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CANADIAN CENTRE FOR BUILDING EXCELLENCE

Engineering Health and Efficiency

COVID and HVAC: A Practical Perspective

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- 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

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, OSSTF, ATU	Consultant on Indoor Air Quality
Membership on advisory boards or speakers' bureaus	American Heart Association, ASHRAE, BOMA, 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

Acronyms: ASHRAE = American Society of Heating, Refrigeration, and Air-Conditioning; ATU = Amalgamated Transit Union Local 113; BOMA = Building Owners and Managers Association Toronto; HRAI= Heating, Refrigeration, and Air-conditioning Institute of Canada; METUS = Mitsubishi Electric Trane US; NASEM = National Academies of Science, Engineering, and Medicine; NFRF = New Frontiers in Research Fund; NSERC = Natural Science and Engineering Research Council of Canada; OSSTF = Ontario Secondary School Teachers' Federation

Motivation and Goals

- March PHO presentation: Why?
- Today: How?

As we move into a new phase of pandemic, how can we achieve safety against COVID-19 and other respiratory viruses/indoor air quality issues

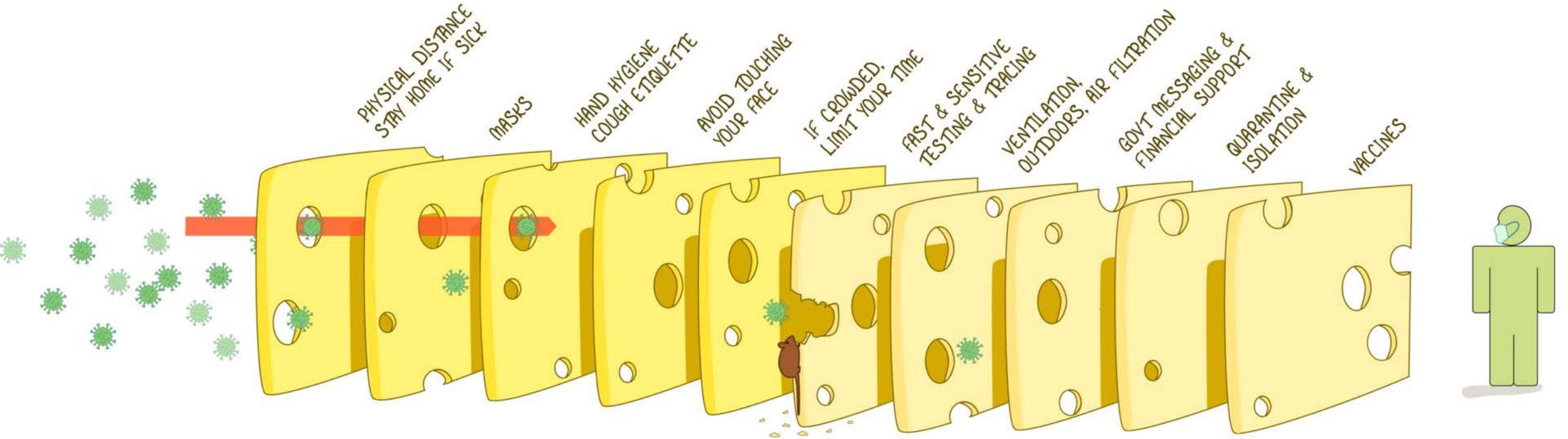
Motivation

- It is not just COVID-19….
- Healthy indoor environments:
  - Improve cognitive performance and learning
  - Increase productivity
  - Improve performance on standardized tests
  - Reduce absenteeism from school and work
  - Reduce asthma frequency and severity
  - Cause students to have higher salaries when they graduate
  - Lower healthcare costs

e.g., Fisk and Rosenfeld (2004) *Indoor Air*
Vakalis et al. (2021) *Crit Rev Environ Sci Tech*

The Swiss Cheese Respiratory Virus Pandemic Defence

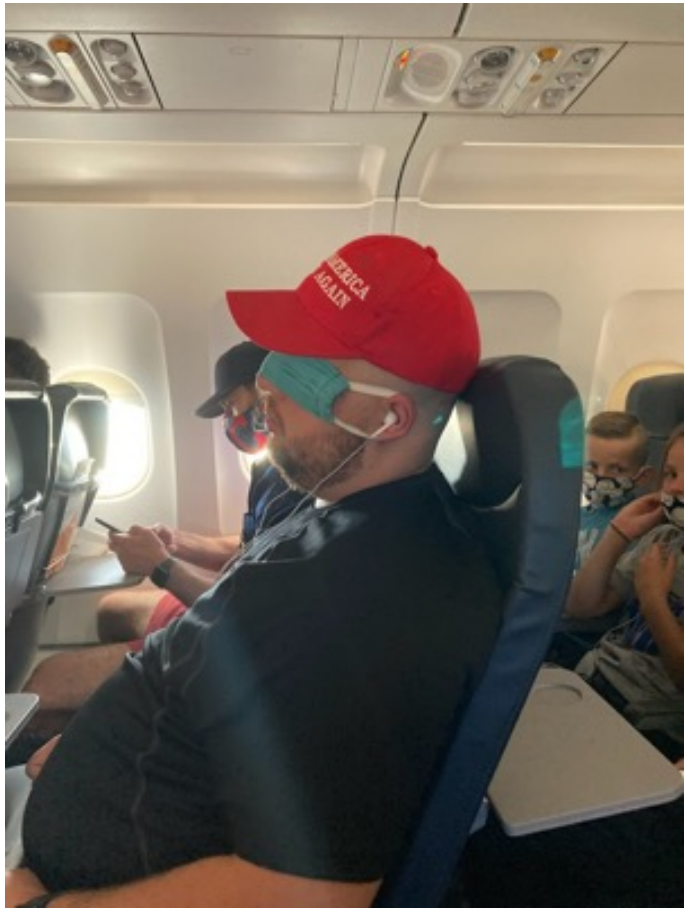
Recognising that no single intervention is perfect at preventing spread



Each intervention (layer) has imperfections (holes).
Multiple layers improve success.

