Testing a commercially available air cleaner's efficacy of removing $PM_{2.5}$

2022 REU Symposium

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Introduction

- Increasing amounts of wildfires.

In 2021, 8,619 wildfires burned almost 2.6 million acres.

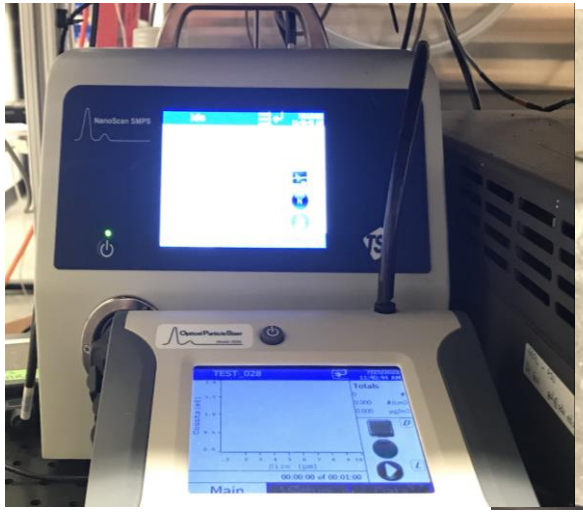
- Particulate matter

$PM_{2.5}$: particulate matter with a diameter of 2.5 micrometers or less. $PM_{2.5}$ can go deep into human lungs and even bloodstream.

- Indoor air cleaning technologies have been proved to be a strong tool to reduce exposure to particulate matter.

Reference: Xu R, Yu P, Abramson MJ, Johnston FH, Samet JM, Bell ML, Haines A, Ebi KL, Li S, Guo Y. Wildfires, Global Climate Change, and Human Health. N Engl J Med. 2020 Nov 26;383(22):2173-2181. doi: 10.1056/NEJMsr2028985. Epub 2020 Oct 9. PMID: 33034960.

Method




Two aerosols:

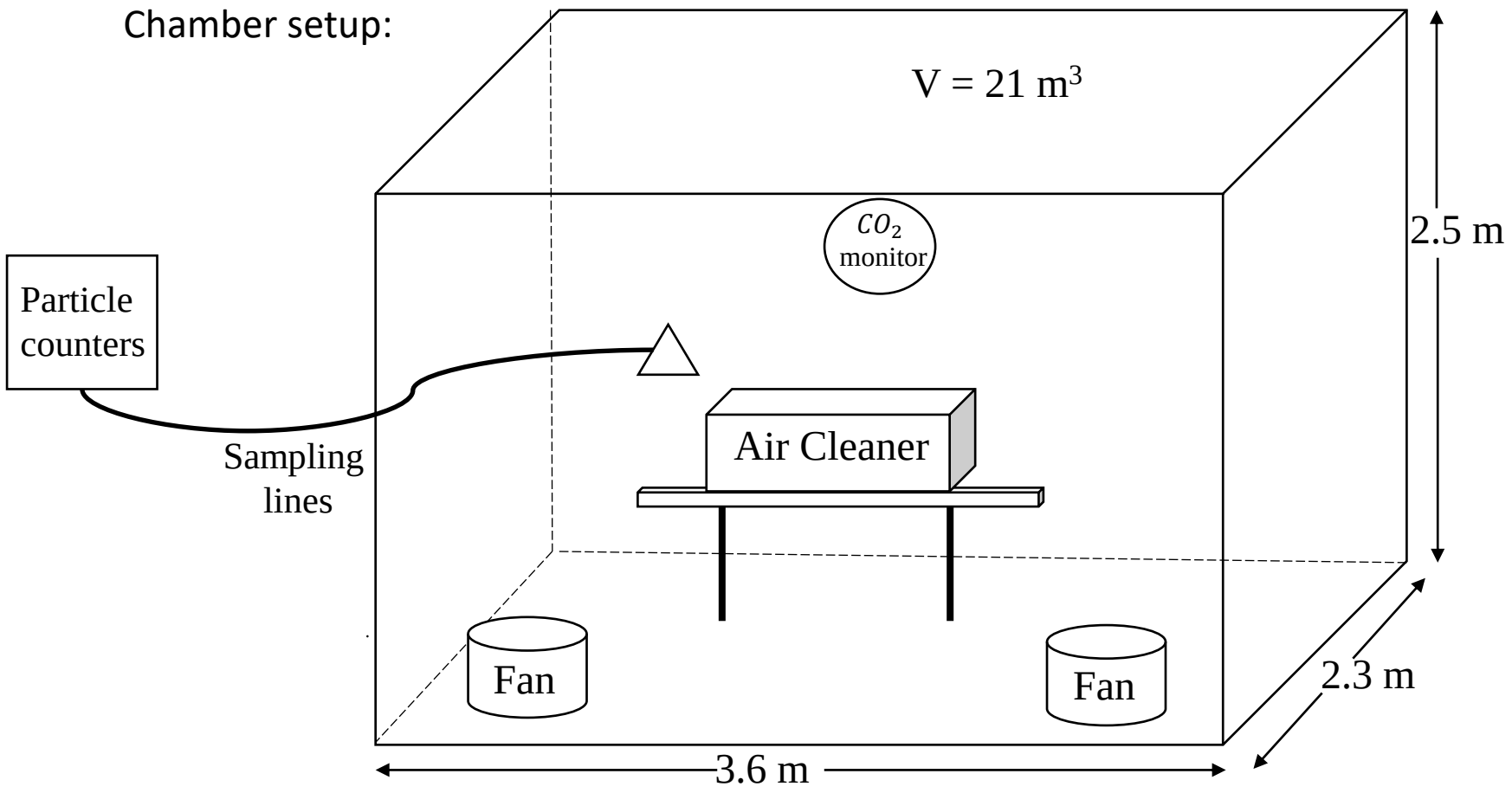
- Burning 0.5 g of pine needles for 45 seconds.
- Smoke in a can (4 seconds).

