The Miller View of the State of knowledge regarding building performance to reduce transmission of airborne pathogens

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Outline

Caveat – so much to say, so little time! I am highlighting a few of my favorite results that are important for indoor air quality management from an infection transmission perspective.

1. Is there Aerosol Transmission through Ventilation Ducts?
2. What Else Have We Learned Since 2020?
3. How Do We Best Mitigate Public Buildings to Reduce Transmission?

Is There Aerosol Transmission Through Ventilation Ducts?

Multiple COVID-19 outbreaks reported along vertical lines in apartment buildings that use natural ventilation ducts to vent bathrooms

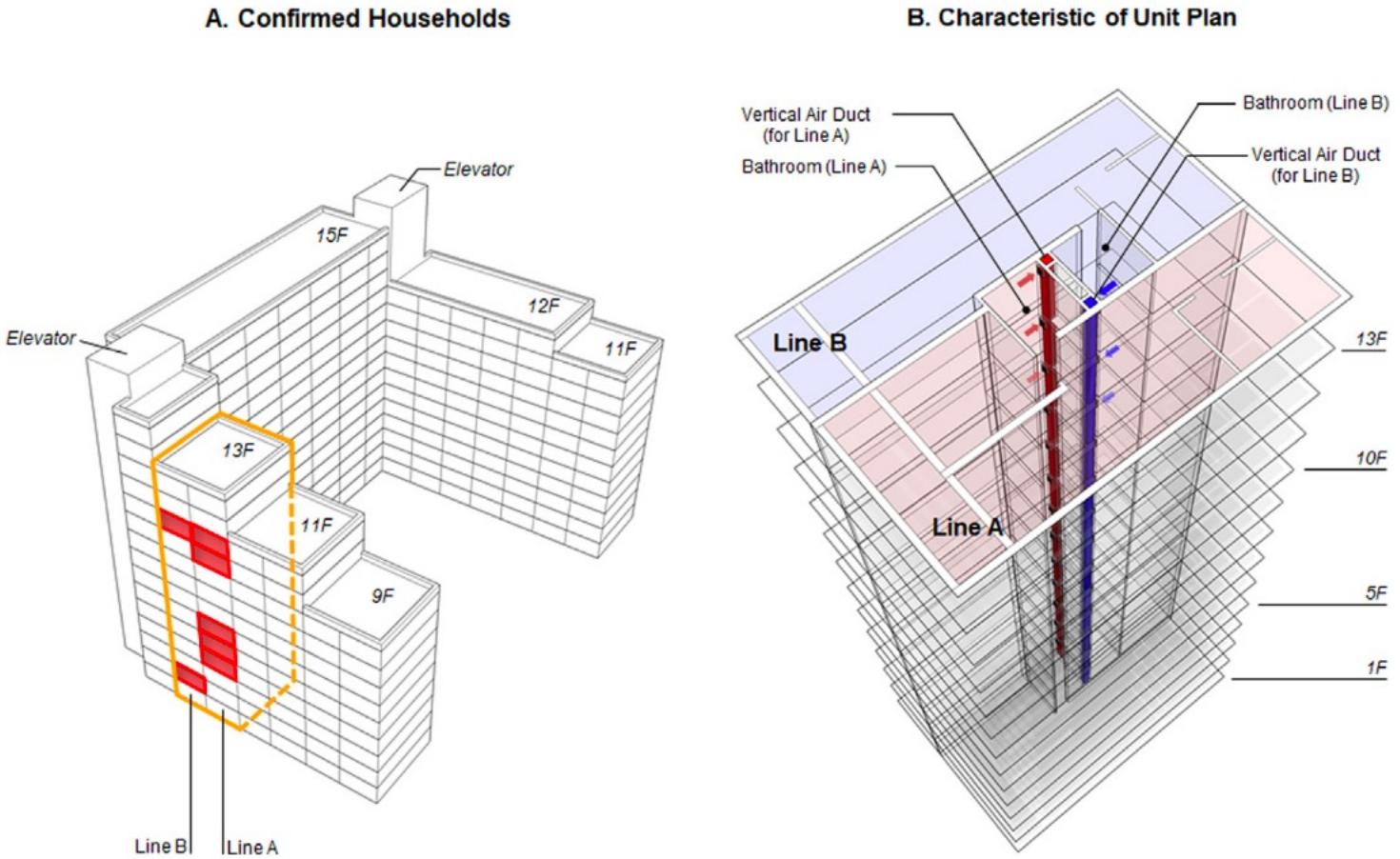
Vertical transmission in Apartment Building

10 cases of COVID-19 in same 2 vertical lines in apartment building in Seoul South Korea

a natural ventilation shaft is located along each vertical line from the bottom to the rooftop.

Each shaft is connected to the units within the same vertical line through the blowhole at the bathroom. (No exhaust fans w/back draft damper).

Drain traps were functioning.

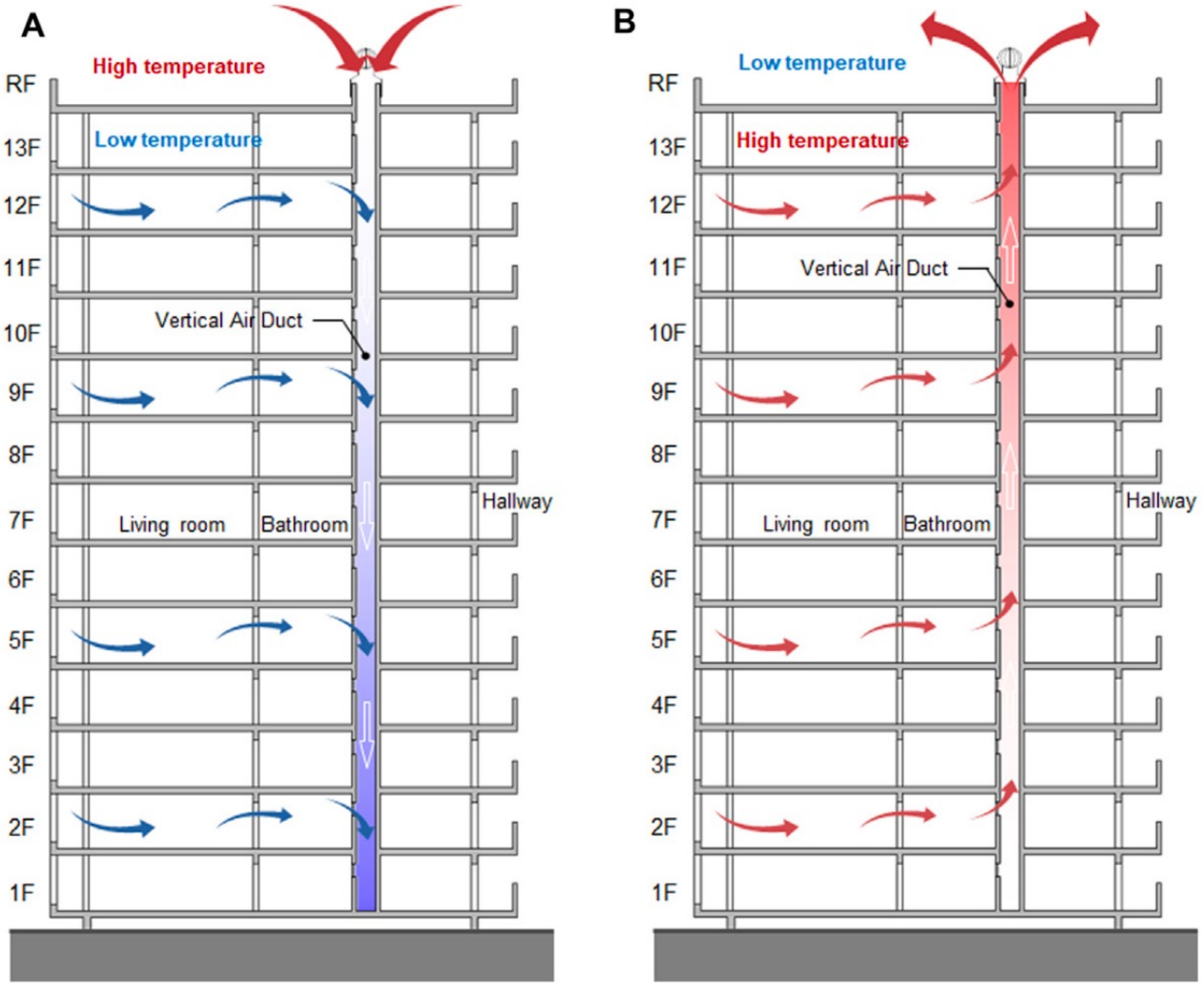


Hwang SE, Chang JH, Oh B, Heo J. Possible aerosol transmission of COVID-1 associated with an outbreak in an apartment in Seoul, South Korea, 2020. International Journal of Infectious Diseases. 2021 Mar 1;104:73-6.

Vertical transmission in Apartment Building

Reverse stack effect when hot outside, cooler inside

stack effect when cold outside and warmer inside



Hwang SE et al. 2021 Mar 1;104:73

Since 2020 …

What else have we learned?

