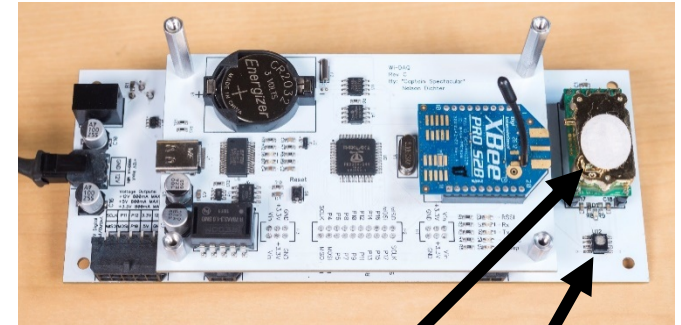


IoT Enabled Buildings

- **Sensing and Communication**
 - Occupancy, lighting, thermostats
- **Controls**
 - Buildings currently under-sensed and under-actuated
 - This could change rapidly
- **Building Performance Diagnosis**
 - Indoor Environmental Quality
 - Code Compliance
 - Air flow pathways and leakage



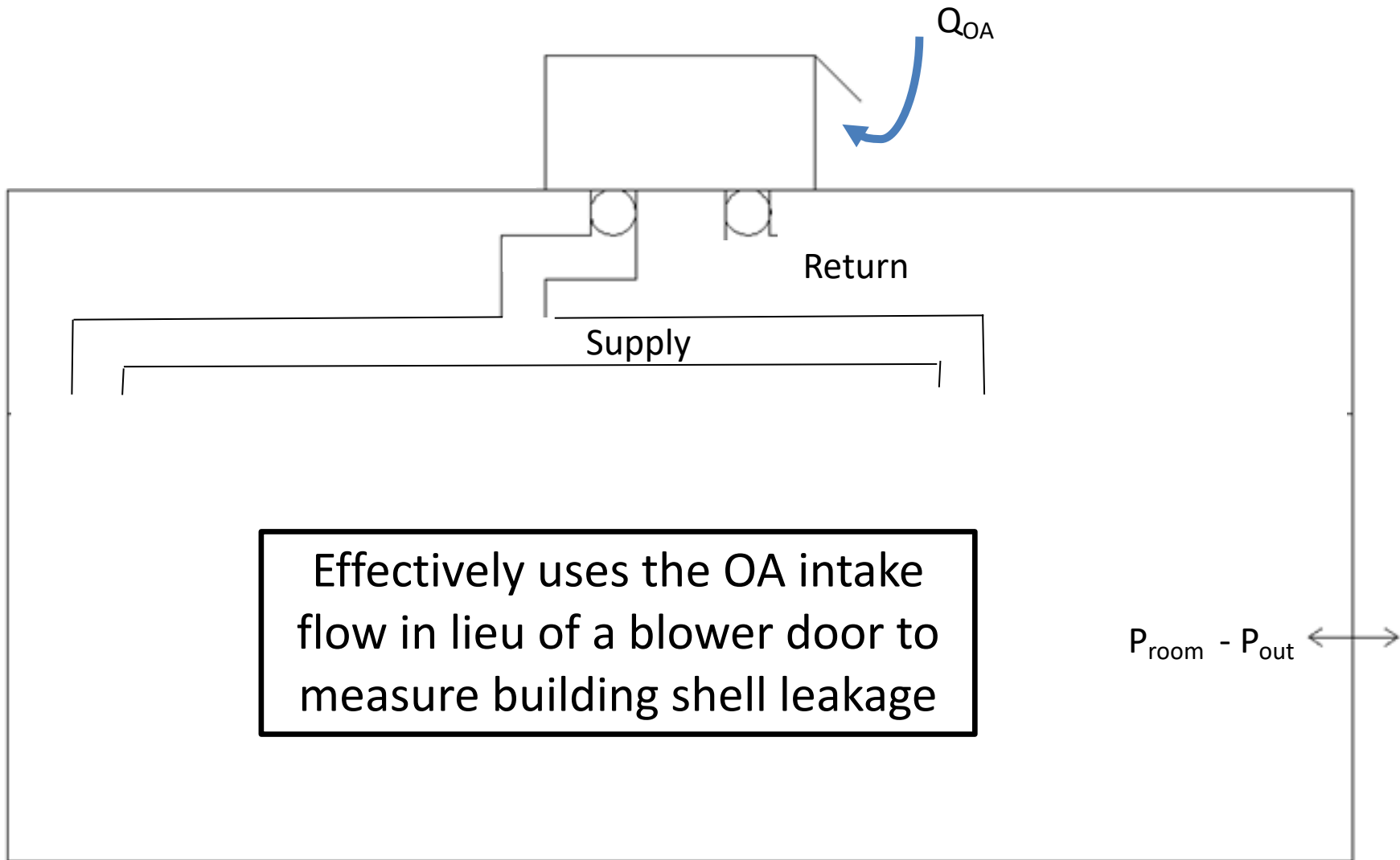
CO₂

Temperature & Relative Humidity



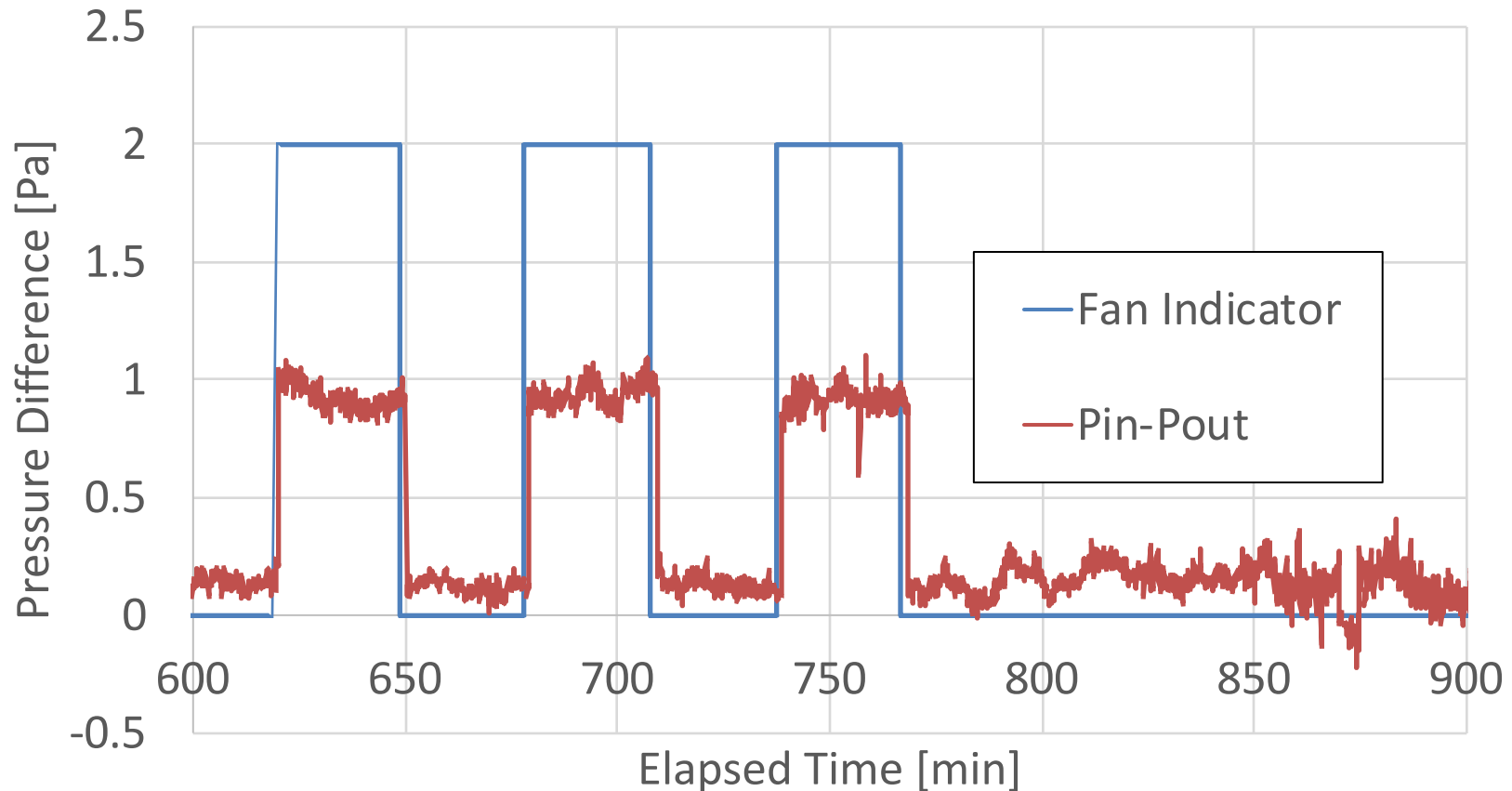
Motion Sensor

Building Leakage Diagnosis with Low-Cost Sensors



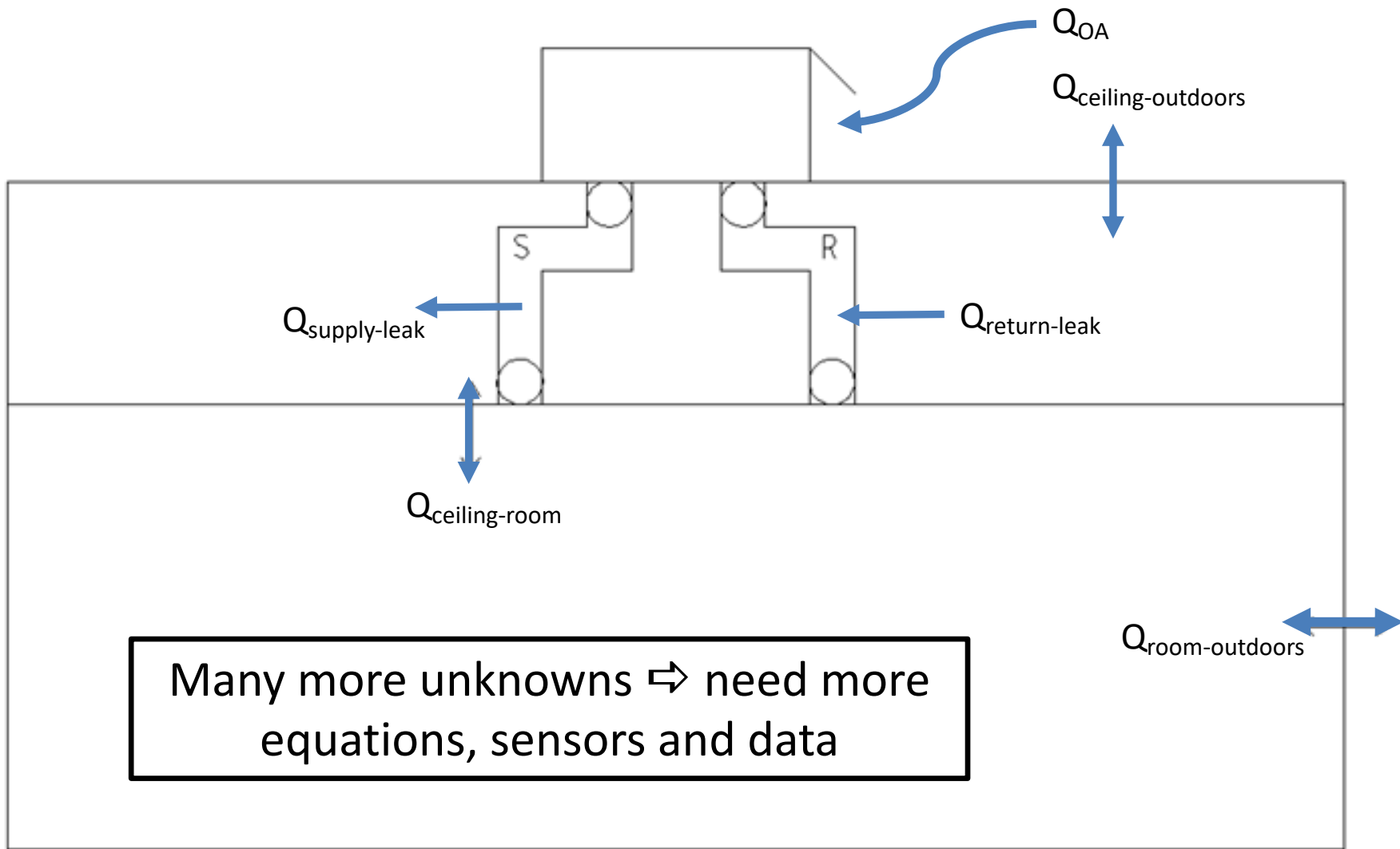
Building Leakage Diagnosis using Low-Cost Sensors:

INITIAL TEST



- OA Intake flow plus changes in pressure difference quantify envelope leakage
- Clear change in $\Delta P_{\text{envelope}}$ associated with fan operation
- Excellent day to day consistency: 5% standard deviation in leakage value

