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Indoor Air Quality and COVID-19

Jeffrey Siegel, jeffrey.siegel@utoronto.ca



PRESENTER DISCLOSURES

Speaker's Name: Jeffrey Siegel

Nature of relationship(s)	Name of for-profit or not-for-profit organization(s)	Description of relationship(s)
Any direct financial payments including receipt of honoraria	Amphenol, Pinchin, METUS, Tier Three	Consultant on Indoor Air Quality
Membership on advisory boards or speakers' bureaus	American Heart Association, ASHRAE, BOMA Toronto, HRAI, NASEM	Position document writing committee, advisory board, workshop organizing committee
Funded grants or clinical trials	NSERC, ASHRAE, NFRF	PI or co-PI on grant

MITIGATING POTENTIAL BIAS

- Content was peer-reviewed to ensure that principles of scientific integrity, objectivity and balance have been respected
- Moderator (with no COI) included to provide a balanced presentation of the prevailing body of scientific information and the current context

Life Expectancy
of Average
Canadian
(years)

Time spent
in home

Time spent in a
transportation
environment

81/72/54/27/4

Time spent
indoors

Time spent
sleeping

Indoor Air Sources

- Combustion
- Building materials
- Cooking
- Cleaning
- Outdoor air quality
- Chemical reactions
- Moisture problems
- Many, many, more



Indoor Air Quality (IAQ)— A brief history

Leviticus 14:33-53 New International Version (NIV)

³³ The LORD said to Moses and Aaron, ³⁴ “When you enter the land of Canaan, your possession, and I put a spreading mold in a house in that land, ³⁵ the and tell the priest, ‘I have seen something that looks like a defiling mold in my order the house to be emptied before he goes in to examine the mold, so that pronounced unclean. After this the priest is to go in and inspect the on the walls, and if it has greenish or reddish depressions that appear to be the wall, ³⁸ the priest shall go out the doorway of the house and close it up for seventh day the priest shall return to inspect the house. If the mold has order that the contaminated stones be torn out and thrown into an unclean must have all the inside walls of the house scraped and the material that is unclean place outside the town. ⁴² Then they are to take other stones to and plaster the house.

⁴³ “If the defiling mold reappears in the house after the stones have been torn scraped and plastered, ⁴⁴ the priest is to go and examine it and, if the mold a persistent defiling mold; the house is unclean. ⁴⁵ It must be torn down—its plaster—and taken out of the town to an unclean place.

“If there is a pile of manure in a space, do not try to remove the odor by ventilation. Remove the pile of manure.”
~ *Max von Pettenkofer, 1858*

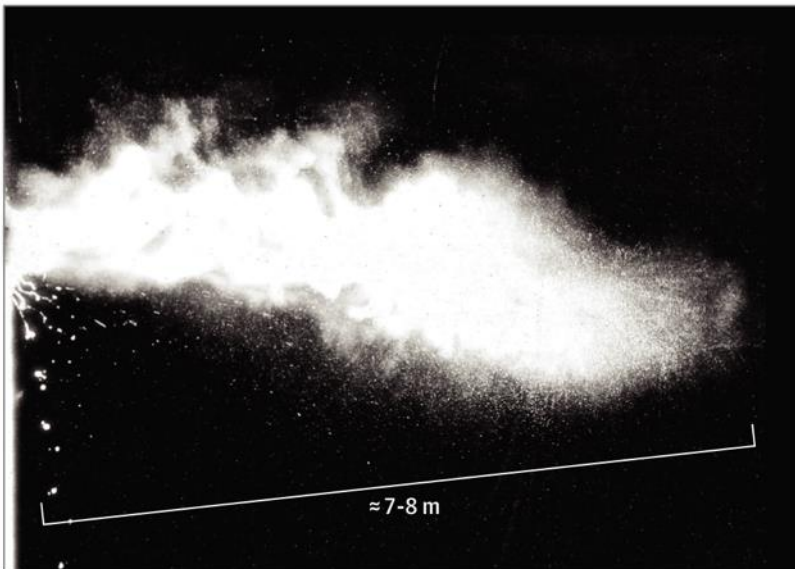
“When `the wise women buildeth her house,’ the first consideration will be to the health of the inmates. The first and most indispensable requisite for health is pure air, both by day and by night.”
~ *Harriet Beecher Stowe, 1869*

Indoor air quality impacts respiratory disease transmission, acute health outcomes (e.g., allergies an asthma), chronic health outcomes, cognitive function, well-being, productivity, etc.

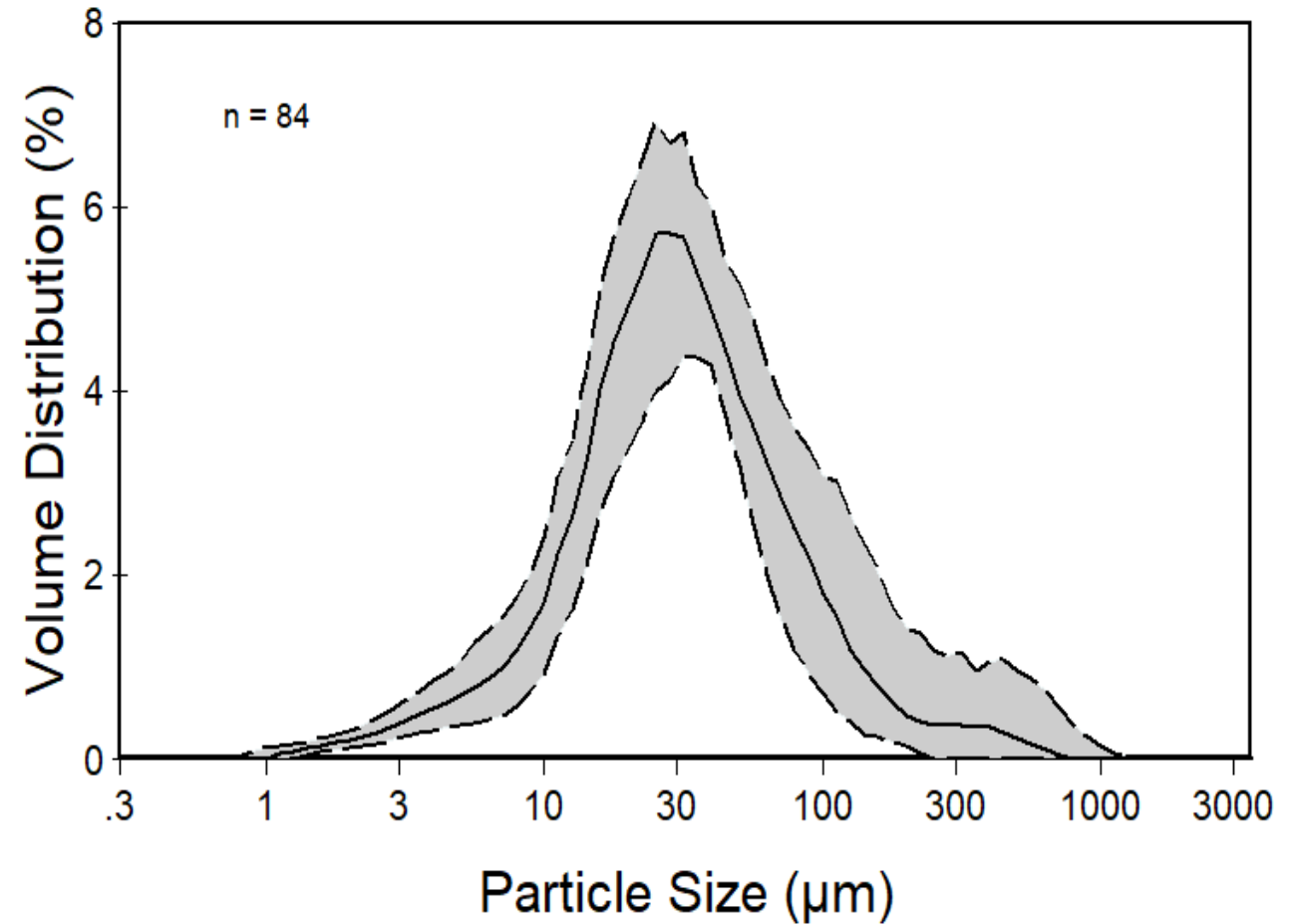
Indoor air quality is largely unregulated, represents the greatest environmental health risk for most Canadians, and poor IAQ disproportionately impacts vulnerable populations.

Now we have COVID-19.....

