervals)



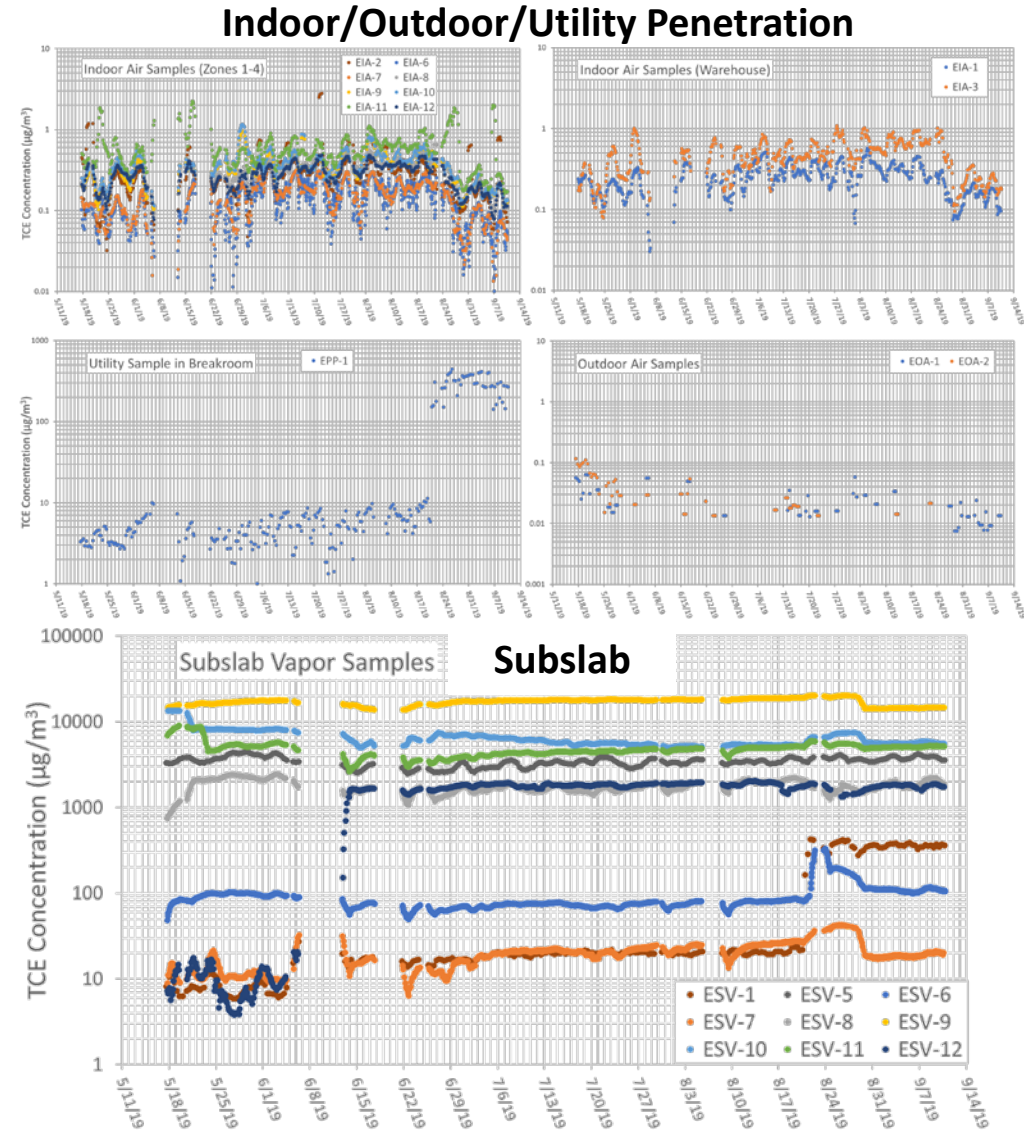
Instantaneous TCE Subslab Concentrations (~4-hr Intervals)



Observations About TCE Spatial and Temporal Trends



- Indoor (24 hr avg) up to 2-orders magnitude > outdoor results
 - Varied temporally by up to ~10X
- Indoor in zones and warehouse similar, except higher at EIA-11 (supply rm) and EIA-2 (bathroom)
- Subslab TCE levels lower near Zone 1 (further from source)
 - Varied temporally by up to ~10X
- Supply Rm 210 AFs of 1E-04 (median) and 2E-04 (90th) (N=585)
- Building-wide or localized VI based on MLE (e.g., magnitude, inter-media comparisons, and ratios)
- Levels at utility penetration 10-100X higher than indoor, but mass flux insufficient to impact breakroom indoor air
- Detection limit of 0.1 $\mu\text{g}/\text{m}^3$ based on 3:1 signal-to-noise ratio (analytical definition of a “real” signal)

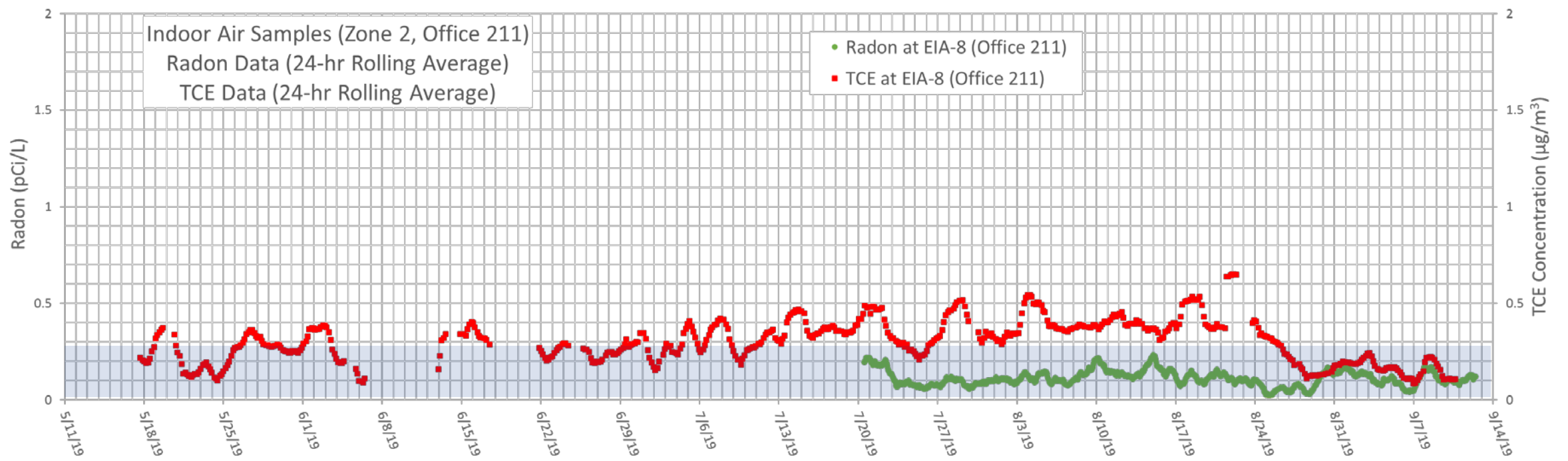
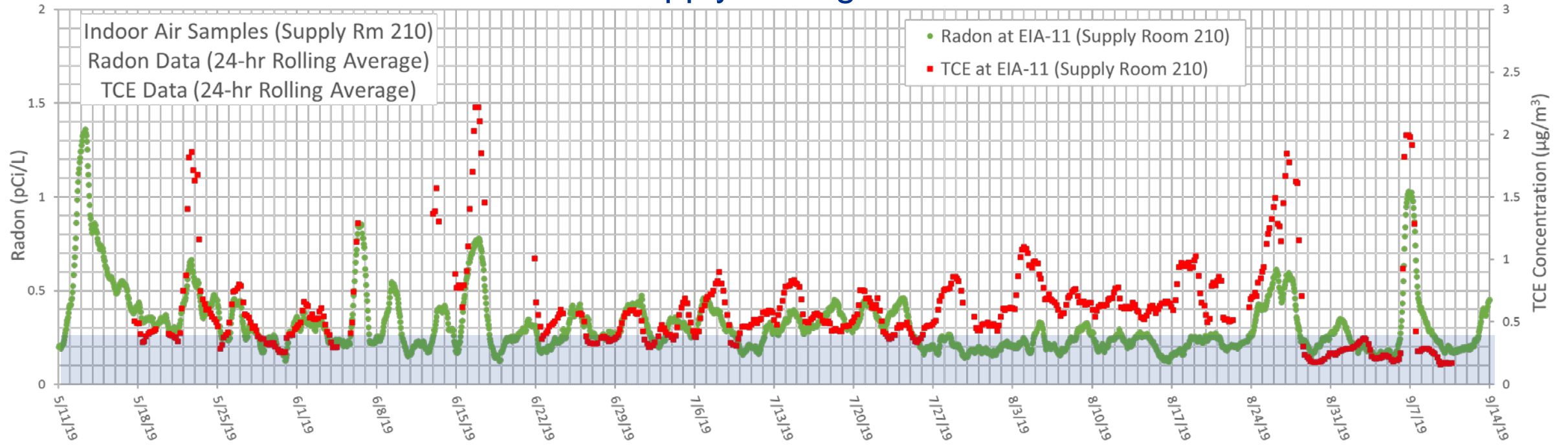


TCE at 0.1 $\mu\text{g}/\text{m}^3$ (3:1 ratio)

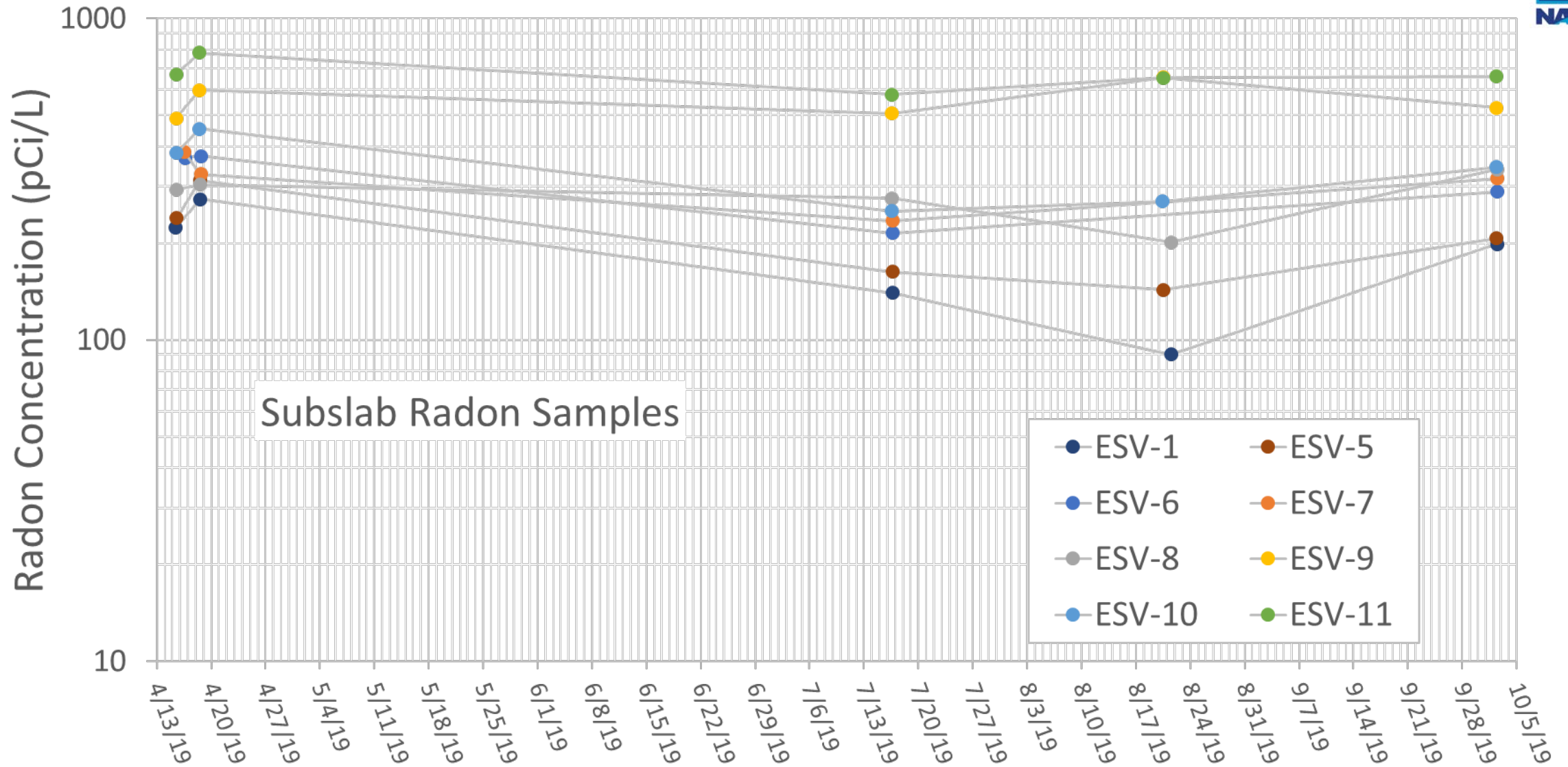
TCE at 0.5 $\mu\text{g}/\text{m}^3$ (35:1 ratio)