Ian M Mackay
virologydownunder.com
With thanks to Jody Lanard, Katherine Arden & the Uni of Qld
Based on the Swiss cheese model of accident causation, by James T Reason, 1990
version 3.0
update: 24oct2020

Challenges with Layers: Layer Porosity



https://www.republicworld.com/world-news/us-news/us-man-uses-face-mask-to-cover-eyes-while-dozing-on-flight.html

https://starecat.com/chinese-man-smoking-a-cigarette-through-hole-in-face-mask/

Challenges with Layers: Layer Bypass

https://news.unl.edu/newsrooms/today/article/teams-buzz-about-mapping-learning-spaces-for-fall/

Hannah Watters, https://www.cnn.com/2020/08/07/us/georgia-teen-photo-crowded-school-hallway-trnd/index.html

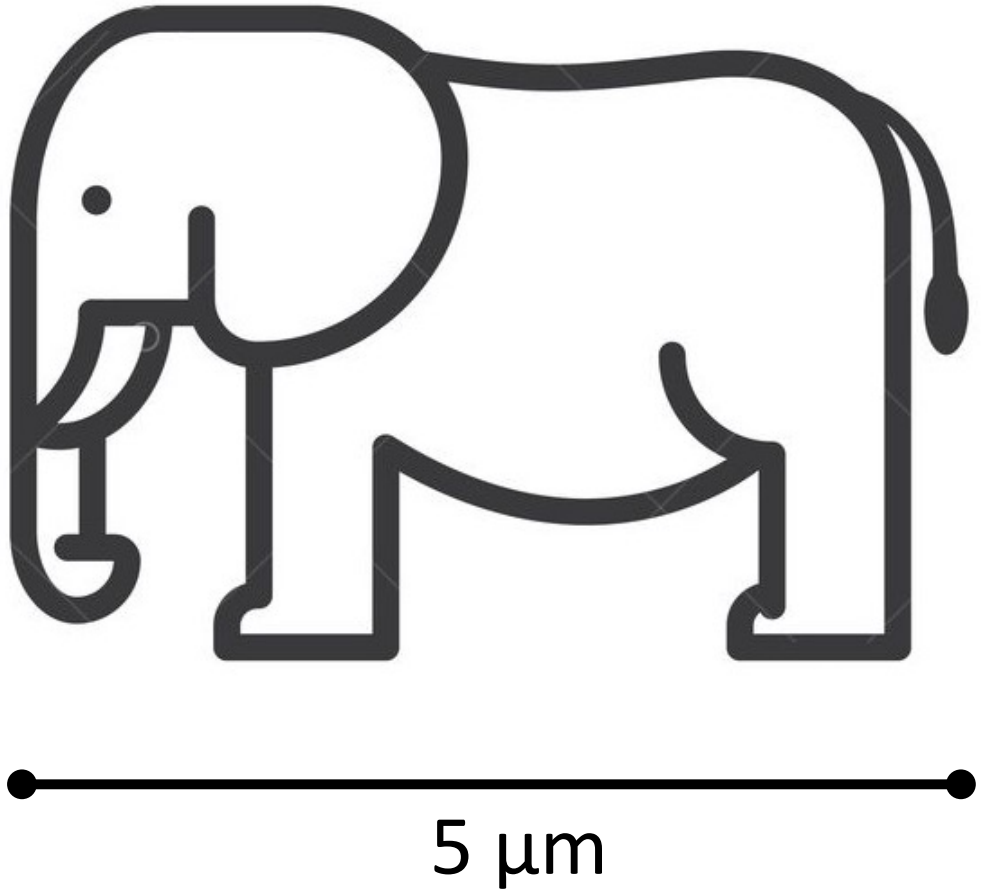
Ventilation and Filtration

Fresh air from outside

Recirculated air that has been filtered to remove infectious respiratory particles

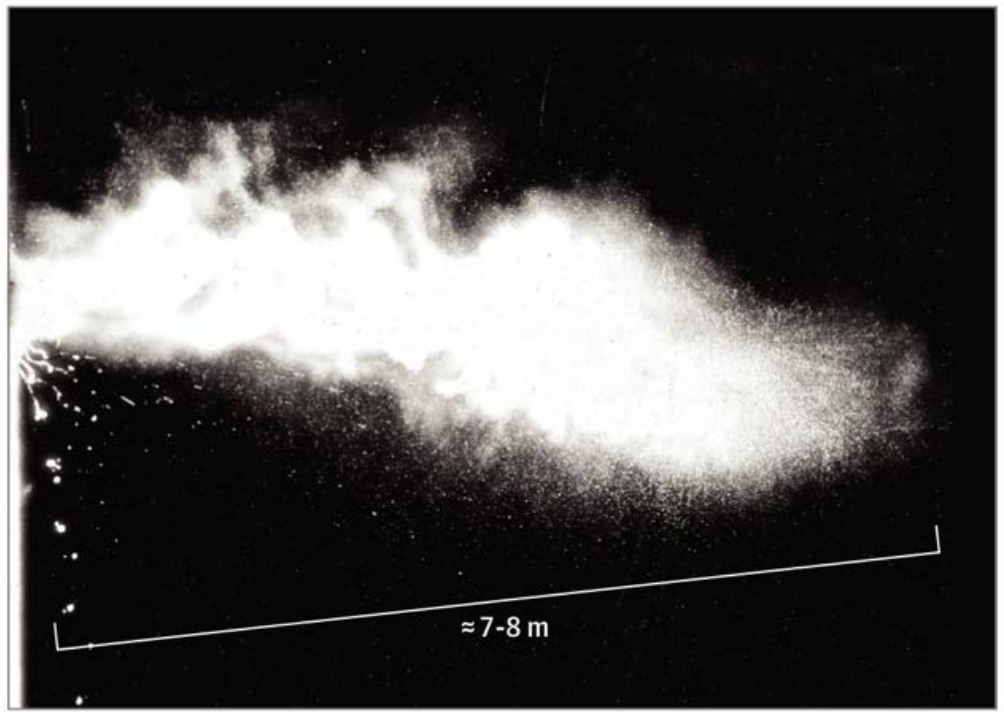
- **Are not silver bullets**
- Are not a replacement for vaccination, masks, physical distancing, etc.
- Have to be done well to make a difference to transmission risk
- Offer benefits beyond COVID-19 transmission risk reduction
- Have been underutilized (generally and specifically in pandemic response)

