Air Cleaners: What Have we Learned and What do we Still Need to Know?

Shelly L. Miller, Professor Mechanical Engineering,

University of Colorado Boulder

Associate Editor Environmental Science & Technology

Currently on sabbatical at Institut de Diagnòstic Ambiental i Estudis de l'Aigua, Barcelona Spain

@ShellyMBoulder, shellym80304.com

What we already know

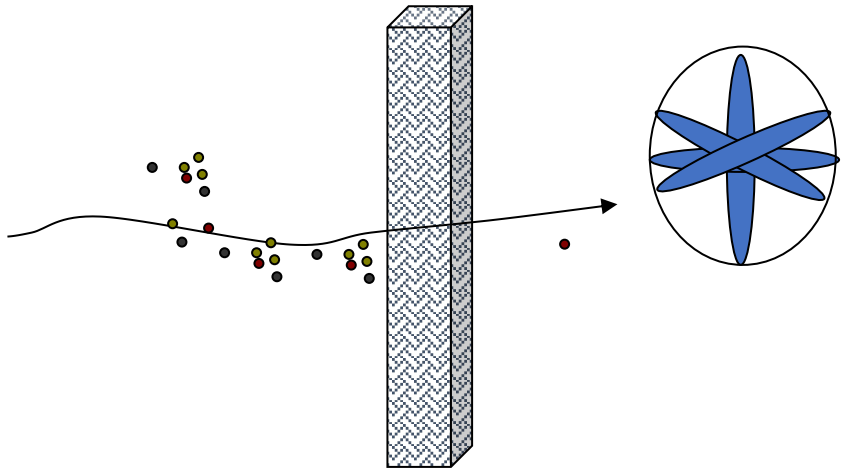
Focus today on Particulate Air Cleaners

Tips

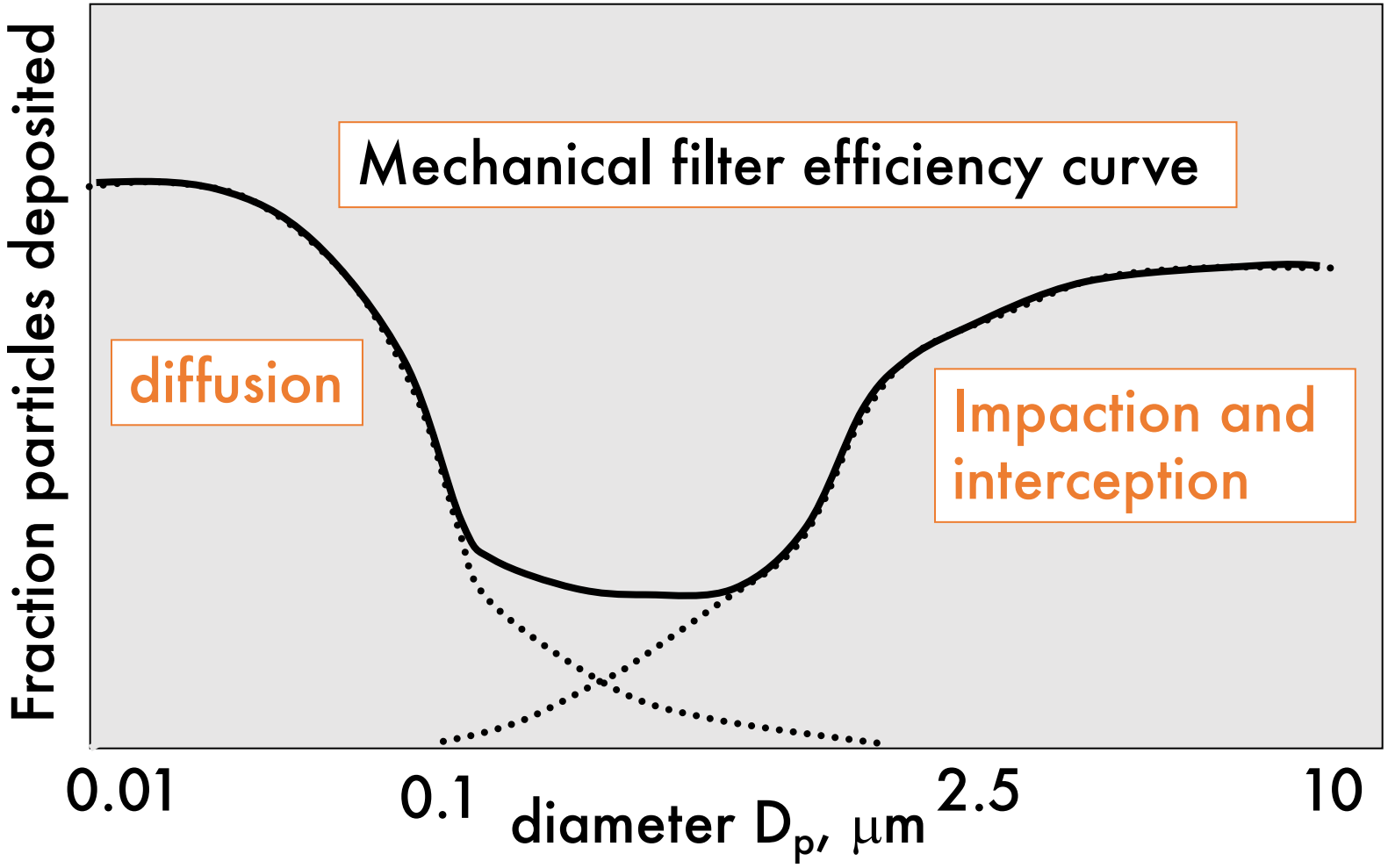
- No air cleaner (not called air purifier) will remove all pollutants from your indoor environment
  - Always first remove at the source (e.g. replace gas stove with electric, get rid of carpeting)
- Air filters remove either gases or particles
  - Many air cleaners contain filters to remove both (activated carbon + HEPA)
- All filters need replacing, they get dirty
- Air cleaners can improve indoor air quality provided:
  - they are sized correctly
  - operated correctly
  - do not emit additional air pollution and are properly maintained

US EPA, Guide to Air Cleaners in the Home, 2nd edition, 2018

Mechanical air cleaners

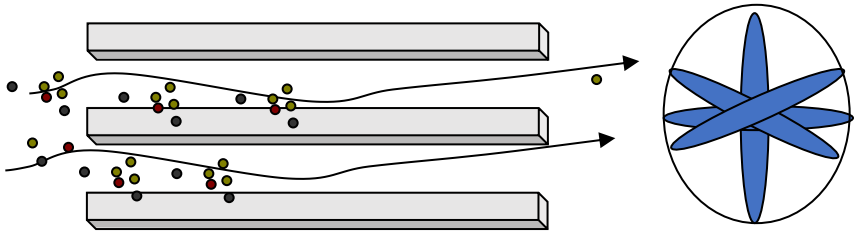


- Fan draws particle-laden air through a fibrous filter media
- Physically removes particles
- Doesn't generate ozone



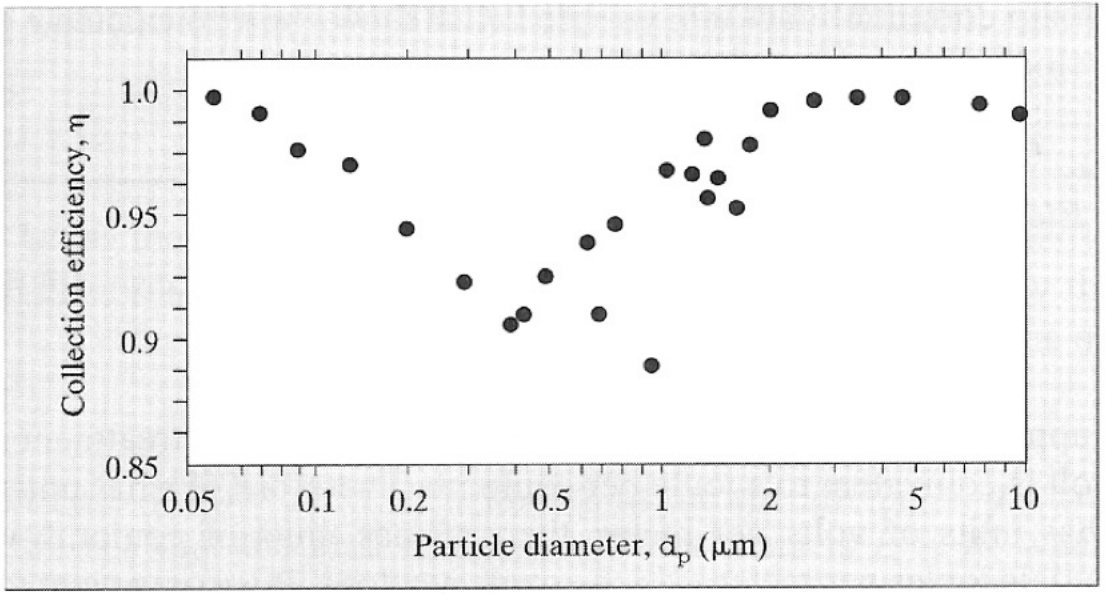
This figure shows typical particle removal efficiency as a function of particle size for a typical fibrous filter

