Twenty-Fourth Westford Symposium on Building Science
August 1-3, 2022

Buildings and Infection Control

Before, During, and After COVID

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The Pennsylvania State University

PennState College of Engineering | ARCHITECTURAL ENGINEERING

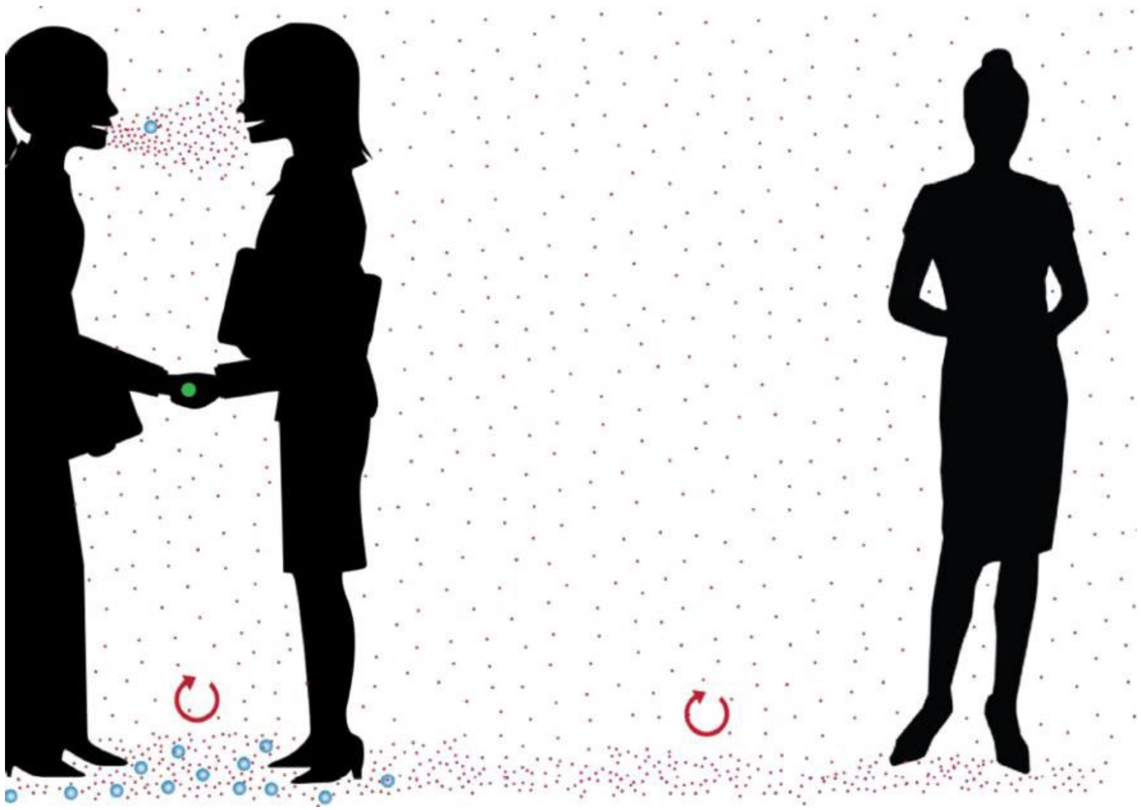
Infectious disease transmission

Current understanding of infectious disease

- Infection = microorganisms multiplying in or on our bodies – viruses, bacteria, fungi
- Infection risk is related to dose, how many active microbes we're exposed to – higher dose, higher risk

Exposure pathways – vary with the pathogen, including

- **Inhalation**
- **Droplet**
- Touching
- Contaminated food and water
- Bodily fluids or tissue

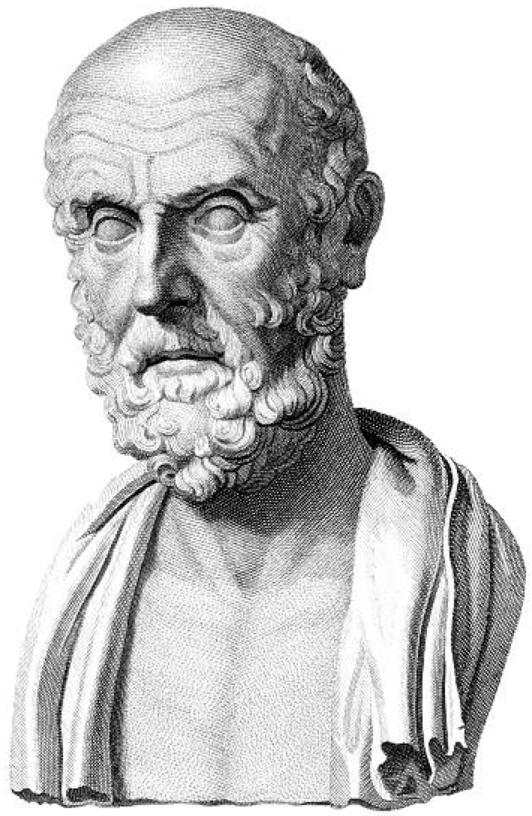


Tang, J.W., et al., 2021. Dismantling myths on the airborne transmission of severe acute respiratory syndrome coronavirus (SARS-CoV-2). *Journal of Hospital Infection*.

Before COVID…way before

Whenever many men are attacked by one disease at the same time, the cause should be assigned to that which is most common, and which we all use most. *This it is which we breathe in*.

~Hippocrates (c. 470 – 360 BC)
Nature of Man, ch. IX

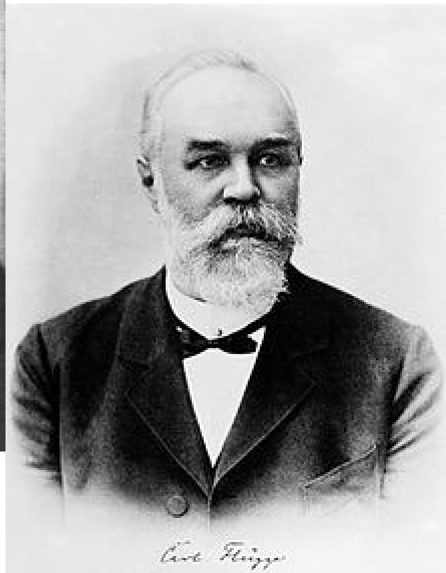


Late 19th Century – Early 20th Century

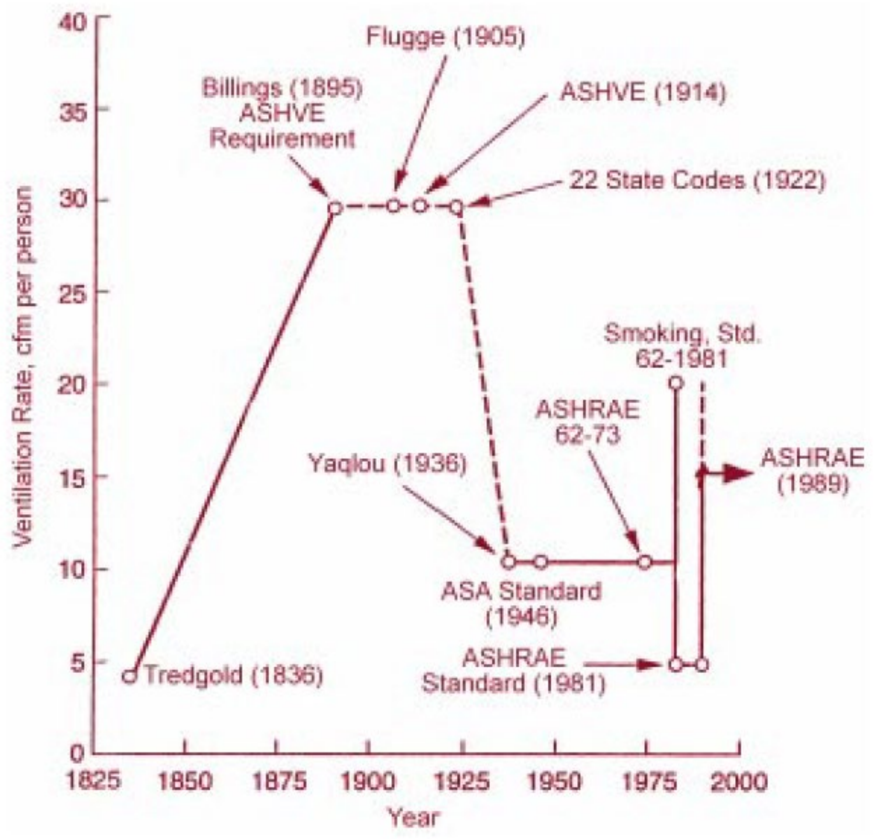
Florence Nightingale (UK)
- Nurse, social reformer, statistician
- Hospital redesign – ventilation, distancing, hygiene

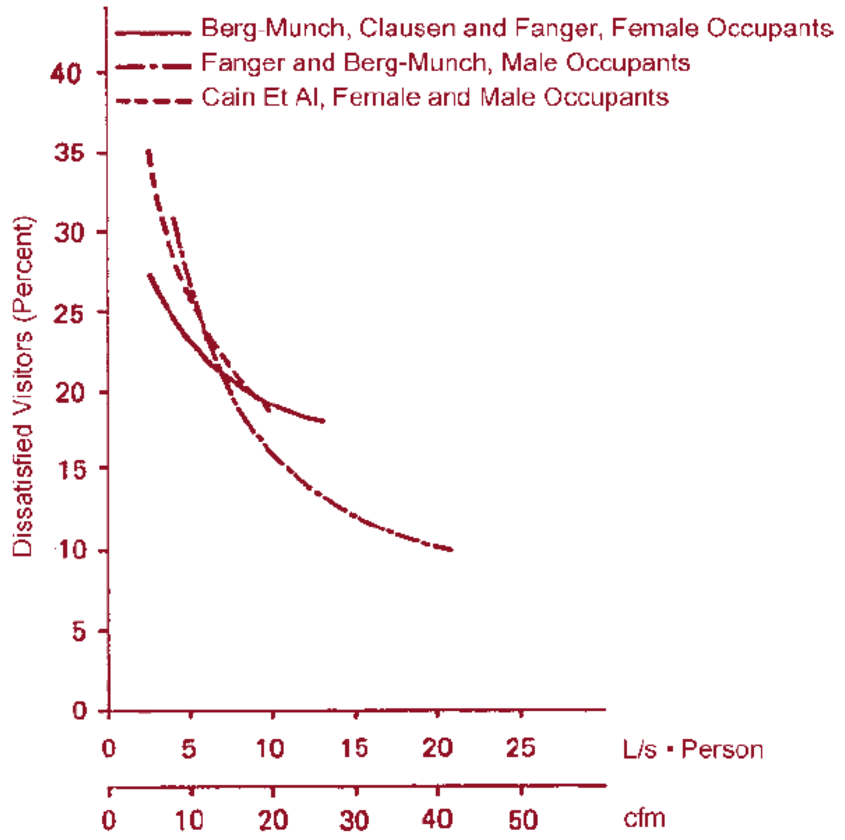
John S. Billings (US)
- Physician
- 30 cfm/pers (14 L/s-pers)
- *Ventilation and Heating (1893)*

Carl Flugge (Germany)
- Bacteriologist, hygienist
- Airborne transmission of by fresh respiratory droplets
- Concurred with Billings on ventilation rates



Long running debate – ventilate for disease or odor control?

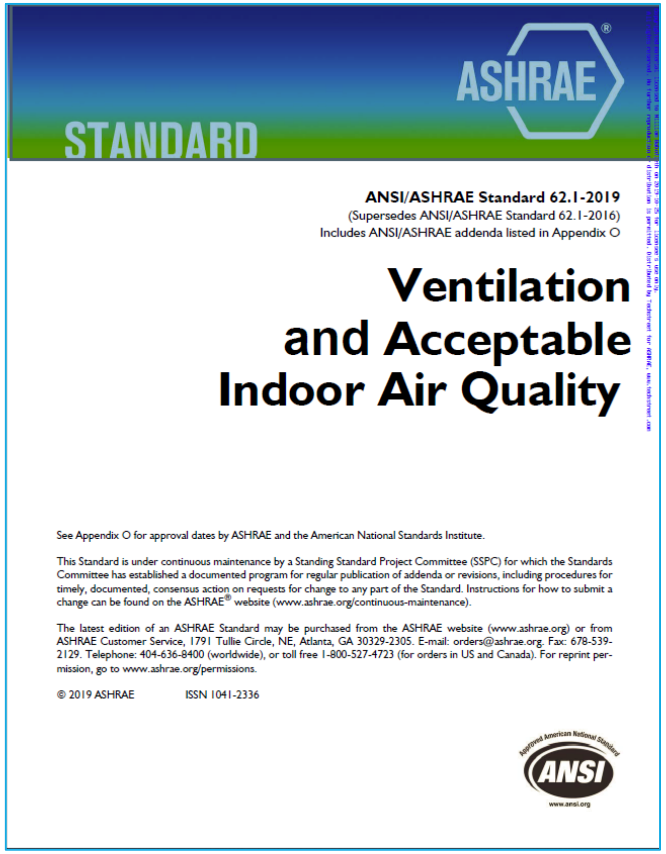




Janssen, J.E., 1999. The history of ventilation and temperature control: The first century of air conditioning. ASHRAE Journal, 41(10), p.48.

Minimum ventilation and filtration today – ventilation targets odors

"(A)ir in which there are no known contaminants at harmful concentrations, as determined by cognizant authorities, and with which a substantial majority (80% or more) of the people exposed do not express dissatisfaction."


STANDARD

ASHRAE

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

Ventilation and 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 change can be found on the ASHRAE® website (www.ashrae.org/continuous-maintenance).

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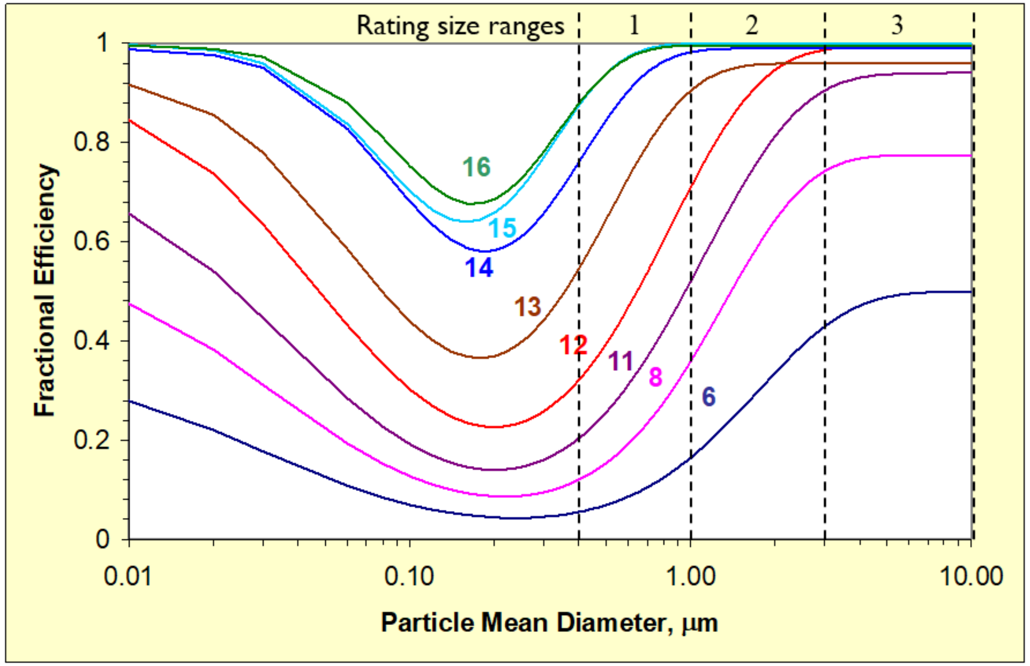
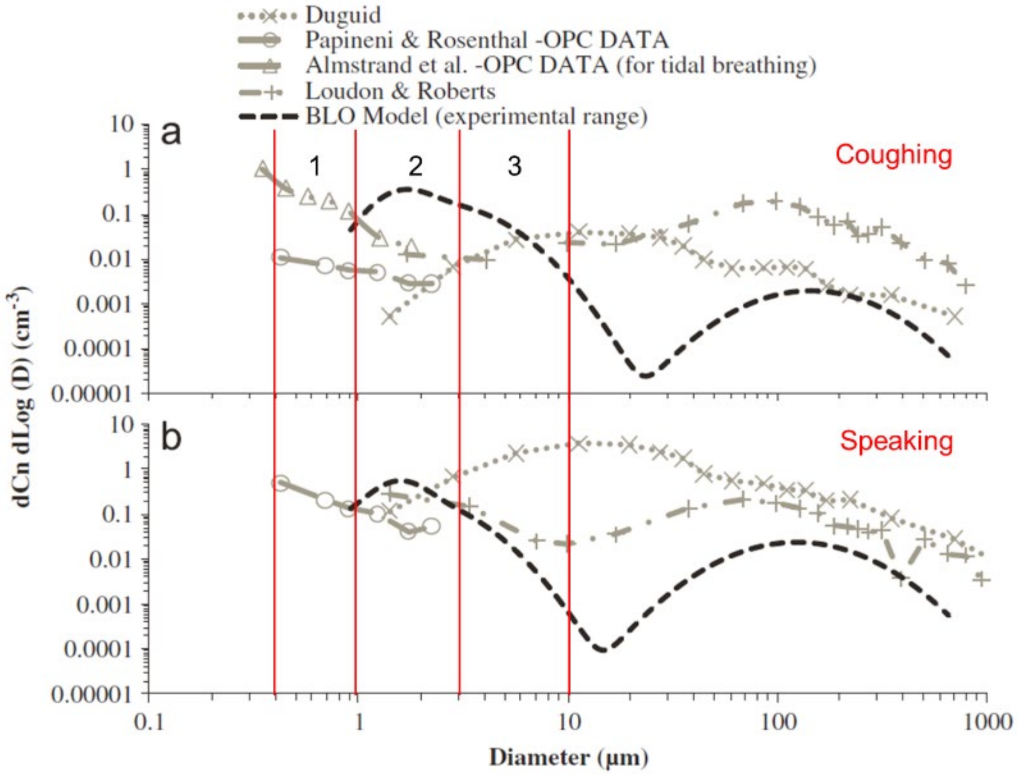
Approved American National Standard
ANSI
www.ansi.org

Filtration protects equipment



Kowalski, W.J. and Bahnfleth, W.P., 2002. MERV filter models for aerobiological applications. Air Media, Summer, 1.



Johnson, et al. 2011. Modality of human expired aerosol size distributions. Journal of Aerosol Science 42:839-851.