The 5 µm Elephant in the Room

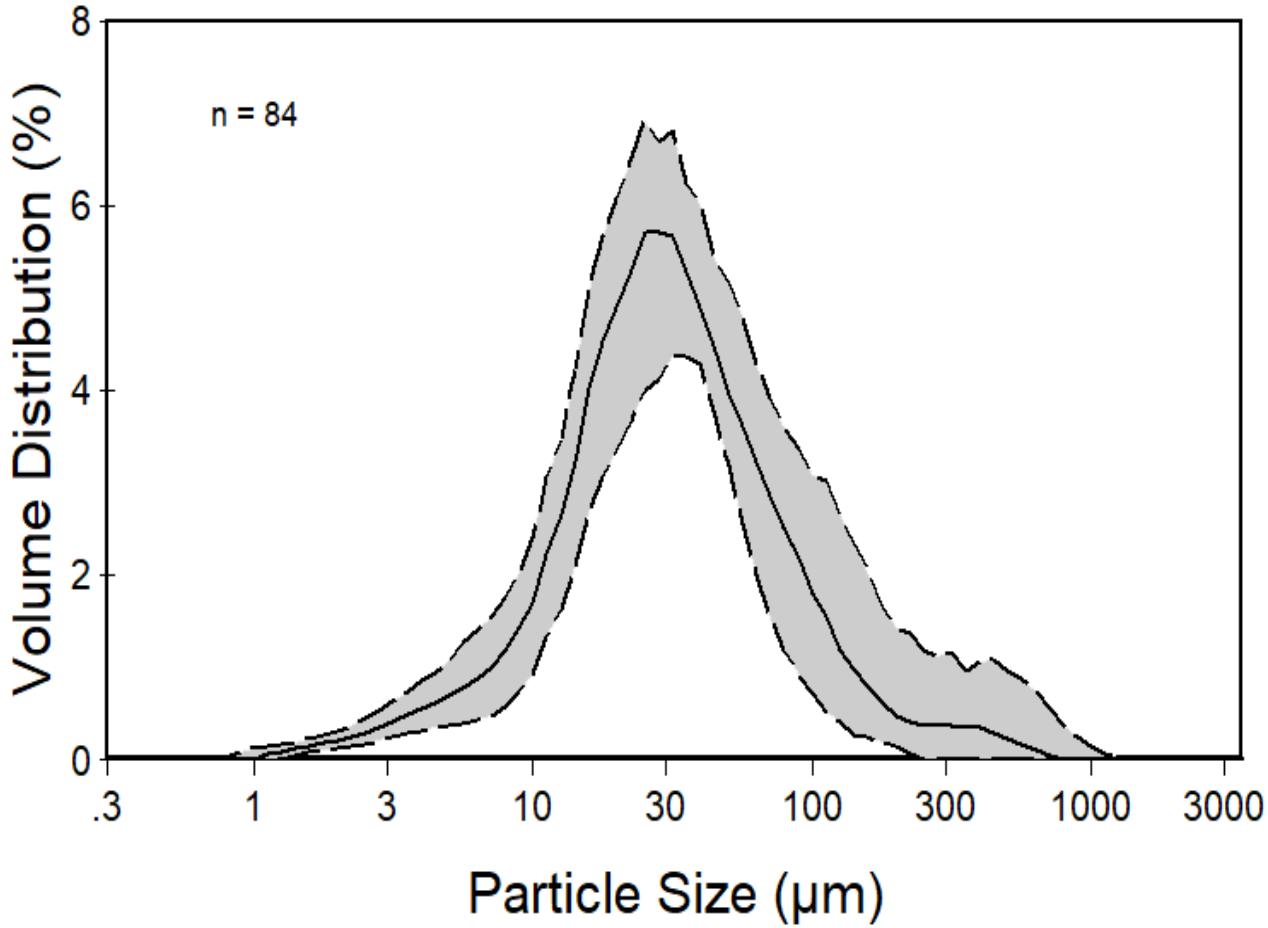


Droplets vs. Aerosol

1. The idea of a particle size threshold doesn't make much sense
2. Acute healthcare environments are very different from community environments
   - Staff knowledgeable about PPE & IPAC
   - Higher ventilation + better filtration (and more likely to be maintained)
   - Disease states of patient
3. Indoor air flows are dynamic, can be large, and are generally unknown
4. Larger particles move much further indoors than 2 m



Bourouiba (2020) JAMA



Mahdavi and Siegel (2021) *Indoor Air*

Some Good News

Mask Use and Ventilation Improvements to Reduce COVID-19 Incidence in Elementary Schools — Georgia, November 16–December 11, 2020

