ENGINEERING SOLUTIONS TO AEROSOLS TRANSMISSION OF SARS-COV-2

- How can improved ventilation reduce the risk of aerosol exposure?
- What is possible with better use of existing ventilation in high-risk settings?
- What retrofitted solutions are recommended?
- What is the value of air purifiers?
- How can engineers help identify solutions properly adapted for specific facilities?

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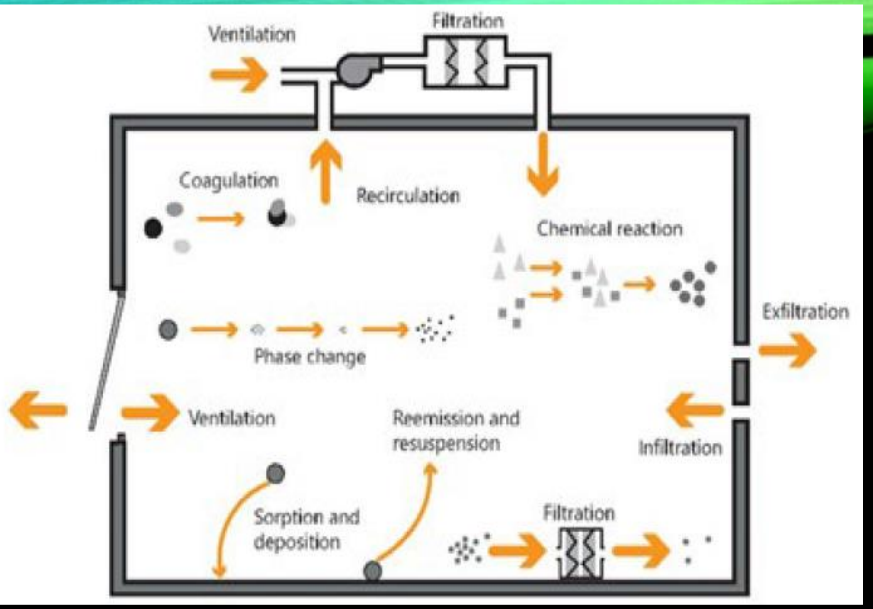
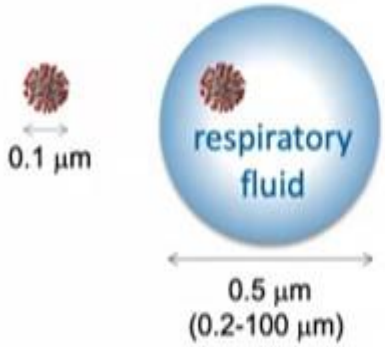
HOW CAN IMPROVED VENTILATION REDUCE THE RISK OF AEROSOL EXPOSURE?



CHARTERED INSTITUTION OF BUILDING SERVICES ENGINEERS
https://cibse.force.com/CPBase__item?id=a0q3Y00000I0NBYQA3