Electronic air cleaners



NOTE: some have no fan (for example, Sharper Image)

- Fan draws particle-laden air through an electrical field
- Charged particles are deposited on oppositely charged collector plates
- Generates ozone if dirty or under certain operating conditions



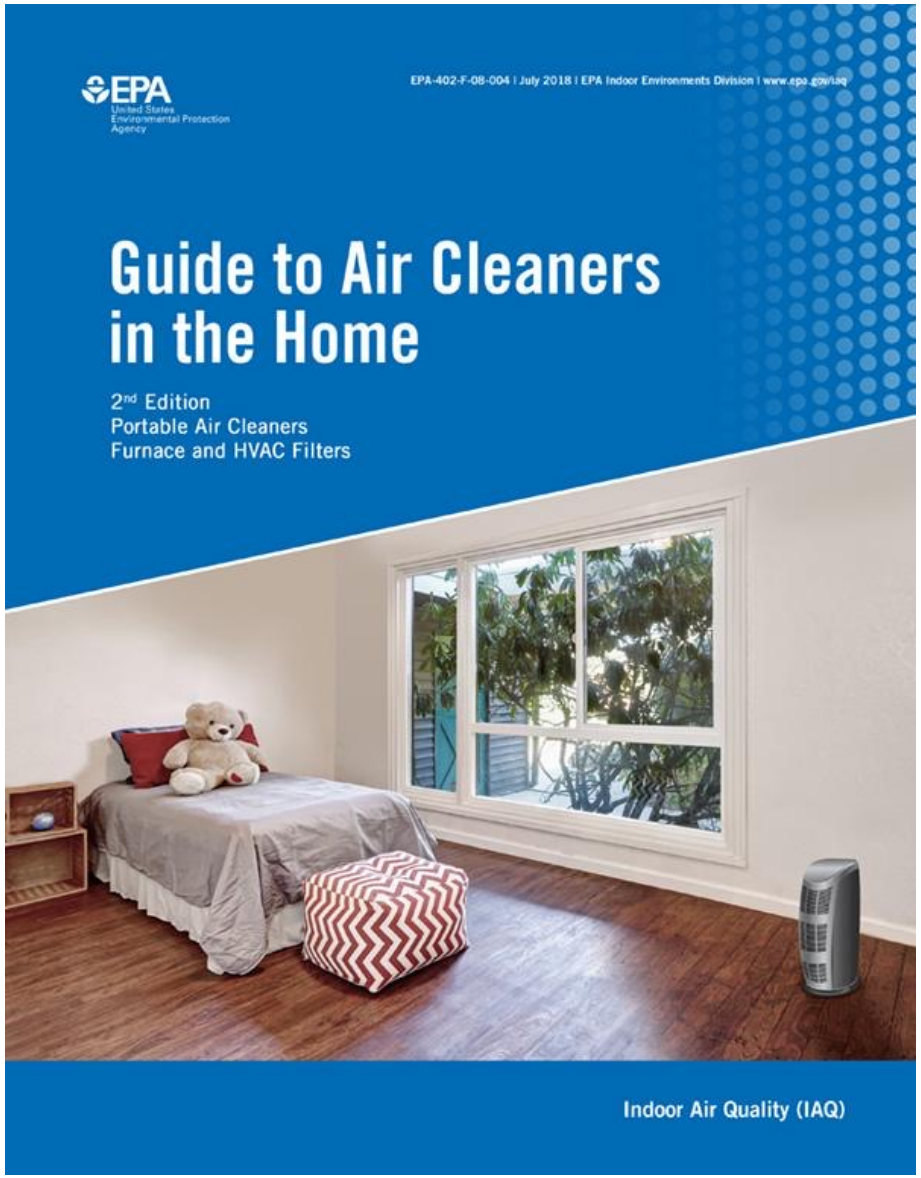
(Nazaroff & Alvarez-Cohen, Figure 7.C.4)

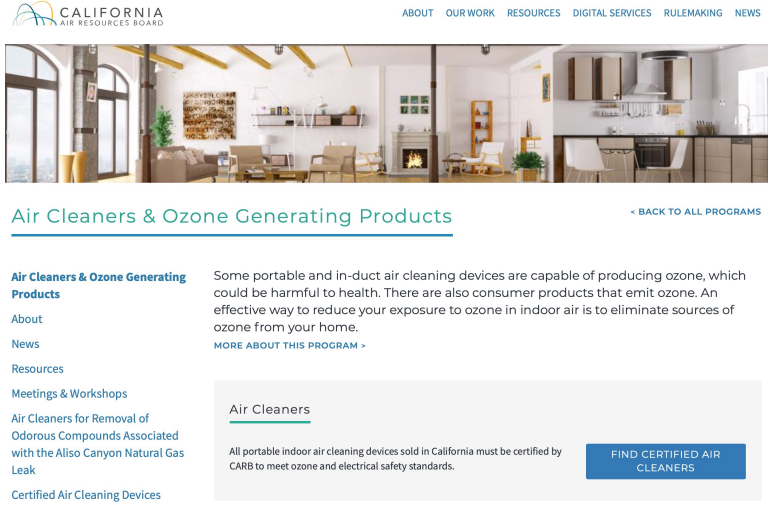
Figure 7.C.4 Measured collection efficiency as a function of particle size for an electrostatic precipitator installed on a pulverized coal boiler. (Reprinted with permission of the Air & Waste Management Association from J.D. McCain et al. [1975].)

Larger particles are removed more efficiently because they acquire a greater electric charge, whereas smaller particles, too, are removed more efficiently because they are subjected to less drag and thus drift more easily, leaving intermediate particles as those that are less efficiently collected. Nonetheless, efficiency easily exceeds 90% for most particles.

Air cleaner standards

- Currently there are no state or federal standards for testing/rating portable air cleaner performance
  - CA tests for ozone emissions, electrical safety
  - CA provides list of certified devices
  - https://ww2.arb.ca.gov/list-carb-certified-air-cleaning-devices
- Many air cleaners certified by the Association of Home Appliance manufacturers in a widely accepted voluntary program
  - https://ahamverifide.org
- US EPA provides excellent guide to air cleaners
  - https://www.epa.gov/indoor-air-quality-iaq/air-cleaners-and-air-filters-home


EPA
United States Environmental Protection Agency
EPA-402-F-08-004 | July 2018 | EPA Indoor Environments Division | www.epa.gov/iaq
Guide to Air Cleaners in the Home
2nd Edition
Portable Air Cleaners
Furnace and HVAC Filters
Indoor Air Quality (IAQ)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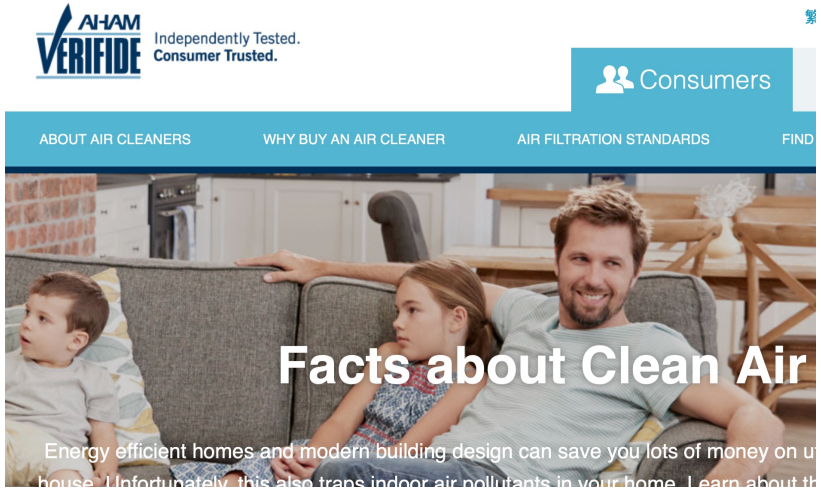
Air Cleaners for Removal of Odorous Compounds Associated with the Aliso Canyon Natural Gas Leak
Certified Air Cleaning Devices
Some portable and in-duct air cleaning devices are capable of producing ozone, which could be harmful to health. There are also consumer products that emit ozone. An effective way to reduce your exposure to ozone in indoor air is to eliminate sources of ozone from your home.
MORE ABOUT THIS PROGRAM >
Air Cleaners
All portable indoor air cleaning devices sold in California must be certified by CARB to meet ozone and electrical safety standards.
FIND CERTIFIED AIR CLEANERS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house. Unfortunately, this also traps indoor air pollutants in your home. Learn about th