Risk management didn't address engineering controls outside healthcare

Get available vaccinations

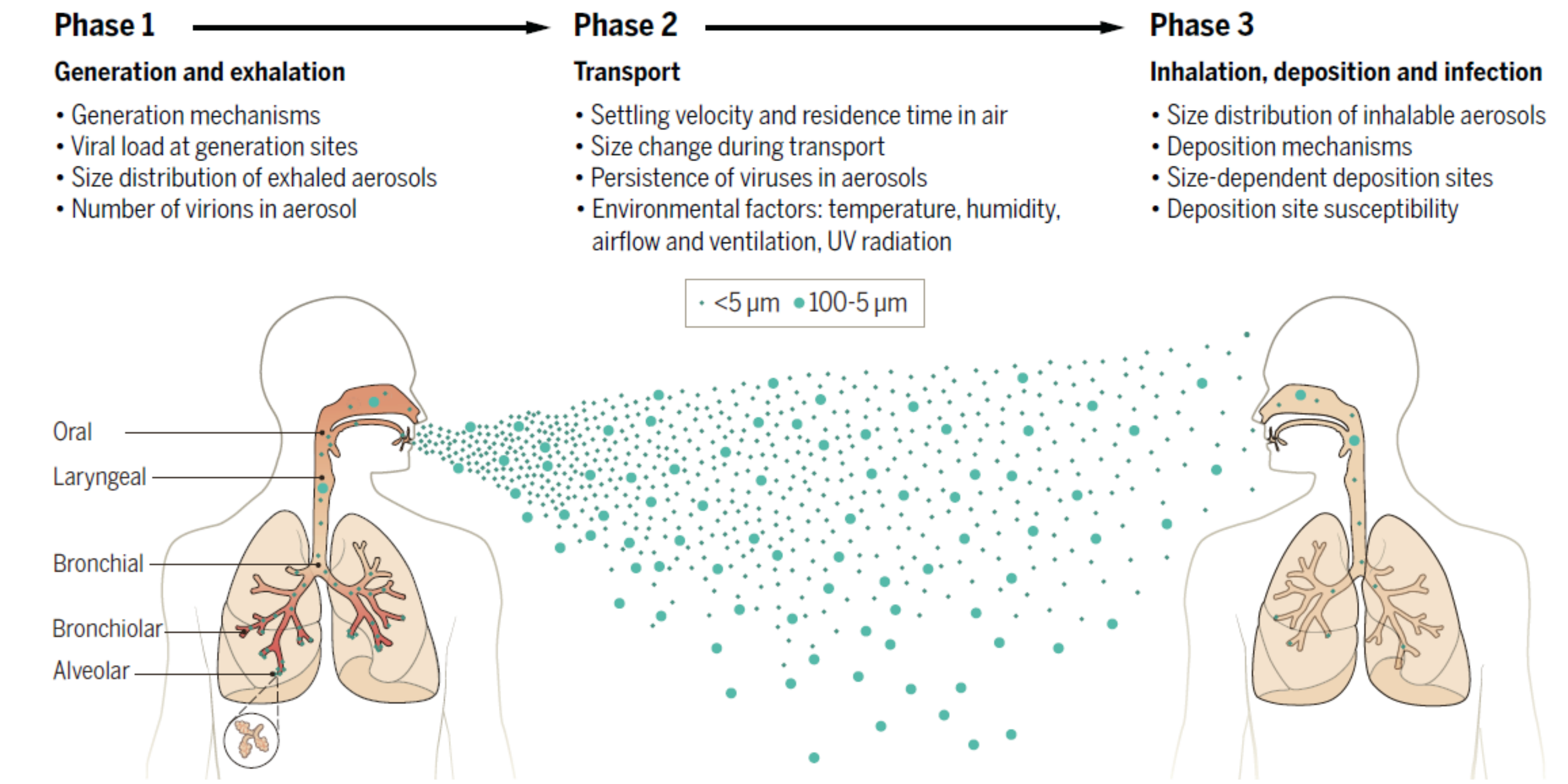
Stay home if you are sick

Cough into your sleeve

Wash your hands frequently

Keep surfaces clean

Quantifying risk – aerosol exposures



Wang et al., Airborne transmission of respiratory viruses
Science 373, 981 (2021) doi.org/10.1126/science.abd9149

Quantifying risk – Wells-Riley model

$$P = 1 - \exp\left(-\frac{Iqpt}{Q}\right)$$

Steady-state

Uniform distribution

1 quantum will infect 63% of those exposed

Quanta determined from data,

Combines emission rate and infectious dose

P = probability of new infections

I = number of infectors

q = quanta (infectious dose) emission rate [1/hr]

p = pulmonary ventilation rate per susceptible [m^3/h]

t = exposure time [hr]

Q = flow rate of uncontaminated air [m^3/h]

Quanta production varies with pathogen

Influenza: ~15 to ~500 per hour (67 and 100 per hour are both commonly used)
(Rudnick and Milton, 2003; Liao et al., 2005; Beggs et al., 2010; Sze To and Chao, 2010)

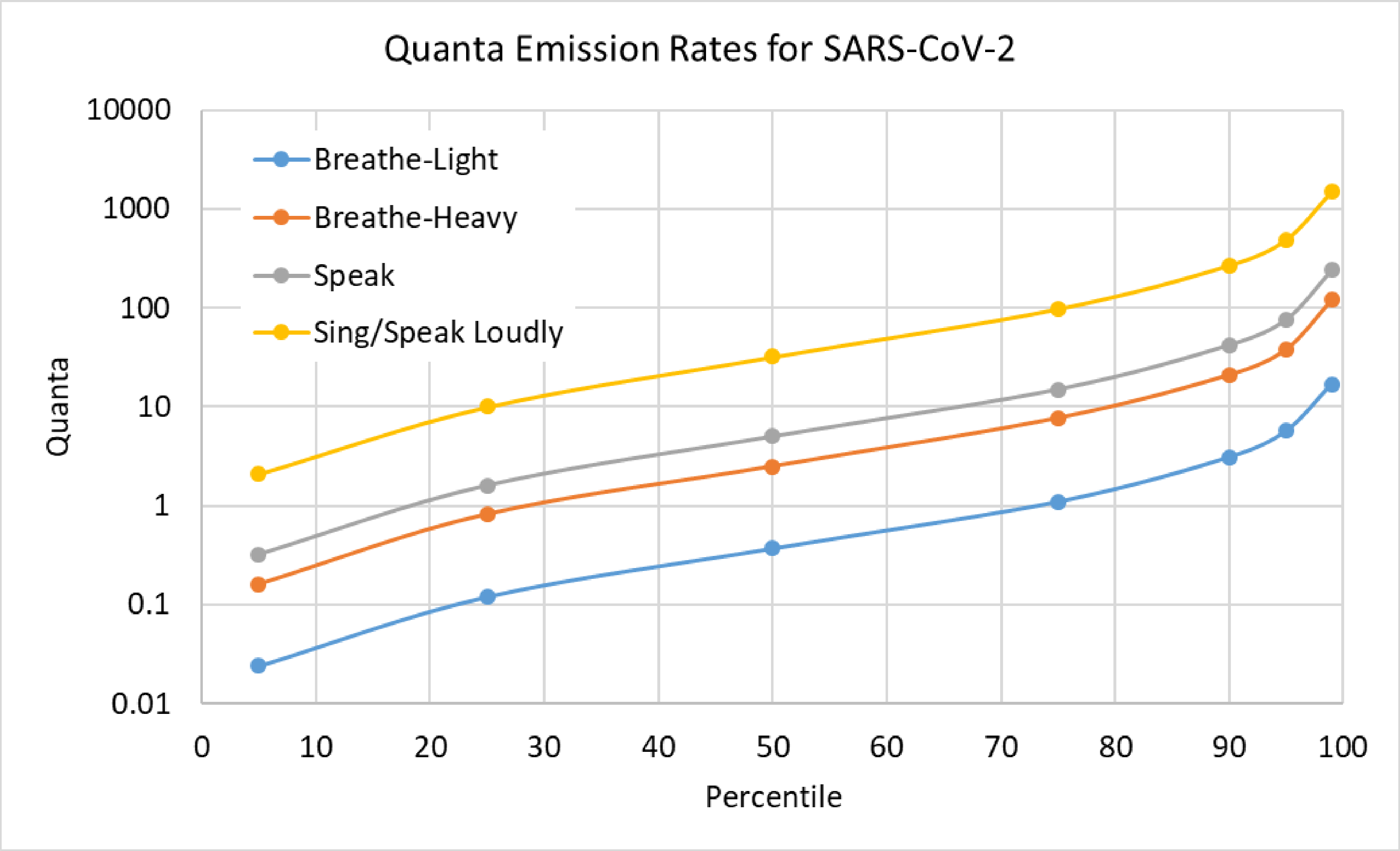
Rhinovirus: ~1 to ~10 per hour
(Rudnick and Milton, 2003)

Tuberculosis: ~1 to ~50 per hour (~13 per hour has been commonly used)
(Nardell et al., 1991; Escombe et al., 2007; Beggs et al., 2010; Chen et al., 2011)

SARS: ~10 to ~300 per hour
(Liao et al., 2005; Qian et al., 2009)

Measles: ~570 to ~5600 per hour
(Riley et al., 1978)

We have SARS-CoV-2 quanta estimates, but they are not very precise



Buonanno, et al. 2020. Quantitative assessment of the risk of airborne transmission of SARS-CoV-2 infection: Prospective and retrospective applications. Environment International, 145

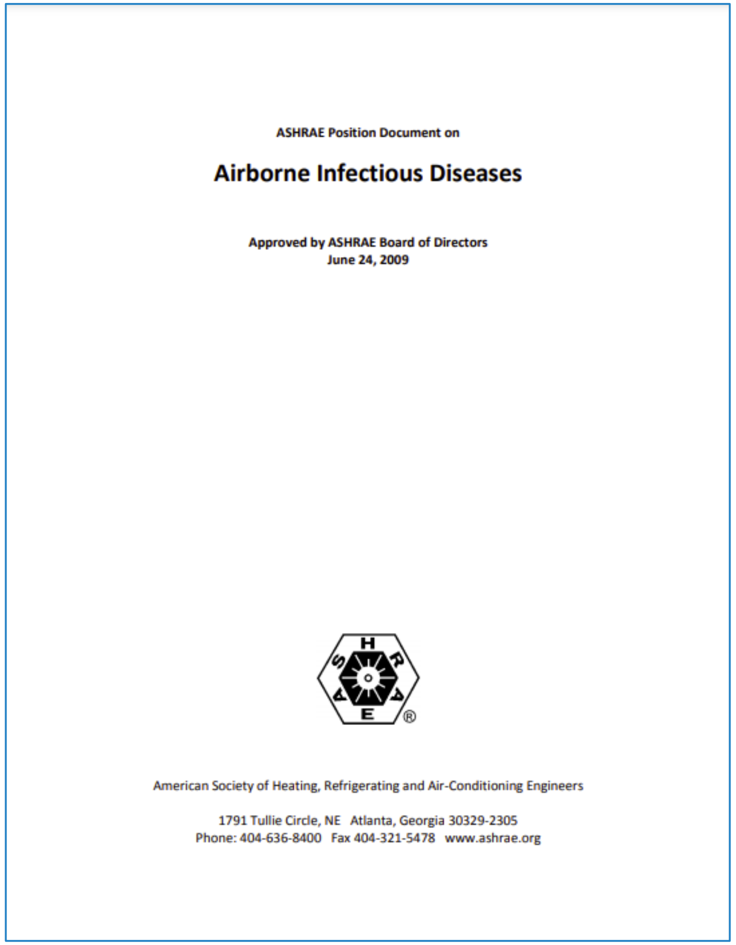
Risk reduction tools were well-known

“Many infectious diseases are transmitted through inhalation of airborne infectious particles…”

“Airborne infectious particles can be disseminated through buildings including ventilation systems”

Airborne infectious disease transmission can be reduced using dilution ventilation, specific in-room flow regimes,... room pressure differentials, personalized and source capture ventilation, filtration, and UVGI.

~ASHRAE (2009)



ASHRAE Position Document on

Airborne Infectious Diseases

Approved by ASHRAE Board of Directors
June 24, 2009

American Society of Heating, Refrigerating and Air-Conditioning Engineers

1791 Tullie Circle, NE Atlanta, Georgia 30329-2305
Phone: 404-636-8400 Fax 404-321-5478 www.ashrae.org

During COVID

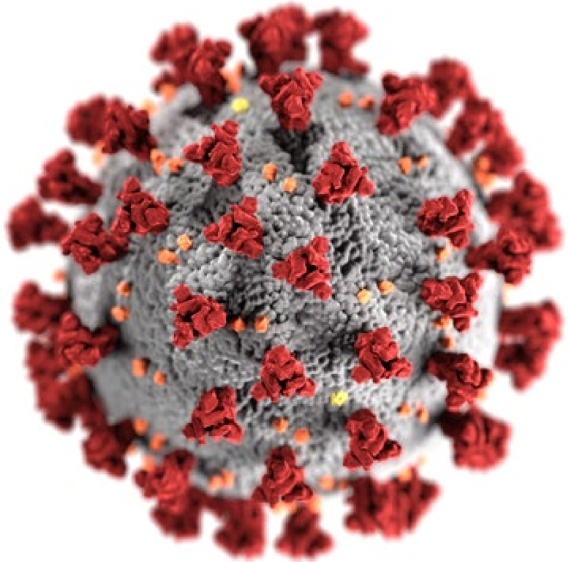
Safer, not safe– a layer of risk mitigation

The available controls are the same

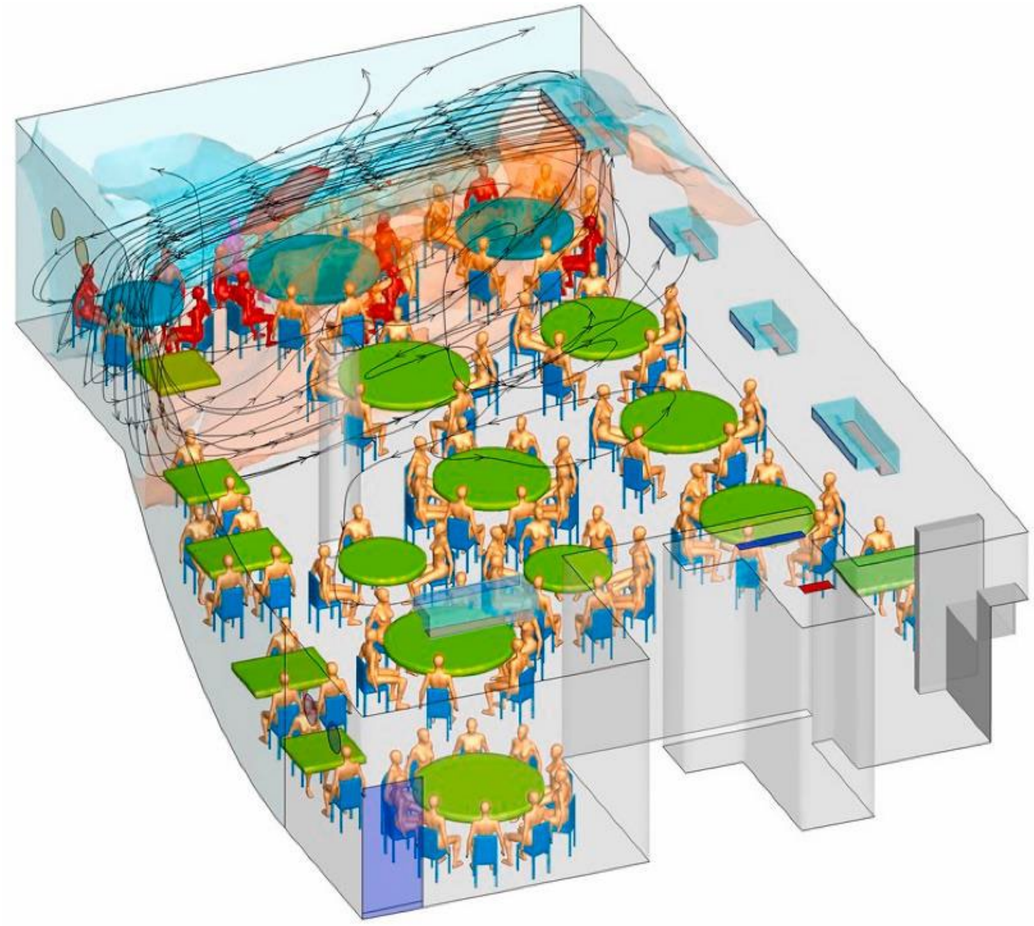
- Ventilation and air distribution – dilute/displace
- Filtration – capture aerosol particles
- Germicidal UV - inactivate

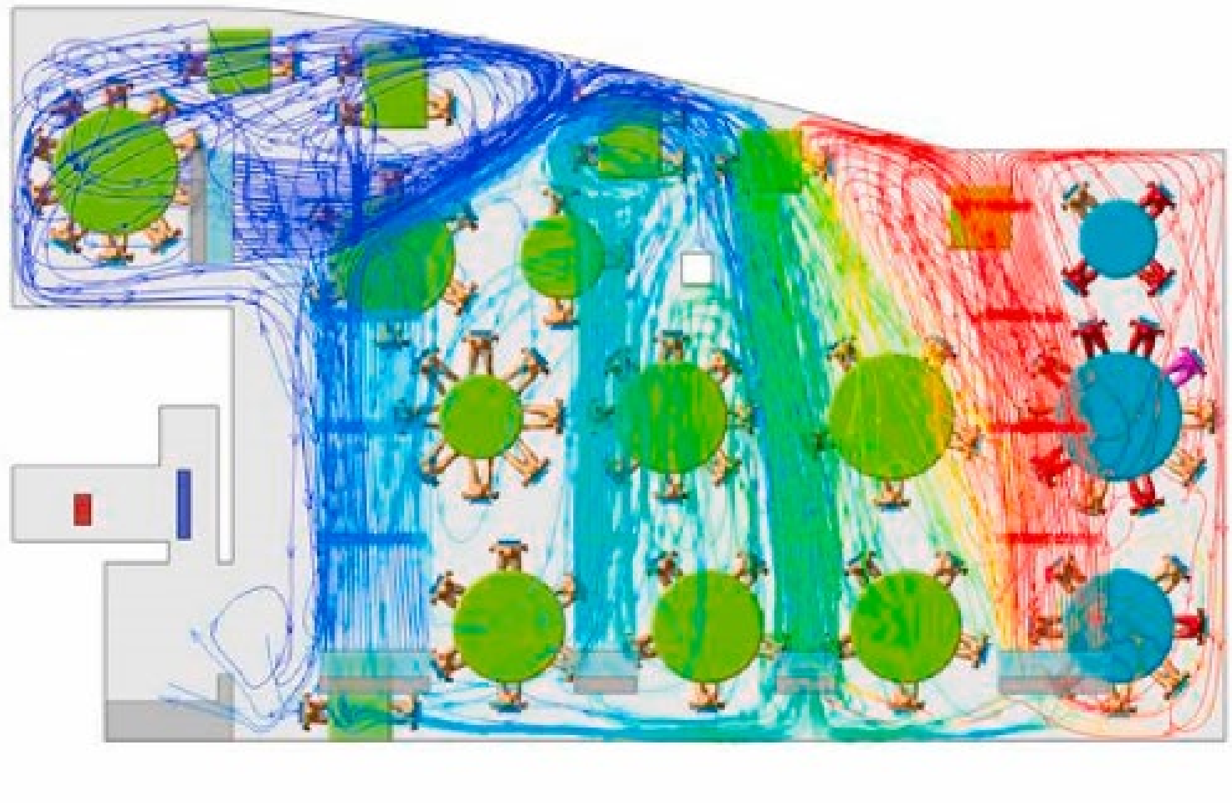
"Equivalent outdoor air" as a concept for combining controls