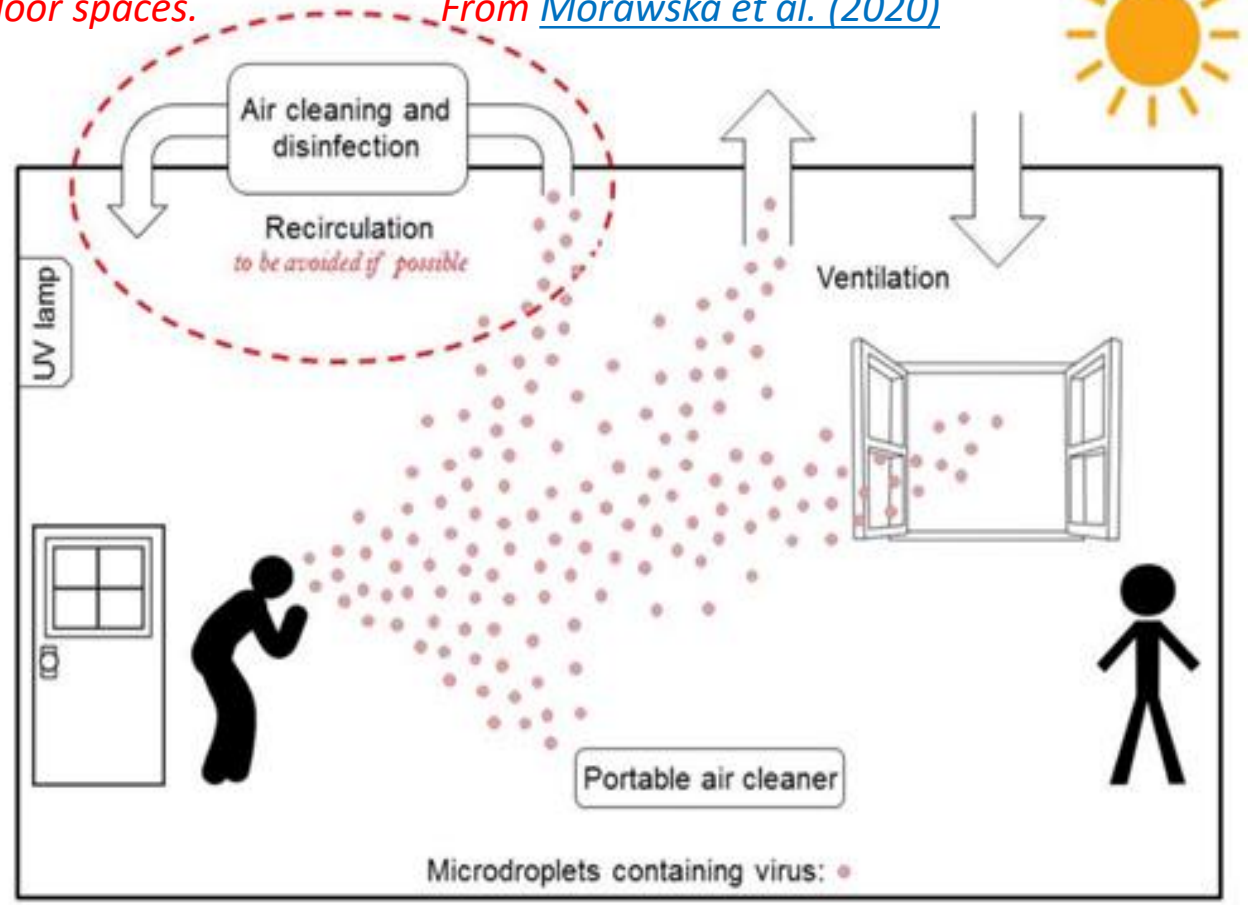
Size of Droplet/Aerosol is Critical

1. Airborne virus is not naked
2. Size of carrier droplet/aerosol defines transport

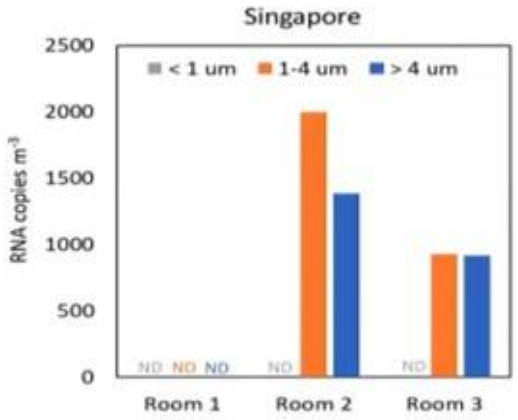


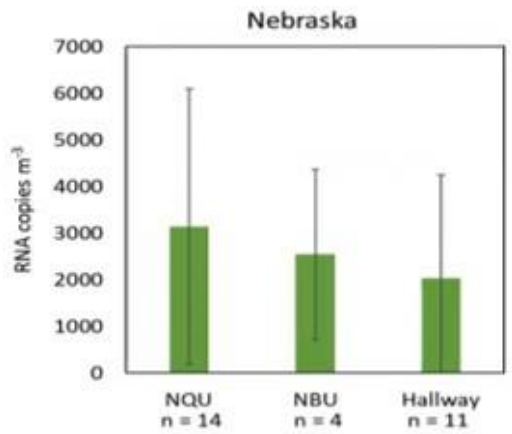
Bourouiba, L. JAMA. 2020;323(18):1837-1838.