http://dx.doi.org/10.15585/mmwr.mm7021e1

Weekly / May 28, 2021 / 70(21);779–784

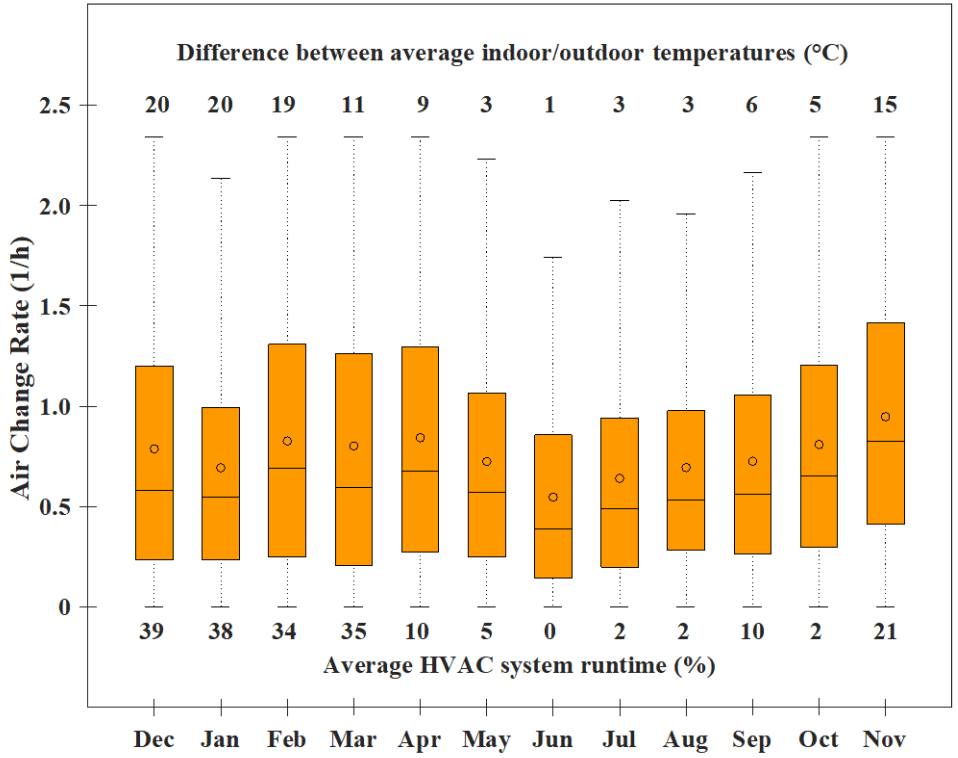
On May 21, 2021, this report was posted online as an MMWR *Early Release.*

Jenna Gettings, DVM[1,2,3]; Michaila Czarnik, MPH[1,4]; Elana Morris, MPH[1]; Elizabeth Haller, MEd[1]; Angela M. Thompson-Paul, PhD[1]; Catherine Rasberry, PhD[1]; Tatiana M. Lanzieri, MD[1]; Jennifer Smith-Grant, MSPH[1]; Tiffiany Michelle Aholou, PhD[1]; Ebony Thomas, MPH[2]; Cherie Drenzek, DVM[2]; Duncan MacKellar, DrPH[1] (View author affiliations)

"COVID-19 incidence was 37% lower in schools that required teachers and staff members to use masks and 39% lower in schools that improved ventilation. Ventilation strategies associated with lower school incidence included dilution methods alone (35% lower incidence) or in combination with filtration methods (48% lower incidence).

What does doing ventilation well mean?

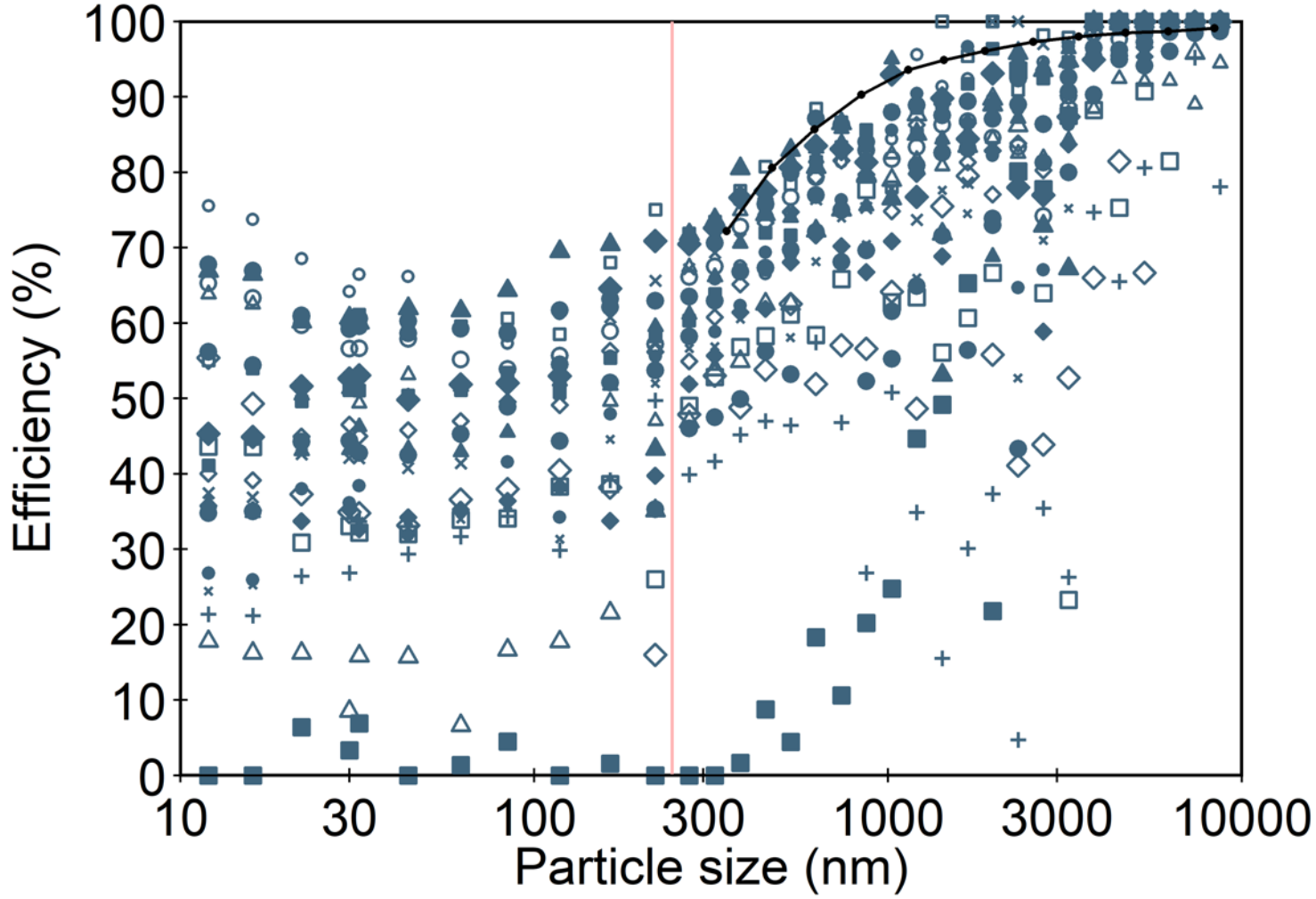
- As much ventilation as possible without compromising
  - Comfort
  - Humidity
  - Temperature
  - Outdoor pollutant concentration
- Open windows?
  - Better than nothing, but uncontrolled
  - May lead to room distribution issues