- My terminology
 - Airborne = in the air
 - Aerosol = suspension of particles and gases



Bourouiba (2020) JAMA

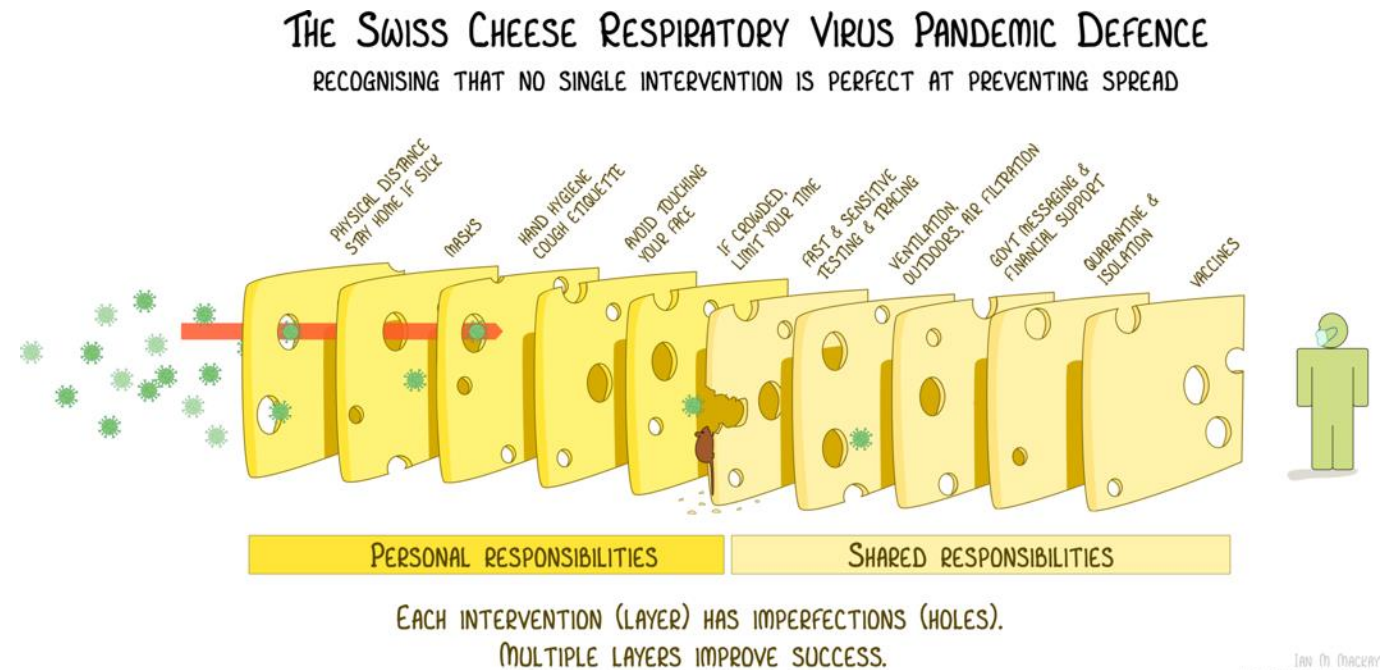


Mahdavi and Siegel (2021) *Indoor Air*

Crowded
Poorly Ventilated
Time in Environment

Filtration and Ventilation are not Silver Bullets

- They do not address close contact
- They are not a replacement for masks, physical distancing, handwashing surface cleaning
- They have to be done well to work



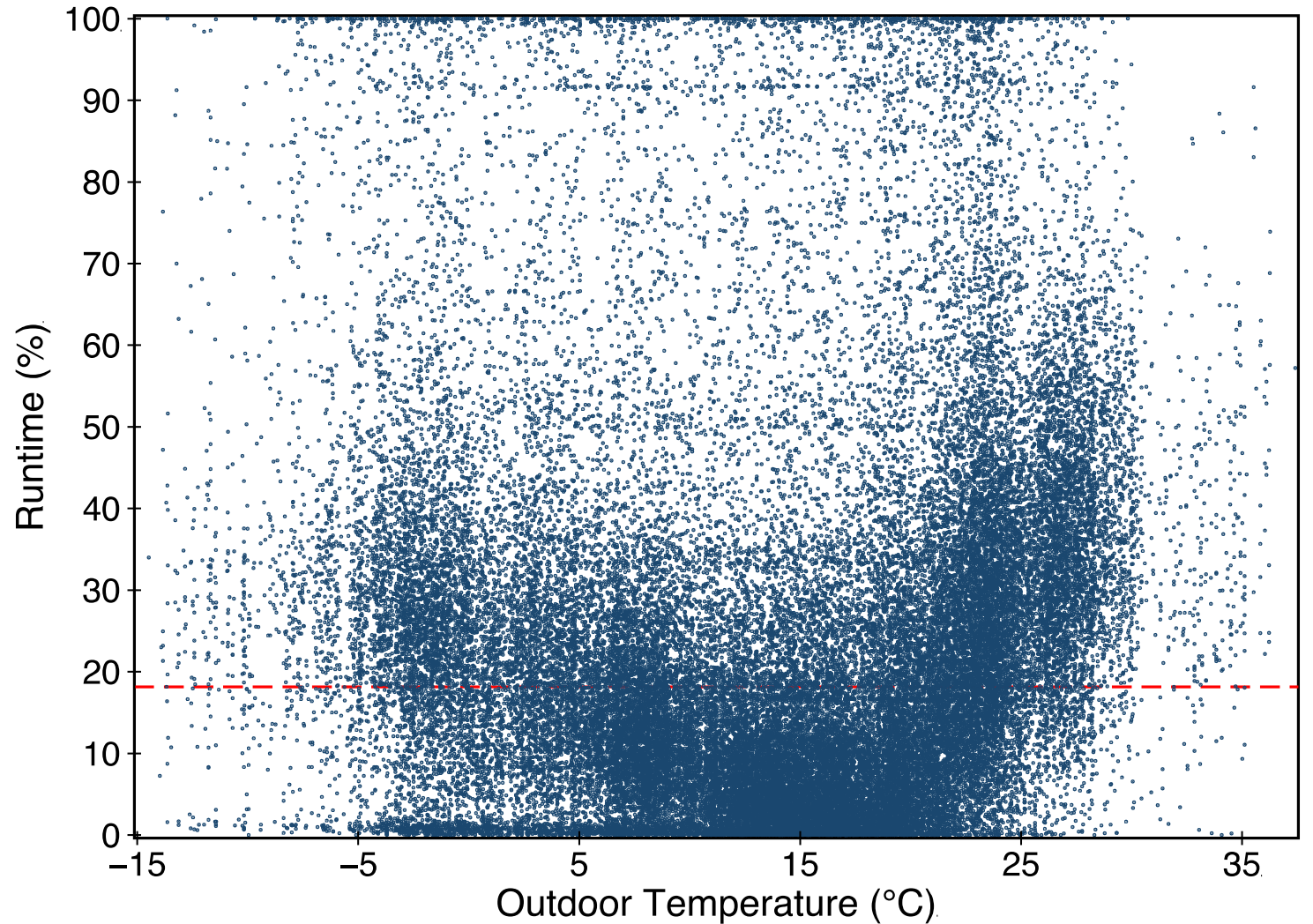
Filtration: Context is Everything

- The virus/particle/droplet/contaminant has to get to the filter before someone else breathes it in
- The filter has to remove the virus/particle/droplet/contaminant
- The removal to the device has to contribute substantially to overall removal