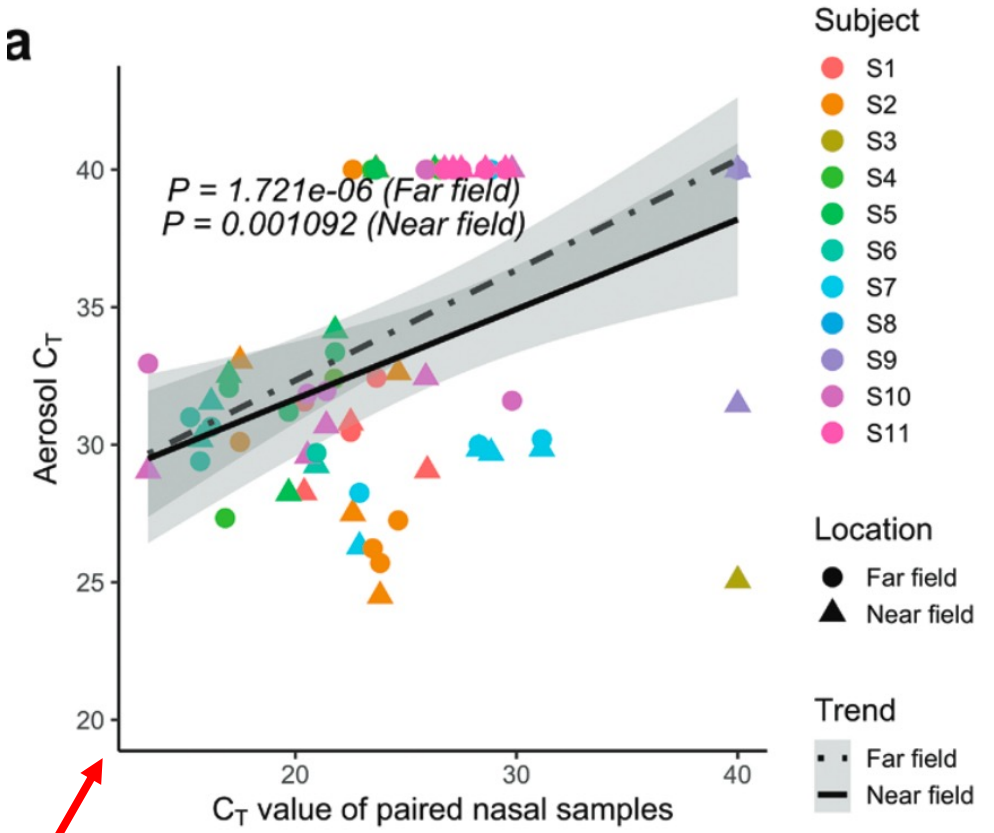
Ventilation and filtration reduce environmental aerosol SARS-CoV-2 viral load

11 COVID-19 diagnosed participants in a chamber

- conducting activities over 3 days
- collected aerosol samples in near and far field, and nasal swabs
- Varied ventilation and filtration (in-room HEPA air cleaners)

High expiratory trials

Regular trials

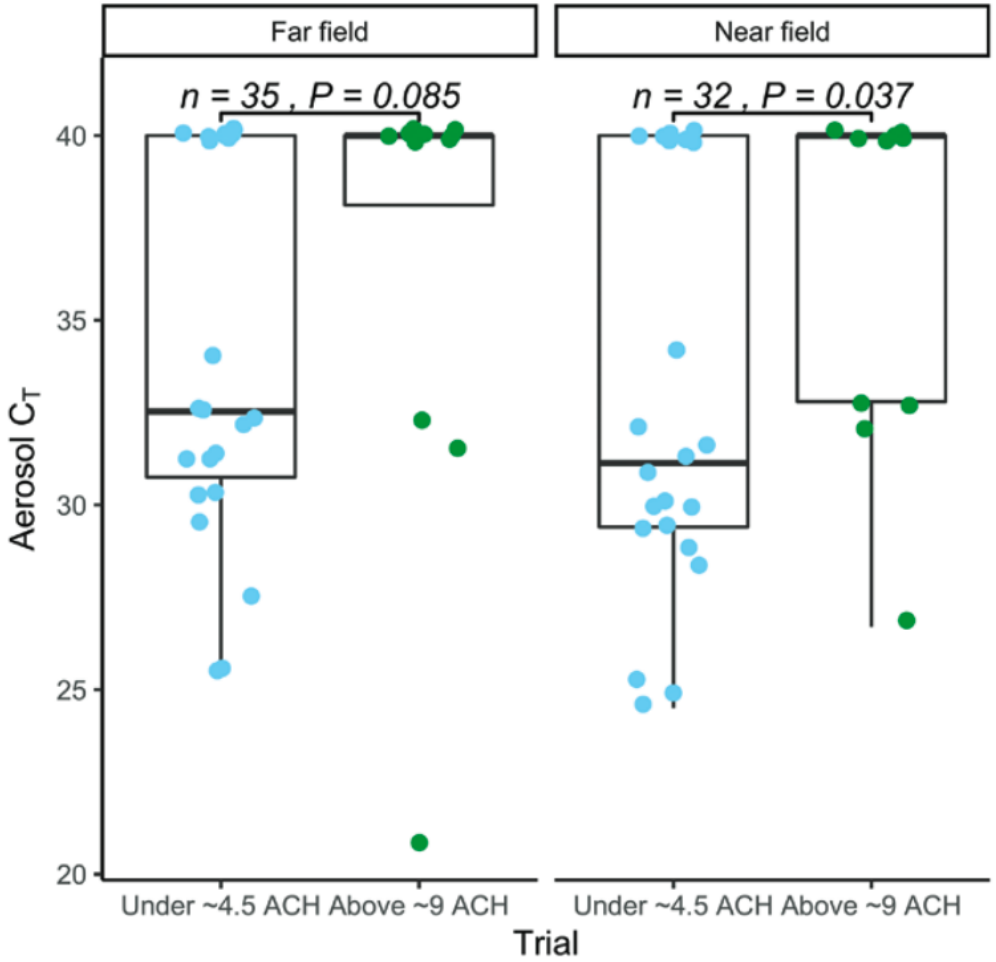


increase in viral load in human nasal samples is associated with increased near and far field viral aerosol loads. Also, far field loads were lower than near field.

Parhizkar H, Dietz L, Olsen-Martinez A, Horve PF, Barnatan L, Northcutt D, Van Den Wymelenberg KG. Quantifying Environmental Mitigation of Aerosol Viral Load in a Controlled Chamber With Participants Diagnosed With Coronavirus Disease 2019. Clinical Infectious Diseases. 2022 Jan 6.

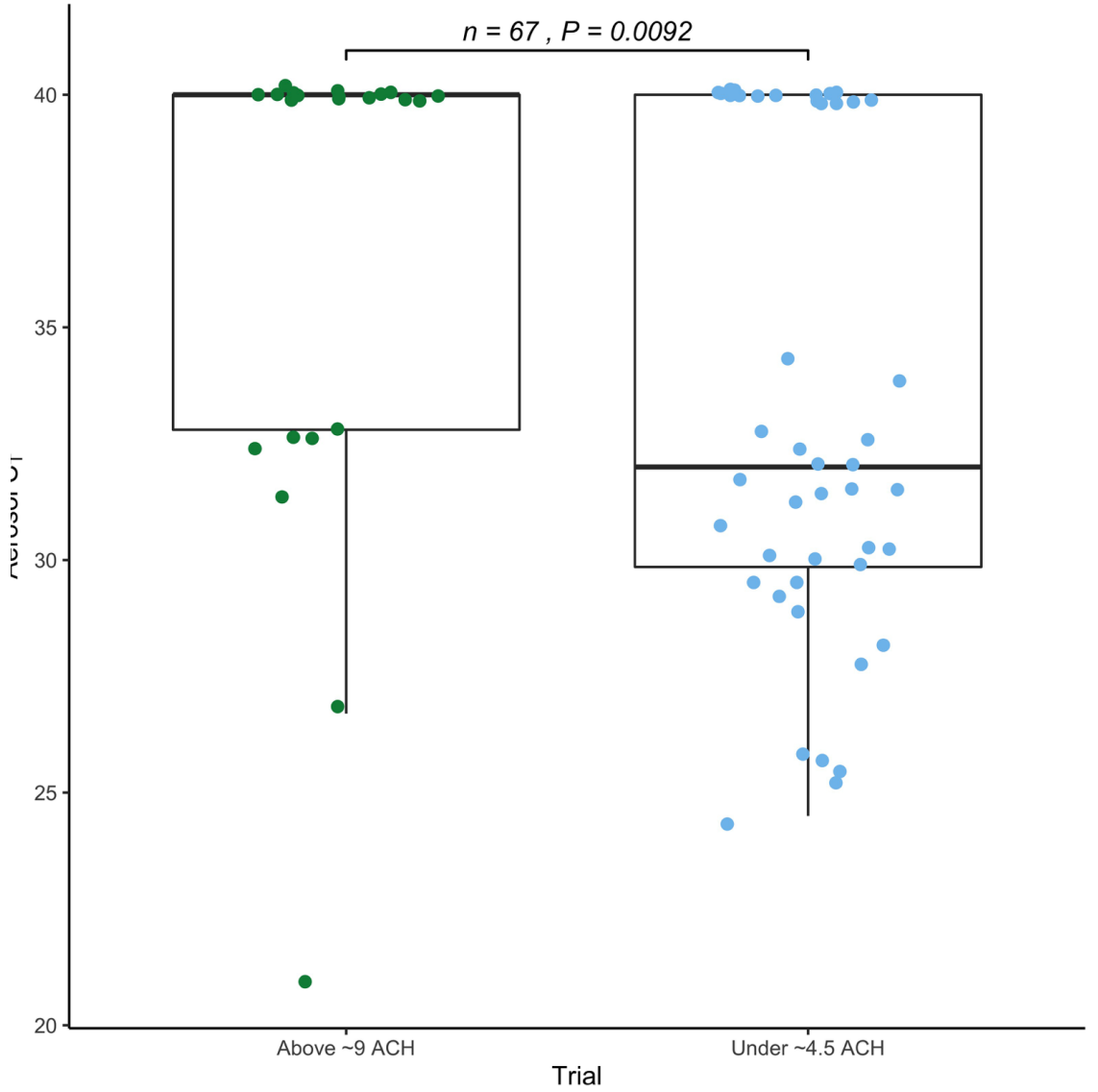
Ventilation and filtration reduce environmental aerosol SARS-CoV-2 viral load