TSI Optical Particle Sizer, TSI P-Trak 8525 Ultrafine Particle Counter. Scanning Mobility Particle Sizer.

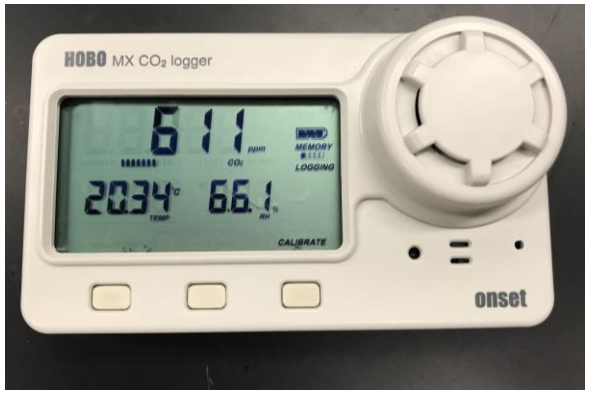
Clean air delivery rate (CADR): measure of the amount of contaminant-free air delivered by an air cleaner.

Reference: Offermann, F.J., R.G. Sextro, W.J. Fisk, D.T. Grimsrud, et al. 1985. “Control of respirable particles in indoor air with portable air cleaners.” Atmospheric Environment 19(11):1761–1771. https://doi.org/10.1016/0004-6981(85)90003-4.

Method


Chamber setup:
V = 21 m3
2.5 m
CO_2 monitor
Particle counters
Sampling lines
Air Cleaner
Fan
Fan
2.3 m
3.6 m

Method



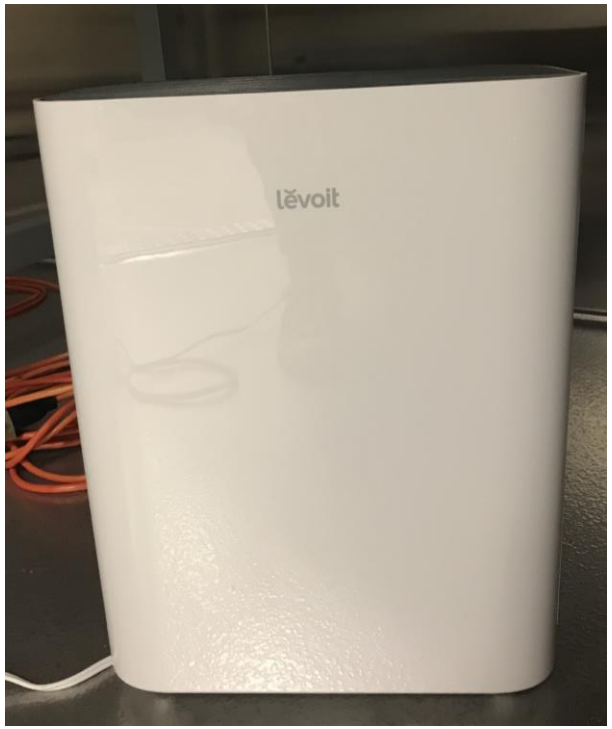
CO_2 mixing testing design:

- Four CO_2 loggers place on each side of the chamber's interior.
- One CO_2 logger outside of the chamber.
- CO_2 was injected into the chamber and allowed to decay for 40 minutes.

Airtightness testing design:

- Inject the aerosol to the chamber and allow it to decay overnight.
- Calculate the air exchange rate to determine the airtightness of the chamber.

Method



Air cleaner testing design:

Background test:

- Measure the background concentration of particles for 10 minutes.
- The injection of aerosol.
- Measure the particle concentration of inside the chamber.

Air cleaner on test:

- Measure the background concentration of particles for 10 minutes.
- Turn on the air cleaner.
- The injection of aerosol.
- Measure the particle concentration of inside the chamber.