The return of CO_2 as an IAQ metric



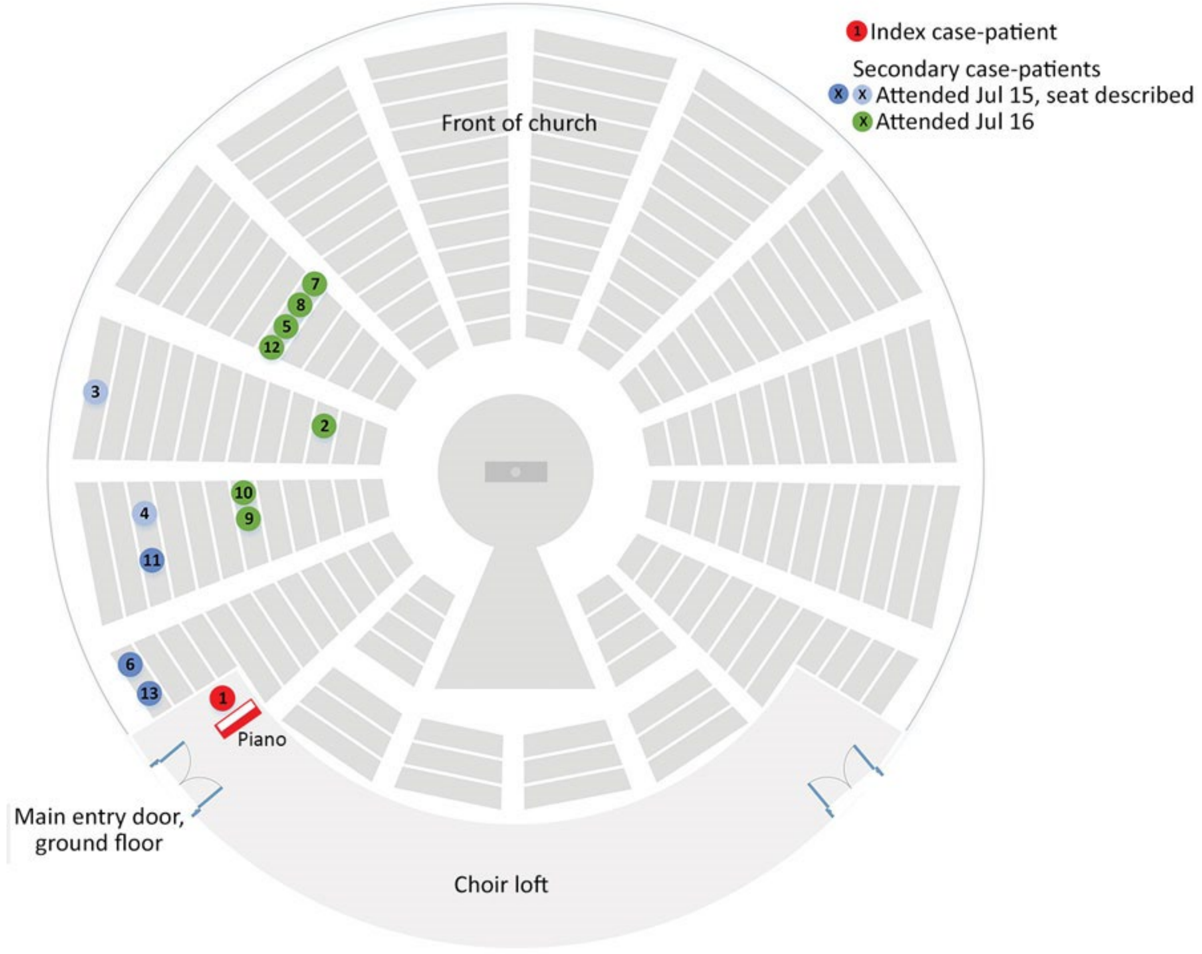
Airborne transmission primarily due to low outdoor air flow, but risk influenced by air flow patterns





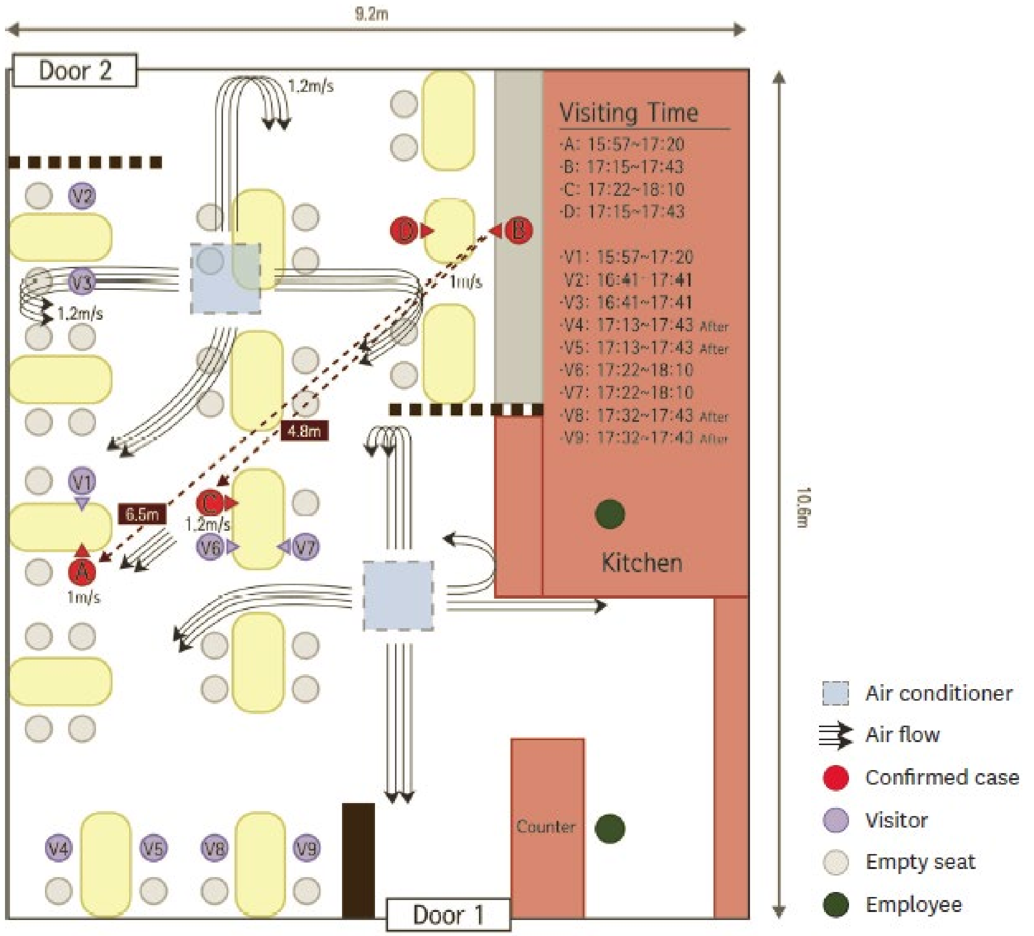
Li, Y., Qian, H., Hang, J., Chen, X., Cheng, P., Ling, H., Wang, S., Liang, P., Li, J., Xiao, S. and Wei, J., 2021. Probable airborne transmission of SARS-CoV-2 in a poorly ventilated restaurant. Building and Environment, p.107788.

Airborne transmission in large open spaces



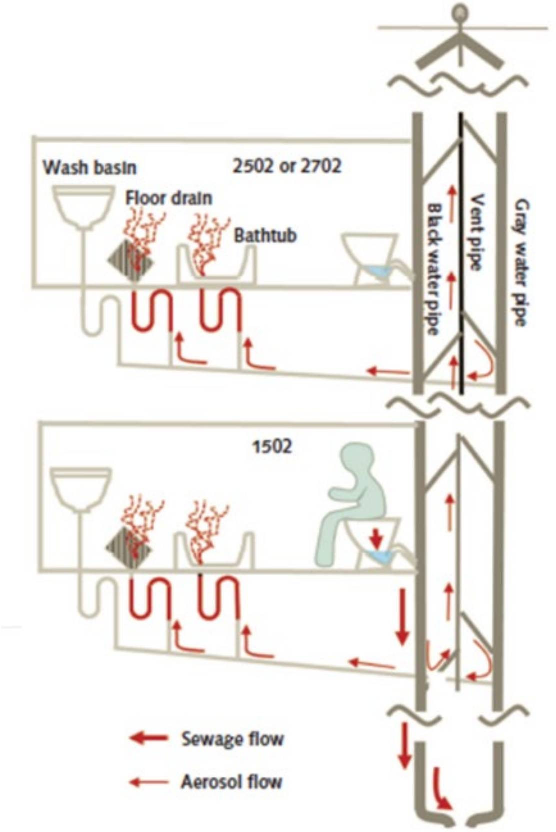
Katelaris AL, et al. 2020. Emerg Infect Dis. 2021;27(6):1677-1680. https://doi.org/10.3201/eid2706.210465

Exposure due to airflow patterns

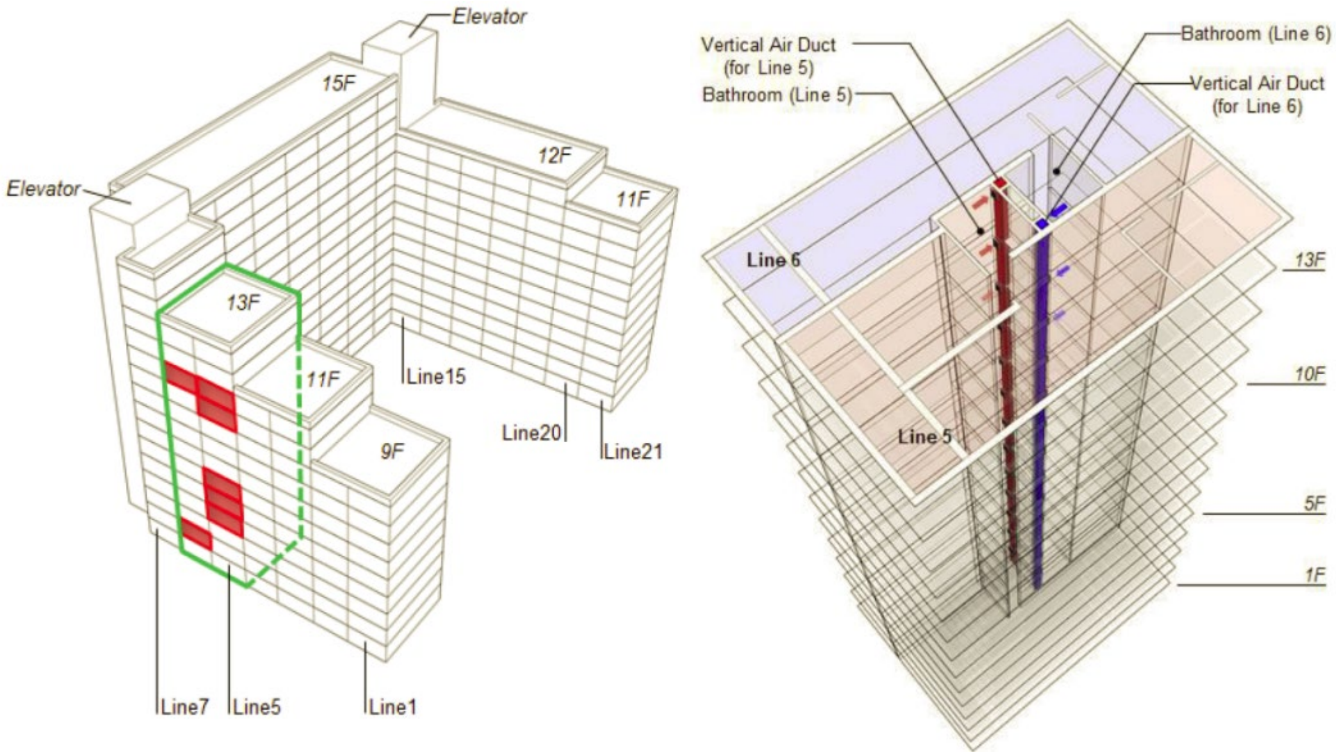


Kwon, K.S., et al., 2020. Evidence of long-distance droplet transmission of SARS-CoV-2 by direct air flow in a restaurant in Korea. Journal of Korean medical science, 35(46). https://doi.org/10.3346/jkms.2020.35.e415

Transmission through plumbing and vent shafts



Kang, M., et. al. 2020 Probable evidence of faecal aerosol transmission of SARS-CoV-2 in a High-Rise Building. Ann Intern Med. doi:10.7326/M20-0928



Kang, M., et. al. 2020 Probable evidence of faecal aerosol transmission of SARS-CoV-2 in a High-Rise Building. Ann Intern Med. doi:10.7326/M20-0928

Transmission through HVAC ductwork

Nursing home in Netherlands

(De Man, et al. 2021. Clinical Infectious Diseases, 73(1), pp.170-171. doi.org/10.1093/cid/ciaa1270)

- Seven wards, no infections in six
- 81% resident infections, 50% healthcare worker infections in the seventh
- Healthcare workers did not move between wards
- Residents had private rooms but were mobile, so cannot completely rule out close contact

Comparison of HVAC systems

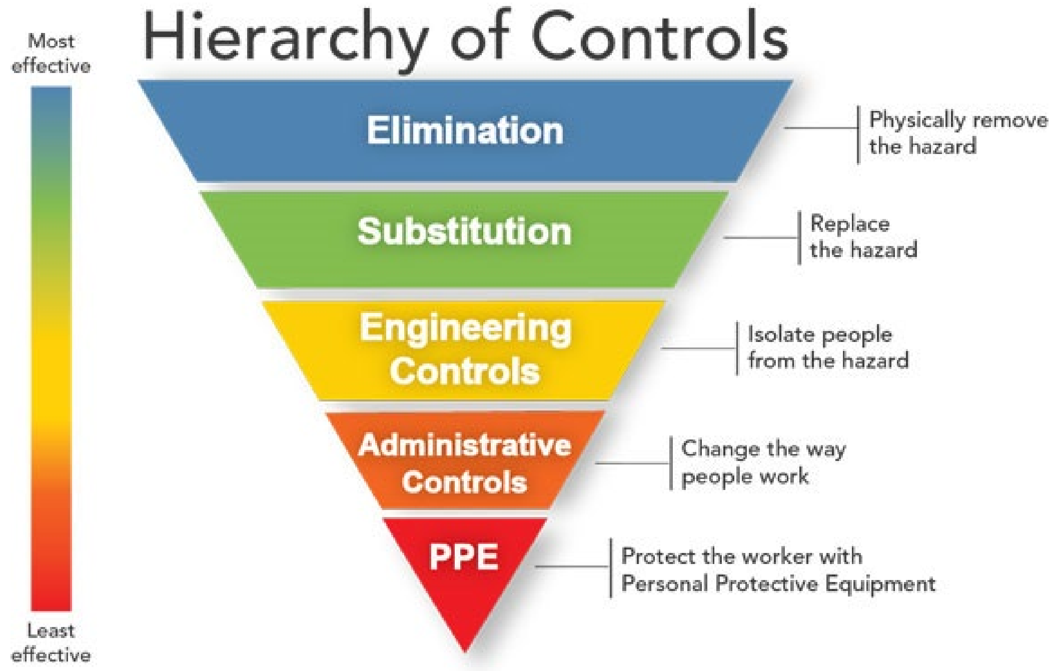
- Six wards had the same system – 100% outdoor air
- Seventh ward – recirculating CO_2-based demand control (close below 1000 ppm), dust filters

The Precautionary Principle

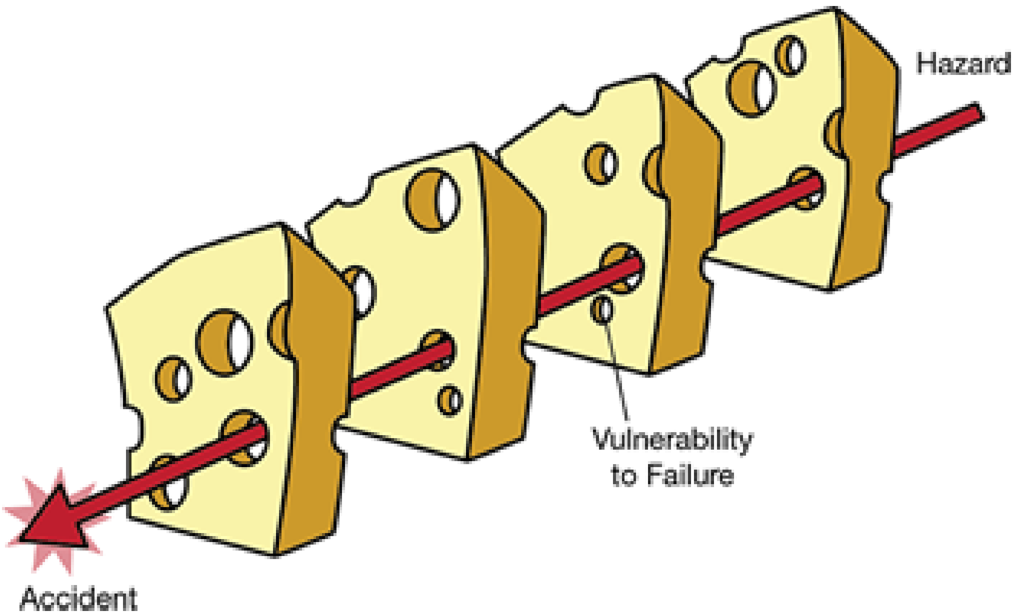
“One should take reasonable measures to avoid threats that are serious and plausible.”

D. Resnik. 2004. The Precautionary Principle and Medical Decision Making. Journal of Medicine and Philosophy, 29(3):281-299.