Alavy et al. (2018) *Bldg Envron*

What does doing filtration well mean?

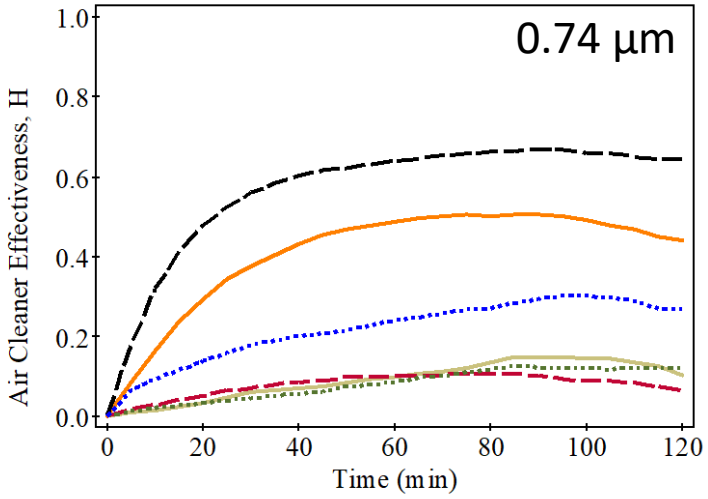
- Using a good filter
- Making sure air goes through it
- Eliminating bypass
- Changing it frequently

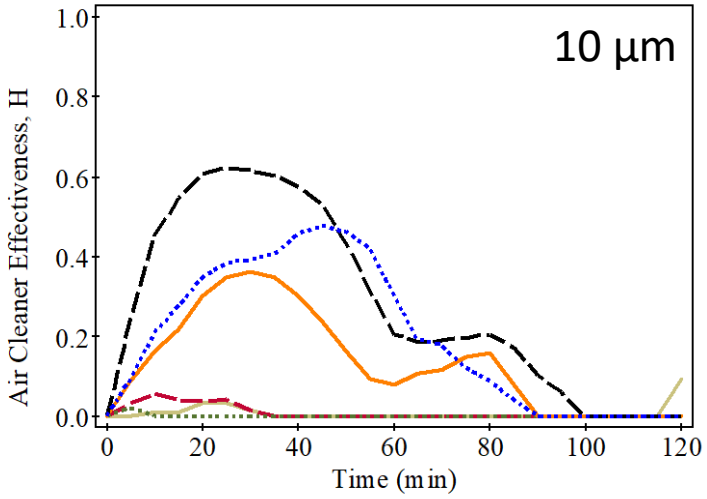


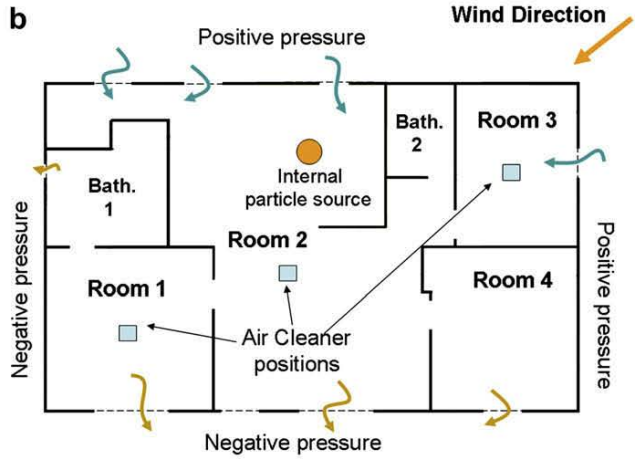
Li and Siegel (2020) *Indoor Air*

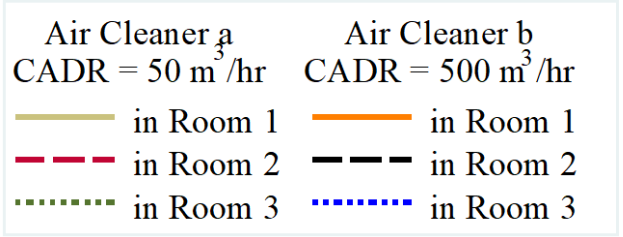
Portable Filtration

- Use filter with high CADR
- Address noise
- Place appropriately
- Change filter when needed
- Avoid unproven technology









Novoselac & Siegel (2009) *Bldg Environ*

What is your goal for ventilation & filtration measures?