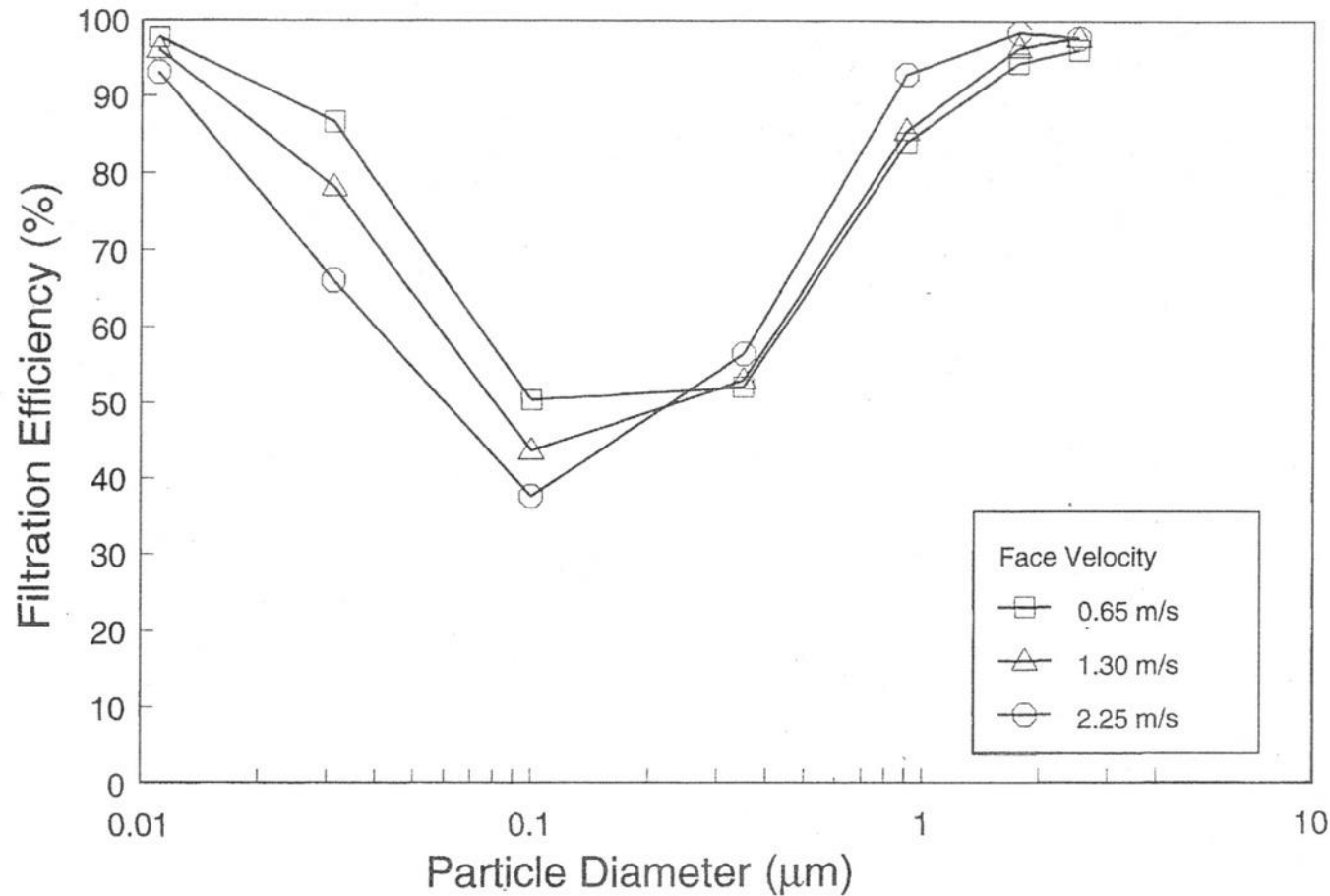
Airflow, In-situ efficiency, Effectiveness

Getting the Particles to a Filter

- Are air flows through system large enough?
- Are filtration and conditioning coupled?
- Is the HVAC air well-distributed in the space?



Efficiency: Classic U-shaped Curve



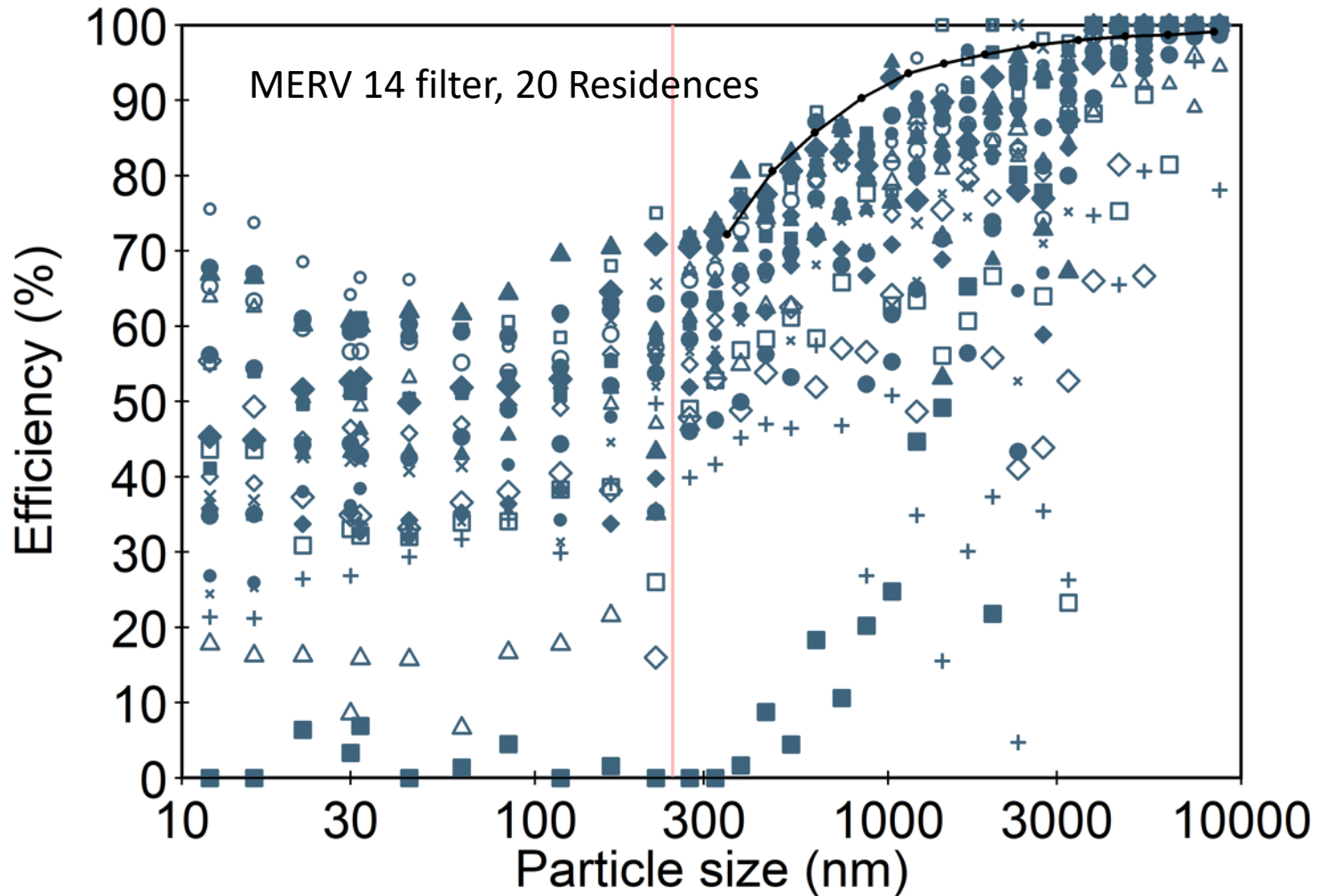
Ref: Hanley et al. (1994) *Indoor Air*

Table 12-1 Minimum Efficiency Reporting Value (MERV) Parameters

Standard 52.2 Minimum Efficiency Reporting Value (MERV)	Composite Average Particle Size Efficiency, % in Size Range, µm		
	Range 1 0.30 to 1.0	Range 2 1.0 to 3.0	Range 3 3.0 to 10.0
1	N/A	N/A	$E_3 < 20$
2	N/A	N/A	$E_3 < 20$
3	N/A	N/A	$E_3 < 20$
4	N/A	N/A	$E_3 < 20$
5	N/A	N/A	$20 \leq E_3$
6	N/A	N/A	$35 \leq E_3$
7	N/A	N/A	$50 \leq E_3$
8	N/A	$20 \leq E_2$	$70 \leq E_3$
9	N/A	$35 \leq E_2$	$75 \leq E_3$
10	N/A	$50 \leq E_2$	$80 \leq E_3$
11	$20 \leq E_1$	$65 \leq E_2$	$85 \leq E_3$
12	$35 \leq E_1$	$80 \leq E_2$	$90 \leq E_3$
13	$50 \leq E_1$	$85 \leq E_2$	$90 \leq E_3$
14	$75 \leq E_1$	$90 \leq E_2$	$95 \leq E_3$
15	$85 \leq E_1$	$90 \leq E_2$	$95 \leq E_3$
16	$95 \leq E_1$	$95 \leq E_2$	$95 \leq E_3$

