Practical Approaches to IAQ Monitoring: From Sensor Selection to Data-Driven Decision Making

Maine Indoor Air Quality Council

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Agenda

- Indoor Air Quality Monitoring Basics
- Indoor Air Quality Sensors, Hardware & Communications
- IAQ Monitoring User Case
- Interactive Activity
- The Future of IAQ Monitoring

Learning Objectives

1. **Understand the Fundamentals of IAQ Monitoring:** Learn the basic principles of IAQ monitoring and how it impacts building environments and occupant health.
2. **Evaluate and Select Appropriate IAQ Sensors:** Gain knowledge about the different types of IAQ sensors available, including their strengths, weaknesses, and use cases.
3. **Analyze and Interpret IAQ Data:** Learn how to read and interpret IAQ data to make informed decisions about building operations and air quality improvements.
4. **Apply IAQ Data in Problem Solving:** Participate in a hands-on exercise to identify IAQ concerns from real data, applying your knowledge to diagnose potential sources of air quality issues.
5. **Stay Current with Emerging Sensor Technologies:** Explore cutting-edge IAQ sensor technologies and how they can be integrated into future-proof monitoring systems.

What is Indoor Air Quality (IAQ) Monitoring?

An IAQ monitor is a device or system that checks the levels of different air contaminants and helps assess how safe the air is to breathe. It can alert people when some of those levels become unsafe.

Bad air quality can affect our comfort, our health, and our cognitive performance.

The COVID-19 pandemic and climate change (eg, wildfires and increased ambient air pollution events) have highlighted the importance of good ventilation and filtration for good indoor air quality.

Air quality monitoring is critical to ensure that IAQ mitigation techniques are working.

The rise of Internet of Things and cloud technology has revolutionized the world of IAQ Monitoring.

After COVID, many companies released IAQ products. It is important to know how to navigate the noise to make sure you use the right product for what you need.

Let's Dive In.

What can we monitor and why?

Temperature and Humidity levels affect comfort and health. Too high humidity can promote mold growth, dust mites, and bacterial proliferation, while too low humidity can cause respiratory irritation and dry skin.

High **Carbon Dioxide** levels can indicate poor ventilation and overcrowding. Elevated CO_2 levels can indicate underventilation which can cause drowsiness, headaches, and reduced cognitive performance. Low CO_2 can indicate overventilation.

Volatile Organic Compounds (VOCs) are emitted as gases from certain solids or liquids, including paints, cleaning supplies, and adhesives. High levels can cause eye, nose, and throat irritation, headaches, and even long-term health issues such as liver or kidney damage.

Formaldehyde (HCHO) is a specific type of VOC commonly found in building materials and household products. It can cause respiratory problems and is classified as a human carcinogen.

Particulate matter can include dust, pollen, soot, and smoke. High concentrations can exacerbate respiratory issues, cardiovascular diseases, and other health problems, especially in vulnerable populations like children and the elderly.

While beneficial in the upper atmosphere, **Ozone** at ground level can cause respiratory problems and other health issues.

Carbon Monoxide (CO) is a colorless, odorless gas produced by burning fuel. High levels can lead to poisoning, causing symptoms ranging from headaches and dizziness to more severe outcomes like loss of consciousness or death.

And Many Others, including **Nitrogen Dioxide**. Produced by combustion processes, NO_2 can irritate airways, reduce lung function, and increase susceptibility to respiratory infections.

Sensors, Hardware & Communications

Hardware: Types of Monitors

Reference instruments

Expensive
Very Accurate
For Reference & Calibration

Handheld instruments

Cheaper
Point in time
Local access

Low Cost Sensors

Real-time monitoring

Low-Cost
Real-time
Access from anywhere

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IAQ Monitors: Wired vs Wireless

Wired Output

0-5V, 4-20mA, Modbus, BACnet, etc.
Cheaper Device
Expensive Installation
Local Access
No Security
Limited # of Sensors

Screen/App

Bluetooth
No subscription
Consumer Type

Wireless Output

WiFi, ZigBee, 5G, etc.
More Expensive Device
Cheaper Installation
Encrypted Communications
Cloud Access
Unlimited data

IAQ Monitors: Types of Wireless

WiFi	**Cell**	**802.15.4**	**Bluetooth**	**LoRa**
Easy to Set Up	Easy to Set Up	Easy to Set Up	**Difficult to Set Up**	Difficult to Set Up
Difficult to Maintain	Easy to Maintain	Easy to Maintain	Difficult to Maintain	Easy to Maintain
Medium Range	Long Range	**Medium Range**	Small Range	Long Range
Cheap	**Expensive**	Cheap	Cheap	Cheap
High Bandwidth	High Bandwidth	Medium Bandwidth	High Bandwidth	**Very Low Bandwidth**

From the Sensors to an App

Example

Aranet 4

Good for short term monitoring

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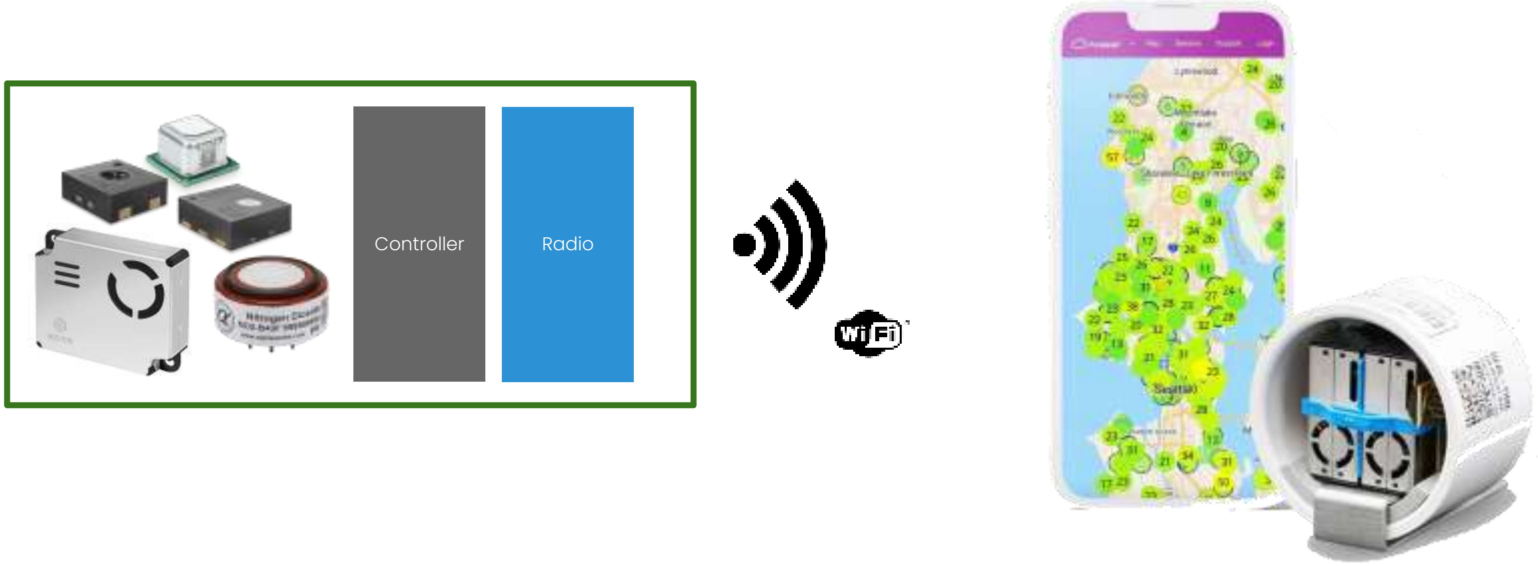
From the Sensors to the Cloud