Trials with <4.5 ACH (including 0 ACH) were associated with significantly higher aerosol viral loads in the near field when compared with trials >9 ACH



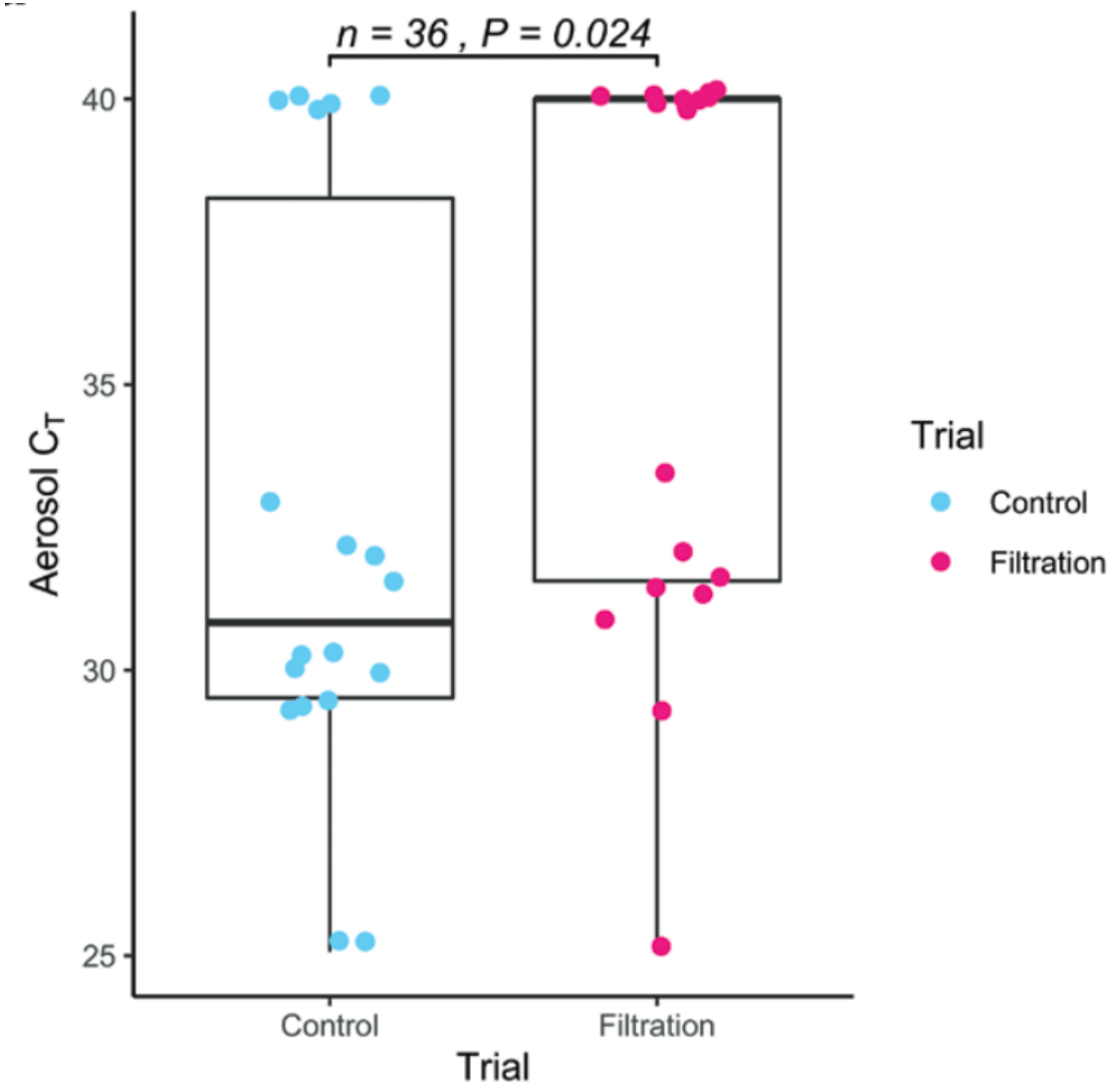
decreased viral load is measured by higher RNA cycle threshold (CT) values

Total room aerosol viral load (near field + far field), higher with <4.5 ACH trials than > 9 ACH ventilation



Parhizkar H, et al. 2022 Jan 6.

Ventilation and filtration reduce environmental aerosol SARS-CoV-2 viral load



HEPA in-room air cleaner trials have lower viral aerosol load compared to no ventilation

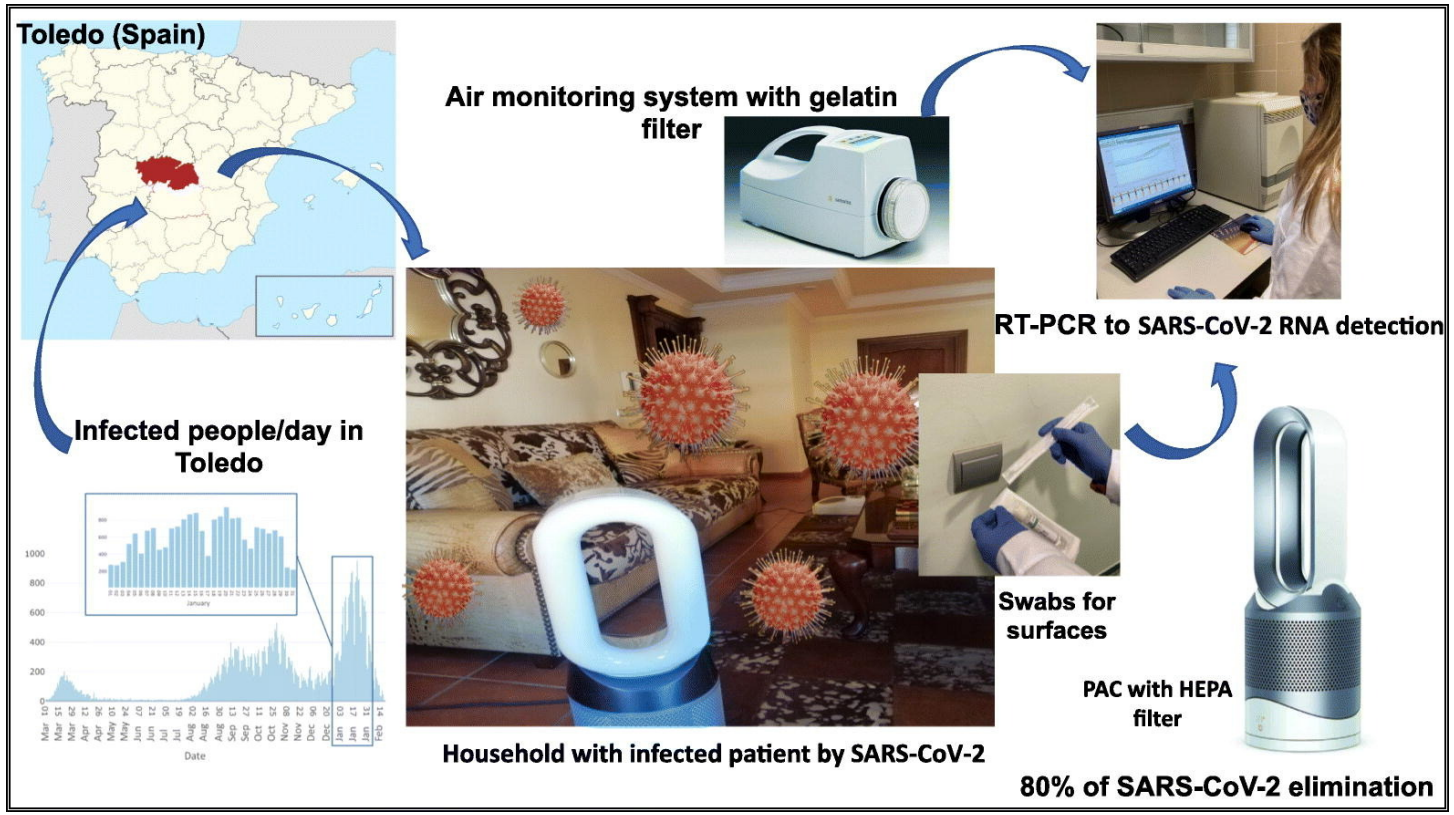
decreased viral load is measured by higher RNA cycle threshold (CT) values

Parhizkar H, et al. 2022 Jan 6.