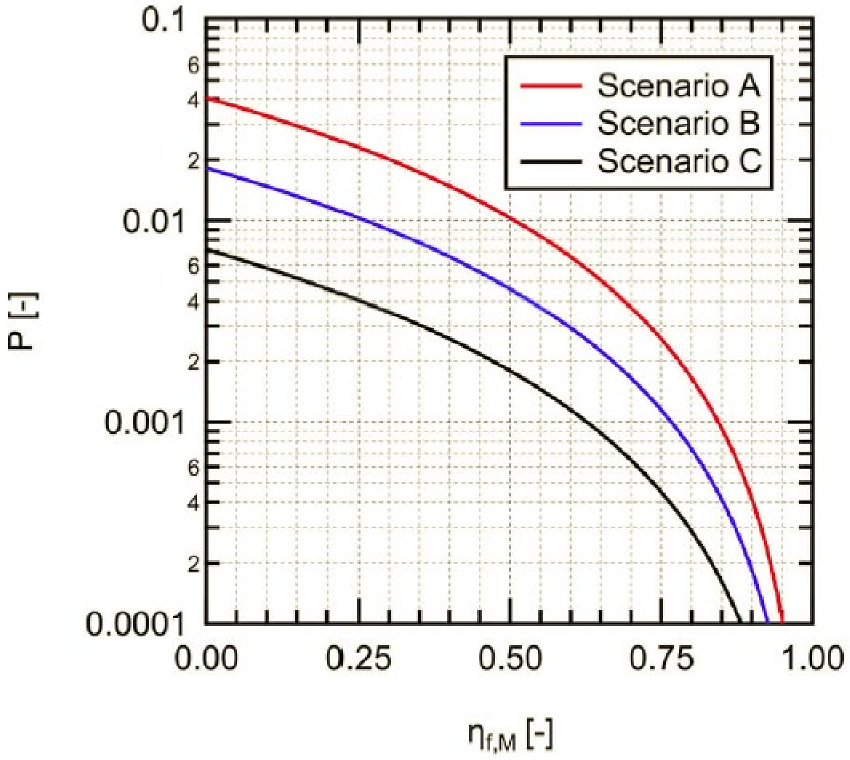
Building design/operation as risk management – “safer, not safe”



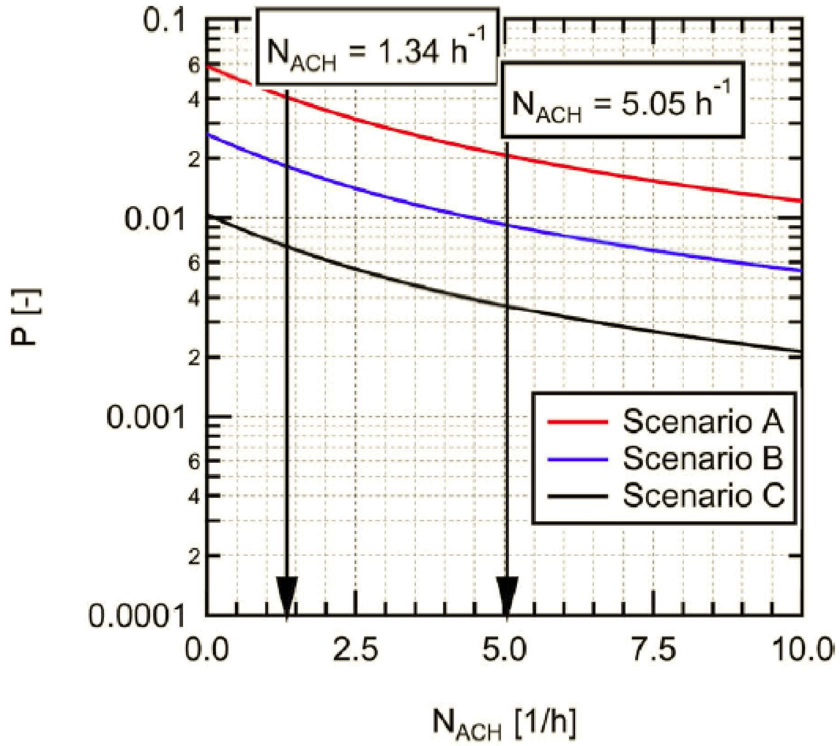
Swiss cheese analogy



Masks vs. increased ventilation



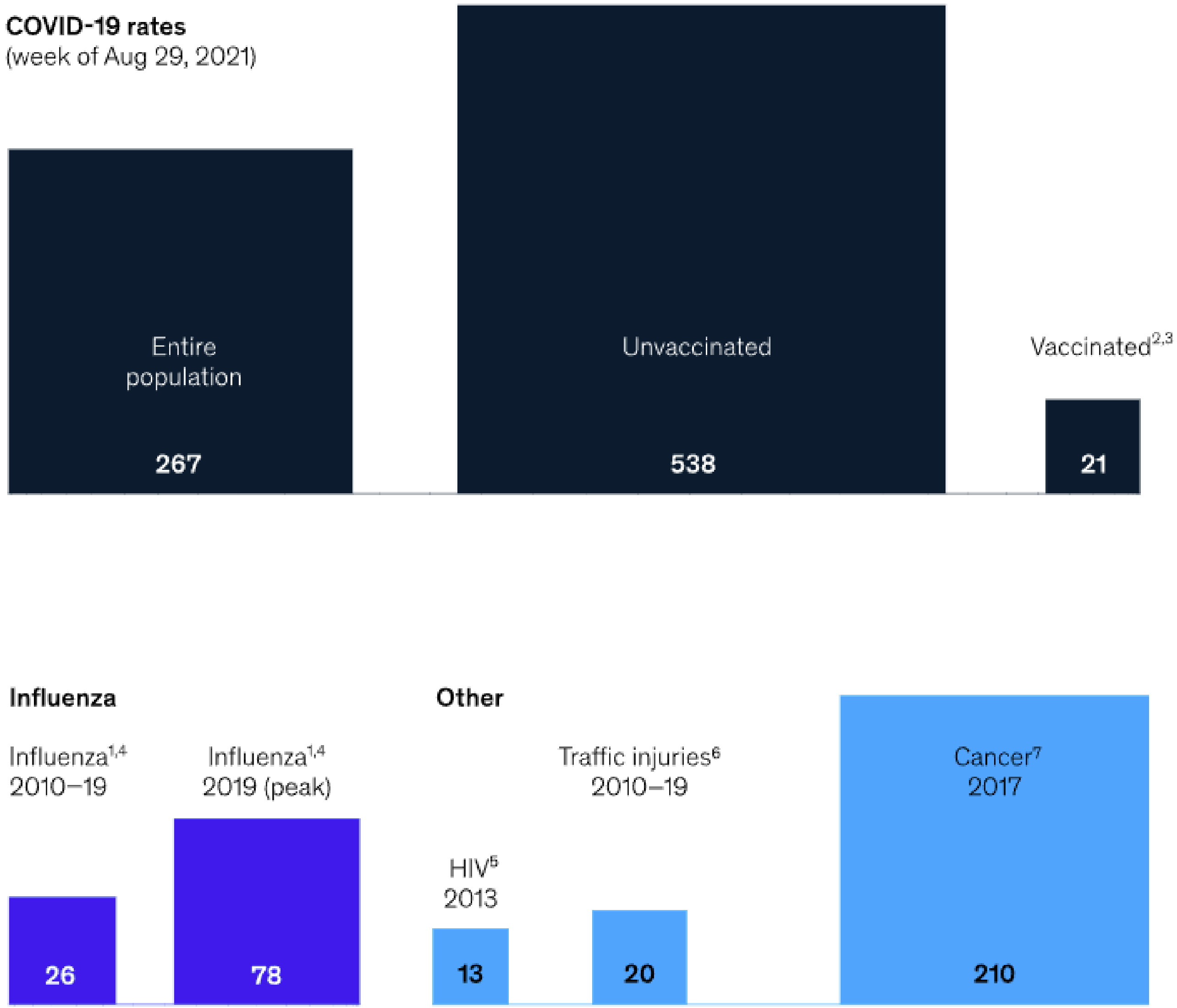
Effect of filter efficiency



Effect of air change rate

Rothamer, et al. 2021. doi.org/10.1080/23744731.2021.1944665

US hospitalizations for COVID-19 and other public-health threats, number per million people



McKinsey and Company

Ventilation – how much?

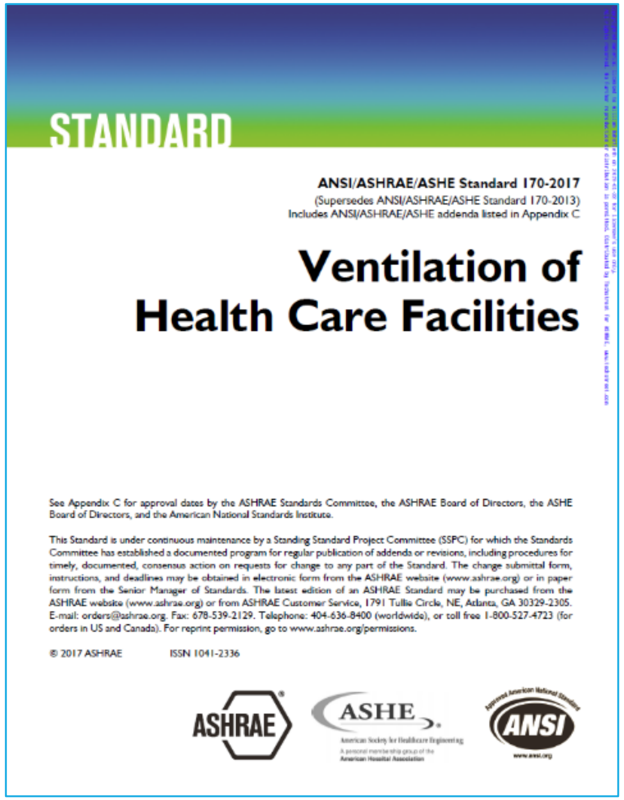
WHO

- 10 L/s-person (~21 cfm/pers) for non-healthcare
- Based on analysis of dilution compared to outdoors

HSPH and others

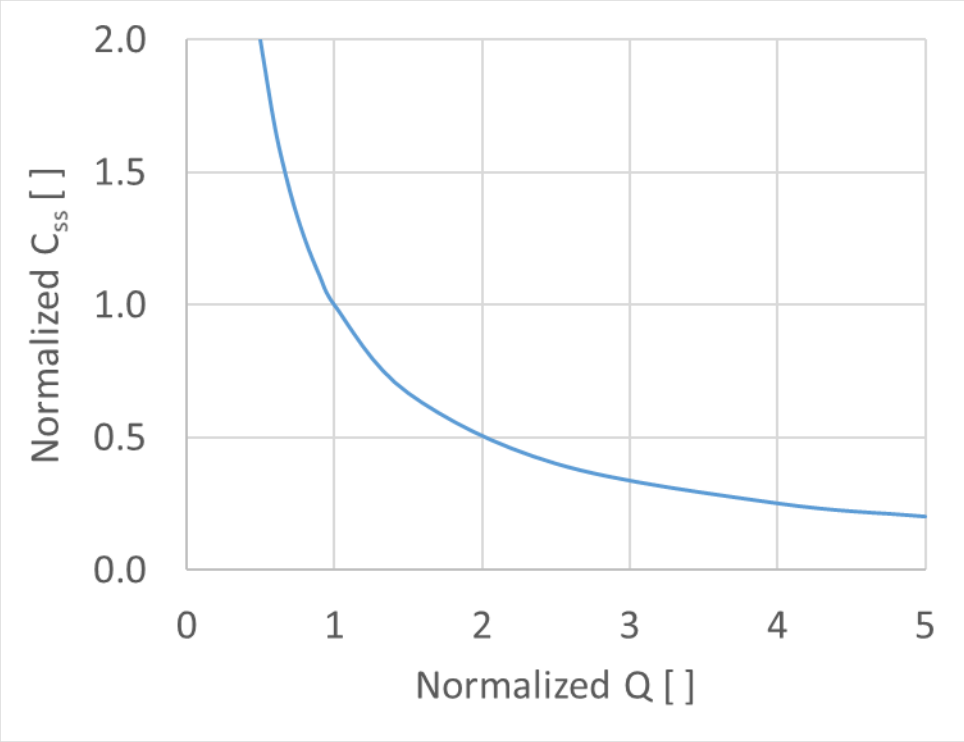
- 4-5 ACH for schools
- Based on analogy to healthcare ventilation

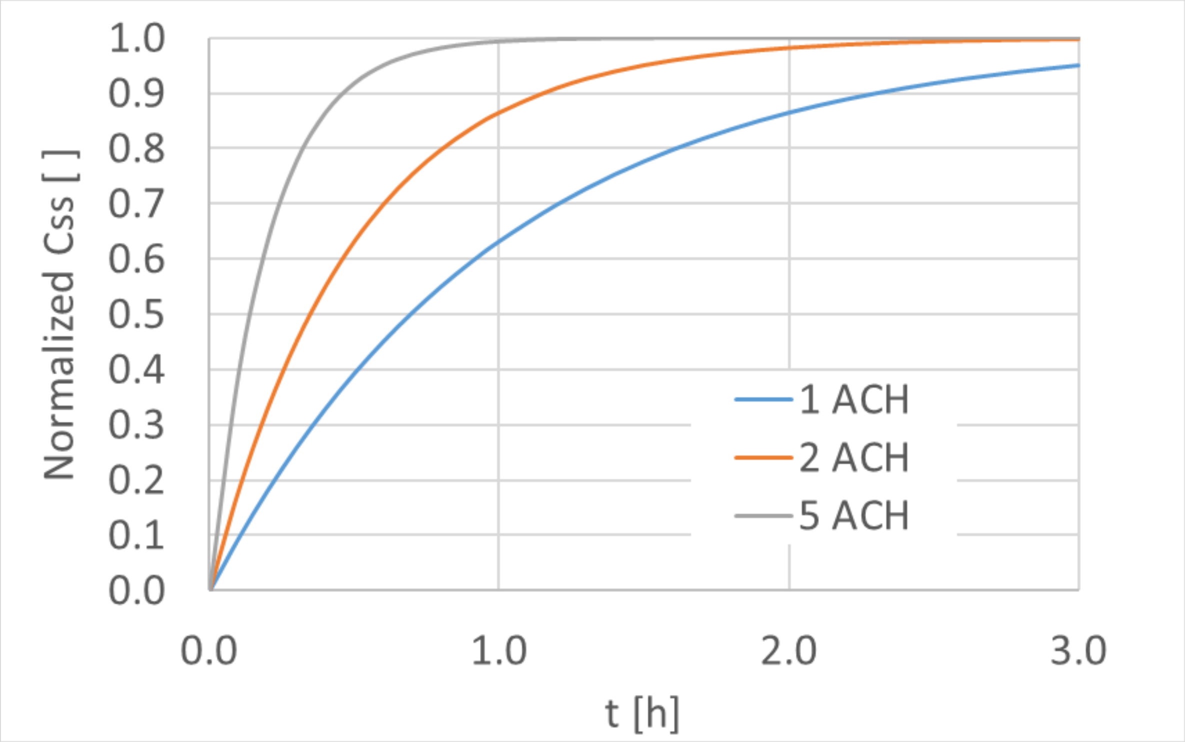
Others develop custom rates using Wells-Riley based models



https://www.who.int/publications/i/item/9789240021280

Lack of agreement on flow rate units - absolute (cfm) vs. relative (air change rate)





Q determines steady state concentration / ACH determines time to steady state (also clearance time)

Air change rate is used in healthcare standards

Non-healthcare standards specify absolute flow rate

Example -ASHRAE Standard62.1 office space

- 5 cfm/person + 0.06 cfm/sf
- Typical density - 5 persons/1000 sf
- For 1000 sf, need 85 cfm = **17 cfm/pers, 8 L/s-pers**
- For 9 foot ceiling height **ACH = 0.47**

cfm/pers is ~80% of WHO recommendation

ACH is <10% of HSPH recommendation

“Strong and sufficient evidence” of an *association* between ventilation and transmission

“Insufficient data” to determine *minimum* ventilation requirements

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

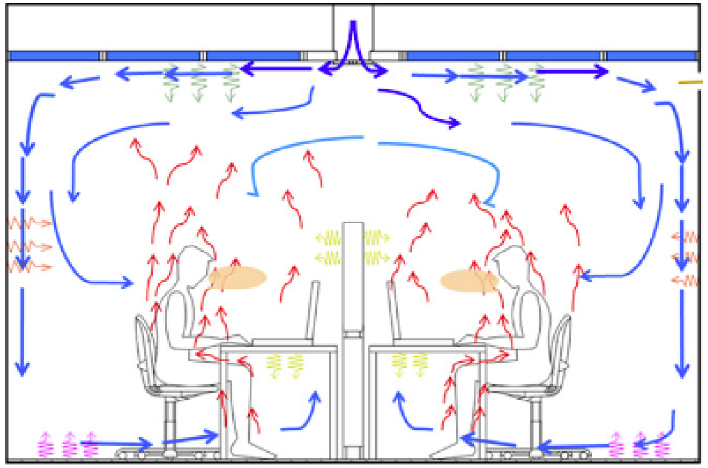
Abstract There have been few recent studies demonstrating a definitive association between the transmission of airborne infections and the ventilation of buildings. The severe acute respiratory syndrome (SARS) epidemic in 2003 and current concerns about the risk of an avian influenza (H5N1) pandemic, have made a review of this area timely. We searched the major literature databases between 1960 and 2005, and then screened titles and abstracts, and finally selected 40 original studies based on a set of criteria. We established a review panel comprising medical and engineering experts in the fields of microbiology, medicine, epidemiology, indoor air quality, building ventilation, etc. Most panel members had experience with research into the 2003 SARS epidemic. The panel systematically assessed 40 original studies through both individual assessment and a 2-day face-to-face consensus meeting. Ten of 40 studies reviewed were considered to be conclusive with regard to the association between building ventilation and the transmission of airborne infection. 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.

Y. Li[1], G. M. Leung[2], J. W. Tang[3], X. Yang[4], C. Y. H. Chao[5], J. Z. Lin[6], J. W. Lu[7], P. V. Nielsen[8], J. Niu[9], H. Qian[1], A. C. Sleigh[10], H.-J. J. Su[11], J. Sundell[12], T. W. Wong[13], P. L. Yuen[14]

Departments of [1]Mechanical Engineering and [2]Community Medicine, The University of Hong Kong, Pokfulam, Hong Kong, [3]Department of Microbiology, The Chinese University of Hong Kong, Shatin, Hong Kong, [4]Department of Building Science and Technology, Tsinghua University, Beijing, China, [5]Department of Mechanical Engineering, The Hong Kong University of Science and Technology, Hong Kong, [6]Division of Building Science and Technology and [7]Department of Building and Construction, City University of Hong Kong, Hong Kong, China, [8]Department of Civil Engineering, Aalborg University, Aalborg, Denmark, [9]Department of Building Services Engineering, The Hong Kong Polytechnic University, Hong Kong, China, [10]National Centre for Epidemiology and Population Health, Australian National University, Canberra, Australia, [11]Medical College, National Cheng Kung University, Tainan, Taiwan, [12]International Centre for Indoor Environment and Energy, Technical University of Denmark, Copenhagen, Denmark, [13]Department of Community and Family Medicine, The Chinese University of Hong Kong, Shatin, Hong Kong, [14]Hospital Authority, Hong Kong SAR Government, Hong Kong, China

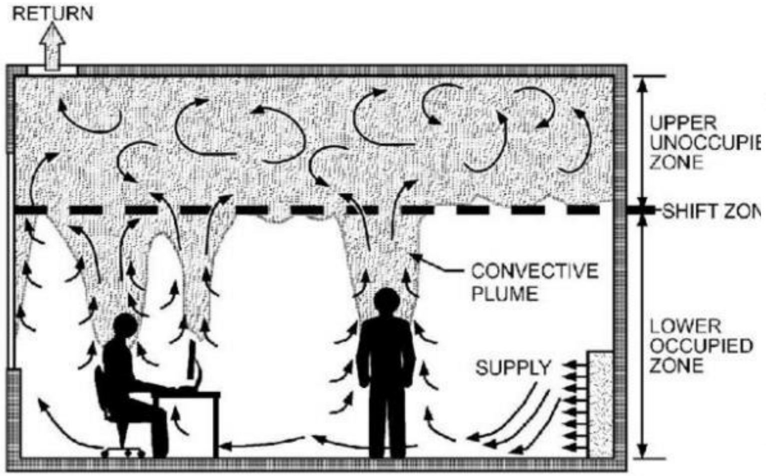
Best approach to air distribution?