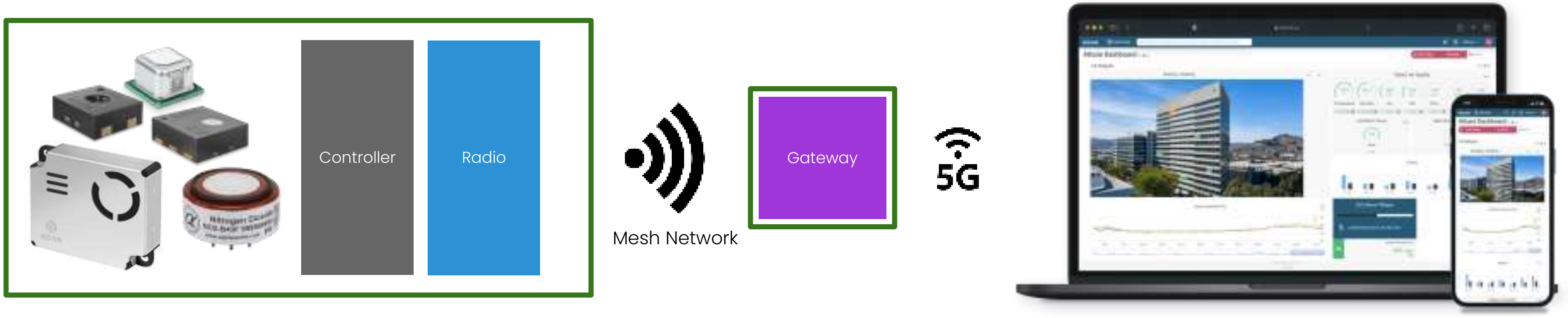


Example

Purple Air, Kaiterra, Airthings

Good for small deployments

From the Sensors to the Cloud



Examples

Attune, Awair

Good for large deployments

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Hardware: Types of Sensor Data

Temperature
Relative Humidity

Small
Very Accurate
Low Drift

CO_2

Small
NDIR
Or Acoustic
(smaller but less accurate)

Hardware: Types of Sensor Data – CO_2

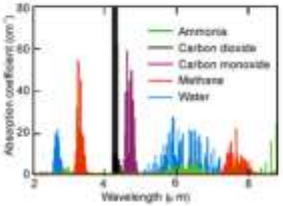
Very Accurate
More Expensive

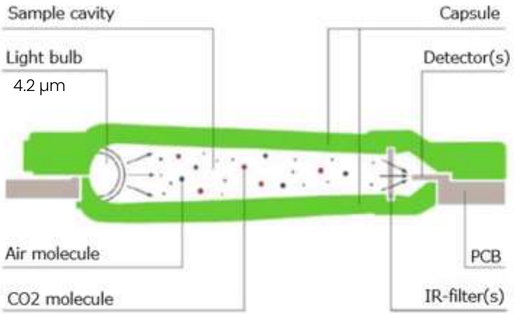
NDIR
(Non-Dispersive Infrared absorption spectroscopy)

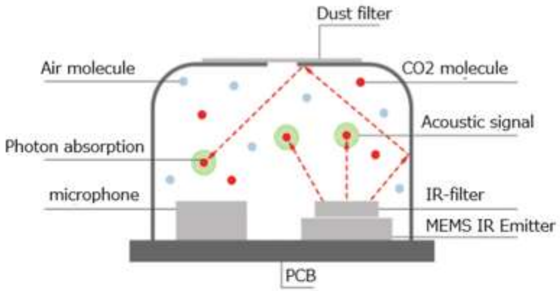
PAS
(Photo Acoustic Spectroscopy)

Smaller
Cheaper
Less Accurate

Not suited for outdoor use? (Wider range of T and RH values)







https://www.dfrobot.com/blog-13487.html
https://www.airgradient.com/blog/co2-sensors-photo-acoustic-vs-ndir-updated/
https://sensirion.com/media/documents/9E7DA521/627C2C8D/CD_IN_SCDxx_Transmissive_and_photoacoustic_NDIR_sensing_D1.pdf

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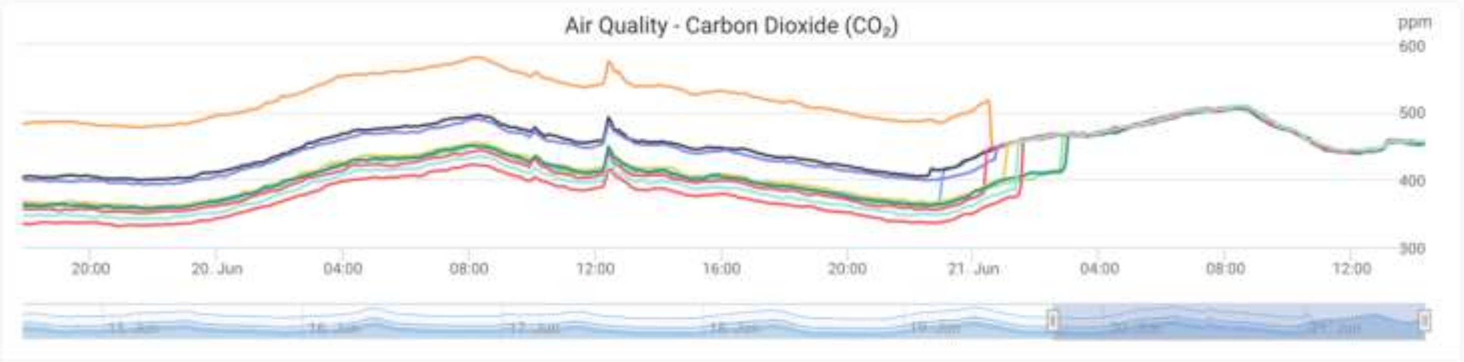
Hardware: Types of Sensor Data – CO_2

Sensors drift over time, Automatic Baseline Correction (ABC) can be used to maintain sensor calibration, **assuming** the sensor reaches 400ppm fresh air levels at least once a week.



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TVOC

Small
MOX Technology
Evolving Rapidly

Other options: PID

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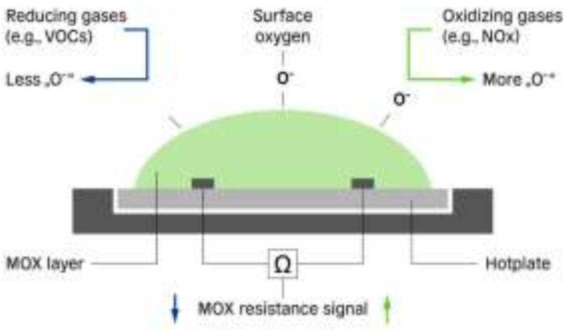
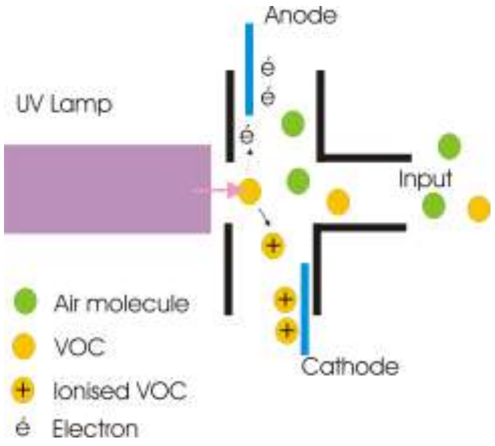
Hardware: Types of Sensor Data – TVOC

Metal Oxide Sensors (MOX)



Photoionization (PID)



Different Lamp Energy (eV) can be used to target specific VOCs

PID VOC sensors can help narrow down types of VOCs but require frequent calibration

https://sensirion.com/media/documents/0083CDF4/6294DFEA/Info_Note_MOX_sensor.pdf
https://sysmatec.ch/en/voc-measurement-with-pid-sensor/
https://www.engineerlive.com/content/how-do-you-choose-voc-sensor

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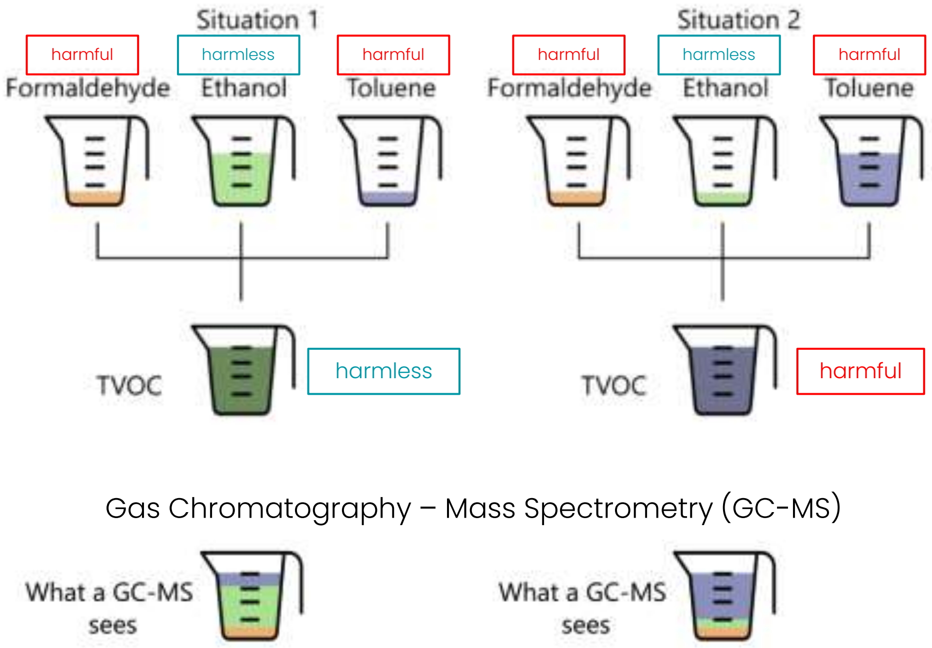
Hardware: Types of Sensor Data – TVOC