USE TO APPROPRIATELY SIZE THE DEVICE

Clean air delivery rate

- airflow rate that represents the effective amount of particle-clean air produced by the air cleaner (Offermann et al., 1985)
- Single-pass efficiency of device (fractional removal of pollutants from the air stream as it passes through device) multiplied by airflow rate through device (Nazaroff, 2000)

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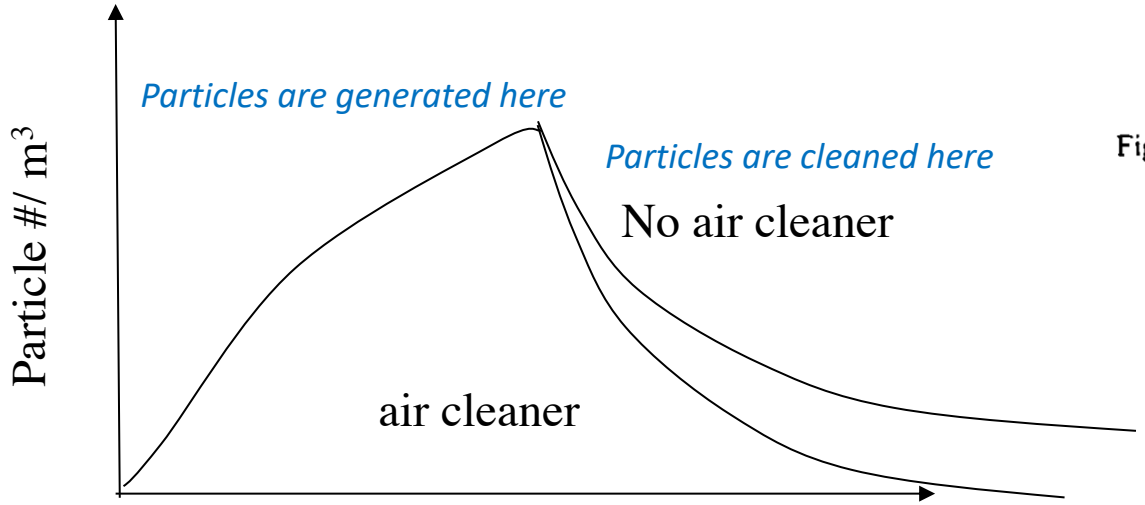


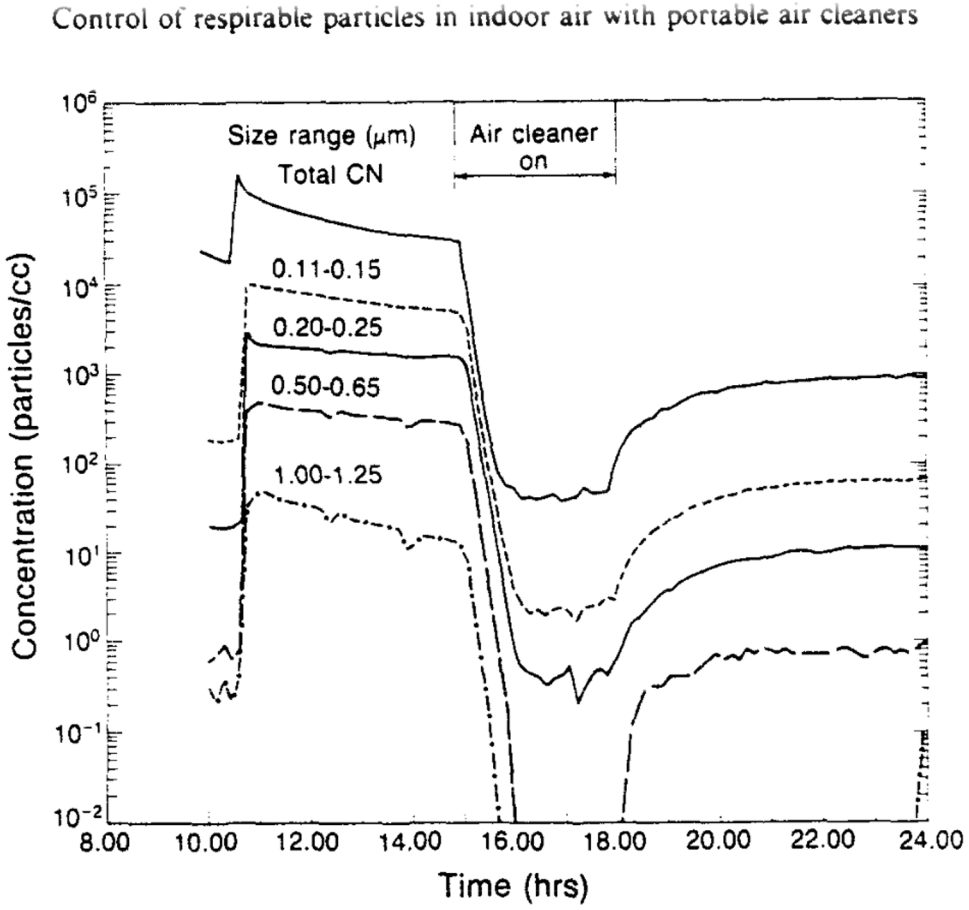


Fig. 3. Semi-log plot of particle concentration as a function of time for a single-room decay experiment using tobacco smoke and a HEPA-type filter.

Harvard CU-Boulder Portable Air Cleaner Tool

SIMPLE TOOL FOR SCHOOLS FOR SELECTING PORTABLE AIR CLEANER FOR ROOMS (input fields are bright yellow)

STEP 1 HOW BIG IS THE ROOM?

Select units of preference	feet	
How big is your room?	500	*Input your room size here in square feet*
How tall are your ceilings?	8	*Input your room size here in feet*

STEP 2 WHAT IS THE 'CLEAN AIR DELIVERY RATE' OF THE AIR PURIFER? (you get this from the manufacturer)

What is the clean air delivery rate of the air cleaner?	300	*Find the CADR from the manufacturer in units of cubic feet per minute, or cfm; if they report multiple*

STEP 3 HOW MUCH OUTDOOR AIR VENTILATION DO YOU HAVE?

How is the ventilation in my school?	Low ventilation	Good ventilation	3	ACH	*This is the approximate minim*
		Enhanced ventilation	4	ACH	*Select this only if your school h*
		Typical school	1.5	ACH	*This is an approximate averag*
		Low ventilation	1	ACH	*Select this if your school has po*

STEP 4 COMBINING AIR CLEANING AND VENTILATION, IS YOUR ROOM MEETING THE TARGET?

Air changes from outdoor air ventilation	1
Air changes from air cleaner	4.5
Total air changes in the room per hour	**5.5**

TARGET IS AT LEAST 5 TOTAL AIR CHANGES PER HOUR

	Ideal (6 ACH)
	Excellent (5-6 ACH)
	Good (4-5 ACH)
	Bare minimum (3-4 ACH)
	Low (<3 ACH)

STEP 5 WHAT SIZE ROOM WILL WORK FOR THIS PORTABLE AIR CLEANER?