AF = Attenuation factor
MLE = Multiple lines of evidence

TCE Versus Radon in Supply Storage Room 210 and Office 211



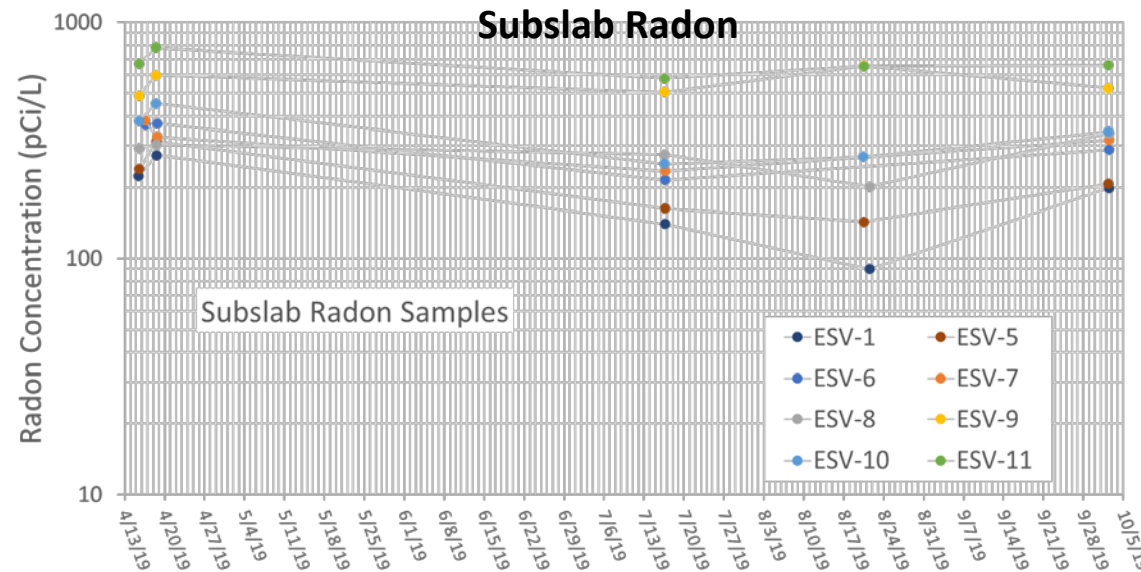
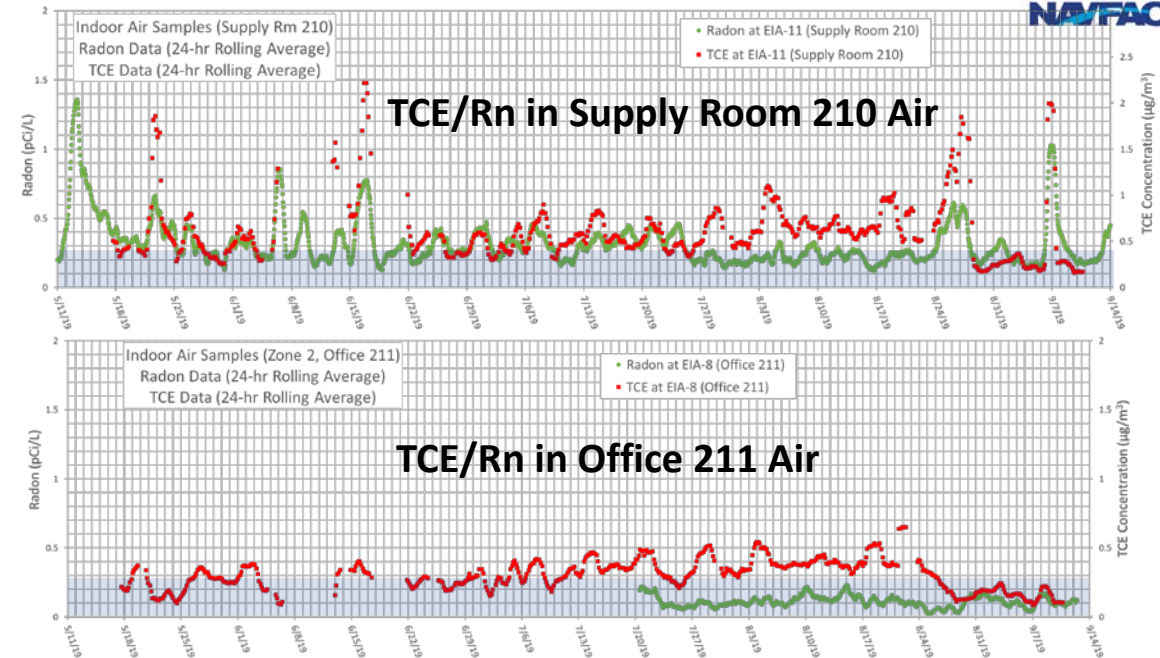
Subslab Radon Concentrations (Instantaneous)



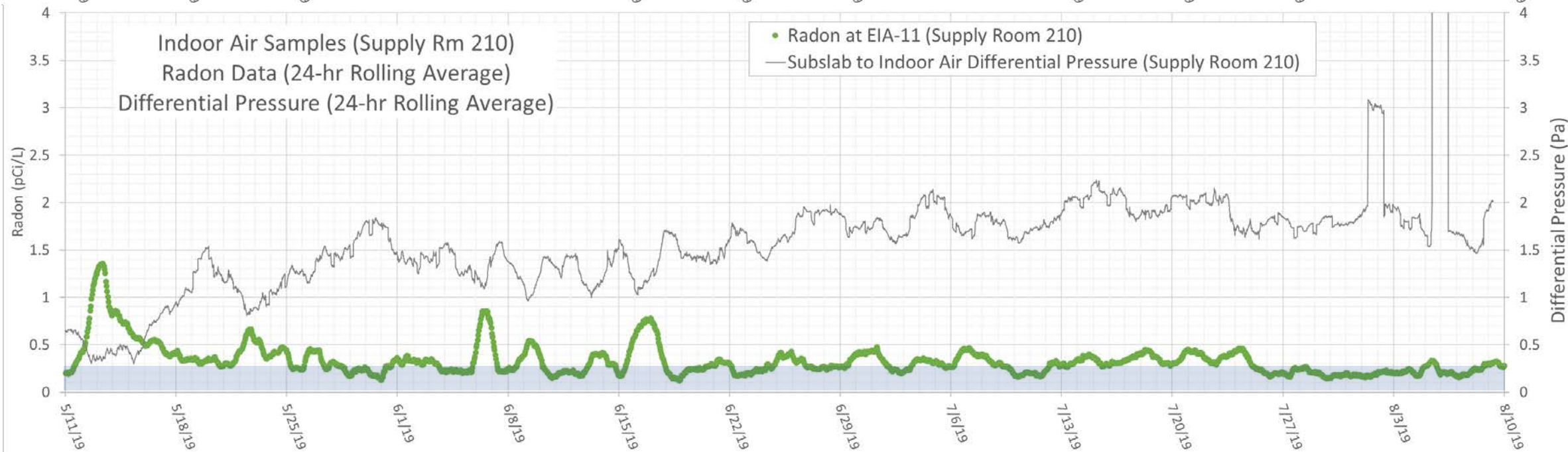
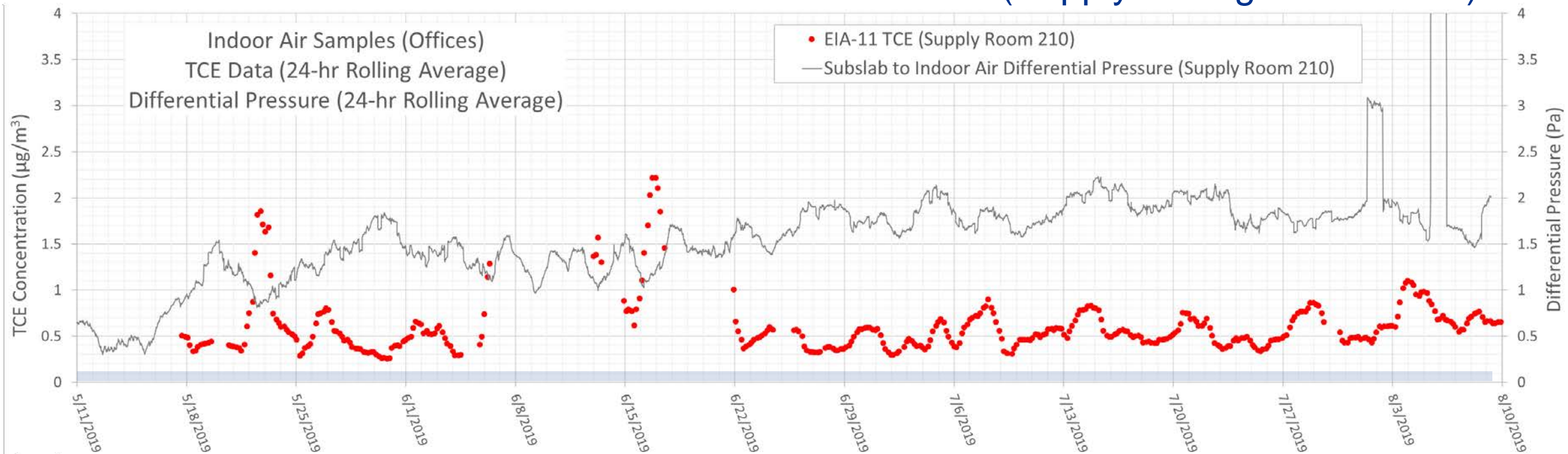
Observations About Radon Versus TCE in Indoor Air (24 hr Rolling Averages)



- Discernable indoor TCE events in Supply Rm 210 correlated with discernable radon events
 - Radon varied temporally by up to ~half an order of magnitude
- No discernable indoor radon peaks in zones without elevated TCE events (e.g., Office 211)
- Subslab radon levels varied by up to ~half an order of magnitude spatially/temporally



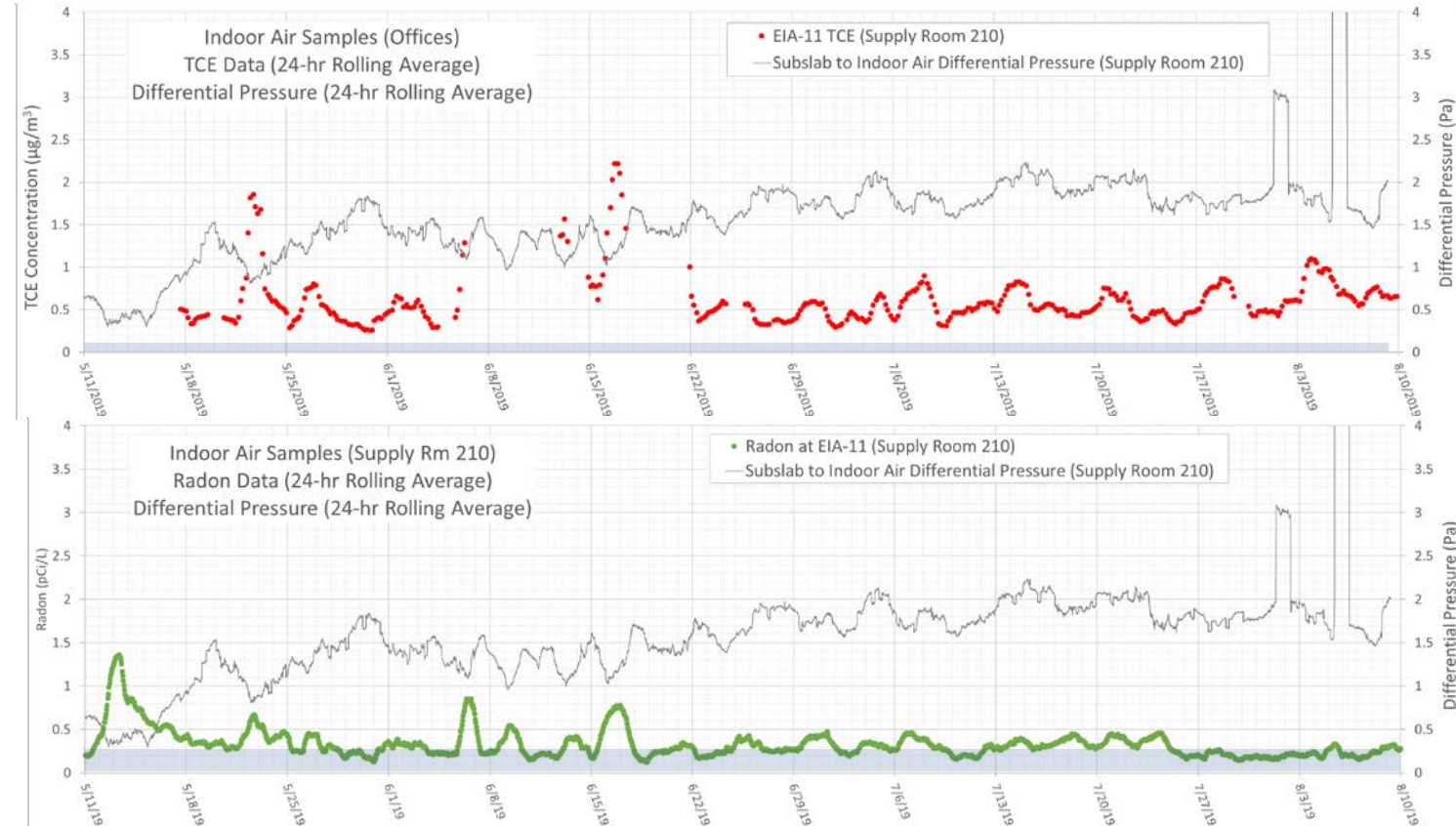
Differential Pressure Versus Indoor TCE and Radon (Supply Storage Room 210)



