Washington State Department of HEALTH

PM2.5 AND CO2 AIR MONITORING IN CHILD CARE FACILITIES USING LOW-COST SENSORS

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PM2.5 or Fine particulate matter

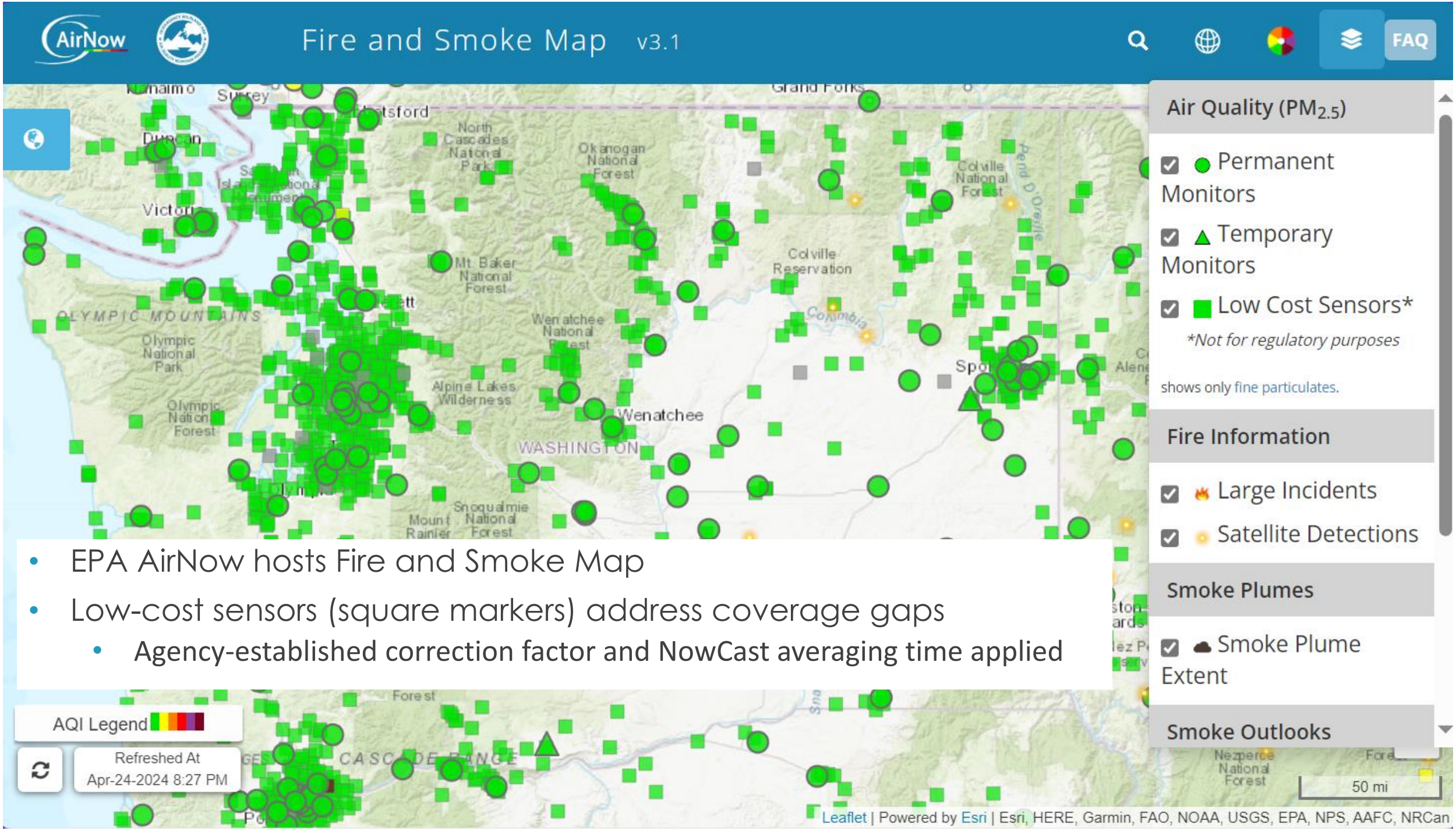
- Exposure to PM2.5 impacts lung, heart, and brain health
- Children are more vulnerable to health risks than adults
- Examples of indoor and outdoor sources of PM2.5 at a child care facility:

Air Quality Index

WA Air Quality Guide for Particle Pollution

Available in 12 languages on our [Smoke from Fires toolkit]

Air Quality Index	*What Should I Do?*
Good 0–50	It's a great day to be active outside and a good time to make a plan if worse air quality is in the forecast.
Moderate 51–100	Some people are especially sensitive to lower levels of particle pollution and should reduce exposure. For example, limit time outside and avoid strenuous outdoor activity. All sensitive groups should watch for symptoms.
Unhealthy for Sensitive Groups 101–150	Sensitive groups should take steps to reduce exposure. Limit time outside, avoid strenuous outdoor activity, and follow tips for cleaner indoor air. Everyone should watch for symptoms as a sign to reduce exposure.
Unhealthy 151–200	Everyone should reduce exposure. Limit time outside, avoid strenuous outdoor activity, and follow tips for cleaner indoor air.
Very Unhealthy 201–300	Everyone should reduce exposure. Stay inside and filter indoor air to keep it cleaner. Go elsewhere for cleaner air, if needed.
Hazardous >300	Everyone should reduce exposure. Stay inside and filter indoor air to keep it cleaner. Go elsewhere for cleaner air, if needed.



- EPA AirNow hosts Fire and Smoke Map
- Low-cost sensors (square markers) address coverage gaps
  - Agency-established correction factor and NowCast averaging time applied

What is a low-cost air sensor?

- Instrument that measures gases and/or particulate matter
- Cost ~$100 to $2000
- Usually designed for general public use
- Accuracy varies by air pollution source and sensor

Maintaining Adequately Low Indoor PM2.5 is Important to Health

- In addition to indoor sources, outdoor PM2.5 infiltrates indoors
- Depends on several factors and can vary across a facility:
  - Leakiness of building
  - Windows & doors
  - Outside PM2.5 concentrations
  - Access to filtration
- Most people spend ~90% of their time indoors

Image Source: pexels.com
Matthis Volquardsen

Image Source:
www.nationalofficetrailer.com

Washington Children and Youth Activities Guide for Air Quality

Unhealthy, Very Unhealthy, or Hazardous:
Cancel outdoor activity….
Limit to light intensity activities indoors if indoor PM2.5 levels are elevated.