Cubic feet per minute (cfm) of clean air from cleaner	300	*This is from the manufacturer (see cell 'c10')*
Cubic feet per minute (cfm) of outdoor air from ventilation	67	*This is calculated from air changes per hour and volume of room*
Total cfm of air cleaning and ventilation	**367**	
Recommended room size for this air cleaner (in square feet)	**550**	*This is the recommended maximum size of the room for this air cleaner to achieve 5 total ACH*

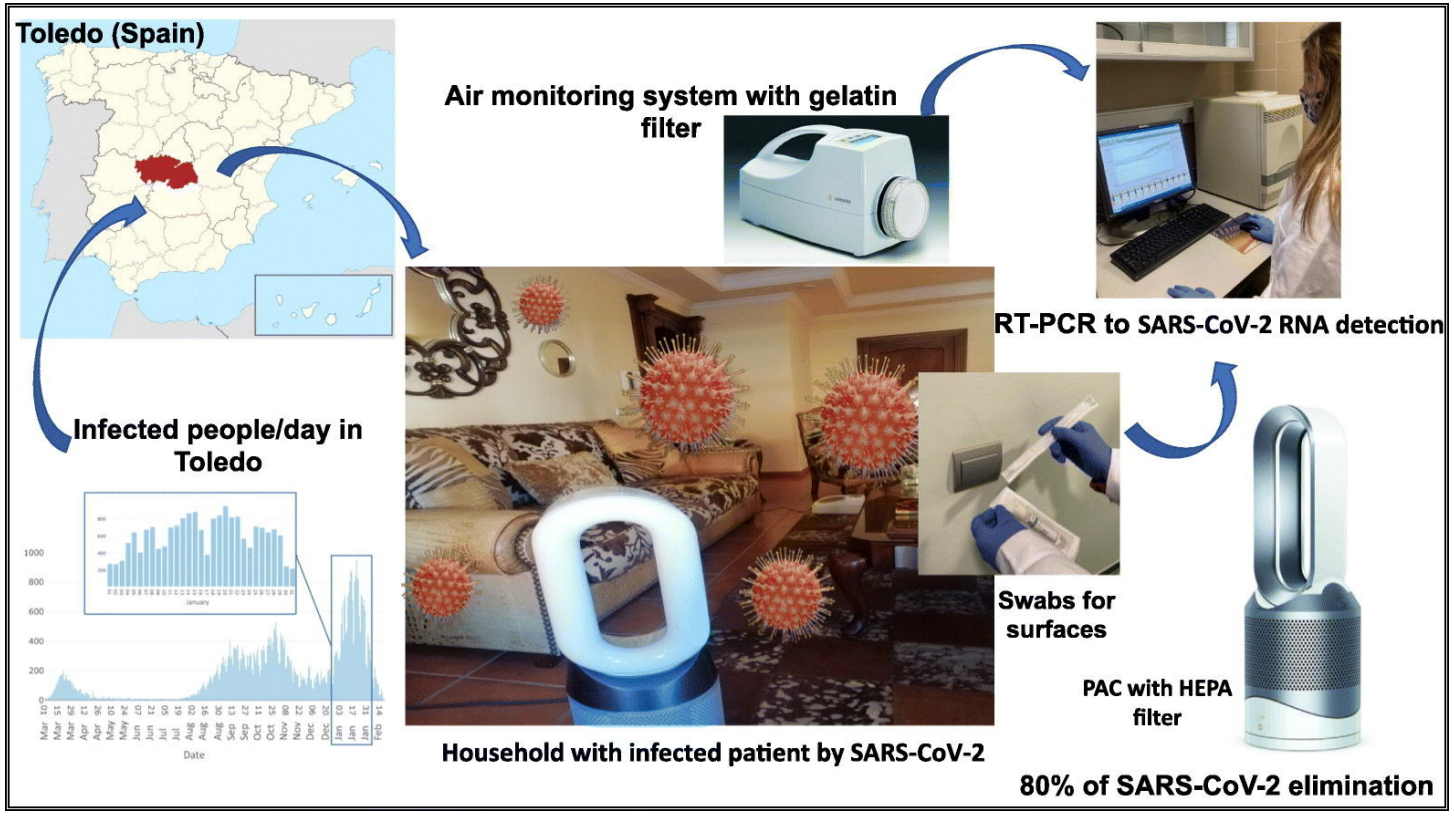
https://tinyurl.com/portableaircleanertool

What we have learned recently

Portable air cleaners reduce airborne SARS-CoV-2 virus

- Homes naturally ventilated, windows and doors closed and home heated (Jan 2021 during 3rd COVID wave in Spain)

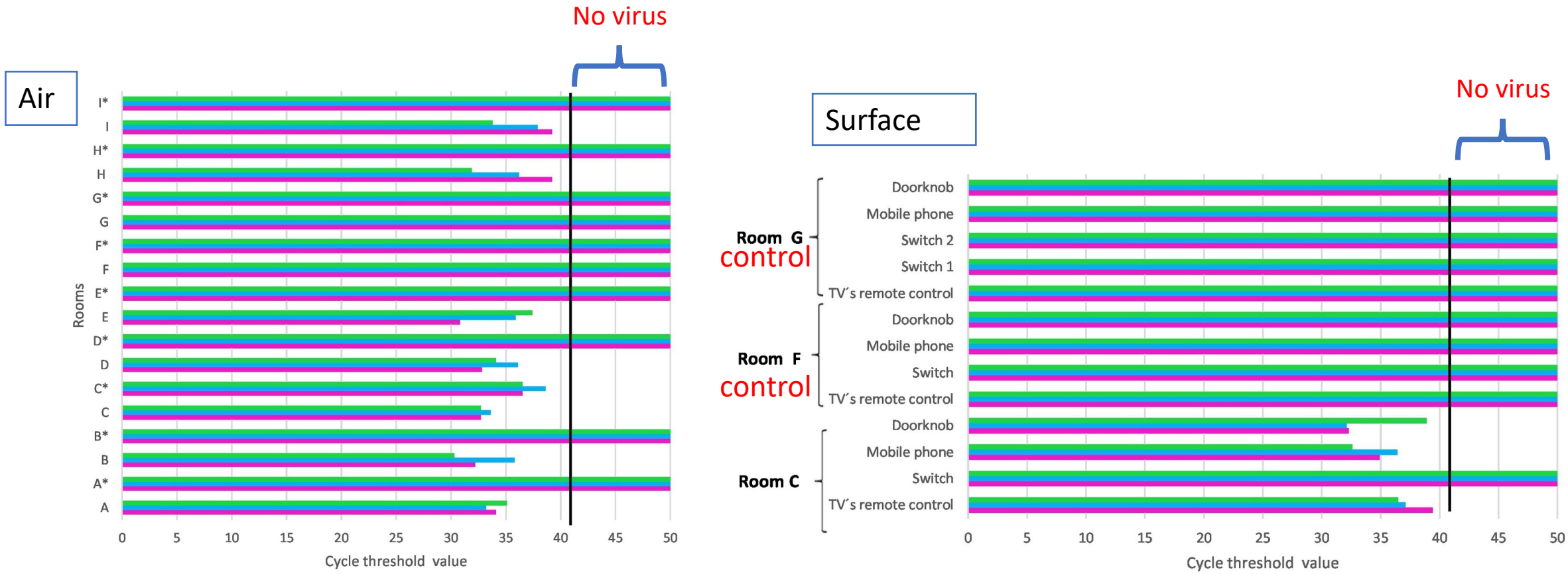
Rodríguez, María, et al. "Are the Portable Air Cleaners (PAC) really effective to terminate airborne SARS-CoV-2?." *Science of The Total Environment* 785 (2021): 147300.



- 9 rooms
- 7 COVID-19
- 2 control
- 13 surface swabs
- 16 air samples

Real-time RT-PCR results for 3 pairs of primers. a) Air samples; **values from samples taken after using the PAC*. b) Surface samples. Black line indicates values of *Ct* ≤ 41, which means positive real-time RT-PCR.

