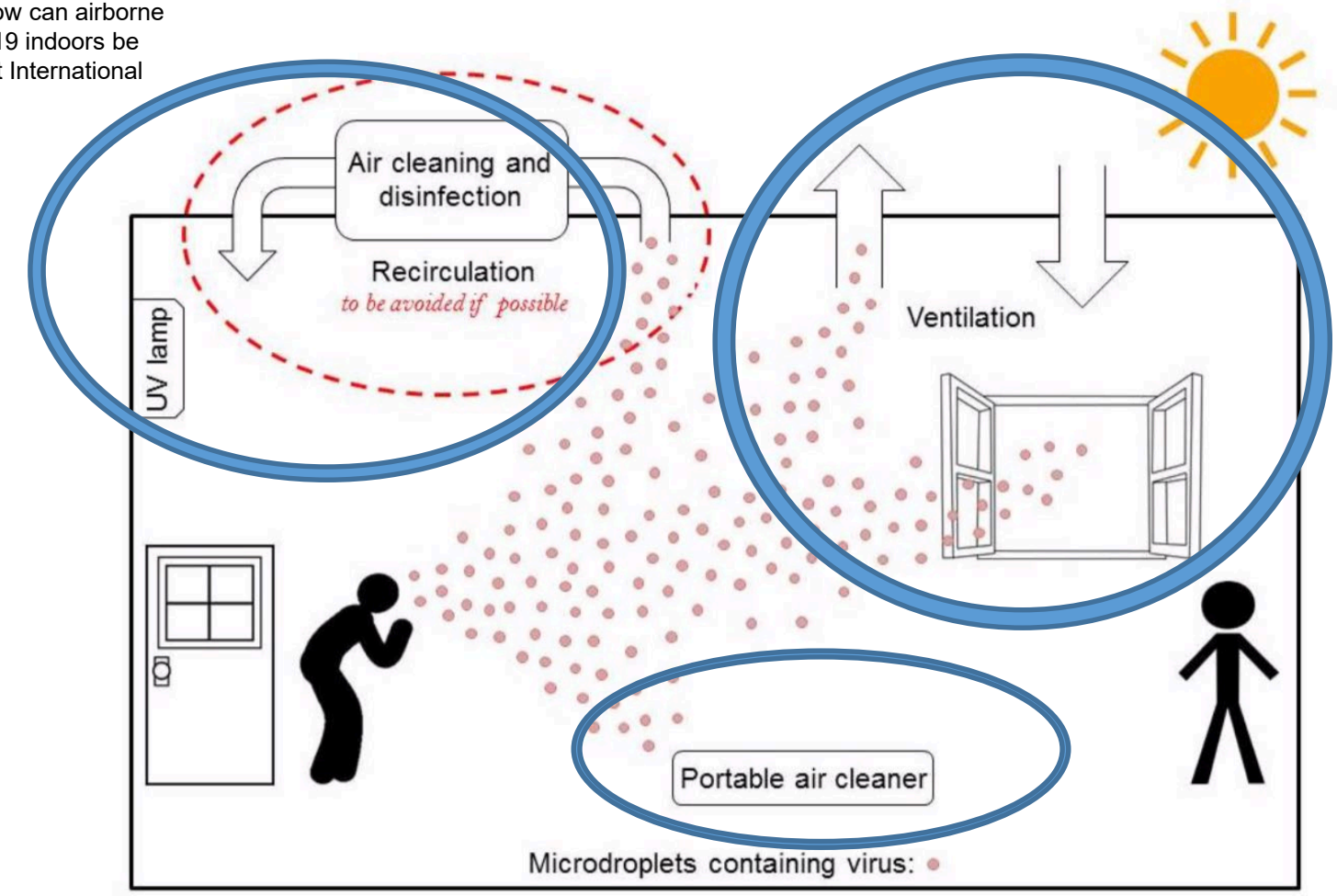
Role the Built Environment Plays in Determining Exposure Risk for SARS-CoV-2

Dr. Shelly L. Miller

Professor Mechanical Engineering

University of Colorado Boulder

Morawska et al 2020. How can airborne transmission of COVID-19 indoors be minimized? Environment International 142, 105832



VENTILATION

What Ventilation Rate is needed?

	High Ventilation Dorm	Low Ventilation Dorm
CO2 concentrations in rooms	1230 ppm	1490 ppm
Dorm rooms' ventilation rates	6 L/s/person	2 L/s/person
# ARI cases / total subjects	1 / 11	47 / 109

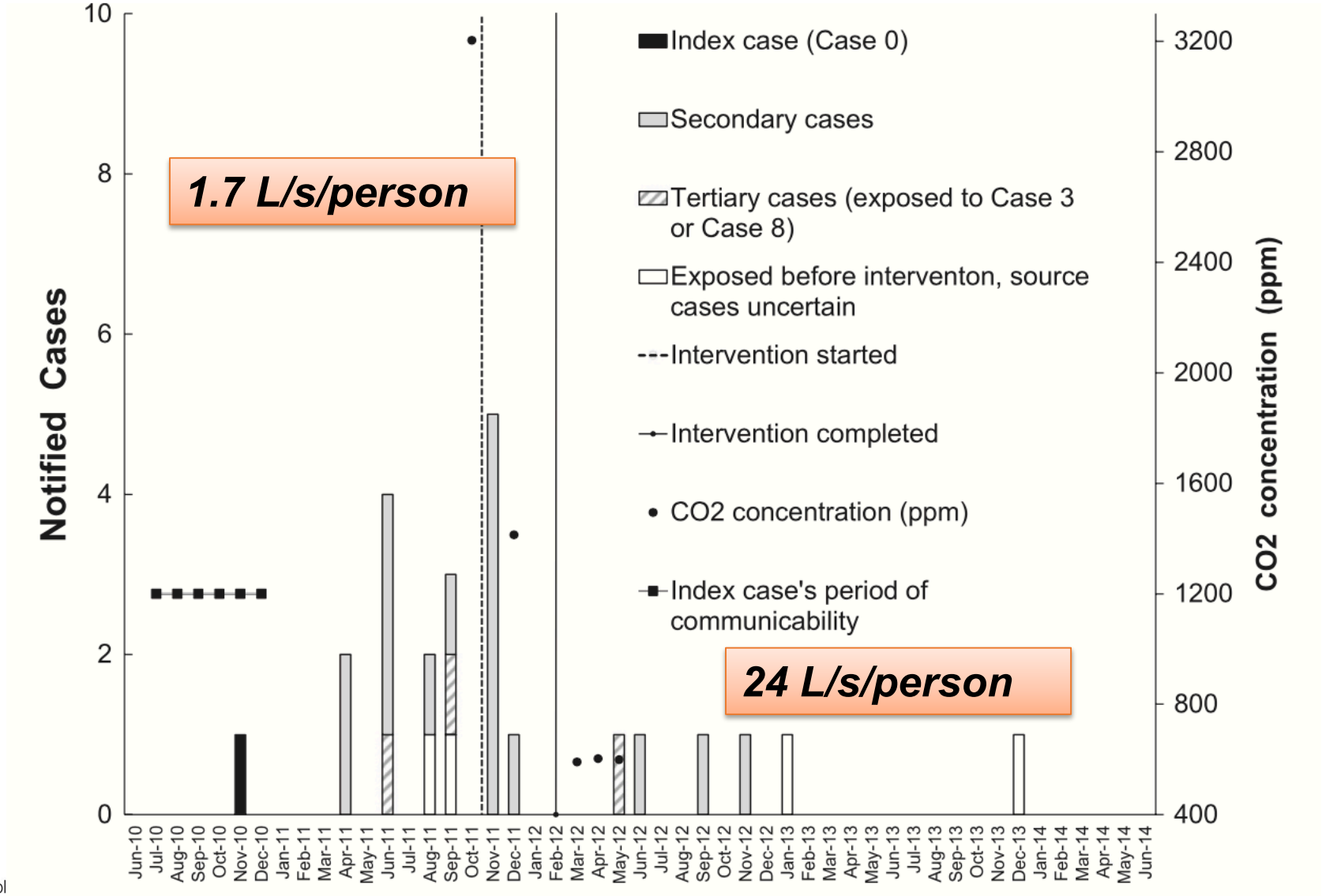
ventilation rates of < **5 L/s per person** may be impacting acute respiratory infections

Zhu S, Jenkins S, Addo K, et al. Ventilation and laboratory confirmed acute respiratory infection (ARI) rates in college residence halls in College Park, Maryland. *Environment International*. 2020;137:105537. doi:10.1016/j.envint.2020.105537

outdoor air supply rates **< 25 L/s per person** increase the risk of sick building symptoms, increase short-term sick leave, and decrease productivity

Wargocki P, Sundell J, Bischof W, et al. Ventilation and health in non-industrial indoor environments: report from a European Multidisciplinary Scientific Consensus Meeting (EUROVEN). *Indoor Air*. 2002;12(2):113-128. doi:10.1034/j.1600-0668.2002.01145.x

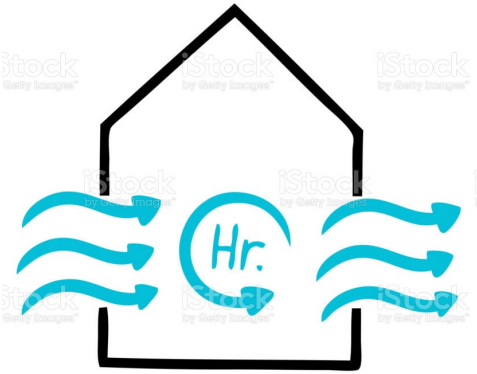
What Ventilation Rate is needed?



