Indoor Air Quality in K-12 Schools
Effective Layered Dose (& Risk) Reduction during COVID-19

Richard L. Corsi, Ph.D., P.E.
H. Chik M. Erzurumlu Dean
Maseeh College of Engineering & Computer Science

Portland State University

www.corsiaq.com
www.safeairspaces.com
@CorsIAQ

KEVIN VAN DEN WYMELENBERG

Professor, Department of Architecture
Director, Institute for Health in the Built Environment
Director, Energy Studies in Buildings Laboratory
Co-Director, Biology and the Built Environment

PhD Built Environment, University of Washington, 2012
MArch, University of Washington, 2002
BS Architectural Studies, University of Wisconsin-Milwaukee, 2000
Lighting Certificate, University of Washington, 2002
Certificate in Urban Planning, University of Wisconsin-Milwaukee, 2000

@wymlenberg
kevinvdw@uoregon.edu

Transparency Declaration: To ensure you are aware of my interests/activities outside of the University of Oregon related to this presentation: I am disclosing that I own Duktile, LLC, through which I offer consulting services related to healthy building consulting and testing. Through Duktile I am a scientific advisor and minority shareholder for Enviral Tech, conducting environmental sampling and testing for building pathogens including SARS-CoV-2.

Perspective

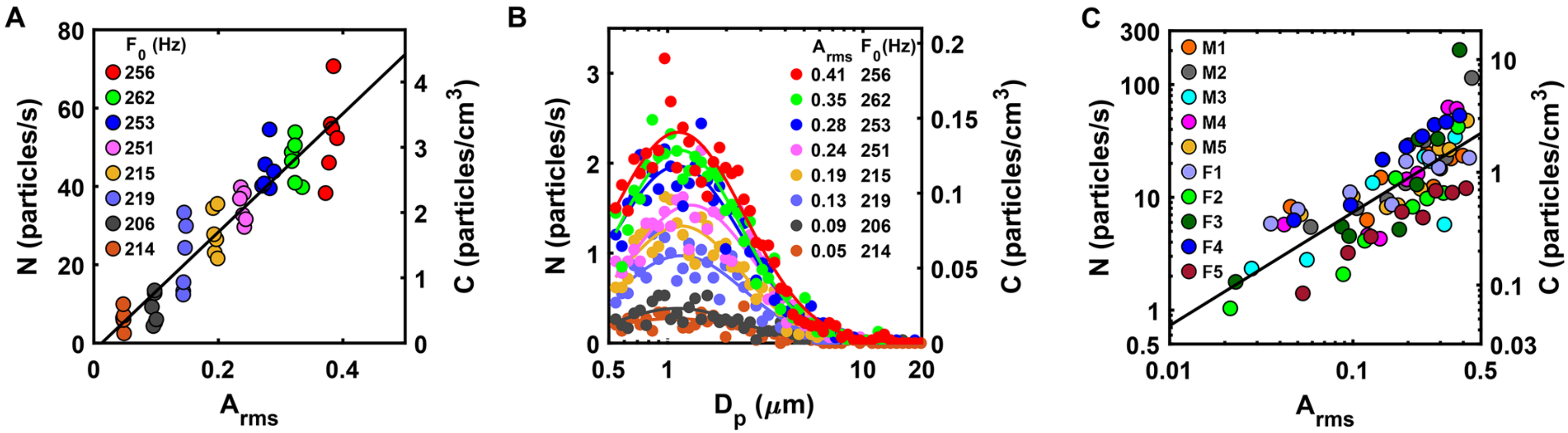
- Great benefits for kids being back in school
- Need ***appropriate*** & significant dose (& risk) reduction
- Layered risk reduction is not rocket science (can do it now)
- Some squandering $$$ on ineffective tech/approaches
  - Confused messaging & slick marketing
- Critical to get it right
- We CANNOT make schools 100% safe
- We can easily make them 95% safer

Sources of Emissions

- Breathing
- Speaking
- Singing
- Coughing
- *Resuspending?*

- Virus not naked (embedded in particles)
- Particles = combo of mucous & saliva
- Aerosol particles critical
  - Tiny (invisible), suspended, penetrate RS

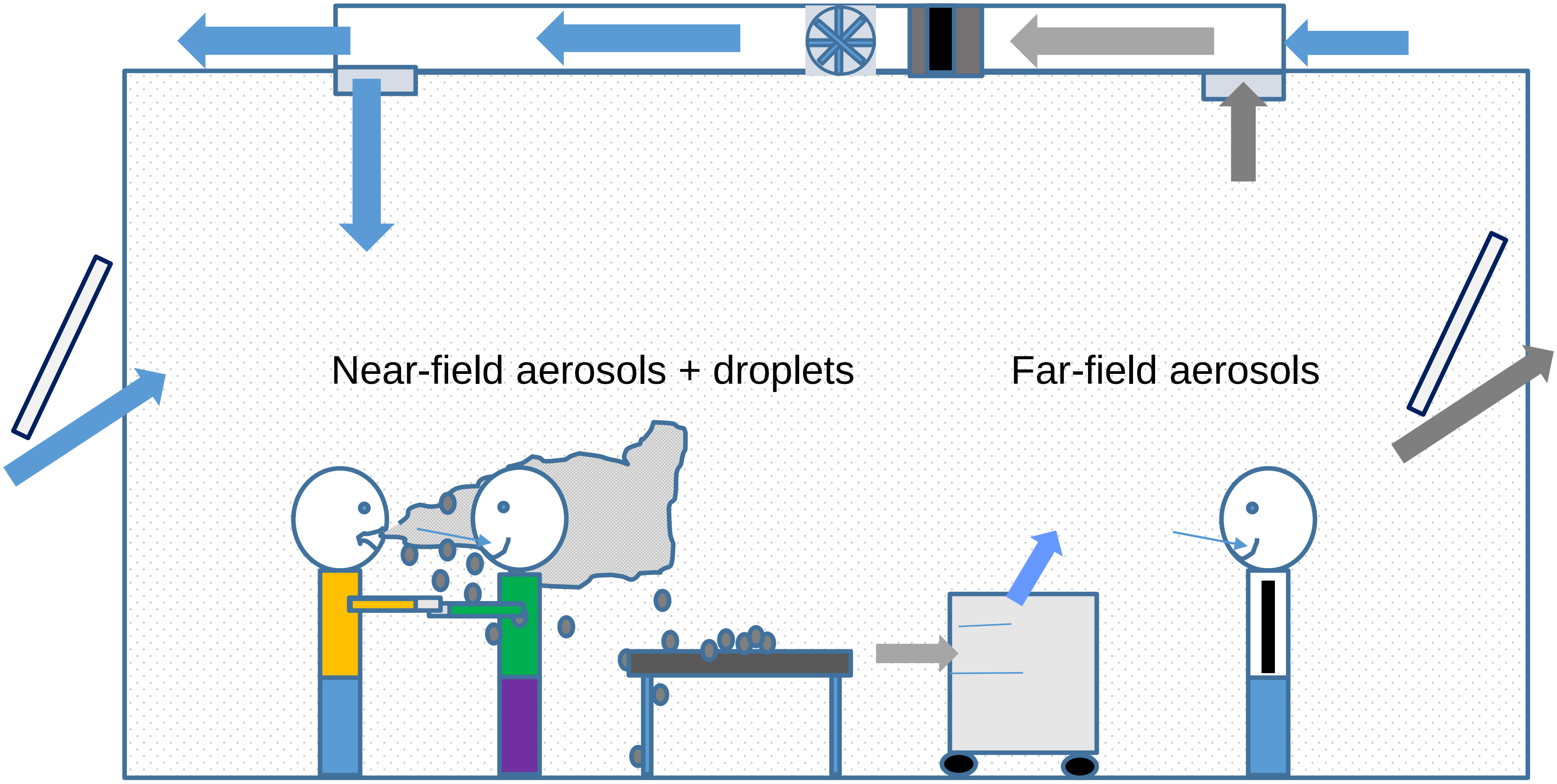
Example: Speaking



Asadi, S. *et al*. *Scientific Reports*, *9:2348 (2019)* doi.org/10.1038/s41598-019-38808-z

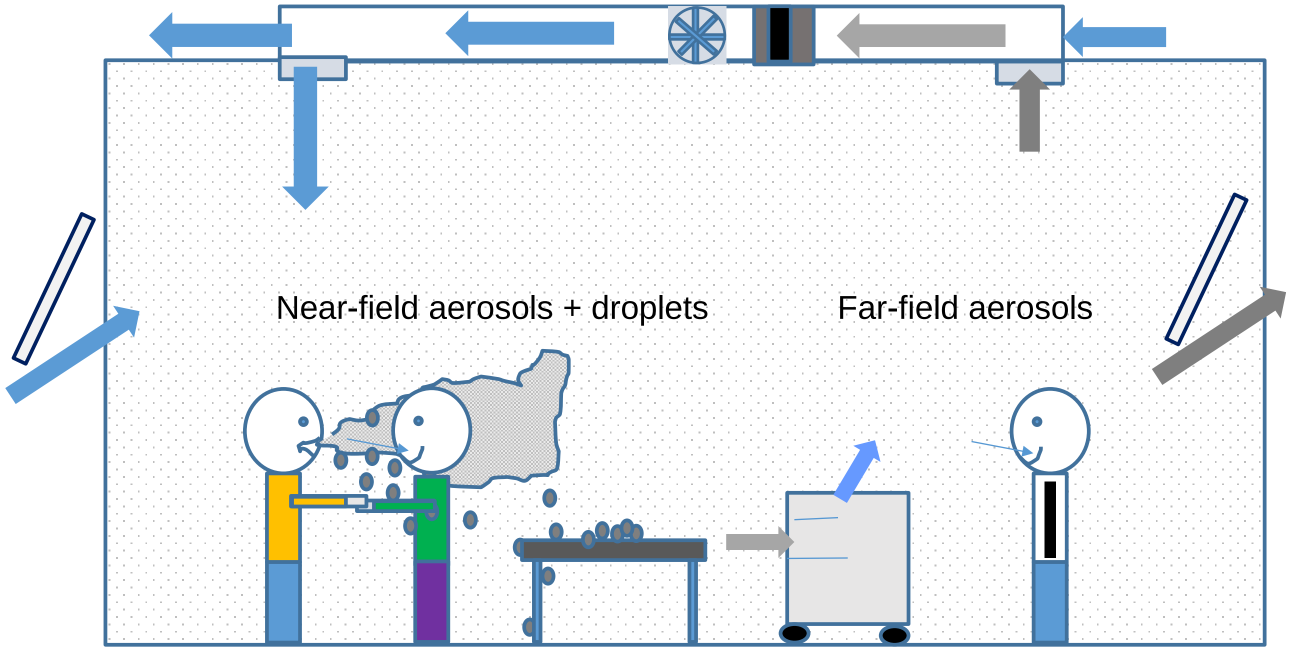
- Breathing ≈ order of magnitude lower than average speaking

Near & Far Fields



Near-field aerosol concentration ≈ 2 to 5 (maybe up to 10 x far-field)

Lowering Risks



Near field

- Universal masks
- Greater physical distance
- Barriers (sometimes)
- Less time

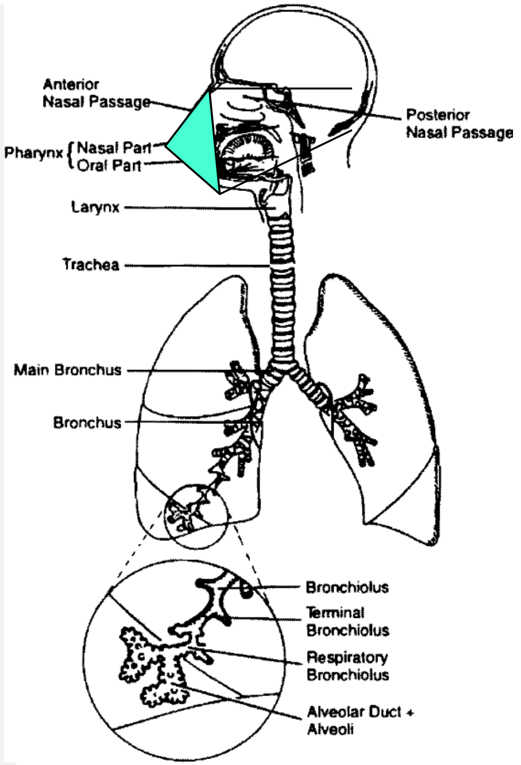
Far field

- Universal masks
- Increased ventilation
- Improved filtration
- UVGI
- Less time

Inhaled Deposited Dose

$$Dose_{inhal,i} = C_i \text{ (\#/L) x } B \text{ (L/min) x } t \text{ (min) x } f_{dep,i}$$

- **C_i = concentration of particles of size i**
  - **emissions; mask; ventilation; control (PAC, etc.)**
- **B = Respiratory minute volume**
  - **activity (can vary significantly)**
- **t = Time in space with an infector**
- **$f_{dep,i}$ = Deposition of particles** of size i in resp sys
  - **particle size; breathing mode; activity; (location)**

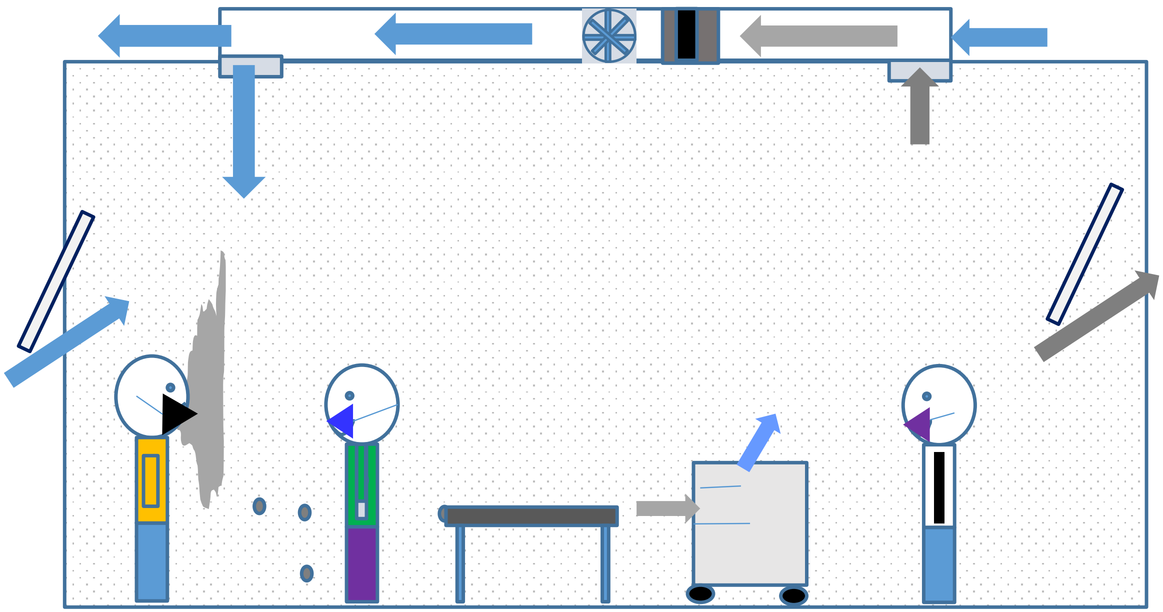


Key to entire pandemic (including schools) = reduce inhaled deposited dose

We have not done what we need to do.