- Target: 6 ACH equivalents (ACH_{eq}) from all measures

- ACH for each measure is delivery rate of clean air ÷ room volume *
  - Ventilation = flow rate of *outdoor* air
  - Central filtration = flow rate through filter × *installed* filter efficiency for particle size of interest
  - Portable filtration = clean air delivery rate (CADR)
  - Ultraviolet (UV) = flow rate through unit × *installed* efficiency for microorganism of interest

*you might have to do a unit conversion (×60) to convert from CFM to CFH, volume and delivery rate should have consistent units

“Easy” Example

- 1000 ft^2 classroom, 10 ft ceilings = 10,000 ft^3 volume, 1410 CFM total delivery - 2/3 recirculated air, MERV 13 filters
- Outdoor Ventilation = 470 CFM × 60 ÷ 10,000 ft^3 = **2.8 ACH**
- Filtration = 940 CFM × 60 * 85% (MERV 13 filter, for 1-3 µm particles) ÷ 10,000 ft^3 = **4.7 ACH**

- Total **= 7.5 ACH eq** – no need for portable filters
  - Concerns – in-situ filter efficiency, ventilation air flow maintenance
  - Maybe – in classroom distribution, blocked registers/grilles

Messier Example

- 1000 ft^2 classroom, 10 ft ceilings = 10,000 ft^3 volume, 705 CFM total delivery - 2/3 recirculated air, MERV 8 filters
- Outdoor Ventilation = 235 CFM × 60 ÷ 10,000 ft^3 = **1.4 ACH**
- Filtration = 470 CFM × 60 * 20% (Standard 52.2, for 1-3 µm particles) ÷ 10,000 ft^3 = **0.6 ACH**

- Total = **2 ACH eq**
  - Need portable air filter(s) for remaining **4 ACH** : CADR = 667 CFM
  - Concerns – air mixing, in classroom manipulation, portable filter maintenance

Other Strategies

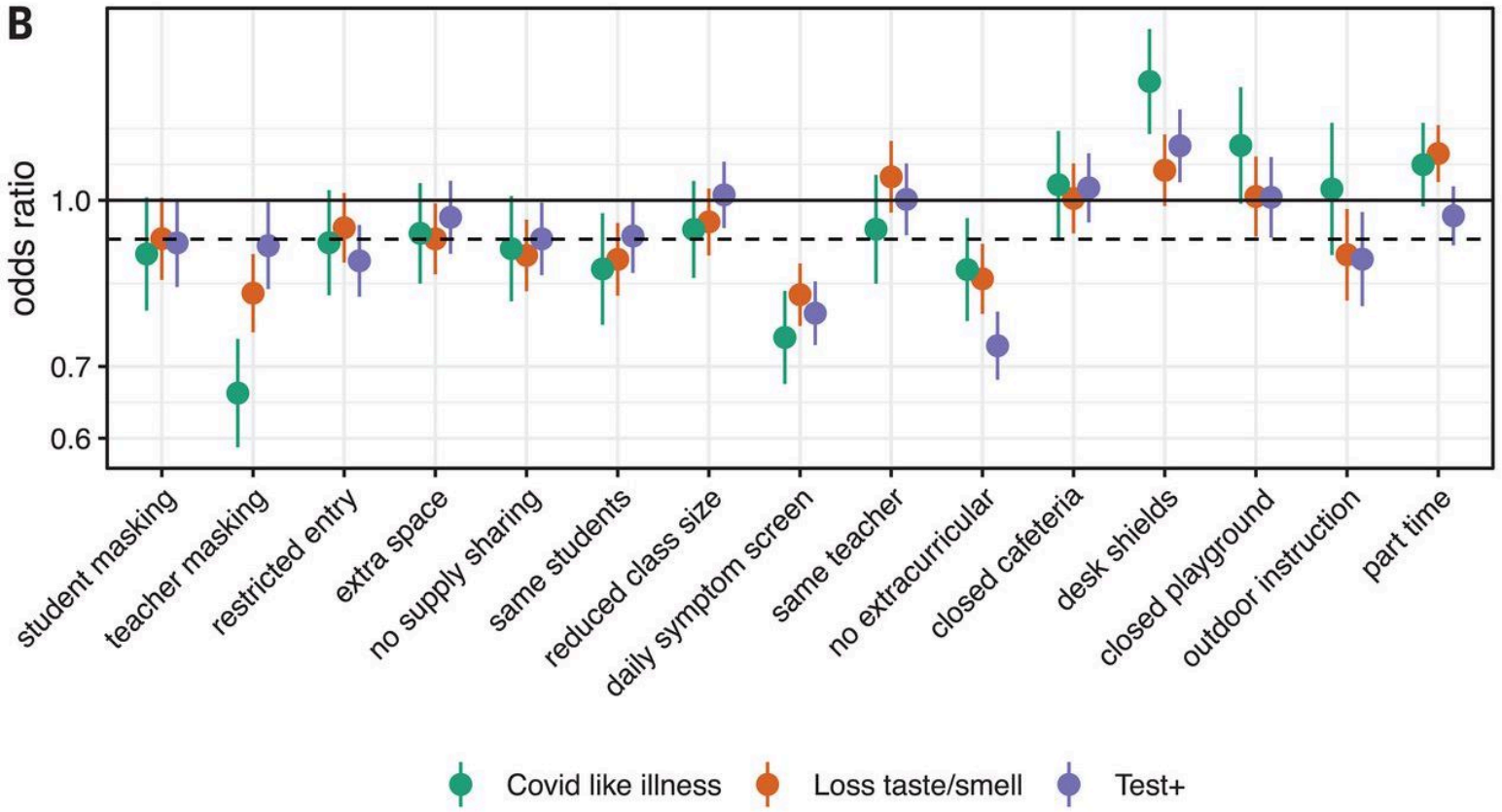
- Room flush outs
  - ASHRAE recommends 3 air changes of outside air or 2 hours post-occupancy
  - Can do it with combined filter and ventilation removal, you have 6 ACH eq – 30 minutes achieves 3 air changes, but be careful of spread within building
  - Can do it with windows (with hesitations)
- UV (upper room and in-duct)
  - Sizing, maintenance, environmental control (esp. RH), ozone emission

Strategies to Avoid (1)