ASHRAE Standard 52.2-2017

Lab Efficiency is Not In-situ Efficiency

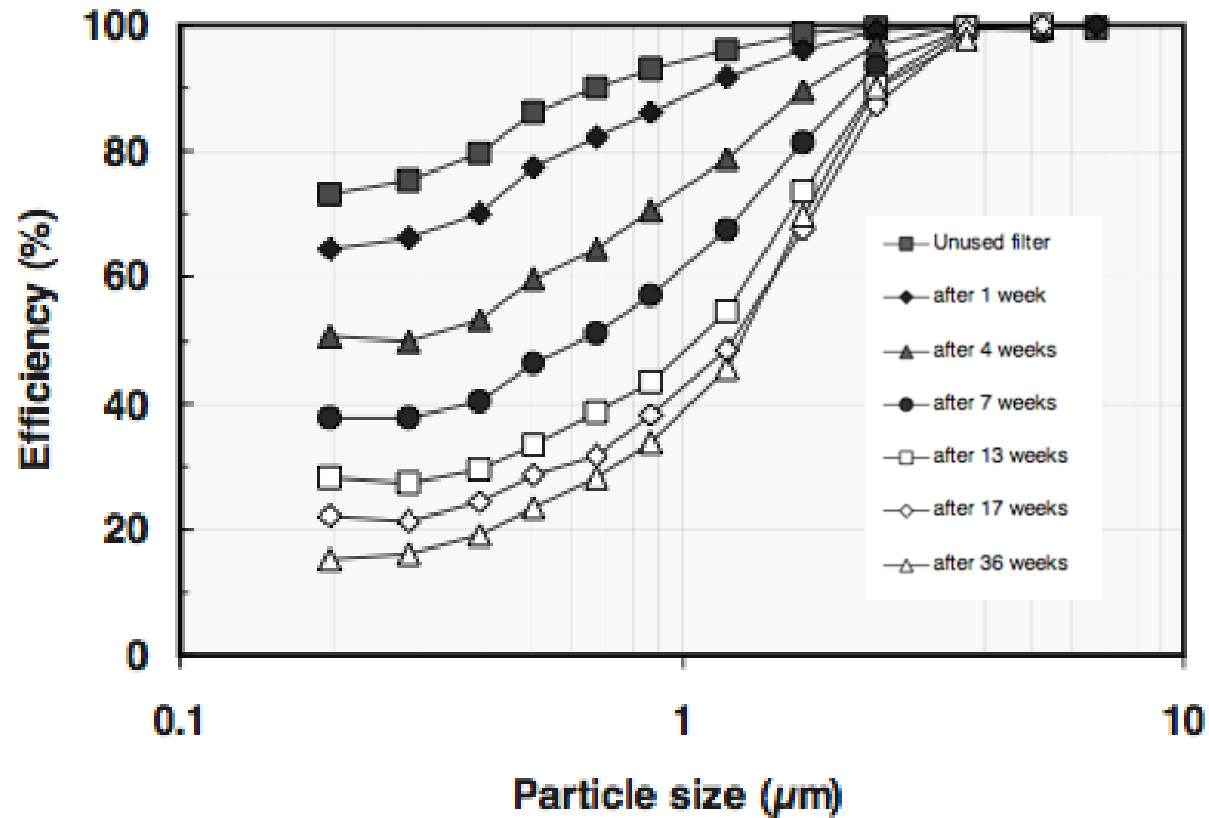


Li and Siegel (2020) *Indoor Air*

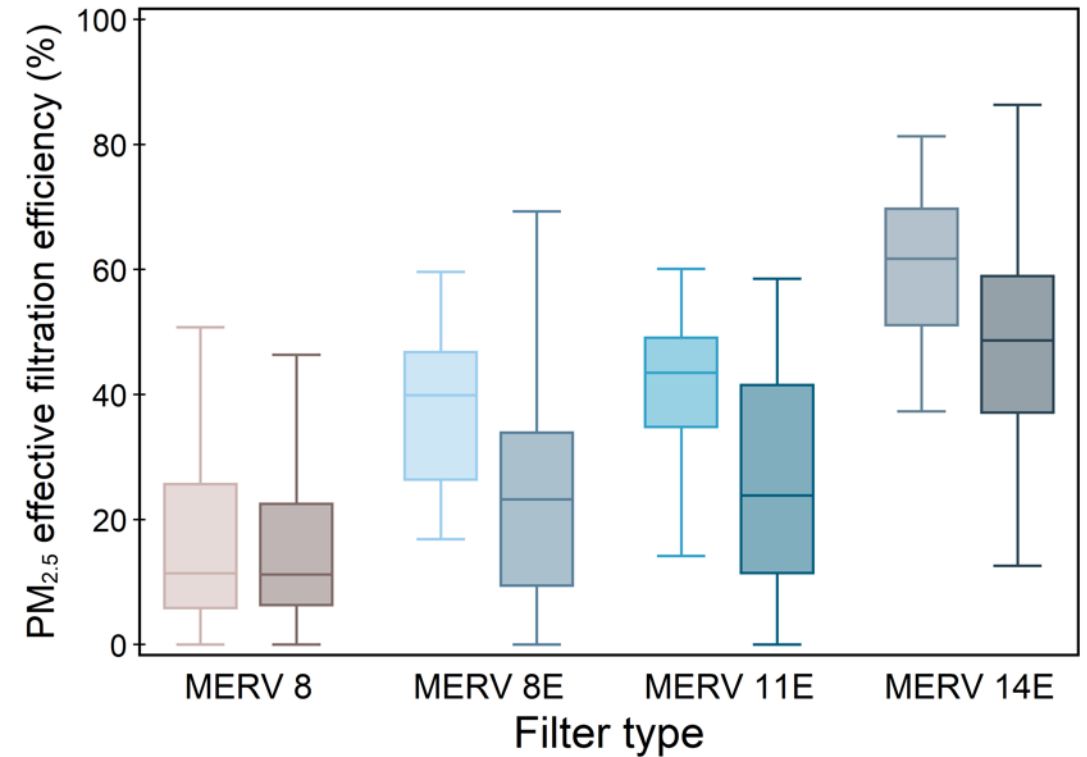


Image: Courtesy Geoffroy Allard

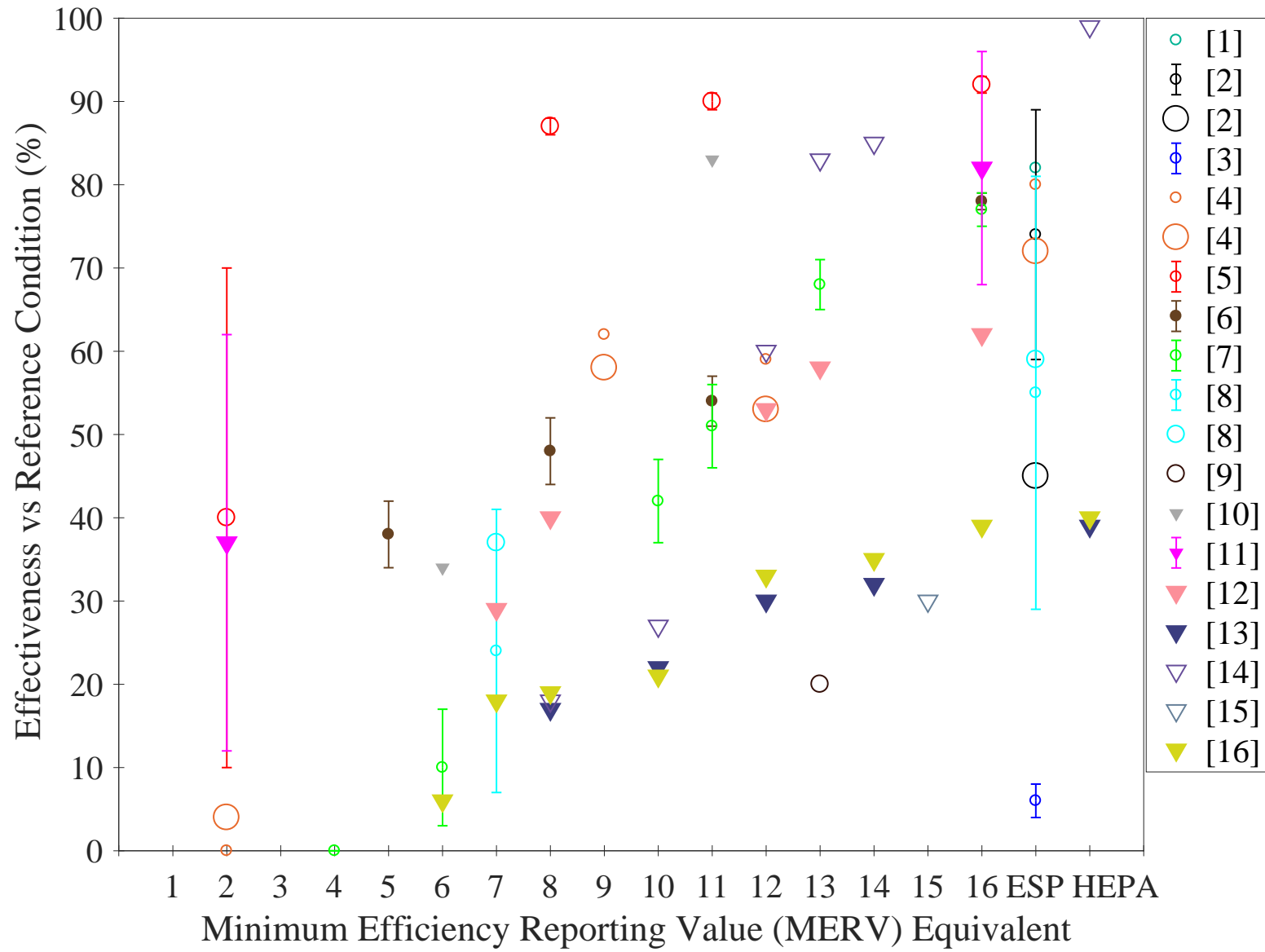
Efficiency: Filter Aging



Ref: Lehtimäki et al. (2002) ASHRAE RP-1189 Report



Li and Siegel (2020) *Indoor Air*



Install a good filter properly, use it well, make sure lots of air goes through it, change it frequently (carefully). Don't rely on it as the only approach.