Method

Air Exchange Rate:

$$-\ln\left(\frac{C_{CO2,t}-C_{CO2,bg}}{C_{CO2,0}-C_{CO2,bg}}\right)=\lambda t$$

λ: air exchange rate (1/min).
$C_{CO2,t}$: CO_2 concentration at time t (ppm).
$C_{CO2,bg}$: steady-state background CO_2 concentration in the chamber (ppm).
$C_{CO2,0}$: CO_2 concentration at time t=0 (ppm).

Loss Rates:

$$-\ln\left(\frac{C_t-C_{bg}}{C_0-C_{bg}}\right)=\beta t$$

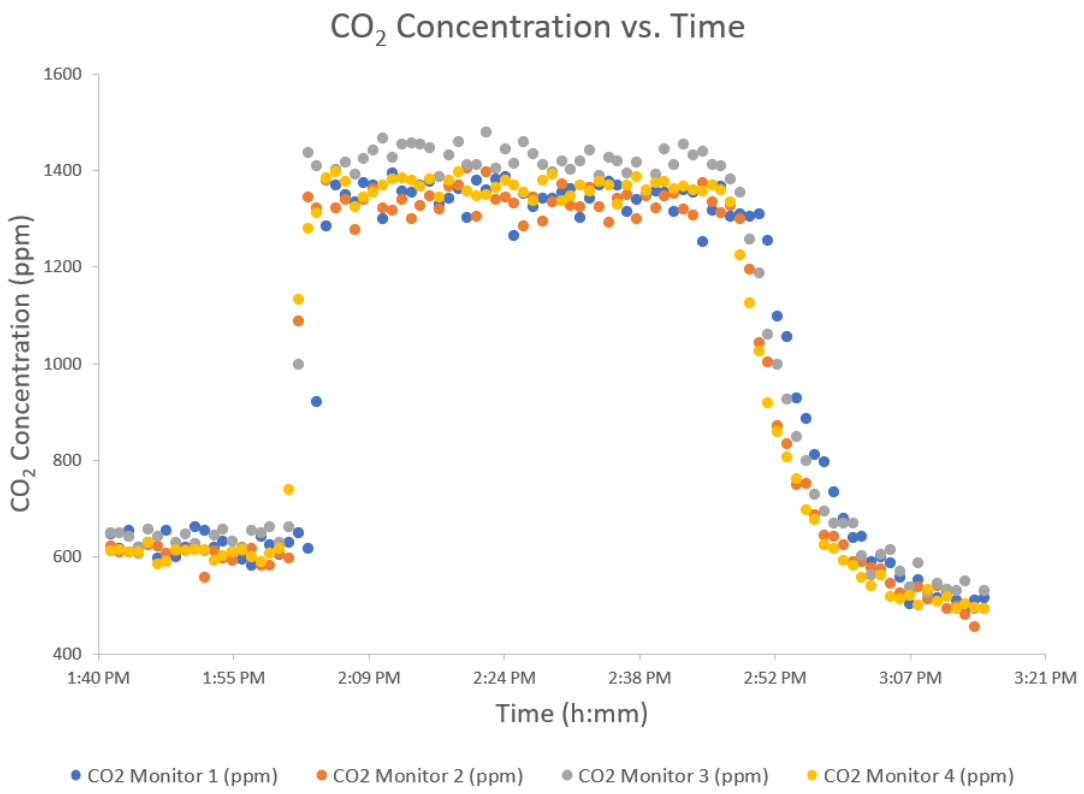
β: particle loss rates (1/min).
C_t: particle concentration at time t (μm/cm^3) or (#/ cm^3).
C_{bg}: steady-state background particle concentration in the chamber. (μm/cm^3) or (#/ cm^3).
C_0: particle concentration at time t=0 (μm/cm^3) or (#/ cm^3).