Du C-R, Wang S-C, Yu M-C, et al. Effect of ventilation improvement during a tuberculosis outbreak in underventilated university buildings. *Indoor Air*. 2020;30(3):422-432.

How Air Change Rates Work

measure of the outside **air** volume added to a space divided by the volume of that space



ASHRAE recommends: *6.7 L/s/person outside air*
Occupancy is 35 students/100 m^2

(6.7 L/s/p) x (35 students/100 m^2) x (46.5 m^2) = 109 L/s

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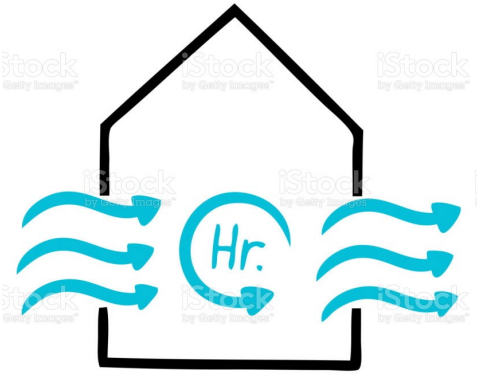

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= 3.5 air changes per hour (ACH)

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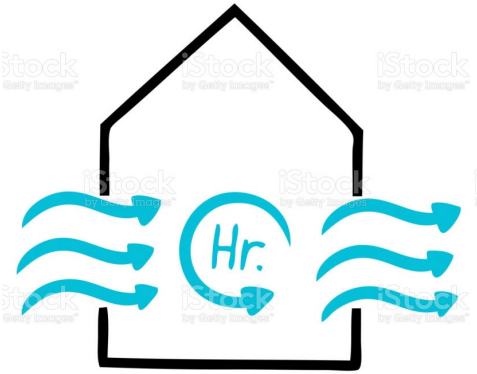

Varies a lot during the day and from one environment to the next!

ASHRAE recommends: *6.7 L/s/person outside air*
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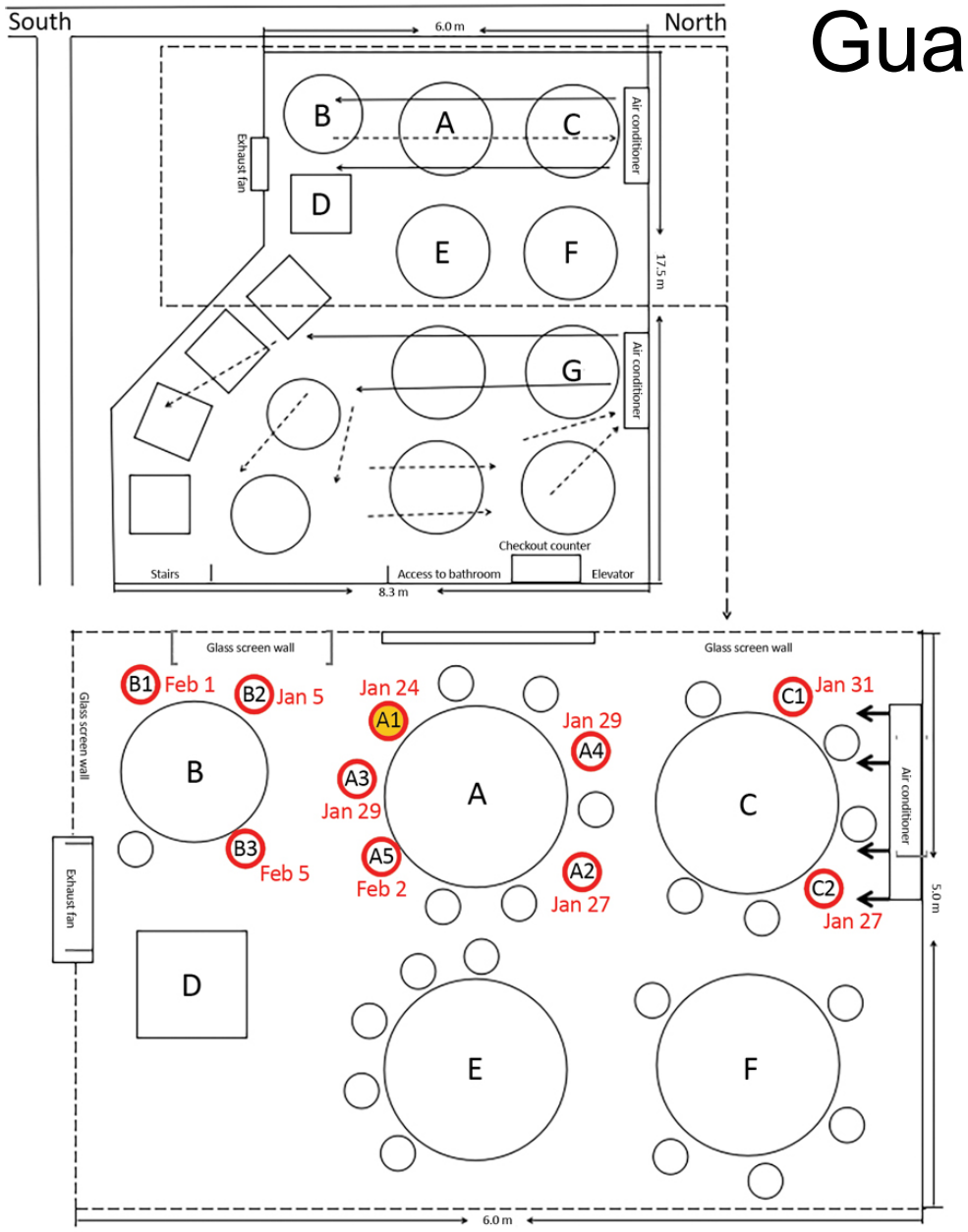
Air Change Rate? 109 L/s ÷ 111,600 L x (3600 s/h)
= 3.5 air changes per hour (ACH)

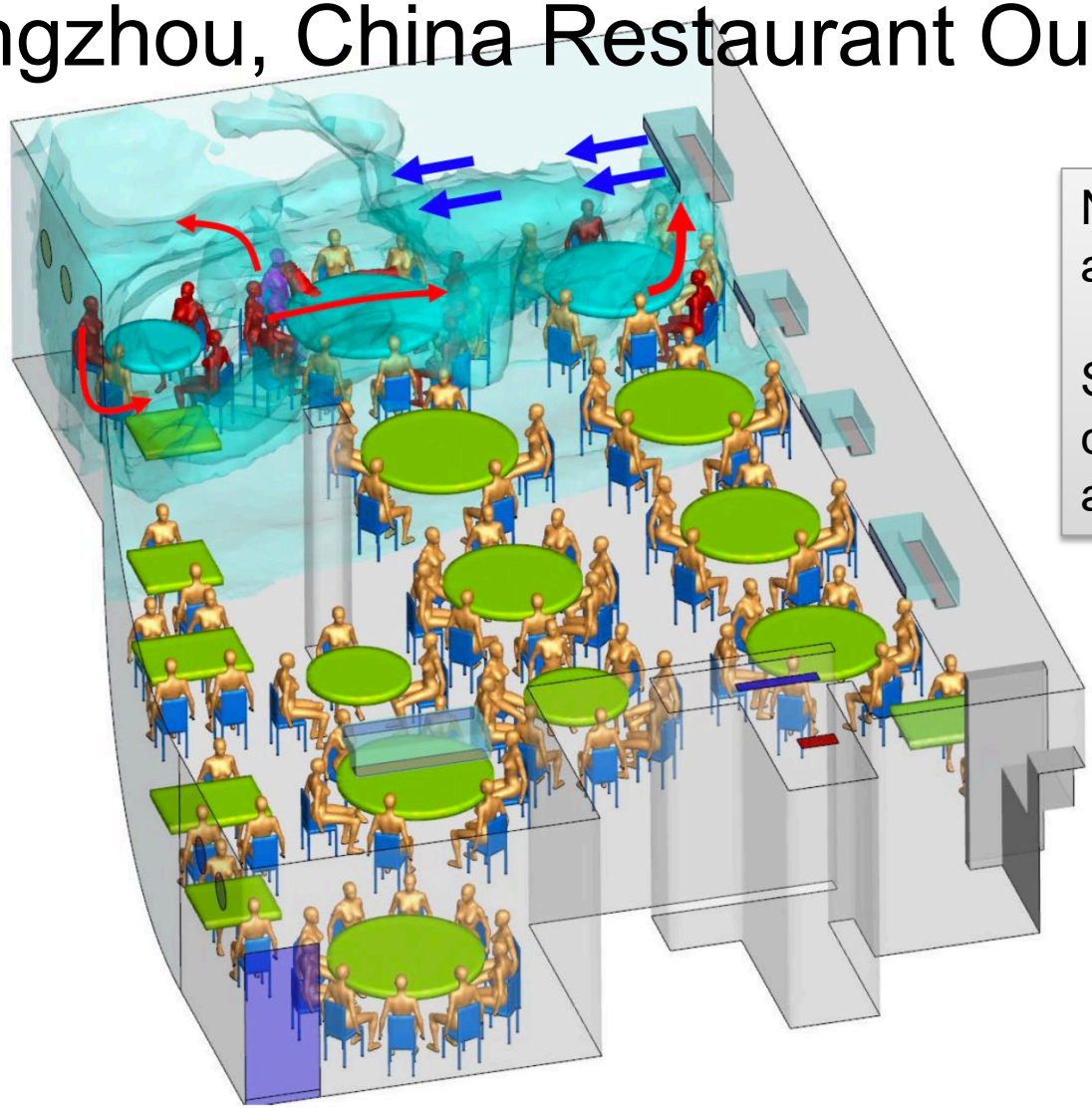
Time for much of the room air to be exchanged with outside air?
= 17 min