MOX TVOC sensors cannot discriminate between VOC types

AI MOX TVOC show some promise of VOC type classification

https://sensirion.com/media/documents/4B4D0E67/6520038C/GAS_AN_SGP4x_BuildingStandards_D1_1.pdf

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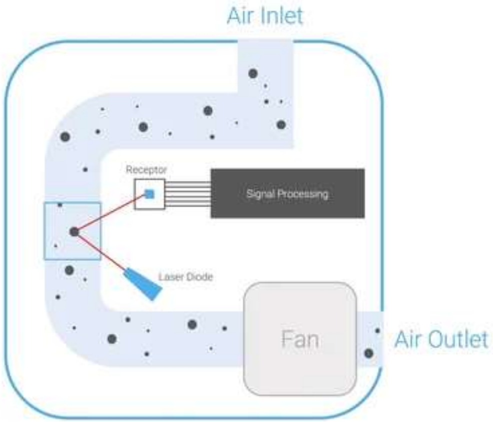
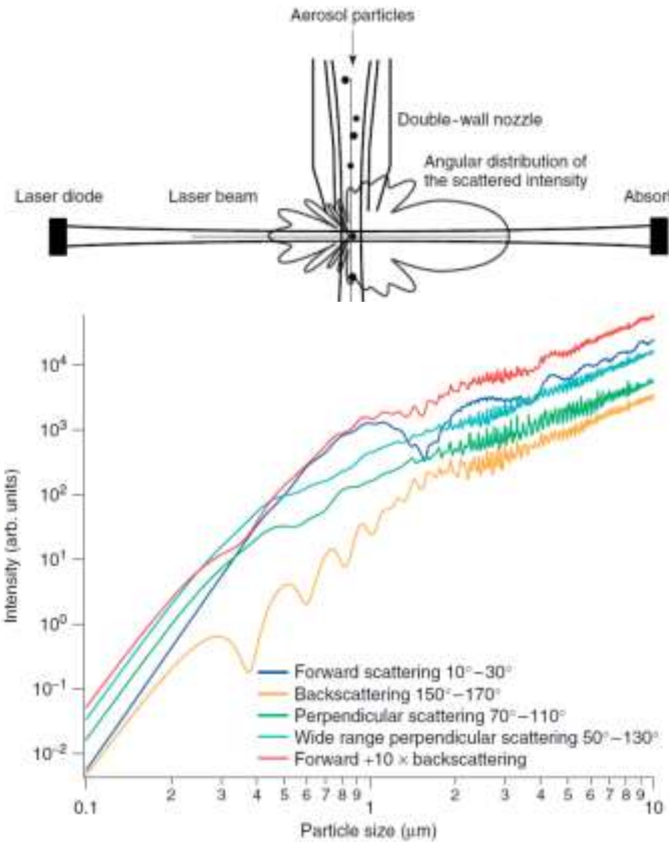
Particulate Matter

Light Scattering
Most difference between devices

Hardware: Types of Sensor Data – PM





Important Factors

Airflow
[can it bring in PM10 particles?]

Scattering Angle
[can it measure size accurately?]

Humidity Compensation
[does it represent true distribution?]

https://blog.attuneiot.com/particulate-matter-sensors

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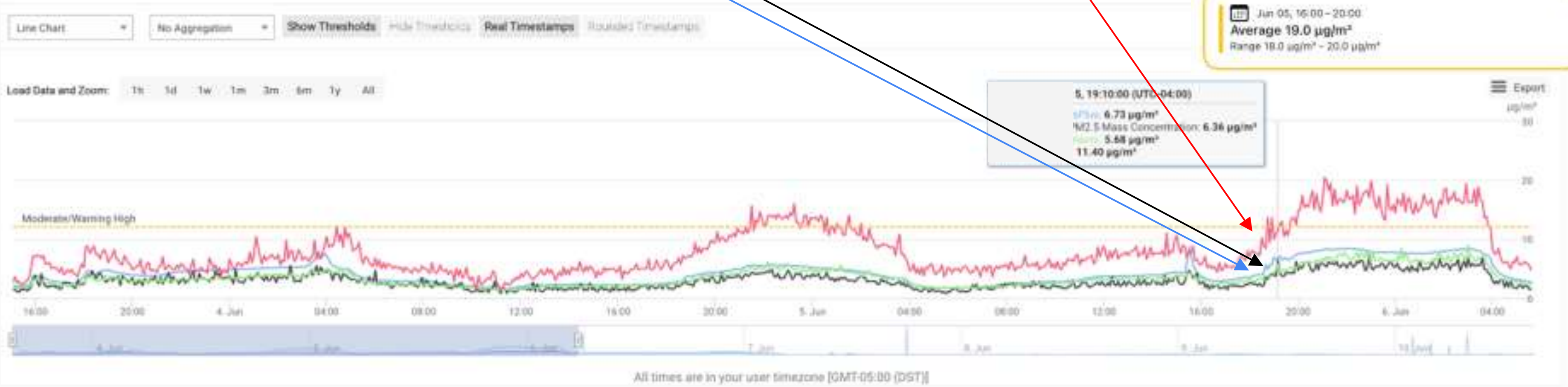
Hardware: Types of Sensor Data – PM

Not all sensors are created equal

$45 vs **$3** PM sensor

Sensor 1 & 2 and Reference Instruments are reading very similar values

Sensors 3 & 4 are reading completely different values



Hardware: Types of Sensor Data – PM

PM Sensors

Sensor Image	Make (Model)	Est. Cost (USD)	Pollutant(s)	*Field R^2	*Lab R^2	*Field MAE (µg/m³)	*Lab MAE (µg/m³)	Summary Report
	Device	$5,000	$PM_{2.5}$	0.66 to 0.81	0.99	2.9 to 5.1	3.0 to 13.3	PDF (723 KB)
	Device	$1,000	$PM_{1.0}$	0.68 to 0.70		2.4 to 2.5		
			$PM_{2.5}$	0.54 to 0.57		4.8 to 5.0		
			PM_{10}	0.03 to 0.05		19.7 to 19.8		
	Device	$300	$PM_{2.5}$	~ 0.0		9.5 to 17.8		
	Sensor	$100	$PM_{1.0}$	0.91	0.99	1.3 to 1.4	0.8 to 1.4	PDF (889 KB)
			$PM_{2.5}$	0.80 to 0.83	0.99	2.0 to 5.1	5.4 to 6.5	
			PM_{10}	0.07 to 0.20	-	10.8 to 24.7	-	

http://www.aqmd.gov/aq-spec/evaluations/criteria-pollutants/summary-pm

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Light Scattering
Most difference
between devices

Special Gases

Formaldehyde
Ozone
CO, NO2, SO2, etc.

A Few Thoughts

- **Sensors:** Use 1 Type of instrument for a study or for Indoor/Outdoor comparison
- **Sensor Accuracy:** Remember the trade offs you made during data collection when you analyze the data
- **Sensor Placement and Coverage:** Proper placement of sensors is crucial for accurate monitoring. Sensors should be placed at representative locations to capture a true picture of the indoor environment.
- **Environmental Factors:** Consider how temperature, humidity, and other environmental conditions might affect sensor readings. Some sensors may require specific conditions to function optimally.