- Air samples and surface swabs **positive** for virus in homes occupied by COVID-19 patients; **negative** in control homes
- Air samples negative for virus (in all but 1) after use of PAC
  - Virus detected in home where PAC was too small for room



DIY Air Cleaners Effective

- Box fan = $20 - $40
- MERV 13 filter 20”x20”x2” = $55 / box of 4
- Apartment = 520 SF, built in ~1970s
- Student project in my class

1. Construct box filter
2. Prepare the same meal 2-3x with and without box fan filter
3. Sensor: Airthinx IAQ
   AQI, PM, CH_2O (formaldehyde), CO_2, VOCs (EtOH and Isobutylene)
4. Collect & interpret continuous sensor data

WITH BOX FAN Air Cleaner
Average $PM_{2.5}$ ~ 91.7% reduction

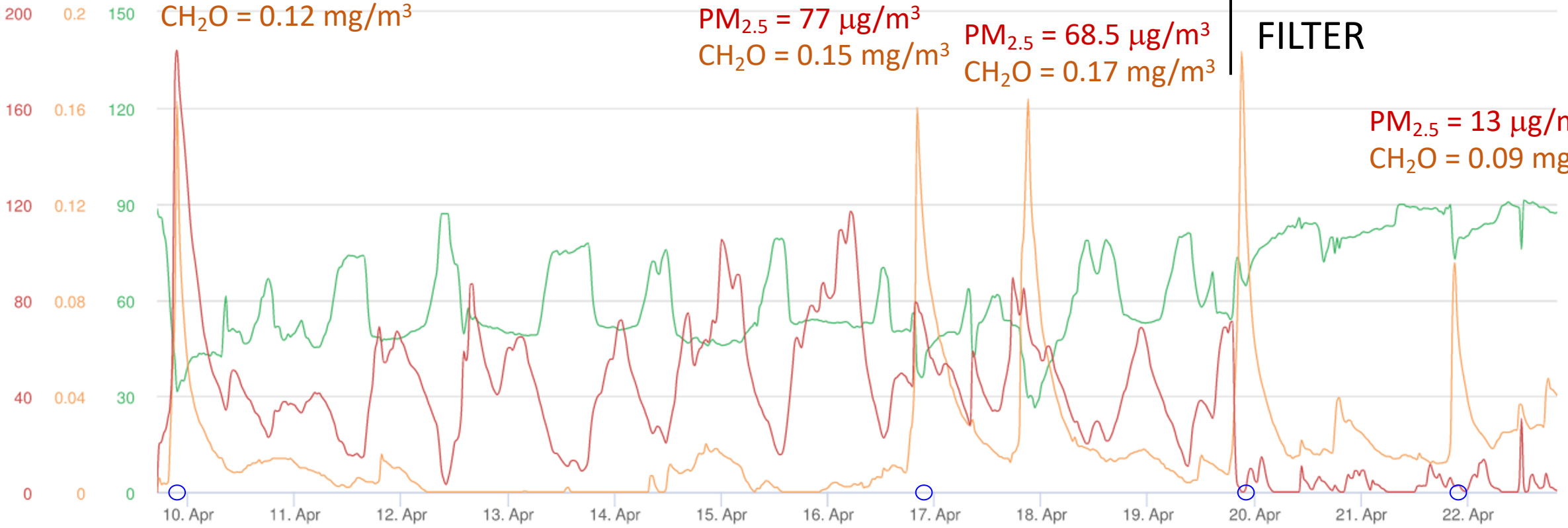
$PM_{2.5}$ = 178 µg/m³
CH_2O = 0.12 mg/m³

$PM_{2.5}$ = 77 µg/m³
CH_2O = 0.15 mg/m³

$PM_{2.5}$ = 68.5 µg/m³
CH_2O = 0.17 mg/m³

WITH BOX FAN FILTER

$PM_{2.5}$ = 13 µg/m³
CH_2O = 0.09 mg/m³



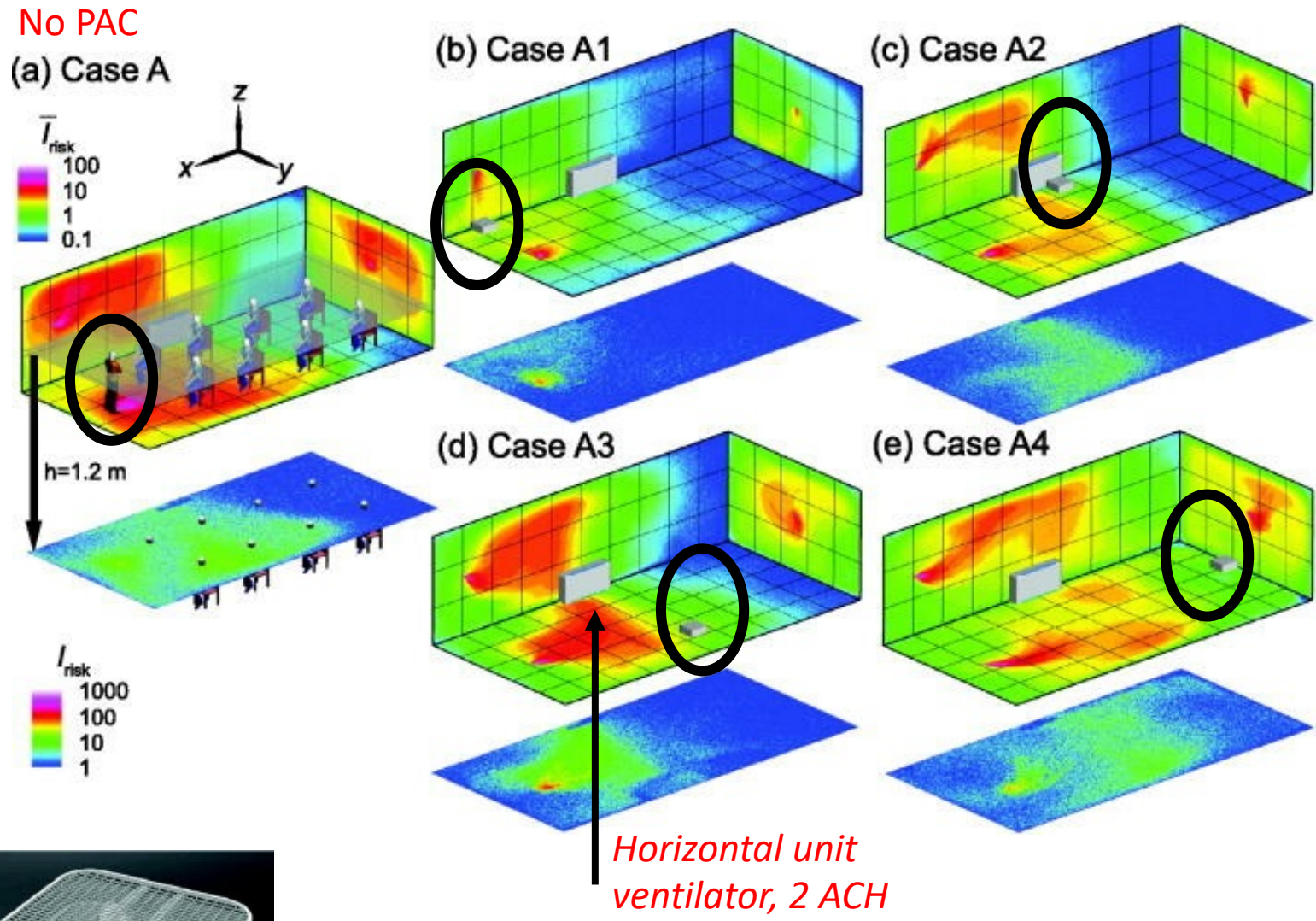
AQ AirThinx		
MIN	AVG	MAX
24	62	93

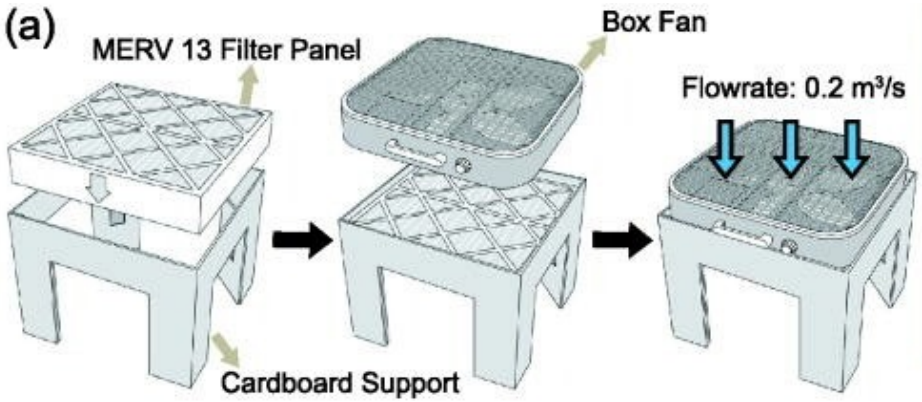
CH_2O mg/m³ AirThinx		
MIN	AVG	MAX
0	0.019	0.323

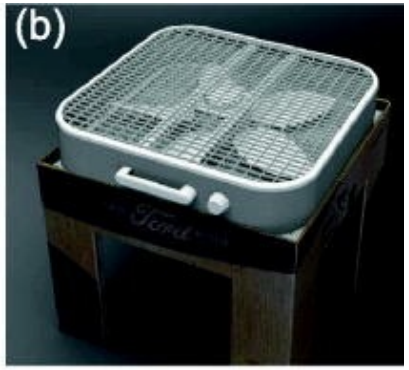
PM2.5 µg/m³ AirThinx		
MIN	AVG	MAX
0	38	194