Activity Duration	Good (0-50 AQI)	Moderate (51-100 AQI)	Unhealthy for Sensitive Groups (101-150 AQI)	Unhealthy, Very Unhealthy, or Hazardous (≥151 AQI)
15 mins to 1 hour (e.g., recess, PE, classes typically held outside)	No restrictions.	Allow children and youth with health conditions to opt out or stay indoors. Limit intensity of activities for these children and youth if needed.	Limit to moderate intensity activities outside. For children and youth with health conditions, further limit intensity or move to an area with safer air quality if needed.	Cancel outdoor activity or move to an area with safer air quality, either indoors with filtered air or to a different location. Limit to light intensity activities indoors if indoor PM2.5 levels are elevated.
1-4 hours (e.g., athletic events and practices)	No restrictions.	Allow children and youth with health conditions to opt out or stay indoors. Limit intensity of activities for these children & youth if needed.	Limit to light intensity activities or to a 1-hour total duration with moderate intensity activities. If intensity level and time cannot be modified, consider canceling outdoor activity or move to an area with safer air quality, either indoors or to a different location. For children & youth with health conditions, further limit time or intensity if needed.	Cancel outdoor activity or move to an area with safer air quality, either indoors with filtered air or to a different location. Limit to light intensity activities indoors if indoor PM2.5 levels are elevated.
> 4 hours (e.g., outdoor school or programming, day camp, overnight camp)	No restrictions.	Move children and youth with health conditions to an area with safer air quality, either indoors or to a different location if needed. Allow children and youth without health conditions to opt out or stay indoors and limit intensity of activities.	Limit to light intensity activities and under 4-hr total duration. If intensity level and time cannot be modified, cancel outdoor activity, or move it to an area with safer air quality, either indoors or to a different location. For children and youth with health conditions, further limit time or intensity if needed.	Cancel outdoor activity or move to an area with safer air quality, either indoors with filtered air or to a different location. Limit to light intensity activities indoors if indoor PM2.5 levels are elevated.

ADDITIONAL CONSIDERATIONS

Close windows and doors when activities are moved indoors. Pay attention to heat.

Indoor air filtration can reduce elevated levels of indoor PM2.5. *See Appendix C.* To measure indoor PM2.5 levels, *see Appendix B.*

Consider time spent in transit in activity duration.

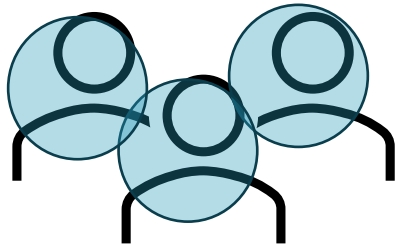
All children and youth 18 and younger are considered a sensitive group. Health conditions include but are not limited to asthma and other lung disease, heart disease, diabetes, and respiratory infection (e.g., RSV and pneumonia).

How PM2.5 measurements can help

- Identify areas of the facility that could use supplemental air filtration
- Get an idea of how well the building air filtration is working
  - Helpful to have both indoor and outdoor measurements
- Make decisions during periods of bad air quality, like wildfire smoke. For example:
  - Should we keep children indoors?
  - Should we keep windows and doors closed?
  - Is air quality bad even indoors? Should play be limited to lighter-intensity activities?

CO_2 (Carbon Dioxide)

- CO_2 indoors comes from people breathing
- If the amount of outdoor air coming inside is the same, but more people are present indoors, CO_2 levels will rise
- Without considering other ways besides ventilation to reduce the spread of airborne diseases, CO_2 levels can give you an idea of the potential for spreading airborne diseases
- Using other methods to reduce disease risk, like vaccination and masking, are still important even if ventilation is high



Goal to keep CO2 levels below 800 ppm

Washington State Department of Health

Ventilation and Air Quality for Reducing Transmission of Airborne Illnesses

Good ventilation and indoor air quality are important in reducing airborne exposure to viruses and other disease vectors, chemicals, and odors. Buildings vary in design, age, heating, ventilation, and air conditioning (HVAC) systems, and their ability to provide adequate ventilation and air filtration.

Because each building and its existing HVAC systems will be different, **consult a professional engineer or HVAC specialist to determine the best way to maximize the system's ventilation and air filtration capabilities for each specific room in the building**. For more detailed guidance, see the Clean Air in Buildings Challenge, EPA (PDF).

General Considerations

- Upgrade filters to MERV 13 if the system can handle the air resistance.
- Change filters as needed and at least every season. Clogged filters decrease HVAC operation, stress the fan motors, and decrease their ability to improve indoor air quality. Visually inspect filter condition and fit (no gaps) monthly.
- Reduce recirculation of indoor air, maximize outside air. Ensure outside air dampers function appropriately as part of scheduled maintenance.
- Aim for 5-6 air changes per hour.
- Monitor CO_2 levels with the goal of keeping levels below 800 ppm.
- Maintain humidity of 40 to 60 percent.
- Ventilate the building 1 hour before occupancy and 2 hours after custodial activities.
- Inspect and maintain local exhaust ventilation in restrooms, kitchens, cooking areas, and labs. Increase exhaust ventilation from restrooms above code minimums.
- Work with building engineer or HVAC specialist to generate air movement that goes from clean-to-less-clean air by positioning air supply and exhaust air dampers.

How CO_2 measurements can help

- Identify areas of the facility that could use more ventilation
- Increasing ventilation means bringing in more outside air
  - Open windows or doors and increase the movement of air inside the building by using fans and opening interior doors
  - Increase the amount of outside air coming in through the HVAC system
  - Balance with PM2.5 when outdoor air quality is bad

Sensor benefits and challenges

Benefits:

- More affordable
- Localized information
  - Outdoors at a facility
  - Indoors throughout a facility
- Immediate information

Challenges:

- Data quality issues
  - Accuracy
  - Maintenance
  - Siting
- Wifi or other connectivity issues
- Difficult to interpret short-term and immediate data
- Can be time consuming

Improving Sensor Guidance Project

Goal: Develop guidance about using low-cost PM2.5 and CO2 sensors to assess indoor and outdoor air quality in child care facilities

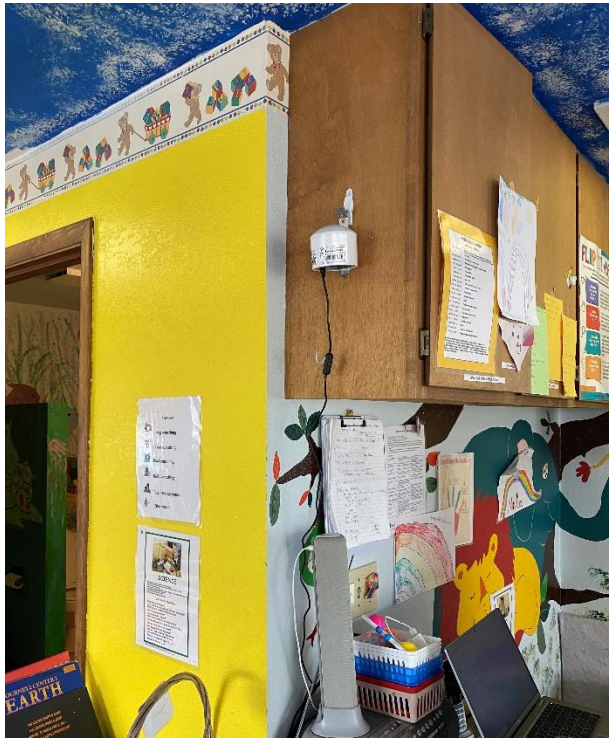
- WA Department of Health
- Tacoma-Pierce County Health Department
- Sampling from May 2022 to May 2023