Use Case

With Building Data,
you can’t manage what you don’t measure

Temperature and Humidity – HVAC Issues

Pre Thermostat Upgrade: HVAC running around the clock, including weekends

Post Thermostat Upgrade: HVAC turns off at night and weekends.
50% Energy Savings

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Temperature and Humidity – HVAC Failures

HVAC Failure leading to increased Temperature in **Server Rooms**

Saturday Night

kW Data for Comparison

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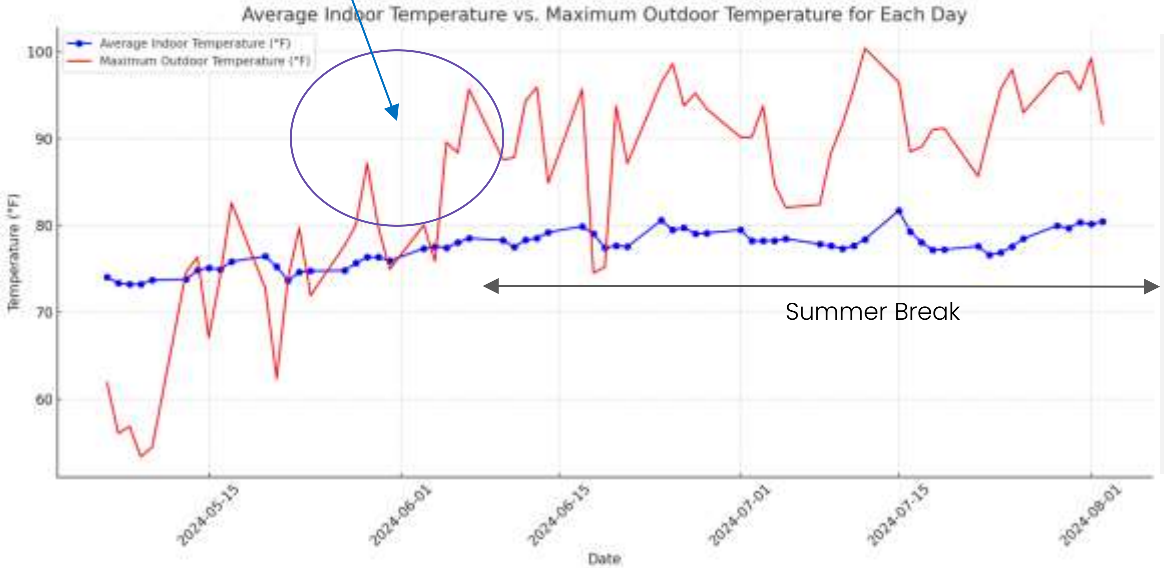
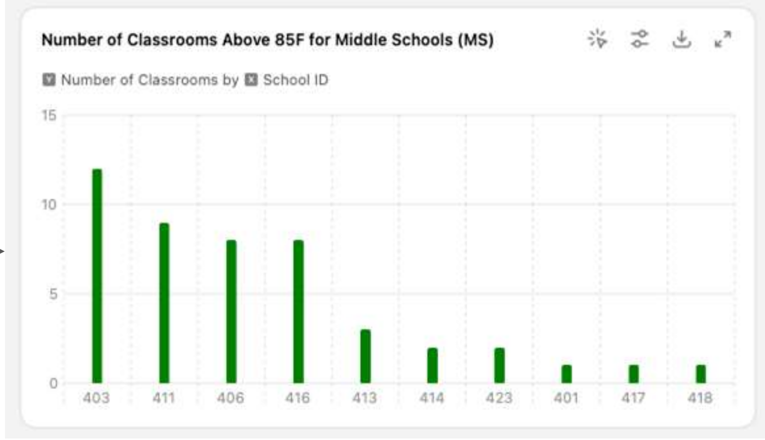
Temperature and Humidity – High Heat Days

High Heat Days



HVAC not able to keep up



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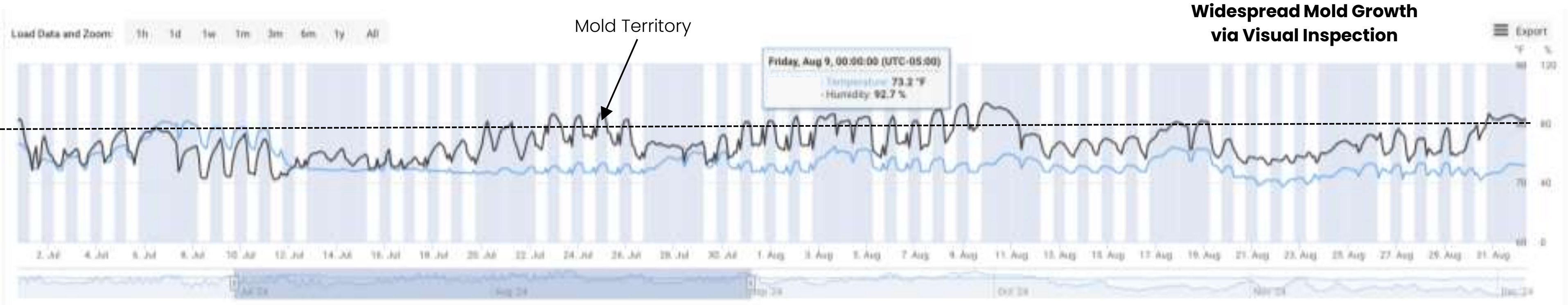
Temperature and Humidity – Mold Detection



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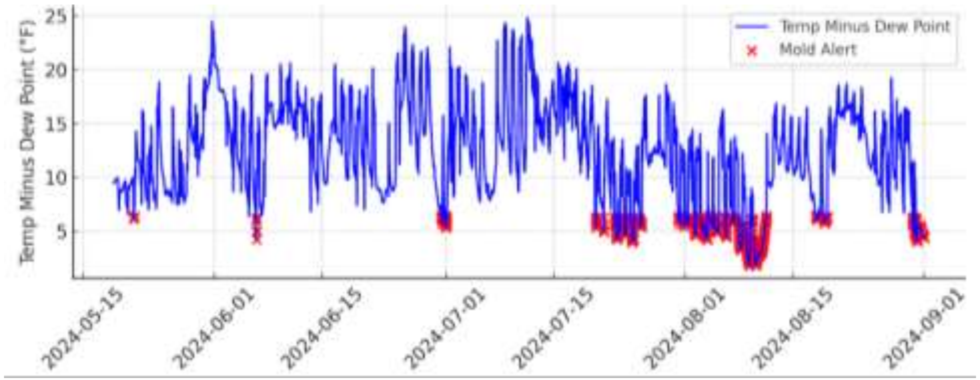
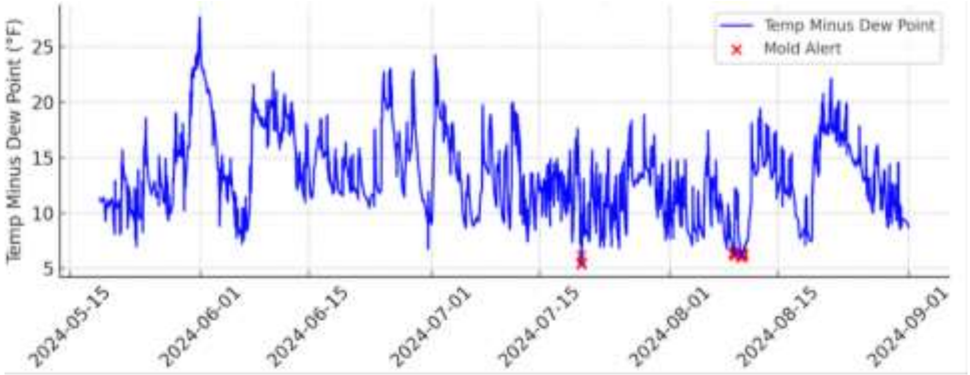


Widespread Mold Growth via Visual Inspection

$$RH_{crit} = \begin{cases} -0.0004578\,T_s^3 + 0.09333\,T_s^2 - 6.306\,T_s + 221.21 \\ \quad \text{when } T_s \le 68°\text{F}, \\ 80 \text{ when } T_s > 68°\text{F} \quad [T_s \text{ in } °\text{F}] \end{cases}$$



Small Localized Occurrences of Mold Growth via Visual Inspection

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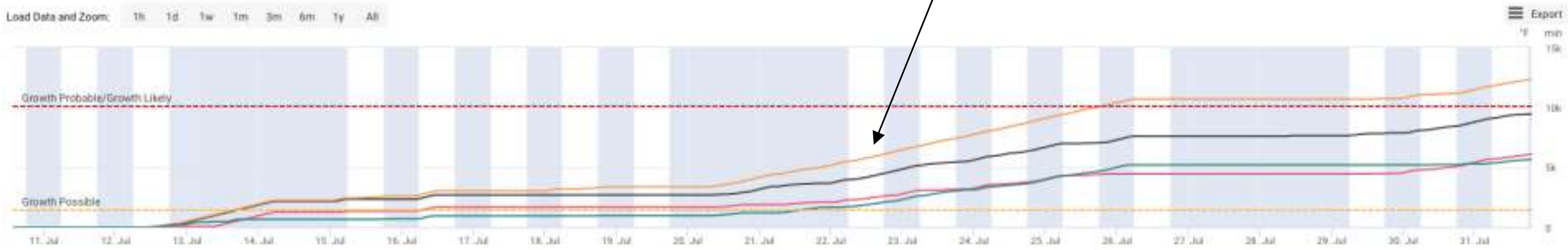
Temperature and Humidity – Mold Detection