- Unproven air cleaning technologies, often with marketing claims
  - High efficiency does not equal high performance
  - High efficiency for very small particles is not a good thing
  - Unrealistic microbiological surrogates/presentation of microorganisms
  - Missing information on ozone emission/byproduct formation
  - Biological kill tests are not reflective of real performance
  - A report from a test lab may not be applicable to real buildings
  - Other organizations that use the product often is reflective of the fact that they did not do their due diligence
  - Almost all testing, including ozone emission testing, can be gamed
  - Sample variation/testing approach can be gamed

Strategies to Avoid (2)

- Plexiglass barriers



Lessler et al. 2021. *Science DOI: 10.1126/science.abh2939*

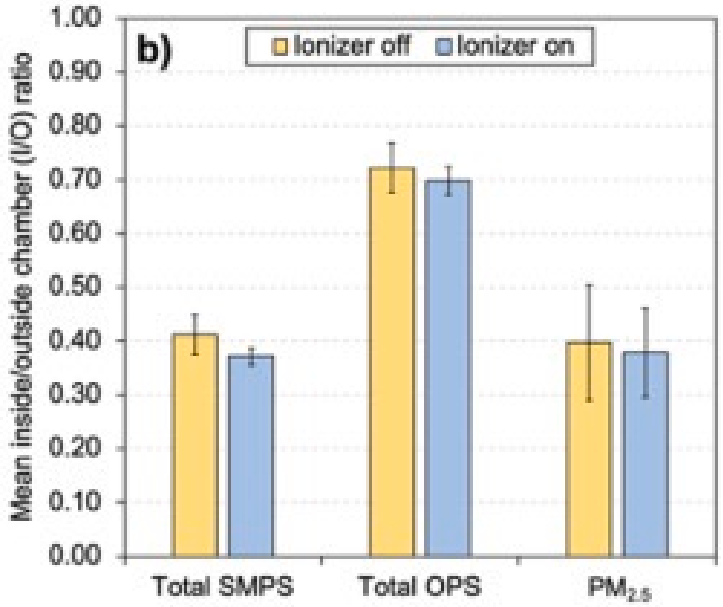
FAQ 1: Should I monitor CO_2?

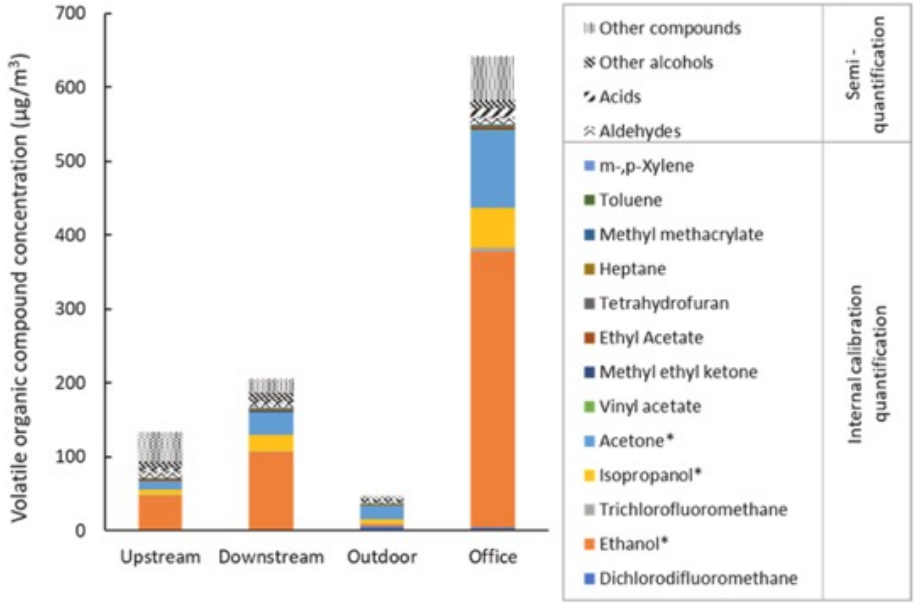
- No, maintenance & resource constrained, no bandwidth to develop clear action plan on what to do based on sensor reading
- Yes, already done everything else and have bandwidth to do carefully

- If you do it:
  - Know your sensor well and do background research
  - Use as a relative measure
  - Use it to measure ventilation ACH, fraction of outdoor air
  - Consider pairing with particle sensor to monitor ACHeq
  - Use them to evaluate your measures
  - Use them for staff/occupant education

FAQ 2: I bought bipolar ionizer/ PCO/ hydroxyl radical air cleaner – what should I do?

- Likely disable unless you can ensure they are not causing harm
- Explain original rationale (e.g., based on information you had at time)





Zeng et al. (2021) *Bldg Environ*

FAQ 3: What is a high-risk space?

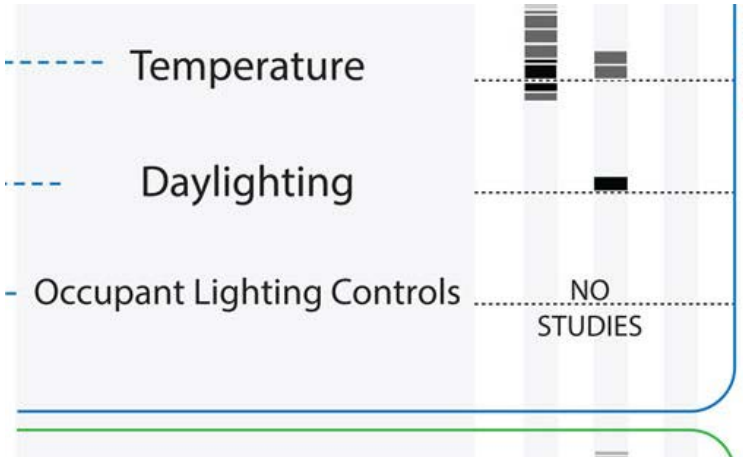
- **Poorly ventilated, time in environment, crowded**
- Environments with likely COVID-positive individuals
- Environments without primary measures (esp. masks)
- Environments with vocalization
- Environments with favorable environmental conditions
- Environments with high air movement/potential for resuspension
- Examples from literature: Restaurants, call centers, fitness clubs, choir practice, cafeterias, long-term care homes, meatpacking plants

FAQ 4: What is good IAQ and how do I know when I have it?