Layered Dose (Risk) Reduction Strategy (LRRS)

- **Reduce Source(s)**
- **Require Masks**
- **Distance from Source**
- **Ventilate**
- Filter
- **Use Portable Air Cleaners**
- Optimize RH
- Disinfect air (UVGI only)
- Disinfect Surfaces*
- **Make Use of Time**
- Modify Activities
- Educate



- LRRS can lead to dose reduction > 95%

See the following webinar for details on each layer:
https://www.epa.gov/iaq-schools/forms/webinar-indoor-air-quality-k-12-schools-addressing-concept-layered-risk-amidst

* Most important surface to disinfect is hands

Reduce Source

Reduce Source(s)

Require Masks

Distance from Source

Ventilate

Filter

Use Portable Air Cleaners

Optimize RH

Disinfect air (UVGI only)

Disinfect Surfaces

Make Use of Time

Modify Activities

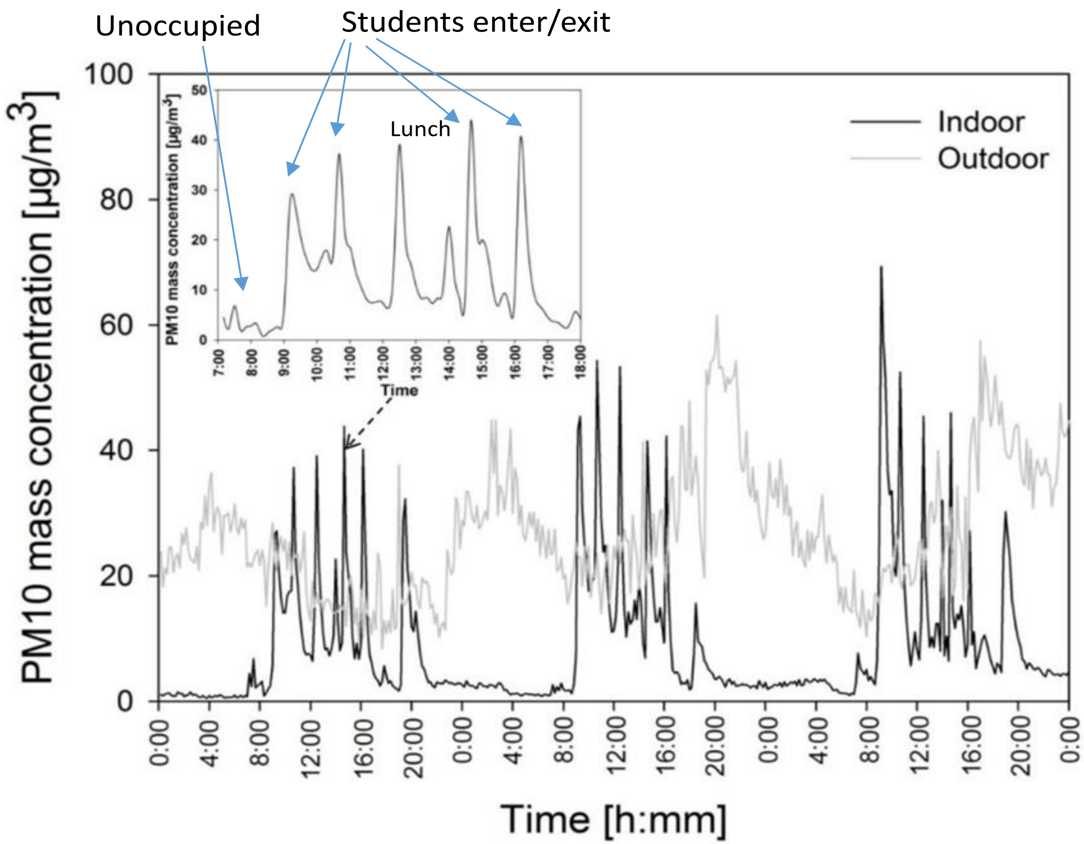
Educate

"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)

$$Dose_{inhal,i} = C_i \text{ (\#/L)} \times B \text{ (L/min)} \times t \text{ (min)} \times f_{dep,i}$$

- Test & isolate
- Require masks (for all)
- De-densify (less occupants; innovate)
- Eliminate certain activities (singing, aerobics)
- Reduce speaking to extent possible

Possible Source: Resuspension of Particles



Ren, J. *et al*. *Building & Environment* (accepted)

Re-suspension as source: VCT < Carpet

Require Masks

- Reduce Source(s)
- **Require Masks**
- Distance from Source
- Ventilate
- Filter
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- Optimize RH
- Disinfect air (UVGI only)
- Disinfect Surfaces
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$Dose_{inhal,i}$ = C_i (#/L) x **B** (L/min) x **t** (min) x $f_{dep,i}$

- Universal mask wearing
- Dual benefits
  - 30% (I) & 30% (R) = 51% dose reduction
  - 60% x 60% = 84% risk reduction

Problem = all masks off, e.g., lunch

- Outdoors if possible
- Quiet lunch (only teacher speaks)
- Rotating pods (teams) for mask off
- Mask down, eat, Mask up, next team up!

Distance from Source (everyone)

- Reduce Source(s)
- Require Masks
- **Distance from Source**
- Ventilate
- Filter
- Use Portable Air Cleaners
- Optimize RH
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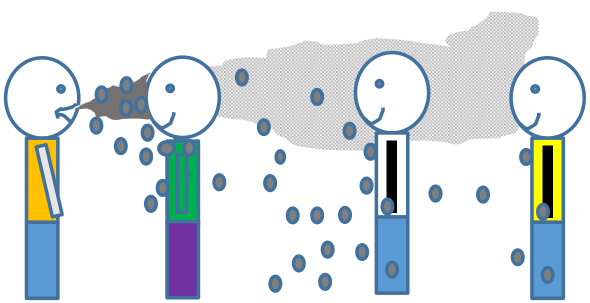
Horizontal distance traveled to settle 1.5 m
At free-stream air speed of 5 cm/s

d_p (µm)	t (1.5 m)	x (m)
0.5	56 hr	10000
1	14 hr	2500
5	33 min	100
10	8 min	25
20	2 min	6
50	20 sec	1

50 -100 µm particles can travel > 6 ft (jet)

Distancing?

- With masks
- Without masks



Ventilate

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$$\text{Dose}_{inhal,i} = C_i\ (\#/L) \times B\ (L/min) \times t\ (min) \times f_{dep,i}$$

- Best = outdoors
- Mechanical (controlled)
- Natural (design openings)
- Infiltration

https://www.nytimes.com/2020/07/17/nyregion/coronavirus-nyc-schools-reopening-outdoors.html

ASHRAE 62.1-2019


ANSI/ASHRAE Standard 62.1-2019
(Supersedes ANSI/ASHRAE Standard 62.1-2016)
Includes ANSI/ASHRAE addenda listed in Appendix O

Ventilation for Acceptable Indoor Air Quality

See Appendix O for approval dates by ASHRAE and the American National Standards Institute.

This Standard is under continuous maintenance by a Standing Standard Project Committee (SSPC) for which the Standards Committee has established a documented program for regular publication of addenda or revisions, including procedures for timely, documented, consensus action on requests for change to any part of the Standard. Instructions for how to submit a

ASHRAE: American Society of Heating, Refrigerating and Air-Conditioning Engineers

https://ashrae.iwrapper.com/ASHRAE_PREVIEW_ONLY_STANDARDS/STD_62.1_2019

ASHRAE Calculation & Position

ASHRAE 62.1- 2019 ***Ventilation for Acceptable Indoor Air Quality*** *(Pre-COVID)*

5 L/s-person; 0.6 L/s-m^2

If 24 students + 1 teacher in 60 m^2 classroom = 5 x 25 + 0.6 x 60 = 161 L/s

161 L/s = 576 m^3/hr; AER = 576 m^3/hr / (60 m^2 x 2.8 m) = **3.4/hr**

ASHRAE Position Document on Infectious Aerosols
Approved by ASHRAE Board of Directors - April 14, 2020

The following modifications to building HVAC system operation should be considered:

- Increase outdoor air ventilation (disable demand-controlled ventilation and open outdoor air dampers to 100% as indoor and outdoor conditions permit).
- Additional recommendations on filtration, portable air cleaners, UVGI, T & RH, etc.

https://www.ashrae.org/file%20library/about/position%20documents/pd_infectiousaerosols_2020.pdf

Ventilate

- Many schools under-ventilated or inappropriately ventilated

Absenteeism (Simons et al., *Am. J. Public Health*, 2010)

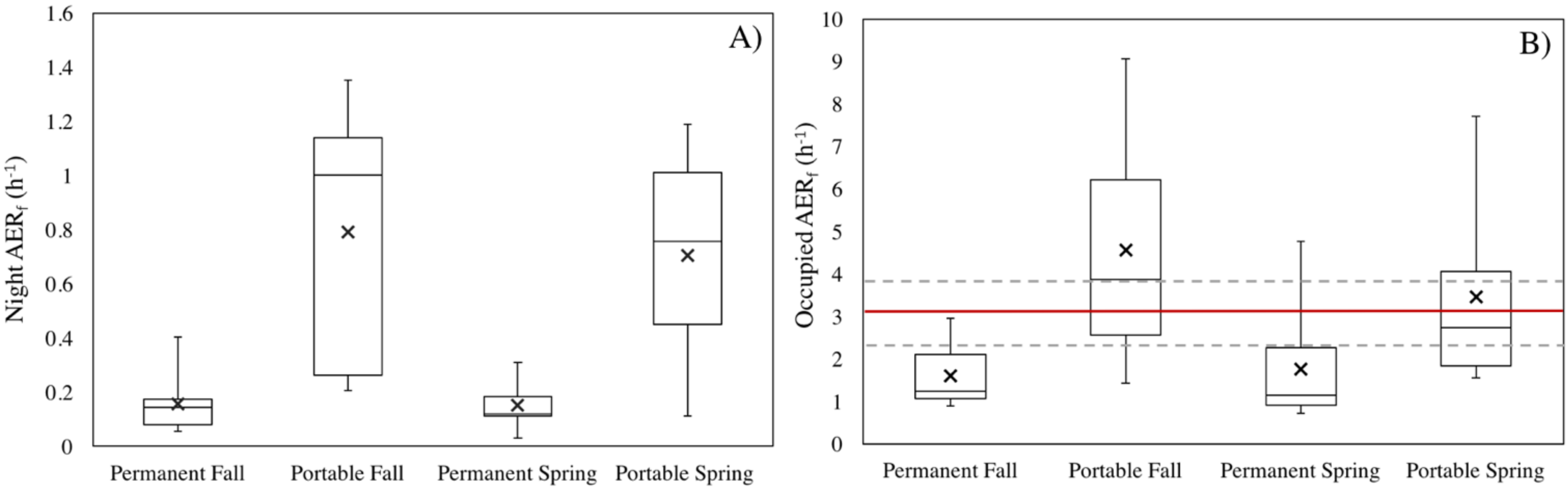
- Association: under-ventilation & absenteeism
- Strongest association: young students

Performance (Haverinen-Shaughnessy et al., *Indoor Air*, 2011)

- 100 southwestern schools/classrooms
- 87% w/ less ventilation than ASHRAE 62.1
- Each 1 L/s-student increase in ventilation:
    - 2.9% increase math; 2.7% read

Ventilation matters (COVID-19 or not)

Air Exchange Rates: Central Texas High Schools



Lesnick, L.A. et al., *ASHRAE Transactions* (2017)

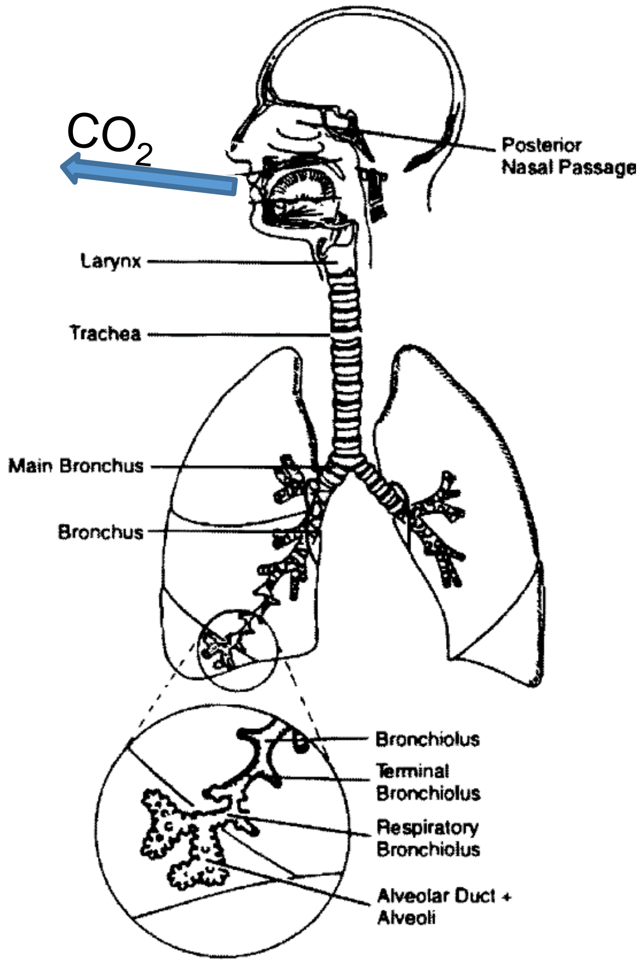
- Permanent classrooms severely under-ventilated (Median < ½ ASHRAE 62.1)
- Generally higher ventilation in portable classrooms (but high variability)
- Portable classrooms – directly connected to outdoors
- Portable classrooms – more natural ventilation opportunities + infiltration

Carbon Dioxide (CO_2) as Surrogate

- CO_2 generated by cells in body
- Released from blood to lungs
- Emitted from mouth & nose

- Concentrations in air (units = ppm)
  - Outdoor = 410 ppm
  - Indoor > 410 ppm (variable; factors?)
  - Breath = 36,000 to 38,000 ppm

- Ventilation indicator
- Ventilation estimator
- Re-breathed fraction estimator



Rebreathed Fraction (RF)

- RF = Fraction of air inhaled that originated from other's breath

$$RF = \frac{CO_{2,indoor} - CO_{2,outdoor}}{CO_{2,breath}}$$

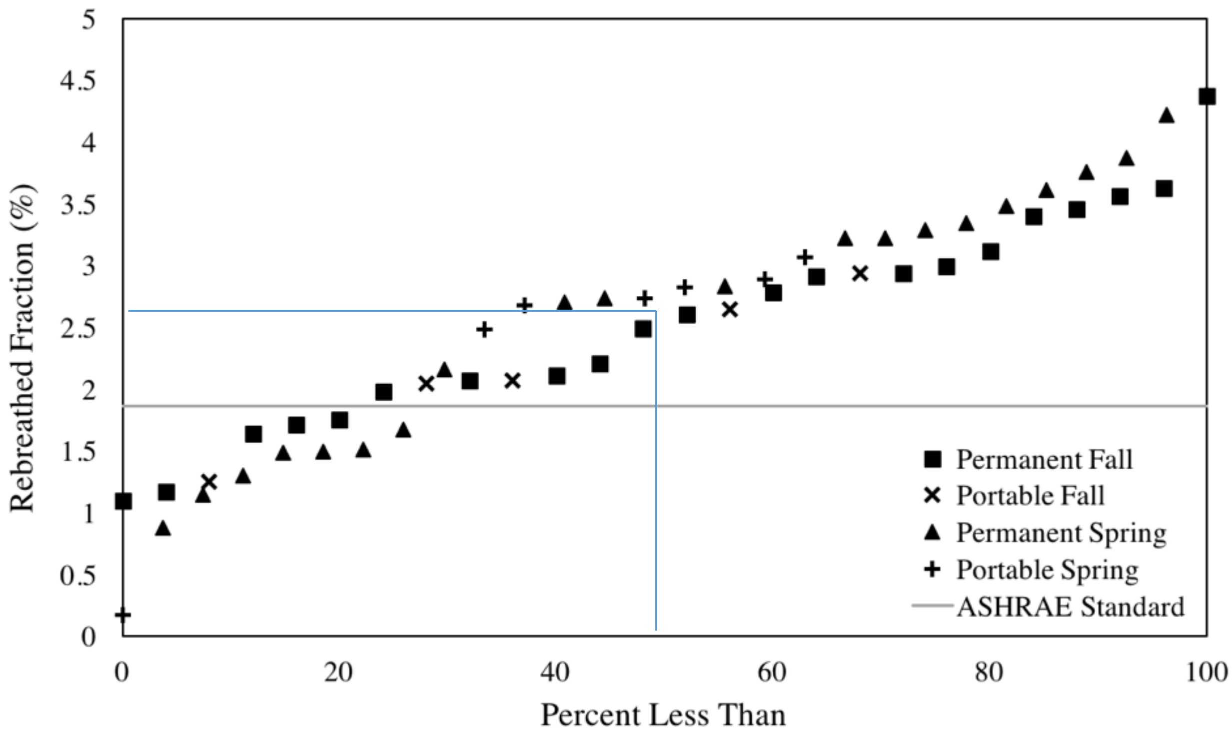
Example: $CO_{2,indoor}$ = 1,110 ppm; $CO_{2,outdoor}$ = 410 ppm; $CO_{2,breath}$ = 36,000 ppm

$$RF = \frac{1{,}110\,ppm - 410\,ppm}{36{,}000\,ppm} = 0.019 = 1.9\%$$

- Elevated rebreathed fraction = greater probability of infection
  - How do we lower CO_2 (or RF)?