Overhead Mixing



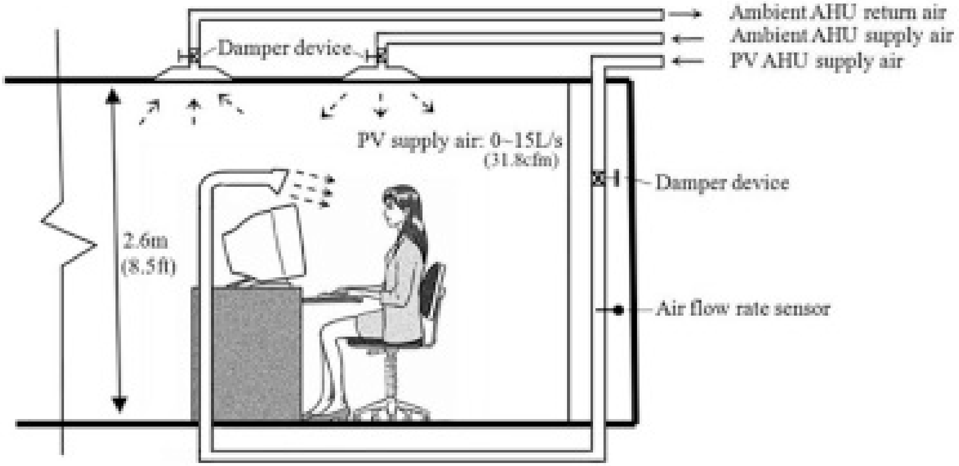
doi:10.1111/ina.12206

Stratified



doi: 10.3390/en10020231

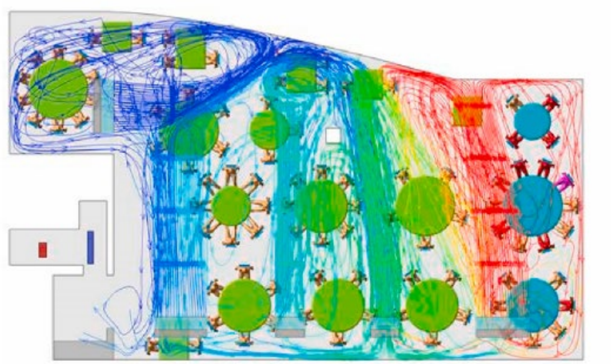
Personal



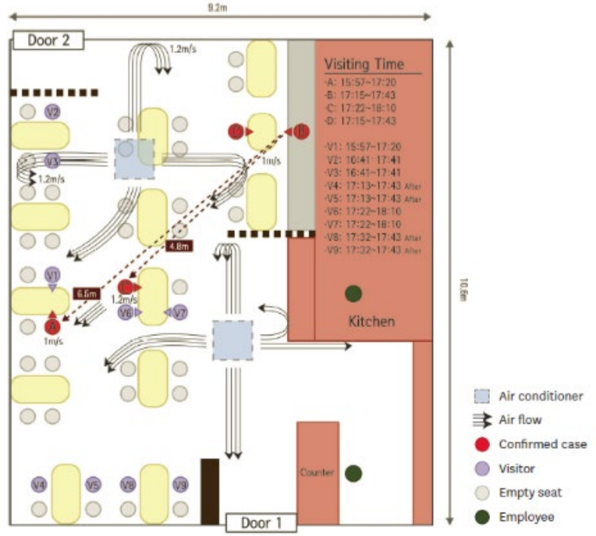
doi.org/10.1016/j.buildenv.2015.11.036

Situationally, any of them may be a good choice – or can fail

Stagnant zones, air currents, detract from performance of mixing systems – but mixing is good for upper room UV



Li, Y., et al., 2021. Building and Environment, p.107788.



Kwon, K.S., et al., 2020. Journal of Korean medical science, 35(46).

Exhaled contaminants may be trapped in breathing zone of stratified systems

Li, Y., P. Nielsen, M. Sandberg. 2011. ASHRAE J. 53(6): 86-88

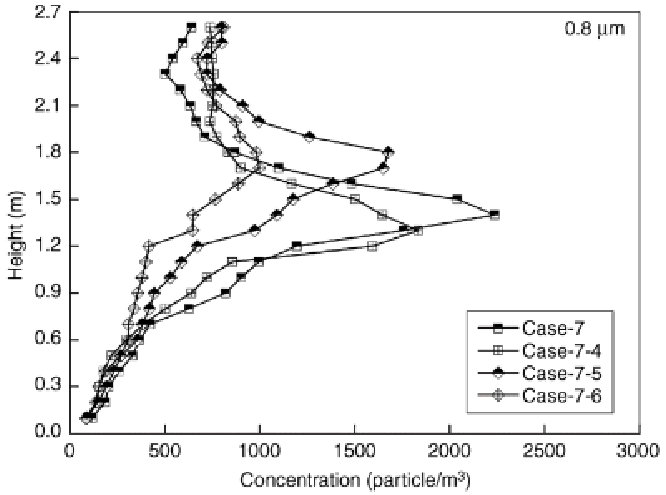
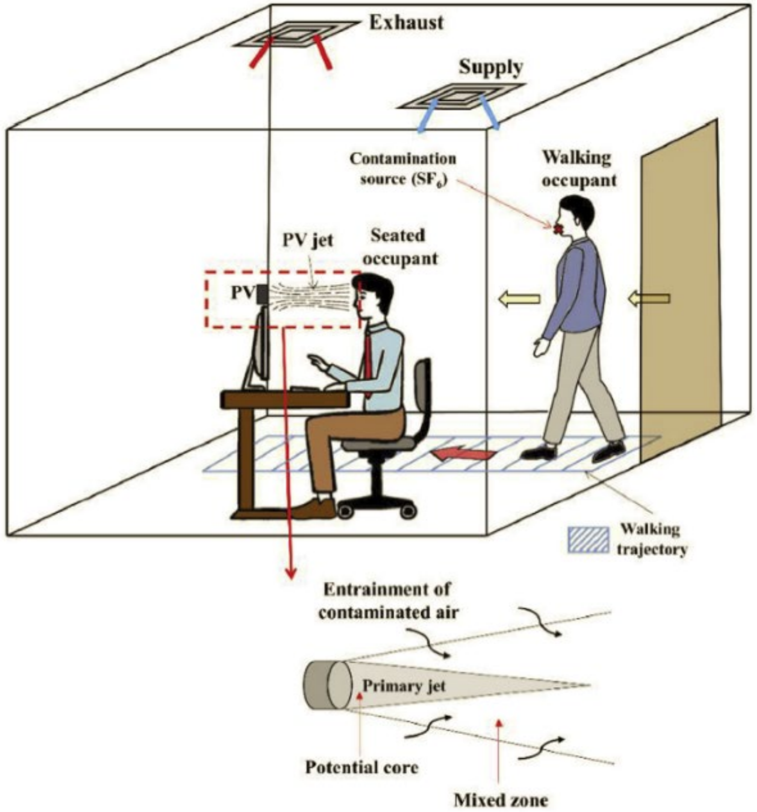


Fig. 10 Average concentrations (0.8 µm) in planes across the room at different height levels

Gao, N., He, Q. and Niu, J., 2012, *Building Simulation* (Vol. 5, No. 1, pp. 51-60).

Ambient flow disturbance degrades personalized ventilation

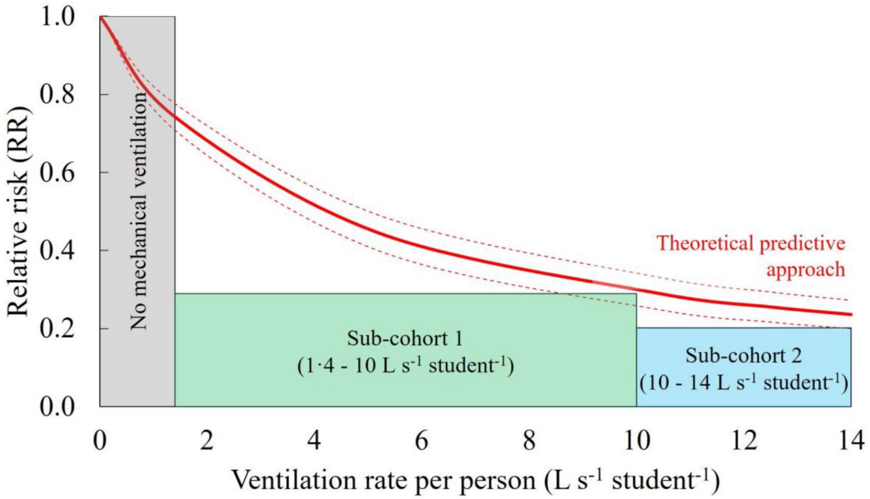


Al Assaad, D., Ghali, K. and Ghaddar, N., 2019. *Building and Environment*, *160*, p.106217.

Mechanical ventilation works, natural ventilation is uncertain

Italian schools study

- 10,000+ classrooms
- 316 retrofitted with mechanical ventilation
- Covid infection rates 80% lower in mechanically ventilated classrooms with 10 – 14 L/s-pers
- 12-15% reduction per unit of ventilation



Increasing ventilation reduces SARS-CoV-2 airborne transmission in schools: a retrospective cohort study in Italy's Marche region

Luca Ricolfi[a,b], Luca Stabile[c], Lidia Morawska[d], Giorgio Buonanno[c,d,*],

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[b] David Hume Foundation, Turin, Italy
[c] Department of Civil and Mechanical Engineering, University of Cassino and Southern Lazio, Cassino, FR, Italy
[d] International Laboratory for Air Quality and Health, Queensland University of Technology, Brisbane, Queensland, Australia

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Email: buonanno@unicas.it

Preprint - https://arxiv.org/abs/2207.02678

“Equivalent Outdoor Air” – conceptual basis for combining controls

Express performance of filters, etc. as a a clean air flow that would have the same effect and add them

- Dilution ventilation (incl. ventilation effectiveness)
- Mechanical filtration
- Inactivation by air cleaners
- Natural mechanisms

Can continue to use current minimum outdoor air flow rates as target totals

Makes high infection control “ventilation” rates attainable, low energy

$$P = 1 - \exp\left(-\frac{Iqpt}{Q} \right)$$

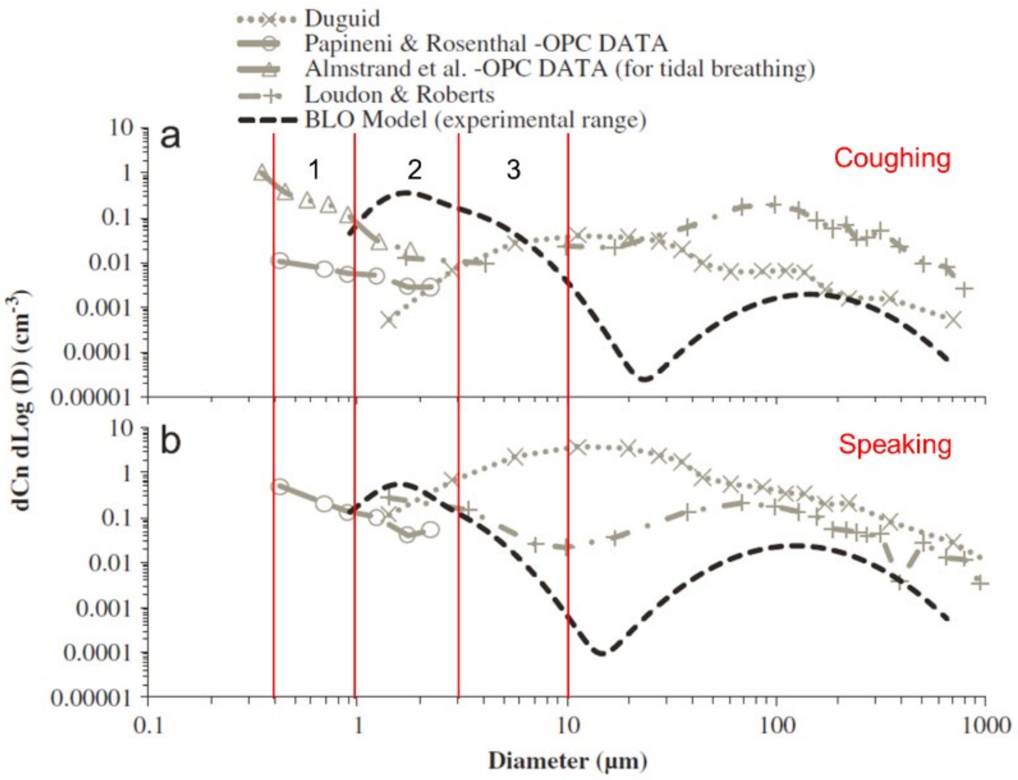
Example – Portable Air Fillter

Fan flow – 500 cfm

Efficiency for infectious aerosol – 85%

Equivalent outdoor air - 500×0.85 = 425 cfm

Filter efficiencies should be higher, MERV 13 recommended



Johnson, et al. 2011. Modality of human expired aerosol size distributions. Journal of Aerosol Science 42:839-851.

	MERV 8	MERV 13
1 (0.3-1μm)	N/A	≥ 50%
2 (1-3 μm)	≥ 20%	≥ 85%
3 (3-10 μm)	≥ 70%	≥ 90%

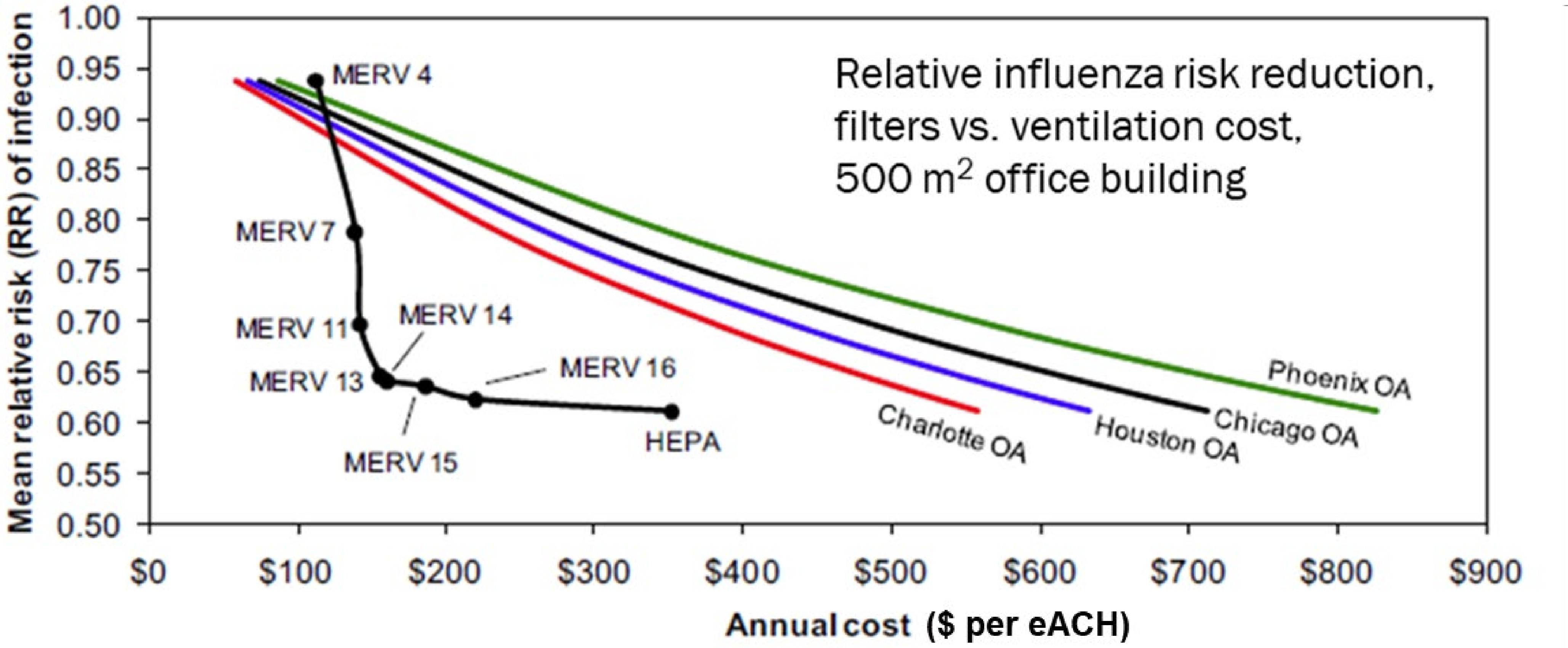
ASHRAE Epidemic Task Force estimate of viral load capture by typical MERV rated filters

Accounts for particle size and assumed distribution of virus in particles

MERV Rating (Based on 52.2-2017)	Filter Droplet Nuclei Efficiency
4	16%
5	24%
6	28%
7	36%
8	49%
9	54%
10	57%
11	67%
12	77%
13	86%
14	93%
15	94%
16	97%

ashrae.org/covid19 – Building Readiness guidance

MERV-13 near optimal filter performance, lower cost than more ventilation



Azimi, P. and Stephens, B., 2013. HVAC filtration for controlling infectious airborne disease transmission in indoor environments: predicting risk reductions and operational costs. *Building and environment*, *70*, pp.150-160.

Standalone air filters are a good retrofit

HEPA filters – recommended, make other disinfection technologies redundant

May include other technologies
- Activated carbon (gases)
- UV (bioaerosols)

Wide range of costs and capacities

More studies needed on sizing and deployment but can be effective

Portable HEPA-UV in a hospital

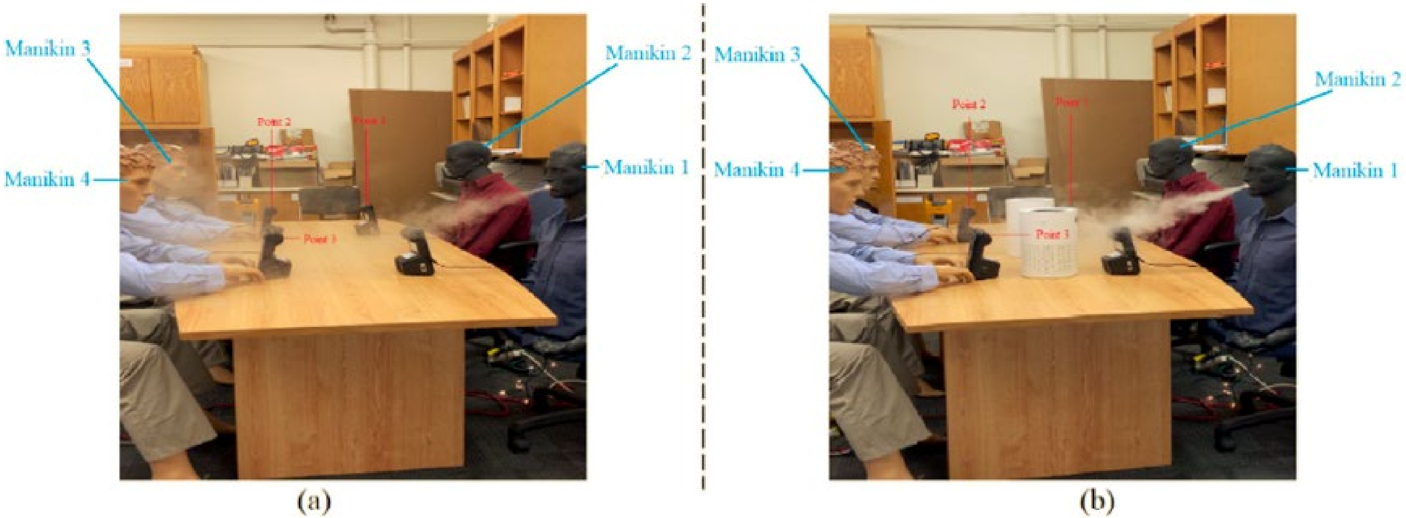
Conway, et al. 2022 *The removal of airborne SARS-CoV-2 and other microbial bioaerosols by air filtration on COVID-19 surge units.* (pre-print) doi.org/10.1101/2021.09.16.21263684

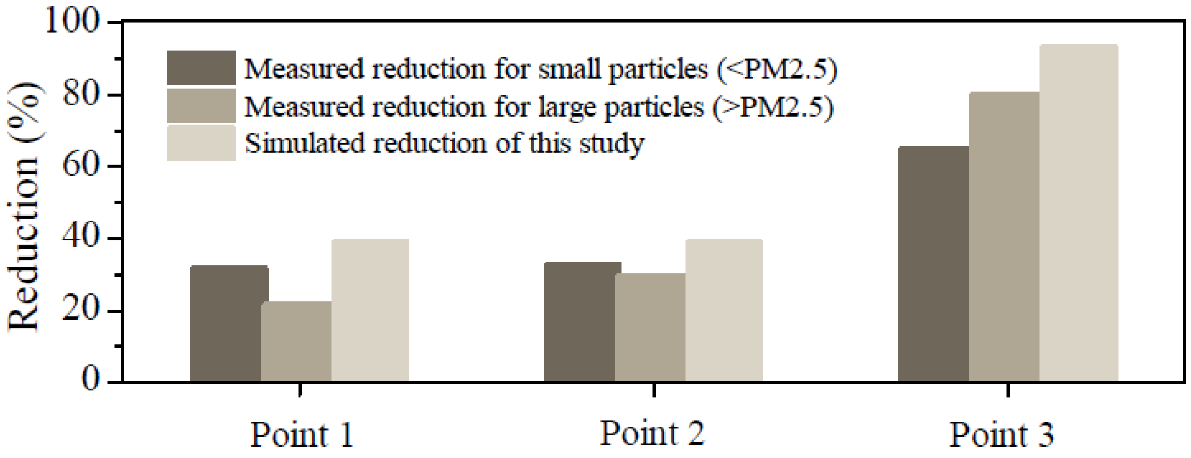
“Airborne SARS-CoV-2 was detected in the ward on all five days before activation of air/UV filtration, but on none of the five days when the air/UV filter was operational;

SARS-CoV-2 was again detected on four out of five days when the filter was off. Airborne SARS-CoV-2 was infrequently detected in the ICU.