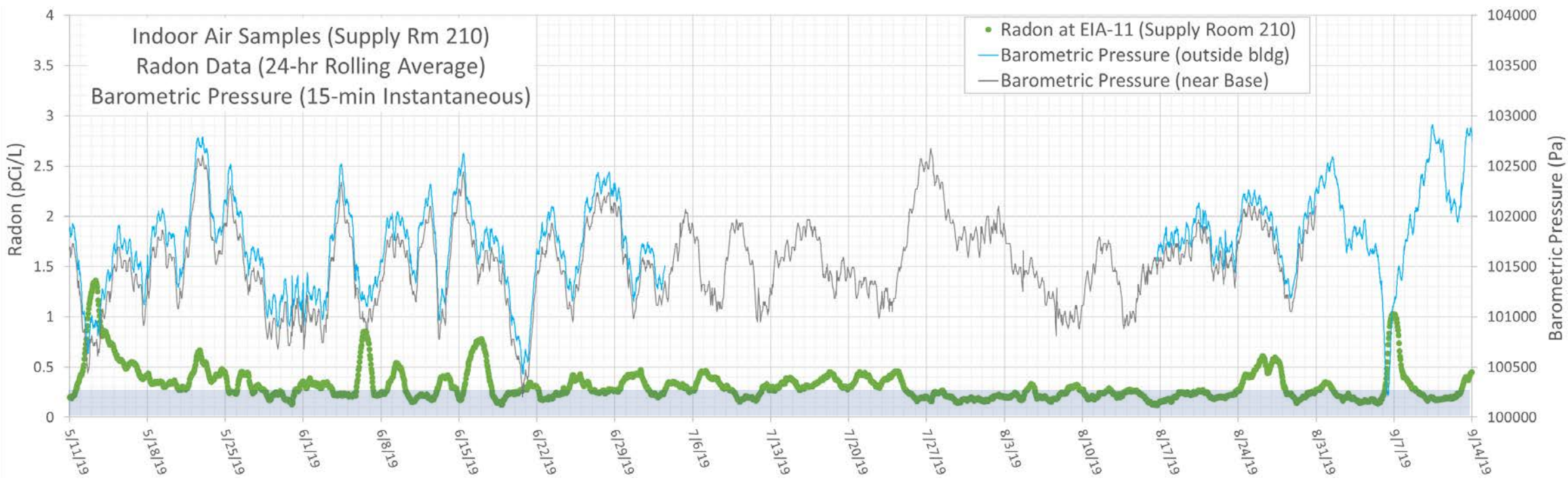
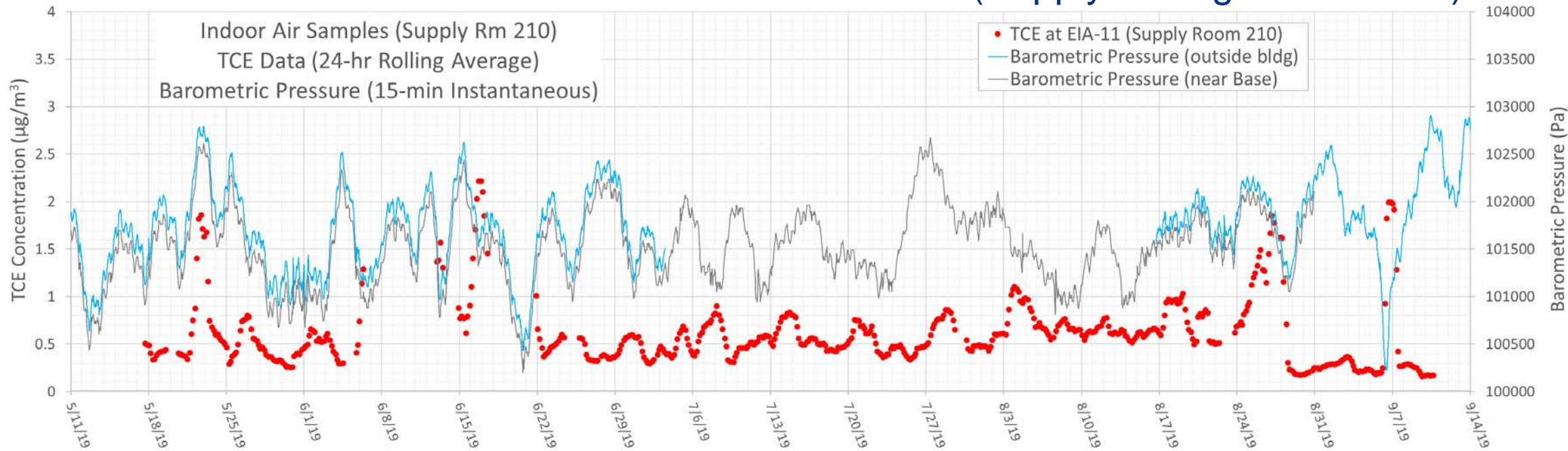
Observations About Differential Pressure Versus TCE and Radon in Supply Rm 210 Indoor Air (24-hr rolling avgs)



- Discernable indoor TCE/radon events in Supply Room 210 correlated with changing indoor-to-subslab differential pressures
- Not all differential pressure changes correlated with a discernable TCE/radon event
- 24-hr rolling average differential pressure readings were consistently positive (~0.5 – 6 Pa)
 - Some 15-min differential pressure readings within 24 hr periods were negative



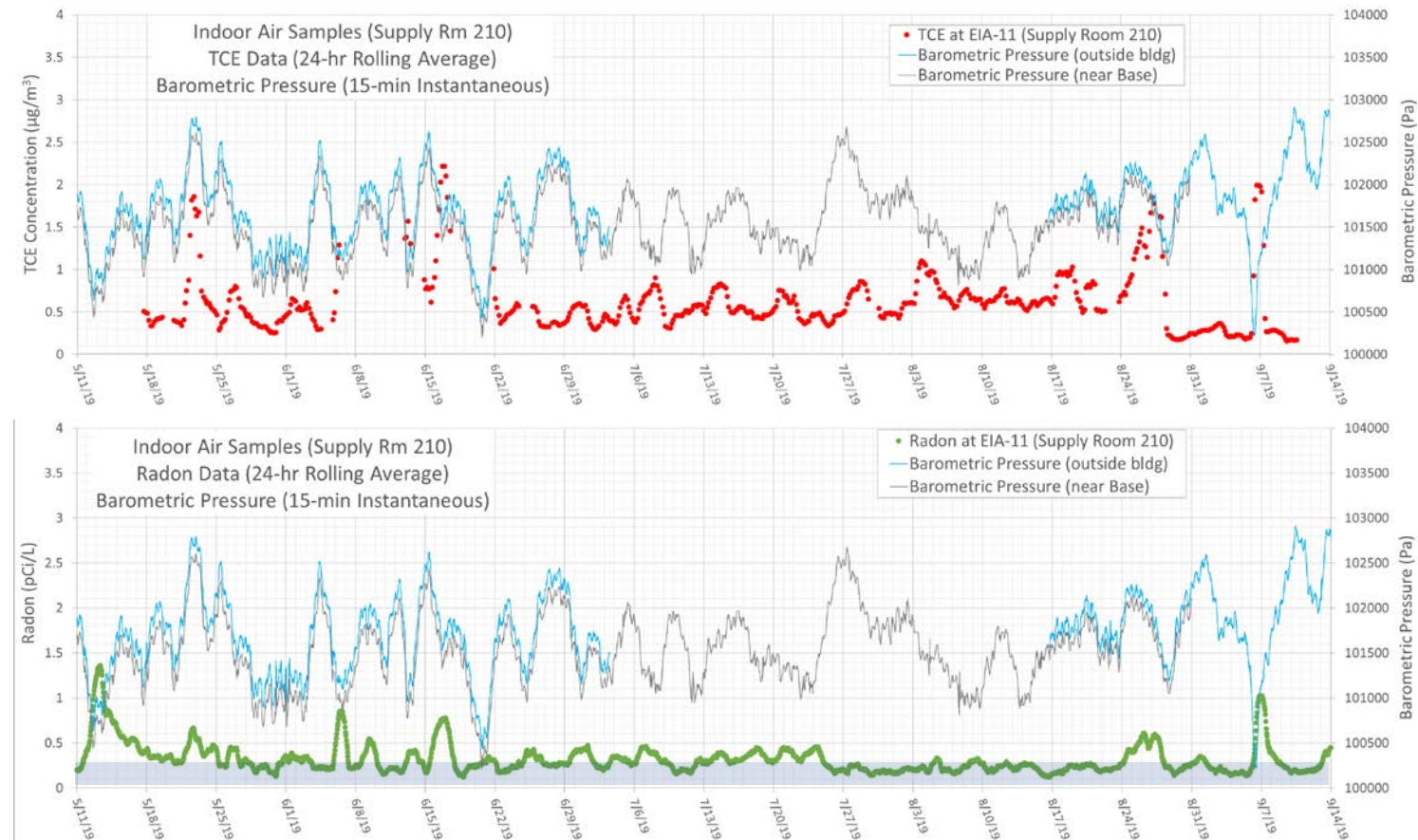
Barometric Pressure Versus Indoor TCE and Radon (Supply Storage Room 210)



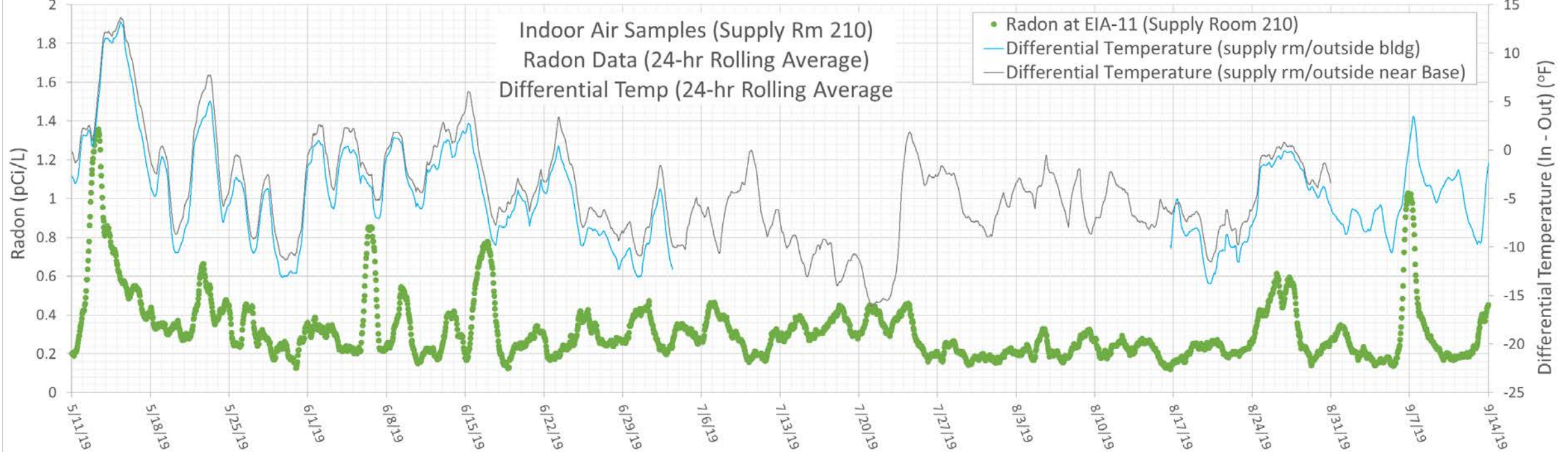
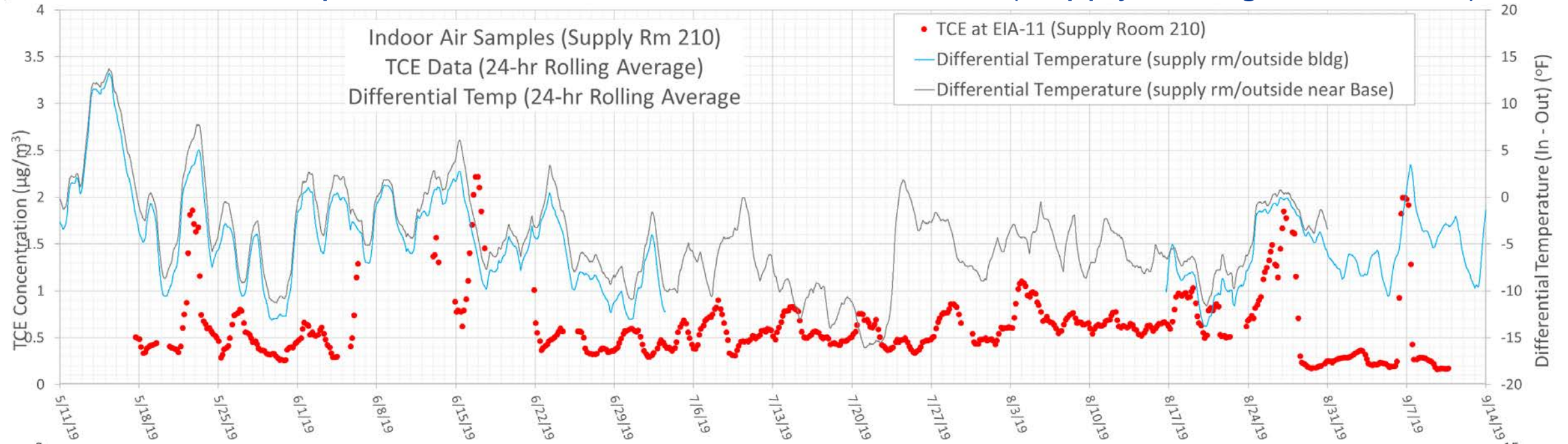
Observations About Barometric Pressure Versus TCE and Radon in Supply Rm Indoor Air (24-hr rolling avgs)