HVAC and Infectious Disease: Ventilation

Indoor Air 2007; 17: 2–18
www.blackwellpublishing.com/ina
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INDOOR AIR
doi:10.1111/j.1600-0668.2006.00445.x

Review Article

Role of ventilation in airborne transmission of infectious agents in the built environment – a multidisciplinary systematic review

There is strong and sufficient evidence to demonstrate the association between ventilation, air movements in buildings and the transmission/spread of infectious diseases such as measles, tuberculosis, chickenpox, influenza, smallpox and SARS. There is insufficient data to specify and quantify the minimum ventilation requirements in hospitals, schools, offices, homes and isolation rooms in relation to spread of infectious diseases via the airborne route.

Li et al. (2007) *Indoor Air*

Challenges with Ventilation

- i. Capacity – Is there enough heating or cooling?
 - Practically, limitation is often on hot/humid days
 - Solutions – use controls to limit ventilation and match occupancy, provide supplementary cooling
- ii. Humidity – Is the relative humidity between 40-60%?
 - Why? – drying of droplets, susceptibility, comfort
 - Solutions – humidify (carefully), supplementary dehumidification
- iii. Outdoor air quality – Is ventilation causing harm?

Indoor Particle Concentrations Associated with Use of Tap Water in Portable Humidifiers

V. Ross Highsmith* and Charles E. Rodes

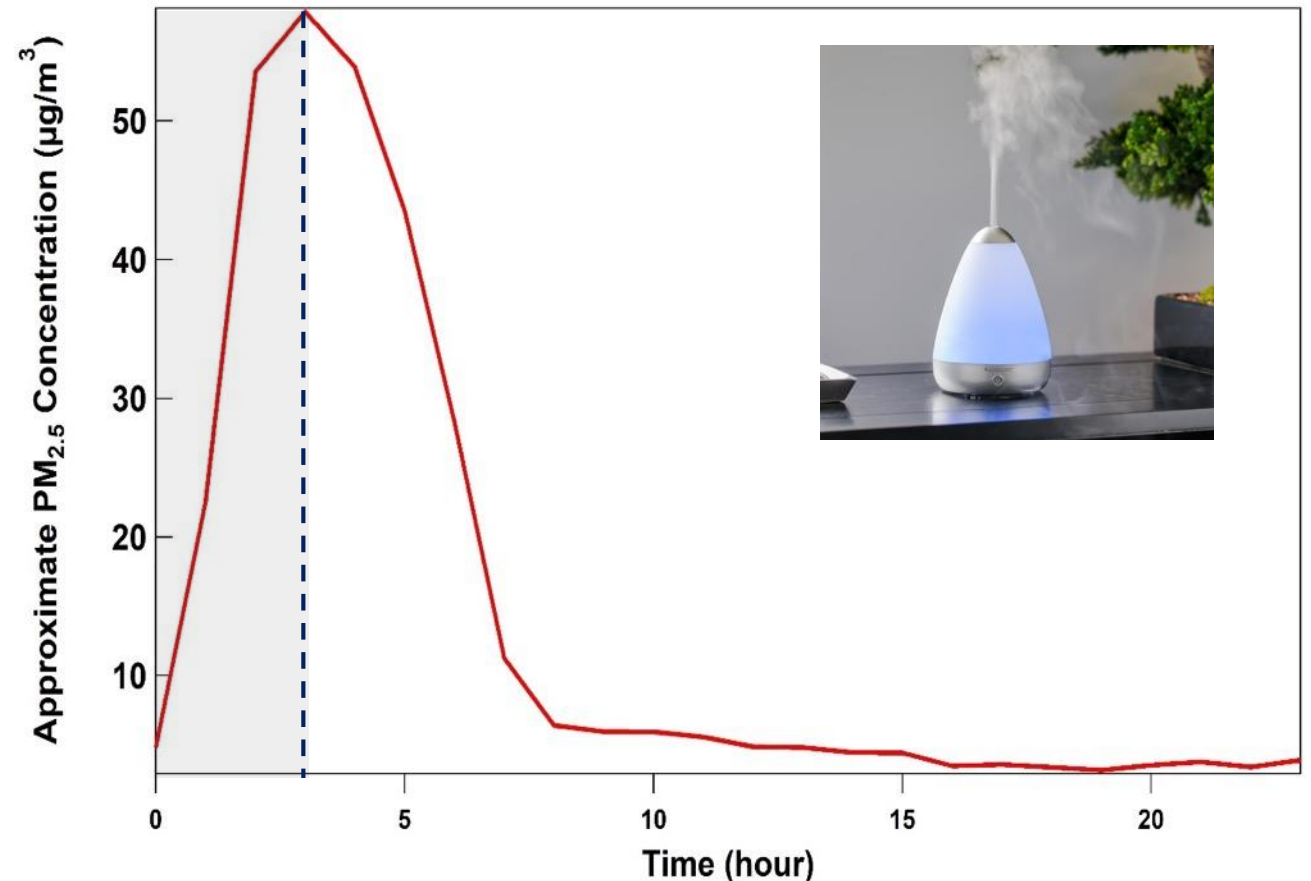
Environmental Monitoring Systems Laboratory, U.S. Environmental Protection Agency,
Research Triangle Park, North Carolina 27711

Richard J. Hardy

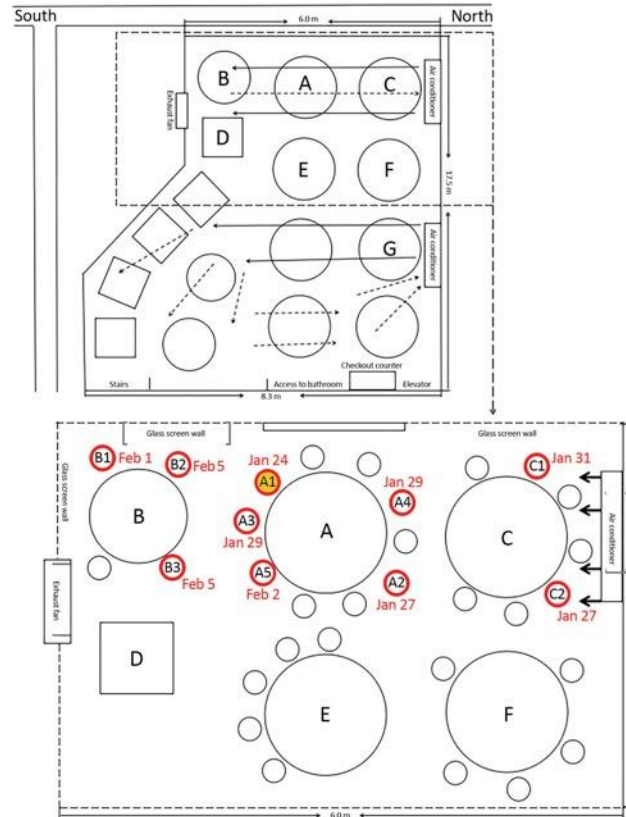
Morrison-Knudsen Engineers, Boise, Idaho 83709

Humidification

- i. Ultrasonic or cool mist
 - Particle generation
- ii. Evaporative
 - Often not effective
- iii. Steam
 - All humidifiers need maintenance, ideally distilled water, management of risk of moisture problem