Time for all of the room air to be exchanged with outside air?
= 51 min

OUTBREAKS DUE TO INADEQUATE VENTILATION

Guangzhou, China Restaurant Outbreak





NO outside air supply

Strong air currents from air conditioner

Early Release - COVID-19 Outbreak Associated with Air Conditioning in Restaurant, Guangzhou, China, 2020 - Volume 26, Number 7—July 2020 - Emerging Infectious Diseases journal - CDC.pdf, n.d.

Li et al. - 2020 - Evidence for probable aerosol transmission of SARS.pdf, n.d.

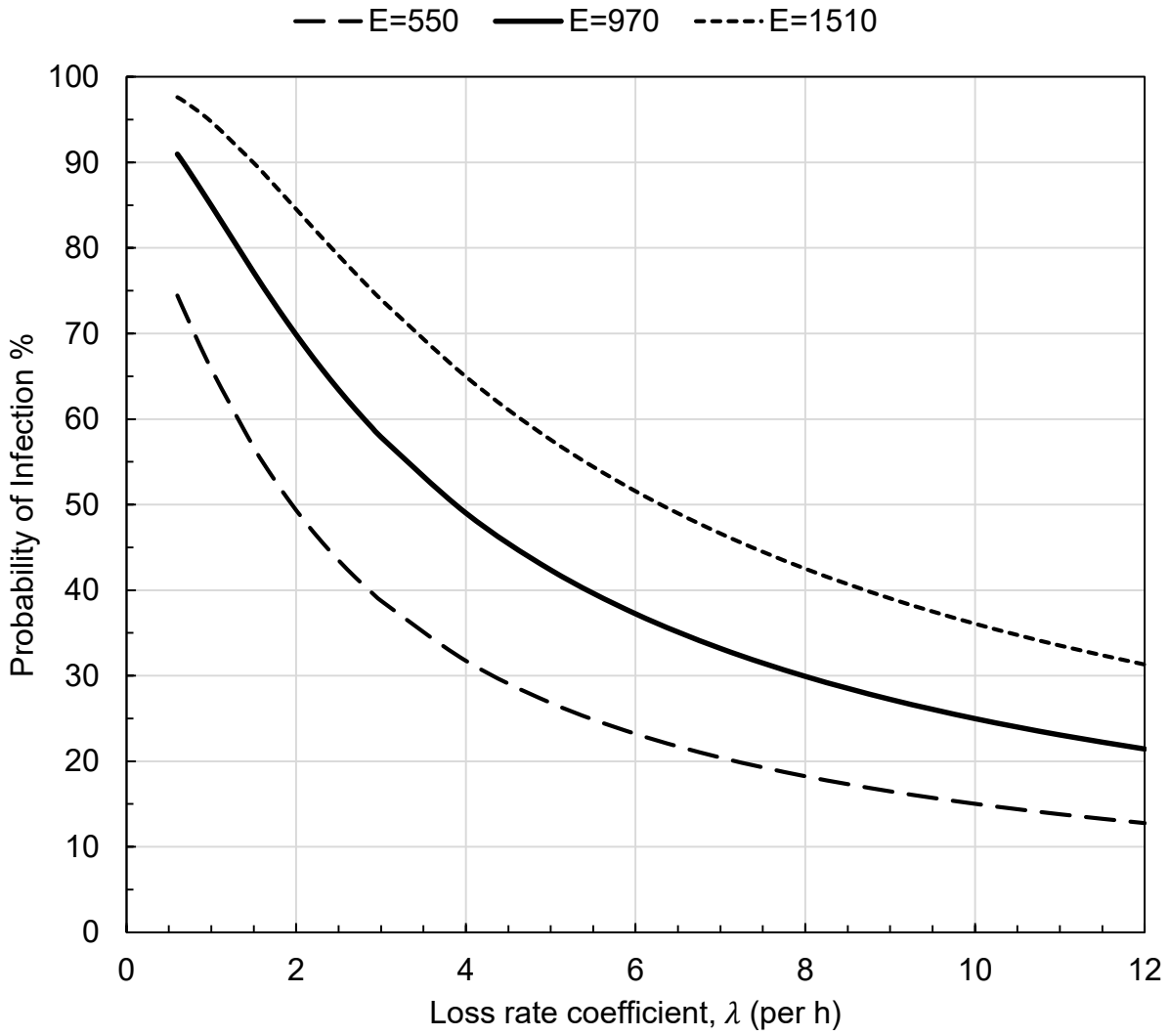
Li, Y., Qian, H., Hang, J., Chen, X., Hong, L., Liang, P., Li, J., Xiao, S., Wei, J., Liu, L., Kang, M., 2020. Evidence for probable aerosol transmission of SARS-CoV-2 in a poorly ventilated restaurant (preprint). Infectious Diseases (except HIV/AIDS).

Skagit Valley Chorale Rehearsal Outbreak

Goal 1: estimate average quanta emission rate (Wells Riley)

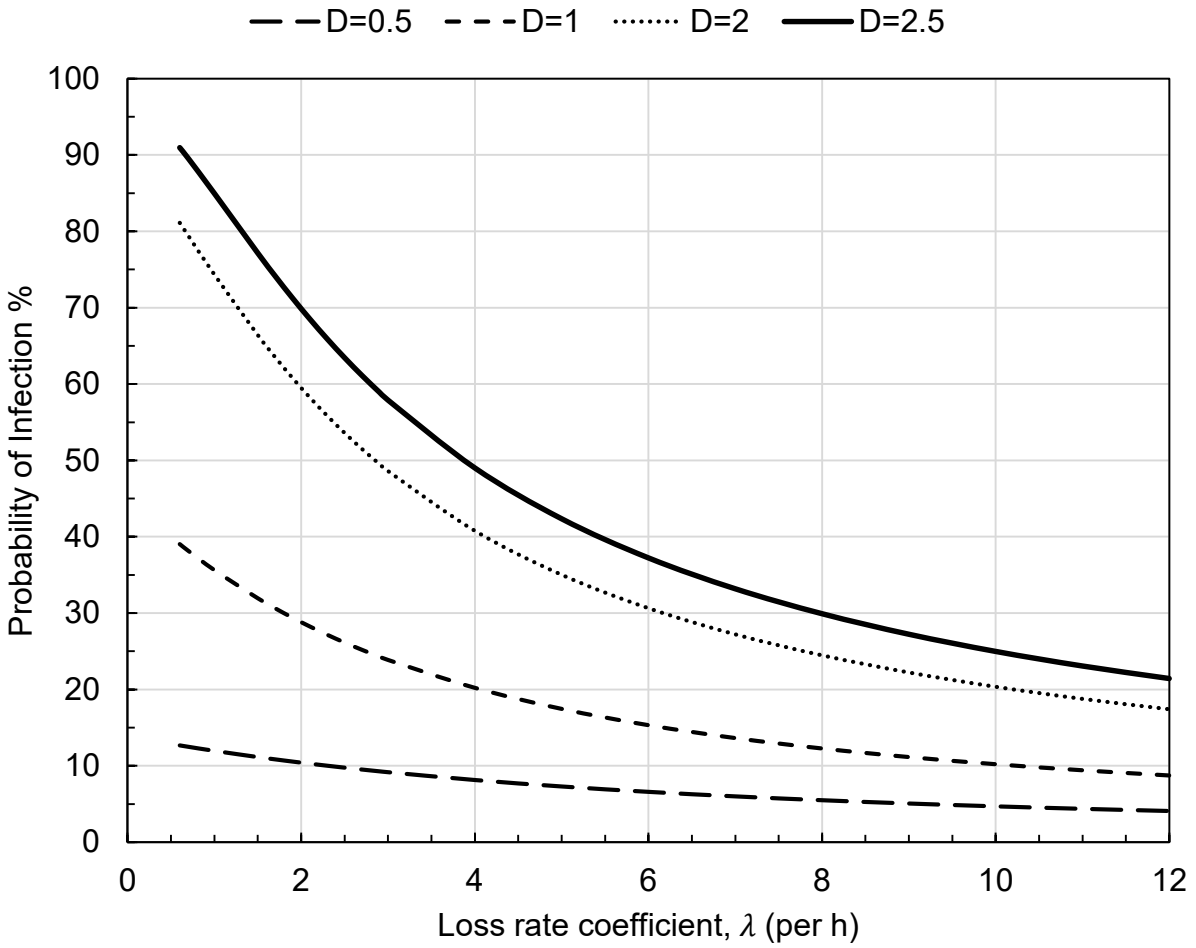
Goal 2: explore how changes in ventilation or duration of event would alter infection risk (Well-Mixed Room Model)