Portable air cleaners reduce airborne SARS-CoV-2 virus

Homes naturally ventilated, windows and doors closed and home heated (Jan 2021 during 3rd COVID wave in Spain)

- 9 households
- 7 COVID-19 +
- 2 controls
- 13 surface swabs
- 16 air samples

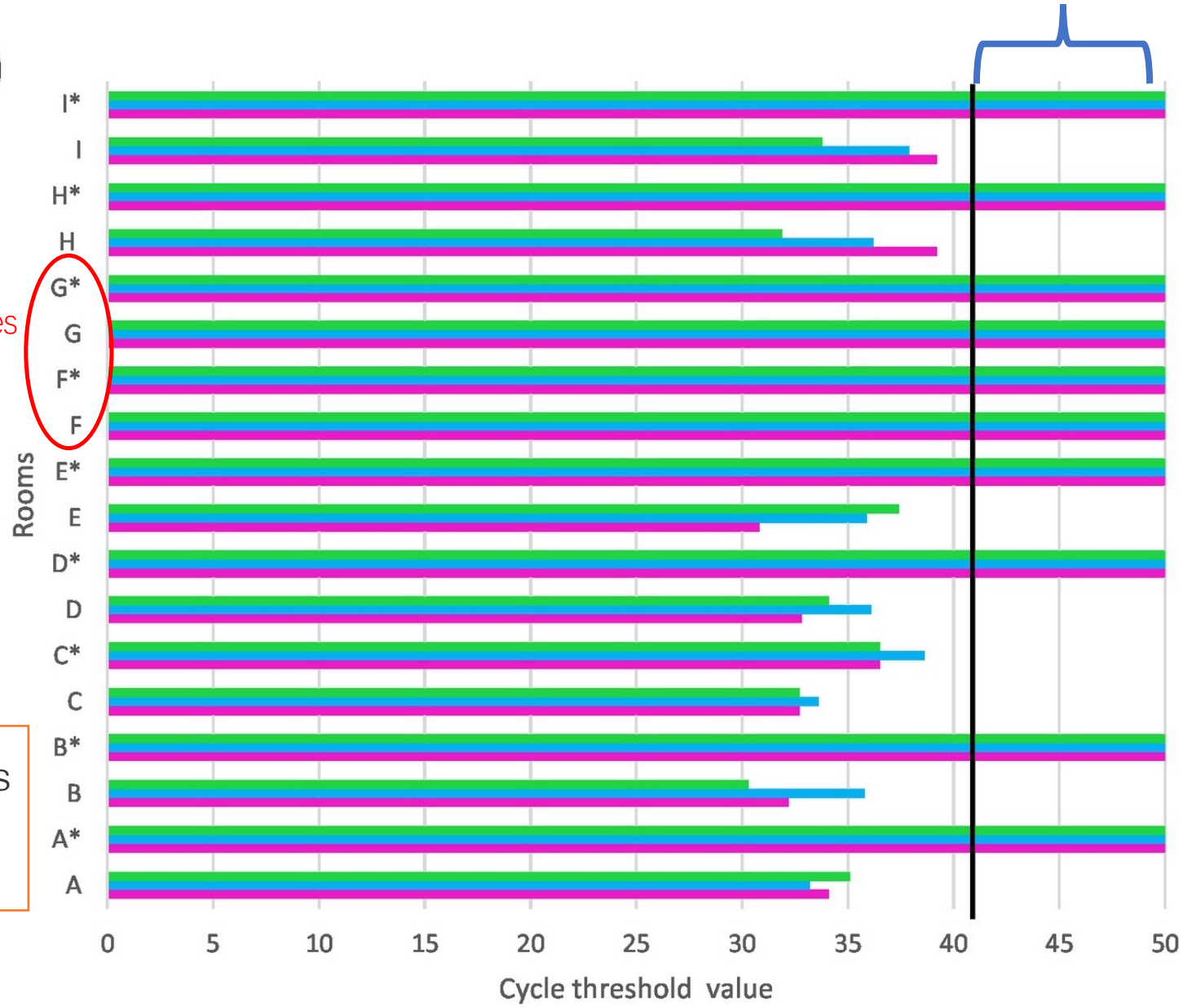


Rodríguez, María, et al. "Are the Portable Air Cleaners (PAC) really effective to terminate airborne SARS-CoV-2?." Science of The Total Environment 785 (2021): 147300.

Real-time PCR results for the air samples

- Air samples **positive** for virus in homes occupied by COVID-19 patients, **Negative** in control homes

- Air samples **negative** for virus (in all but 1) after use of PAC, Virus detected in home where PAC was too small for room size



Black line indicates values of Ct ≤ 41, which means positive real-time RT-PCR

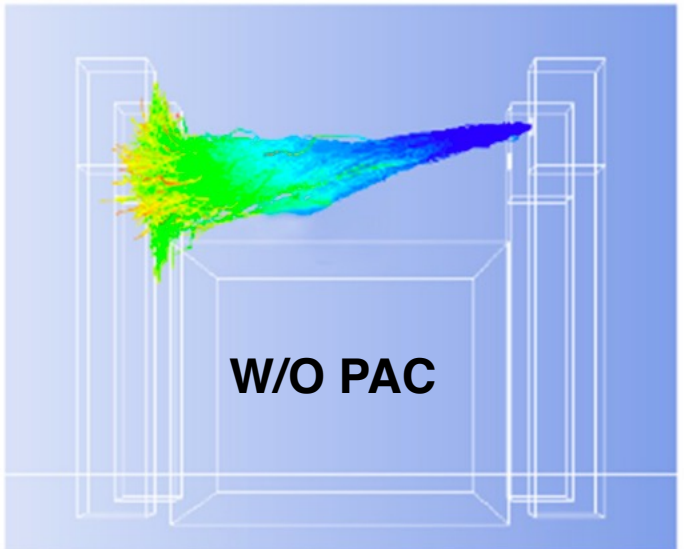
*values from samples taken after using the portable air cleaner

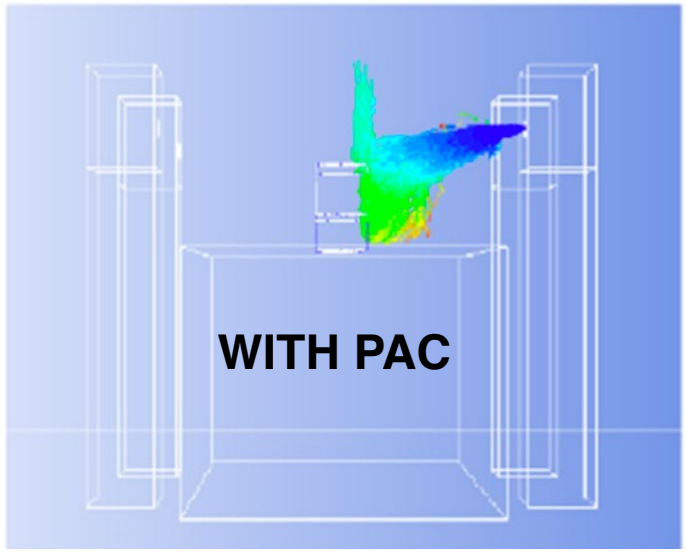
Rodríguez, María, et al. (2021)

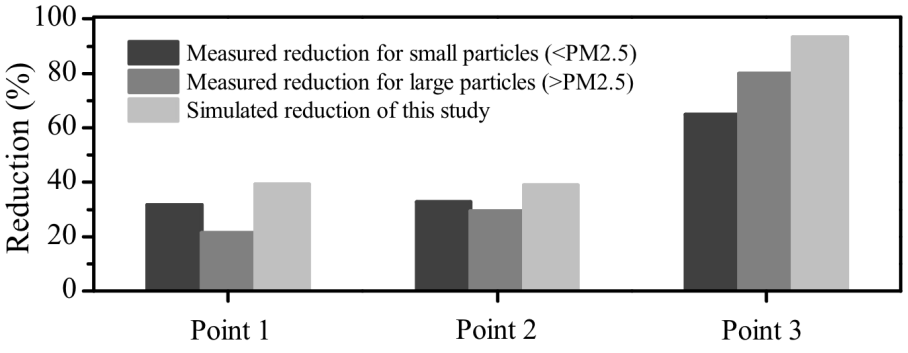
Portable air cleaners provide localized cleaning

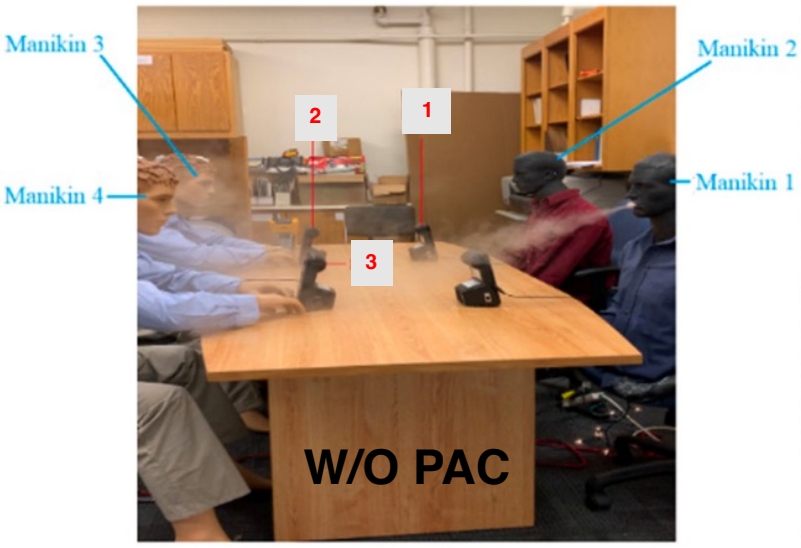
PACs commonly used to clean an entire space and are sized accordingly.

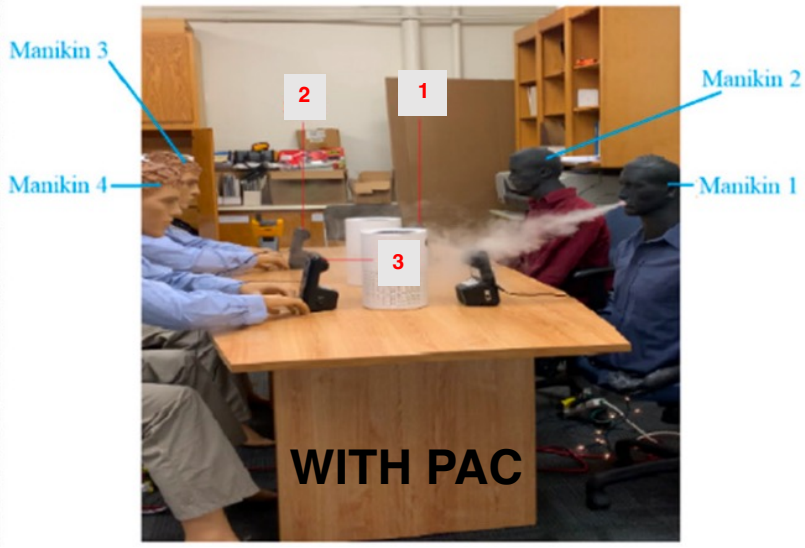
Recent study shows PACS 40-90% effective at cleaning localized spaces such as between people seated at a table











Zhai, Z. (John), Li, H., Bahl, R., & Trace, K. (2021). Application of Portable Air Purifiers for Mitigating COVID-19 in Large Public Spaces. *Buildings*, *11*(8), 329.