Childcare Settings in this Project

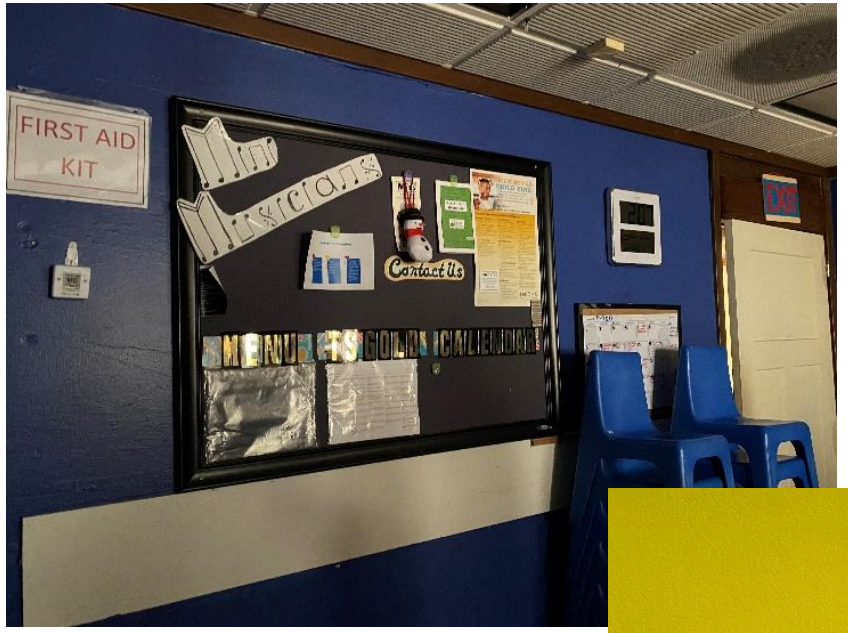
Characteristic	Facility 1	Facility 2	Facility 3	Facility 4
Size (square feet)	1500	7000	5000	8000
Floor plan	Open	Individual rooms	Open	Individual rooms
Ventilation system pulls in outside air	No	Yes	Yes	Only the large room pulls in outside air
Source of air pollution nearby	Bus garage, freeway, busy street	Freeway, busy street, construction, residential BBQ	Busy street	No major pollution source nearby
Captured a period of wildfire smoke	Yes	Yes	No	No

Project Sensors & Siting

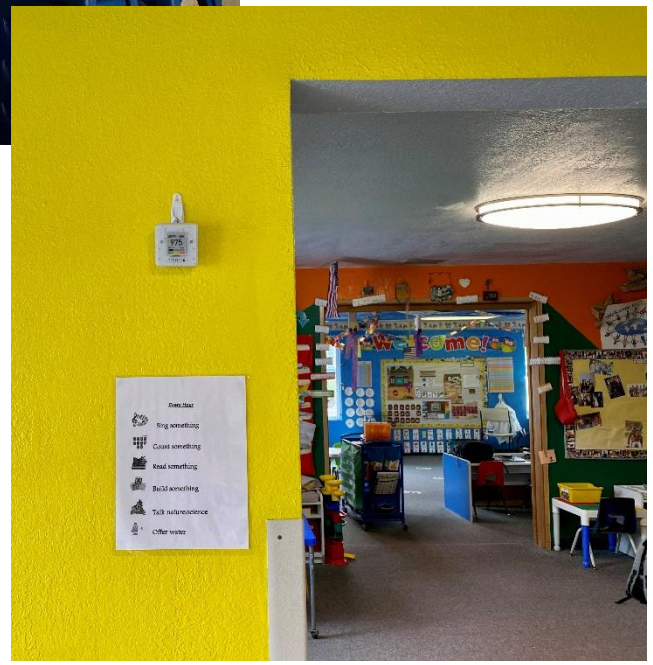
- Air sensor placement:
  - Goal to capture air representative of what occupants were breathing
  - Out of the way



Purple Air PM2.5 sensors



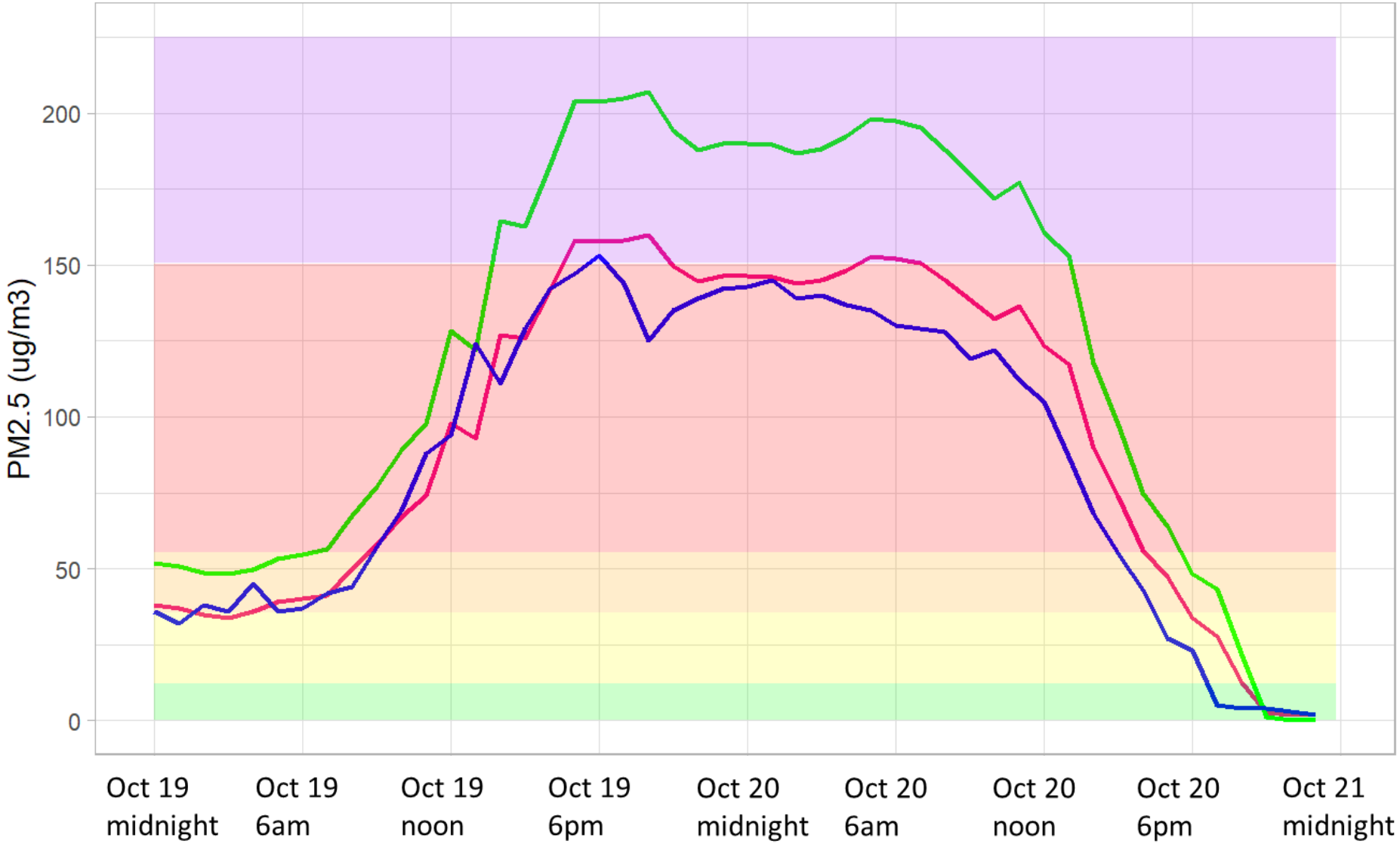
Aranet CO2 sensors



Handheld sensor: TemTop

Sensor data needs to be corrected

PM2.5 air quality during the two worst wildfire smoke days in Tacoma of 2022: October 19th and 20th
Corrected and uncorrected Purple Air data compared with regulatory monitor data



Regulatory monitor

Sensor with correction factor

Sensor without correction factor

There can be big differences between corrected and uncorrected low-cost sensor data

Average PM2.5 concentrations

During non-wildfire smoke periods, average hourly PM2.5 concentrations during facility open hours were 4-7 µg/m^3 indoors and 5-9 µg/m^3 outdoors.