Miller SL, Nazaroff WW, Jimenez JL, Boerstra A, Buonanno G, Dancer SJ, Kurnitski J, Marr LC, Morawska L, Noakes C. Transmission of SARS-CoV-2 by inhalation of respiratory aerosol in the Skagit Valley Chorale superspreading event. MedRxiv. 2020 Jan 1.



Probability of infection for for varying aerosol quanta emission rates (E, q h^{-1}

Probability of infection for varying event duration (D, h).



WHAT DO WE STILL NEED TO KNOW?

- What ventilation rate for airborne infectious disease control?
- How to provide high ventilation rates with outside air while minimizing energy use?

FILTRATION

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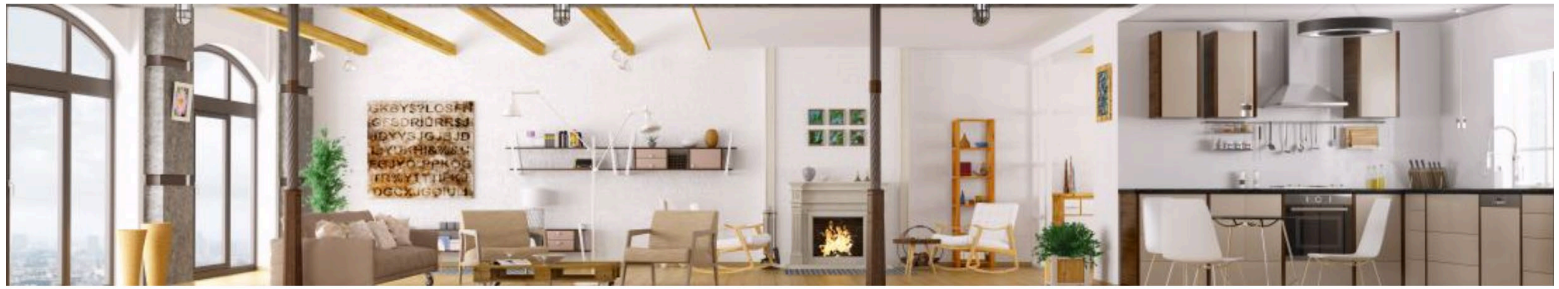

Air Cleaners & Ozone Generating Products

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Meetings & Workshops

Air Cleaners for Removal of Odorous Compounds Associated with the Aliso Canyon Natural Gas Leak

Certified Air Cleaning Devices

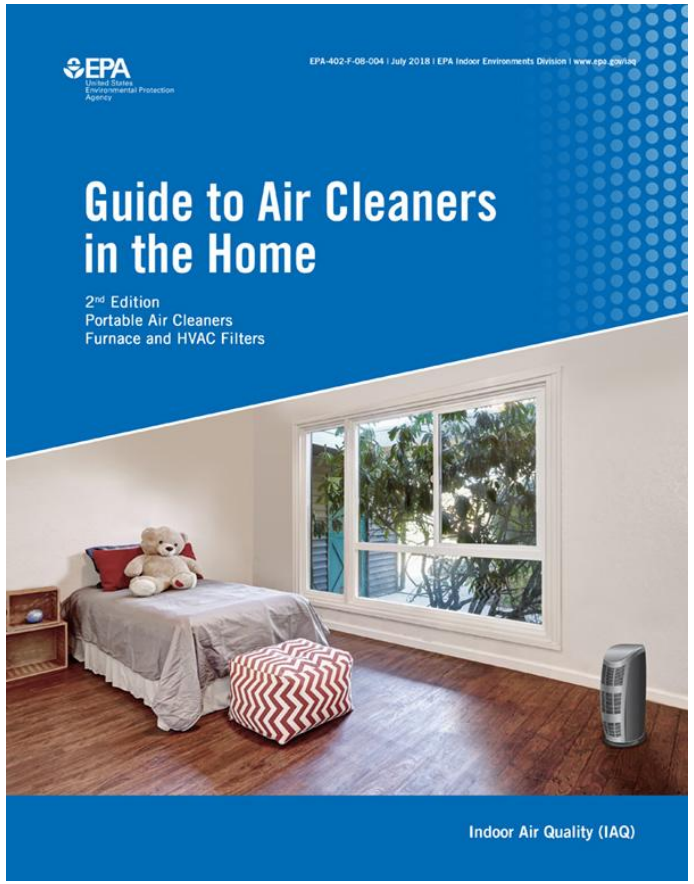
Some portable and in-duct air cleaning devices are capable of producing ozone, which could be harmful to health. There are also consumer products that emit ozone. An effective way to reduce your exposure to ozone in indoor air is to eliminate sources of ozone from your home.

MORE ABOUT THIS PROGRAM >

Air Cleaners

All portable indoor air cleaning devices sold in California must be certified by CARB to meet ozone and electrical safety standards.

FIND CERTIFIED AIR CLEANERS



CALIFORNIA AIR RESOURCES BOARD

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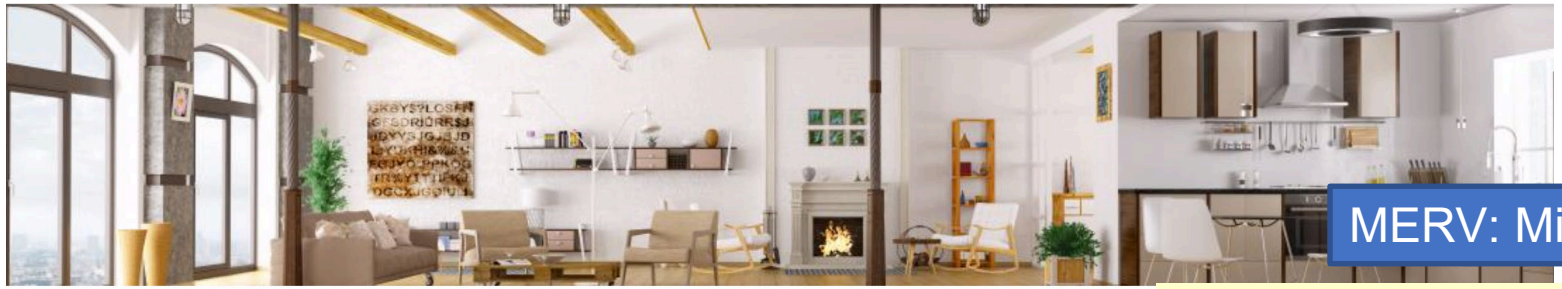

MERV: Minimum Efficiency Reporting Value

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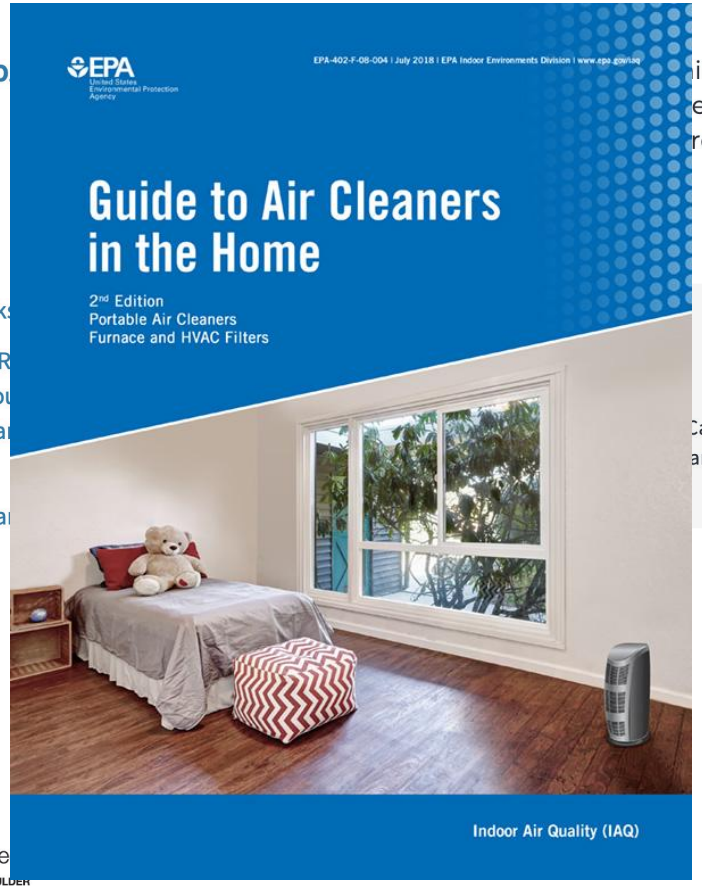
Certified Air Clea…