Rebreathed Fraction

Central Texas High Schools (Year 1)

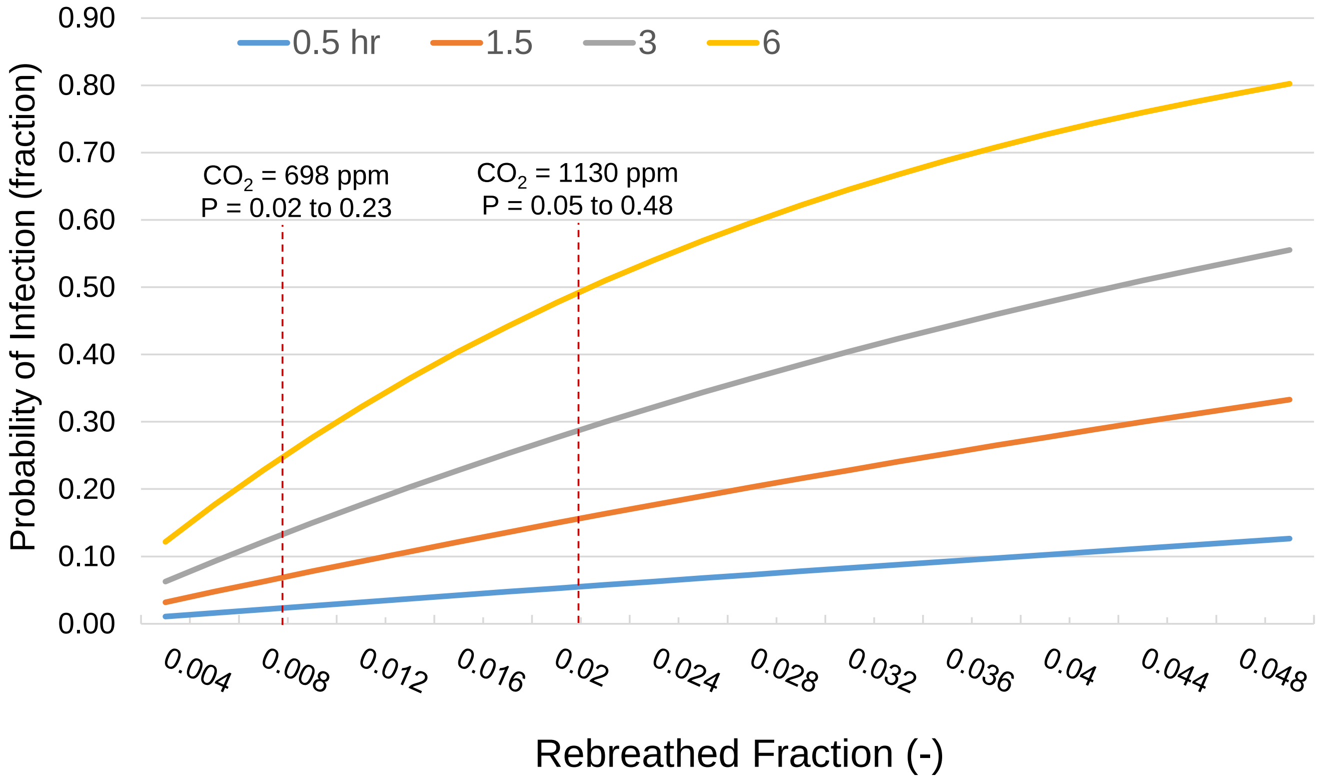


Lesnick, L.A. et al., *ASHRAE Transactions* (2017)

Median RF = 0.025 to 0.027 (2.5 to 2.7%)

Similar to previous K-8 results

Estimates: Probability of Infection



Rudnick-Milton model w/ 1 infector amongst 25 occupants

(no masks; times varied from 0.5 to 6 hours)

At RF = 0.008 w/ mask + good portable HEPA can lower 6 h curve to 0.5 h

Portable Air Cleaners (PAC)

- Reduce Source(s)
- Require Masks
- Distance from Source
- Ventilate
- Filter
- **Use Portable Air Cleaners**
- Optimize RH
- Disinfect air (UVGI only)
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- Make Use of Time
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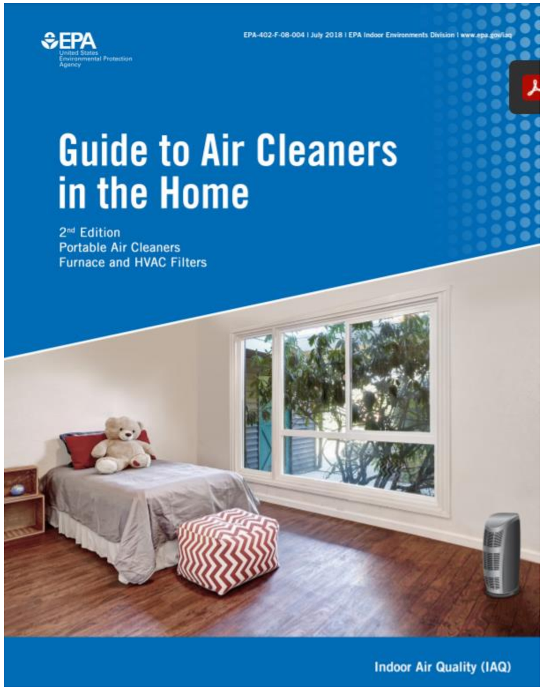
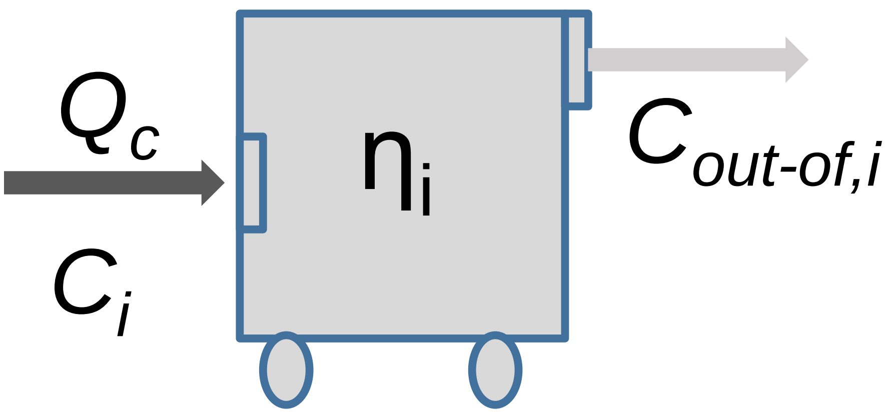
$$\text{Dose}_{inhal,i} = C_i\ (\#/L) \times B\ (L/min) \times t\ (min) \times f_{dep,i}$$



https://www.epa.gov/sites/production/files/2018-07/documents/guide_to_air_cleaners_in_the_home_2nd_edition.pdf

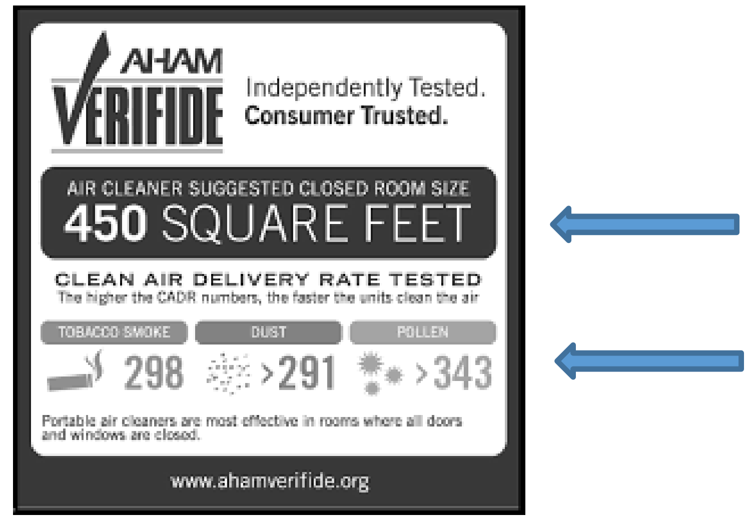
PAC: Clean Air Delivery Rate (CADR)

What is CADR? Equivalent amount of unpolluted outdoor air brought into an indoor space without bringing in outdoor air.



$$C_{out-of,i} = (1 - \eta_i)C_i$$

$$CADR_i = \eta_i Q_c$$



EPA.gov

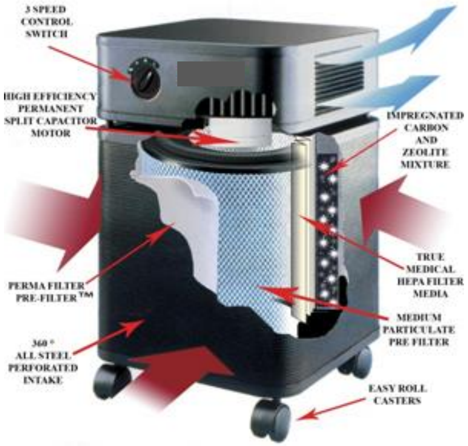
Association of Home Appliance Manufacturers (AHAM)

η_i = single-pass removal fraction for particles of size i (-)

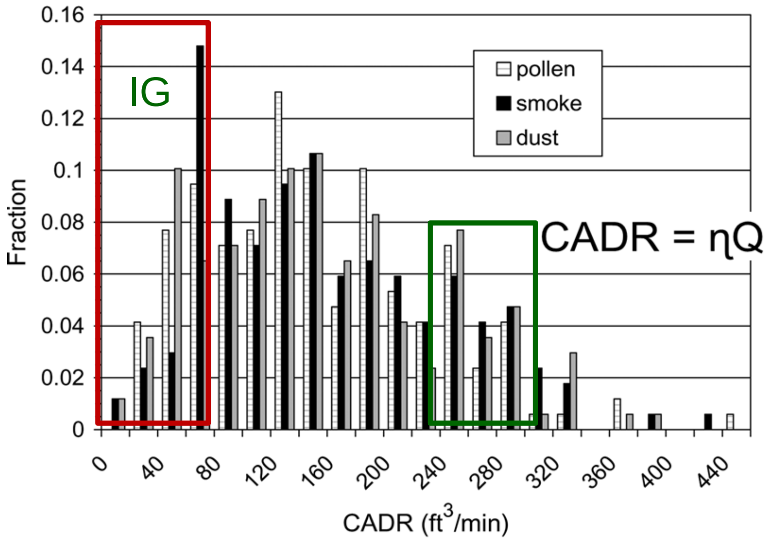
Q_c = volumetric flow rate or air through PAC (e.g., ft^3/min)

Portable HEPA Air Cleaner

- Proven: HEPA-based portable air cleaner
- **H**igh **E**fficiency **P**articulate **A**ir
- Key: Clean Air Delivery Rate (CADR)
- CADR = η x Q
  - η = single pass removal fraction (-)
  - Q = volumetric flowrate (ft^3/min)
- Example: η = 0.6; Q = 500 ft^3/min
- CADR = 300 ft^3/min (510 m^3/hr)



http://www.sheffield-pottery.com/



Shaughnessy, R.J., and Sextro, R.G., *J of Occupational and Environmental Hygiene*, 3: 169–181(2006)

Portable HEPA: Equivalent Air Changes/hr

- Equivalent air changes per hour = EqACH = **CADR/V**
- Example: V = 600 ft^2 x 8 ft = 4,800 ft^3
- CADR = 300 ft^3/min
- **EqACH** = 300 ft^3/min/4,800 ft^3 = 0.0625/min (or x 60 = **3.8/hr**)

$$C_i = \frac{E_i}{\left\{\lambda + k_i + \frac{CADR}{V}\right\} \times V}$$

If λ = 2/hr; k_i negligible

2 + 3.8 = 5.8/hr

66% reduction (ε = 0.66)

Add to 64% masks = 88%!

Note – significant benefit when ventilation rates cannot be increased, e.g., wildfire season, system limitations

The Cost (per Classroom & Student)

Good portable HEPA air filter (w/ CADR = 300 scfm) for 600 to 800 square ft classroom

Assume 25 students per classroom

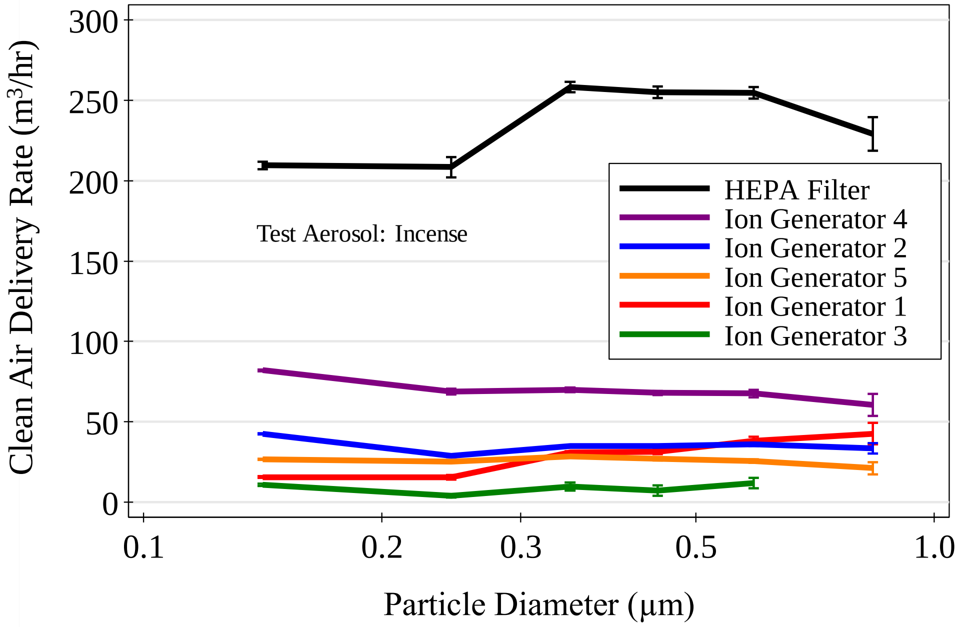
- Capital cost (one time): < $250 (< $10/student)
- Recurring cost (filters @ 2x/yr): < $150 (< $6/student/yr)
- Recurring cost (electricity): $29/yr ($1.16/student/yr)
- Total 3 year cost: < $790 (< $11/student)

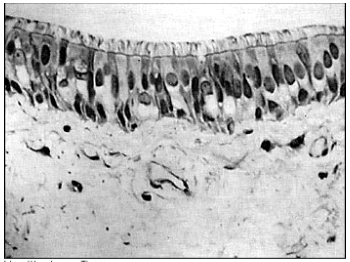
50 classrooms = $40,000 ***every three years*** for a substantial risk reduction

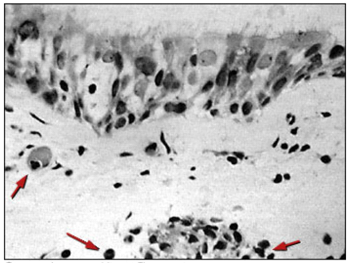
Other Technologies - BEWARE

- Often slick marketing / fancy names
- Company tests look good but can be highly deceiving
- Analyses of data suggest CADR 10-15 x LOWER than HEPA
- Stick to PROVEN technologies (portables or central)
- Portables: HEPA air filters w/o any fancy gimmicks
- Aim for CADR (certified) of 300 scfm (or higher)
- **Don’t waste $ on unproven (or ineffective) technologies**

Portable HEPA vs. Ion Generators (IG)




Healthy Lung Tissue


Ozone-damaged Lung Tissue

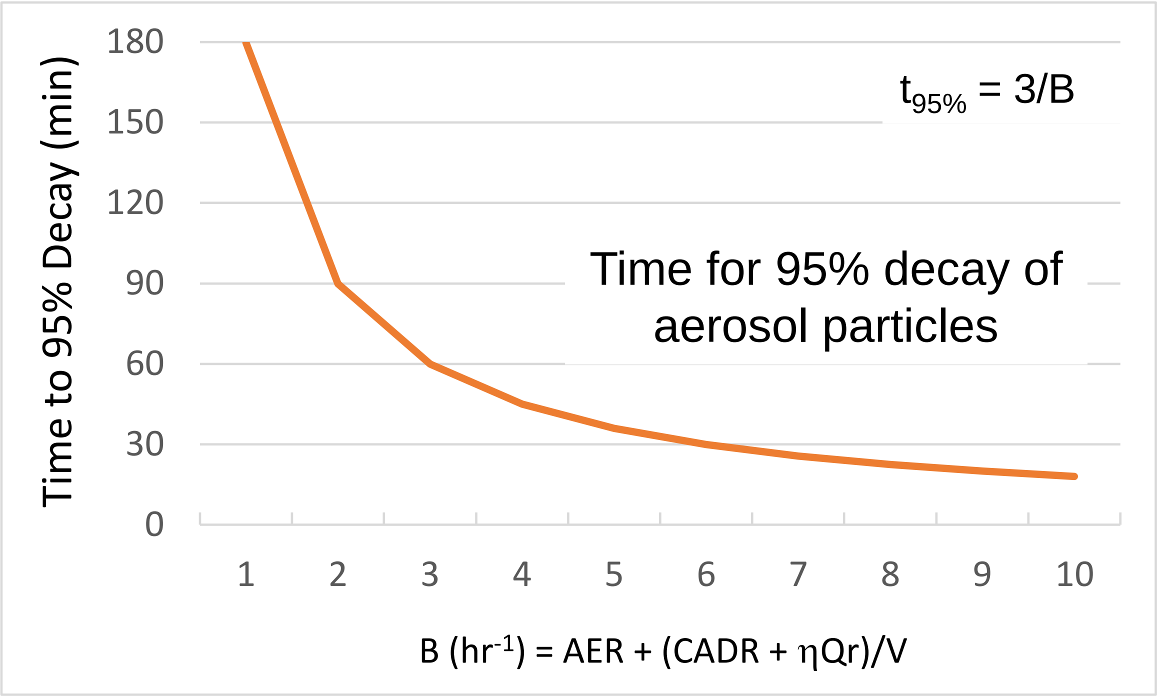
(Micrographs from American Thoracic Society, from *American Review of Respiratory Diseases,* Vol. 148, 1993, Robert Aris et al., pp. 1368 -1369.)