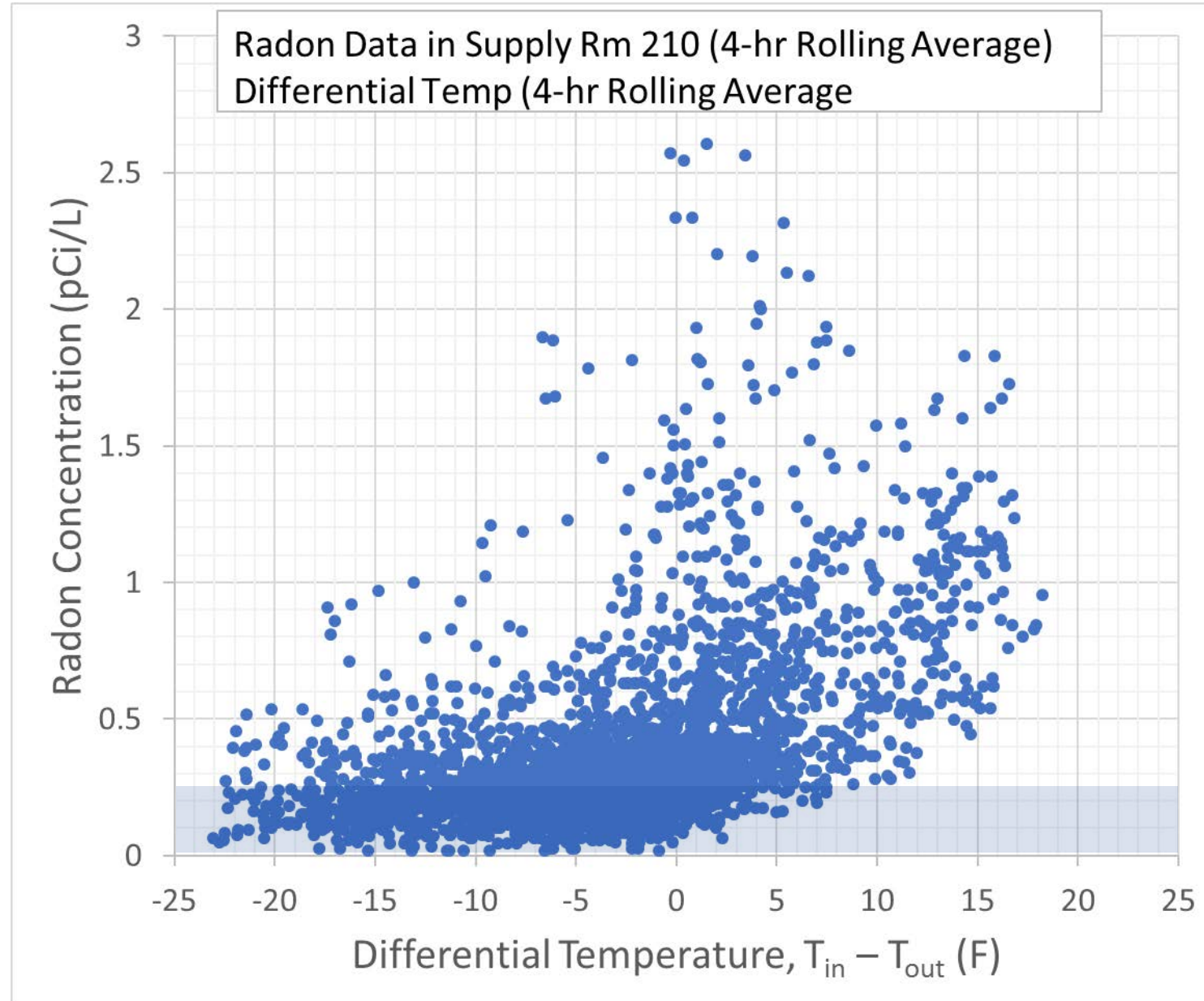
- Discernable indoor TCE/radon events in Supply Room 210 appear to correlate with changing barometric pressures
 - ...mostly with dropping pressures (stack effect), except for a few TCE peaks
- Not all outdoor barometric changes correlated with discernable TCE/radon events



Differential Temperature Versus Indoor TCE and Radon (Supply Storage Room 210)



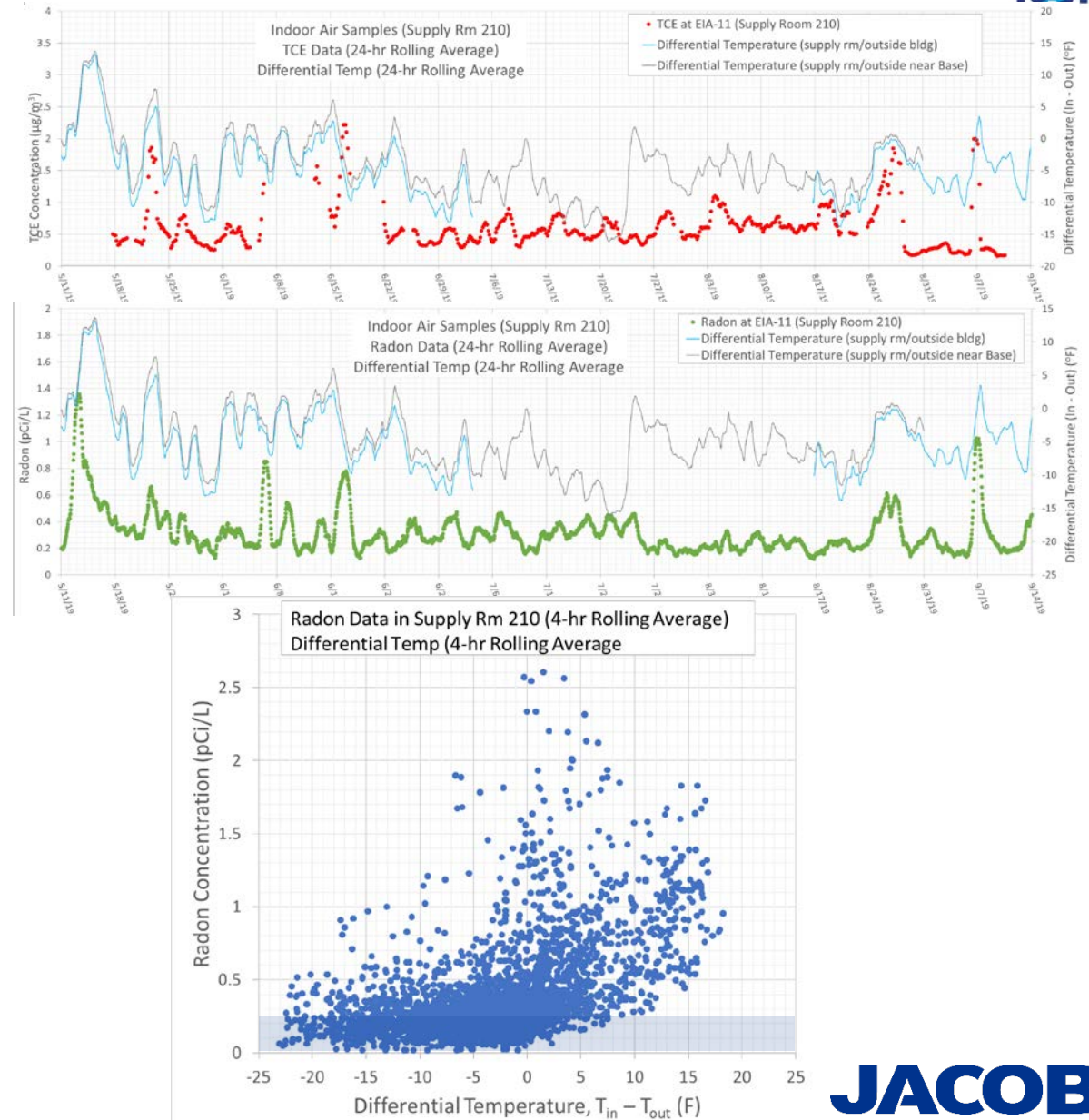
Differential Temperature Versus Radon Indoor Concentrations (Supply Room 210)



Observations About Differential Temperature Versus TCE/Radon in Supply Room 210 Indoor Air (24-hr rolling averages)



- Discernable indoor TCE/radon events in Supply Room 210 appear to correlate with changing indoor-to-outdoor air differential temperatures
 - ...increasing (stack effect) or dropping differential temperatures – lag period?
- Not all changing differential temperatures correlated with discernable TCE/radon events
- Possible increased probability of discernable/higher indoor radon at differential temperatures starting at $\sim 0^{\circ}$ F and above





Thank you!

Questions?