Median hourly PM2.5 concentration indoor/outdoor ratios were 0.7-1.1.

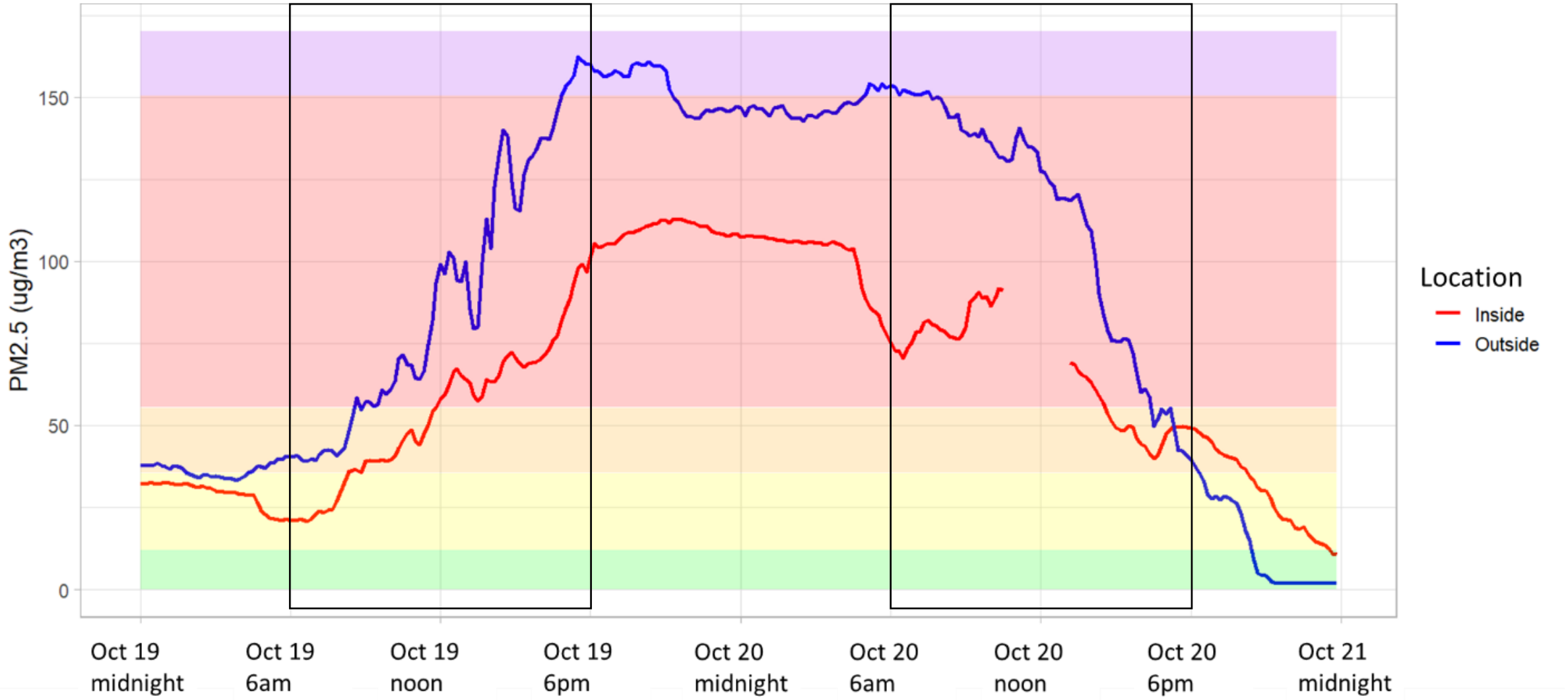
Average hourly PM2.5 concentrations during facility open hours during wildfire smoke:

	Facility 1		Facility 2	
	Mean (SD)	Median (IQR)	Mean (SD)	Median (IQR)
Indoor PM2.5 (µg/m^3)	11 (7)	9 (5,17)	48 (25)	47 (27,67)
Outdoor PM2.5 (µg/m^3)	80 (46)	71 (34,129)	81 (46)	72 (41,126)

Median hourly indoor/outdoor ratio was 0.1 in Facility 1 and 0.7 in Facility 2.

Air quality can change substantially over the course of a child care day

10-minute PM2.5 air quality during the two worst wildfire smoke days of 2022 in Tacoma