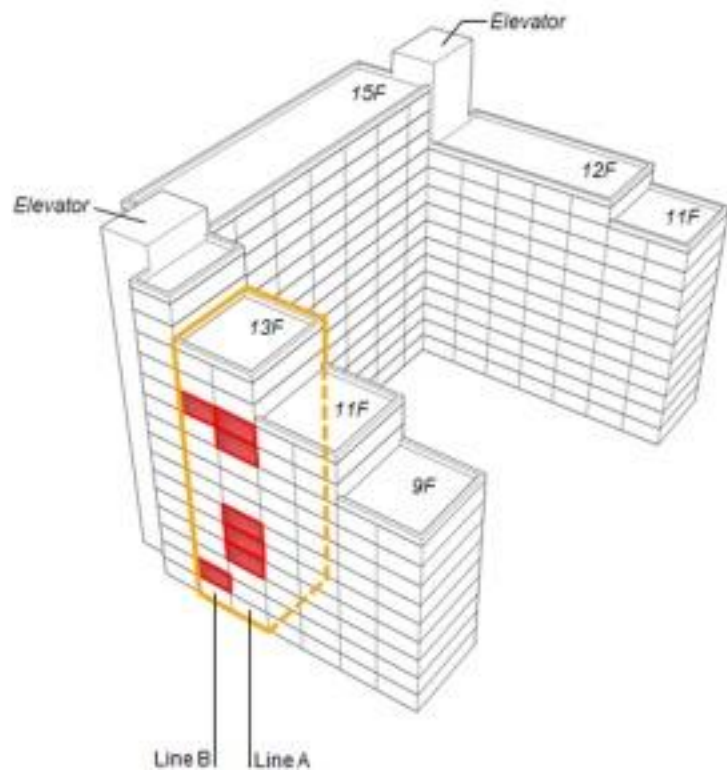
Air Movement



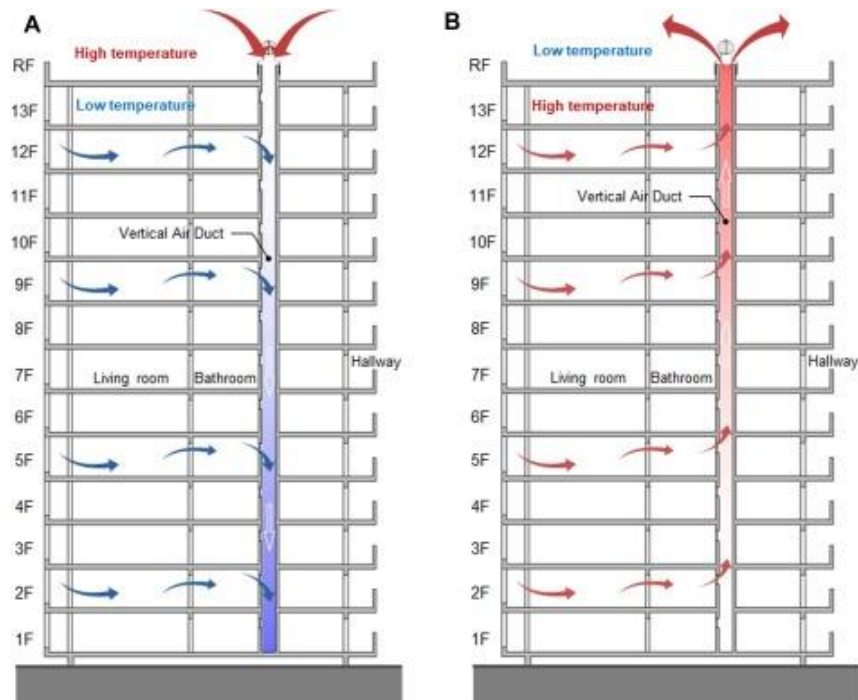
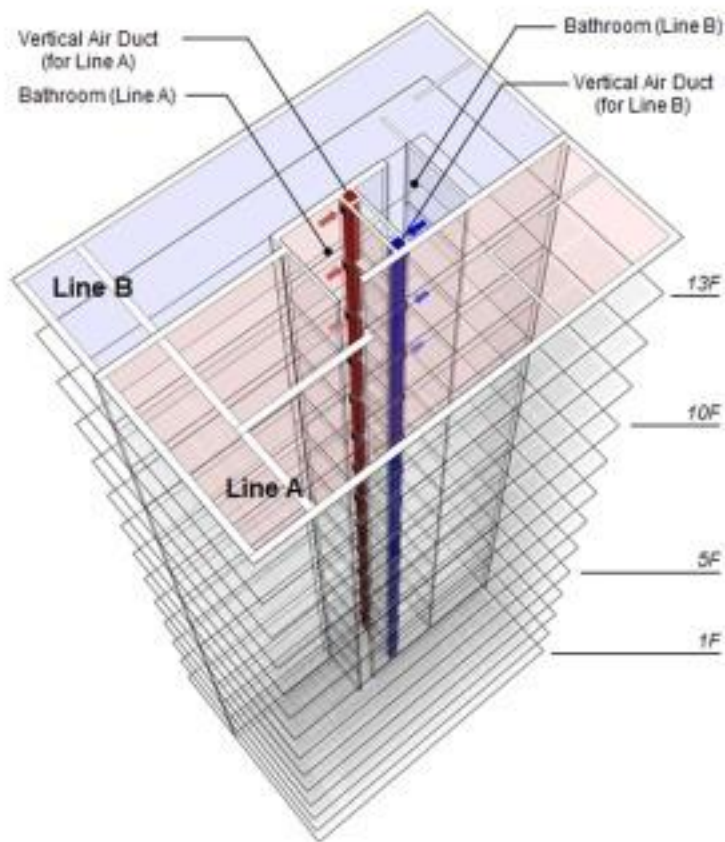
On January 23, 2020, family A traveled from Wuhan and arrived in Guangzhou. On January 24, the index case-patient (patient A1) ate lunch with 3 other family members (A2–A4) at restaurant X. Two other families, B and C, sat at neighboring tables at the same restaurant. Later that day, patient A1 experienced onset of fever and cough and went to the hospital. By February 5, a total of 9 others (4 members of family A, 3 members of family B, and 2 members of family C) had become ill with COVID-19.

Lu J, Gu J, Li K, Xu C, Su W, Lai Z, et al. COVID-19 Outbreak Associated with Air Conditioning in Restaurant, Guangzhou, China, 2020. *Emerg Infect Dis.* 2020;26(7):1628-1631. <https://dx.doi.org/10.3201/eid2607.200764>

A. Confirmed Households



B. Characteristic of Unit Plan



Possible aerosol transmission of COVID-19 associated with an outbreak in an apartment in Seoul, South Korea, 2020