Loren Lund

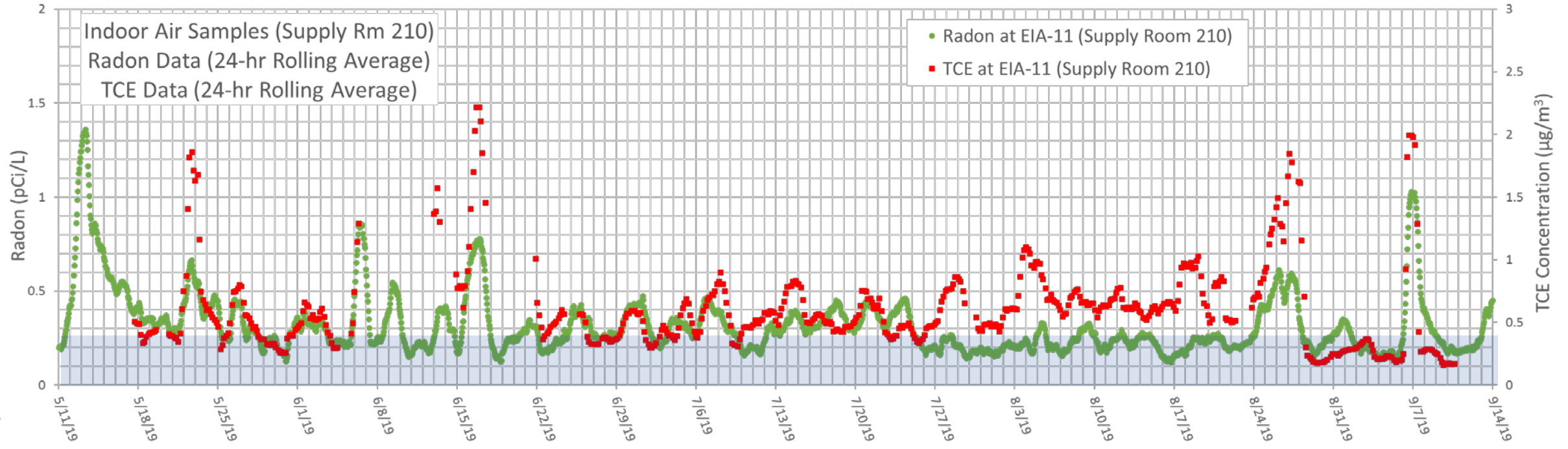
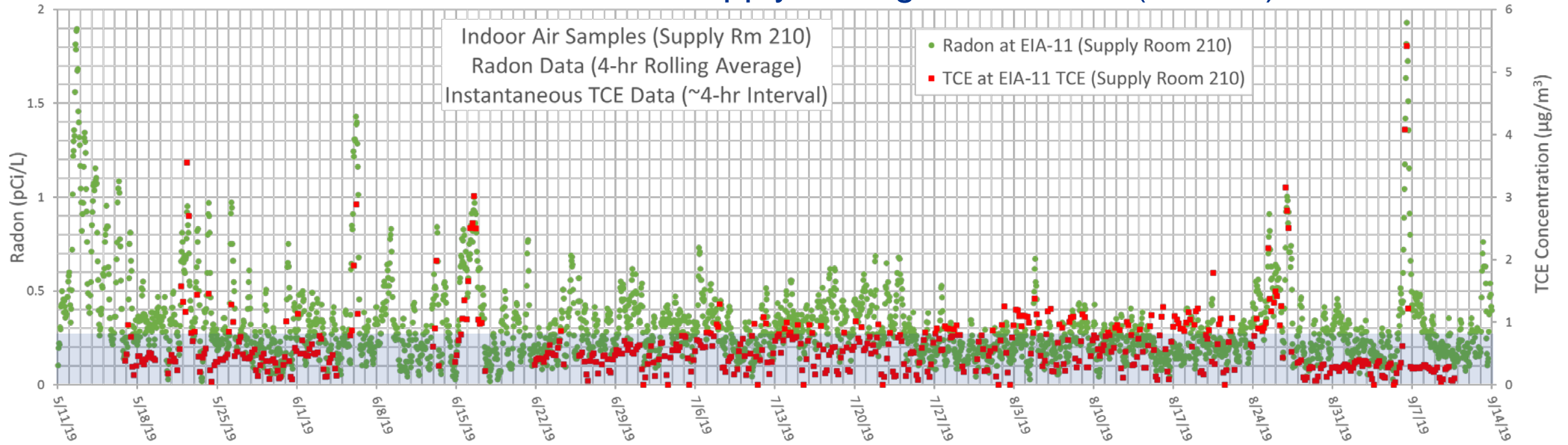
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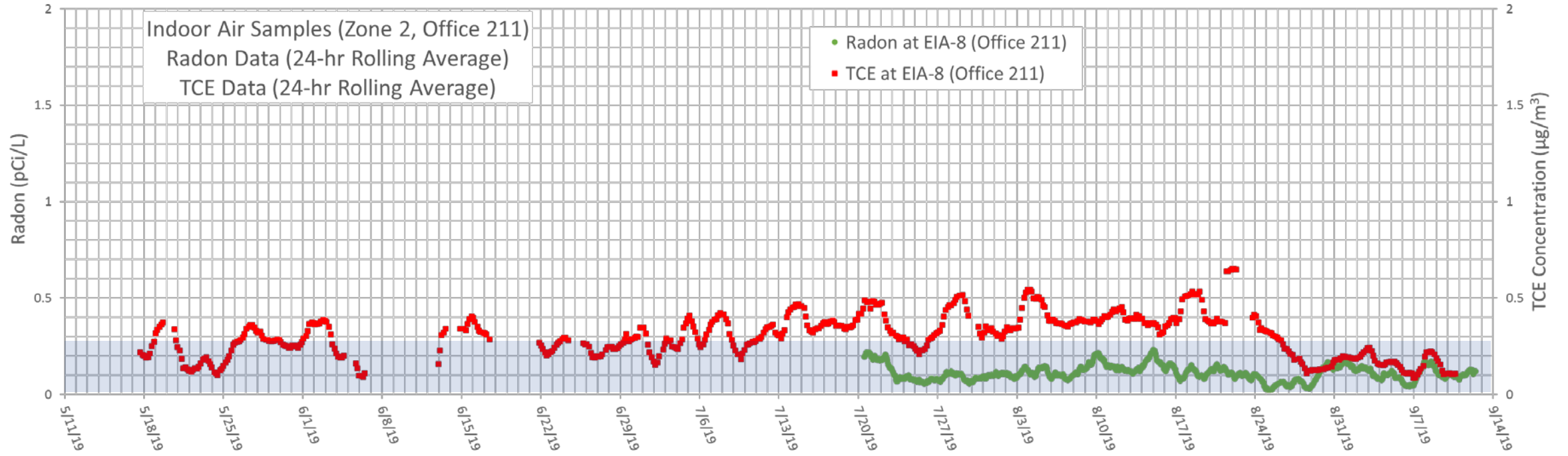
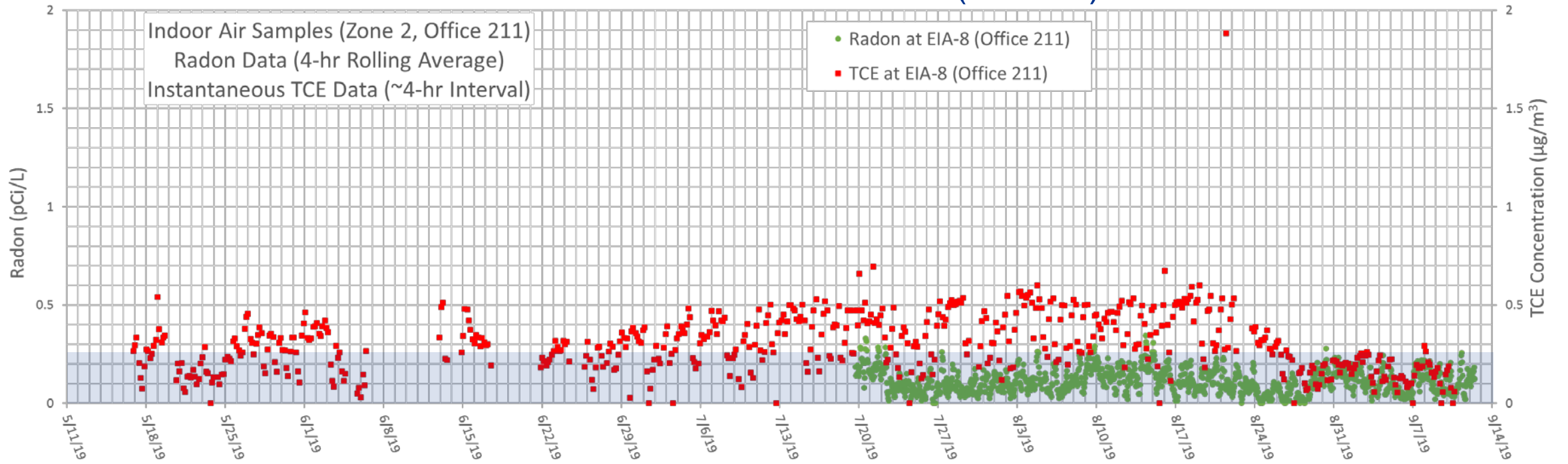
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Supplemental Slides

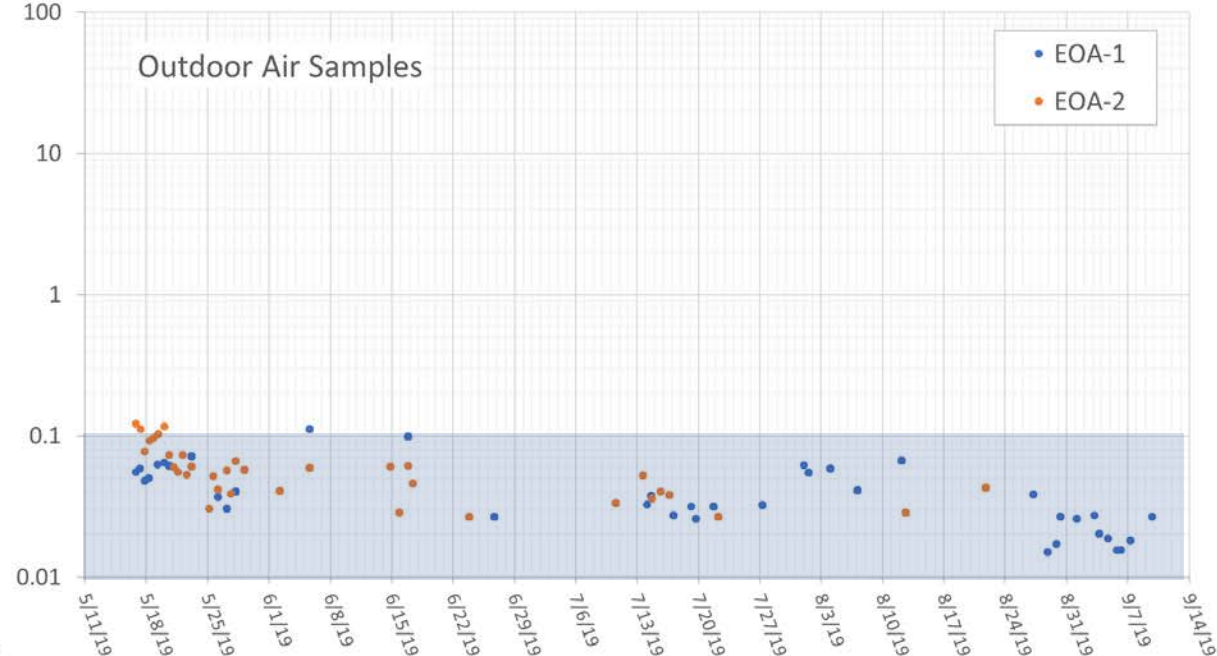
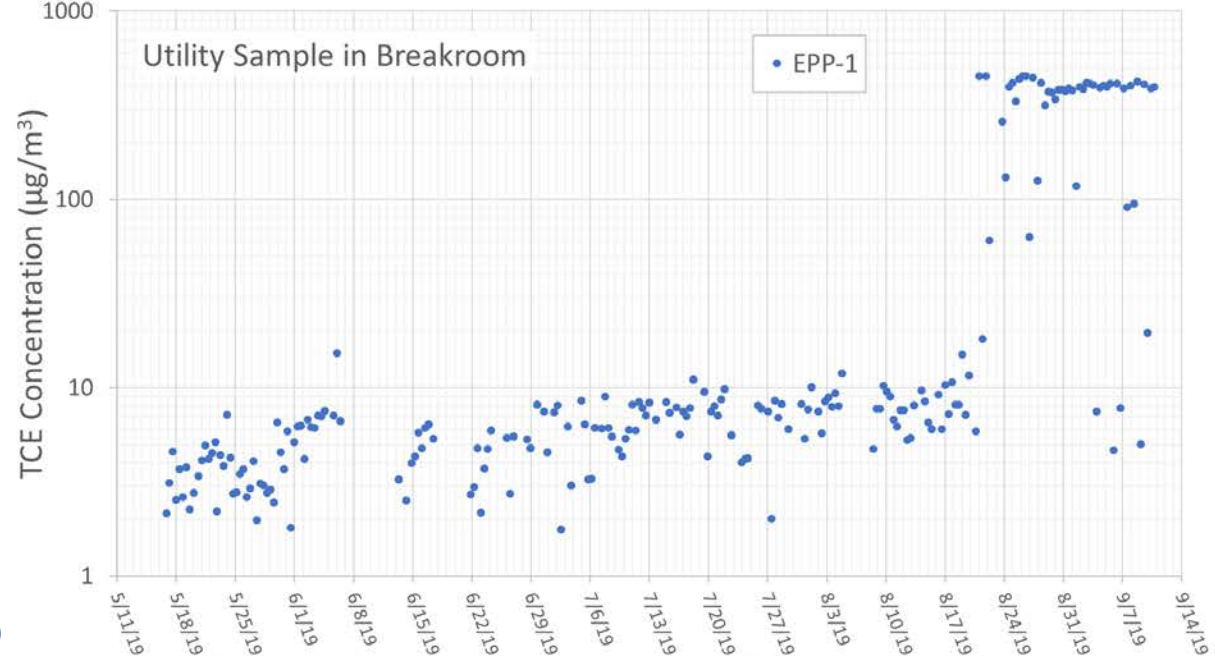
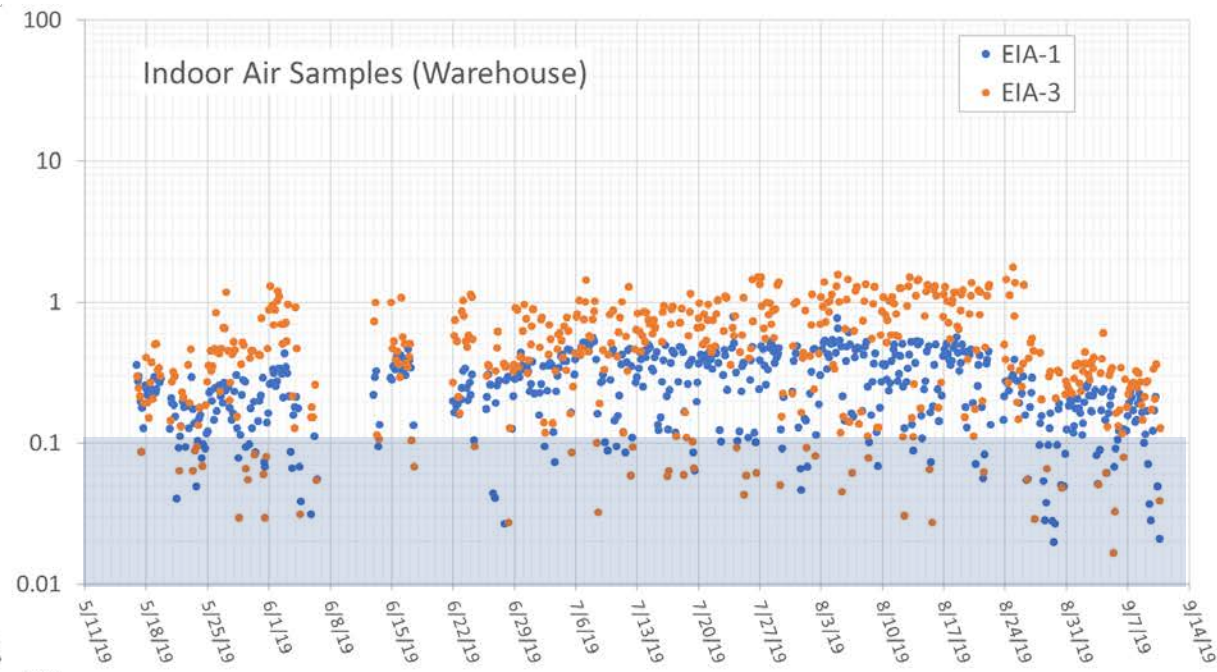
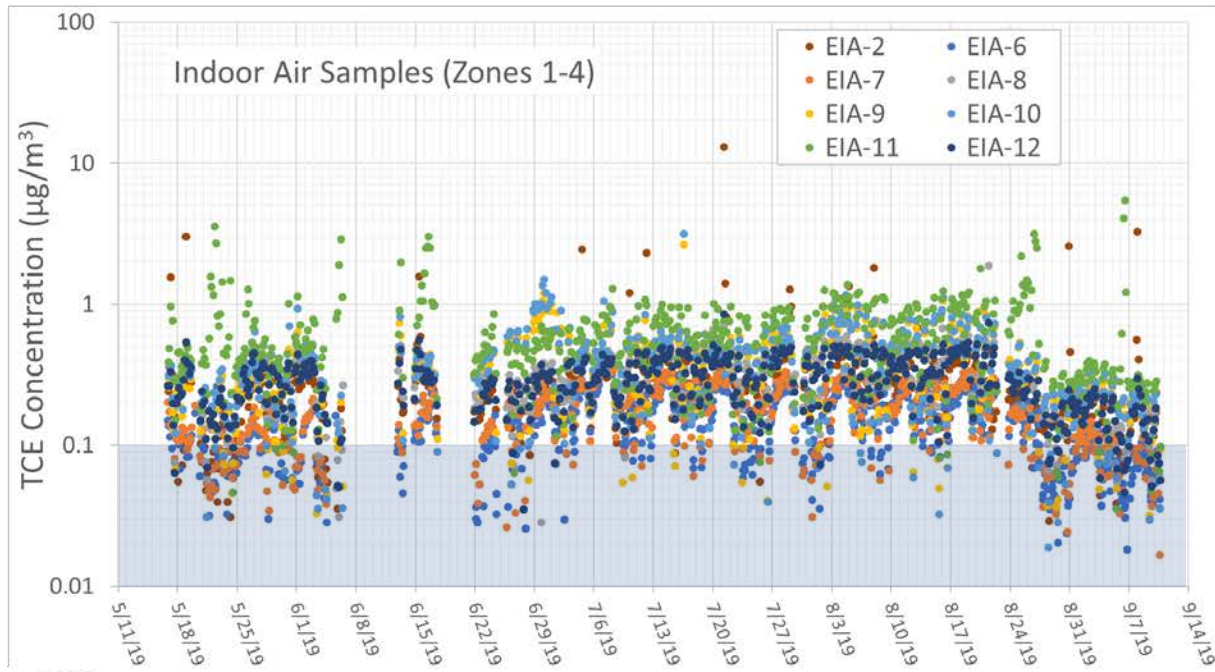
Radon Versus TCE in Supply Storage Room 210 (Zone 4)