Placement of Air Cleaners Matters

- Best placement is closest to source
- Most rooms pretty well mixed, but pollutant concentrations higher nearest emission (near-field effect)







- If source unknown, best to place near the HUV with the air flowing downwards
- aerosol concentration reduced more efficiently by adding air cleaners compared with raising the flow rate of HUV alone

Pitfalls

- The air cleaner is too small for the space
- Don’t buy an air cleaner based on the filter efficiency, but rather on the CADR
- Be wary of new technology that has not been adequately tested in real environments to back up the company claims
- The air cleaner uses technology that generates additional air pollution like oxidants
- The fan used in the filter does not have enough power to pull enough air through the filter (small fan, too large pressure drop)
- The filter in the air cleaners does not fit well and there is airflow bypass
- The air cleaner is run on medium speed because it is too loud

Ionizers

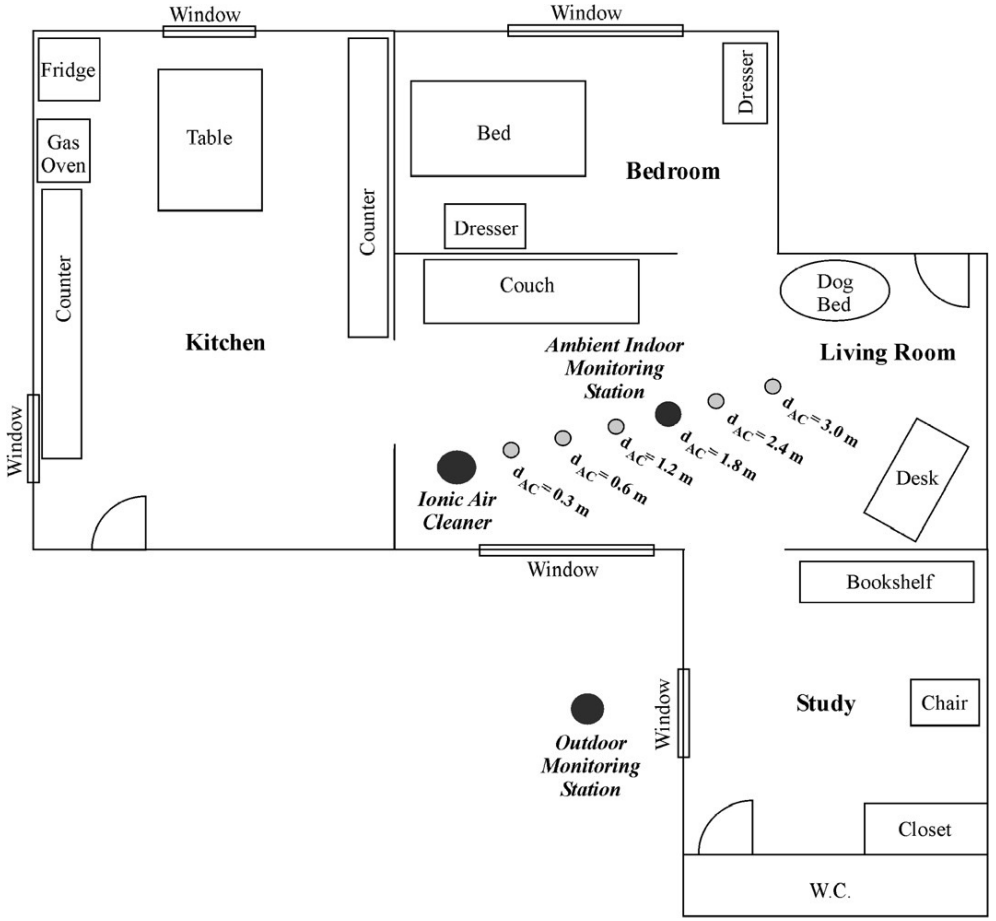
- Efficiency of PM removal in realistic settings poorly understood
  - few studies avail in uninhabited laboratory settings
- Gas-phase ions react with VOCs to form oxidized products, often similar to what happens outdoors

Collins, Douglas B., and Delphine K. Farmer. "Unintended Consequences of Air Cleaning Chemistry." *Environmental Science & Technology* 55.18 (2021): 12172-12179.