Seo Eun Hwang^{a,b}, Je Hwan Chang^{c,d}, Bumjo Oh^a, Jongho Heo^{e,f,*}

<https://doi.org/10.1016/j.ijid.2020.12.035>

Exhaust air from nearby buildings
Outdoor air intake

Re-entrainment
Recirculation duct

Exhaust

Legend



Air handling unit



Air supply duct



Air return duct



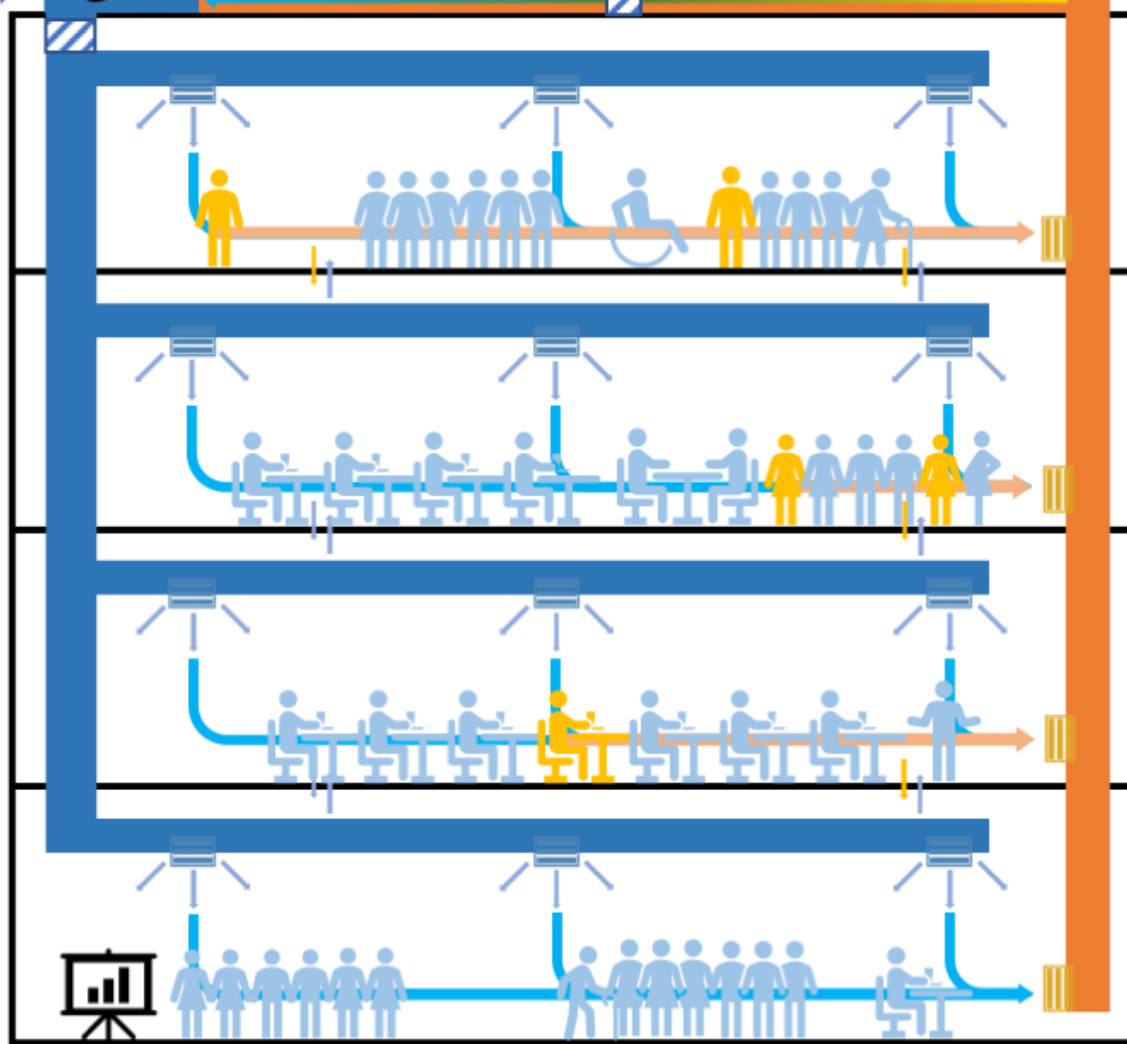
High efficiency particle filter

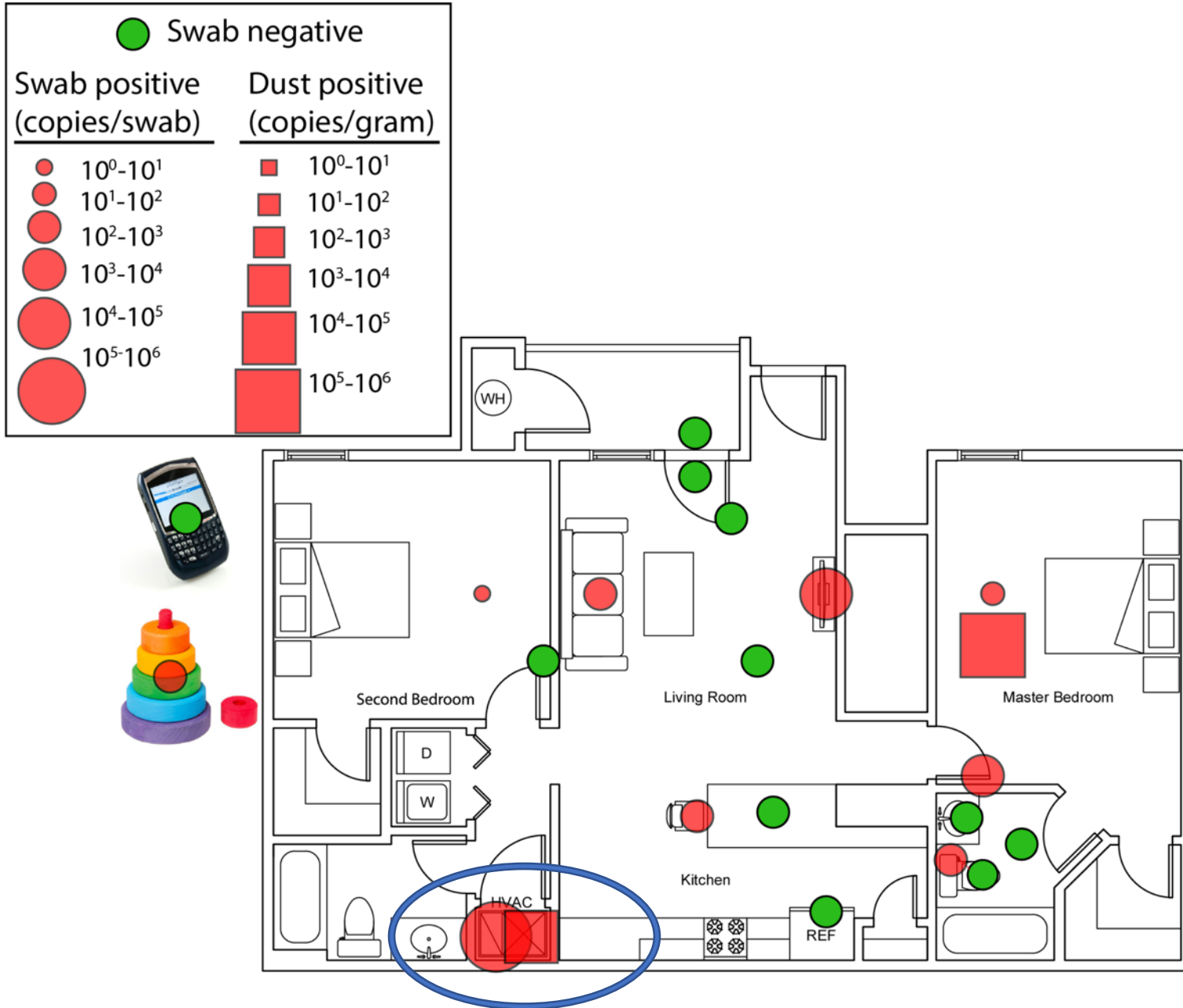


Infected individuals



Healthy individuals





What Else Can We Do?

Stronger Inferred Evidence

- Ultraviolet disinfection
- Portable air cleaners

Weaker inferred Evidence

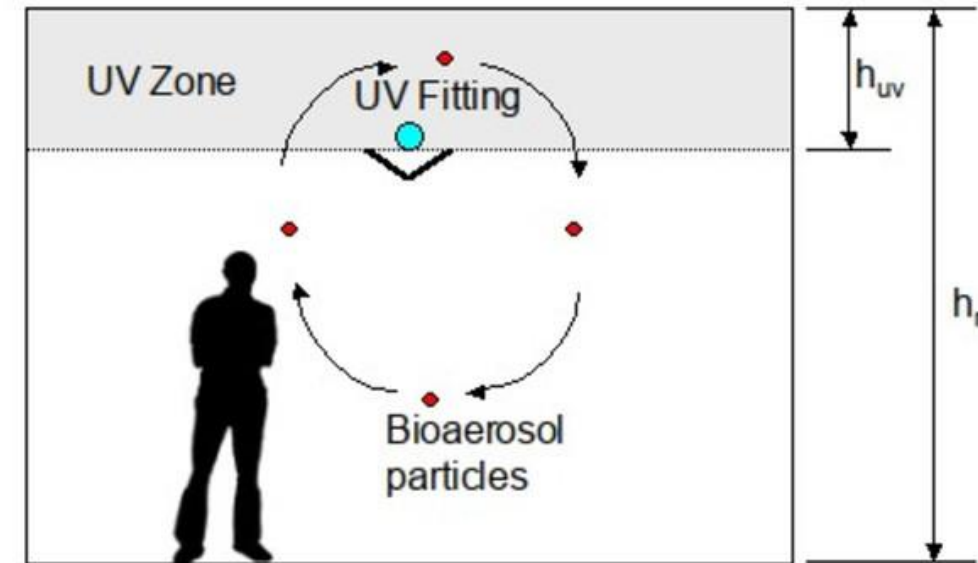
- Room flush outs
- CO₂ monitoring
- Open windows