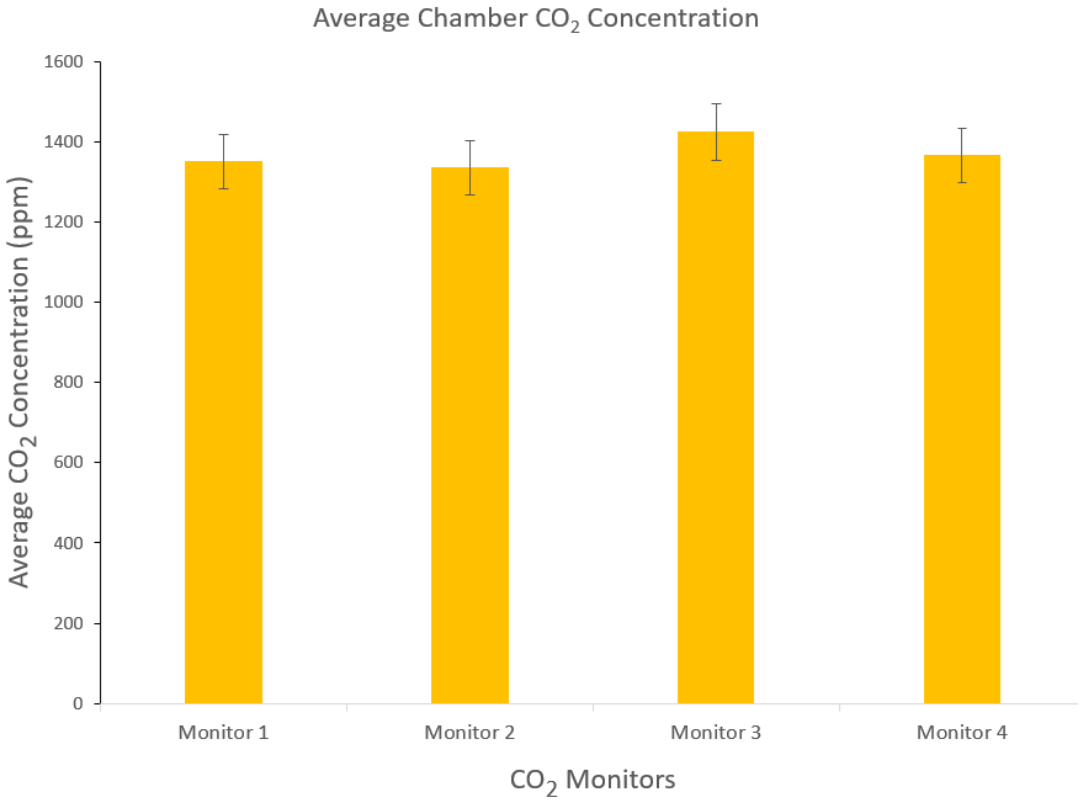
CADR:

$$CADR = V\ (\beta_{on} - \beta_{off})$$

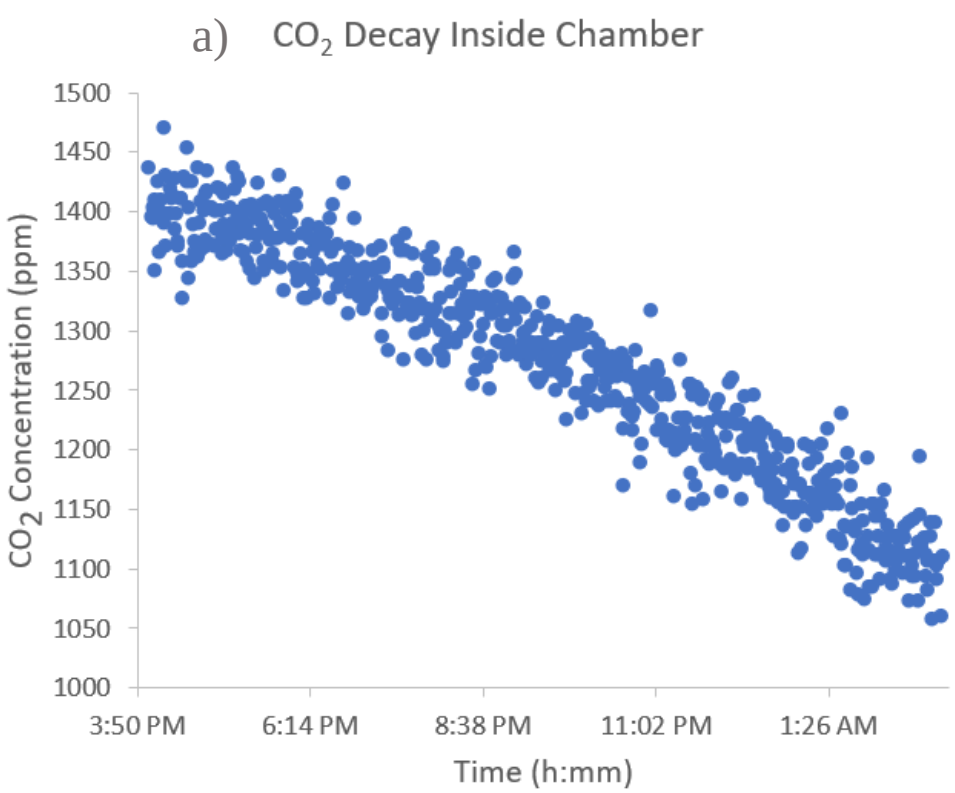
CADR: clean air delivery rate (cfm)
V: volume of the chamber.
β_{on}: first-order contaminant loss rates measured in a space with air cleaner on (1/min).
β_{off}: first-order contaminant loss rates measured in a space with air cleaner off (1/min).