Mold will start germinate as early as after 24 hours in the right conditions

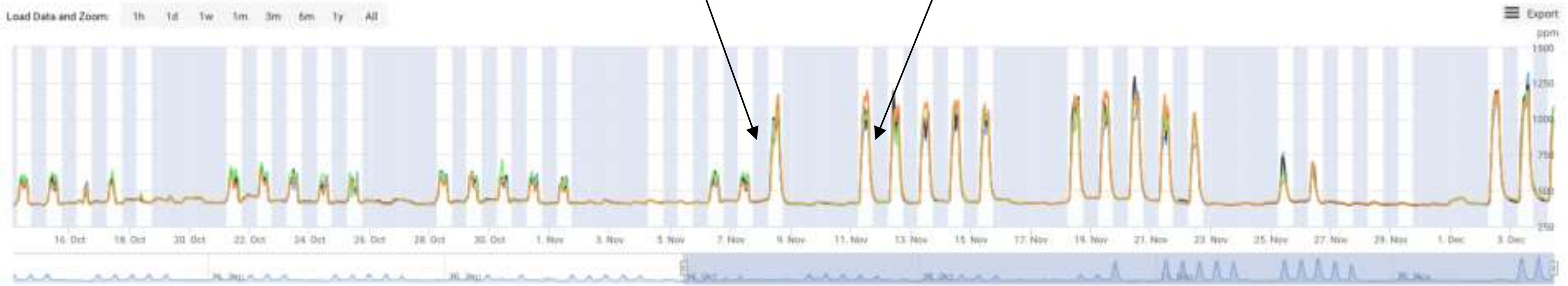
Amount of time under Mold Growth Conditions



Carbon Dioxide (CO_2) – Ventilation Levels

Change in Ventilation Settings?

CO_2 Levels in 4 different Classrooms



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Carbon Dioxide (CO_2) – Ventilation Rates

eACH:

- Data to be analyzed when there are no CO2 sources in the room
- Helpful to take into account natural ventilation, e.g. doors or window open

Calculations based on CO_2 in IAQ

$$ACH = 1/\Delta t \ln[(C1 - CR)/(C0 - CR)]$$

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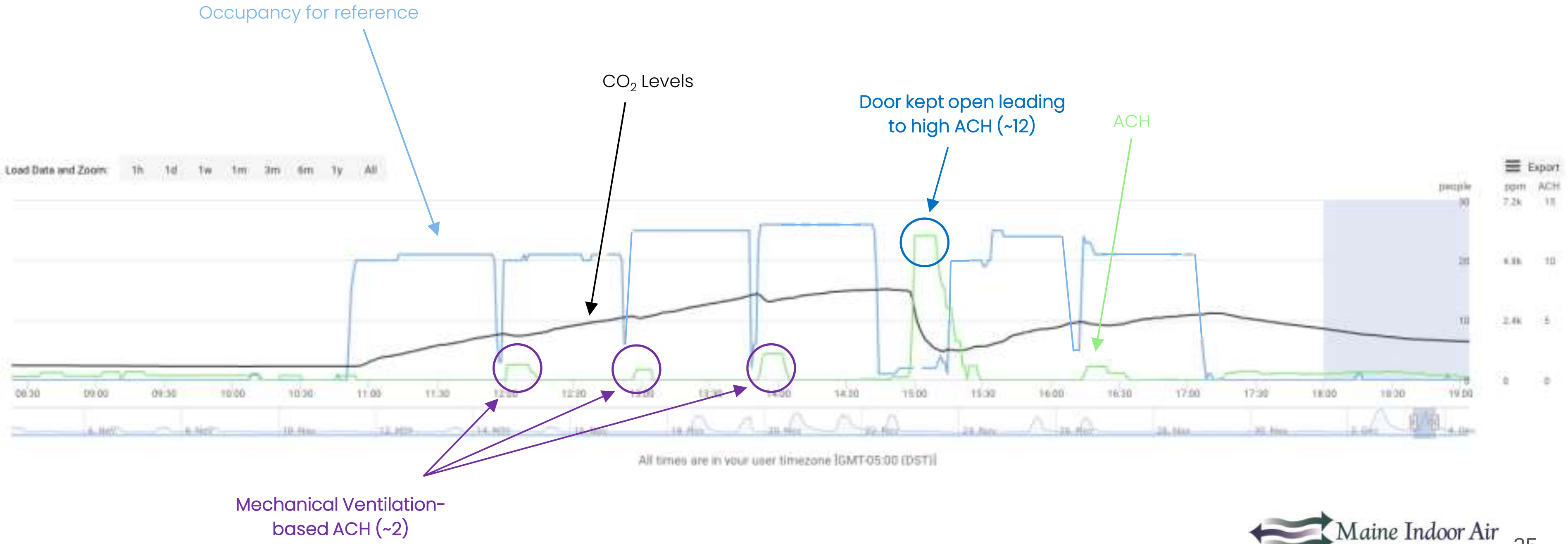
Carbon Dioxide (CO_2) – Ventilation Rates



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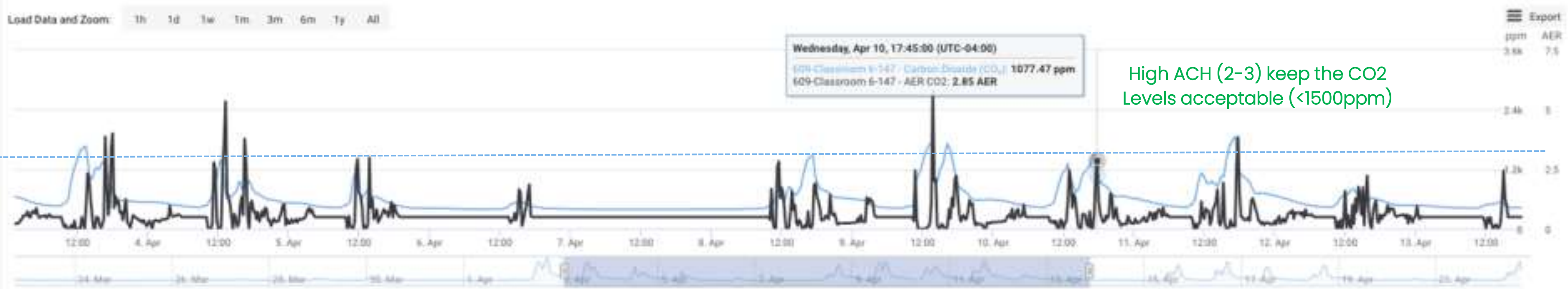