Filtration significantly reduced the burden of other microbial bioaerosols in both the ward (48 pathogens detected before filtration, two after, p=0.05) and the ICU. (45 pathogens detected before filtration, five after p=0.05).”

Simulating a restaurant with air cleaners on tables





Zhai, et al. (2021) https://doi.org/10.3390/buildings11080329

Do-it-yourself air cleaners work, are safe

Moderate efficiency with high flow rate can create a significant equivalent OA flow

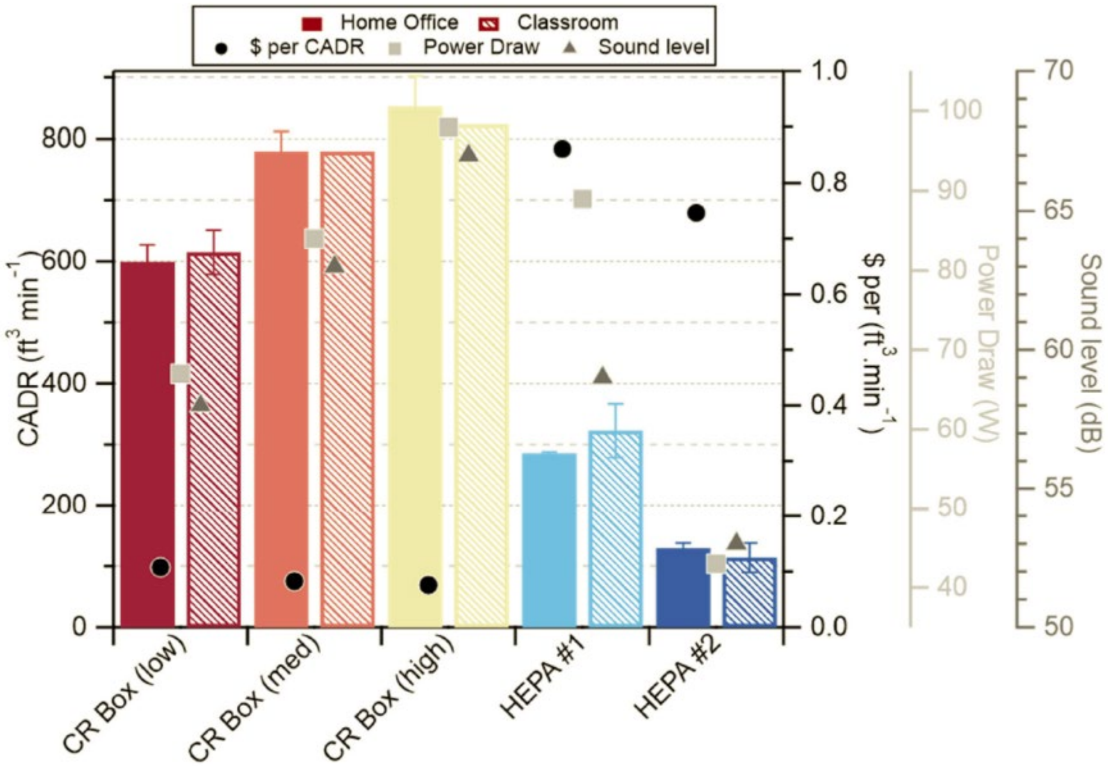
Typically done with a box fan and four filters- MERV 13 and sometimes higher “Corsi-Rosenthal Box”

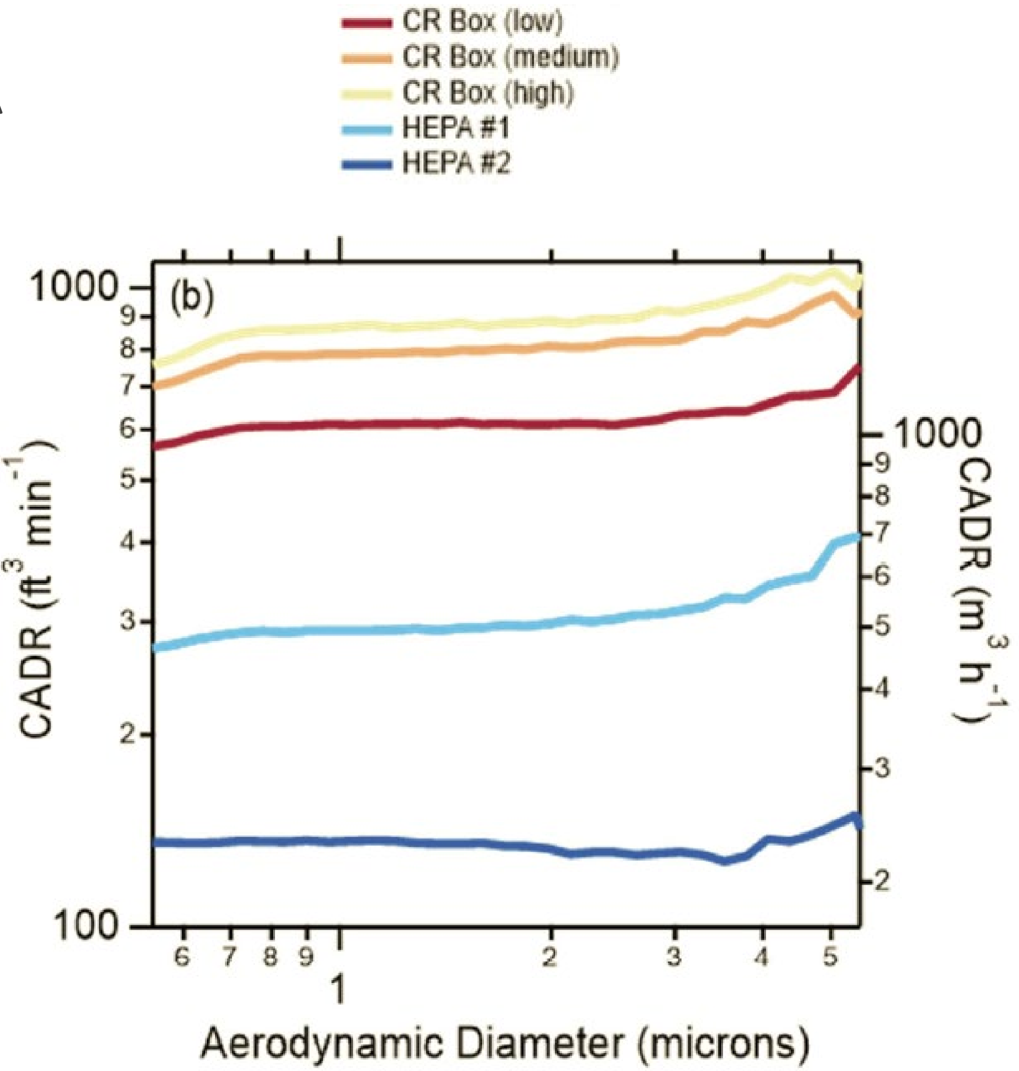
Discussed previously by EPA as a possible temporary wildfire smoke control

Safety tested by UL

www.epa.gov/coronavirus/air-cleaners-hvac-filters-and-coronavirus-covid-19

CADR - MERV 13 DIY vs. HEPA





Rachael Dal Porto, Monet N. Kunz, Theresa Pistochini, Richard L. Corsi & Christopher D. Cappa (2022) Characterizing the performance of a do-it-yourself (DIY) box fan air filter, Aerosol Science and Technology, 56:6, 564-572, DOI: 10.1080/02786826.2022.2054674

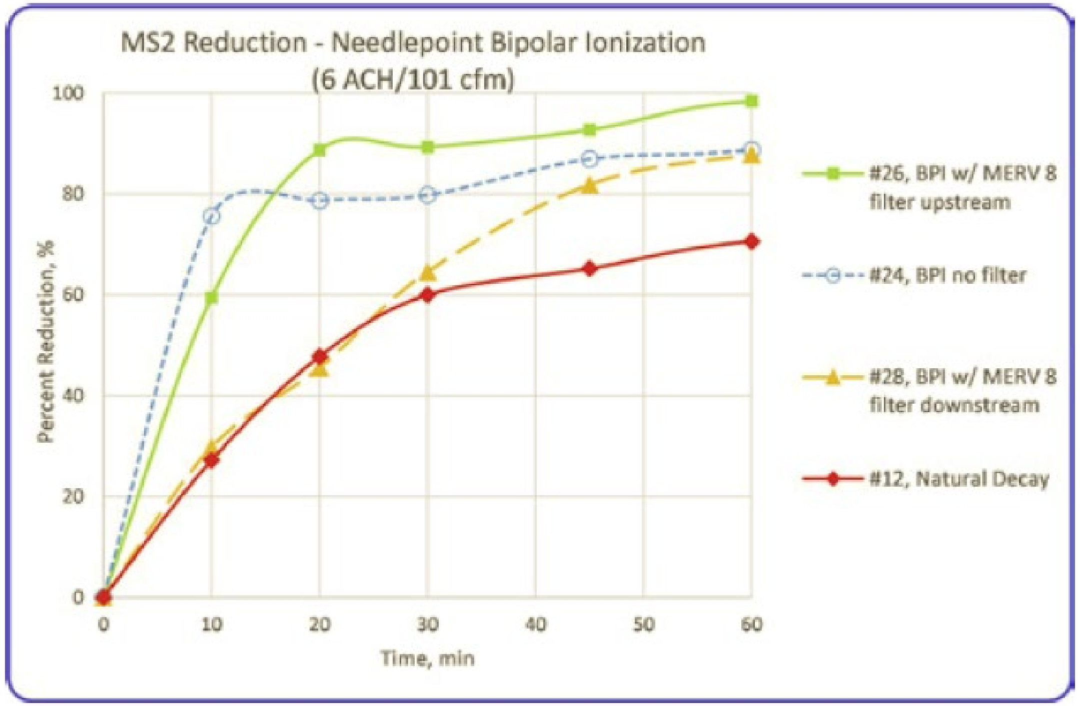
Other disinfection technologies

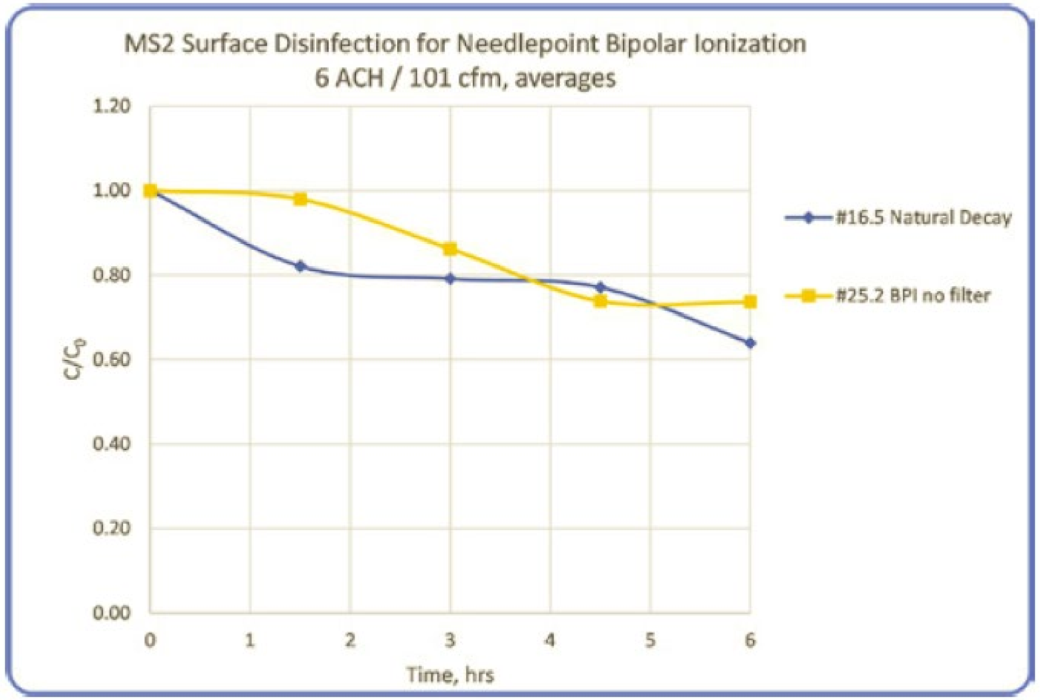
- Additive air cleaners – add oxidants to air
  - Bipolar ionization
  - Hydrogen peroxide gas
  - Photocatalytic oxidation
  - Triethylene glycol
  - Etc.

Independent tests have not lived up to manufacturers’ claims

Few standards for performance and safety

Typical Chamber Tests for an Additive Air Cleaner





https://www.jp.trane.com/content/dam/Trane/Commercial/global/about-us/wellsphere/Technology%20Whitepaper%20-%20Bipolar%20Ionization.pdf

Germicidal UV should be used more

Studied and applied for more than 100 years

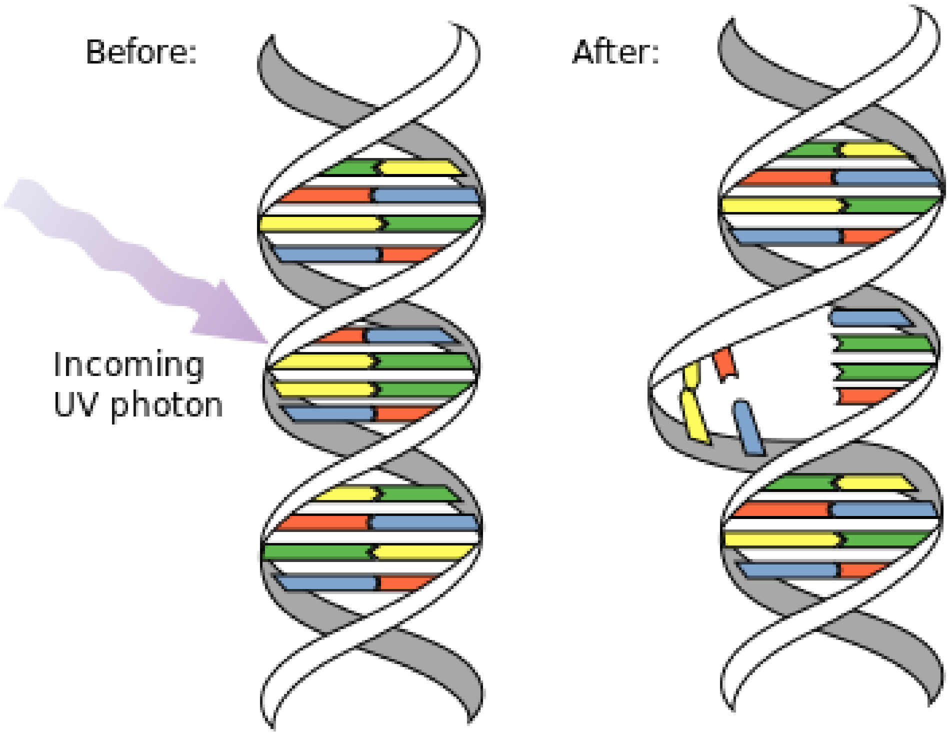
- Operating room air disinfection – 1936
- School classroom air disinfection - 1937

Approved for tuberculosis prevention by US CDC

254 nm UV-C produced by mercury vapor lamps is most common source – not safe for human exposure

LEDs and Kr-Cl lamps are making other wavelengths, potentially safer, possible

Order of 10 – 100 eACH



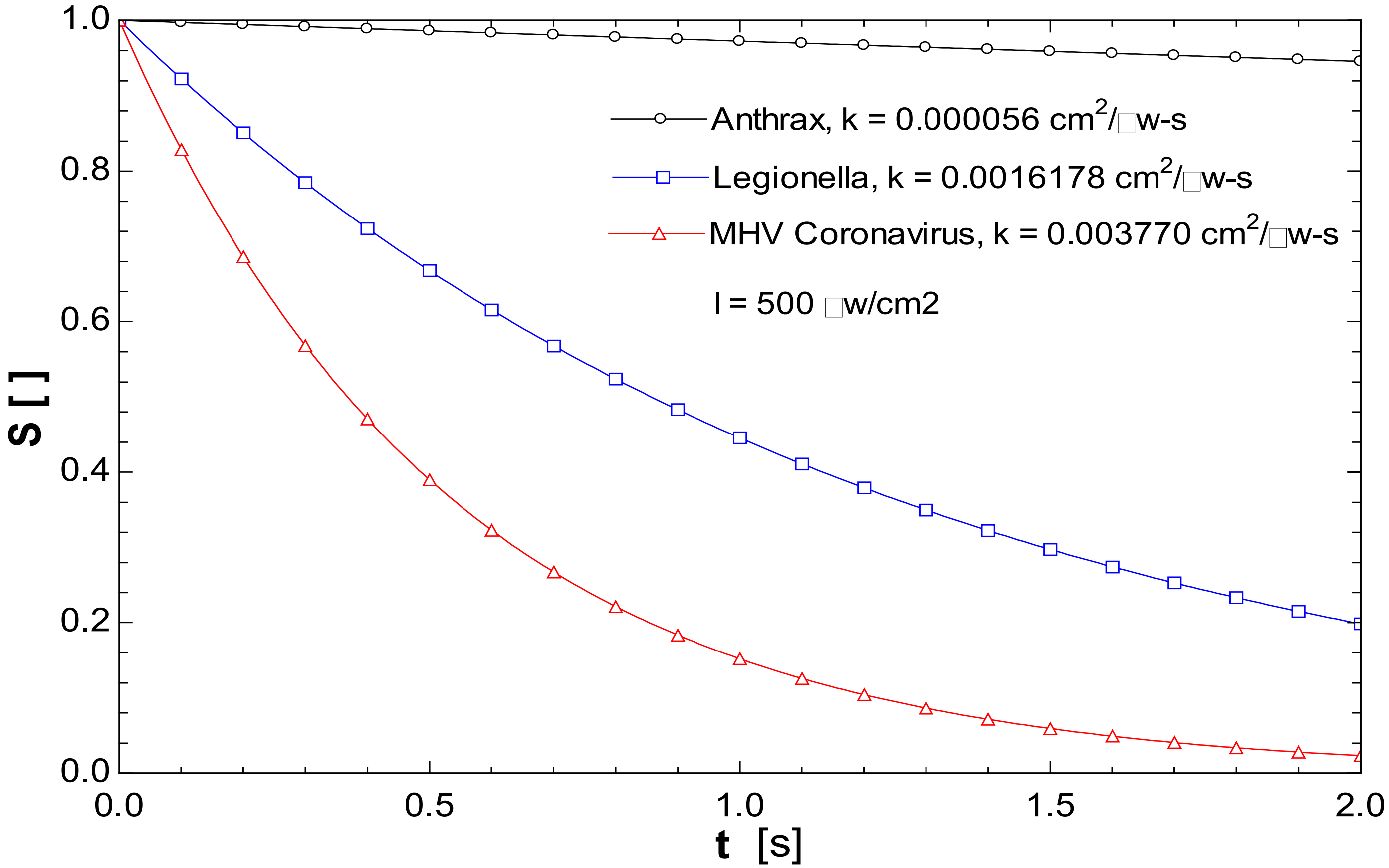
Microbial characteristics influence UV-C performance