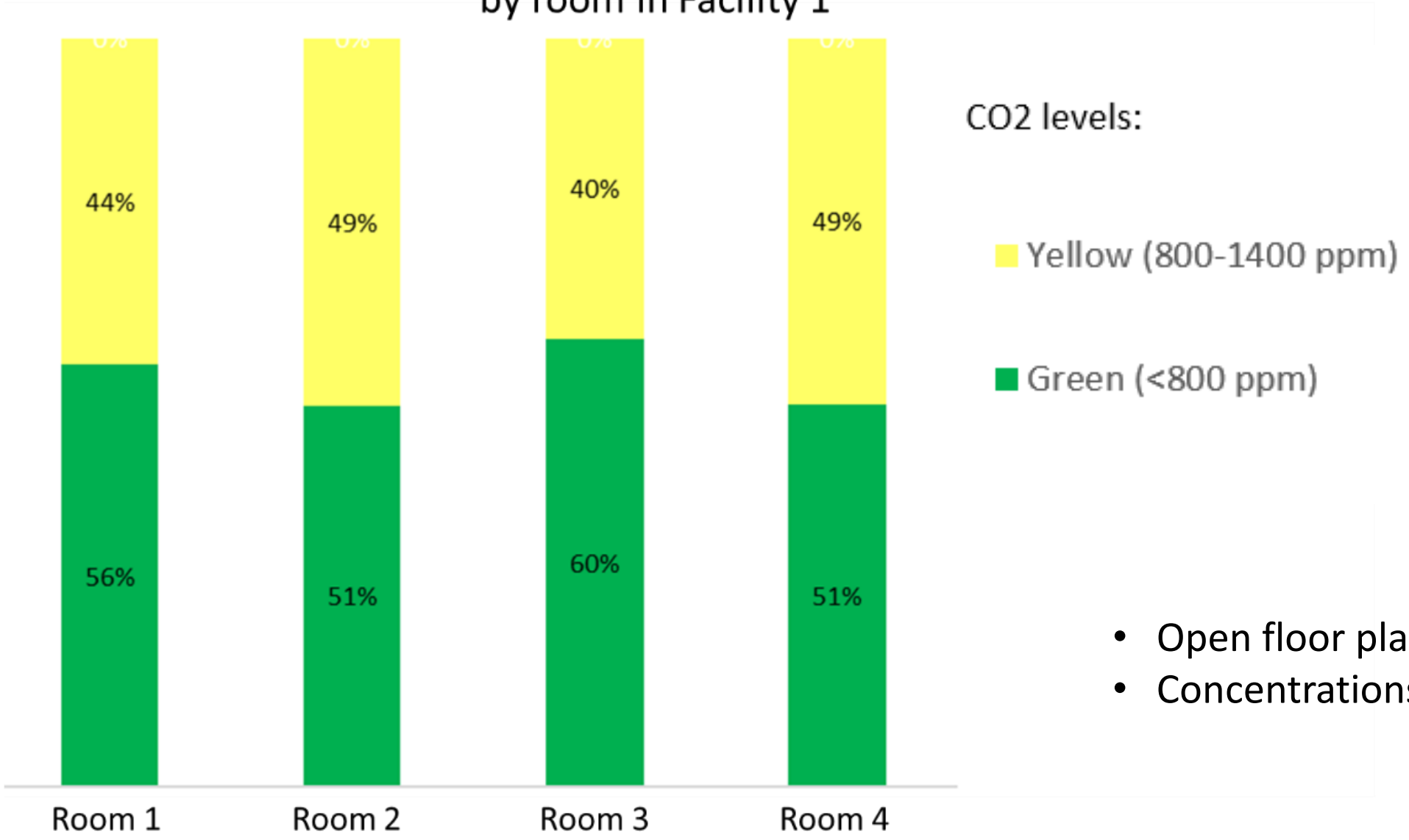


Average CO2 concentrations

- Multiple Aranet sensors per facility
- Base stations very difficult to use without IT support
- Aranet sensors hold 1-week of data
- Wide range of mean concentrations across facilities
- Mean concentrations slightly higher during colder weeks

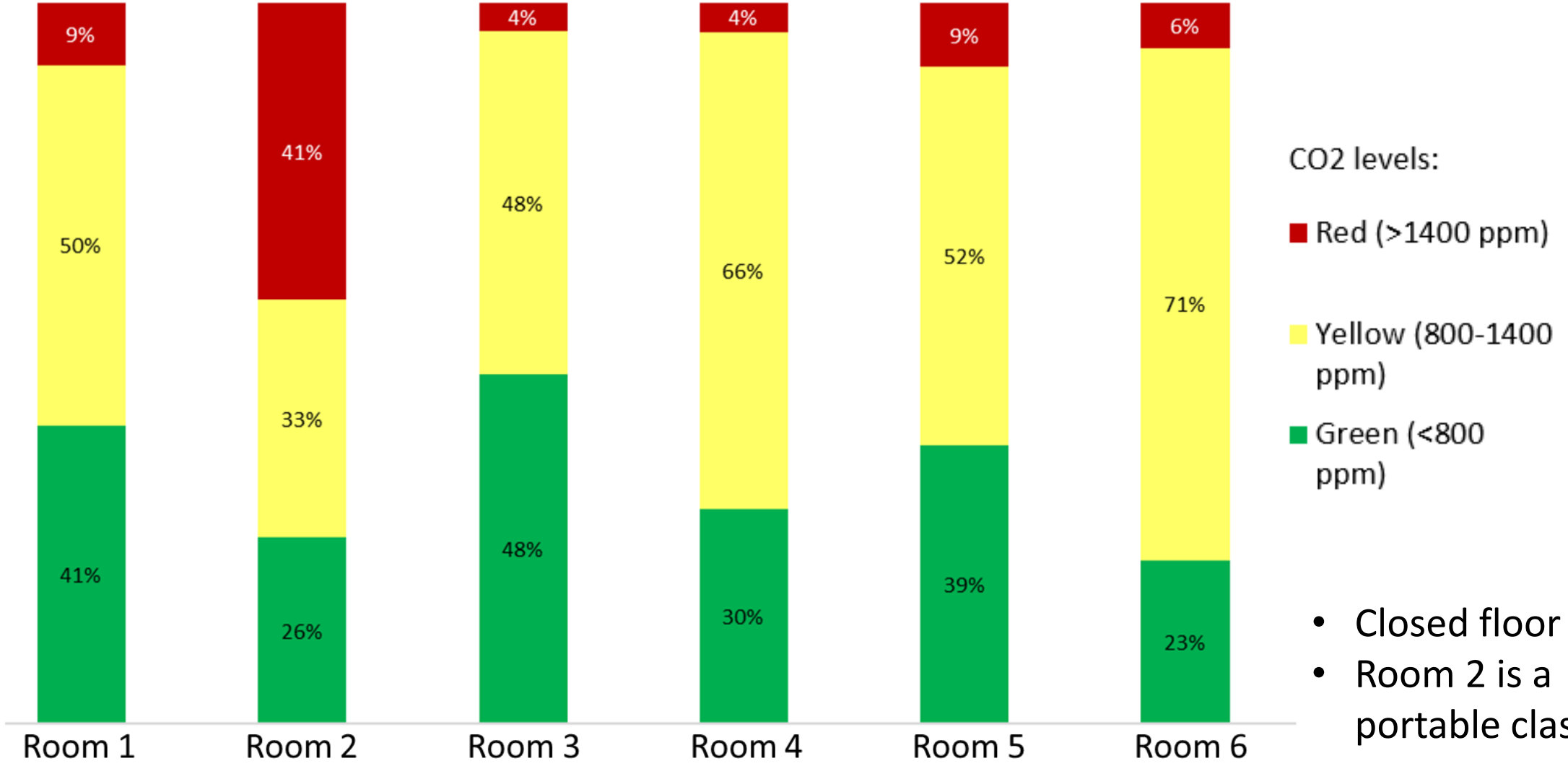
	Facility 1 Mean (Range)	Facility 2 Mean (Range)	Facility 3 Mean (Range)	Facility 4 Mean (Range)
Warmer week CO2 (ppm)	766 (750,785)	922 (788,1248)	1561 (1372,1750)	949.3 (485,1209)
Colder week CO2 (ppm)	810 (788,832)	1041 (838,1279)	2023 (1823,2223)	N/A

Percent of time that 10-minute CO2 concentrations were in different categories by room in Facility 1