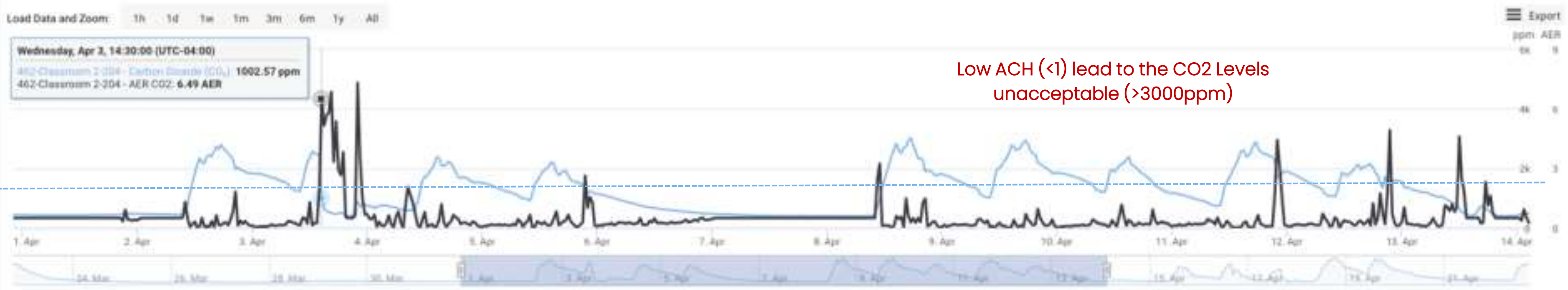

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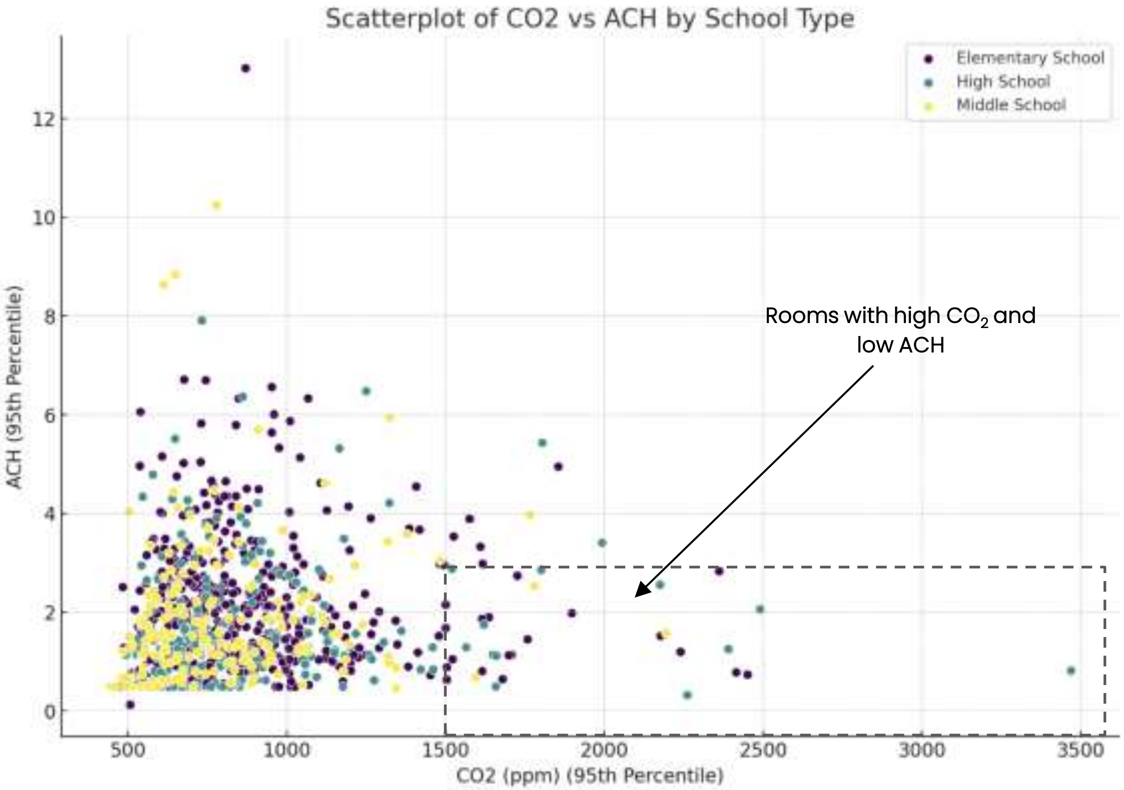
Carbon Dioxide (CO_2) – Ventilation Rates



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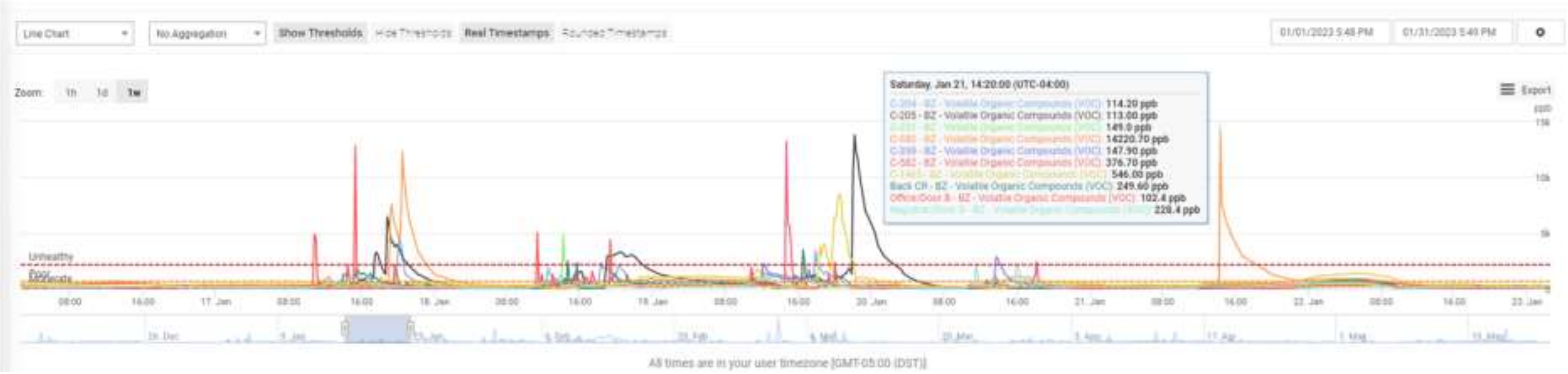
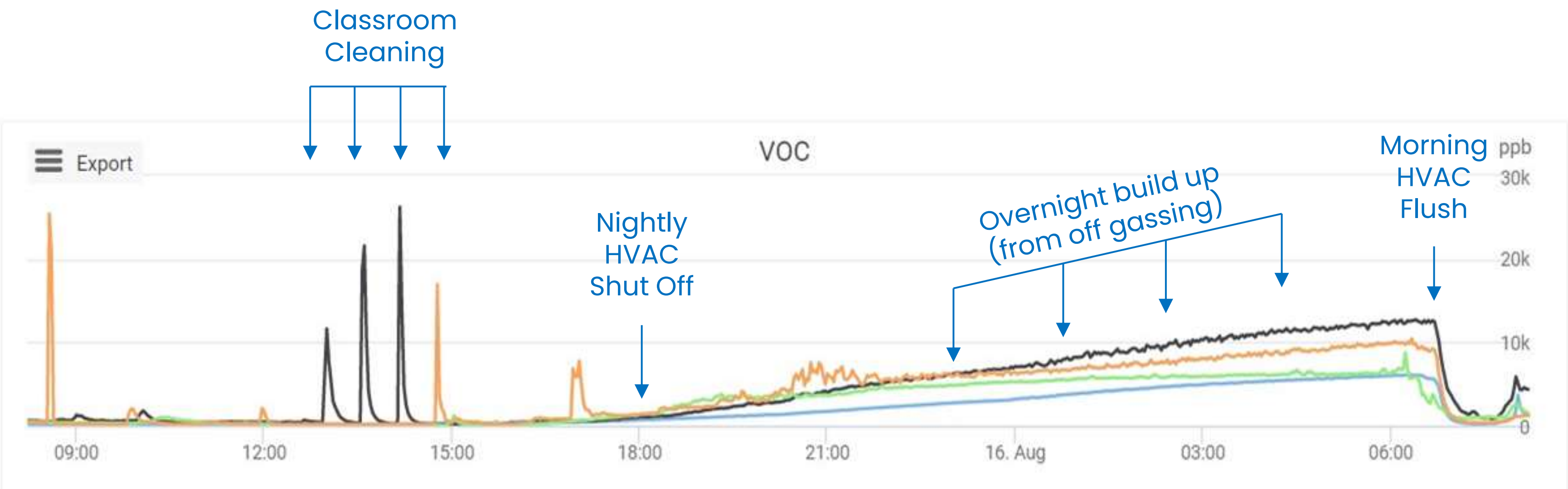
Total Volatile Organic Compounds (TVOC)

Continuously elevated levels of TVOC across multiple classrooms highlighted poor ventilation and over-use of cleaning products. This triggered a HVAC retrofit project to improve Ventilation, IAQ, Energy Efficiency, and Cleaning Protocols



Total Volatile Organic Compounds (TVOC) - Events



Total Volatile Organic Compounds (TVOC) - Events

Interpreting TVOC data can be challenging

Particulate Matter (PM) – Wild Fires

Office Building

Wildfire PM Impact

School

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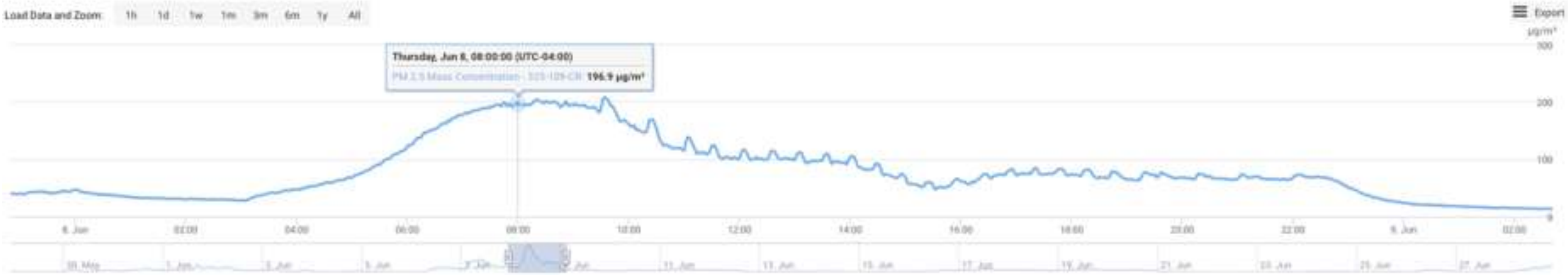
Particulate Matter (PM) – Wild Fires



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Particulate Matter (PM) – Wild Fires

Performance Results

PM2.5 data from the active monitoring system has been used to determine the effectiveness of filtration during the Canadian wildfire events in early June when PM2.5 concentrations were highest during operating hours.