- IG: Can have high single pass removal efficiency *η*
- IG: Generally very low flow (recall CADR = η x Q)
- Quiet is nice for the ears but not necessarily for the air
- IG = Potentially significant ozone source

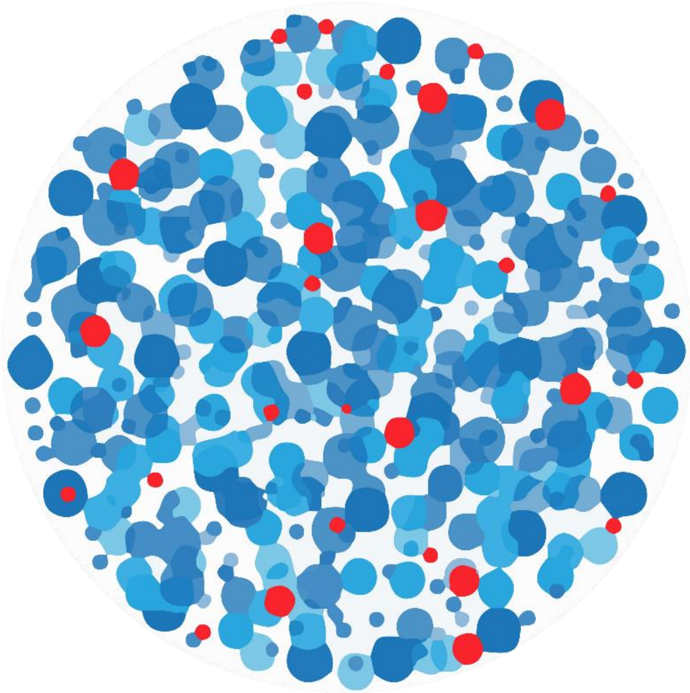
Make Use of Time

- Reduce Source(s)
- Require Masks
- Distance from Source
- Ventilate
- Filter
- Use Portable Air Cleaners
- Optimize RH
- Disinfect air (UVGI only)
- Disinfect Surfaces
- **Make Use of Time**
- Modify Activities
- Educate

- Reduce continuous time indoors
- Reduce time w/ mask down at lunch
- Outdoor calm time after physical activity
- Classroom particle decay periods



A quantitative risk estimation platform for SARS-CoV-2 aerosol transmission in the built environment



The SAFEAIRSPACES COVID-19 Aerosol Relative Risk Estimator

Safeairspaces.com

Dr. Richard Corsi

(Dean of the Maseeh College of Engineering and Computer Science, Portland State U)

Dr. Kevin Van Den Wymelenberg

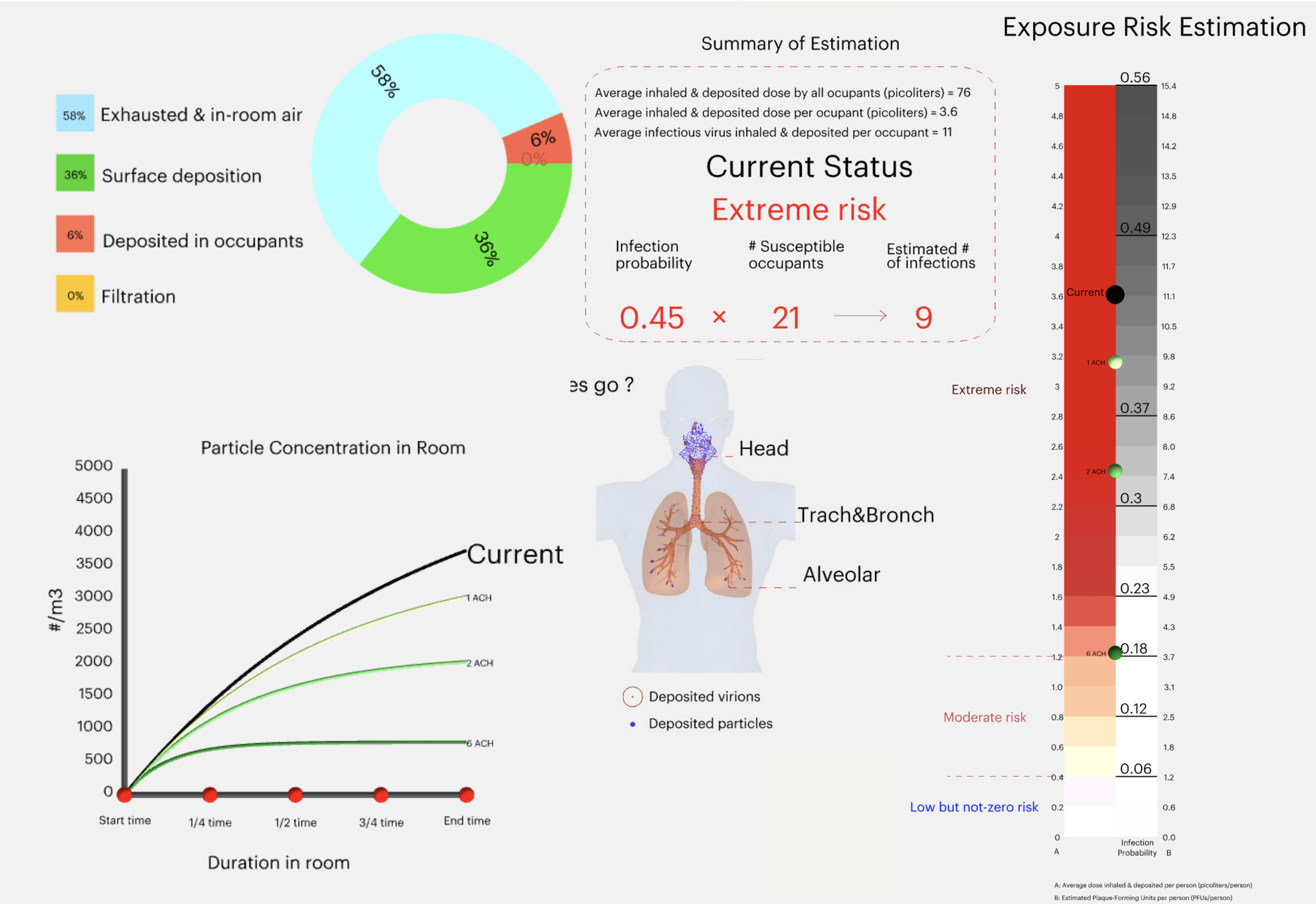
(Professor and director at the University of Oregon College of Design, IHBE and ESBL)

Hooman Parhizkar

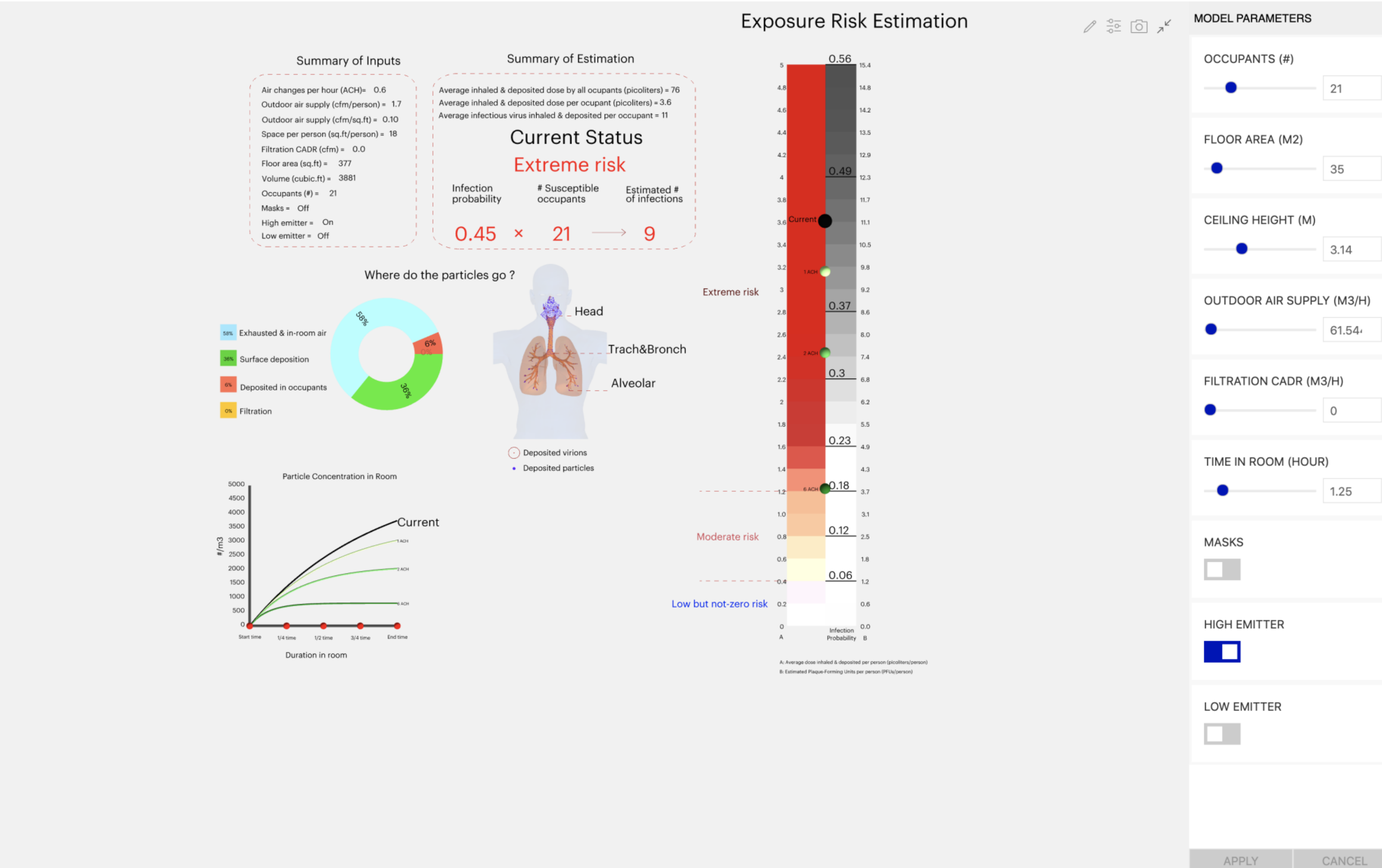
(Doctoral Candidate)

UNIVERSITY OF OREGON | College of Design

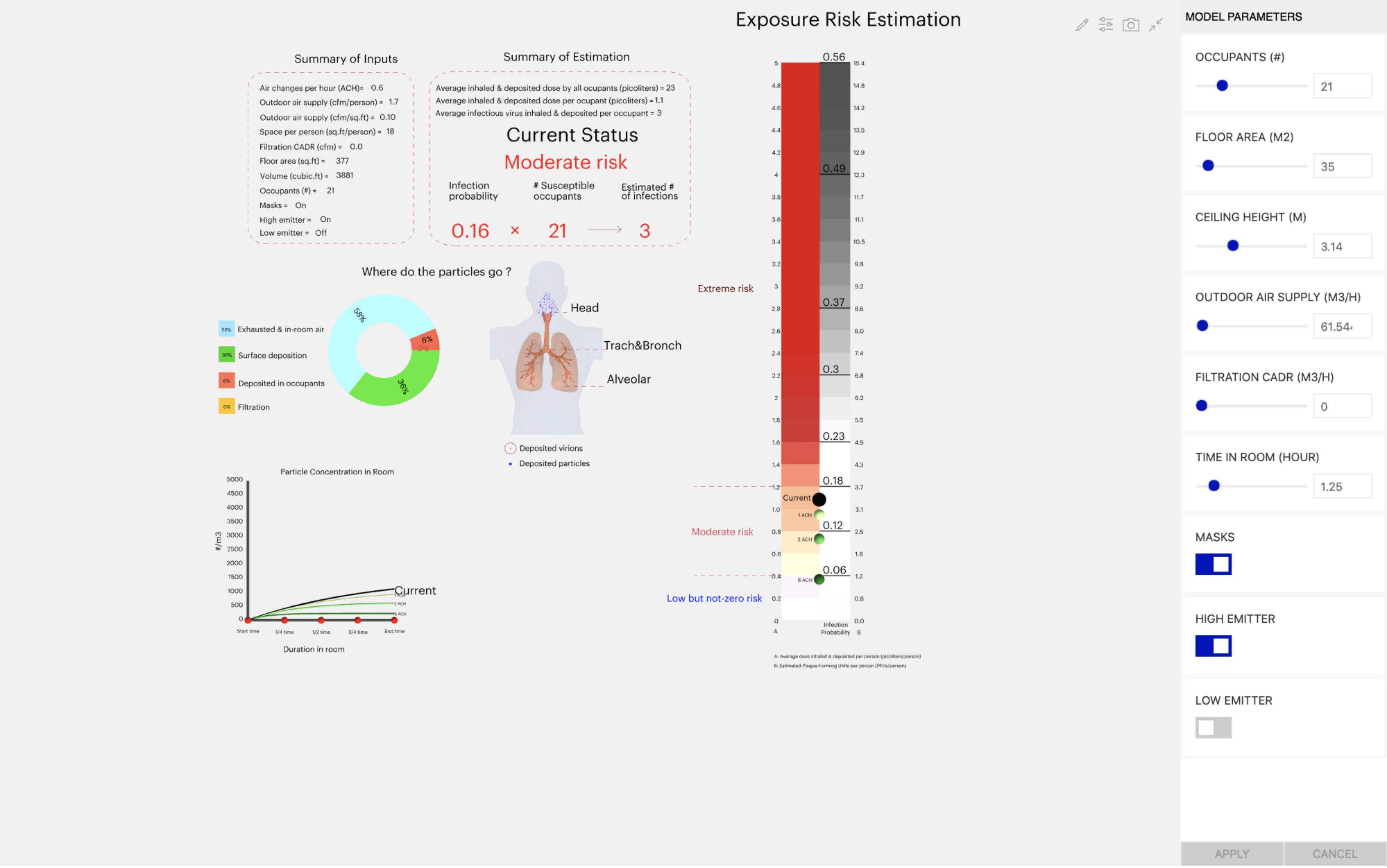
Case 1: SafeAirSpaces Baseline (Guangzhou Restaurant)