…ing devices are capabl…
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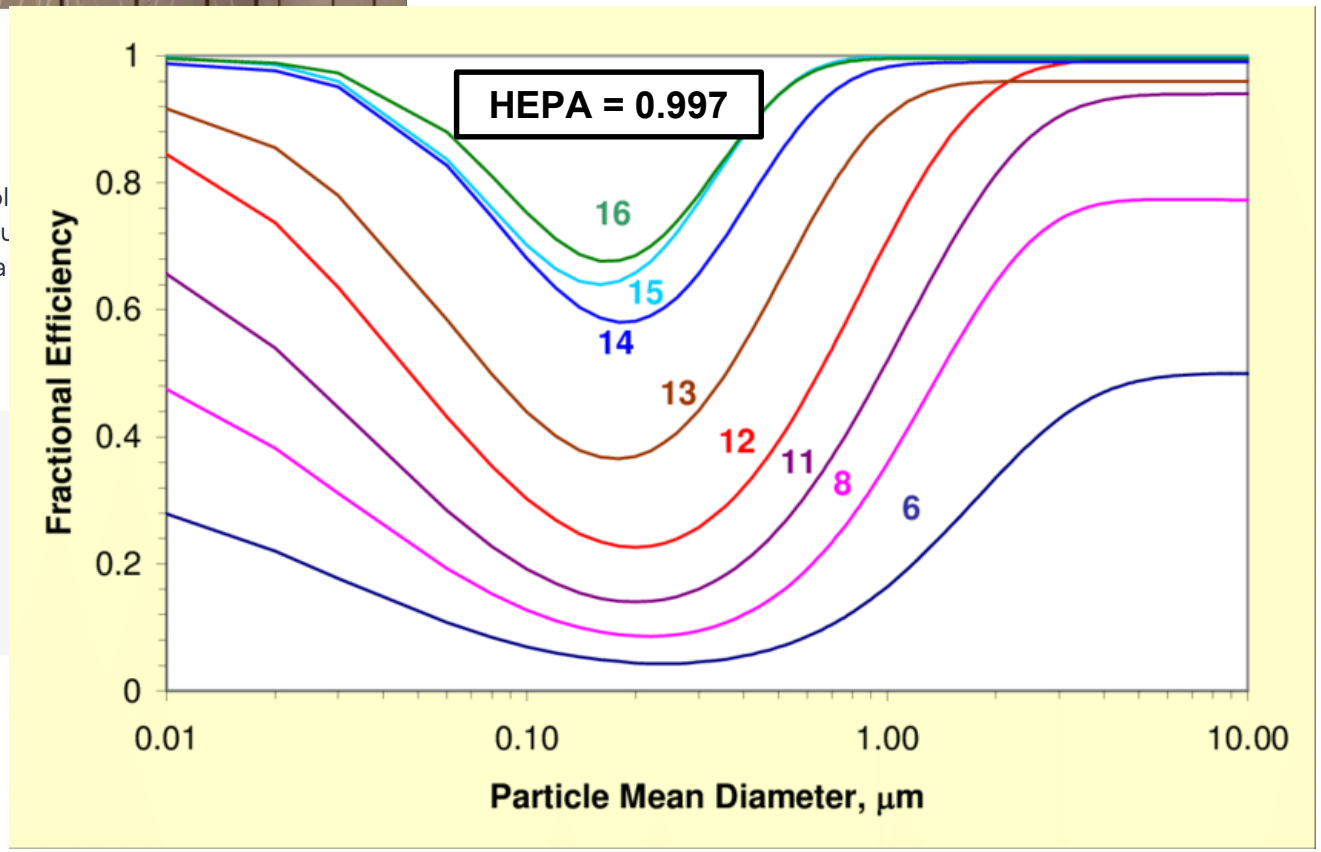
…California must be certified by …ards.

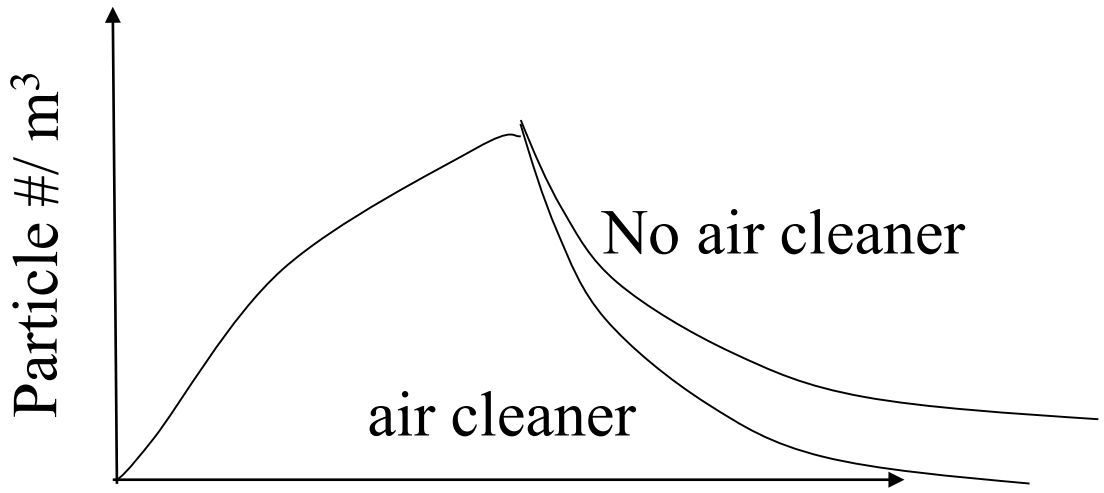


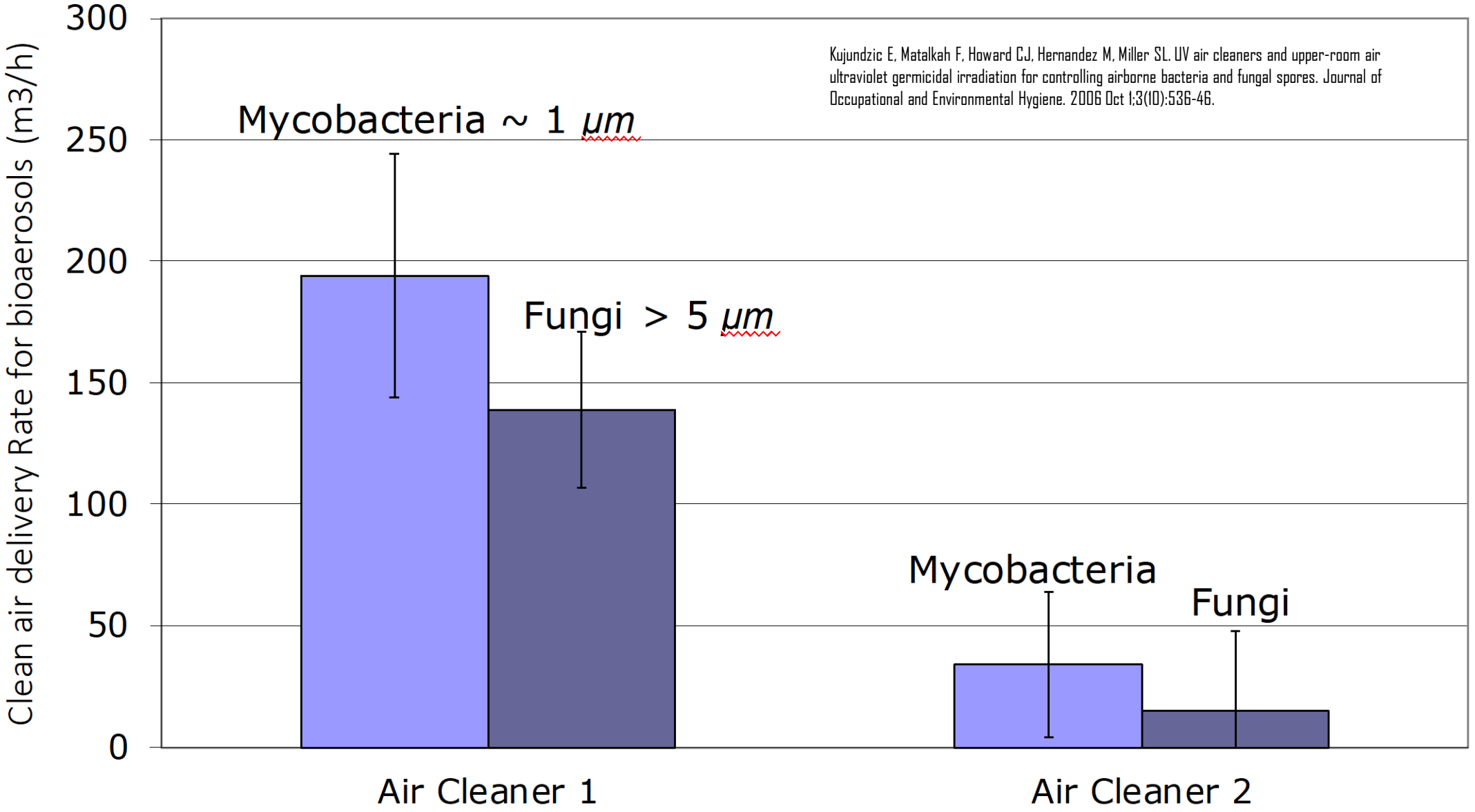
Kowalski, Wladyslaw & Bahnfleth, William. (2002). MERV Filter Models for Aerobiological Applications. Air Media.