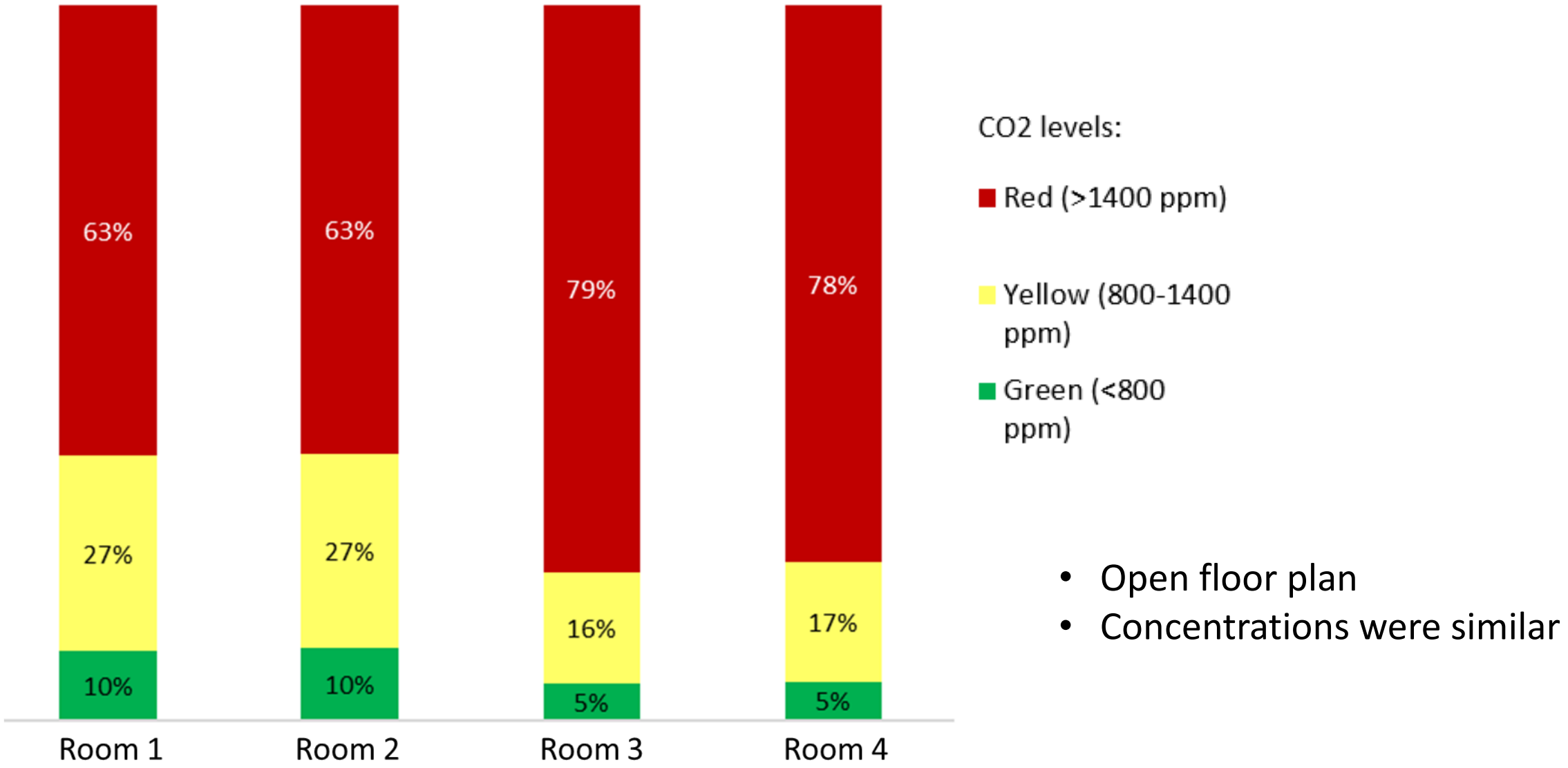


- Open floor plan
- Concentrations were similar

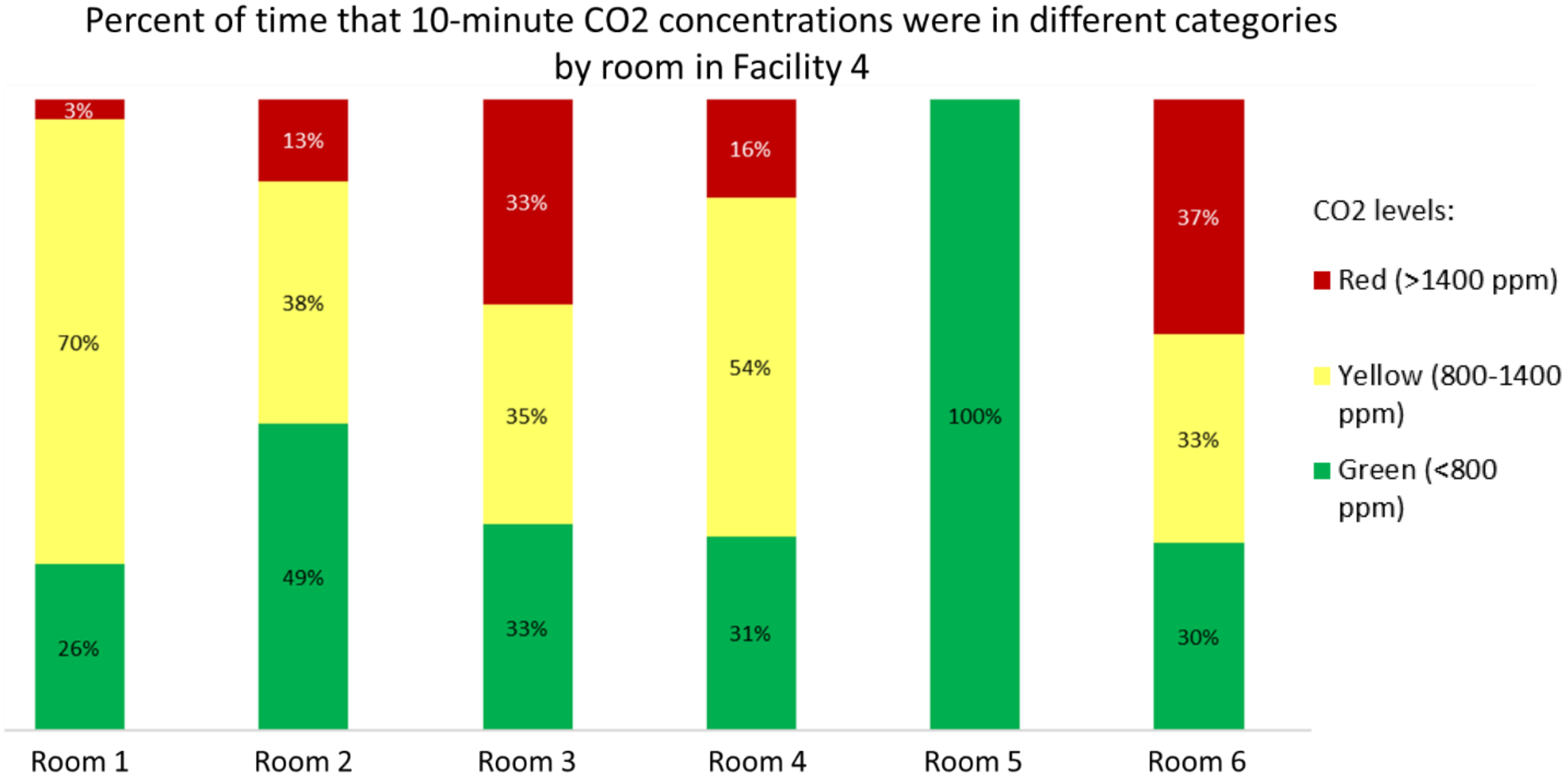
Percent of time that 10-minute CO2 concentrations were in different categories by room in Facility 2