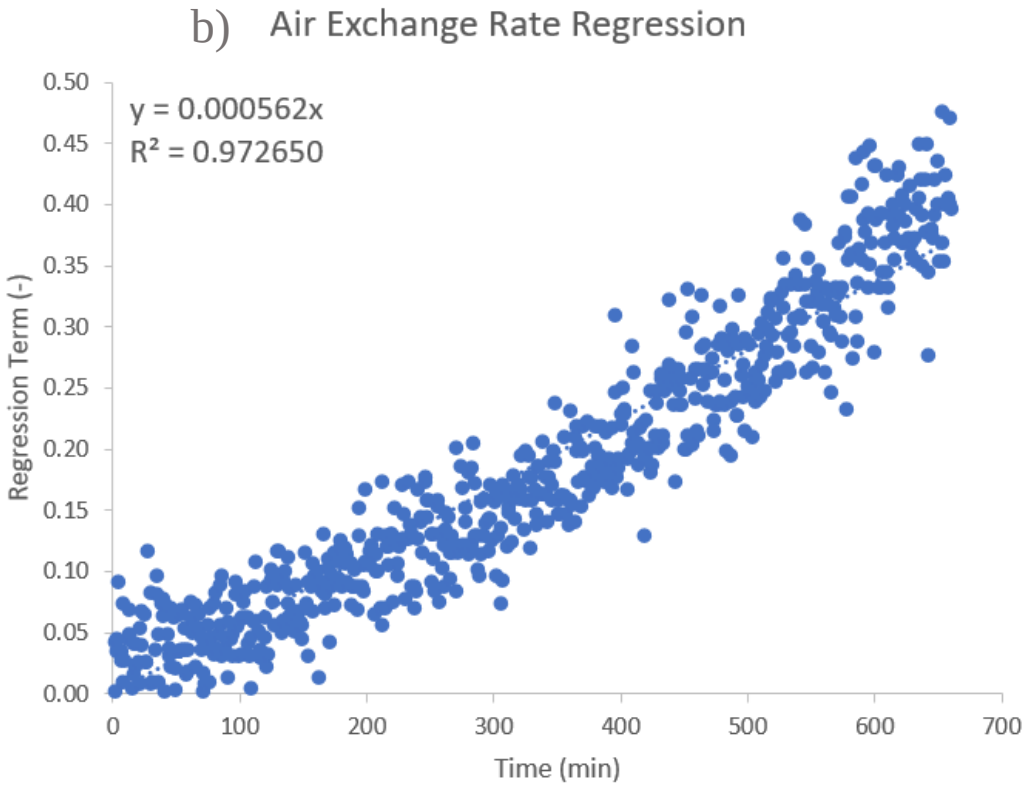
Results


CO_2 Concentration vs. Time
CO_2 Concentration (ppm)
1600
1400
1200
1000
800
600
400
1:40 PM
1:55 PM
2:09 PM
2:24 PM
2:38 PM
2:52 PM
3:07 PM
3:21 PM
Time (h:mm)
CO2 Monitor 1 (ppm)
CO2 Monitor 2 (ppm)
CO2 Monitor 3 (ppm)
CO2 Monitor 4 (ppm)


Average Chamber CO_2 Concentration
Average CO_2 Concentration (ppm)
1600
1400
1200
1000
800
600
400
200
0
Monitor 1
Monitor 2
Monitor 3
Monitor 4
CO_2 Monitors