College of Engine…
UNIVERSITY OF COLORADO BOULDER

Quantifying air cleaner performance

What is the airflow rate that represents the effective amount of particle-clean air produced by the device? This is the CLEAN AIR DELIVERY RATE - CADR

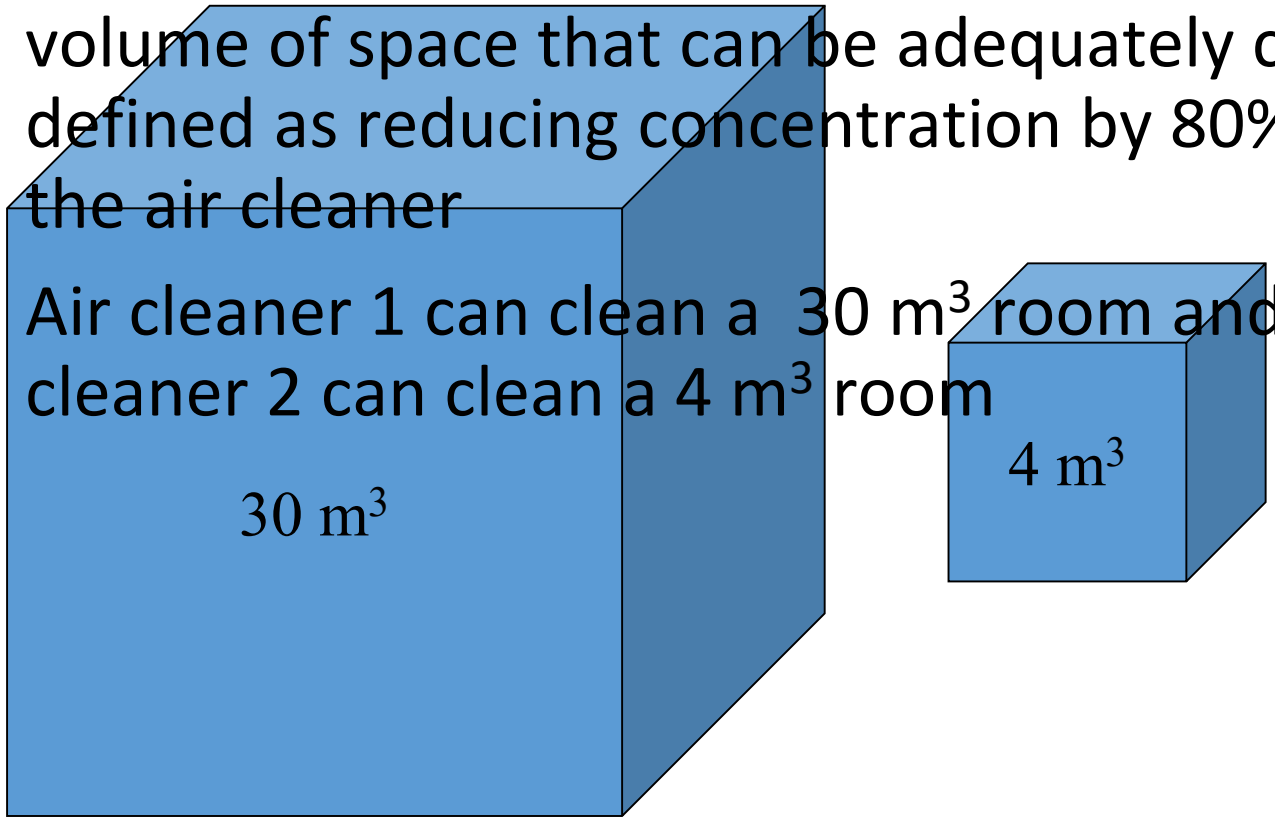




Kujundzic E, Matalkah F, Howard CJ, Hernandez M, Miller SL. UV air cleaners and upper-room air ultraviolet germicidal irradiation for controlling airborne bacteria and fungal spores. Journal of Occupational and Environmental Hygiene. 2006 Oct 1;3(10):536-46.

How big of a room can the air cleaners clean?

- Another way of looking at data is to predict volume of space that can be adequately cleaned -- defined as reducing concentration by 80% -- by the air cleaner
- Air cleaner 1 can clean a 30 m^3 room and air cleaner 2 can clean a 4 m^3 room

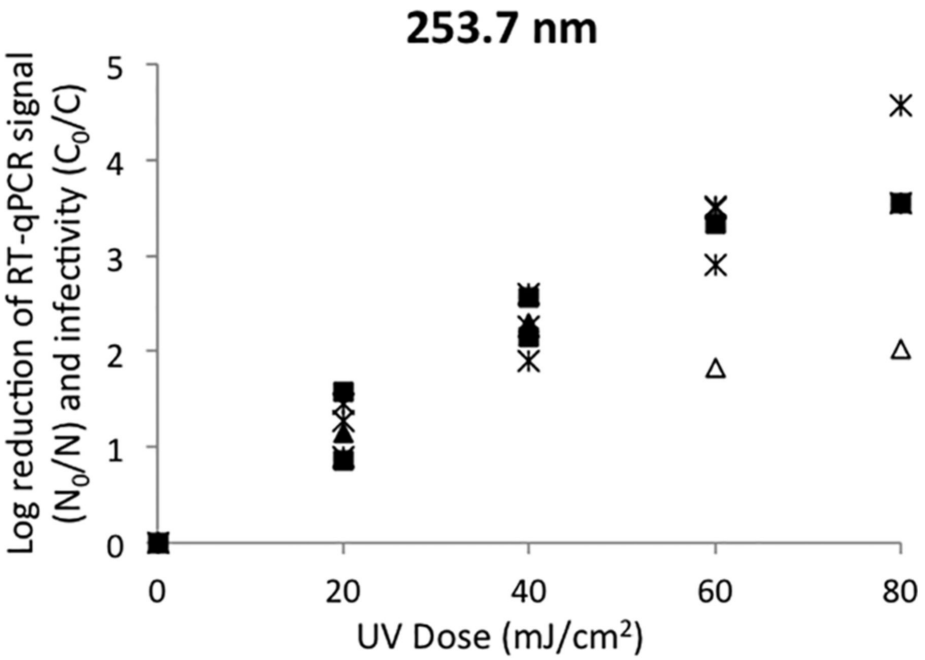


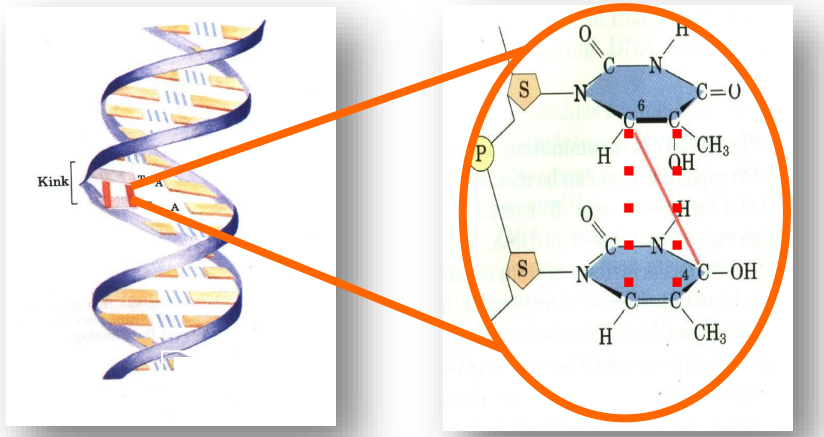
WHAT DO WE STILL NEED TO KNOW?