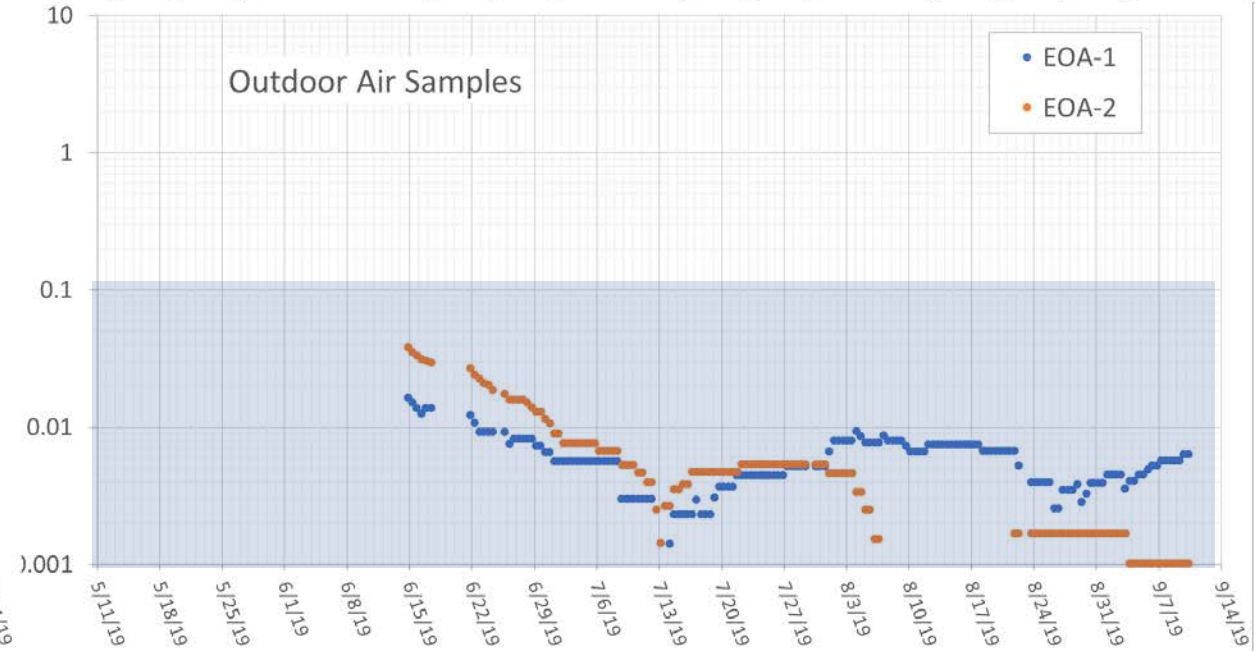
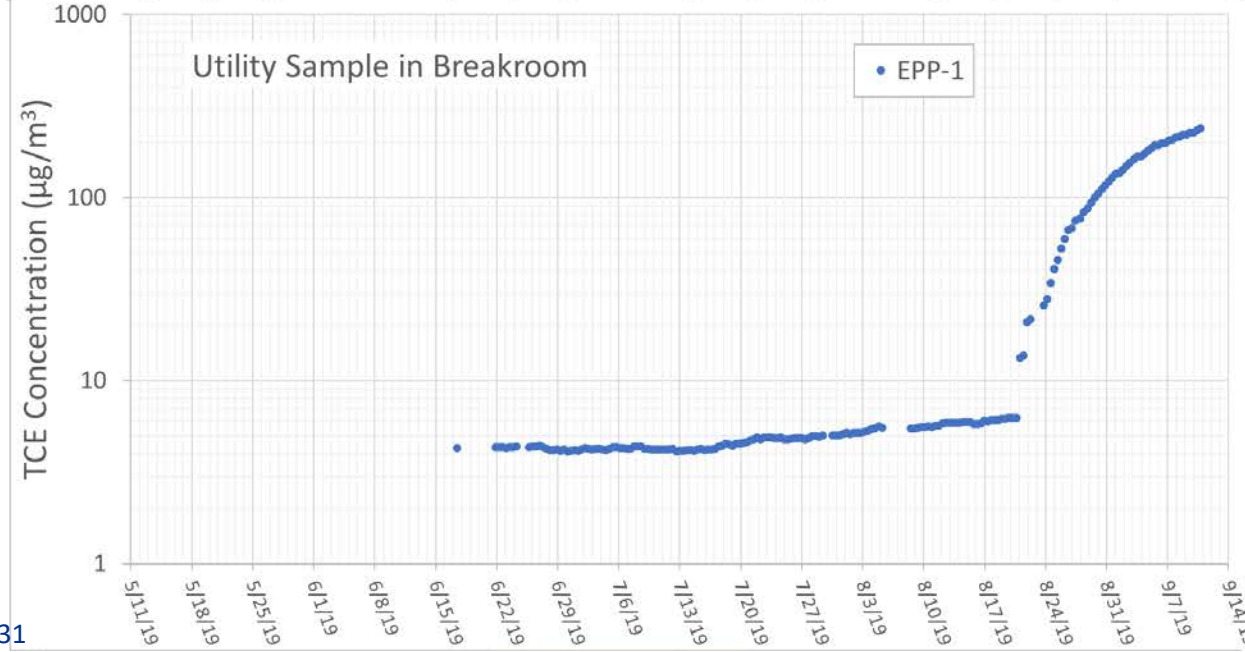
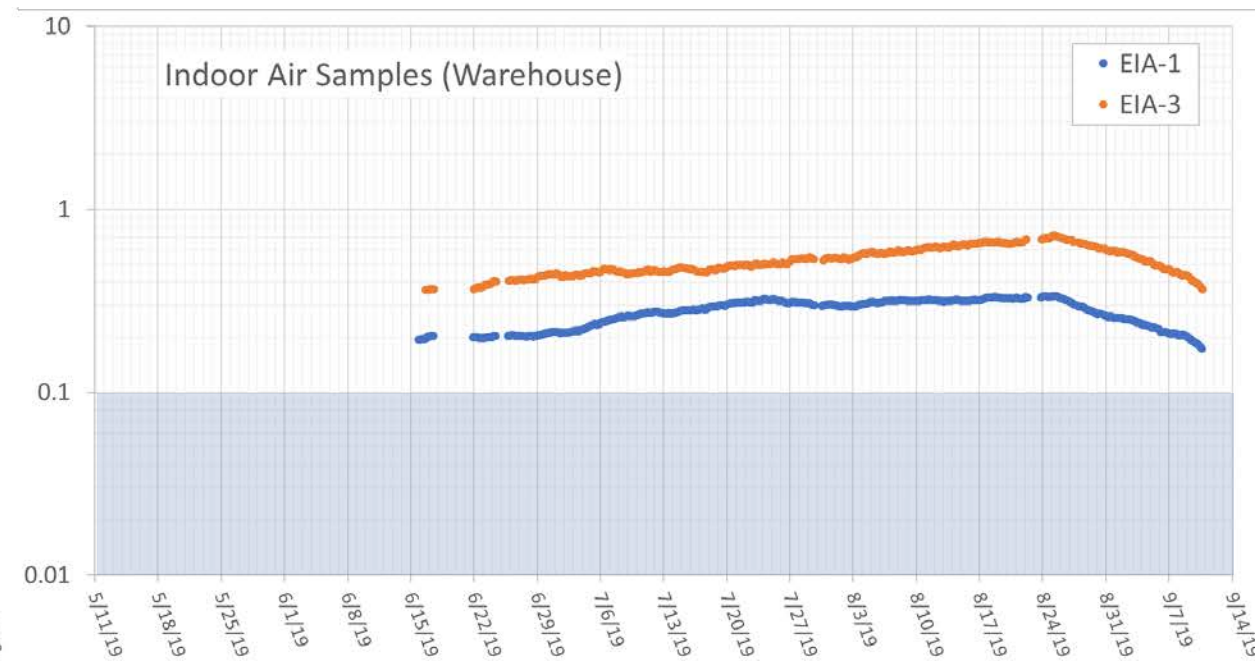
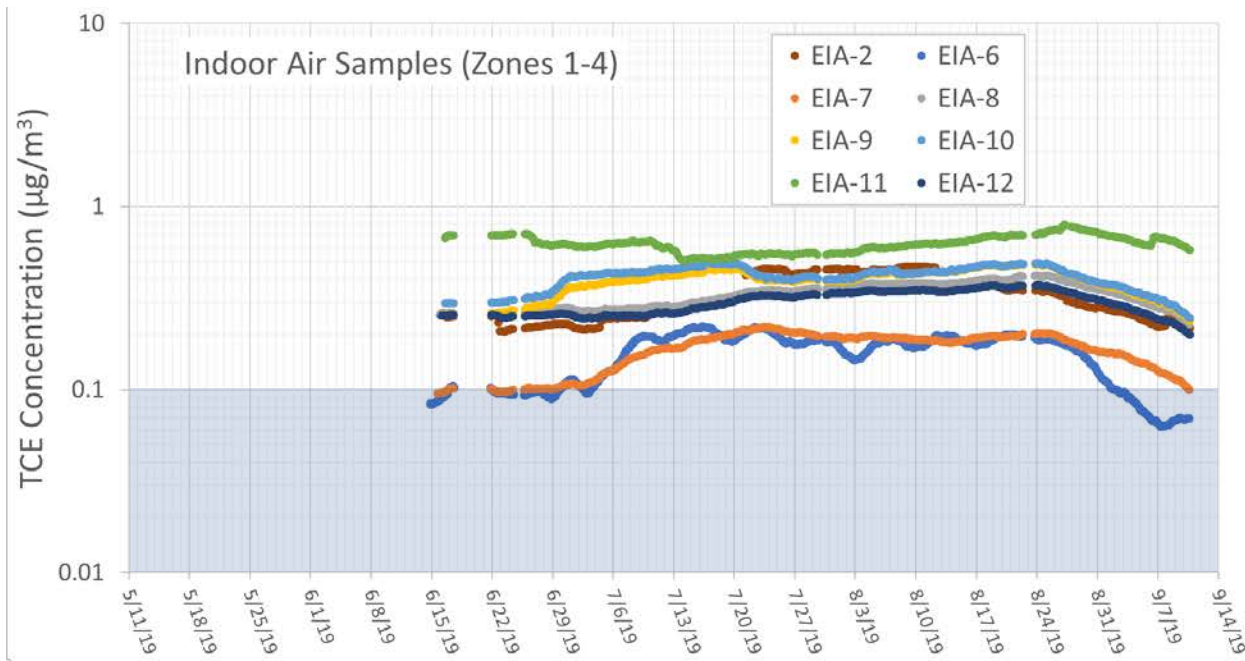
Radon Versus TCE in Office 211 (Zone 2)