Pilot test
Unpublished data

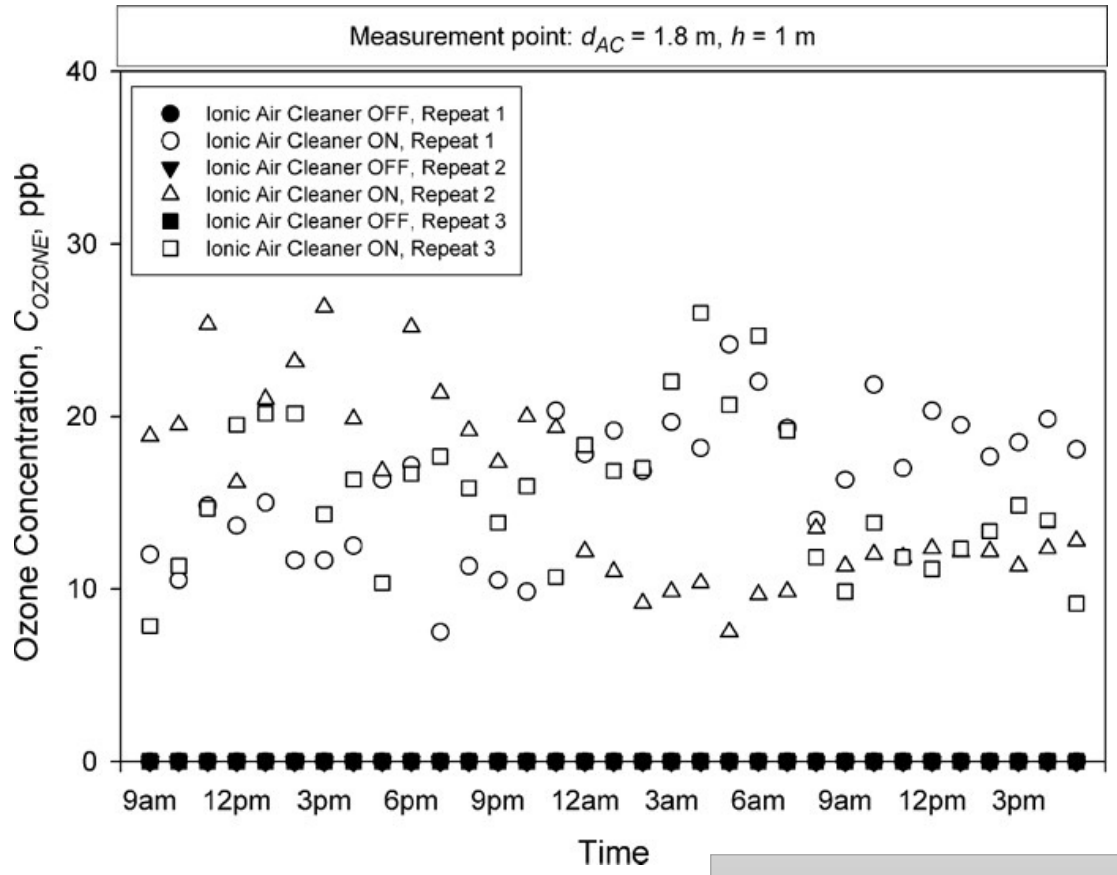
Ionizer Testing in a Home

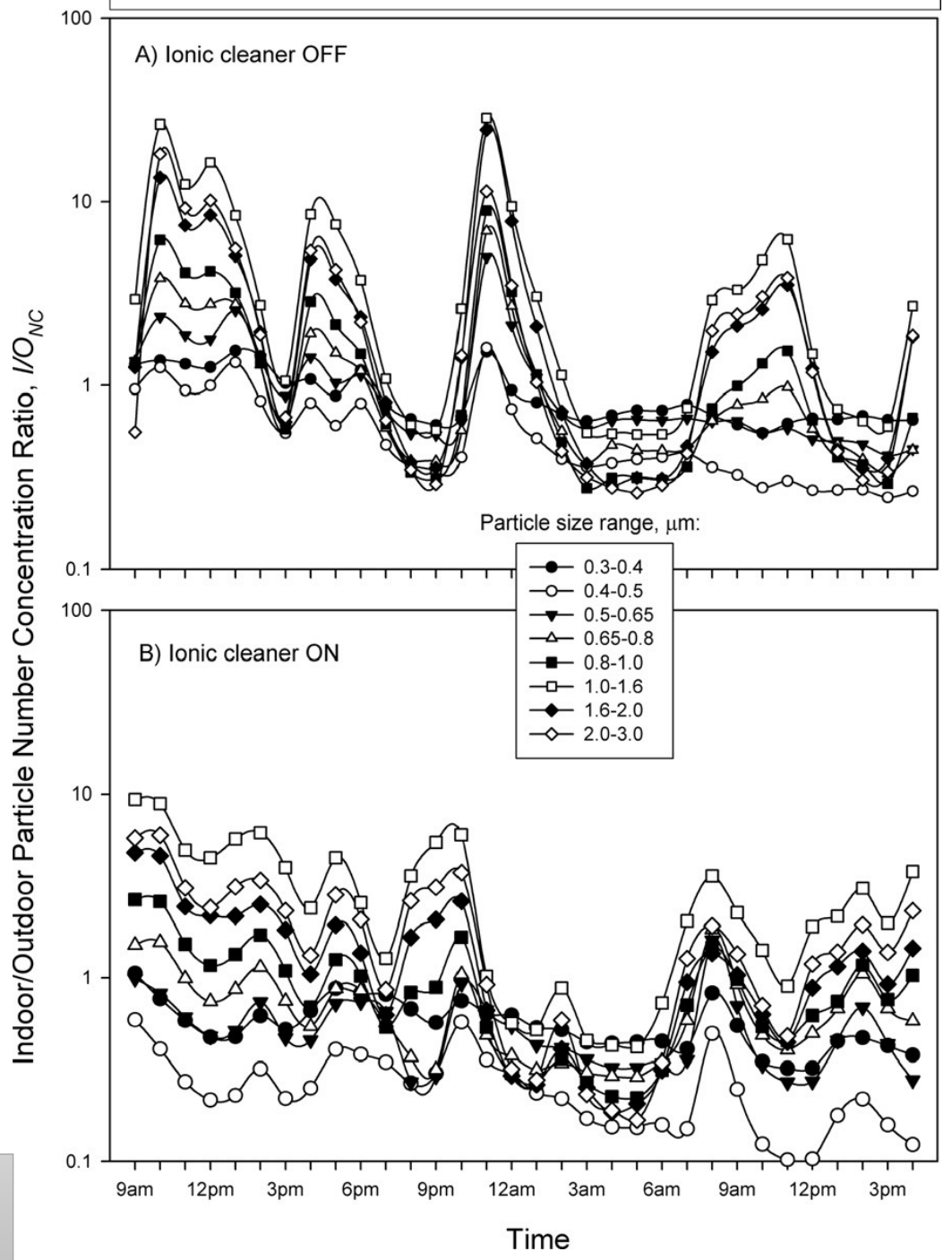
- Furnished 1 bed 150 m^3 apartment
- Study done in living room
- Occupants and dog engaged in normal activities
- Closed windows no ventilation



Berry, D., Mainelis, G. and Fennell, D., 2007. Effect of an ionic air cleaner on indoor/outdoor particle ratios in a residential environment. *Aerosol science and technology*, *41*(3), pp.315-328.

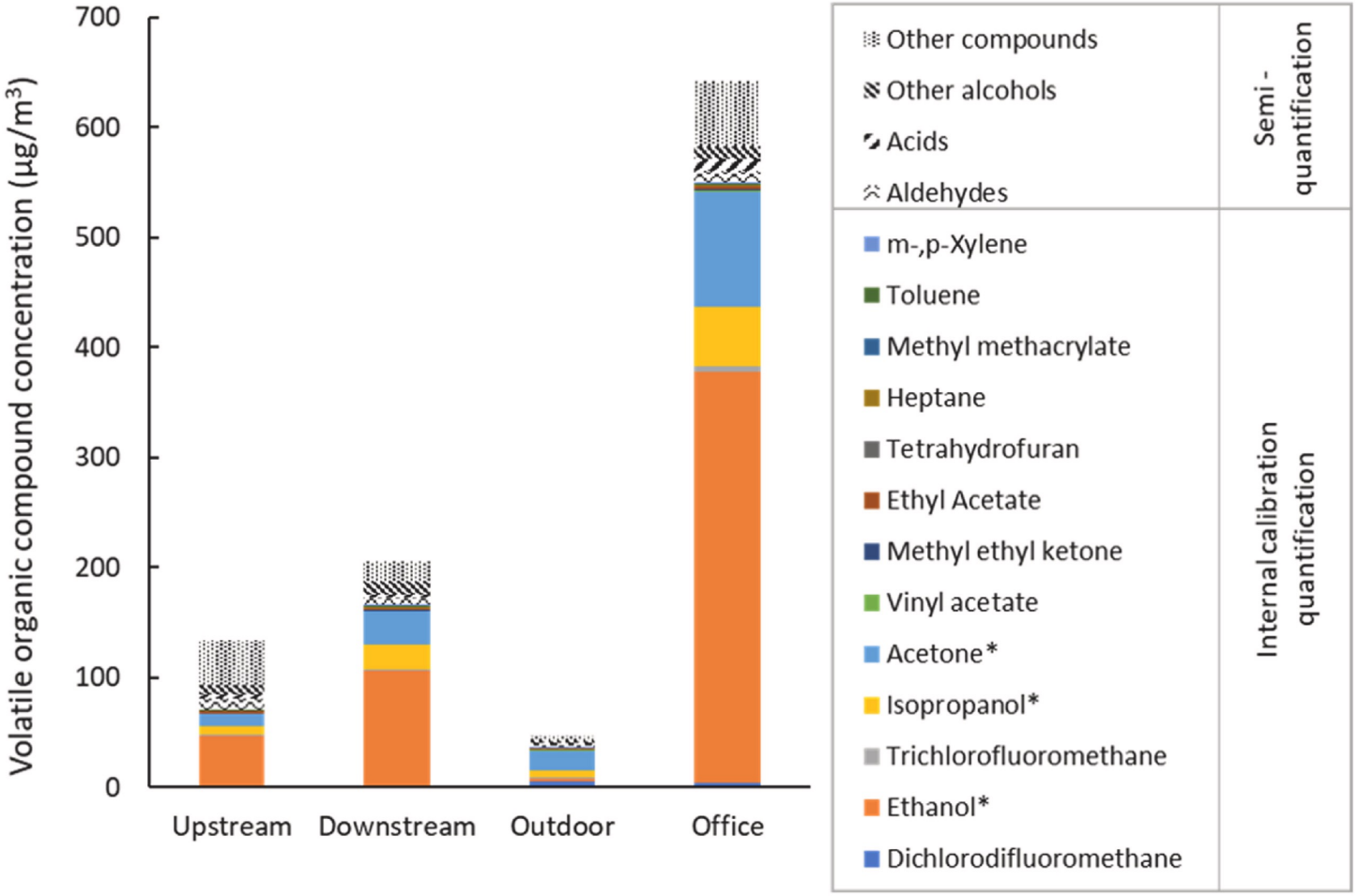
- No significant different with ionic cleaner on for I/O mass or number concentration ratios
- Ozone generated when ionizer was on





Pilot test
Unpublished data

Lab and field test to evaluate in-duct bipolar ionization device



- Ionization decreased some hydrocarbons (e.g. xylenes, increased others (e.g. acetone, ethanol, toluene)
- Minimally impacted particles, ozone and nitrogen dioxide
- small increased loss rates in $d_p < 0.15$ um
- Small decrease in loss rates in $d_p > 0.3$ um
- No impact on PM2.5 mass concentrations

Zheng, Y., et al., *Building and Environment*, 195 (2021) doi.org/10.1016/j.buildenv.2021.107750