- Where is the best placement for air cleaners given typical air flow patterns?
- How best to upgrade filtration efficiency in HVAC systems with existing systems?

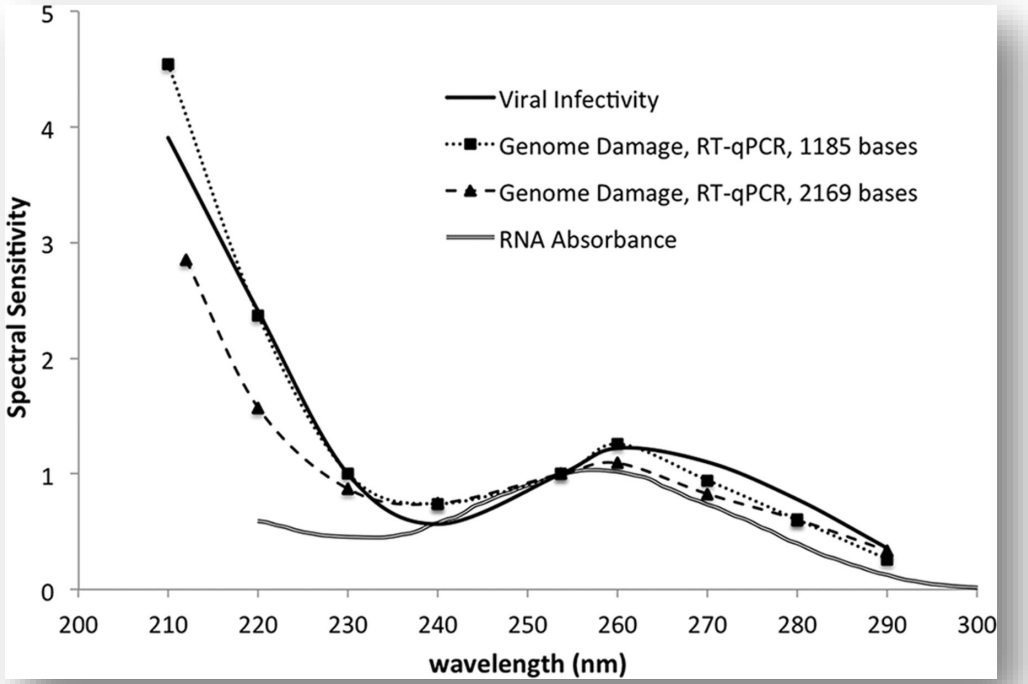
GERMICIDAL ULTRAVIOLET LIGHT

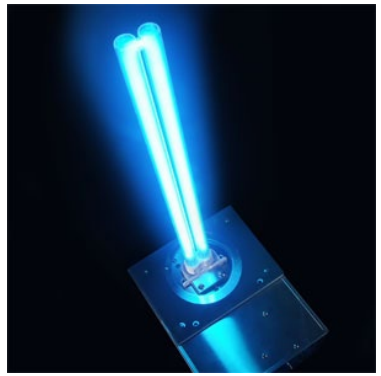
Germicidal UV damages DNA/RNA





dimers form between adjacent thymine nucleotides inactivates cells



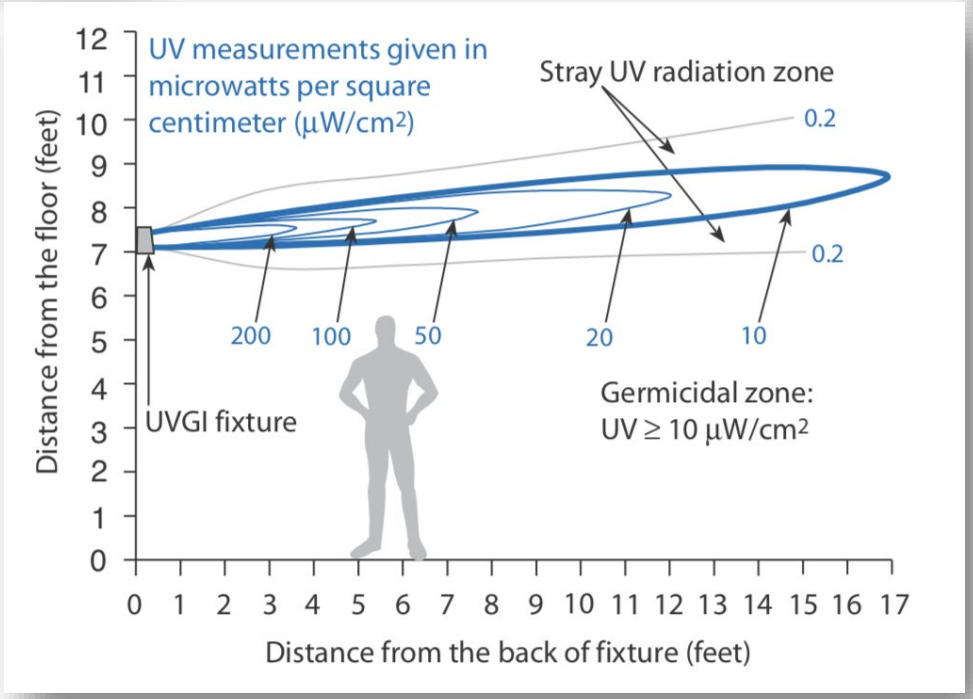


Beck et al. 2016

Rooms in which HVAC retrofits are difficult to do but additional air changes are needed to reduce risk of infections (e.g. hospital ERs, treatment and isolation rooms)

Rooms in which infectious aerosol may be generated (e.g. hospital treatment and isolation rooms) and additional control is needed

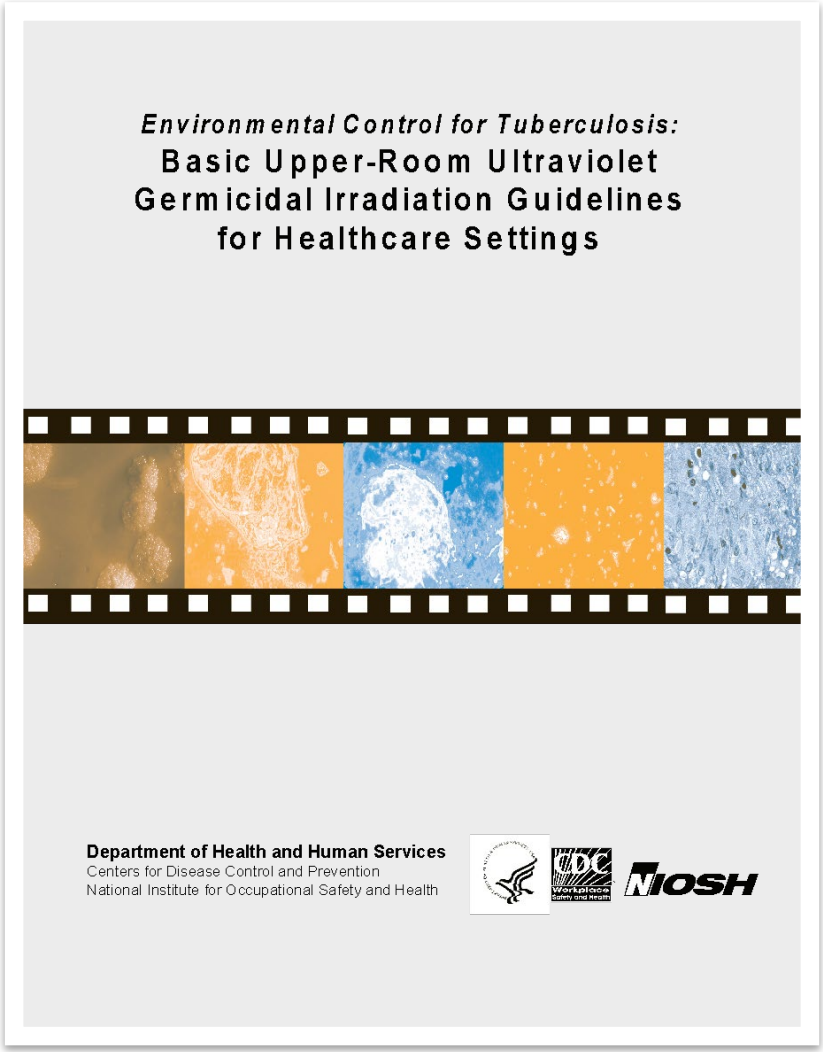
Upper-Room Air Disinfection



Lighting Research Center
Rensselaer Polytechnic Institute

Crowded environments where unsuspected infectious persons may be present (e.g. jails, homeless shelters, hospital waiting rooms)