Putting it all together…

Building and Environment 219 (2022) 109184

Contents lists available at ScienceDirect

Building and Environment

journal homepage: www.elsevier.com/locate/buildenv

Evaluating SARS-CoV-2 airborne quanta transmission and exposure risk in a mechanically ventilated multizone office building

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Mitigation Strategies in Public Buildings?

What is the best way to reduce risk of infection using ventilation/filtration/UV/masking?

Our approach

Education

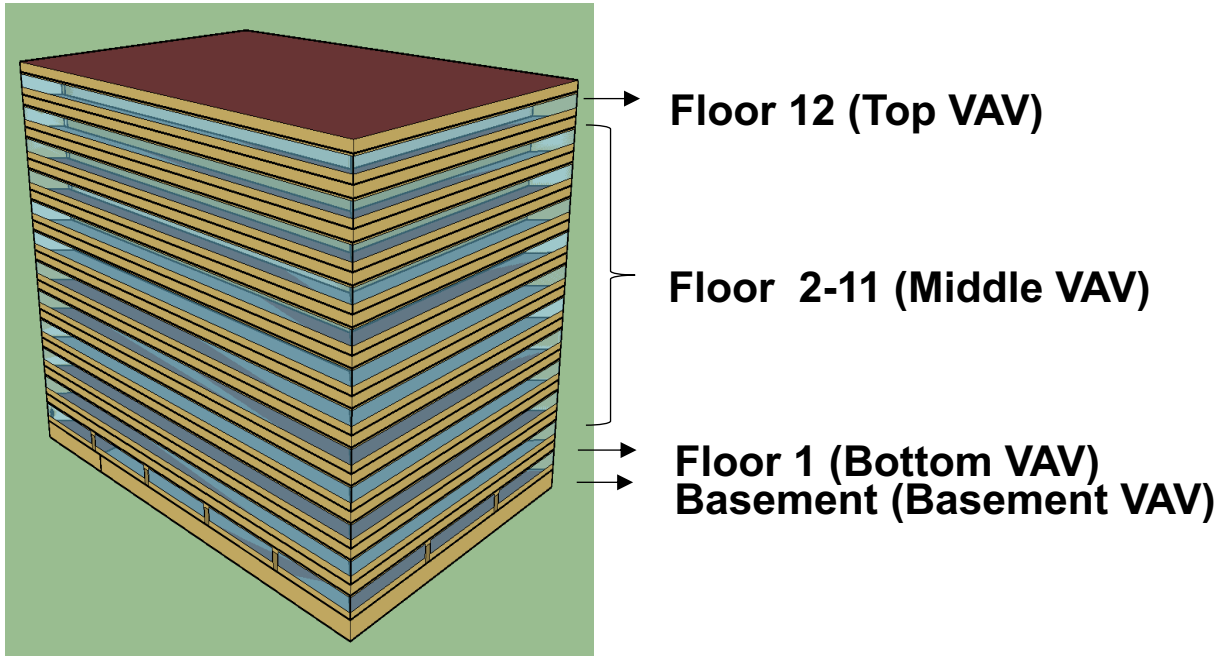
Retail

Hotel

Commercial Office

- Model multi-zone public buildings using a NIST tool CONTAM
- Air is mixed only within each zone
- Location/season: Chicago in winter
- Estimate how infection risk is reduced when using
  - Ventilation, MERV filters in ducts
  - HEPA air cleaners
  - UV upper-room and in-duct
  - Masks

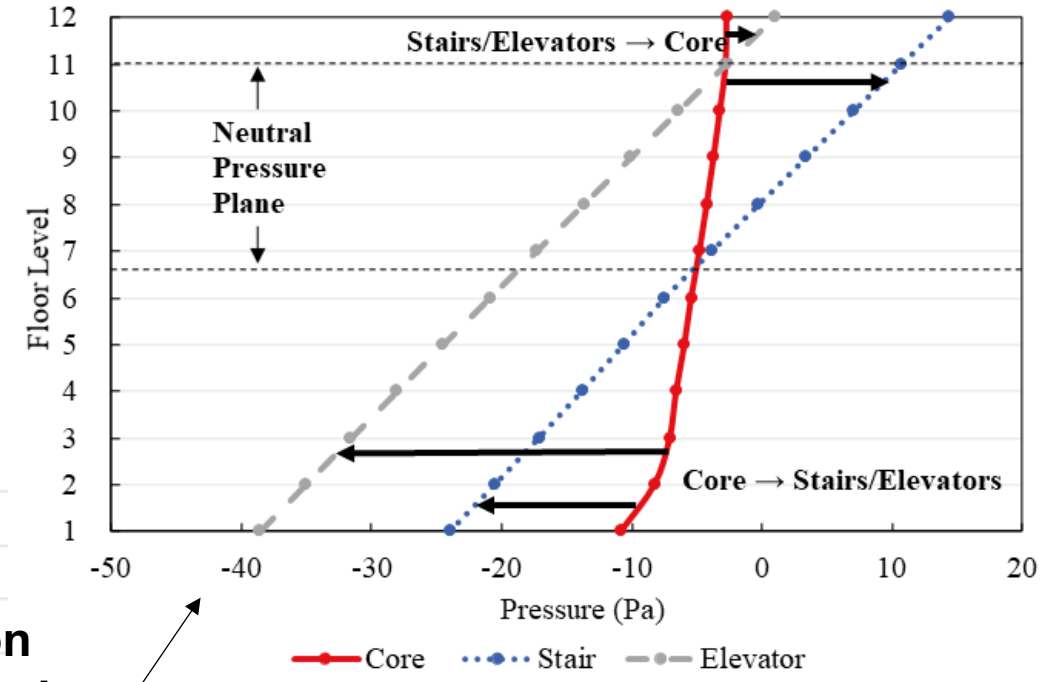
Results: Large Commercial Office Building



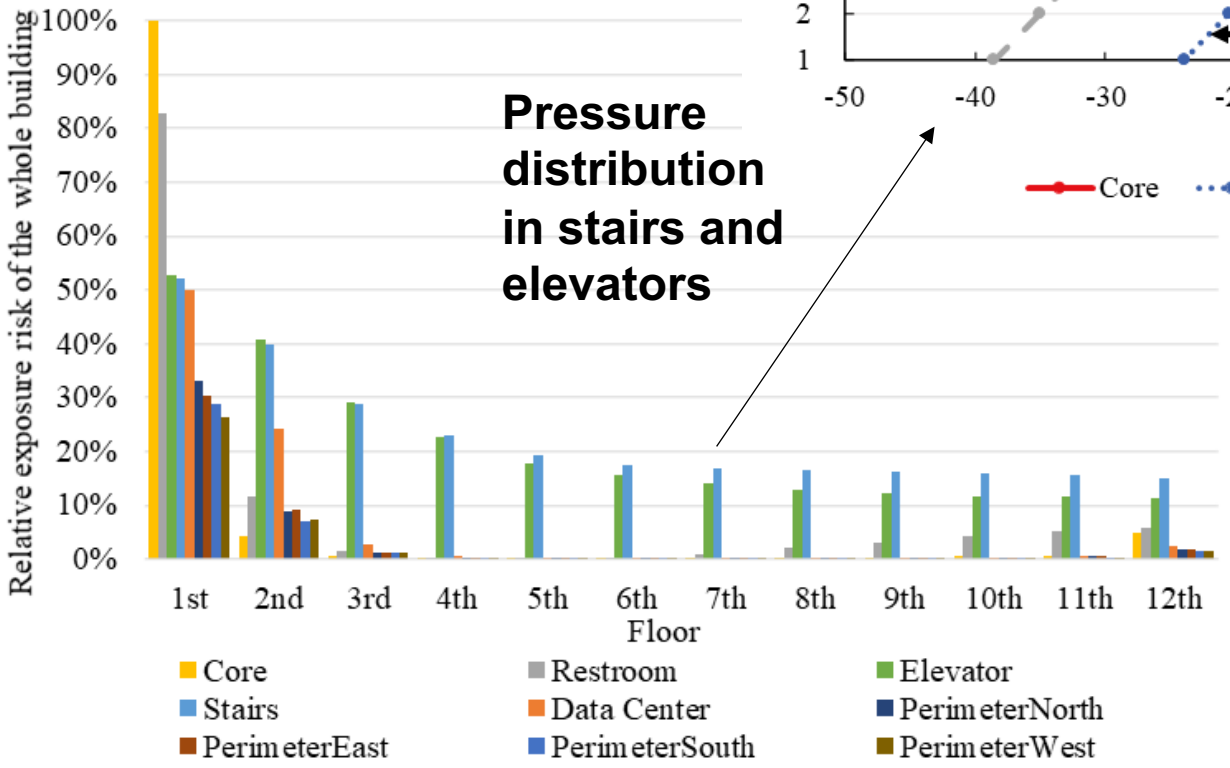
VAV System	Basement	Floor 1	Floor 2-11	Floor 12
Supply/Return (m^3/s)	4.63/4.17	11.65/10.49	9.44/8.49	10.33/9.30
Baseline OA (%)	26	14	17	16

- Model average probability of infection by long-range aerosol transmission
- One infected person resting or standing, speaking loudly all day on floor 1
- susceptible occupants 9 h in the building (9:00 – 17:00)
- 134 occupants per floor core zone
- mask exhalation is 50% efficiency and inhalation is 30% efficiency
- HEPA air cleaners or UV-in-room 4 ACH deployed in source zone
- UV-duct 87% single pass efficiency