- Closed floor plan
- Room 2 is a portable classroom

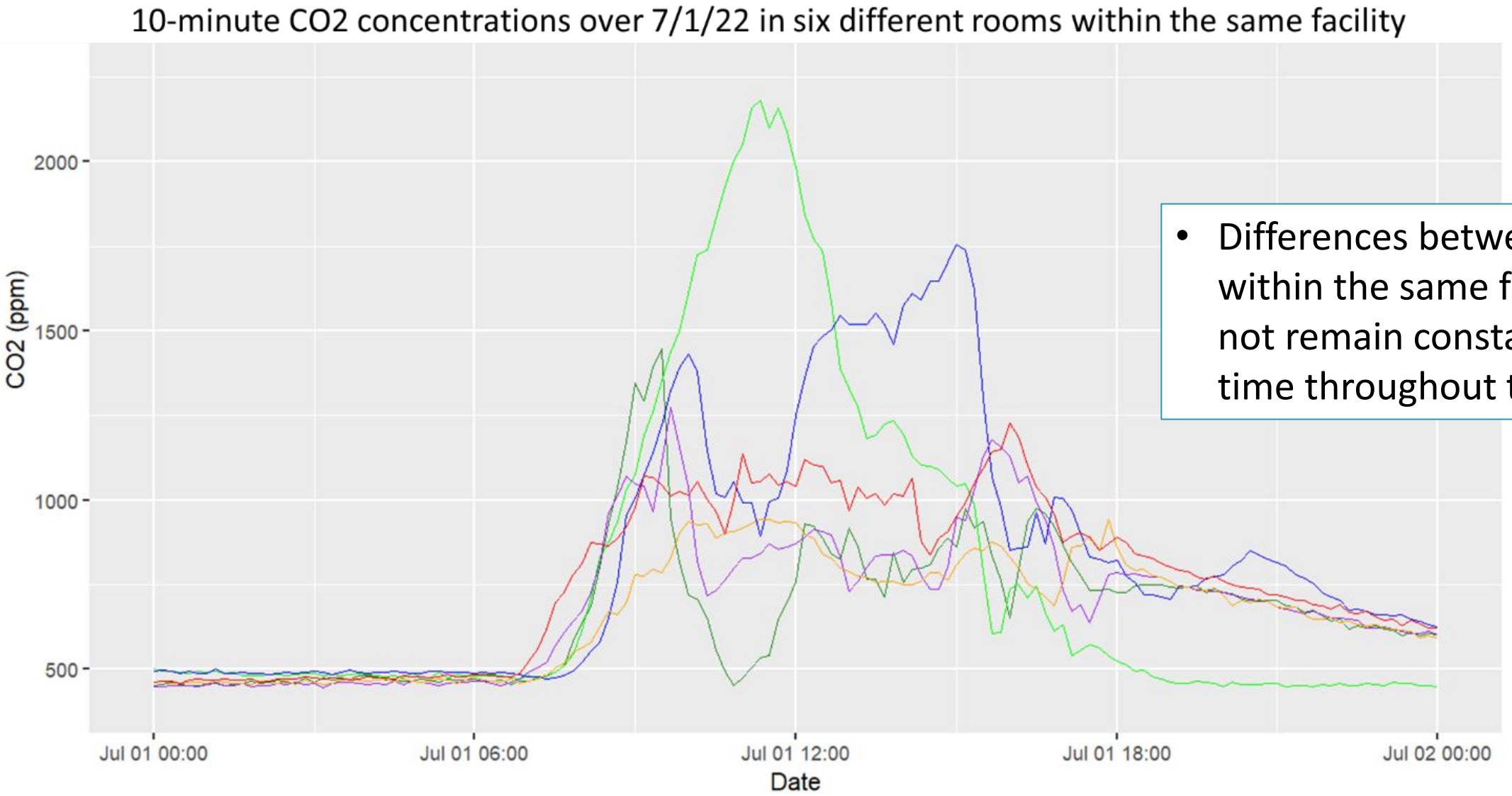


- Open floor plan
- Concentrations were similar



- Closed floor plan
- Room 1 often had windows open
- Room 5 is a large room and the only room pulling in outside air through HVAC

CO2 concentrations varied substantially over the course of each day, throughout facility open hours



- Differences between rooms within the same facility did not remain constant over time throughout the day

Main takeaways from PM2.5 and CO2 monitoring

- Wide range of air quality conditions → facility specific measurements
- Range in CO2 concentrations within facility → room specific measurements
- Air quality can change a lot over the course of a day → check short-term measurements when making decisions about activities happening soon and opening and closing windows and doors
- Indoor/outdoor comparisons of PM2.5 differ between wildfire smoke and non-wildfire smoke periods → wildfire smoke measurements

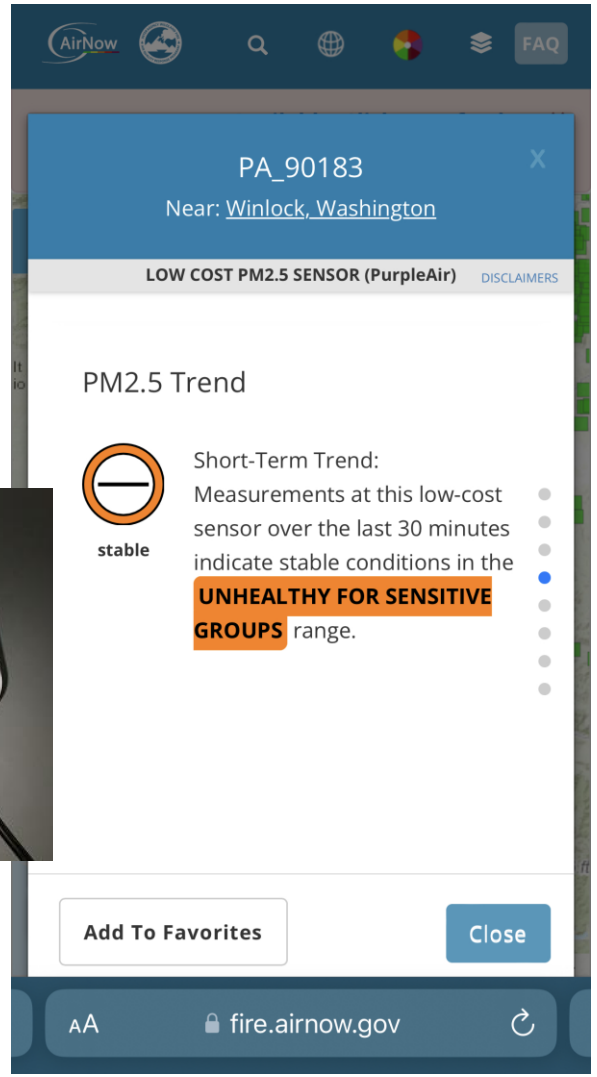
Main Lessons Learned

- Difficulty keeping sensors connected
  - Use an out of the way outlet
  - IT support needed for more complex internet connections
- Protocol difficult to use
  - Create a quick reference guide
- It is helpful to have a handout for child care staff describing the sensors and how to view the data
- It is challenging for outside agency staff to collect handheld sensor measurements from facilities because of the time required to collect measurements
  - Handheld sensor measurements may be more useful for immediate decision-making for use by child care and school staff
- Suggested actions resulting from data more helpful if very specific
- Challenge: lack of indoor standards for PM2.5 and CO2