CU Boulder Experimental Set-Up

Ceiling Duck – Supply Air

Room Sample Lines

Gas Valve Switching

Picarro – CH4, CO2, CO, H20

Ozone – O3

NOx box – NOx, NO, NO2

Make-up Flow Pump

GC

Vocus PTR

Electrostatic Classifier

CPC

Aerosol Valve Switching

Butanol Scrubber

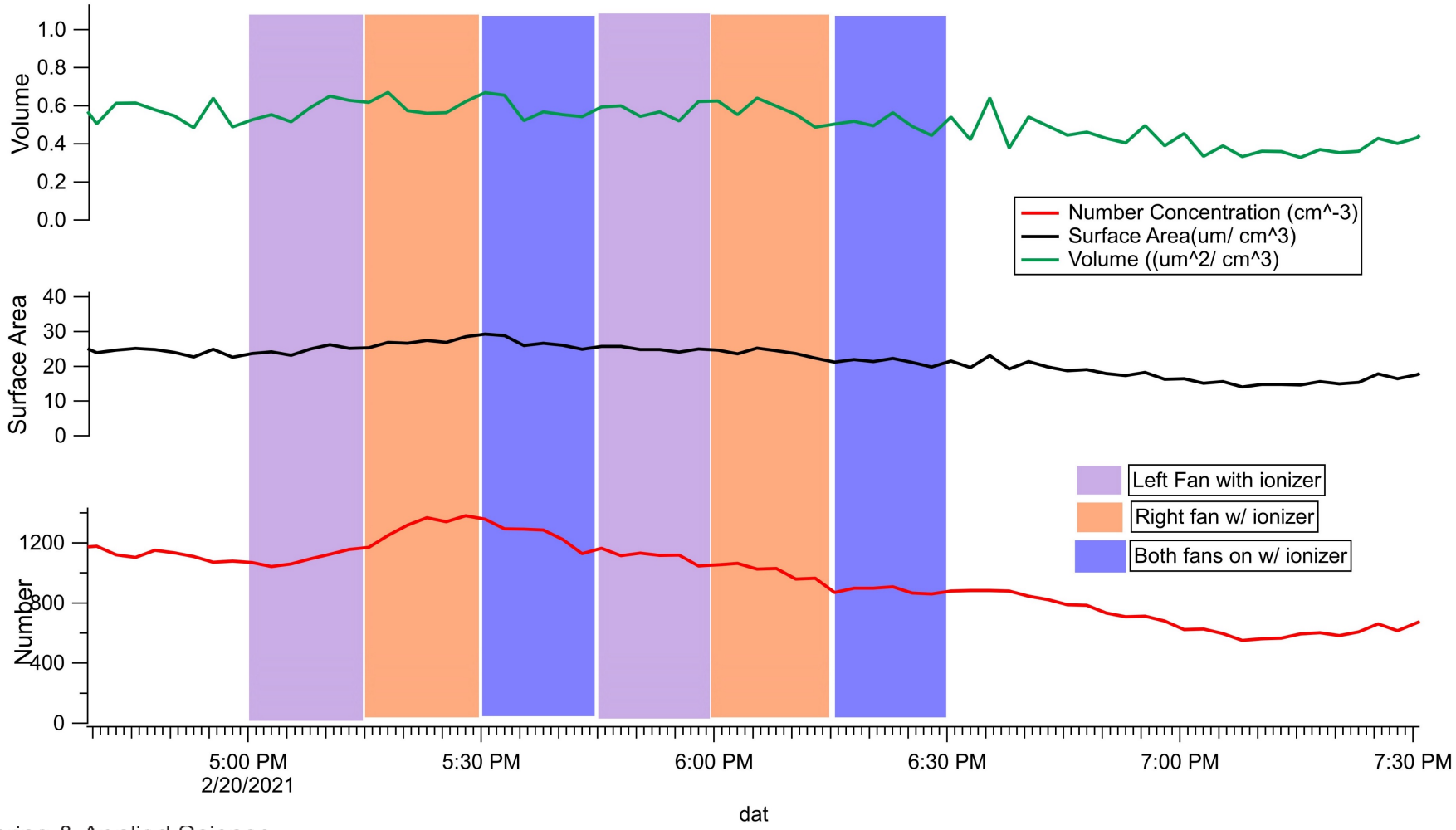
Primary Species

VOC – Gas Phase

SMPS -- Particles

Particle levels do not change with ionizer on

For this period no discernable buildup or reduction of particles as a result of the ionizers being on, minimal effect from switching of fans



Pilot test
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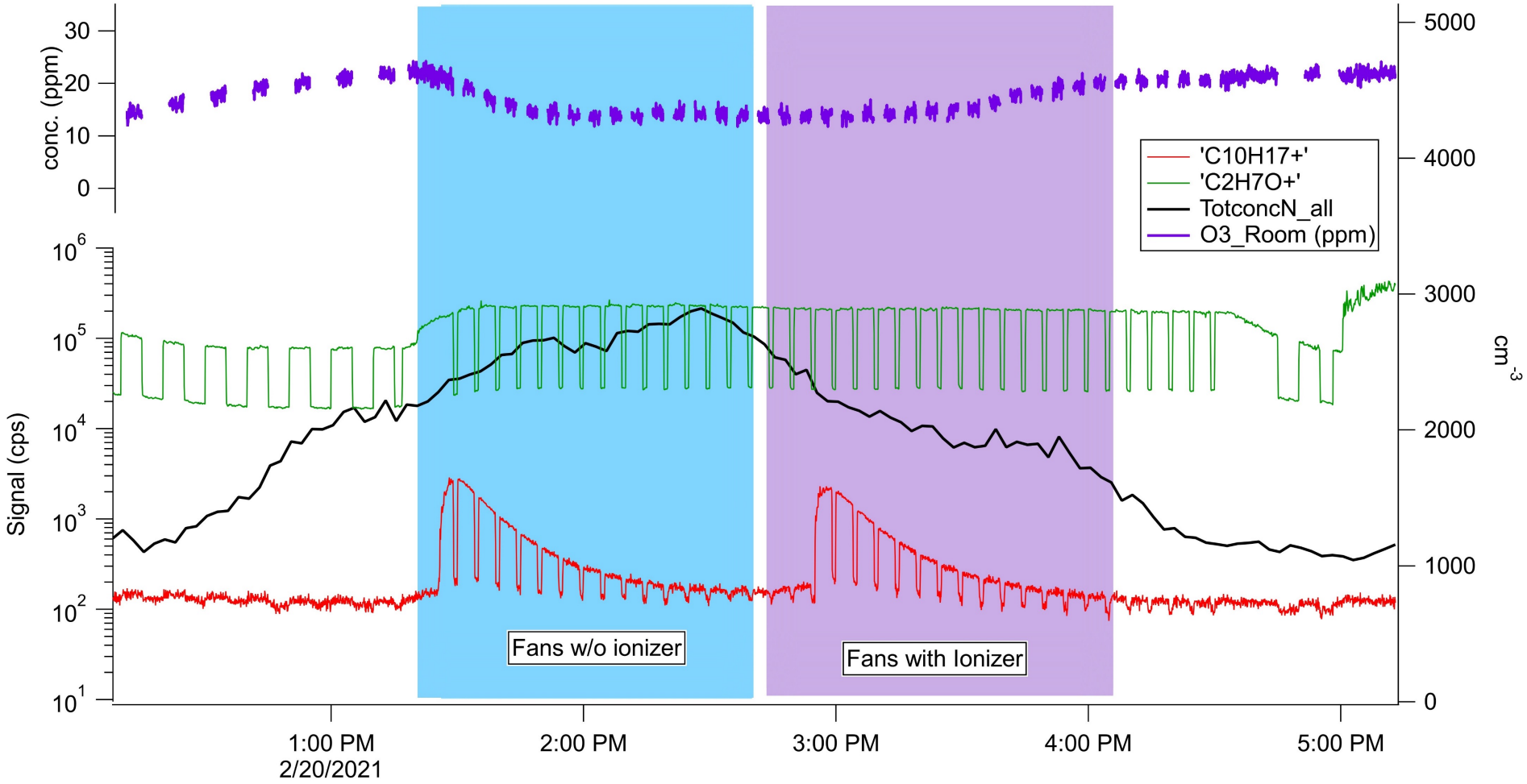
No measurable impact on VOCs



- Initial results don't show an obvious correlation between the ionizers and number of particles
- Fans do seem to impact concentration through flow (i.e. top trace) independent of ionizer being on or off
- Also potentially slight effects on ozone

Summary

- Portable air cleaners do work and work well for reducing airborne particles concentrations
- Mechanical filtration safest option for improving IAQ
- Sizing of air cleaner relative to size of room extremely important
- Maintenance is critical
- Lots of products being sold on market that look great, sound great, but are they great? May not be!

Summary

- Portable air cleaners do work and work well for reducing
- So stick to what we know, note
- what we have been learning
- recently, and avoid pitfalls
- Lots of products being sold on market that look great, sound great, but are they great? May not be!