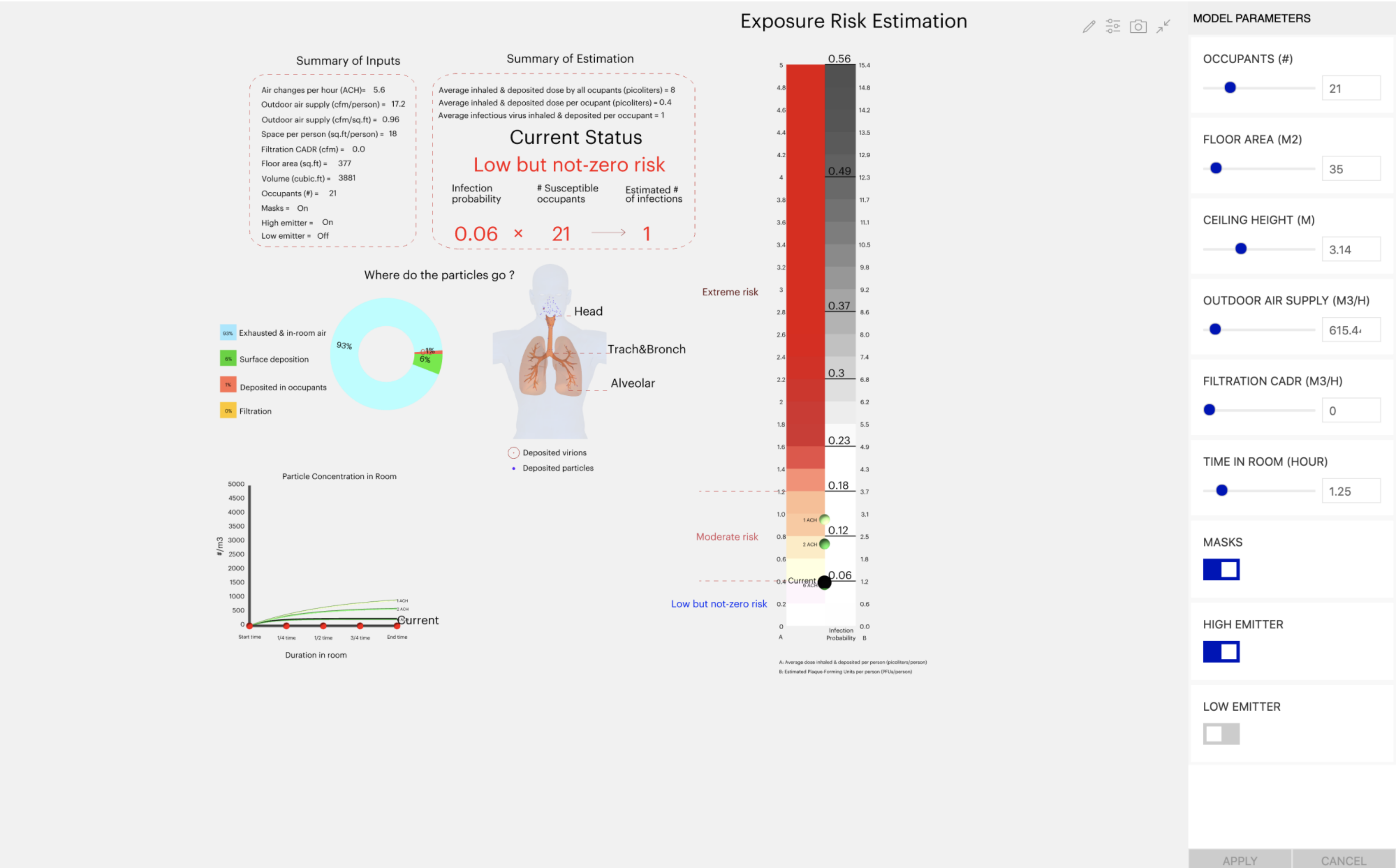
Case 1: Guangzhou Restaurant – Baseline



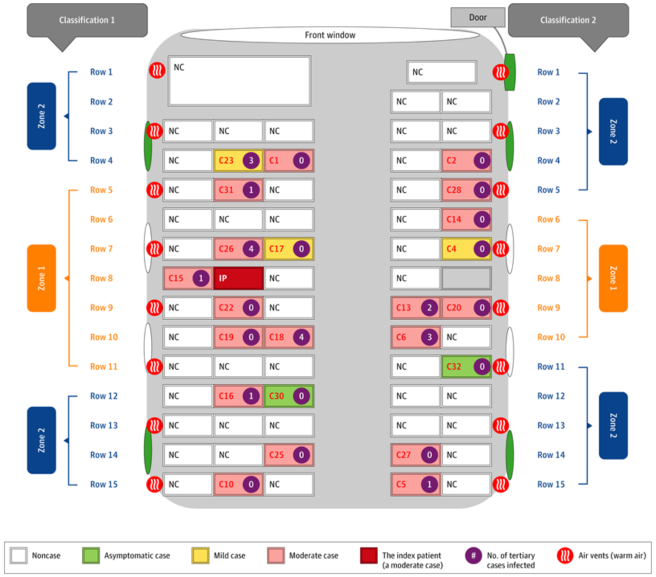
Case 1: Guangzhou Restaurant + Masks



Case 1: Guangzhou Restaurant + Masks + 6 Air Changes



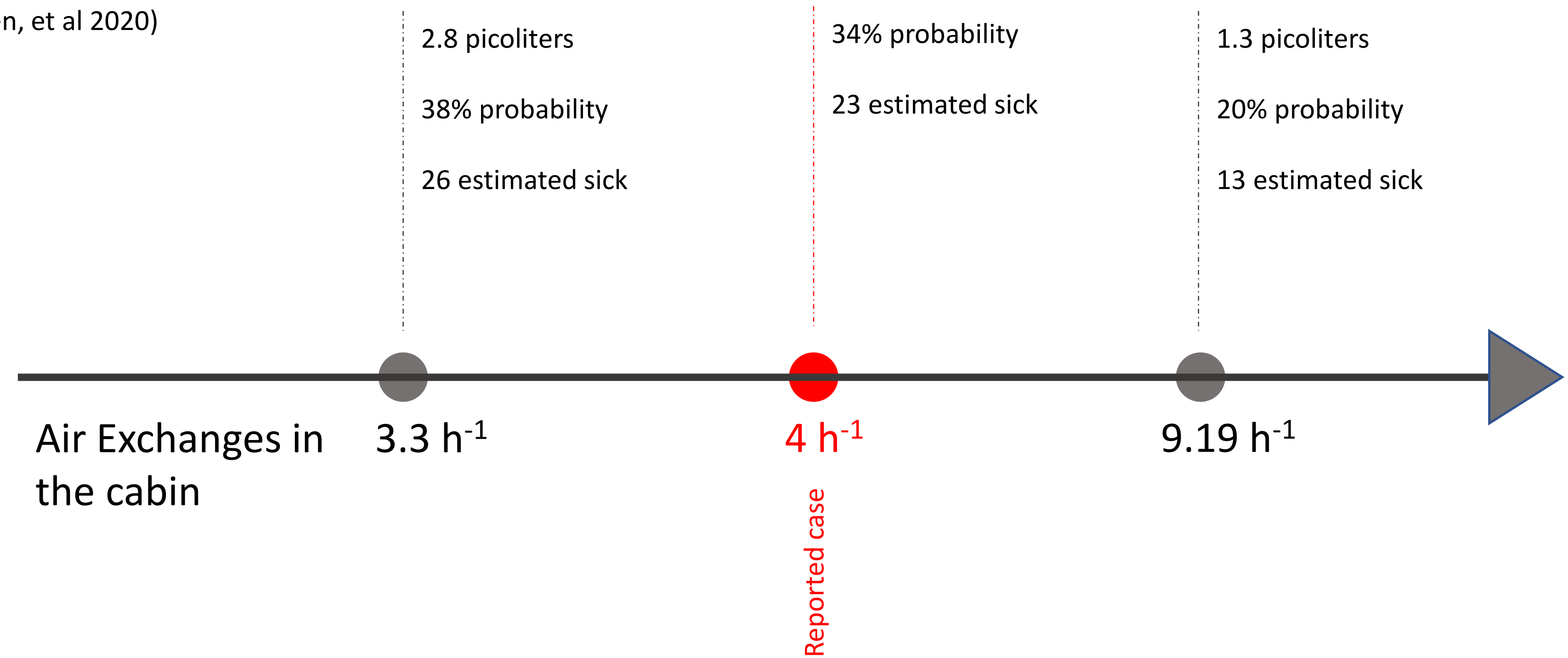
Case 2: A Bus Ride in China



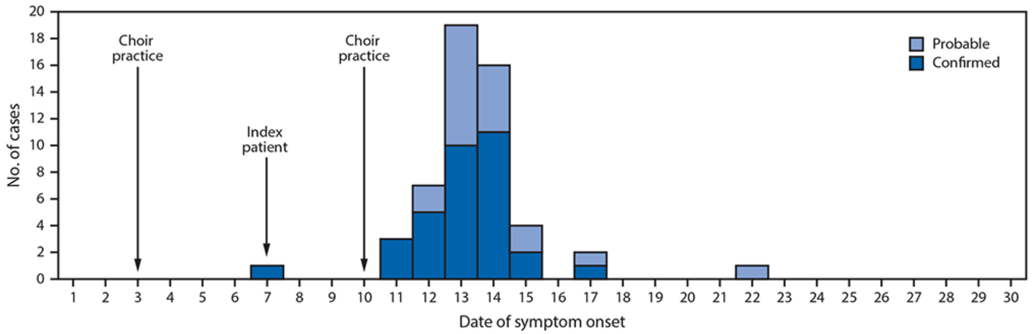
(Shen, et al 2020)

Bus Ride Outbreak Assumptions

Occupants (#)	68	Outdoor Air Supply (m^3/hr)	3.3 -9.19
Time of event (hr)	1.66	Filtration CADR (m^3/h)	0
Volume (m^3)	80	Low emitter	Off
High emitter	On	Reported attack rate	34%

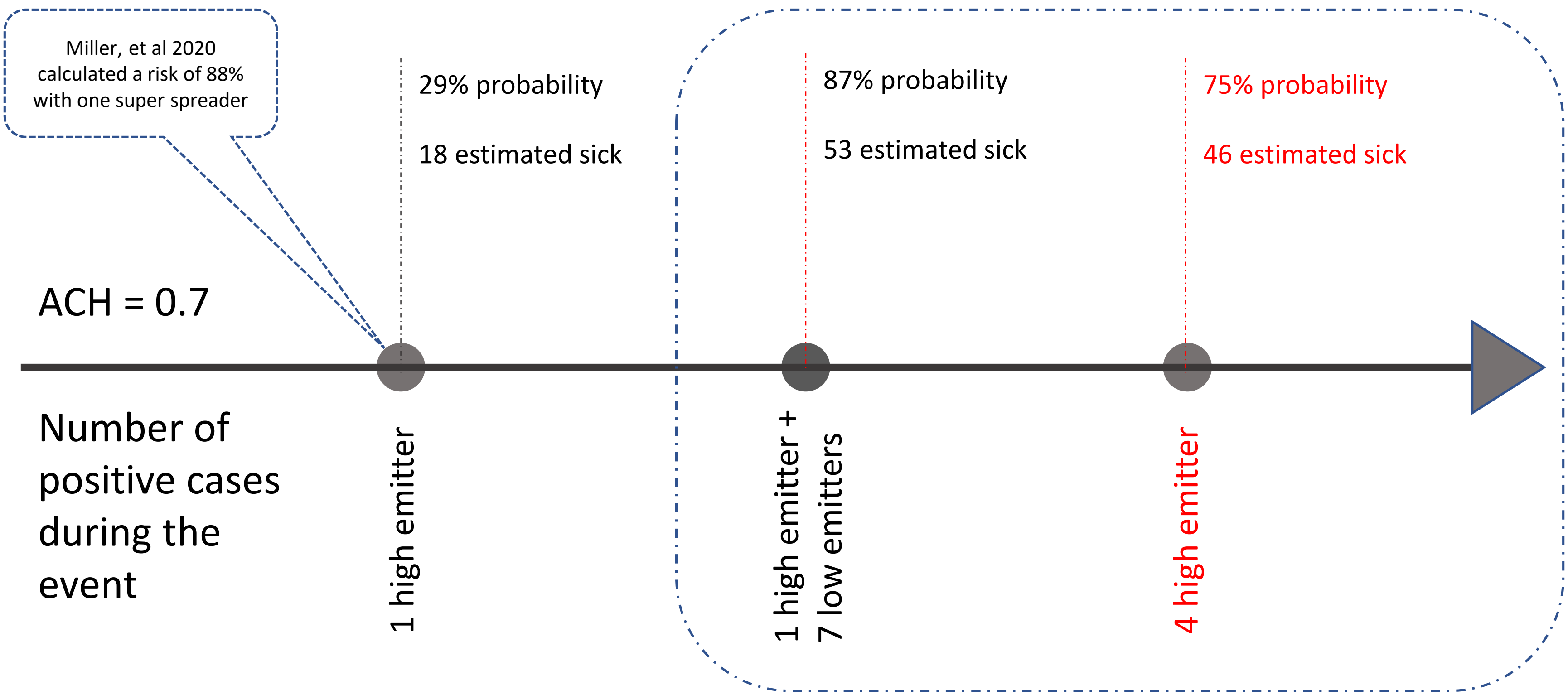


Case 3: Choir rehearsals in Skagit Valley

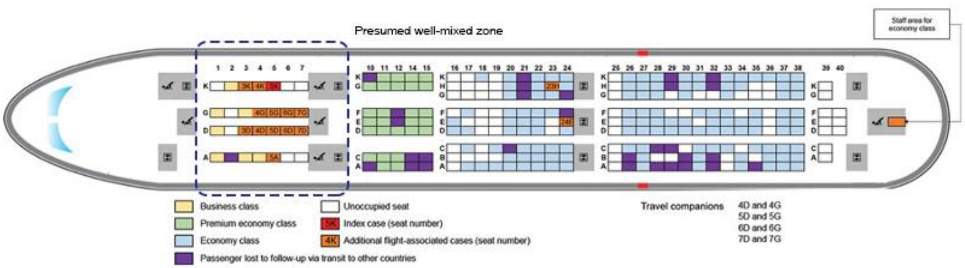


(CDC 2020)

Skagit Valley outbreak			
Occupants (#)	61	Outdoor Air Supply (m3/hr)	0.7,
Time of event (hr)	2.5	Filtration CADR (m3/h)	0
Volume (m³)	810	Fractional time speak	0.5
Speak multiplier	1.5	Reported attack rate	87%

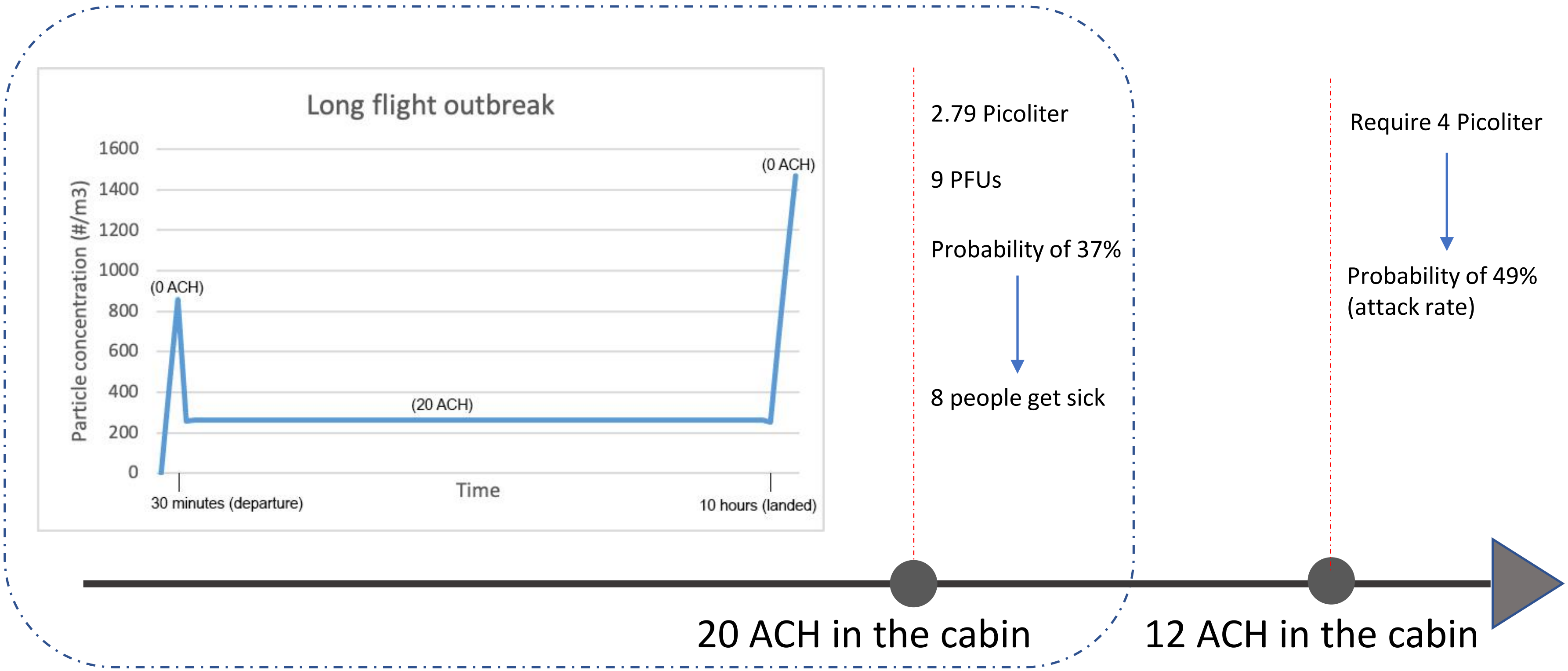


Case 4: A long flight from London to Hanoi



(NC. ET AL 2020)

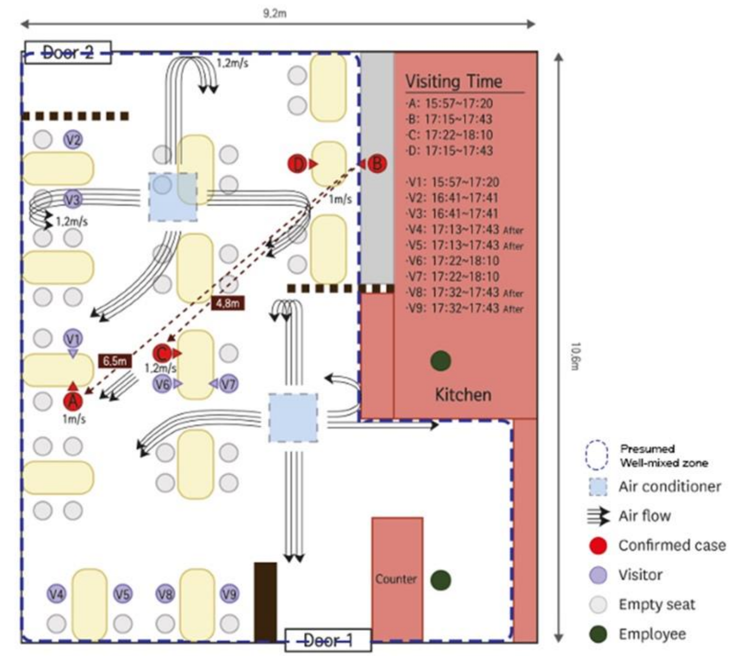
Long flight outbreak			
Occupants (#)	21	Outdoor Air Supply during flight (m3/hr)	20 ACH
Time of event (hr)	0.5 (boarding) 9.5 (flight) 0.5 (departure)	Outdoor Air Supply during boarding & departure (m3/hr)	0
Volume (m³)	165 m³	Filtration CADR (m3/h)	0
Speak multiplier	1	Fractional time speak	0.2



Case 5: A restaurant in South Korea

South Korea restaurant outbreak			
Occupants (#)	13	Outdoor Air Supply (m^3/hr)	0.2
Time of event (hr)	0.92	Filtration CADR (m^3/h)	0
Volume (m^3)	~185	Fractional time speak	0.2
Speak multiplier	1.5	Attack rate	15.4%

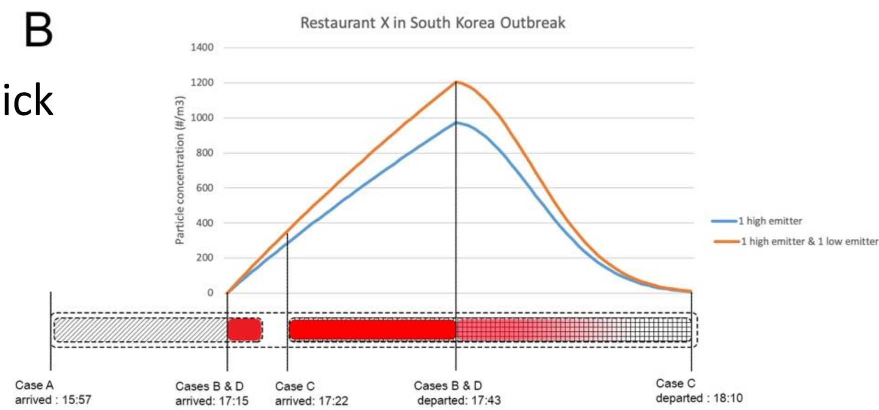
A



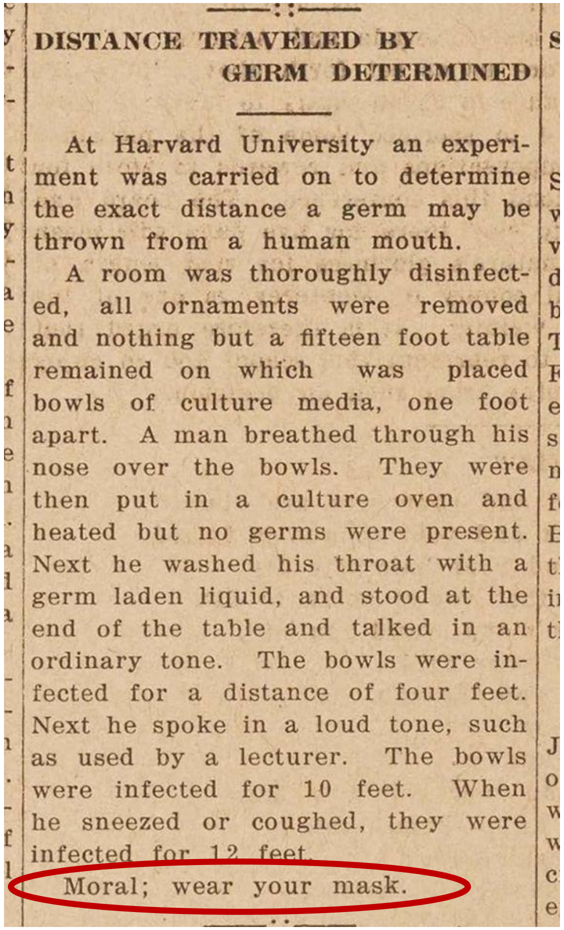
(Case C) Probability of 9% → 1 person gets sick

(Case C &.D) Probability of 13.4% → 2 persons gets sick

B



Closure



DISTANCE TRAVELED BY GERM DETERMINED

At Harvard University an experiment was carried on to determine the exact distance a germ may be thrown from a human mouth.