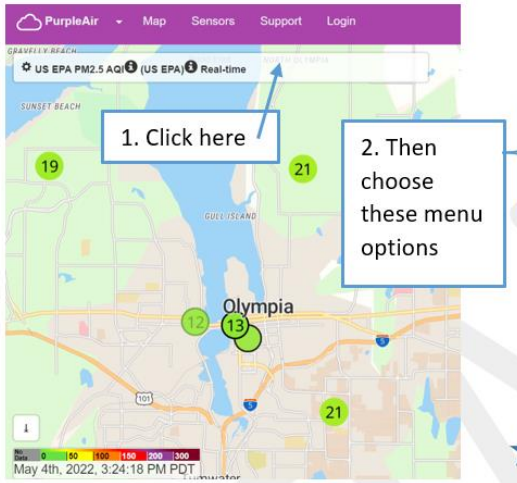
Summary of Sensor Guidance – will continue to evolve!

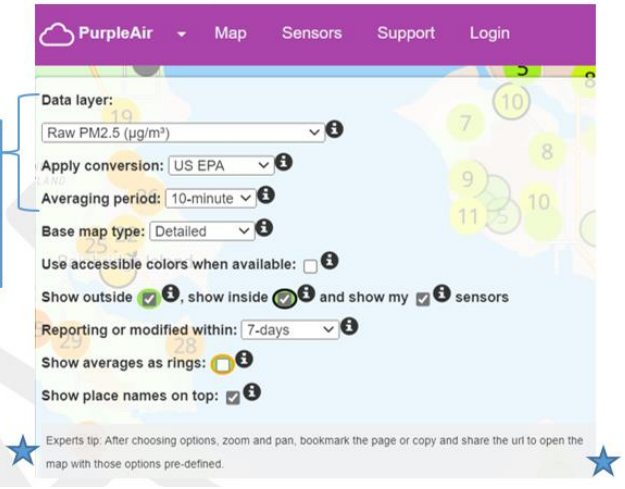
- Benefits and challenges of different monitoring strategies
- Siting sensors indoors and outdoors
- Improve general understanding of air quality
  - Daily (6-hr) stationary indoor and outdoor PM2.5 measurements each day for a week. Repeat each season & daily during poor outside air quality events
- Inform decisions during periods of poor outside air quality
  - Collect measurements throughout the facility with a handheld sensor
    - Immediate decision-making about activities (i.e. location, activity intensity or duration)
    - Is there something happening in this room/area right now that should be changed?
  - Assess PM2.5 measurements at decision points throughout the day
  - Interpret PM2.5 levels with WA Children and Youth Activities Guide for Air Quality
- Check ventilation needs
  - Assess CO2 measurements throughout the day

Examples of immediate information

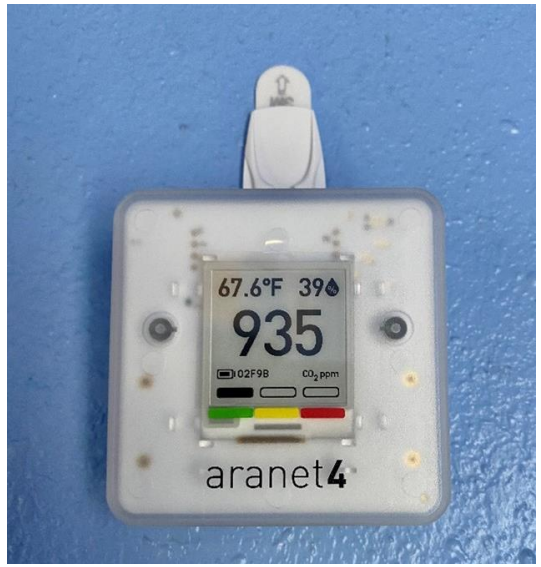


"Trend" (~30-minute) AQI category from Purple Air sensors displayed on the EPA Fire and Smoke map





10-minute data on Purple Air map with EPA correction factor applied



Sensor with a near real-time display

Handheld sensor with a near real-time display

Washington Children and Youth Activities Guide for Air Quality

Please view the guide appendices

Appendix A: Outdoor Air Quality Monitoring for Decision Making During Wildfire Smoke Events

Wildfire smoke can fluctuate throughout the day, or it can linger and be stable. It is c
makes it challenging to plan activities in advance. Forecasts and current measureme
making around canceling, modifying, delaying, or ending activities early. For longer
measurements throughout the day. When decisions need to be made several hours
conditions at the time of the activity.

The Washington Smoke Blog (https://wasmoke.blogspot.com) is the best source of outdoor air quality information when making decisions about outdoor activities when there is wildfire smoke. Use a combination of forecasts and current measurements from agency monitors and/or outdoor low-cost air sensors, as described below. Your regional clean air agency may have additional information for your area.

For activities planned in advance, use forecasts for your area or in the area the activity is occurring. Forecasts up to 5 days in advance, including the current day, are available on the WA Smoke Blog map by regions. The forecasts for the first 2 days are more accurate than for days 3-5. Written blog posts and comments

Appendix B: Indoor Air Quality Monitoring

A portable handheld sensor can show how indoor PM2.5 levels vary throughout a facility. A stationary indoor sensor can track changes in indoor air quality over longer periods. See Wildfire Smoke Guidance for Canceling Events or Activities and Closing Schools section "Indoor PM2.5 Measurement in Schools" for more information about using indoor sensor data for decisions that need to be made in advance. Use the information below for immediate decision-making.

If you don't have an indoor air sensor:

If you're not sure whether indoor PM2.5 levels are lower than outside, assume levels are similar and increase steps to reduce exposure, including filtration methods. Using a low-cost sensor can give you a better idea of your indoor PM2.5 levels. If you're considering purchasing a low-cost PM2.5 sensor, check the performance evaluations developed by the South Coast AQMD. A Field R-squared value near 1 and a relatively low Field MAE indicate a better-performing sensor.

If you do have an indoor air sensor and/or a portable handheld sensor:

Low-cost sensors can be used to take PM2.5 measurements to check indoor air quality. They are generally less accurate than agency air monitors, though correction factors can be applied to reduce bias. Sensor measurements can vary in three important ways: whether correction factors are applied (for example, a Purple Air that is used indoors with the US EPA correction factor applied), the time interval used for data averaging, and whether the sensor displays the AQI or the PM2.5 concentration in µg/m3 units. To the extent possible, only compare data that is similar in these three ways (e.g., do not compare uncorrected sensor data to corrected sensor data or AQI breakpoints; do not compare real-time sensor data to longer-term averages). EPA provides a calculator to convert between PM2.5 concentrations and AQI values: https://www.airnow.gov/aqi/aqi-calculator.

Thank you

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Thank you to the child care facility staff!!

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This project was supported by cooperative agreement EH20-2005 funded by the Centers for Disease Control and Prevention.