Floor-to-floor quanta transmission and exposure risk

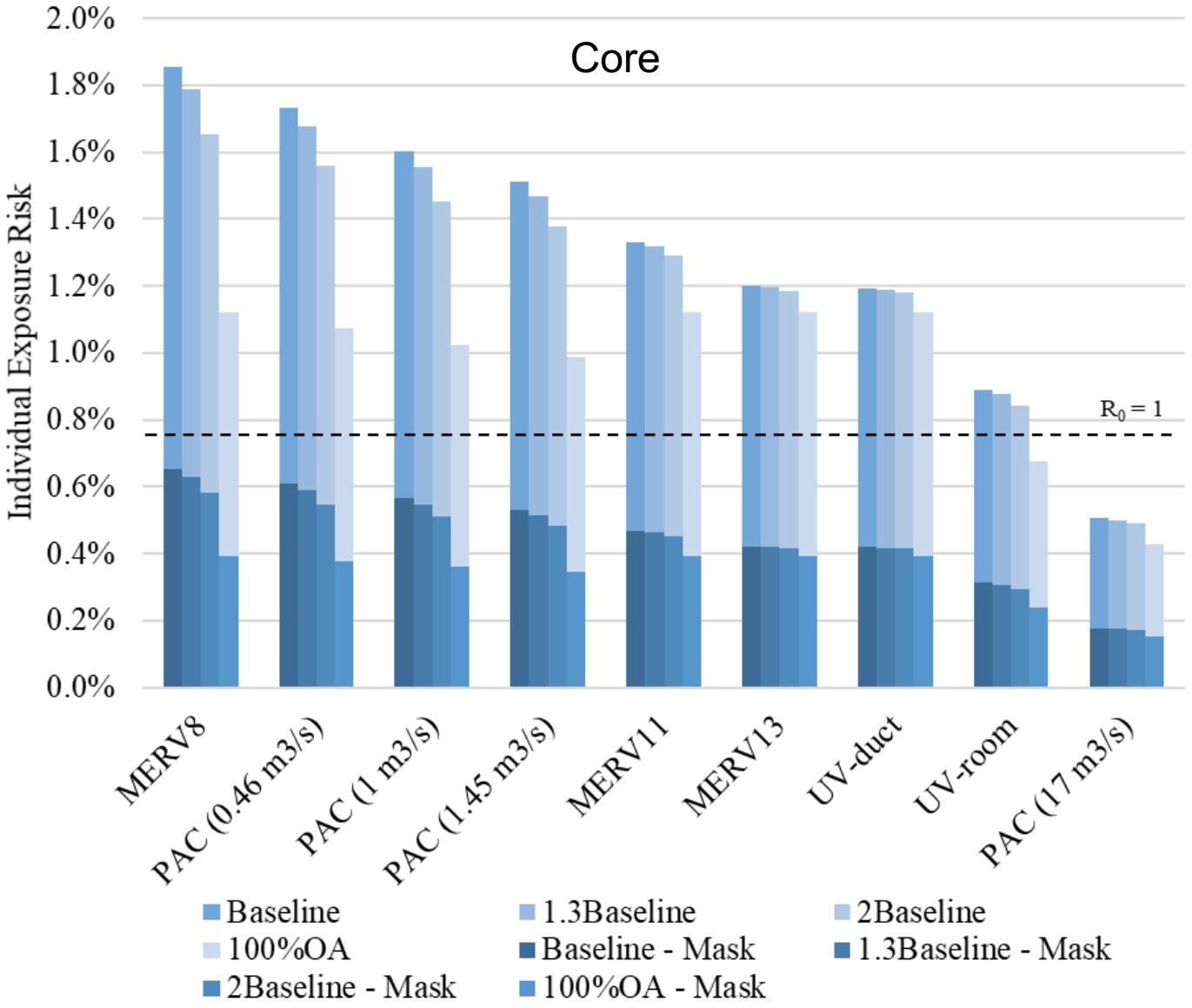


Pressure distribution in stairs and elevators



- 1st-floor Core Zone has highest exposure risk, followed by Restroom, Elevator Shaft, Stair.
- On higher floors, elevator shaft and stair are the most infective zones.
- Floor-floor transmission is possible because of dynamics of pressure distributions in a whole building.
- Higher floors could become vulnerable due to the combined impacts of the stack effects and pressurization of the HVAC systems.

Mitigation of exposure risk in the infectious zone



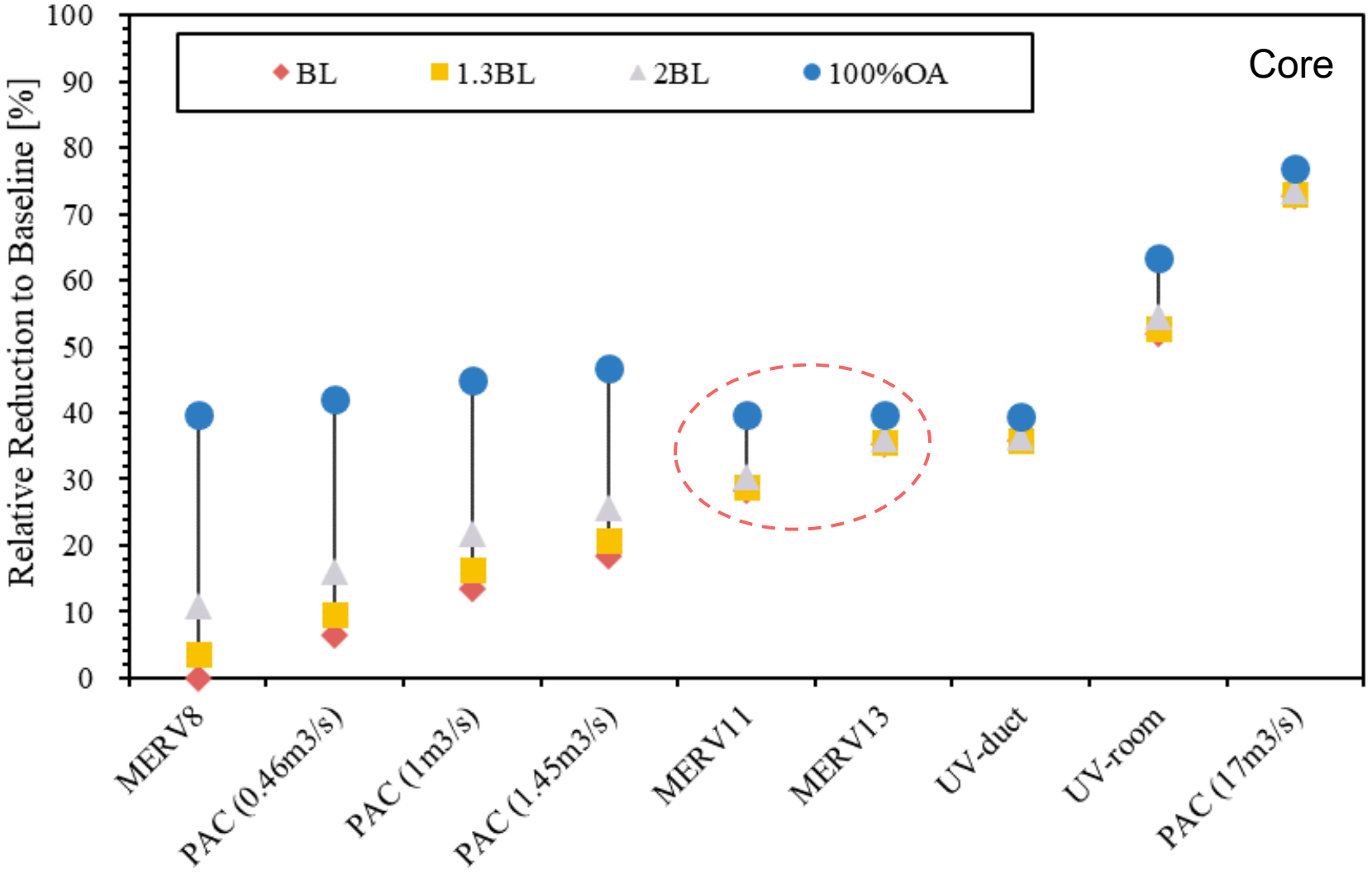
Risk level set at $R_0 = 1$, so for the core zone with 134 occupants it is 0.75%