Microbial survival after UVC exposure

$$S = \exp\left(-kIt\right)$$

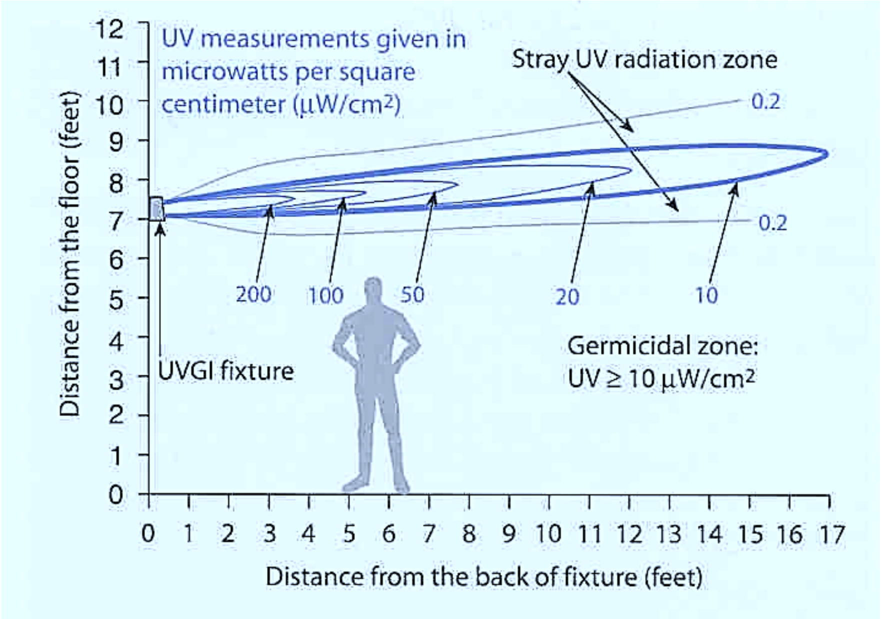
- S = surviving fraction of initial population
- k = deactivation rate constant (cm^2/µW-s)
- I = UV fluence (µW/cm^2)
- t = duration of exposure (s)

Coronavirus k is large – highly susceptible
~10X value for TB



Germicidal UV applications

Upper Room UVGI



In-Duct/Coil UVGI

Portable Surface Treatment UVGI

Upper room UV– Philadelphia school study

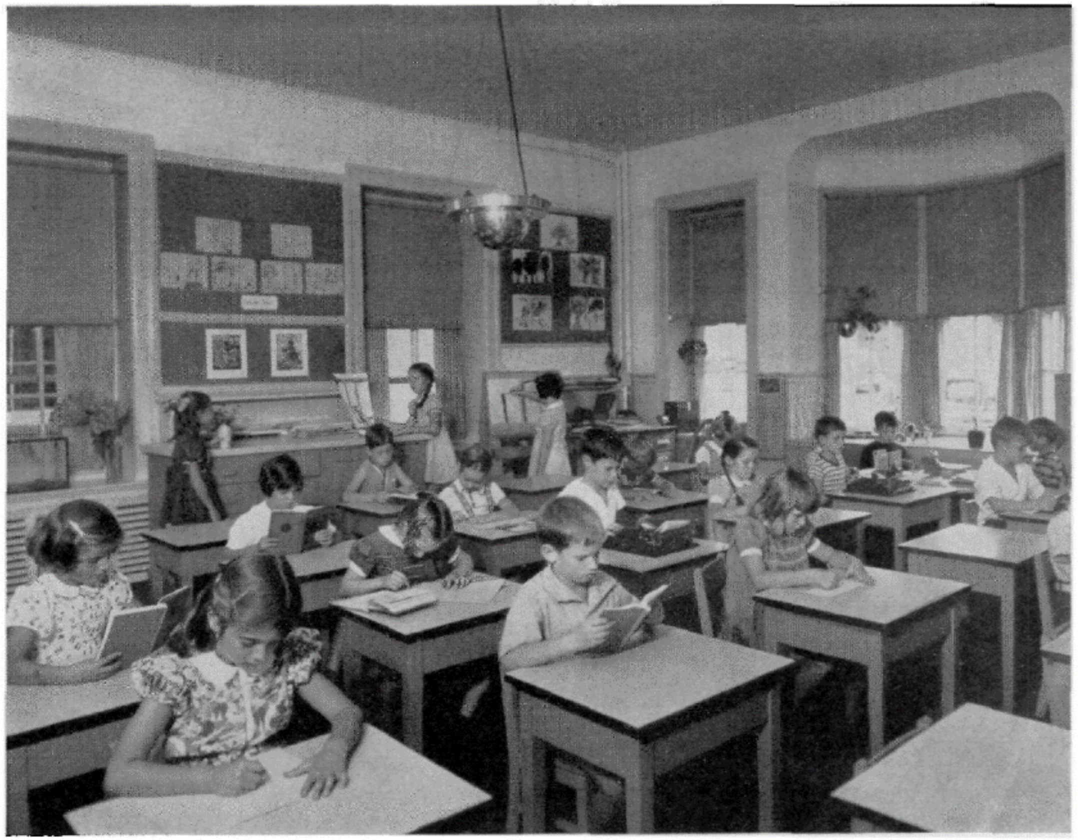
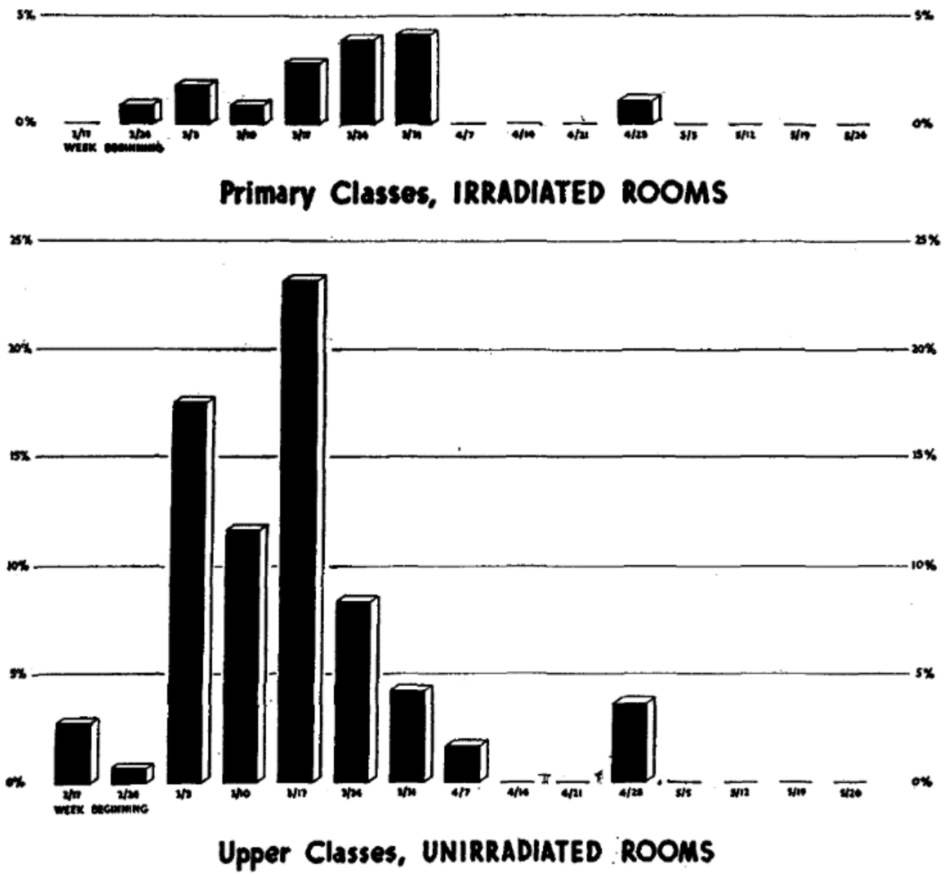


FIGURE 1. Classroom, Germantown Friends School, central radiant sources.

Weekly new measles cases, control and treated



Wells, W.F., Wells, M.W. and Wilder, T.S., 1942. The environmental control of epidemic contagion. I. An epidemiologic study of radiant disinfection of air in day schools Am J Hyg, 35, pp.97-121.

Promising results for germicidal light at multiple wavelengths

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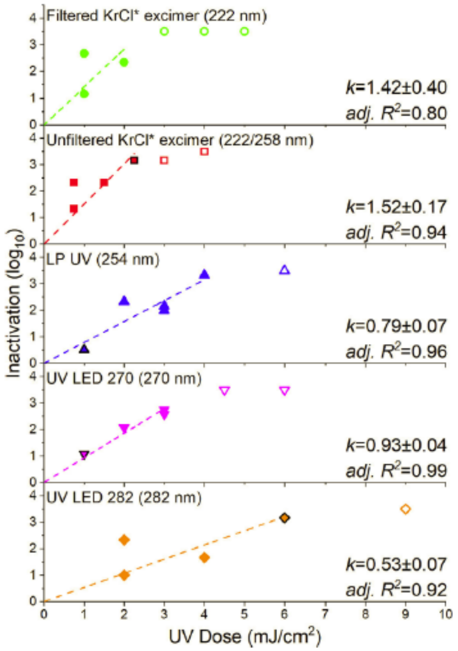
PUBLIC AND ENVIRONMENTAL HEALTH MICROBIOLOGY

Check for updates

UV Inactivation of SARS-CoV-2 across the UVC Spectrum: KrCl* Excimer, Mercury-Vapor, and Light-Emitting-Diode (LED) Sources

Ben Ma,[a] Patricia M. Gundy,[b] Charles P. Gerba,[b] Mark D. Sobsey,[c] Karl G. Linden[a]



https://journals.asm.org/doi/full/10.1128/AEM.01532-21

www.nature.com/scientificreports

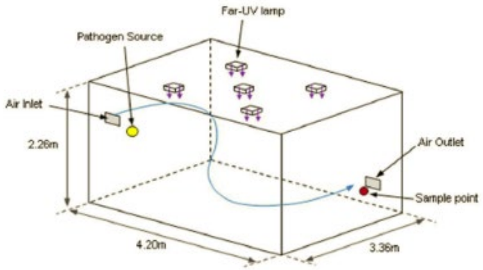
scientific reports

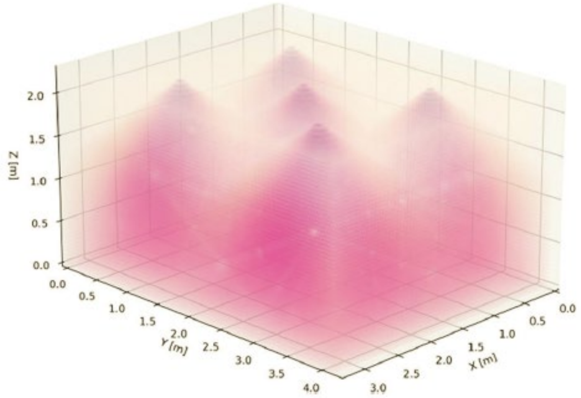
Check for updates

OPEN

Far-UVC (222 nm) efficiently inactivates an airborne pathogen in a room-sized chamber

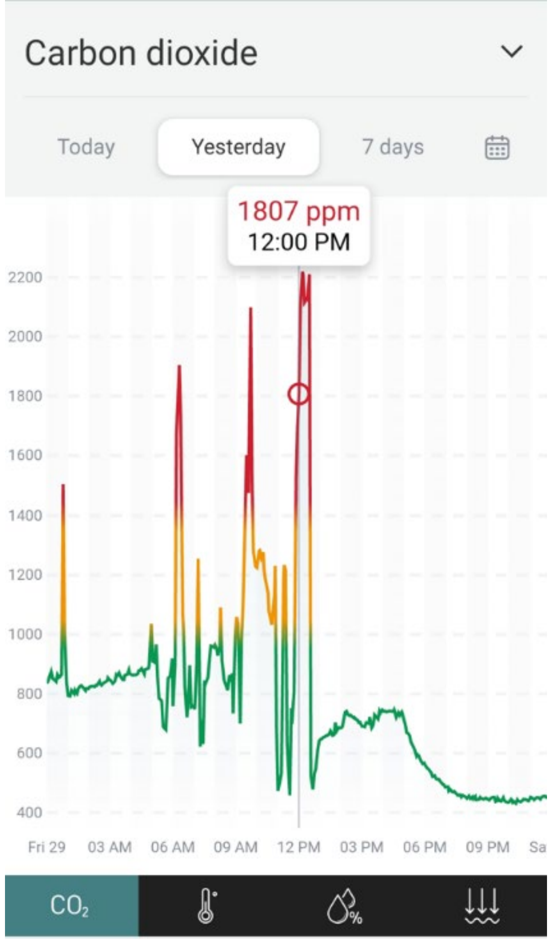
Ewan Eadie[1], Waseem Hiwar[2], Louise Fletcher[2], Emma Tidswell[2], Paul O'Mahoney[1,3], Manuela Buonanno[4], David Welch[4], Catherine S. Adamson[5], David J. Brenner[4], Catherine Noakes[2] & Kenneth Wood[6]

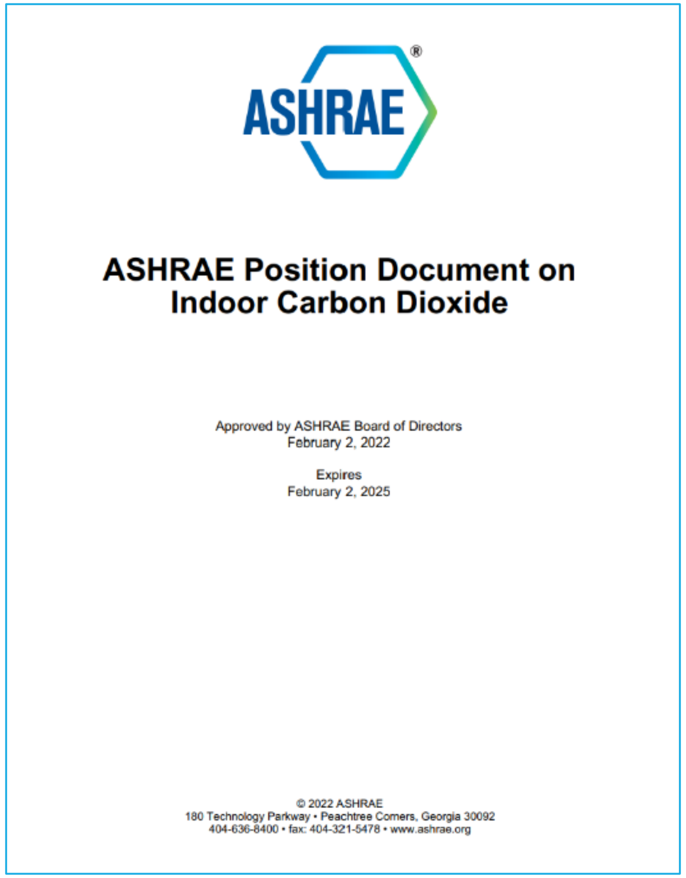




https://www.nature.com/articles/s41598-022-08462-z

CO_2 measurement – useful with caveats




ASHRAE

ASHRAE Position Document on Indoor Carbon Dioxide

Approved by ASHRAE Board of Directors
February 2, 2022

Expires
February 2, 2025

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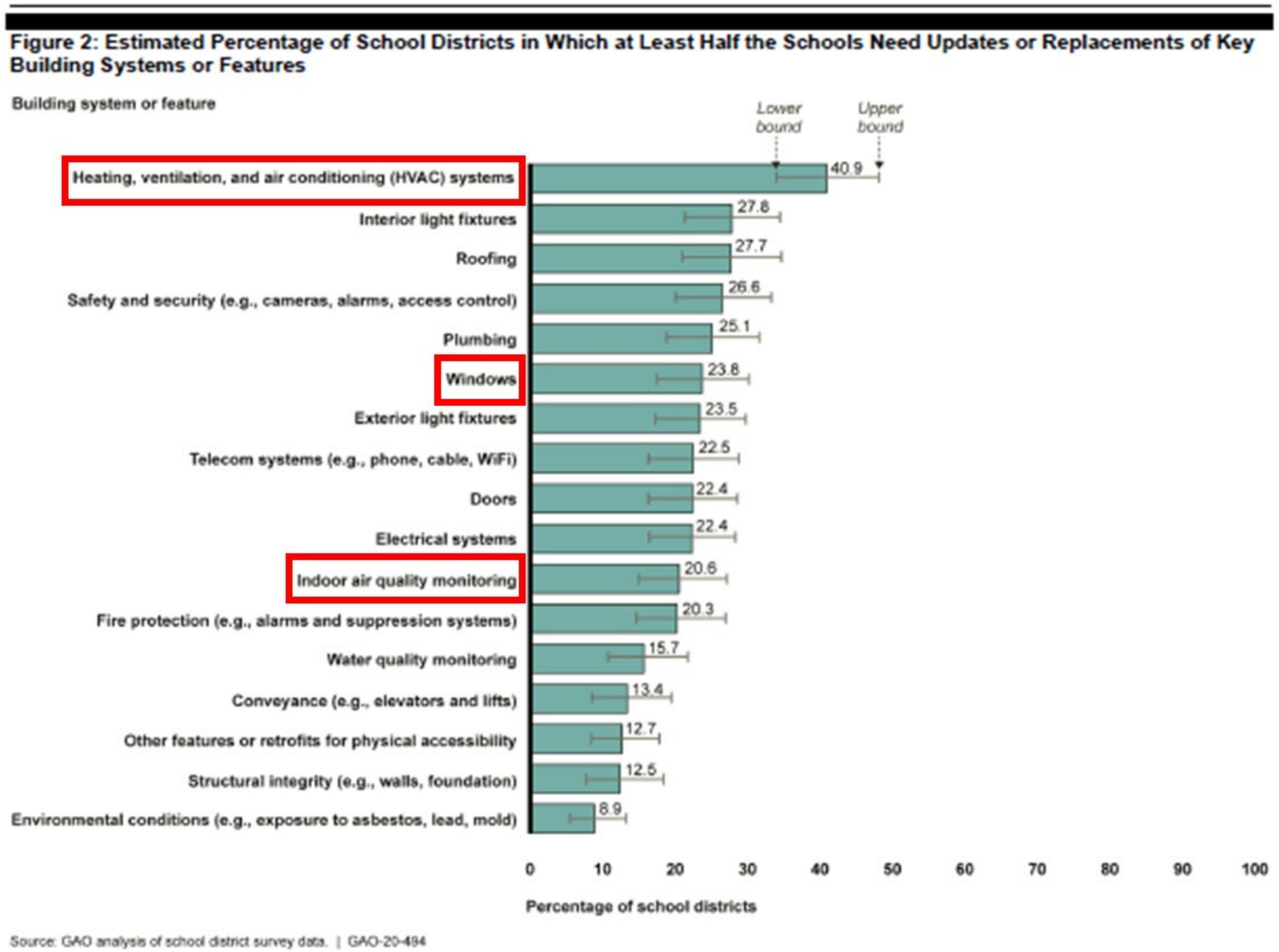
Don't neglect maintenance!



https://www.gao.gov/assets/710/707374.pdf

ASHRAE Epidemic Task Force Guidance

Core Recommendations

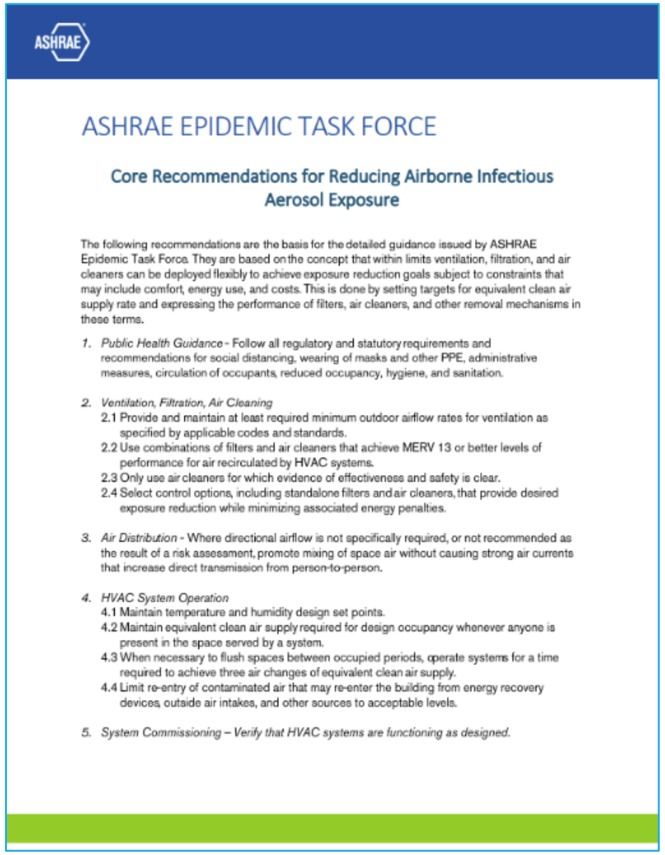
Building Readiness

- Assessment, planning, implementation
- Tools to assist user – equivalent outdoor air calculator

Facility-specific guidance

- Healthcare
- Commercial
- Schools
- Residential (single and multifamily)

ashrae.org/covid19



ASHRAE

ASHRAE EPIDEMIC TASK FORCE

Core Recommendations for Reducing Airborne Infectious Aerosol Exposure

The following recommendations are the basis for the detailed guidance issued by ASHRAE Epidemic Task Force. They are based on the concept that within limits ventilation, filtration, and air cleaners can be deployed flexibly to achieve exposure reduction goals subject to constraints that may include comfort, energy use, and costs. This is done by setting targets for equivalent clean air supply rate and expressing the performance of filters, air cleaners, and other removal mechanisms in these terms.