Potential Harms

- Untested air cleaning devices

Ultraviolet Disinfection

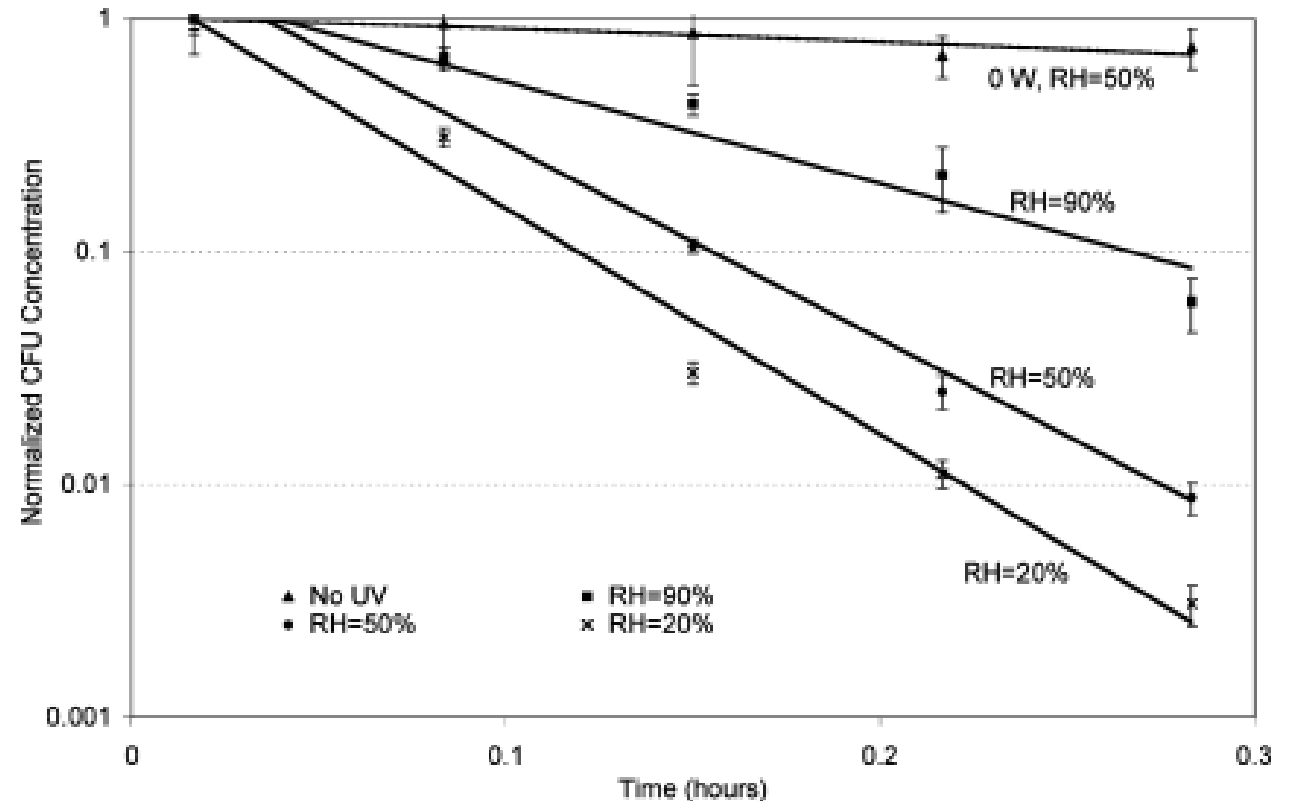
- Evidence for other microorganisms and limited evidence for SARS-CoV-2
 - Properly sized and maintained in-duct systems
 - Upper room UV systems in high-risk locations
- Suggest caution because of insufficient UV dose
 - Coil irradiation systems
 - Portable systems



<https://peerj.com/articles/10196/>

Effective Use of Ultraviolet Disinfection

- Safety/interlocks
- Airflow
- UV compatibility of materials
- Environmental conditions
- Avoid ozone emission
- Maintenance
- Far-UV (wavelength ~ 220 nm)
 - Demonstrated efficacy
 - Higher safety
 - Ozone emission is unknown



Xu et al. (2005) *Environ. Sci. Tech.*
<https://doi.org/10.1021/es0504892>

HVAC and Infectious Disease: Portable Filtration

Effectiveness of In-Room Air Filtration and Dilution Ventilation for Tuberculosis Infection Control

<https://doi.org/10.1080/10473289.1996.10467523>

S. Miller-Leiden, C. Lobascio, and W. W. Nazaroff
University of California, Berkeley, California

J.M. Macher
Environmental Health Laboratory Branch, California Department of Health Services, Berkeley, California

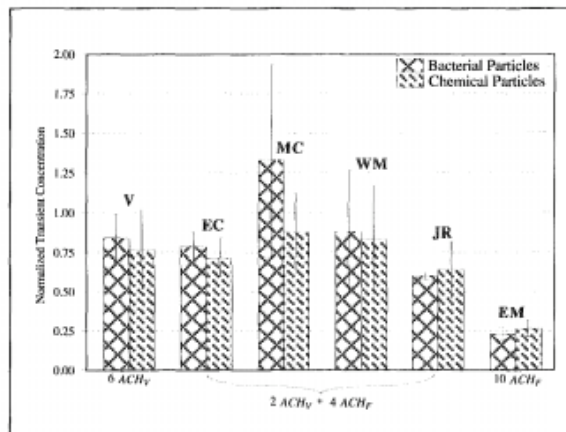
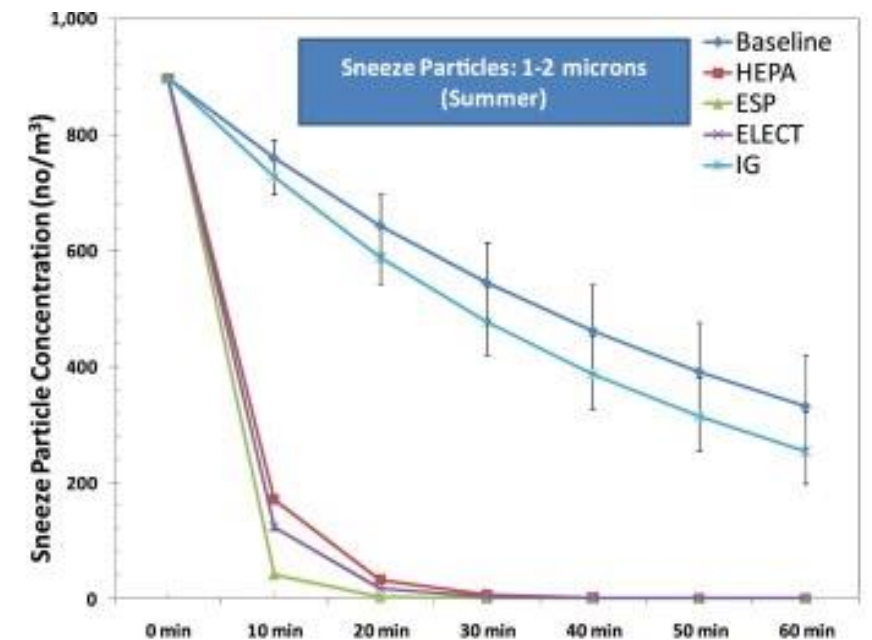


Figure 7. Normalized transient concentrations for experiments with chemical and bacterial aerosols. Each shaded bar represents the room-average concentration measured during scenarios with ventilation only (V), with PAFs (EC, MC, WM, JR), and with a CMAF (EM). Error bars represent the standard deviation of the concentrations measured at different room locations. The difference between the chemical and bacterial particle values was not statistically significant at the 0.05 level using a paired *t*-test.



Removing indoor particles using portable air cleaners: Implications for residential infection transmission

Effective Use of Portable air Cleaners

- Clean air delivery rate (CADR) is the most important parameter associated with an air cleaner
 - Most focus on efficiency – this is incomplete
- Calculate room air changes through the air cleaner (ACH)
- $ACH = CADR \times 60 \div \text{room volume}$, CADR is in CFM, room volume in ft^3
 - 3/hour for general protection
 - 6/hour for higher risk spaces (comes from tuberculosis literature)
- Secondary: Noise, placement, maintenance (filter change)

Additional Approaches

- Room flush outs between occupancy
 - 3 ACH or 2 hours
- CO₂ monitoring
 - CO₂ is an indicator, not a guarantee
 - Accurate and representative measurement is a major concern
 - CO₂ as a control parameter requires attention
- Open windows
 - An open window is a hole not airflow
 - Ventilation increases, but amount is unknown
 - Impact on space can be highly variable



Ref: Allergy Cosmos

“Reduce up to 99% of allergies, odors, mold, germs, and other contaminants.”

“40X better than a HEPA filter”

“Ions: Mother Nature's Little Air Scrubbers.”

“The only air purifier to clean a whole room.”

“True-HEPA rated.”

“Our technology is in The Whitehouse”

“Captures and destroys pollutants 1000 times smaller than HEPA filters.”

What About Other Air Cleaning Technologies

- Photocatalytic oxidation
- Plasma
- Ionization
- Sprays (chemical and biological)

This is a suitable place to give a most earnest warning against the use of so-called secret remedies and patent medicines.... Pettenkofer (1883)

- These are **not** terms with firm definitions
- There is not independent evidence of efficacy
- There is evidence of harm (ozone emission, ion concentration, byproduct formation)

Buyer Beware.....

Overall Summary

- Filtration and ventilation have a role in protecting our buildings from COVID-19, but
 - They are not magic and don't work by themselves
 - They have to be implemented carefully and thoughtfully
- Suggested approach
 - Reinforcement of primary measures (masks, physical distancing, handwashing/surface cleaning)
 - Better ventilation and filtration improve overall health, productivity, and cognitive function and reduce healthcare costs and sick leave
 - COVID-19 risk reduction is an additional benefit
 - Consider additional measures for high-risk spaces

HVAC & building measures should be in our toolkit.
They take investment, but benefits far exceed costs.
Single biggest challenge is overcoming decades of inaction.
Substantial opportunity to address health disparities that
arise because of indoor air exposures.

Further Questions: jeffrey.siegel@utoronto.ca