CDC NIOSH Upper Room Air Studies



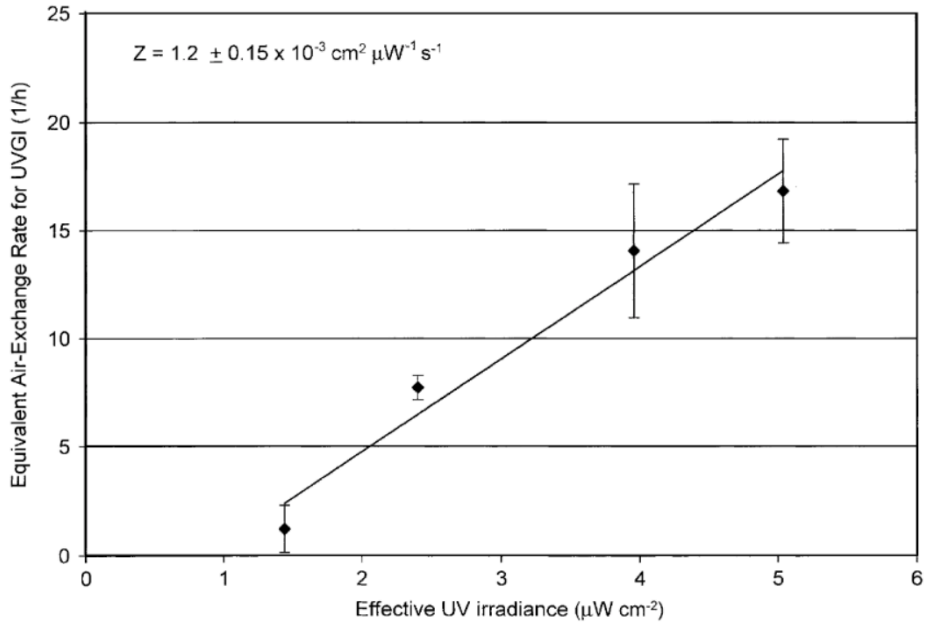
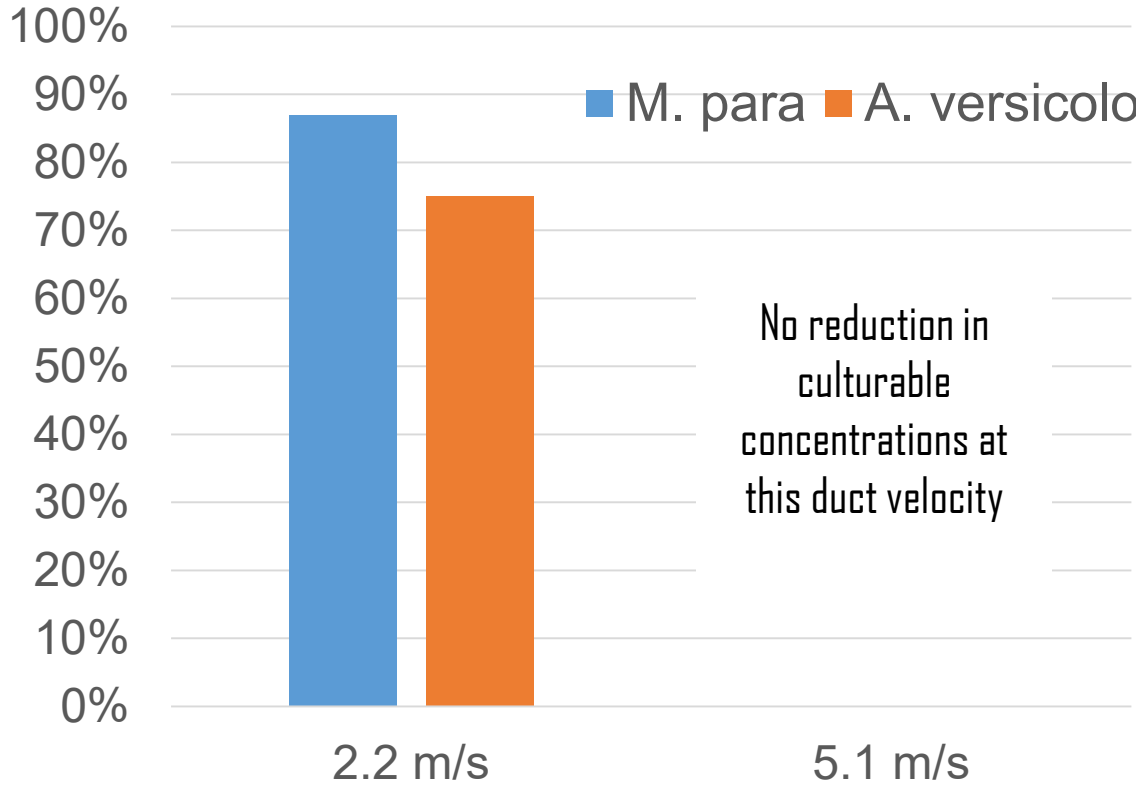


Fig. 7. UVGI inactivation rate as a function of effective UVGI spherical irradiance for *M. parafortuitum*. Effective UVGI spherical irradiance is the irradiance measured by actinometry in the upper-room zone only normalized to the fraction of room volume irradiated by UV (0.3/2.5 m).

We found that among different engineering control measures, UVGI singly is the optimal strategy combined with effective isolation and vaccination interventions for containing influenza, measles, and chickenpox. Liao et al. 2008

Xu, P. et al. 2003; Xu, P., et al. 2005

UV In-Duct Air Disinfection



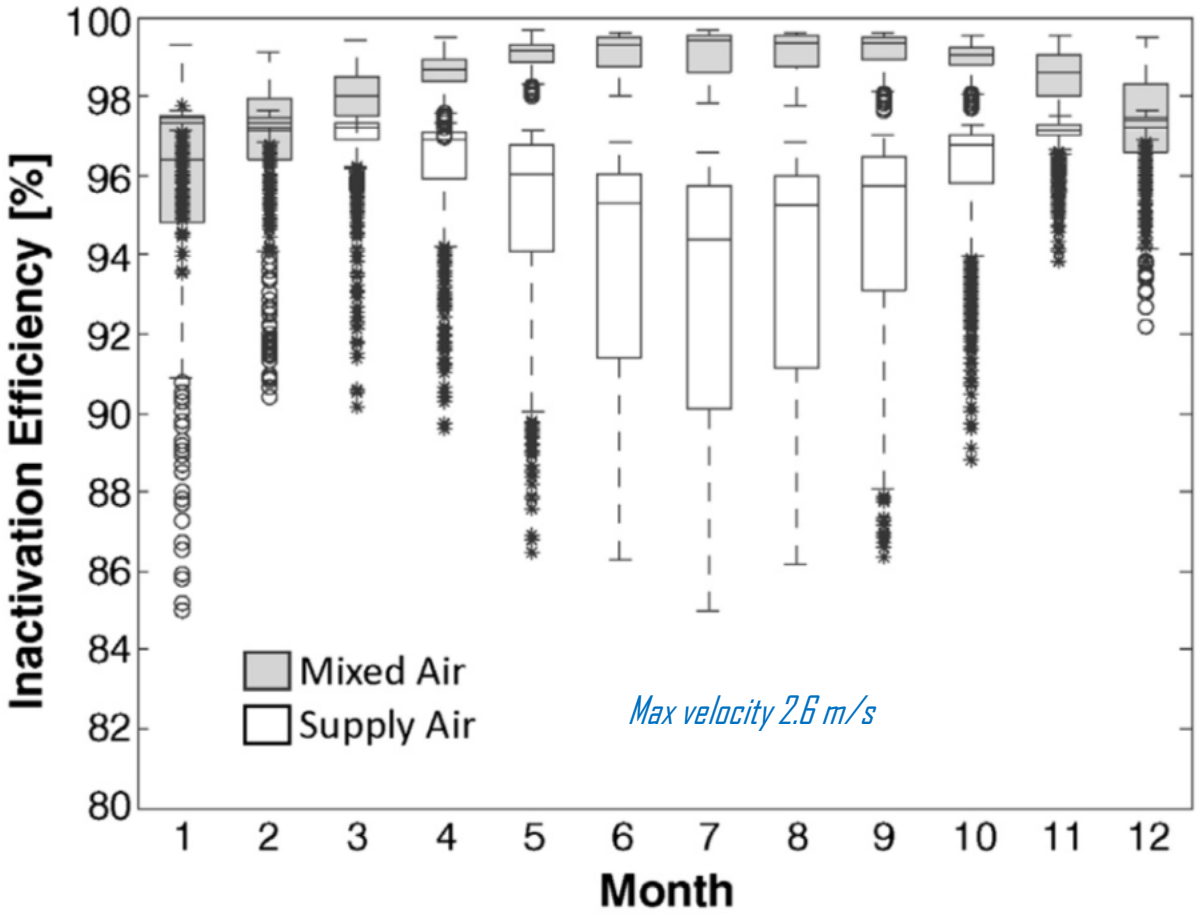


Fig. 9. Inactivation efficiency for devices installed at mixed and supply air locations in New York.

Lee and Bahnfleth 2013; Kujundzic et al. 2007

WHAT DO WE STILL NEED TO KNOW?

- What is the best gUV design for specific spaces?
- What is impact on CoV-2 transmission?
- What about other light wavelengths or LEDs?