Results

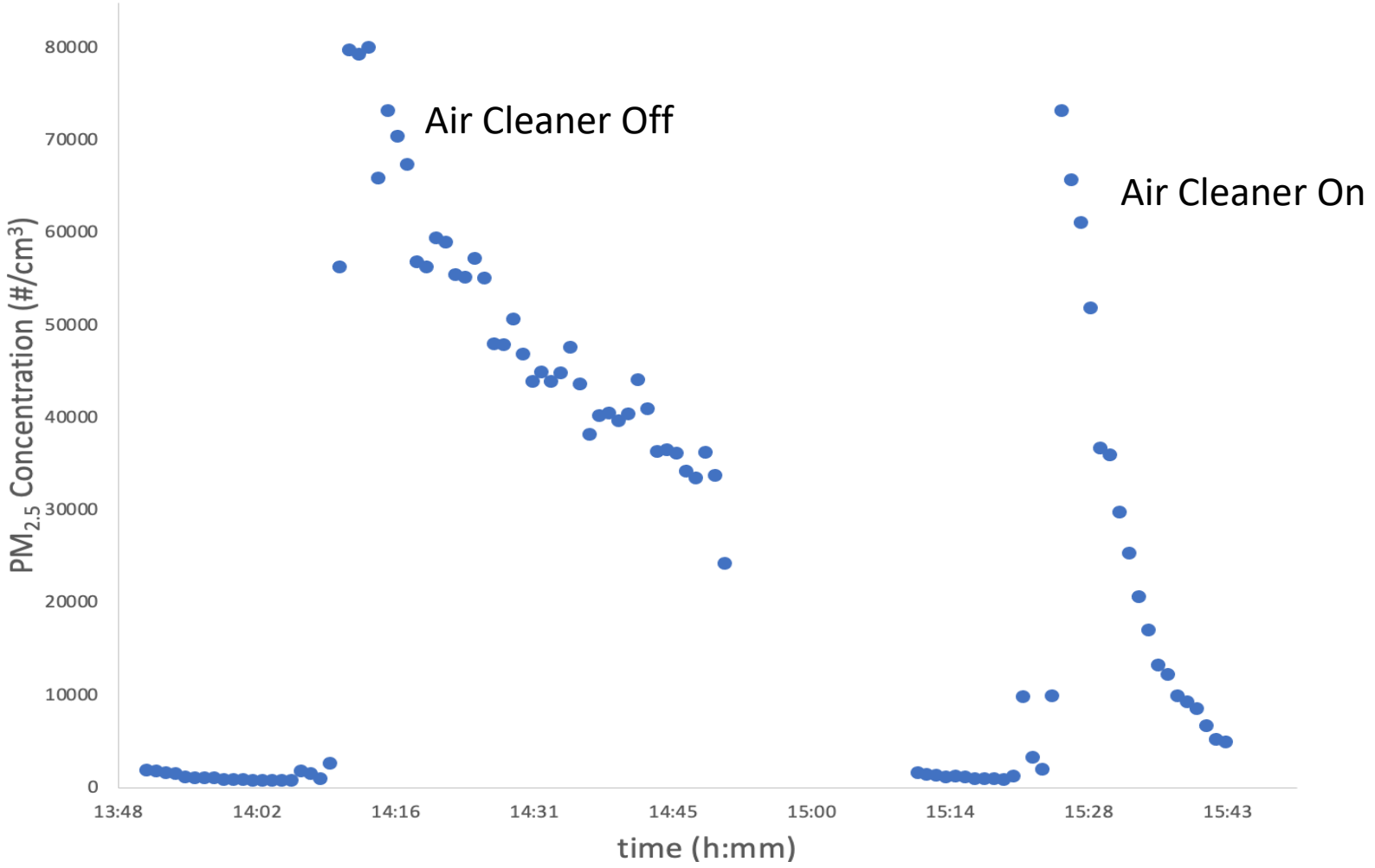




Standard of airtightness : 0.03 air changes per hour (ACH)

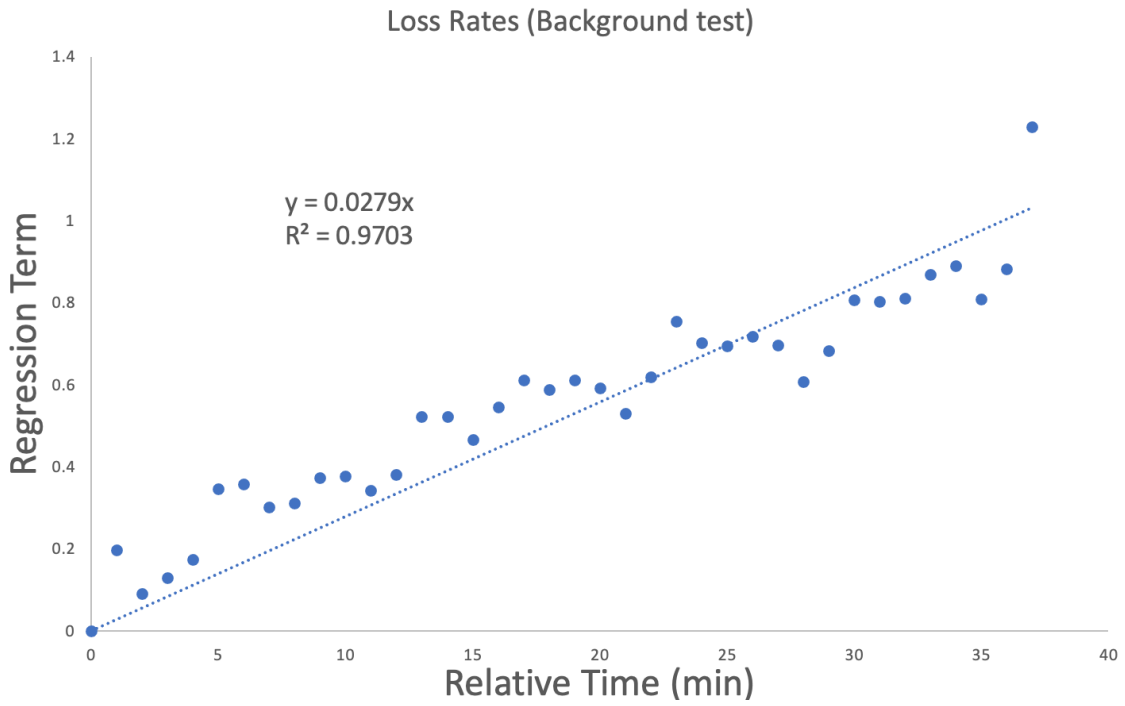
Reference: ANSI/AHAM AC-1-2020 - Method for Measuring Performance of Portable Household Electric Room Air Cleaners.