Exposure risk without masks in light blue, and with masks in dark blue

Every strategy works with universal masking

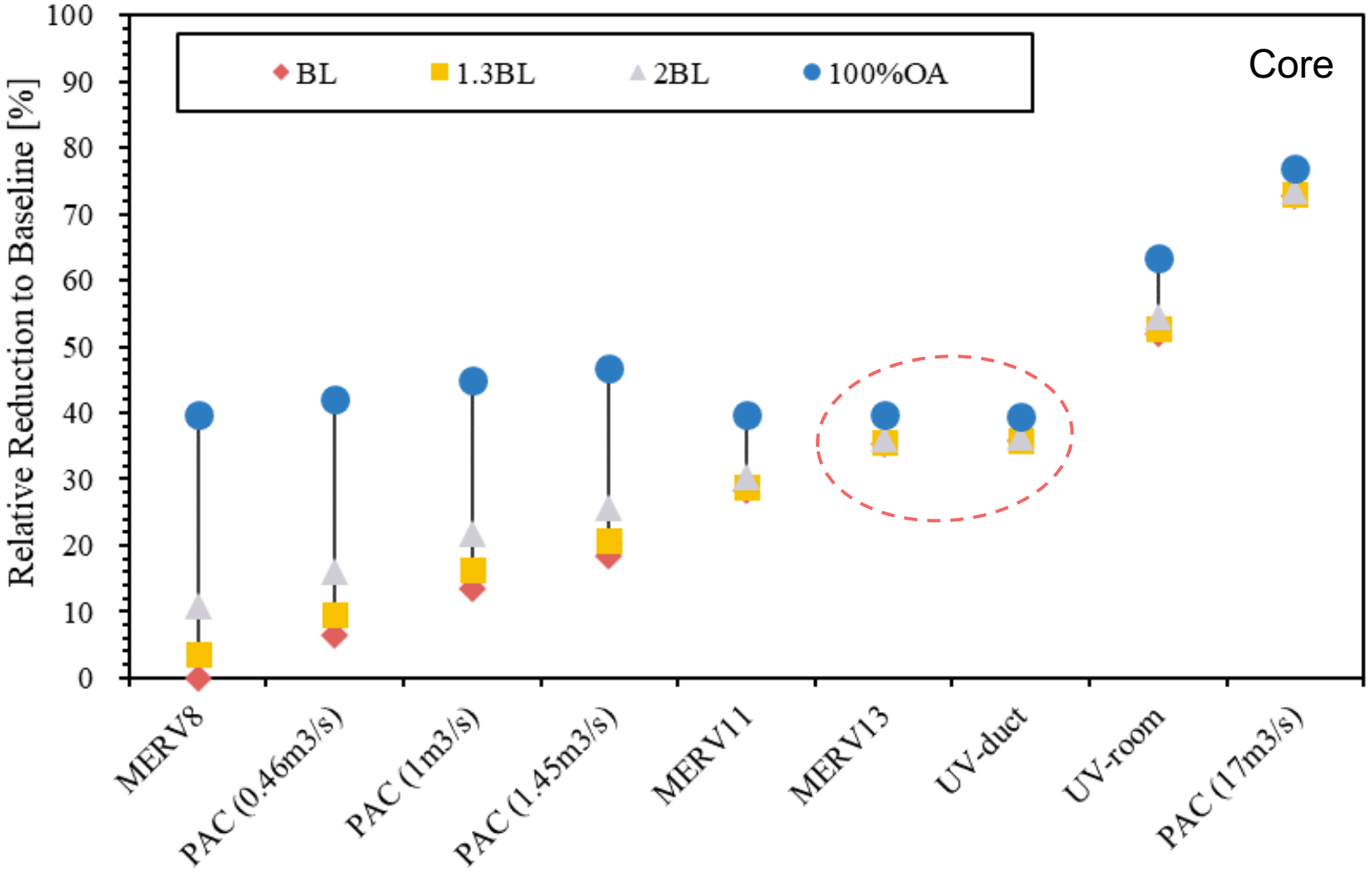
UV in-room plus 100% OA or large industrial air cleaner only work when no masks are used

Relative risk reduction compared to baseline ventilation in the infectious zone



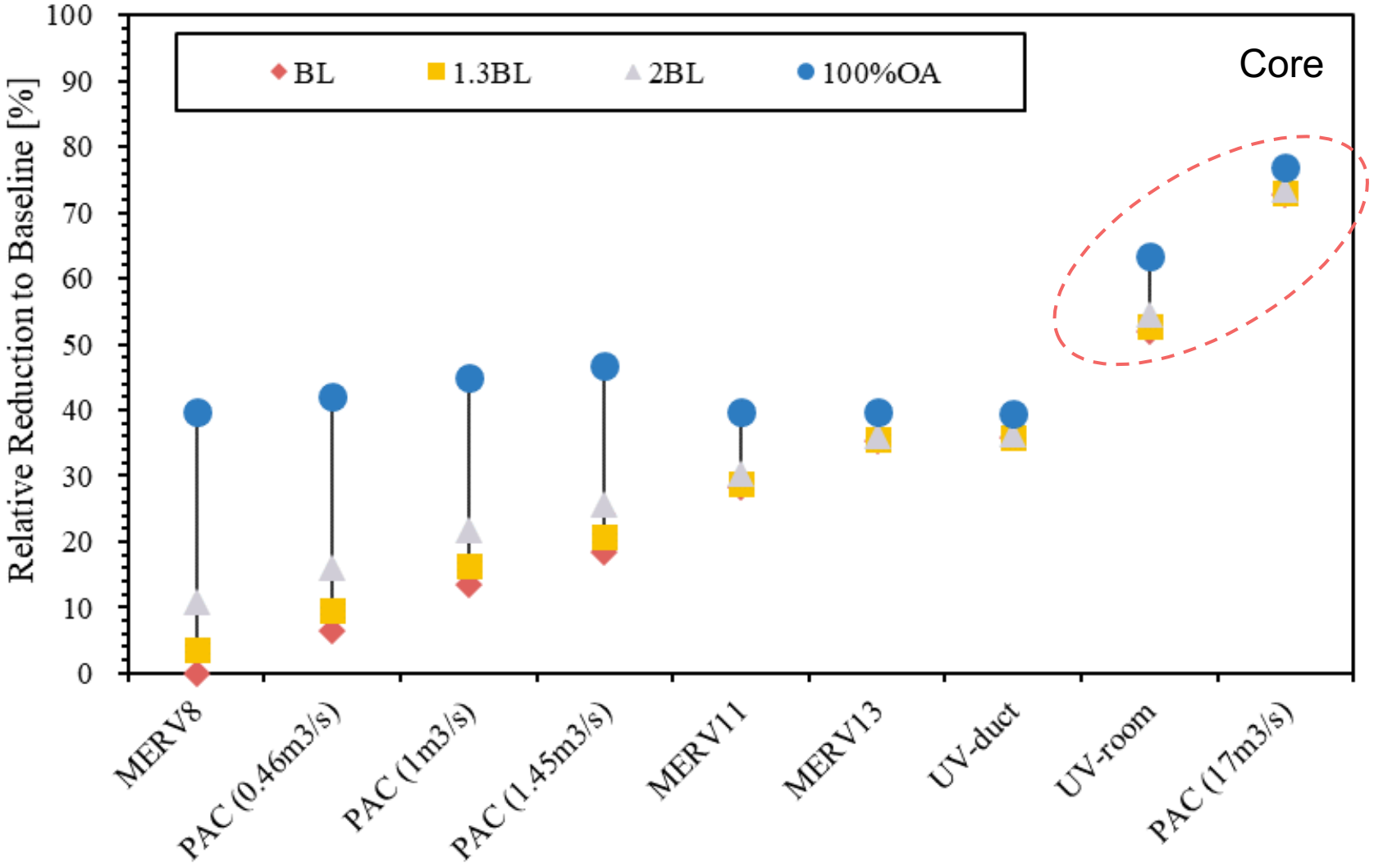
Upgrading the MERV filters from 8 to 11 and MERV13 are more effective than adding small PACs to the core zone at baseline ventilation

Relative risk reduction compared to baseline ventilation in the infectious zone



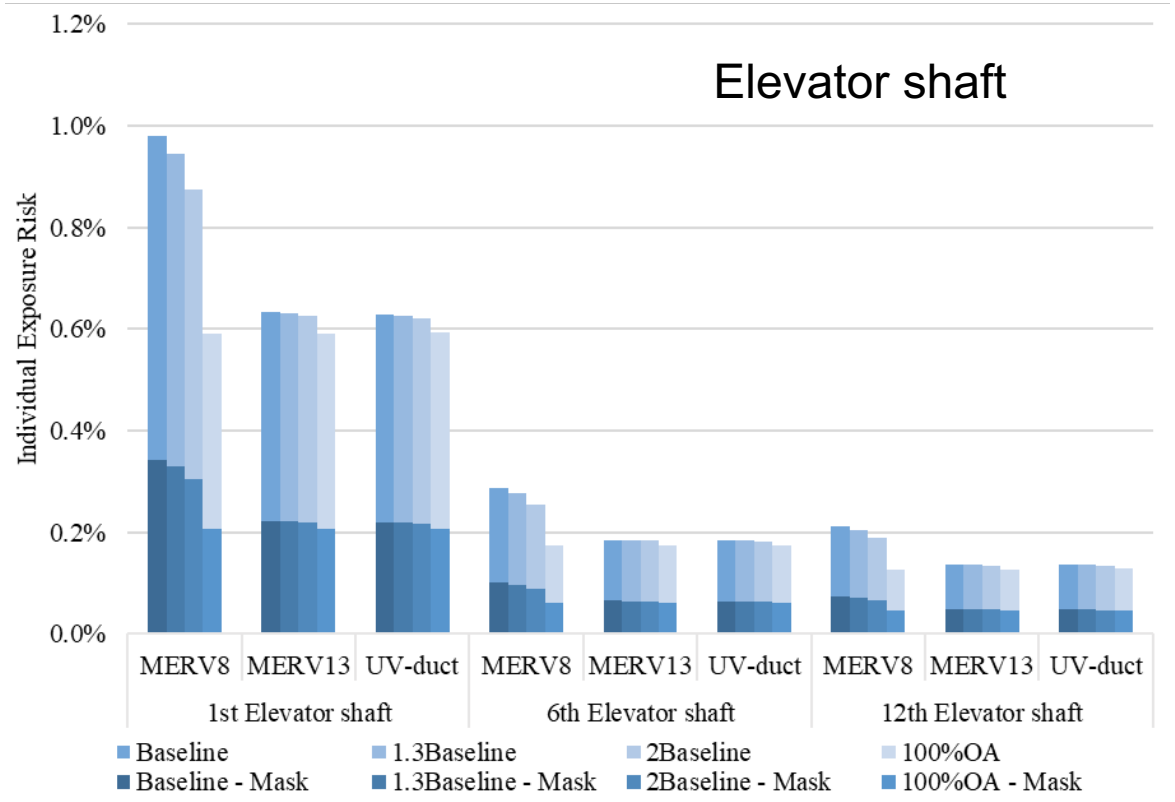
The use of MERV13 and in-duct germicidal UV with the Baseline OA provides similar performance to that of 100% OA