Location	Outside Air PM2.5 Concentration	Supply Air PM 2.5 Concentration	PM2.5 Removal	Percent Below Recommended Limit
Boston Office Building	60.0 μg/m³	6.0 μg/m³	90%	50%
New York Office Building	35.0 μg/m³	3.0 μg/m³	92%	75%
Washington, D.C. Office Building	136.0 μg/m³	4.2 μg/m³	97%	65%

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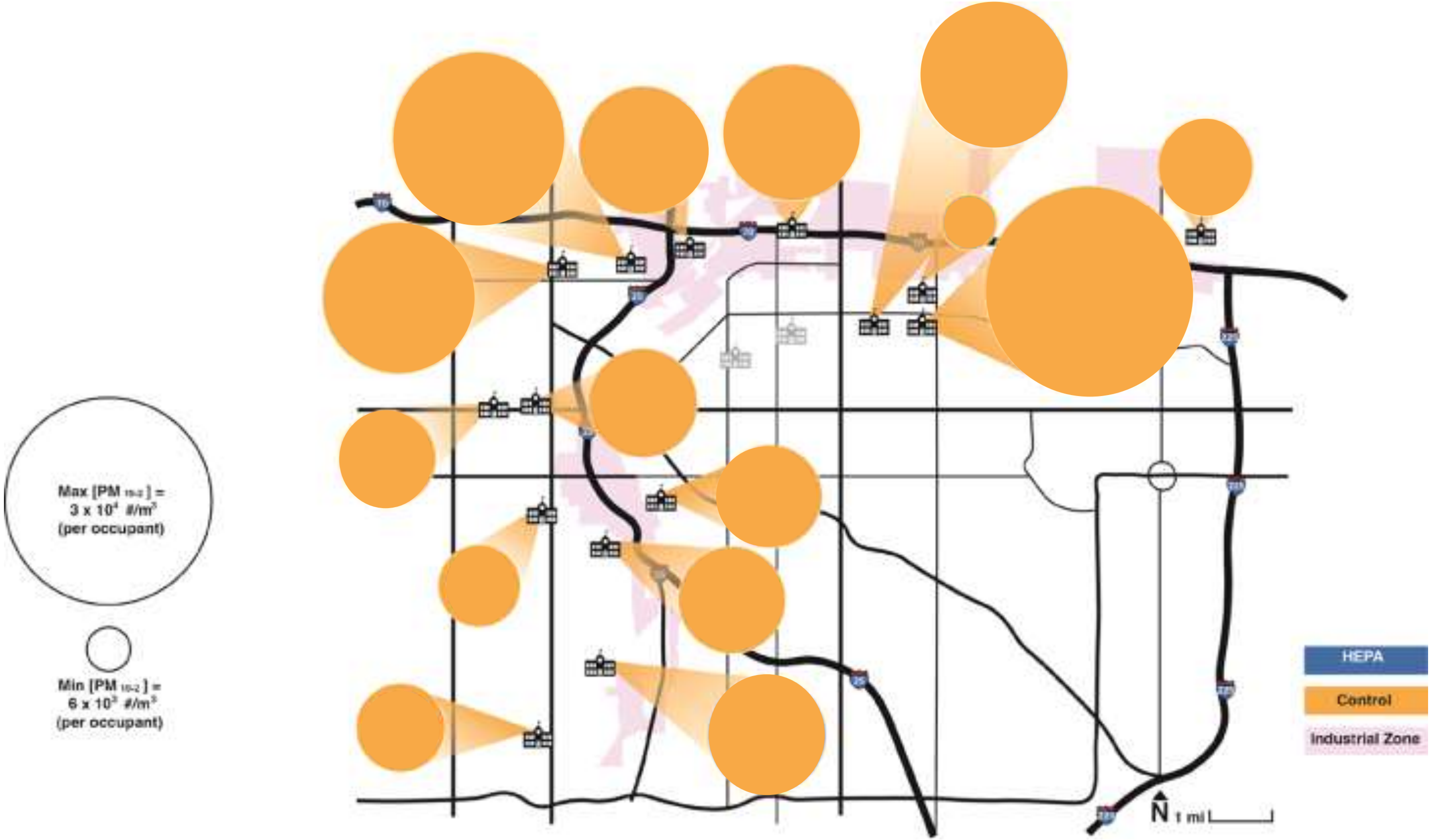
Particulate Matter (PM) – Pollution and HEPA Filters



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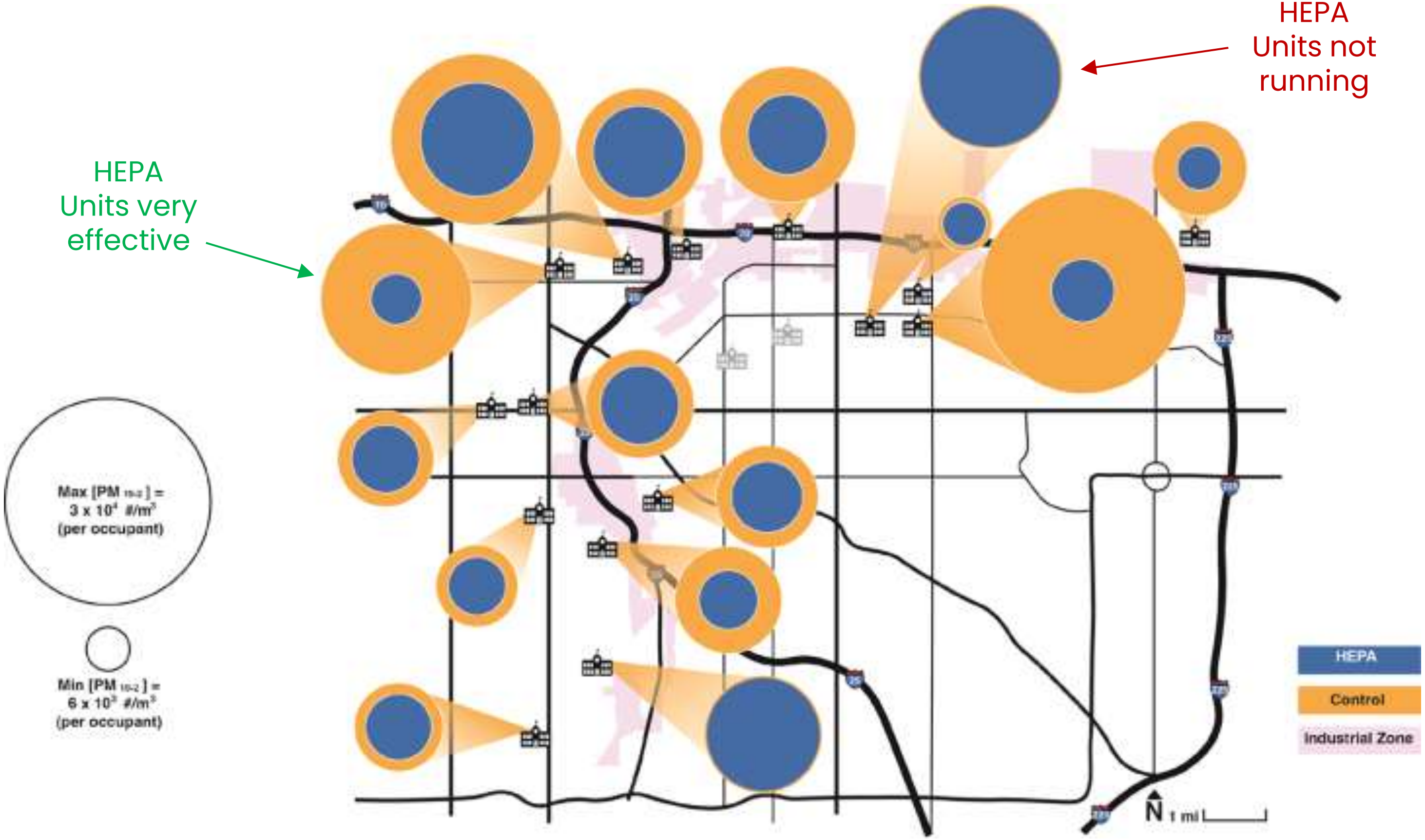
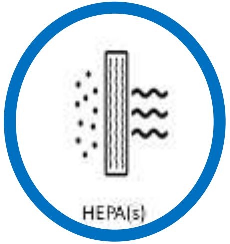
Particulate Matter (PM) – Pollution and HEPA Units