A room was thoroughly disinfected, all ornaments were removed and nothing but a fifteen foot table remained on which was placed bowls of culture media, one foot apart. A man breathed through his nose over the bowls. They were then put in a culture oven and heated but no germs were present. Next he washed his throat with a germ laden liquid, and stood at the end of the table and talked in an ordinary tone. The bowls were infected for a distance of four feet. Next he spoke in a loud tone, such as used by a lecturer. The bowls were infected for 10 feet. When he sneezed or coughed, they were infected for 12 feet.

Moral; wear your mask.

- Schools critical for EVERYBODY
- Multiple benefits for children
- Need schools to be safe as possible
- Layered dose (risk) reduction works
- Use tools to educate and plan
- A number of useful tools and resources are attached to this presentation, as well as more detailed slides on individual dose and risk reduction strategies.
- See also – www.corsiaq.com

Some Additional Resources

ASHRAE Epidemic Task Force - Schools

https://www.ashrae.org/file%20library/technical%20resources/covid-19/ashrae-reopening-schools-and-universities-c19-guidance.pdf

EPA Tools for Schools, etc.

Environmental Topics | Laws & Regulations | About EPA | Search EPA.gov

CONTACT US | SHARE

Creating Healthy Indoor Air Quality in Schools

Promote a healthy learning environment at your school to reduce absenteeism, improve test scores and enhance student and staff productivity.

EPA Supports Healthy Indoor Environments in Schools During COVID-19 Pandemic

- Indoor Air Quality Home Page
- Frequently Asked Questions

SUBSCRIBE — Subscribe to IAQ and Schools Email Updates

Adopting IAQ Best Practices

- Why It's Important
- Take Action to Improve IAQ in Schools
- Framework for Healthy Indoor Environments

Learning and Training

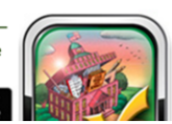
- On-Demand Training Webinars
  - IAQ Knowledge-to-Action Professional Training Webinar Series

School IAQ

Assessment Mobile App

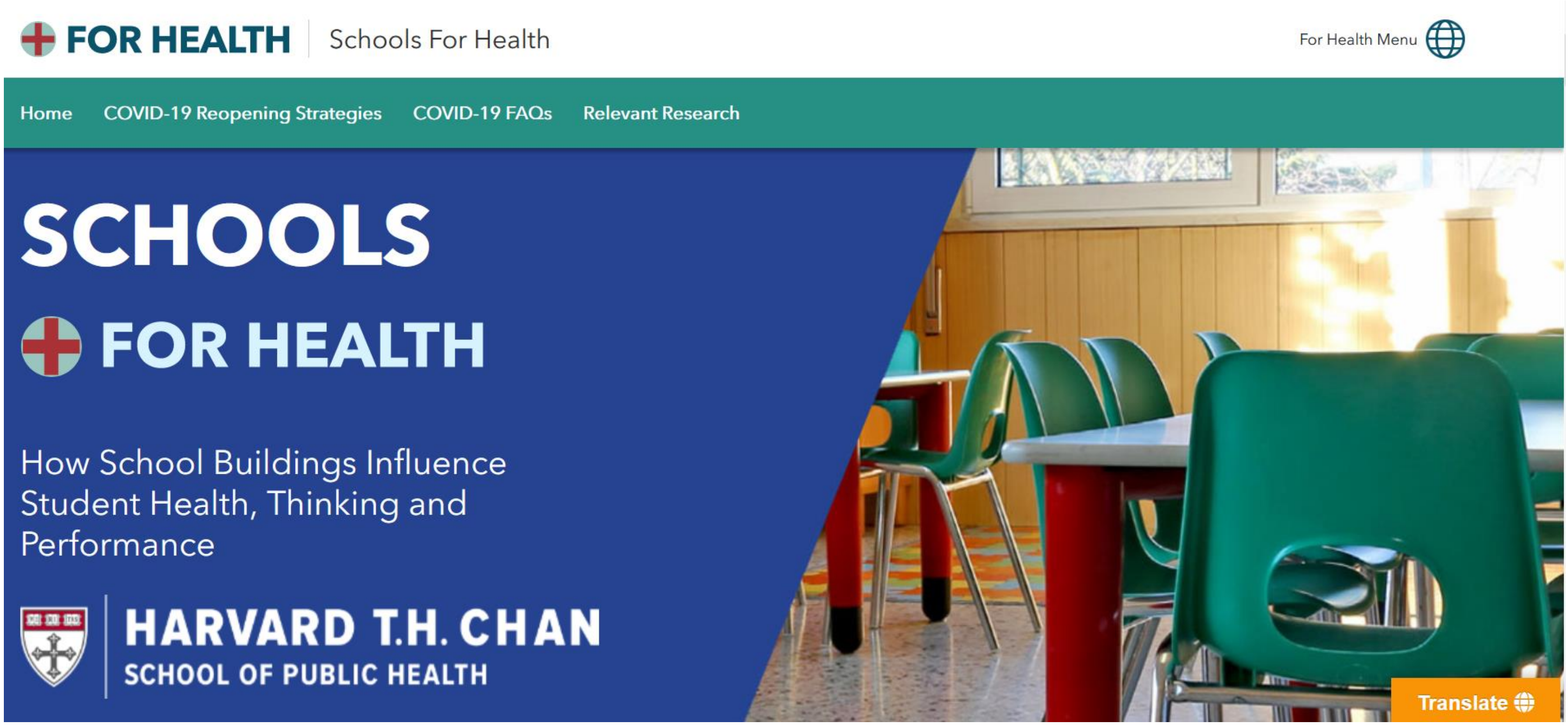
Assess, then address — EPA has made it easy!

Download on the App Store



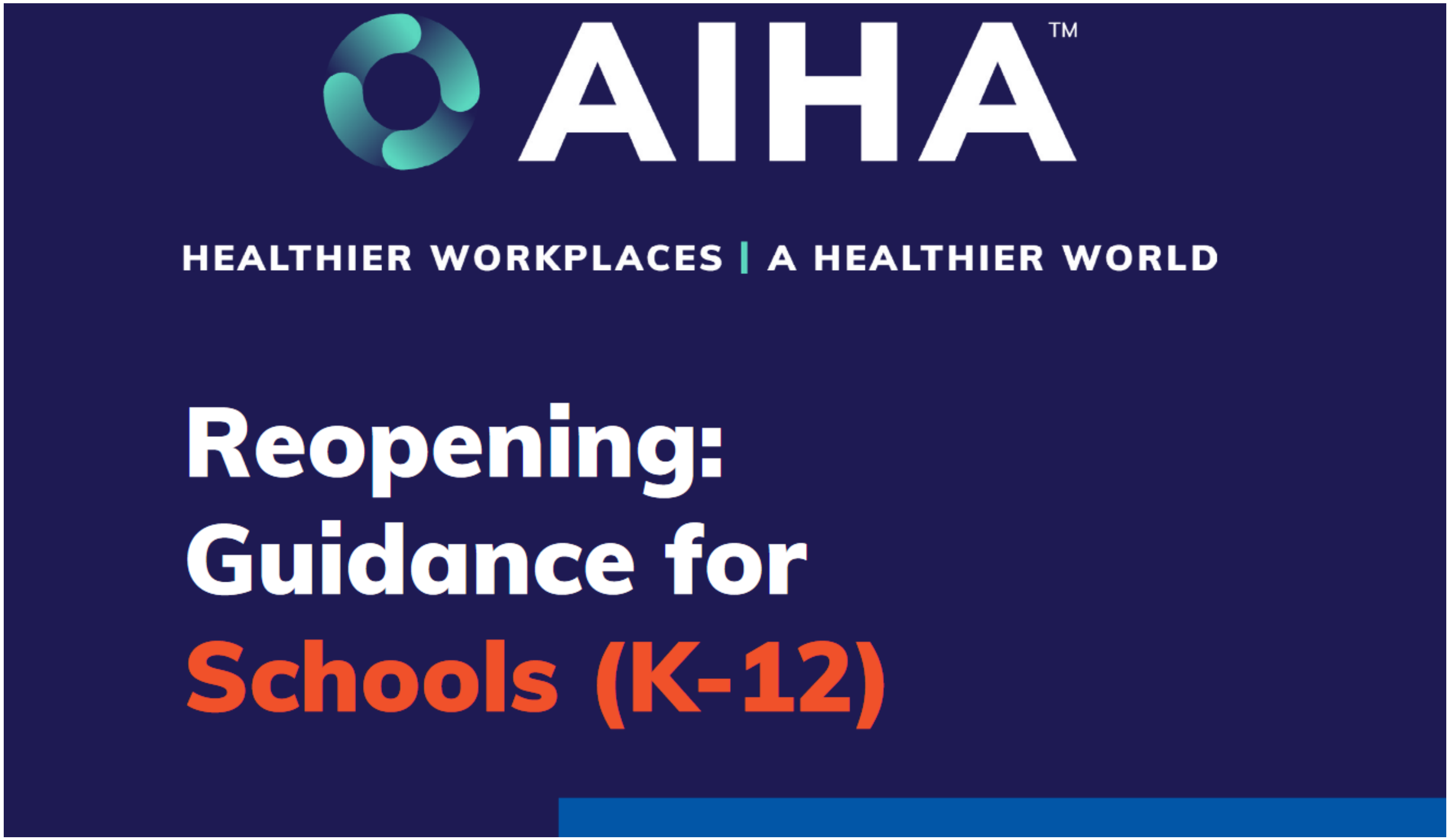
https://www.epa.gov/iaq-schools

Harvard T.H. Chan School of Public Health



https://schools.forhealth.org

AIHA – Reopening Guidance



https://aiha-assets.sfo2.digitaloceanspaces.com/AIHA/resources/Reopening-Guidance-for-Schools-K-12_GuidanceDocument.pdf

FATIMA Model (NIST)

NIST

Search NIST

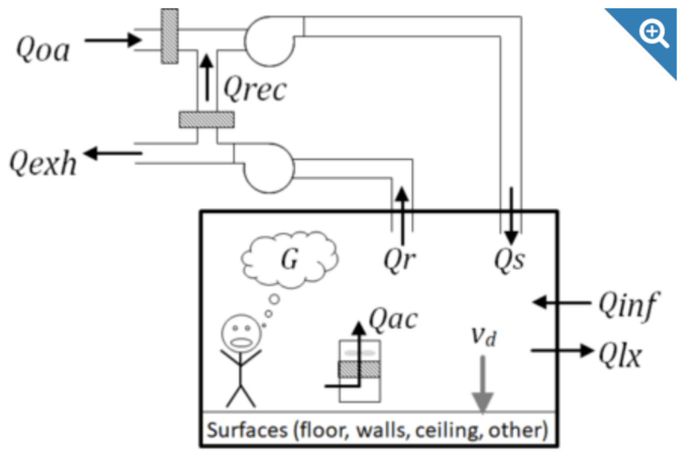
Menu

SOFTWARE

FaTIMA

The web-based tool *Fate and Transport of Indoor Microbiological Aerosols* (FaTIMA) allows for the determination of the indoor fate of microbiological aerosols associated with ventilation, filtration, deposition and inactivation mechanisms. FaTIMA provides a representation of a single, well-mixed zone that is served by a mechanical ventilation system and incorporates particle source and removal mechanisms. The simple mechanical ventilation system model

/www.nist.gov/sites/default/files/images/2020/05/12/FaTIMA.png



Type of Software
Web Application

Last Updated
2020-09-04

NIST Author
William Stuart Dols

Brian Polidoro

https://www.nist.gov/services-resources/software/fatima

CU Boulder Aerosol Transmission Estimator

University of Colorado Boulder

Aerosol Transmission Estimator

http://tinyurl.com/covid-estimator

A	B	C	D	E	F	G
Estimation of COVID-19 aerosol transmission: master spreadsheet, adapt this one to your case - Default values are for						
This is a general spreadsheet applicable to any situation, under the assumptions of this model - *See notes specific to this case (if applicable) at the very bottom*						
Important inputs as highlighted in orange - change these for your situation						
Other, more specialized inputs are highlighted in yellow - change only for more advanced applications						
Calculations are not highlighted - don't change these unless you are sure you know what you are doing						
Results are in blue -- these are the numbers of interest for most people						
Environmental Parameters						
	Value			**Value in other units**		**Source / Comments**
Length of room	25	ft		7.6	m	Can enter as ft or as m (once entered as m, changing in ft does
Width of room	20	ft	=	6.1	m	Can enter as ft or as m (once entered as m, changing in ft does
	500	sq ft		47	m2	Can overwrite the m2 one. If you want to enter sq ft, enter "=B1
Height	10	ft	=	3.1	m	Can enter as ft or as m (once entered as m, changing in ft does
Volume				142	m3	Volume, calculated. (Can also enter directly, then changing dim
Pressure	0.95	atm				Used only for CO2 calculation
Temperature	20	C				Use web converter if needed for F --> C. Used for CO2 calcul
Relative Humidity	50	%				Not yet used, but may eventually be used for survival rate of vi
Background CO2 Outdoors	415	ppm				See readme
Duration of event	50	min		0.8	h	Value for your situation of interest
Number of repetitions of event	180	times				For e.g. multiple class meetings, multiple commutes in public tr

- Tutorials in English & Spanish: https://www.youtube.com/channel/UChUCsAMXy8f01R3rWqj4z6A
- Many calculators inspired in this one or derived independently, all consistent to my knowledge

69

Courtesy Jose L. Jimenez

Aerosol Science & Indoor Air Researchers

http://tinyurl.com/preguntas-espanol

https://tinyurl.com/FAQ-aerosols

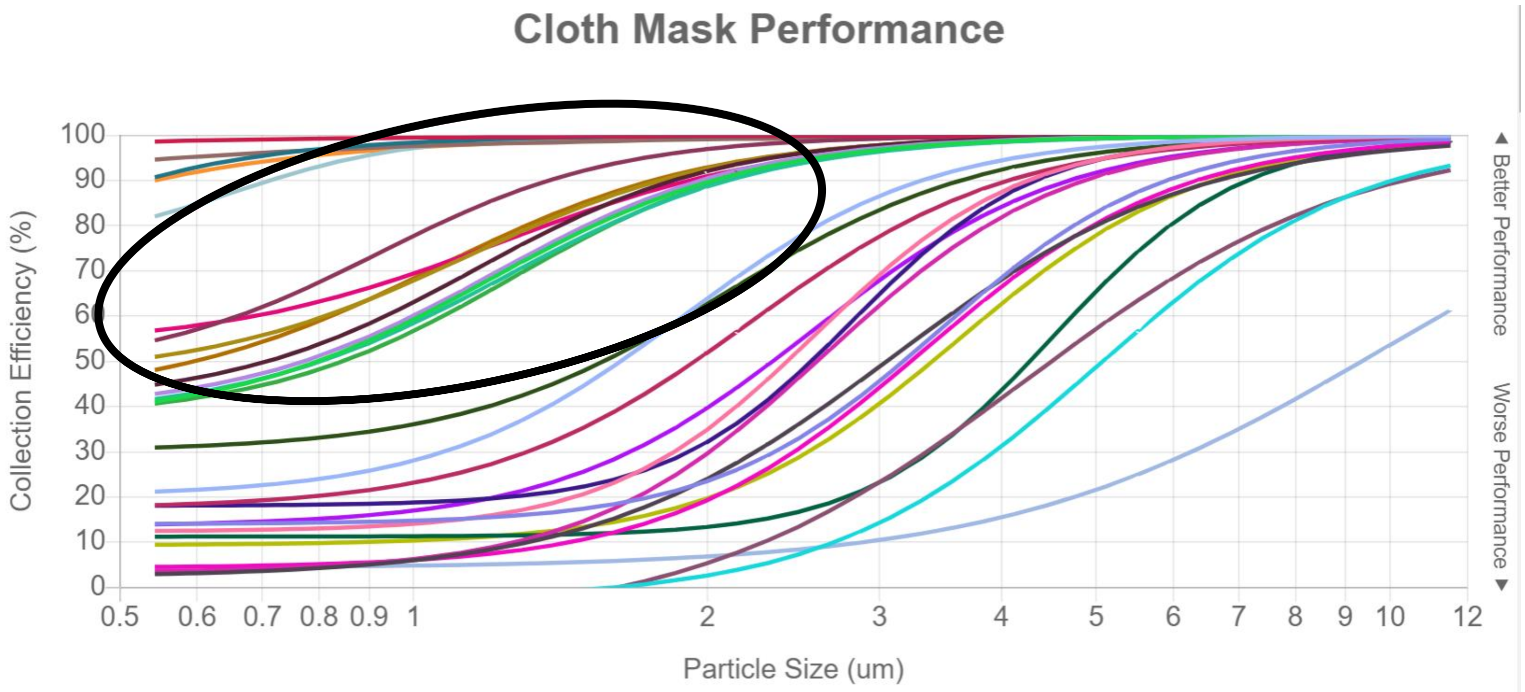
FAQs on Protecting Yourself from COVID-19 Aerosol Transmission

Shortcut to this page: https://tinyurl.com/FAQ-aerosols
Version: 1.65, 15-Sep-2020

If you want to jump over other details and go straight to the recommendations, click here.