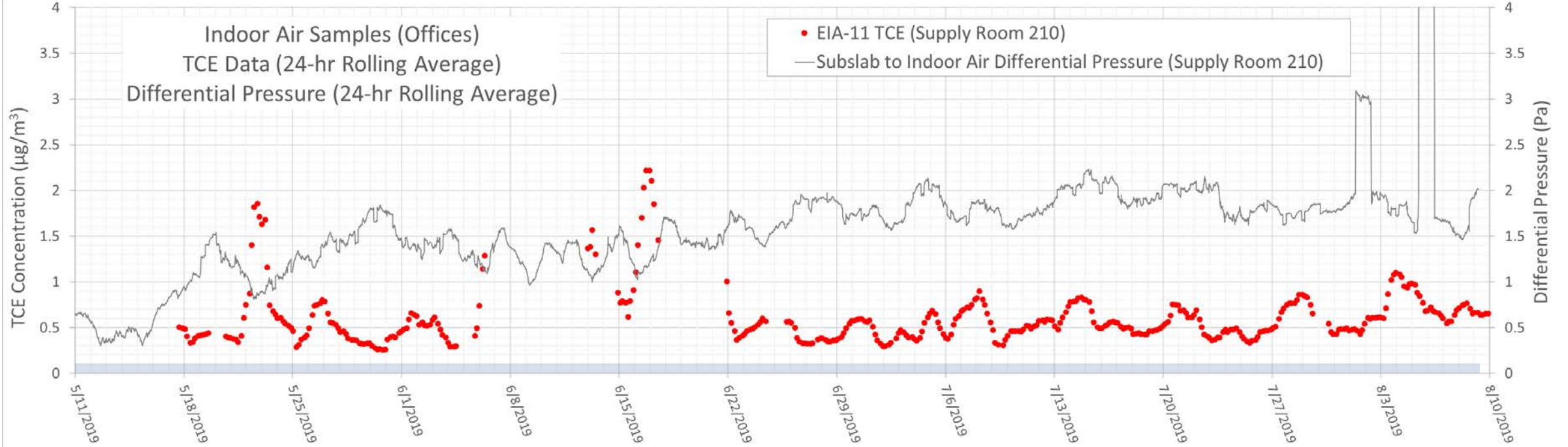
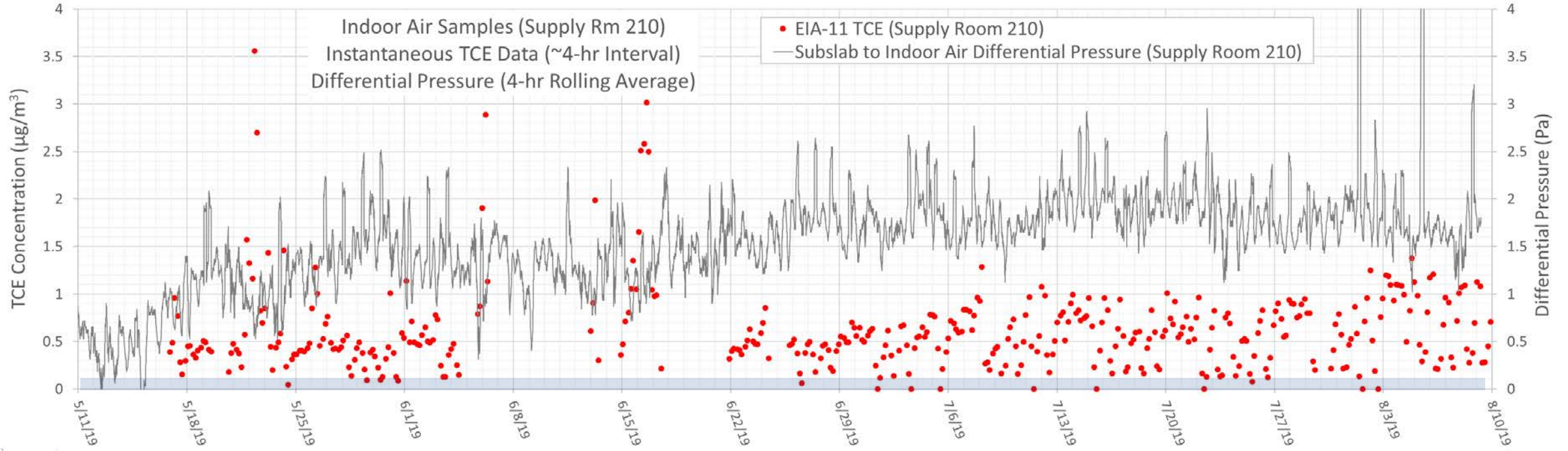
TCE Instantaneous Indoor Results (~4-hr intervals)



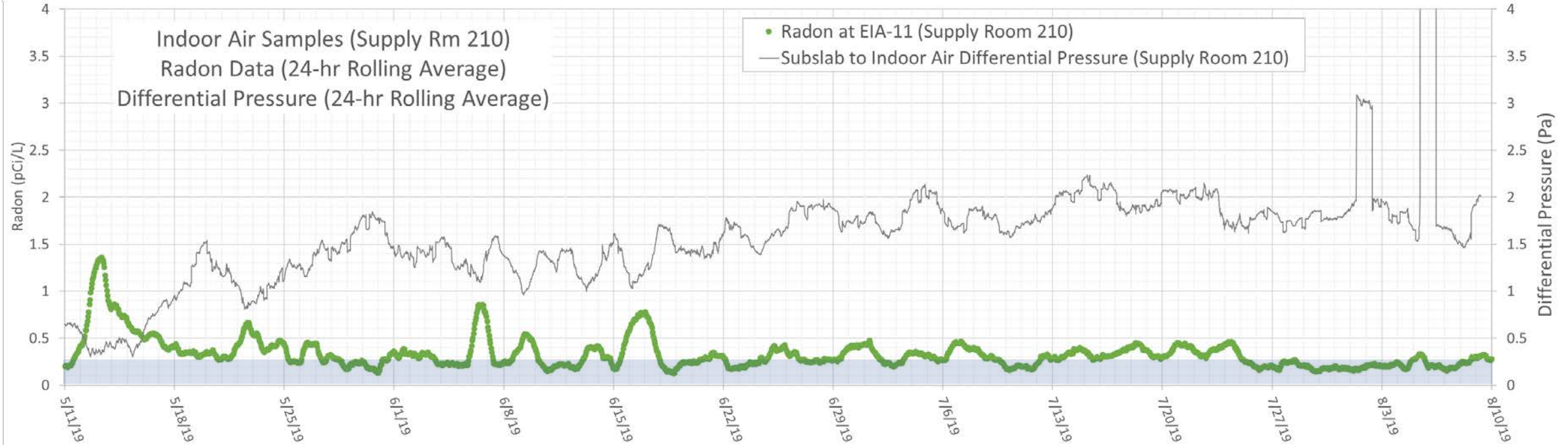
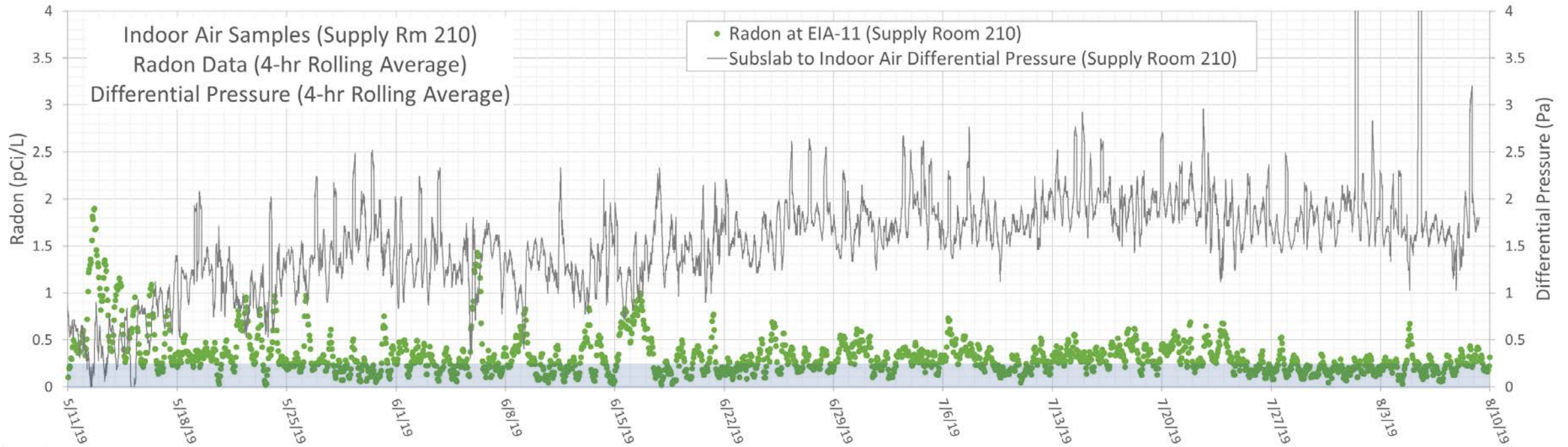
TCE 21-day Rolling Averages of Discrete Results (~4-hr Intervals)