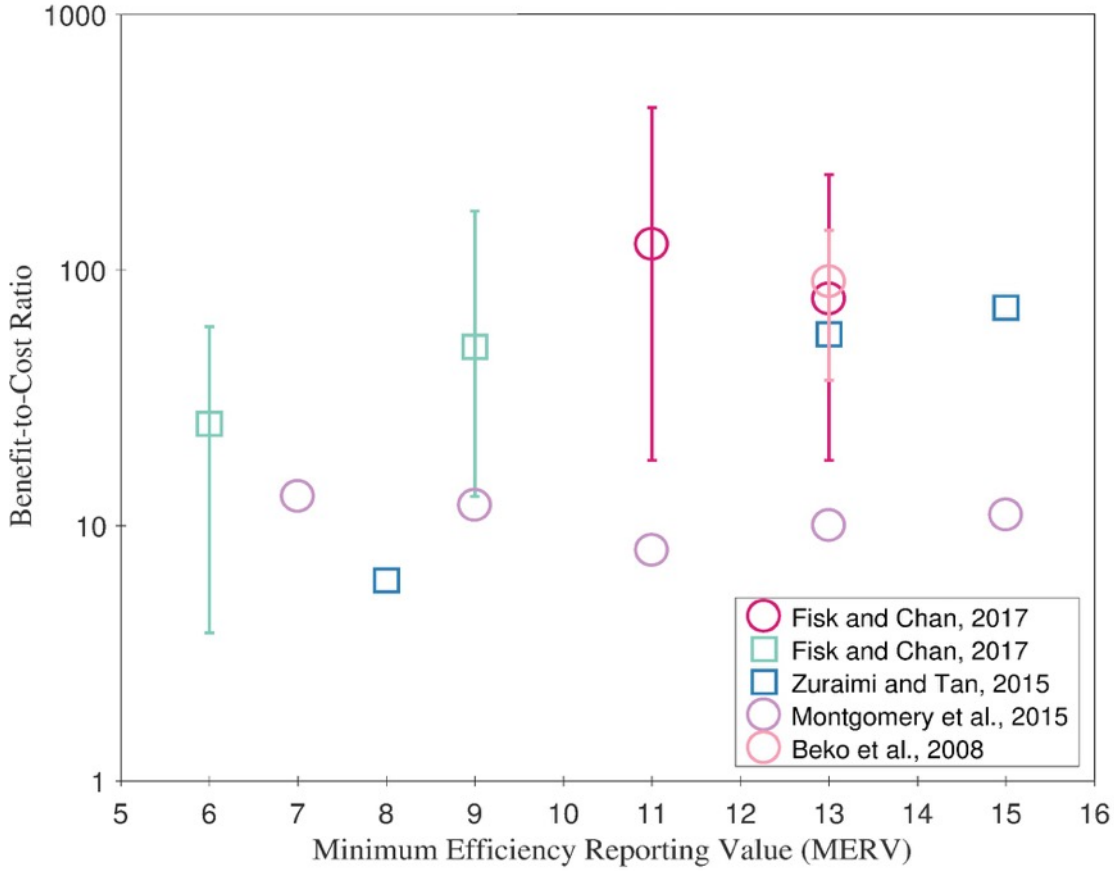
- Complicated question, with no really good answer
- Suggestion: Define operationally with an assessment: Source control, good ventilation, supplemental filtration
- Definition I like less: Monitor and keep pollutants low
  - $PM_{2.5}$ as low as possible (below 4 $\mu g/m^3$ if you need a number)
  - CO_2 below 800 ppm
  - TVOCs?, formaldehyde < 8 ppb

Parting Comment 1

- Worst case scenario is that we only improve indoor air quality



Vakalis et al. (2021) *Crit Rev Envrion Sci Tech*



Alavy and Siegel (2019) *Sci Tech Built Environ*

Parting Comment 2

- We have systematically underinvested in HVAC systems
- Opportunity 1: Design and operate for indoor air quality
- Opportunity 2: Do building-aware infectious disease research and outbreak investigation
- Opportunity 3: Do research to develop evidence basis

> The absence of evidence of the benefit for transmission risk reduction is not evidence.
>
> Adapted from a comment from David Miller

- Challenge: Unscrupulous air cleaning manufacturers taking advantage of public interest and lack of technical knowledge and government engagement

Parting Comment 3

- Poor indoor air quality disproportionately impacts racialized and marginalized communities
- Housing quality is strongly correlated with health disparities
- Addressing indoor air quality should be part of national strategy
- COVID-19 could be a catalyst for engagement with indoor air
- Canada has an opportunity to take global leadership of this issue

Overall Summary

- Filtration and ventilation have a role in protecting us from COVID-19, but
  - They are not magic and don’t work by themselves
  - They have to be implemented carefully and thoughtfully
- Suggested approach
  - Emphasis on primary measures (including fixing deficient ventilation/HVAC)
  - Increase ventilation and filtration where possible
  - Address high-risk spaces
  - Value benefits of improved indoor air

Questions?

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Messy Example

- 1000 ft^2 classroom, 10 ft ceilings = 10,000 ft^3 volume, no central HVAC
- How to get to 6 ACH eq?
  - Open windows – highly variable, most assume 2-4 ACH, I would be conservative
  - Portable HEPA filters = 1000 CFM (noise is going be an issue)
    - Teacher needs training on how to operate
  - Unit ventilator
  - Combination HRV + HEPA filter

Extraordinary Example

- Intensive support classroom: no masks for students, some aerosol generating activity, close contact between staff and students, challenges with adherence to cleaning/hygiene procedures
- Is 6 ACH enough? Maybe not, but it is a lot better than lower
- Additional measures
  - Upper-room UV system
  - Very low occupancy
  - Ducted-exhaust system