Some Additional Slides

Cloth Mask Performance



- Performance = strong function of material(s) & fit
- Particle size dependent
- Nice resource
  - Select materials (includes data on breathability)

http://jv.colostate.edu/masktesting/

Drs. John Volcken & Christian L'Orange

Ventilate

- Reduce Source(s)
- Require Masks
- Distance from Source
- **Ventilate**
- Filter
- Use Portable Air Cleaners
- Optimize RH
- Disinfect air (UVGI only)
- Disinfect Surfaces
- Make Use of Time
- Modify Activities
- Educate

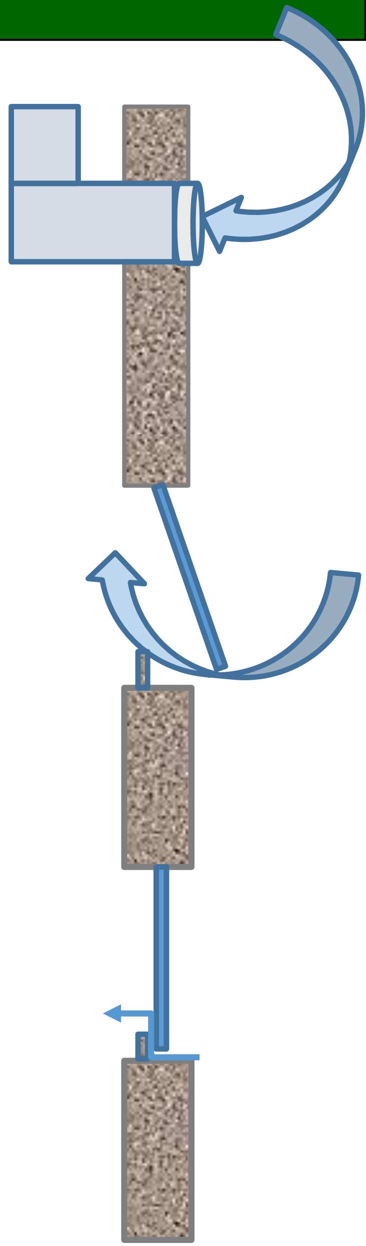
$$Dose_{inhal,i} = C_i\ (\#/L) \times B\ (L/min) \times t\ (min) \times f_{dep,i}$$

- Best = outdoors
- Mechanical (controlled)
- Natural (design openings)
- Infiltration

https://www.nytimes.com/2020/07/17/nyregion/coronavirus-nyc-schools-reopening-outdoors.html

Ventilation Modes

- **Outdoors** (whenever possible)
  - Restaurants, sidewalk sales, office patios
- **Mechanical**
  - Highly controlled but variable across systems
  - Outdoor air intake w/ dampers
  - Outdoor air mixed w/ recirculated air
- **Natural** (design openings)
  - Intentional openings
  - Results highly variable
  - Unintended consequences
  - Box fan can add control
- **Infiltration** (unintentional openings)
  - Cracks around envelope, etc. (collective leakage area)
  - Always acts; wide variation; unintended consequences

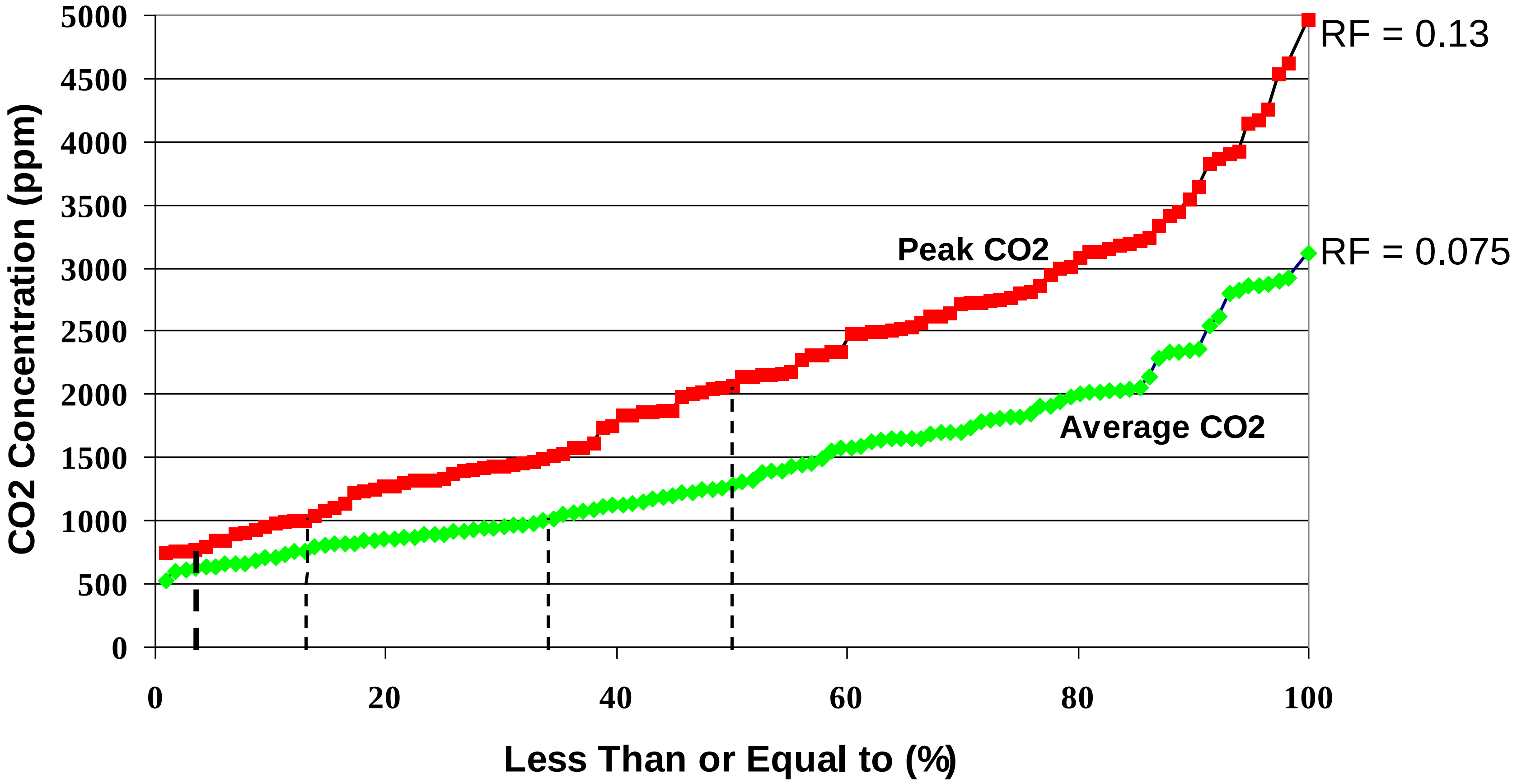


Carbon Dioxide (CO_2) as Surrogate

- **Elevated CO_2 = inadequate ventilation**
- Typical (pre-pandemic): Limit to 700 ppm above outdoors
- "Acceptable" control of body odors, etc.
- Adverse impacts have been noted at elevated CO_2
  - Increased absences in schools (Shendell et al., *Indoor Air*, 2004)
  - Worse test scores (Haverinen-Shaughnessy et al., *Indoor Air*, 2011)
  - Speed, errors, attendance (Wargocki et al., *Building & Environ*, 2020)
  - Cognitive performance of pilots (Allen et al., *JESEE*, 2019)

CO_2: Cumulative Distributions

115 K-8 classrooms; all day sampling; two school districts



Median average RF = 0.025 (2.5%); Median peak RF = 0.044 (4.4%)

< 15% with average RF < 0.01; < 5% with peak RF < 0.01

Rudnick-Milton Model

$$P = 1 - e^{-\left(\frac{RF_{avg} \times I \times q \times t}{n}\right)}$$

P = Probability that a susceptible person will become infected (0 - 1)

RF_{avg} = Average rebreathed fraction over time of exposure t (-)

I = Number of infectors in the indoor space (-)

q = quanta generation rate (1/hr)

t = Exposure time (hr)

N = Number of people in the space (-)

RF_{avg} x I/n = fraction of rebreathed fraction due to infectors; P increases as …..?

Filter

- Reduce Source(s)
- Require Masks
- Distance from Source
- Ventilate
- **Filter**
- Use Portable Air Cleaners
- Optimize RH
- Disinfect air (UVGI only)
- Disinfect Surfaces
- Make Use of Time
- Modify Activities
- Educate

$$\text{Dose}_{inhal,i} = \mathbf{C_i}\ (\#/L) \times \mathbf{B}\ (L/min) \times \mathbf{t}\ (min) \times \boldsymbol{f}_{dep,i}$$

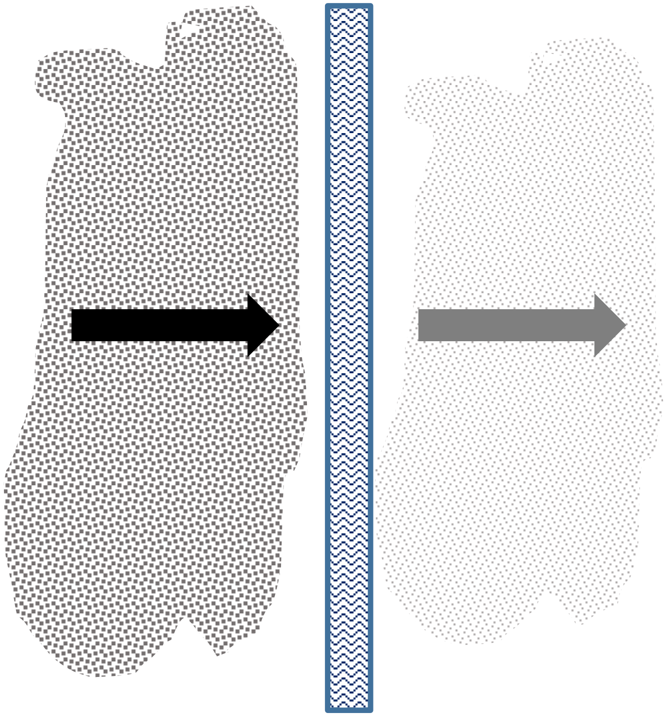
Replacement of MERV-8 w/ MERV-13 filters at Portland State University

Filtration Mechanisms

$$\text{Dose}_{inhal,i} = \mathbf{C_i}\ (\#/L) \times \mathbf{B}\ (L/min) \times \mathbf{t}\ (min) \times \boldsymbol{f}_{dep,i}$$

$$C_i = \frac{E_i}{\{\lambda + k_i + r_i\} \times V}$$

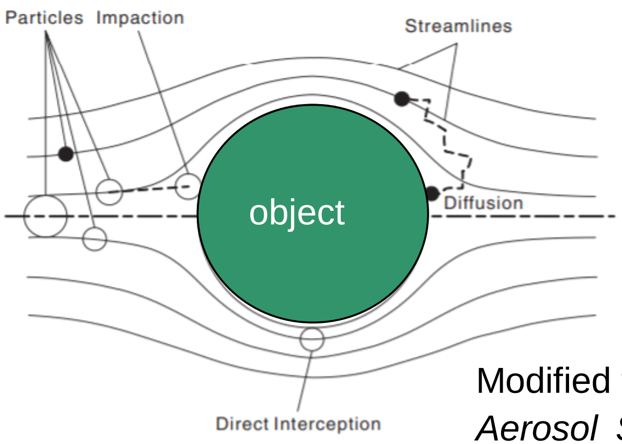
$$C_i = \frac{E_i}{\left\{\lambda + k_i + \frac{\eta_i Q_c}{V}\right\} \times V}$$



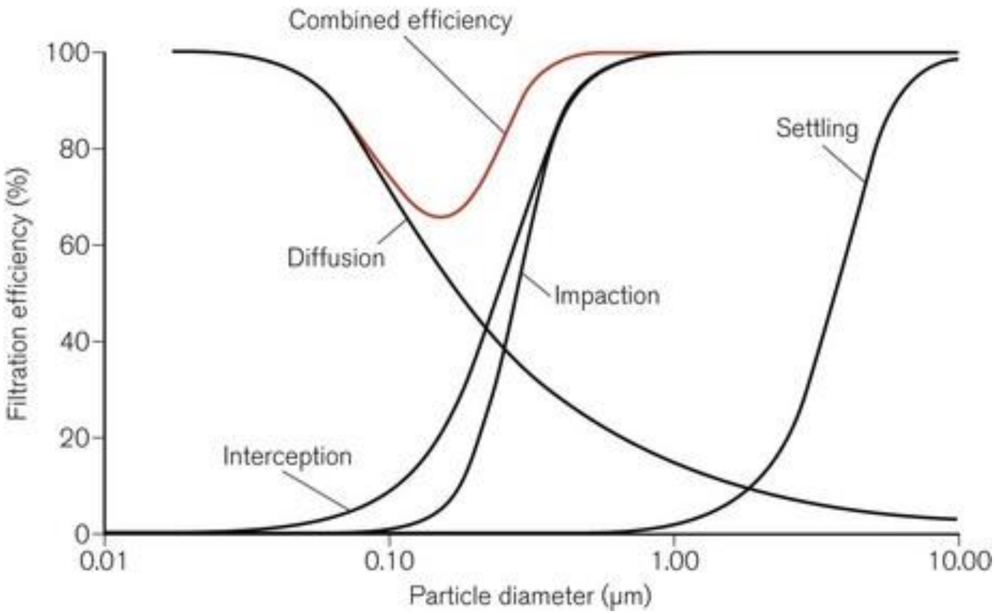
η_i = fractional removal of particles of size I in filter (-)

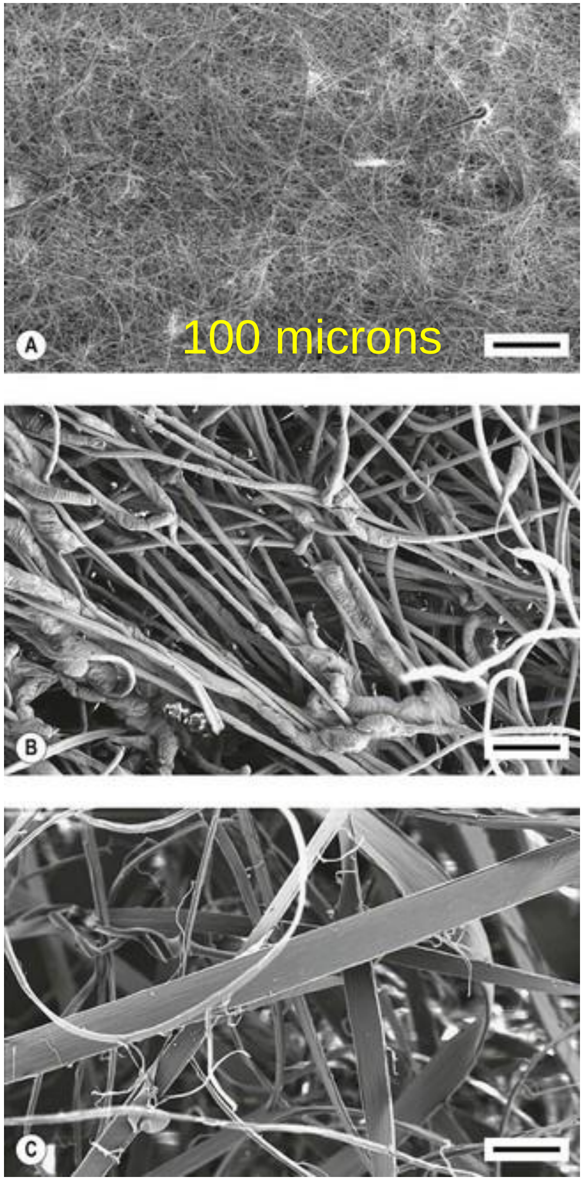
Q_c = volumetric flowrate of air through filter (m^3/hr)

Filtration Mechanisms



Modified from Wang, W., *et al.* *Aerosol Sci & Technol*, 46:843–851, 2012





Reducing Airborne Infectious Aerosol Exposure

ASHRAE EPIDEMIC TASK FORCE

Core Recommendations for Reducing Airborne Infectious Aerosol Exposure

1. *Public Health Guidance* - Follow all regulatory and statutory requirements and recommendations for social distancing, wearing of masks and other PPE, administrative measures, circulation of occupants, reduced occupancy, hygiene, and sanitation.

2. *Ventilation, Filtration, Air Cleaning*
   - 2.1 Provide and maintain at least required minimum outdoor airflow rates for ventilation as specified by applicable codes and standards.
   - 2.2 Use combinations of filters and air cleaners that achieve MERV 13 or better levels of performance for air recirculated by HVAC systems.
   - 2.3 Only use air cleaners for which evidence of effectiveness and safety is clear.
   - 2.4 Select control options, including standalone filters and air cleaners, that provide desired exposure reduction while minimizing associated energy penalties.

3. *Air Distribution* - Where directional airflow is not specifically required, or not recommended as the result of a risk assessment, promote mixing of space air without causing strong air currents that increase direct transmission from person-to-person.

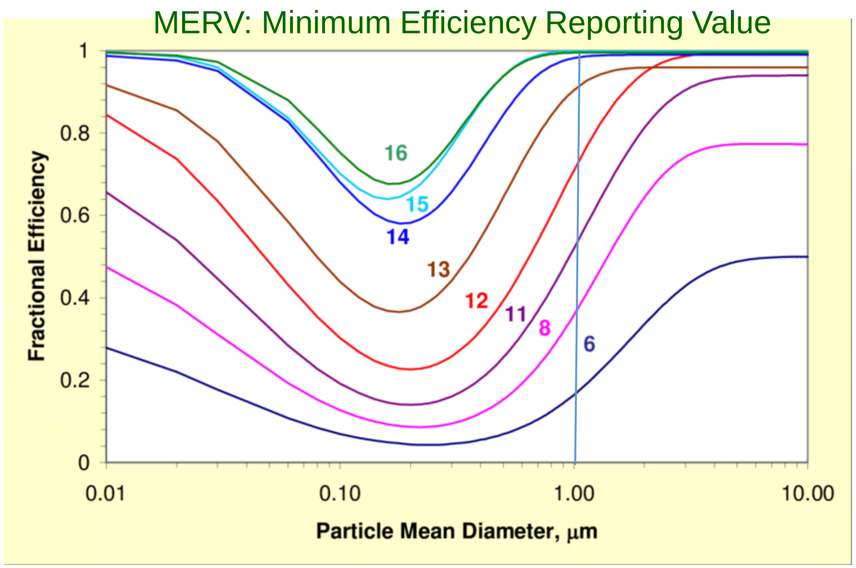
4. *HVAC System Operation*
   - 4.1 Maintain temperature and humidity design set points.
   - 4.2 Maintain equivalent clean air supply required for design occupancy whenever anyone is present in the space served by a system.
   - 4.3 When necessary to flush spaces between occupied periods, operate systems for a time required to achieve three air changes of equivalent clean air supply.
   - 4.4 Limit re-entry of contaminated air that may re-enter the building from energy recovery devices, outside air intakes, and other sources to acceptable levels.