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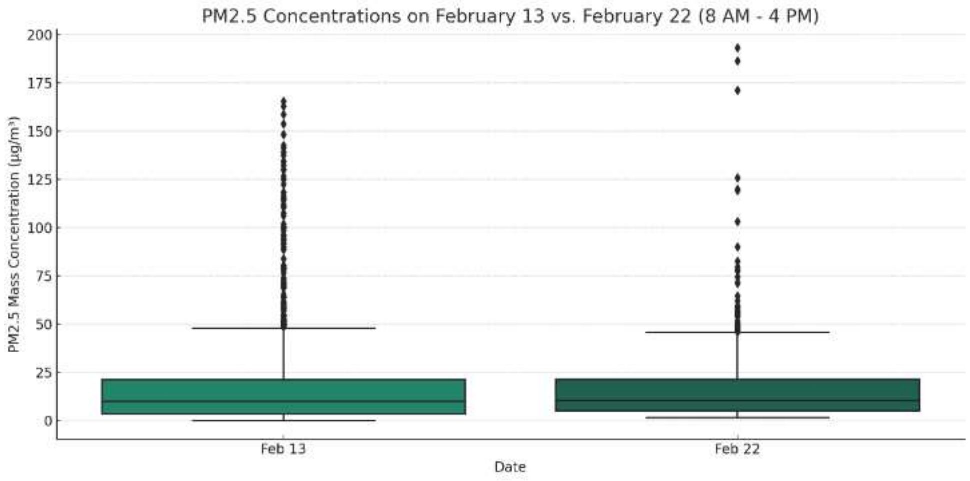
Particulate Matter (PM) – Construction



February 13 [construction] February 22 [no construction]

Parents worried construction near a school would impact Air Quality inside the school.

After data analysis, we were able to show that it was not the case, the 2 days are not significantly different

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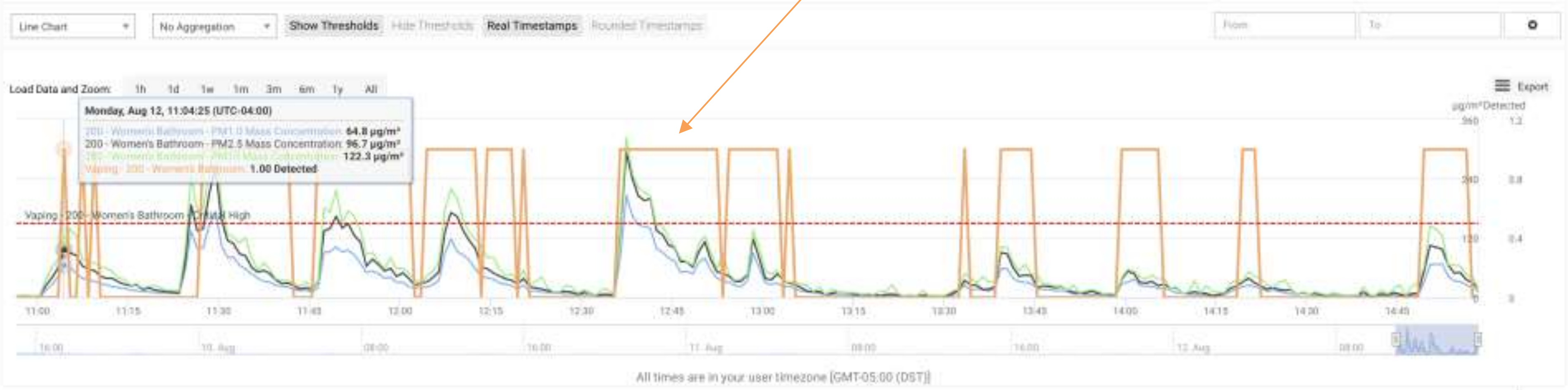
Particulate Matter (PM) – Vaping Detection

With accurate PM sensors, Vaping can be detected based on the distribution of particles size

Vaping



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Particulate Matter (PM) – Vaping Detection

Election Day

Amount of time (min) with Vaping detected per Bathroom

Veteran's Day

Activity: Source Identification

Setup

Sensor installed in a large well ventilated space

Sources applied right next to the sensor

Data collected every 10 seconds

Humidity, CO2, TVOC, and PM2.5 sensors

Possible Answers:
1. Vaping
2. Candle Burning
3. Deodorant Spray
4. Ozone Generator
5. Mouthwash Breath
6. Exhaled Breath
7. Febreze Spray
8. Coffee Smell

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Wrap Up

The future of Low Cost Sensors and IAQ Monitoring

Smallest PM Sensor

Machine Learning to detect specific VOCs

The future of Low Cost Sensors and IAQ Monitoring

what is the correlation between occupancy and co2 level for each range of enthalpy difference ?

To assess the correlation between occupancy and CO_2 levels for different ranges of enthalpy difference, I will divide the data into bins based on the enthalpy difference and compute the correlation for each range. Let's proceed.

Finished analyzing

Always expand output?

python

Copy code

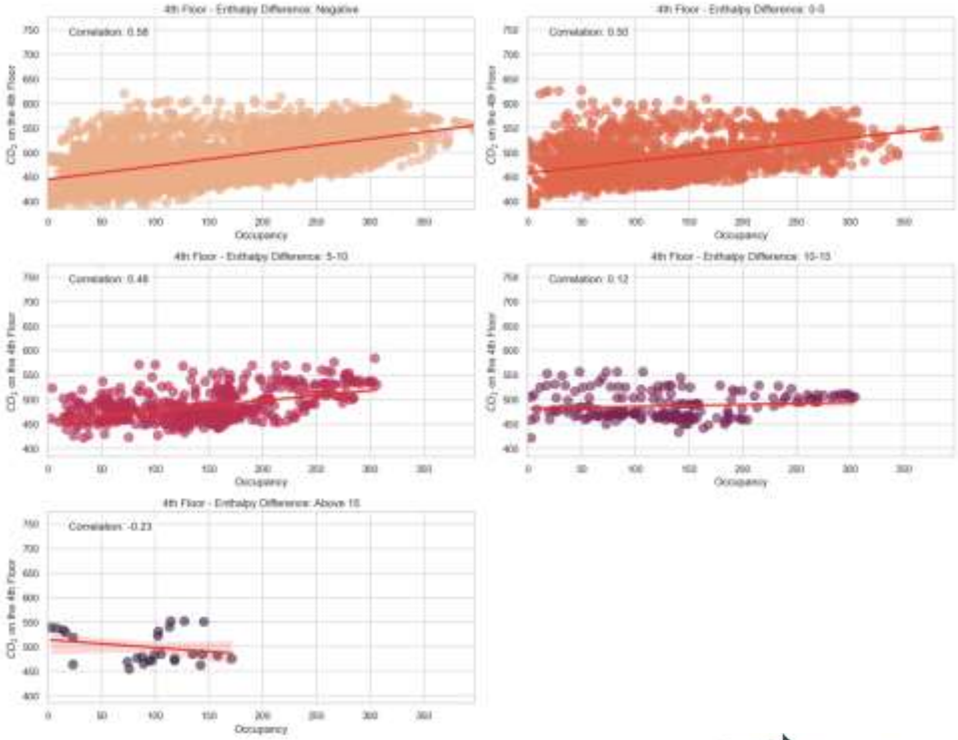
```python
# Binning the data based on the enthalpy difference
bin_labels = ['Very Low', 'Low', 'Moderate', 'High', 'Very High']
sorted_data['Enthalpy Difference Bin'] = pd.cut(sorted_data['Enthalpy Difference'], b

# Calculate the correlation between Occupancy and CO₂ levels for each enthalpy bin
correlation_results = sorted_data.groupby('Enthalpy Difference Bin').apply(lambda df:
correlation_results
```

Result

```
Enthalpy Difference Bin
Very Low      0.589797
Low           0.373188
Moderate      0.489576
High          0.282733
Very High    -0.482607
dtype: float64
```

Here's the correlation between occupancy and CO_2 levels on the 11th floor for each range of enthalpy difference:

- **Very Low Enthalpy Difference:** Positive cor tion of 0.59
- **Low Enthalpy Difference:** Positive correlation of 0.37



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Q&A

Julien Stamatakis - julien@attuneiot.com
Attune - info@attuneiot.com