Ceiling Plenum Ductwork \Rightarrow Flow/Pressure plus Temperature/Humidity Analysis

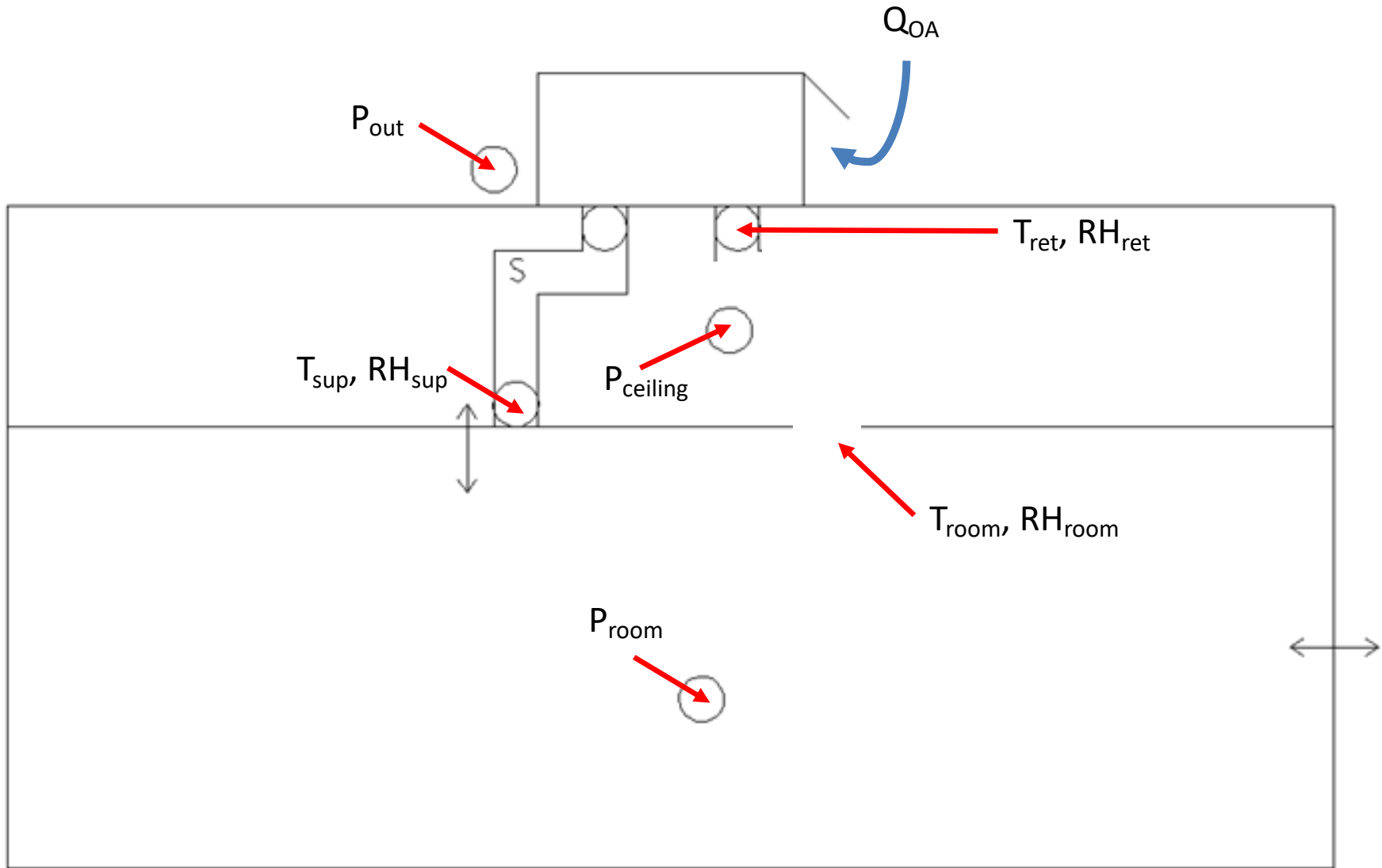


Use of Absolute Pressure Transducers to Measure Differential Pressure

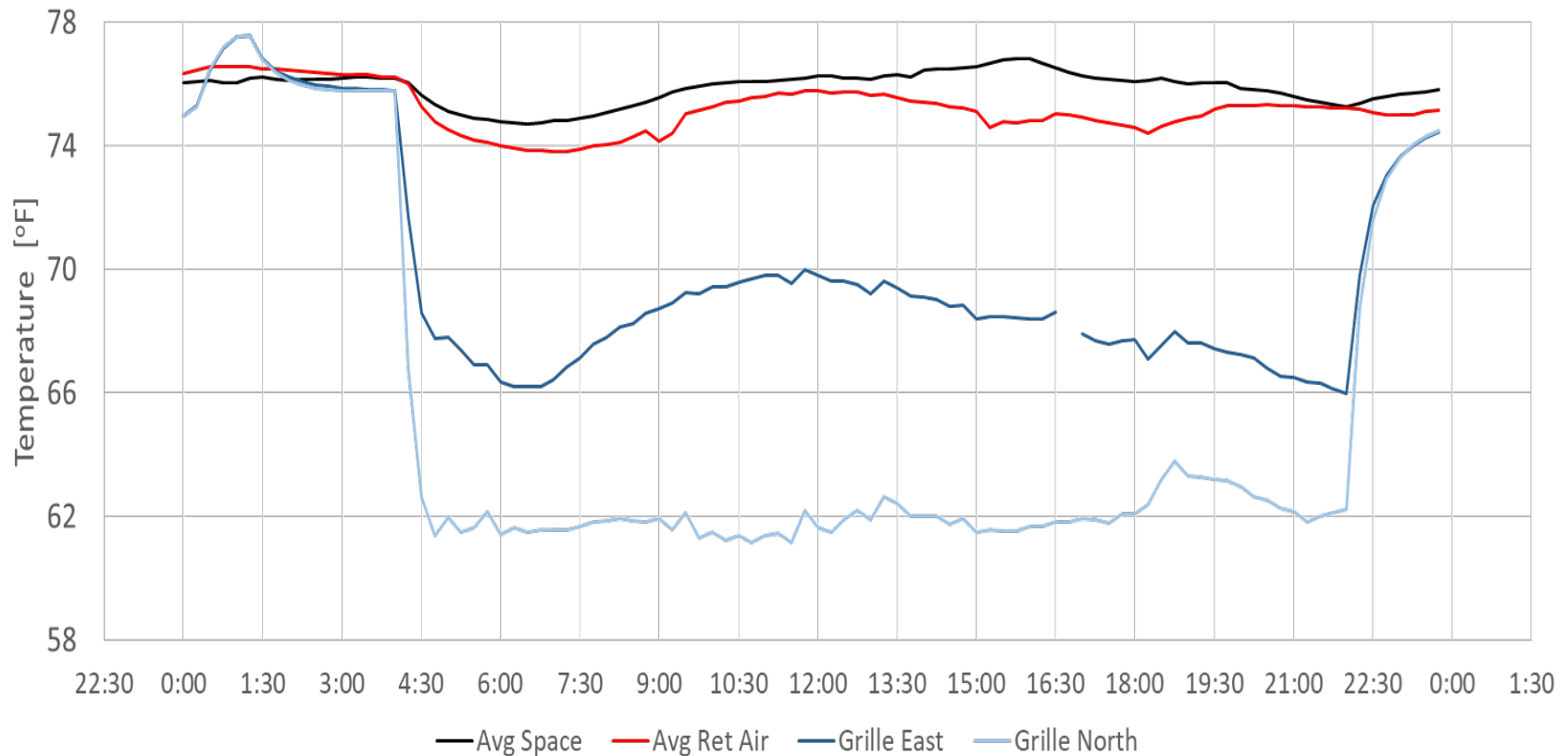


- Wireless absolute-pressure sensors eliminate need to run tubing between zones (**significantly reduces disruption**)
- Small, inexpensive sensors currently used as altimeters - **also measure temperature and humidity**