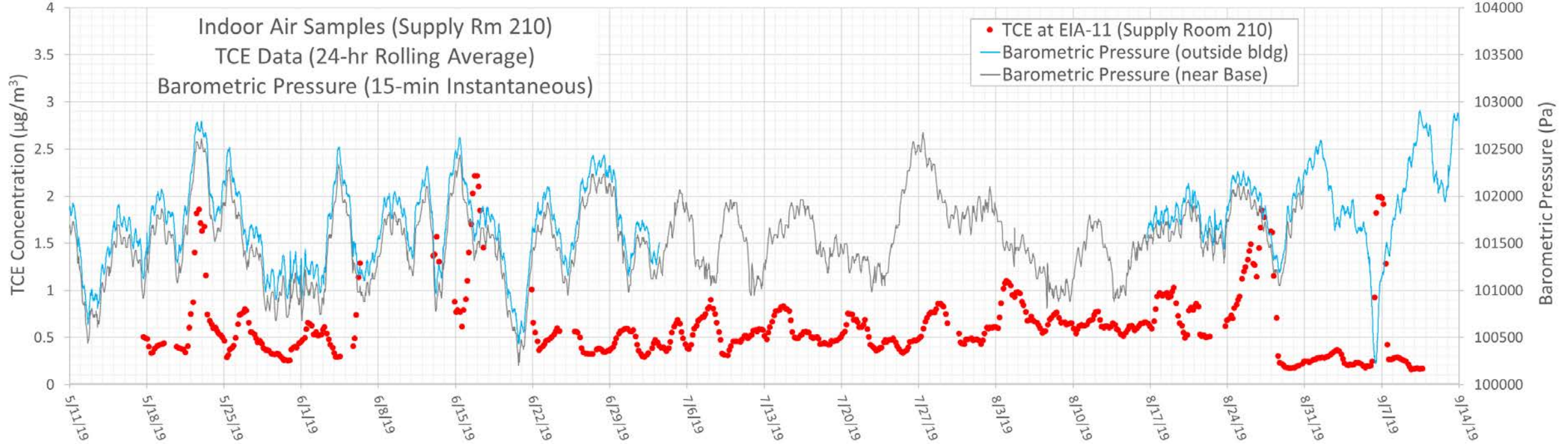
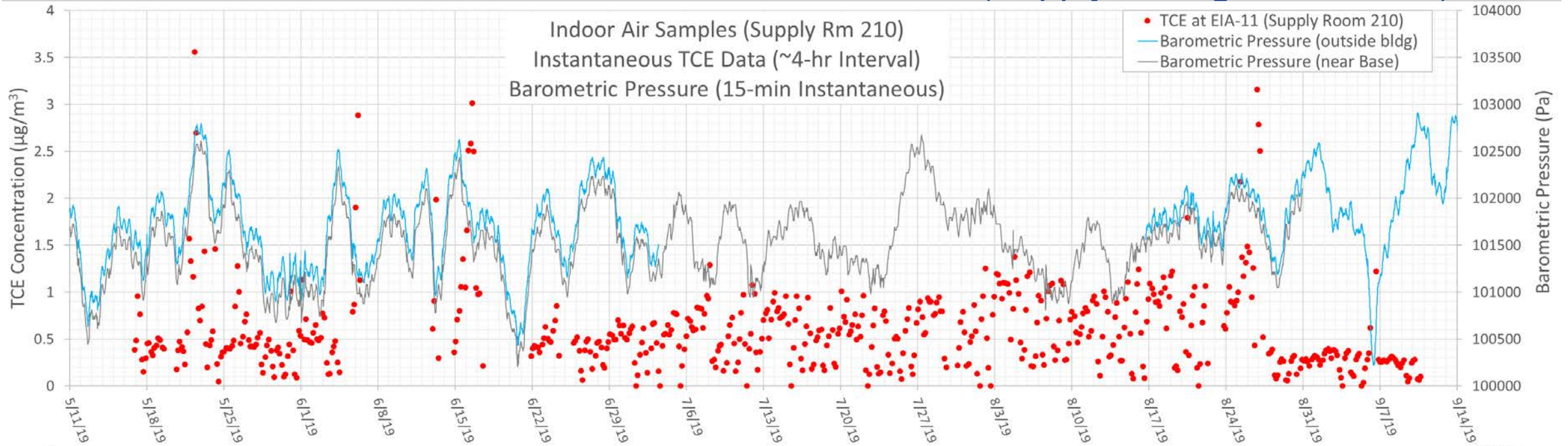
Differential Pressure Versus TCE Indoor Concentrations (Supply Storage Room 210)



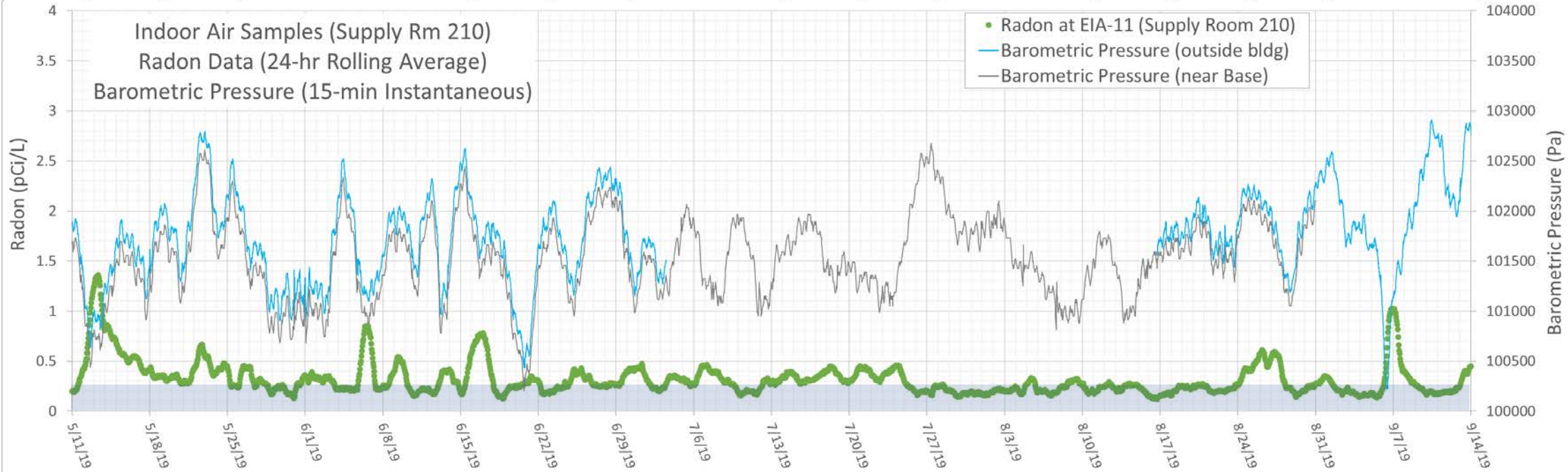
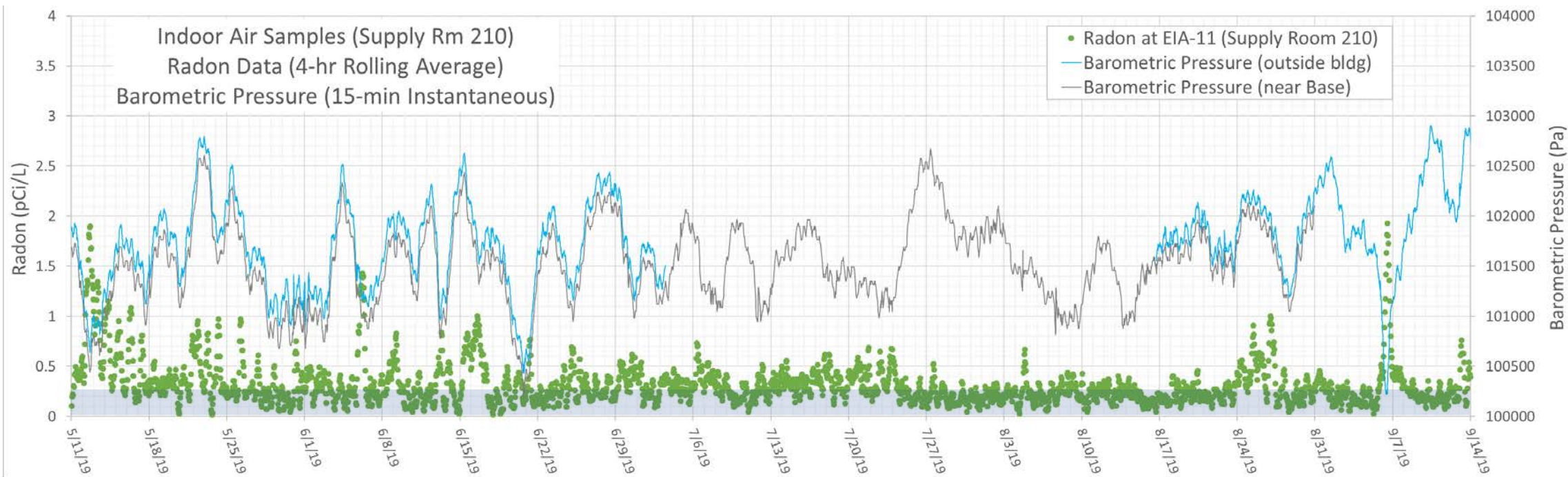
Differential Pressure Versus Radon Indoor Concentrations (Supply Storage Room 210)



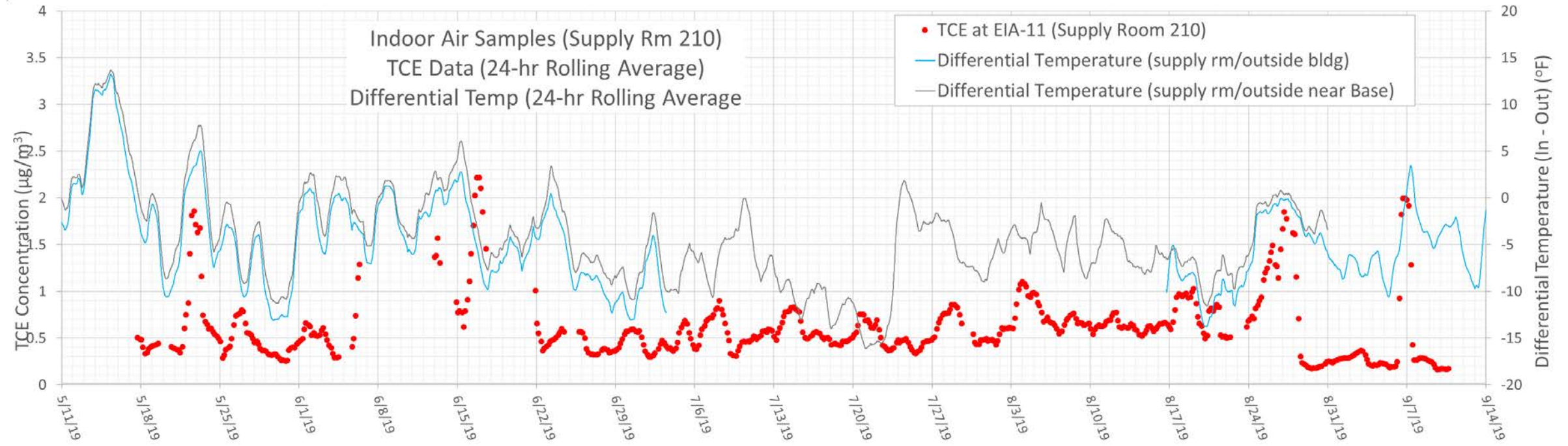
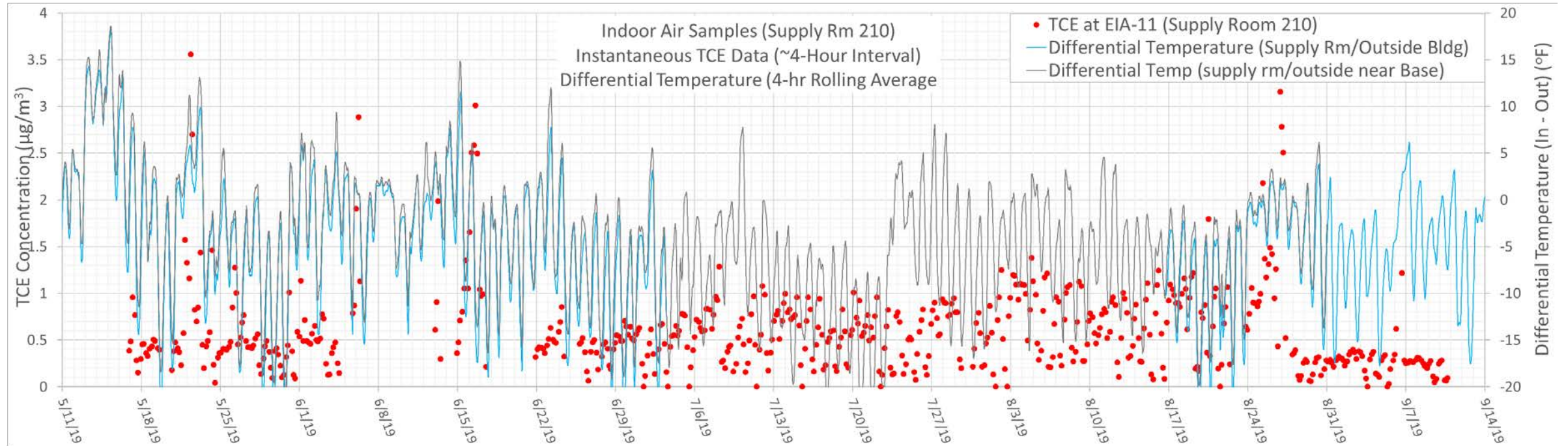
Barometric Pressure Versus TCE Indoor Concentrations (Supply Storage Room 210)



Barometric Pressure Versus Radon Indoor Concentrations (Supply Storage Room 210)



Differential Temperature Versus TCE Indoor Concentrations (Supply Storage Room 210)



Differential Temperature Versus Radon Indoor Concentrations (Supply Storage Room 210)