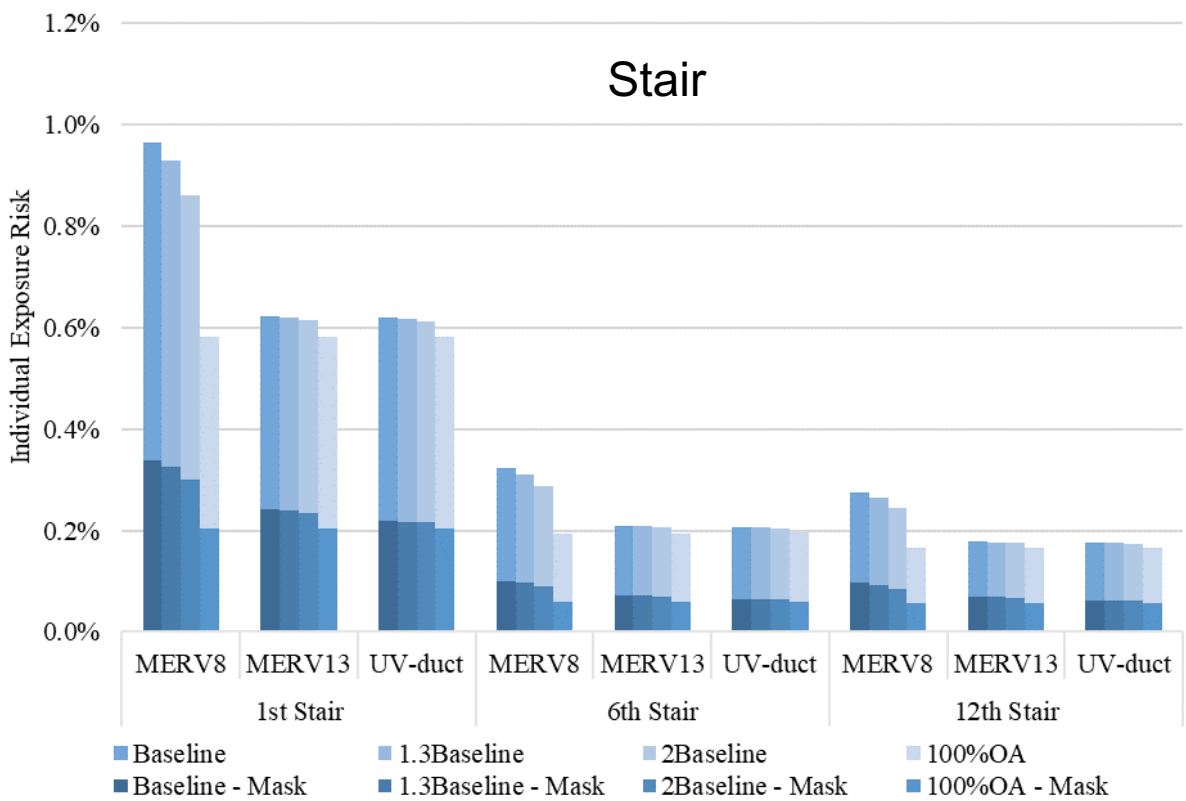
Relative risk reduction compared to baseline ventilation in the infectious zone



Using UV-room provides most risk reduction as does a very large air cleaner

Mitigation of exposure risk in elevator shaft and stairs

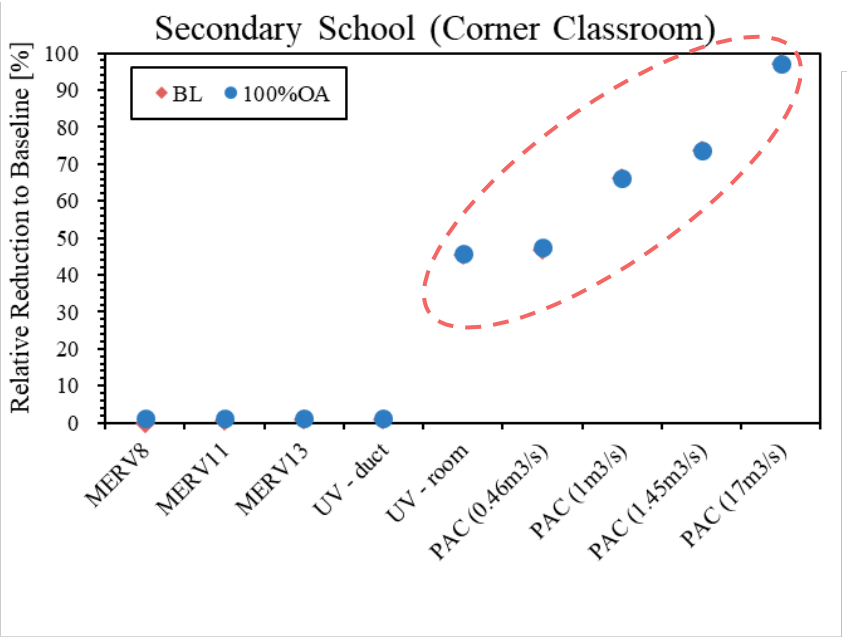


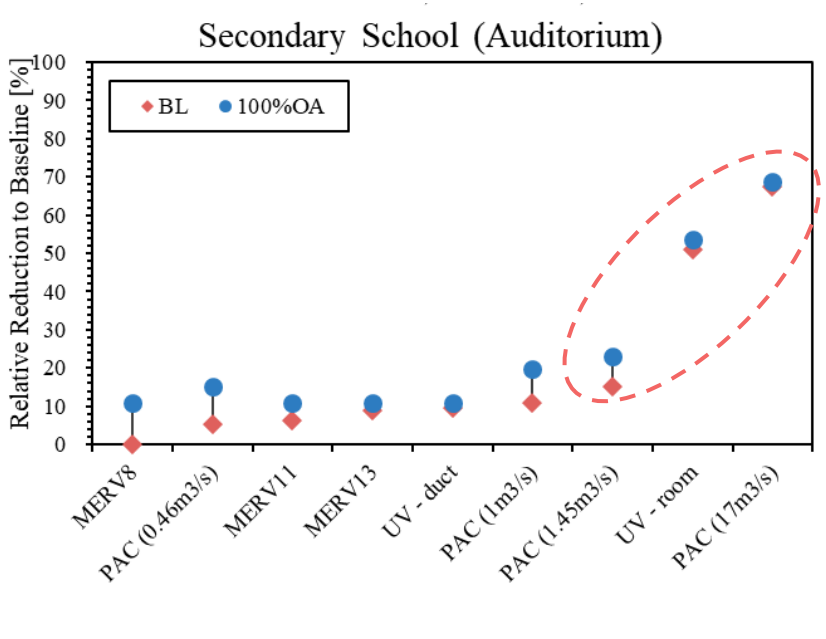


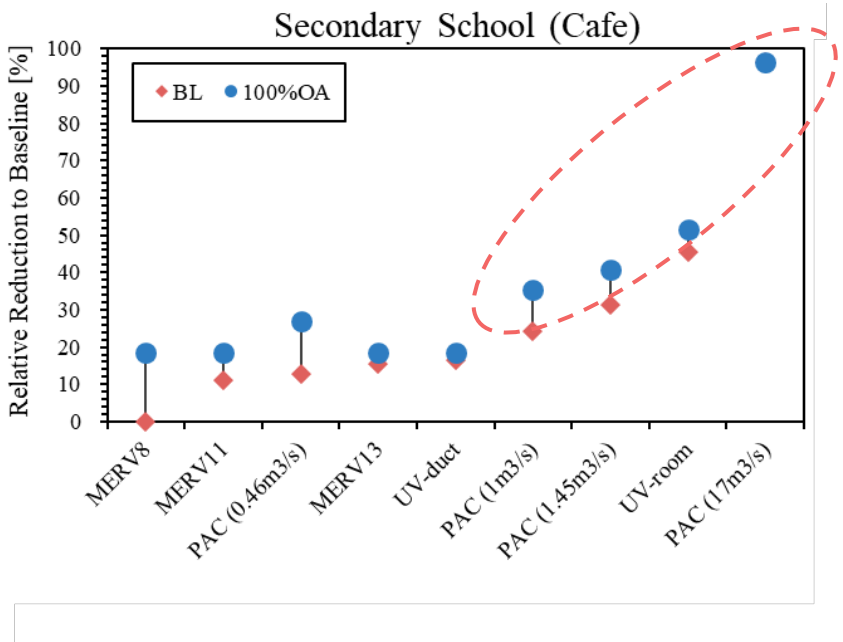
Mitigations in the HVAC ducts of the building reduce risks in the source zone and reduce the transmission between floors

For schools…When is in-room mitigation compared to building system control is a good strategy?

Secondary School	HVAC system type	Supply rates (m^3/s)	OA ratio (%)	ACR (Baseline, h^{-1})	Max Occupancy	Duration of Exposure
Corner Classroom	variable air volume	0.26	73	1.70	37	8:00 - 15:00 (7h)
Auditorium	constant air volume	4.1	70	1.31	1596	15:00 - 19:00 (4h)
Café	constant air volume	2.95	70	3.05	67	9:00 - 14:00 (5h)







Relative reduction to the baseline case ($(P_{baseline} - P_{strategy})/ P_{baseline}$)

Summary

- Ventilation and air cleaning reduce viral aerosol loads indoors from COVID-19 infected individuals
- For public buildings with reduced outdoor air supply, improving MERV filtration and increasing OA reduces infection risk throughout the building
- For buildings with high outdoor air supply additional air cleaning needed particularly in smaller spaces to reduce risk
- In-room germicidal UV is only air cleaning strategy to universally reduce risk to acceptable levels in all buildings in all scenarios, and so is masking