Pressure Humidity Analysis: Plenum Return

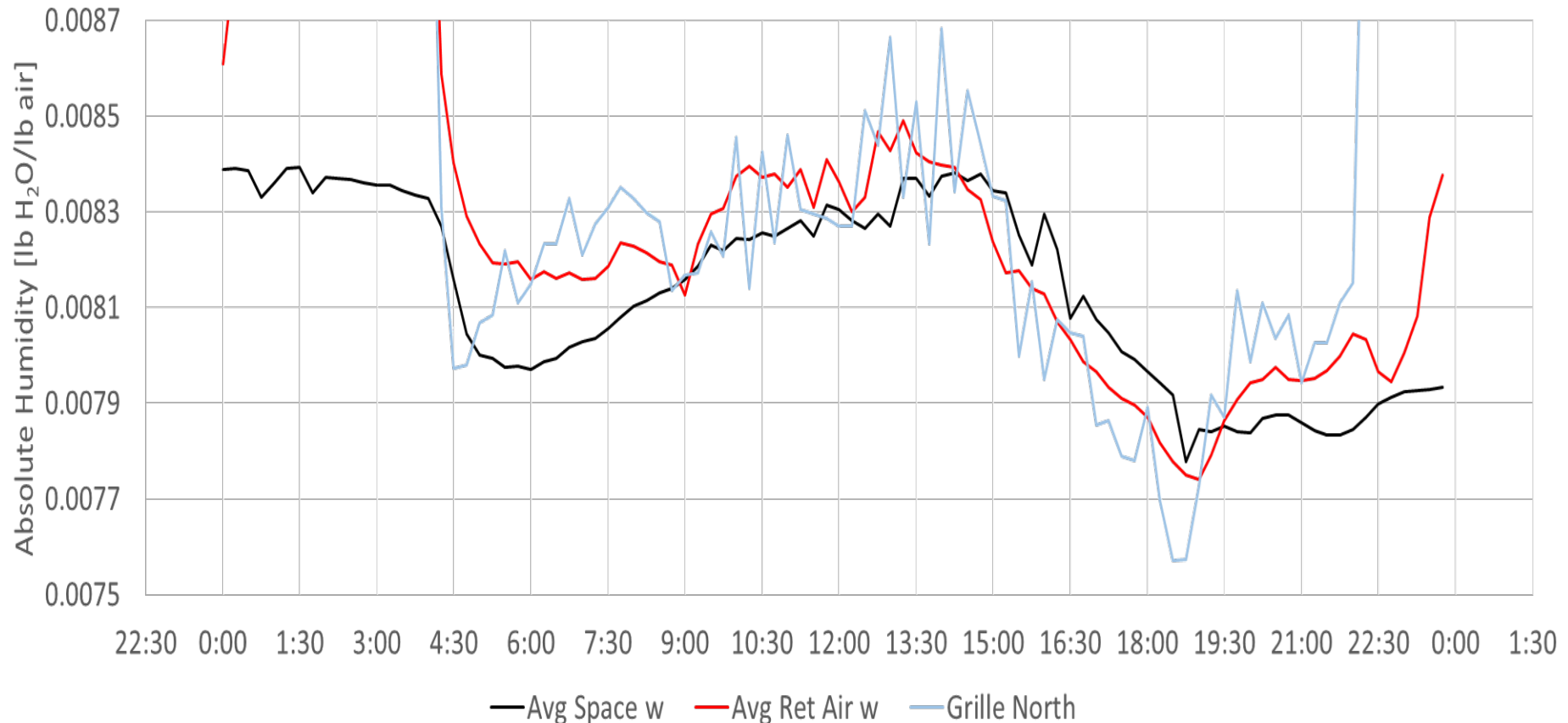


LA Office Building FIELD TEST: **SUPPLY** Leakage from Temperatures



- » Normal Operation shows **Ceiling Plenum Exit Temperature** between Room and **Supply Ducts**
- » **Supply, Plenum-Exit** and Room Temperatures provide **indication** of Supply Duct leakage

LA Office Building FIELD TEST: **SUPPLY** Leakage from Absolute Humidity



- » Normal Operation shows **Ceiling Plenum Exit** humidity between Room and **Supply Duct**
- » **Supply, Plenum-Exit** and Room humidities provide determination of % **Supply Duct Leakage**

LA Office Building FIELD TEST: **SUPPLY** Leakage from ASHRAE Standard 215



Measured Supply Leakage downstream of two VAV boxes
with ASHRAE Std 215 = 12-30%

Pressure/Humidity Analysis

Testing Methodology

- One-time measurement of Outdoor-Air (OA) flow
- Short-term (e.g. one-week or possibly one-night) continuous measurements of Temperatures, Humidities and Pressures
- Normal or On-Off operation of fan, cooling, and/or heat
- Possibly modification of fan-speed, OA damper position, and/or ceiling tiles

Analysis Methodology

- Conservation of mass (air) for building and ceiling plenum
- Conservation of mass (water) for ceiling plenum and return ductwork
- More unknowns than equations \Rightarrow need for different operating modes
- **Machine-learning algorithms?**

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