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.*

The future?

IAQ standards that include infection risk mitigation

IAQ control that doesn’t rely on outdoor air to do everything

Increased use of alternatives/complements to outdoor air

Integrated IAQ design based on equivalent clean air delivery

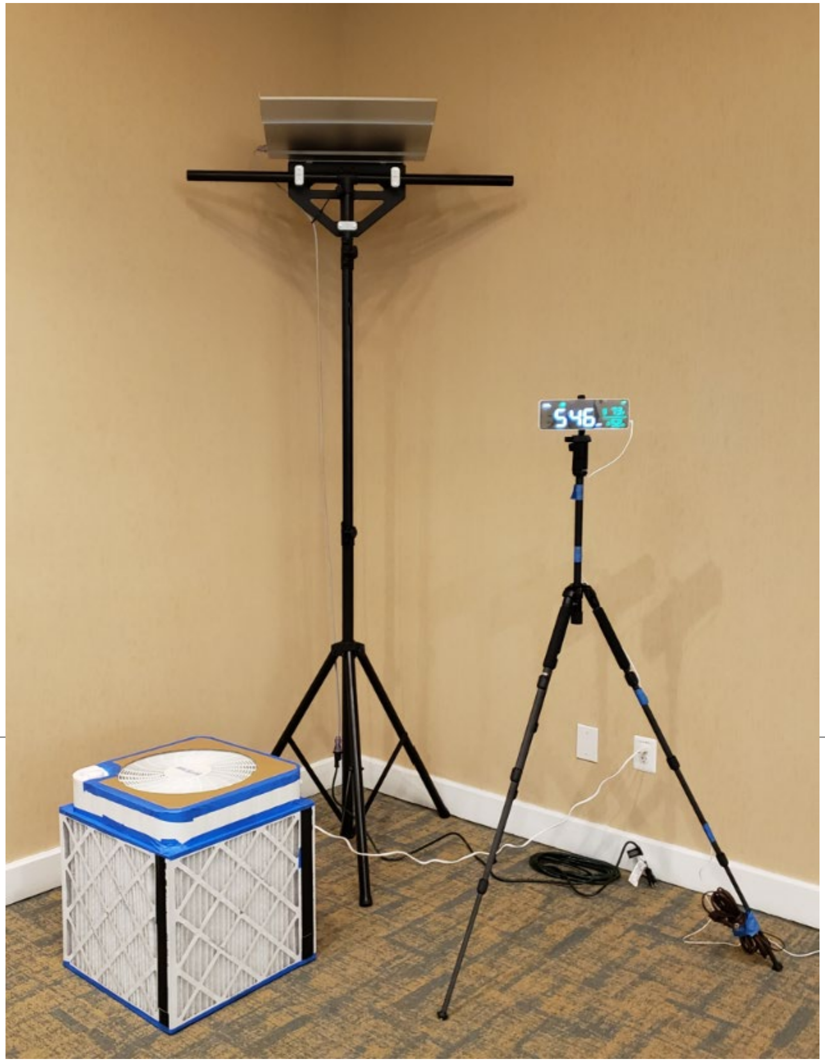
Systems that target indoor particulate matter control

Design for multiple operating modes (normal, epidemic, wildfire…)

Next generation demand control – beyond CO_2

Real-time disclosure of indoor air quality - dashboards

Applying Risk Mitigation Principles to the Westford Regency Ballroom



Acknowledgements

Germicidal UV Systems

- Bill Palmer – AeroMed Technologies

HVAC assessment, adjustment and filter upgrade

- Lew Harriman – Mason Grant
- Mike Browne – Advanced Building Analysis
- Sam Kenney – Advanced Building Analysis
- Jim Albertelli…and Nick– Westford Regency facility management
- Todd DeMonte – Madison Industries

Anybody I've missed

Westford Regency Ballroom

Dimensions (approximate) 120’×58’×13’

Area 6960 ft^2

Volume 90,480 ft^3

Served by three VAV rooftop air handling units

ASHRAE 62.1 requirements

- Lecture Classroom 65 pers/1000 sf → 452
- OA per person 7.5 cfm/pers, OA per sf 0.06 cfm/sf
- Design OA 3808 cfm

Ventilation per person 8.4 cfm/pers

Outdoor change rate (13’) 2.5 ACH, (9’) 3.76 ACH

Estimated steady state CO_2 concentration 1719 ppm

Ballroom HVAC Assessment, Tuning, Filter Upgrade

Performed by a multidisciplinary team, consistent with good commissioning practice, ASHRAE guidance

Initial site visit

- Which RTU’s serve which spaces?
- Determine manufacturers, models and capacities.
- Open all units - Confirm filter sizes and quantities
- Locate and confirm which thermostat controls which unit
- Confirm that units can be set to run in “FAN ON” mode (constant recirculation through MERV-13 filters)
- Confirm room dimensions, ceiling heights and supply-return locations

Ballroom HVAC Assessment, Tuning, Filter Upgrade

Pre-Conference visit

- Upgrade filters
- Measure outdoor air

Filter upgrade

- Replace six existing MERV 8 filters with MERV 13
- Some field modification of filters needed because *manufacturer specified* filters did not fit





Ballroom HVAC Assessment, Tuning, Filter Upgrade

Ventilation measurement

- Initial measurement found zero flow in all units!
- Dampers closed – working great!
- Undetermined control issue fixed by another field modification

Air flows were measured at two fan settings, below 62.1 minimum in all cases

Supply air flow rates were estimated for each mode

Ballroom ventilation/filtration summary

Totals assuming ASHRAE outdoor air and 4000 cfm supply air per unit

Outdoor air: 3808 cfm, 8.4 cfm/pers, 2.5 ACH(13’)

Measured outdoor air: 1461 – 2269 cfm, 38 – 60% of ASHRAE Standard 62.1

Equivalent outdoor air from recirculated air (8192 cfm) with MERV 8 (49%) and MERV 13 (86%) viral aerosol removal per ASHRAE

- MERV 8 – 4014 cfm, 8.9 cfm/pers, 2.7 eACH
- MERV 13 – 7045 cfm, 15.6 cfm/pers,4.7 eACH

Outdoor air + AHU filtered air

- MERV 8 – 7822 cfm, 17.3 cfm/pers, 5.2 eACH
- MERV 13 – 10, 853 cfm, 24.0 cfm/pers, 7.2 eACH

Similar for measured OA because of trade-off with recirculation

Ventilation/filtration summary - design

Assuming ASHRAE minimum ventilation, maximum supply air flow

	cfm	cfm/pers	ACH or eACH
Outdoor Air	3808	8.4	2.5
Recirculated Air	8192		
Filtered Clean Air			
MERV 8	4014	8.9	2.7
MERV 13	7045	15.6	4.7
Total, OA + Filter			
MERV 8	7822	17.3	5.2
MERV 13	10,853	24.0	7.2

Exceeds WHO recommendation and the 6 eACH guideline for MERV 13

Ventilation/filtration summary – low flow

Assuming ASHRAE minimum ventilation, minimum supply air flow

	cfm	cfm/pers	ACH or eACH
Outdoor Air	3808	8.4	2.5
Recirculated Air	992		
Filtered Clean Air			
MERV 8	486	1.1	0.3
MERV 13	853	1.9	0.6
Total, OA + Filter			
MERV 8	4294	9.5	2.8
MERV 13	4661	10.3	3.1

OK at design, but needs help at part load because of reduced recirculation!

Corsi-Rosenthal Boxes

“Standard” fan + four MERV 13 design

Fan flow ~500 cfm for each of four

Estimated clean air delivery

- 1780 cfm
- 3.8 cfm/pers
- 1.1 eACH

Somewhat undersized for the room

Fan flow dropped significantly in application

AHAM recommends 4 ACH CADR as a guideline

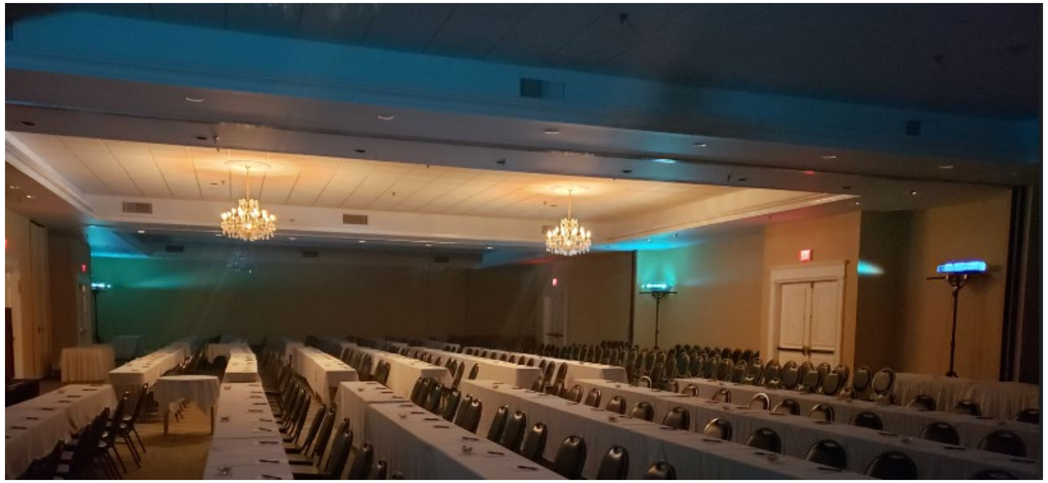
Upper room UV installation

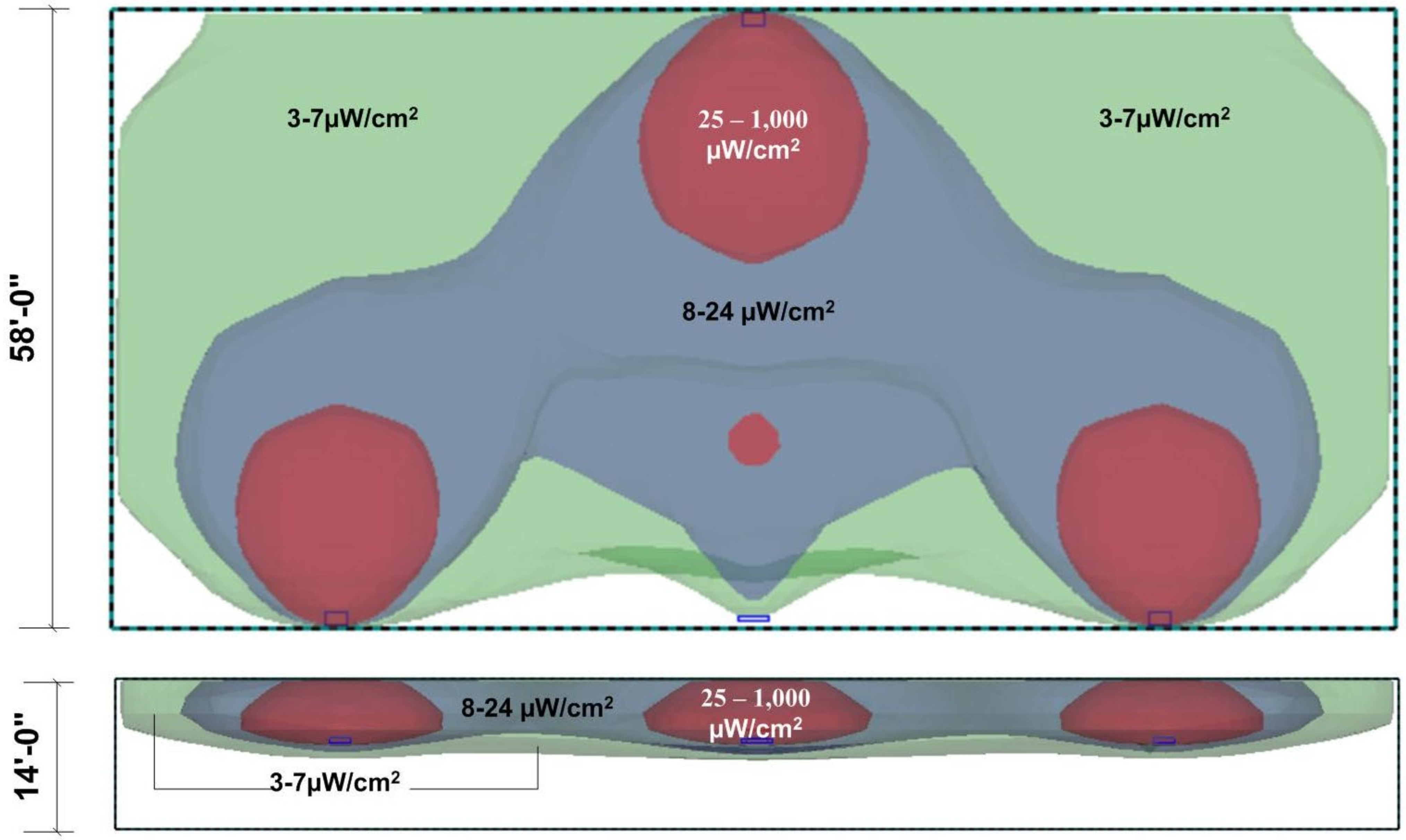
Four AeroMed fixtures

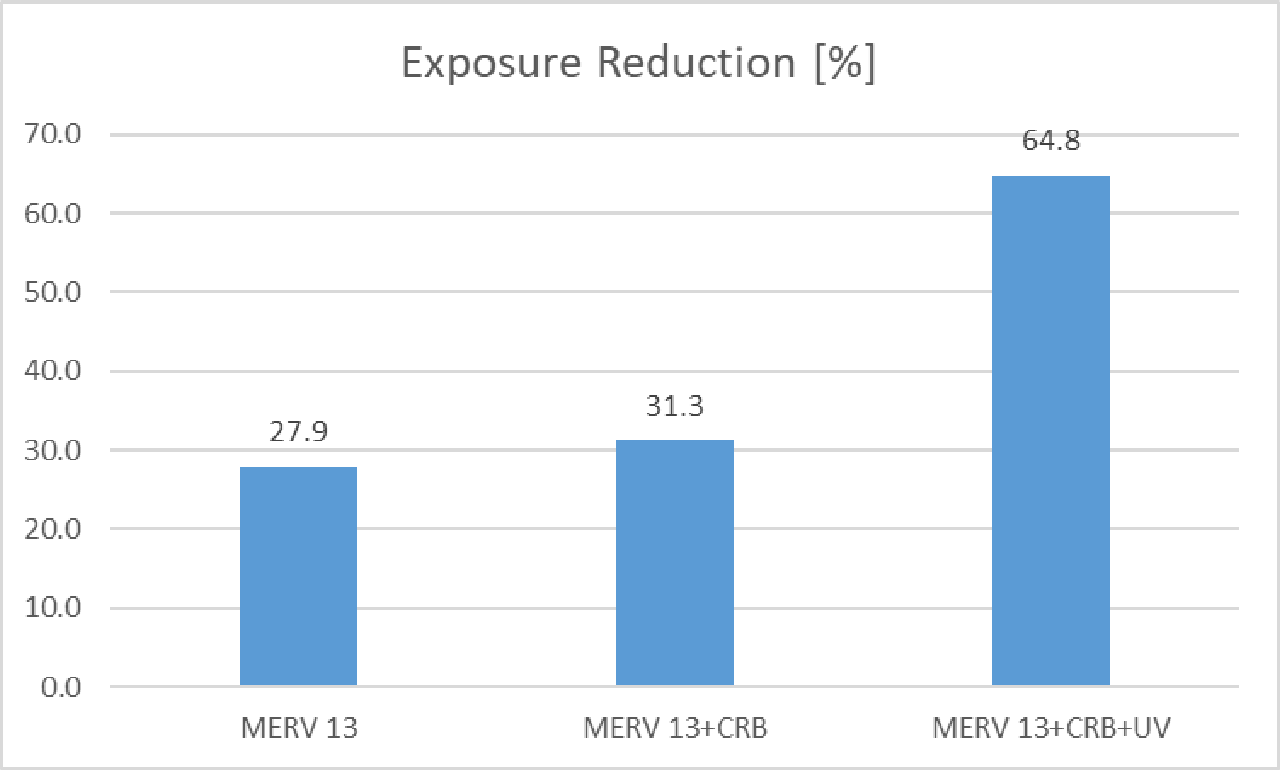
- Three open (higher output)
- One louvered (focus beam for lower ceilings)

Sizing scaled to data for tuberculosis control that achieves 24 eACH with 12 mW/m^3

Total power: 15.5 W




58'-0"
3-7μW/cm²
25 – 1,000 μW/cm²
3-7μW/cm²
8-24 μW/cm²
14'-0"
8-24 μW/cm²
25 – 1,000 μW/cm²
3-7μW/cm²



Relative risk reductions with 70% vaccinated, 4 infectors, no mask baseline

- No system changes but 50% N95 use – 55%
- MERV 13 + CR Box – 37%
- MERV 13 + CR Box + UV – 63%
- MERV 13 + CR Box +UV + 50% N95 – 92%

Final thoughts

Our industry needs to think about infection risk in in indoor environments – apply the precautionary principle

Risk assessment is imprecise, but we know how to lower risk significantly using a few simple tools

HVAC can't eliminate risk – it should be part of a multi-layered strategy deployed as needed

More and more outdoor air is not the best way to reduce risk – effectiveness or energy use. We should use filtration and especially UV more to reach desirable levels of control

Thank you!

wbahnfleth@psu.edu