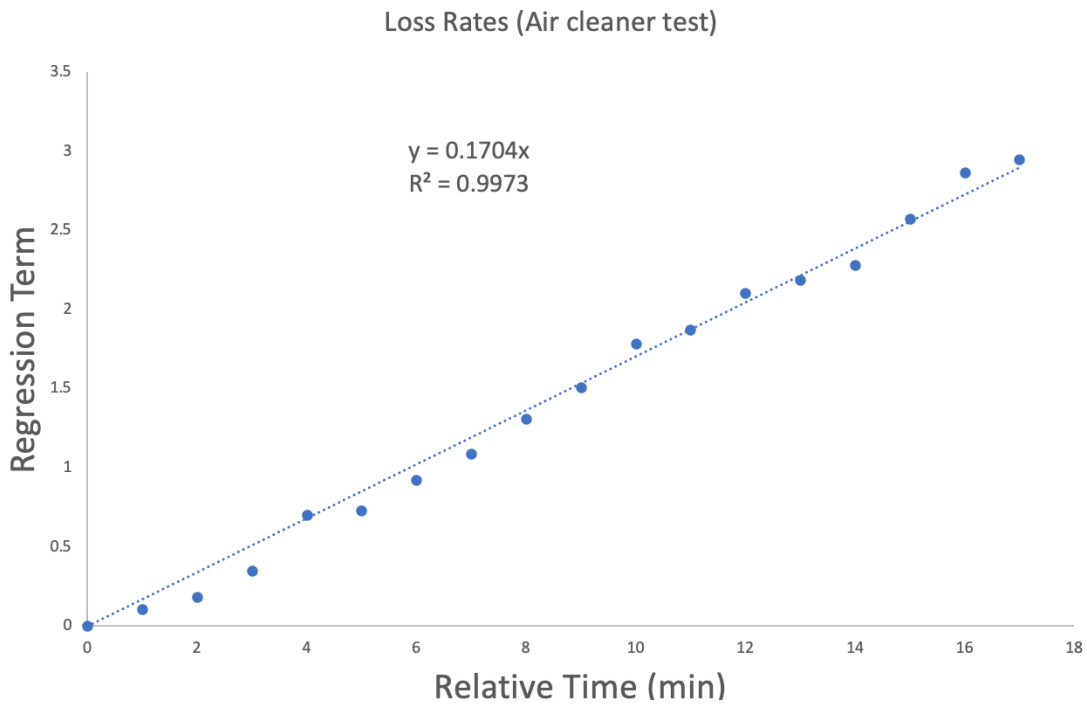
Results



- Pine needles experiment.
- Sample plot of $PM_{2.5}$ concentration vs. time

Results

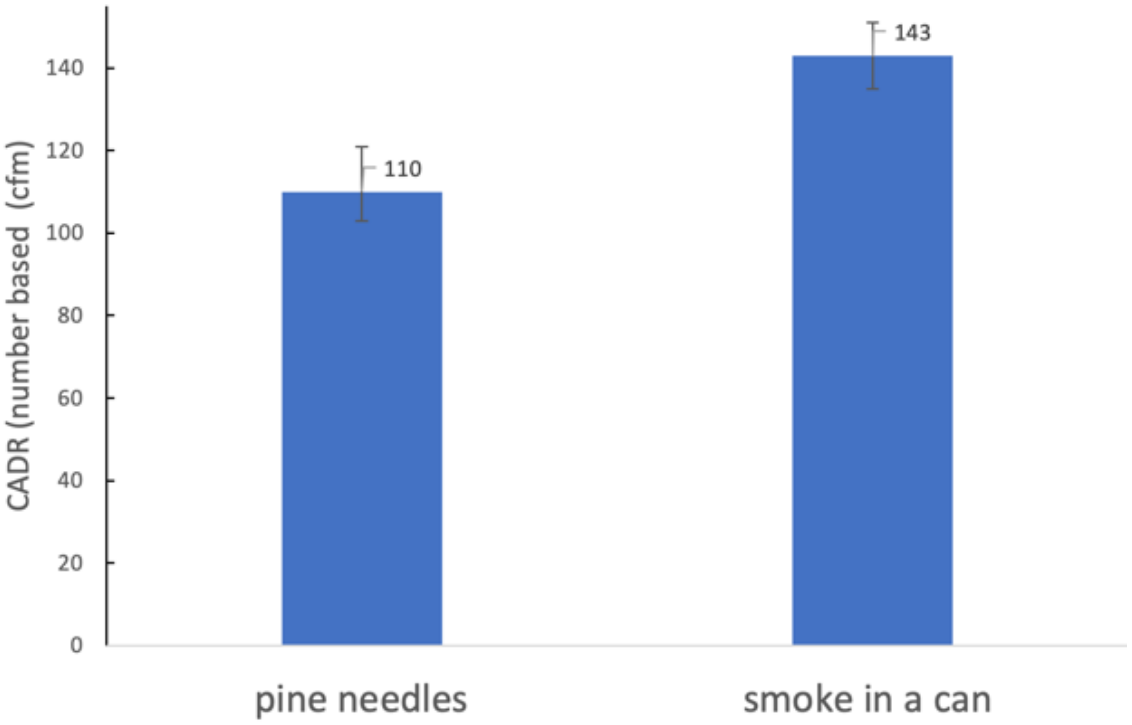


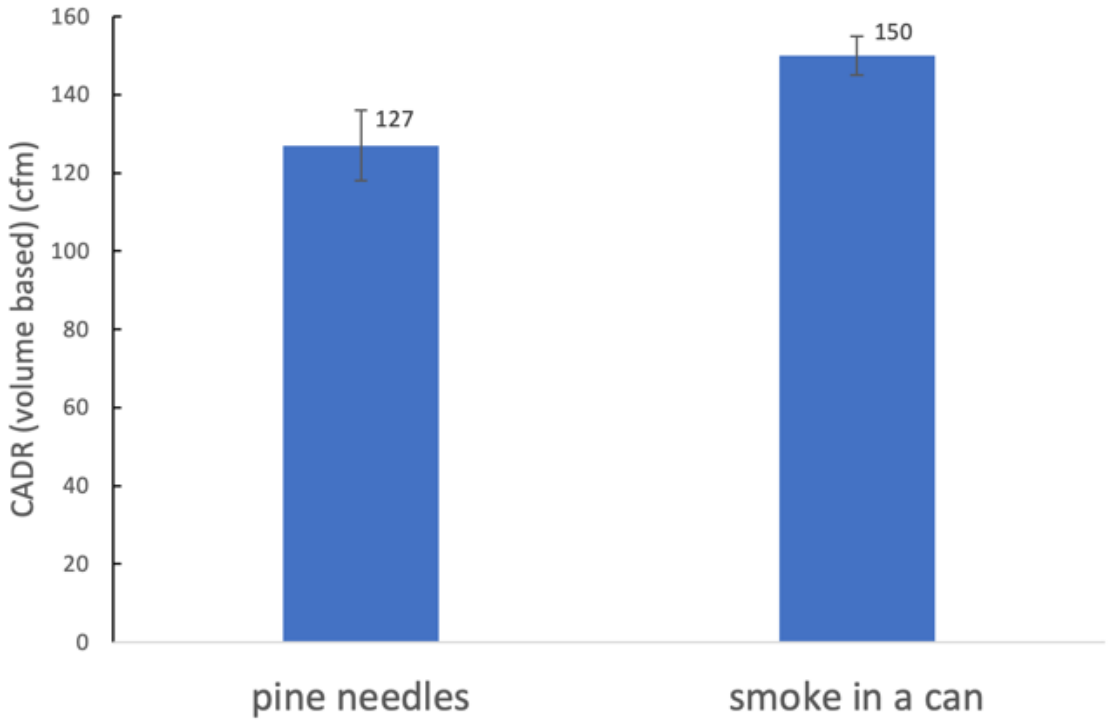


CADR= $V\ (\beta_{on} - \beta_{off})$

$=741\ ft^3 \times (\ 0.1704\ min^{-1} - 0.0279\ 1/min^{-1}\ ) = 110\ cfm$

Results


CADR (number based (cfm)
0
20
40
60
80
100
120
140
110
143
pine needles
smoke in a can


CADR (volume based) (cfm)
0
20
40
60
80
100
120
140
160
127
150
pine needles
smoke in a can

Conclusion

Significance

- Aerosols tested simulates the natural smoke generated from wildfire events.
- A protocol for future experiments.

Future Work

- More air cleaner testing
- Low-cost air cleaner
- Gas phase

Reference

1. ANSI/AHAM AC-1-2020 - Method for Measuring Performance of Portable Household Electric Room Air Cleaners.

2. Offermann, F.J., R.G. Sextro, W.J. Fisk, D.T. Grimsrud, et al. 1985. “Control of respirable particles in indoor air with portable air cleaners.” Atmospheric Environment 19(11):1761–1771. https://doi.org/10.1016/0004-6981(85)90003-4

3. Xu R, Yu P, Abramson MJ, Johnston FH, Samet JM, Bell ML, Haines A, Ebi KL, Li S, Guo Y. Wildfires, Global Climate Change, and Human Health. N Engl J Med. 2020 Nov 26;383(22):2173-2181. doi: 10.1056/NEJMsr2028985. Epub 2020 Oct 9. PMID: 33034960.

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WHERE DISCOVERIES BEGIN

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