5. *System Commissioning – Verify that HVAC systems are functioning as designed.*

MERV-Rated Filters

"Improve central air and other HVAC filtration to MERV-13 or the highest level achievable." (ASHRAE pandemic response

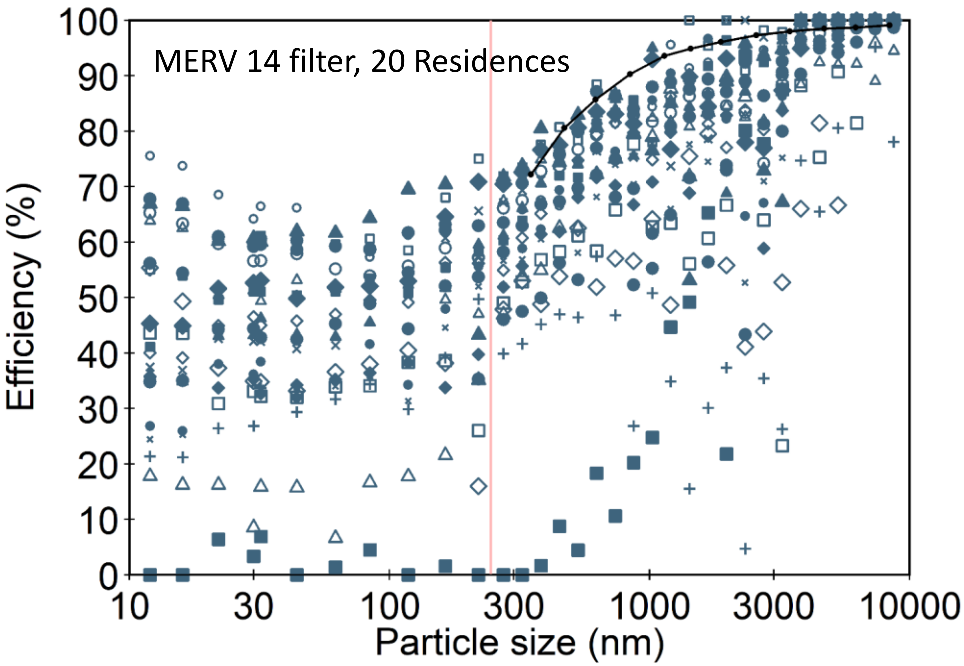
ASHRAE Position Document on Infectious Aerosols (2020)



- Theoretical
- Can be worse
- System problems?

Kowalski & Bahnfleth (2002)
https://www.researchgate.net/figure/Composite-of-all-MERV-filter-models-based-on-initial-conditions_fig3_237558312

Important to Check for By-Pass



Li and Siegel, *Indoor Air* (2020)

Courtesy of Dr. Jeffrey Siegel, U Toronto

Courtesy of Dr. Atila Novoselac, UT Austin (not a MERV 13 or 14)

Important to inspect for by-pass

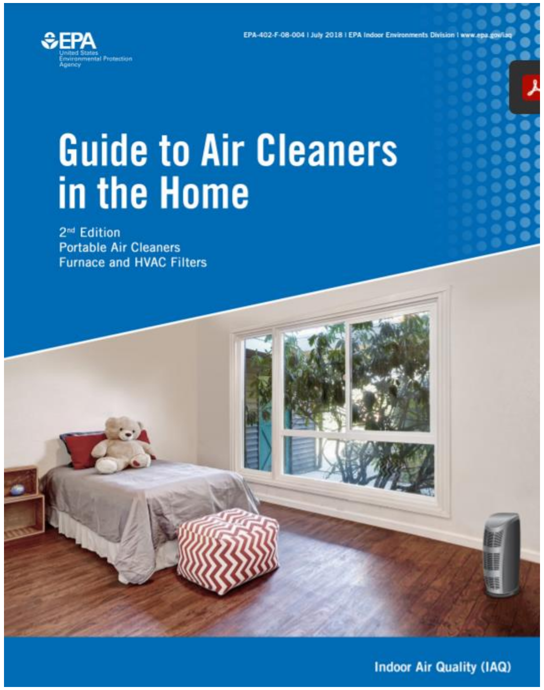
Filter Microbiomes

- Filters have microbiomes (e.g., fungi growth on filter cake)
- Respiratory viruses have been found on filters
- Take precautions when changing filters (central or PAC)
- Do not agitate
- Mask / goggles
- Gloves / hand hygiene
- Bag it

Portable Air Cleaners (PAC)

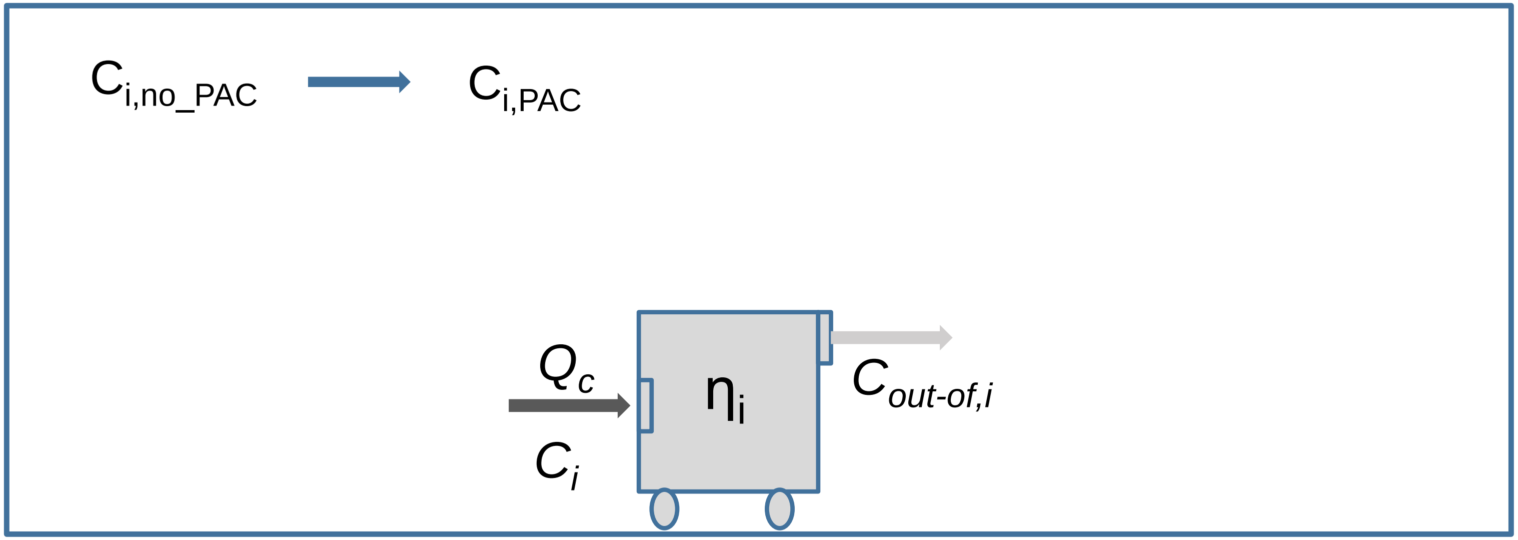
- Reduce Source(s)
- Require Masks
- Distance from Source
- Ventilate
- Filter
- **Use Portable Air Cleaners**
- Optimize RH
- Disinfect air (UVGI only)
- Disinfect Surfaces
- Make Use of Time
- Modify Activities
- Educate

$$\text{Dose}_{inhal,i} = \mathbf{C_i}\ (\#/L) \times \mathbf{B}\ (L/min) \times \mathbf{t}\ (min) \times \boldsymbol{f}_{dep,i}$$



https://www.epa.gov/sites/production/files/2018-07/documents/guide_to_air_cleaners_in_the_home_2nd_edition.pdf

PAC: Effectiveness (ε)



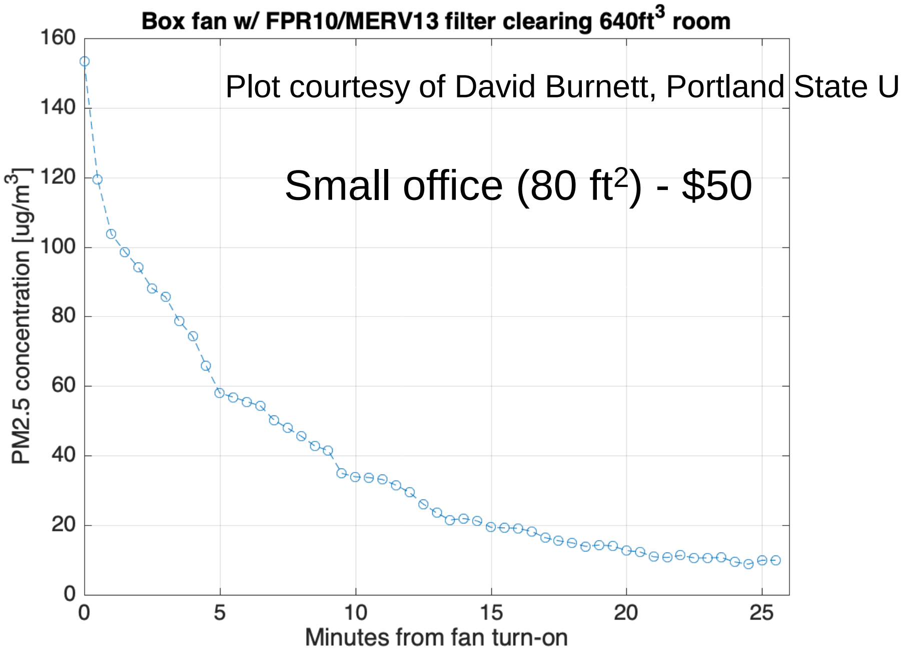
$$\varepsilon = 1 - \frac{C_{i,PAC}}{C_{i,no\_PAC}}$$

We want an effectiveness (ε) as large as possible.

AHAM area designation assumes $\varepsilon = 0.8$ for specific conditions.

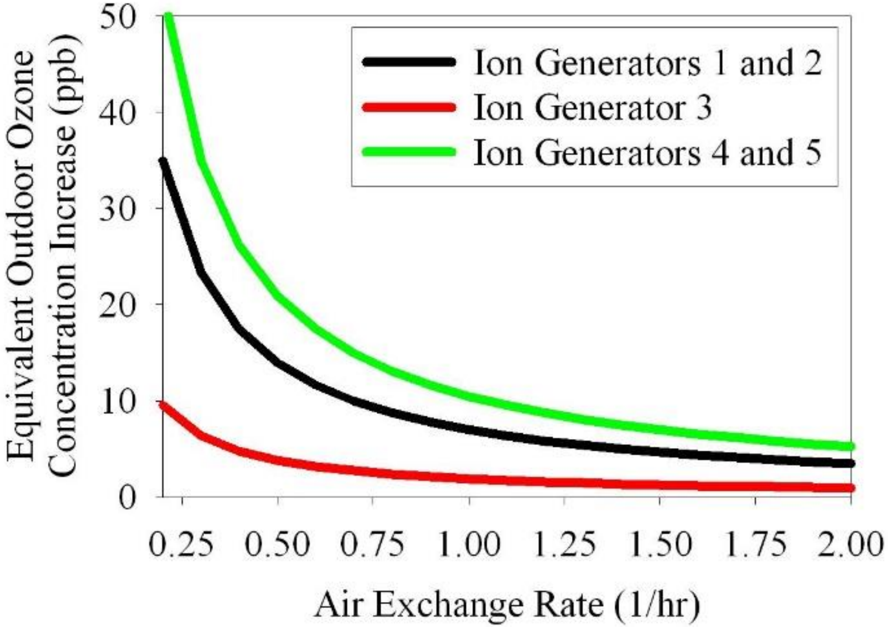
DIY - Portable Air Cleaners

@JimRosenthal4

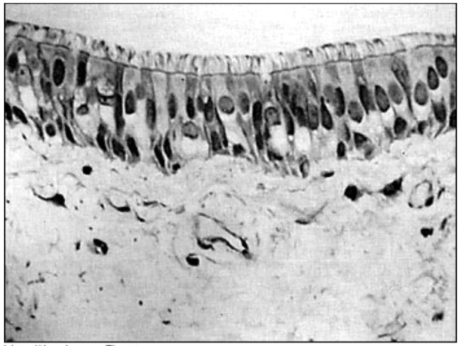


- Box fan sucking through filter
- Multiple filters in parallel (benefits)
- Cost = $80 to $150
- Reports of good performance

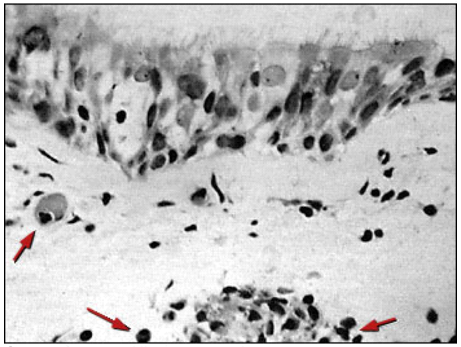
Ion Generators and Ozone Generation



Zhao, P., *et al*., *Proc. Indoor Air 2005* (2005)



Healthy Lung Tissue



Ozone-damaged Lung Tissue

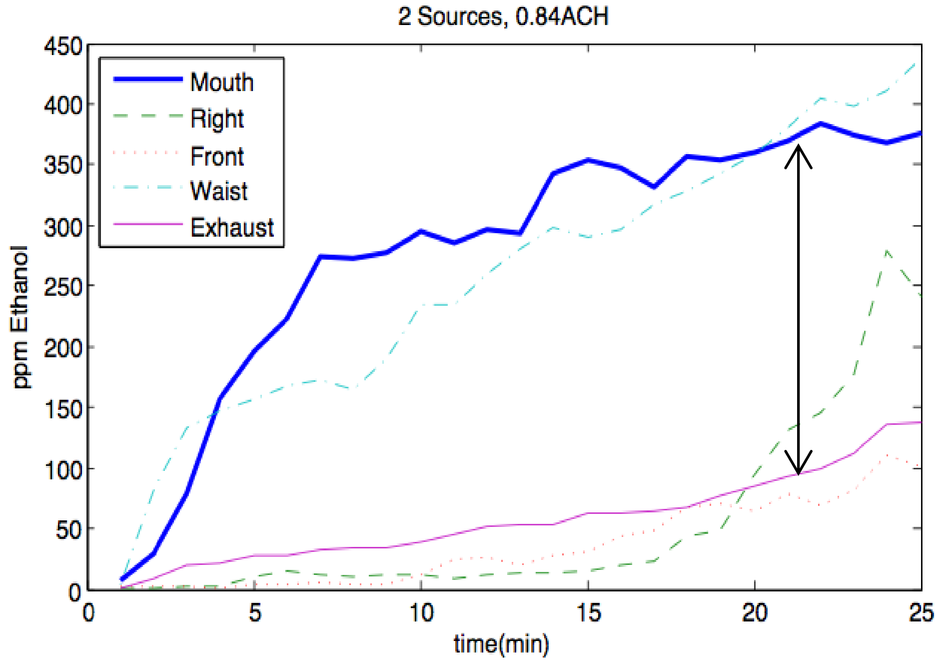
(Micrographs from American Thoracic Society, from *American Review of Respiratory Diseases,* Vol. 148, 1993, Robert Aris et al., pp. 1368 -1369.)

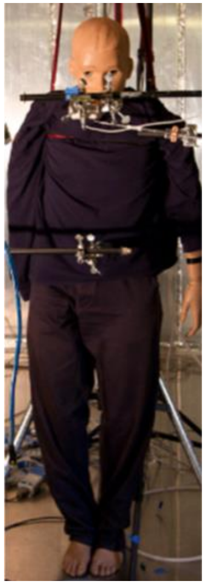
Disinfect Surfaces

- Reduce Source(s)
- Require Masks
- Distance from Source
- Ventilate
- Filter
- Use Portable Air Cleaners
- Optimize RH
- Disinfect air (UVGI only)
- **Disinfect Surfaces***
- Make Use of Time
- Modify Activities
- Educate

Deep & frequent cleaning is expensive, has some value, but not nearly that of inhalation dose reduction

Concerns: residual, reaction products, applications





Dissertation: Dr. Clive (Matt) Ernest, UT Austin

* Most important surface to disinfect is hands

Educate

- Reduce Source(s)
- Require Masks
- Distance from Source
- Ventilate
- Filter
- Use Portable Air Cleaners
- Optimize RH
- Disinfect air (UVGI only)
- Disinfect Surfaces
- Make Use of Time
- Modify Activities
- **Educate**

- Entire school community
  - Admin, teachers, staff, students, parents
- Target modes of communication
  - People absorb differently
- English & Spanish
- Make use of existing tools
  - e.g., SafeAirSpaces
  - Explore to educate