The effects of ventilation in removing virus-containing aerosols from indoor spaces. *From Morawska et al. (2020)*



SARS-CoV-2 in Air Samples



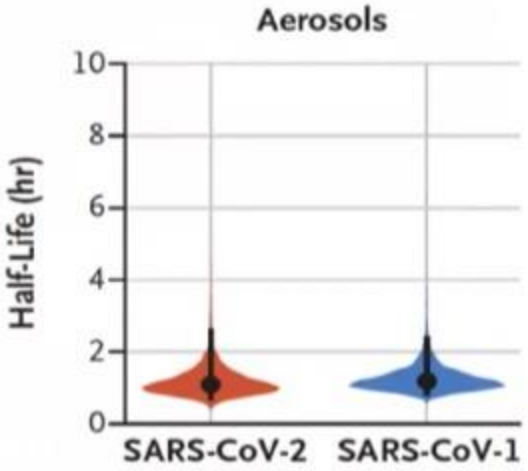


HOW CAN IMPROVED VENTILATION REDUCE THE RISK OF AEROSOL EXPOSURE?

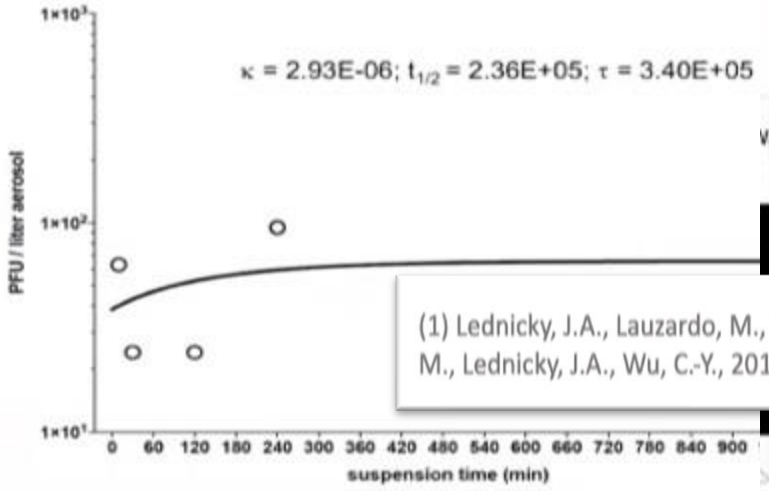
Infectious SARS-CoV-2 in Aerosols

Exemples of transmission in hospitals and long term care institutions

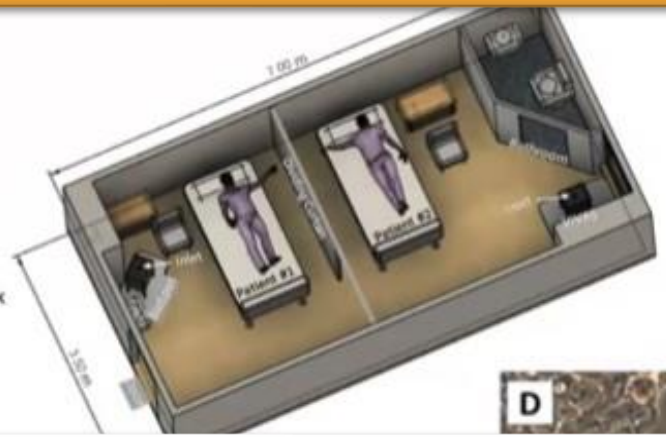
SARS-CoV-2 Survival in Aerosols



Half-life is 1.1 hours at 65% RH



Virus survives 16 hours at 53% RH



(1) Lednicky, J.A., Lauzardo, M., Fan, Z.H., et al., 2020, Viable SARS-CoV-2 in the air of a hospital room with COVID-19 patients, *medRxiv* (2
M., Lednicky, J.A., Wu, C.-Y., 2019, Collection, particle sizing and detection of airborne viruses, *J Appl Microbiol*

Federal Facilities Council Webinar: Heating, Ventilation, and Air Conditioning Strategies in Response to COVID-19

Engineering Controls for COVID-19 Aerosol Risk Mitigation

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Professor, The Pennsylvania State University, USA
Chair, ASHRAE Epidemic Task Force

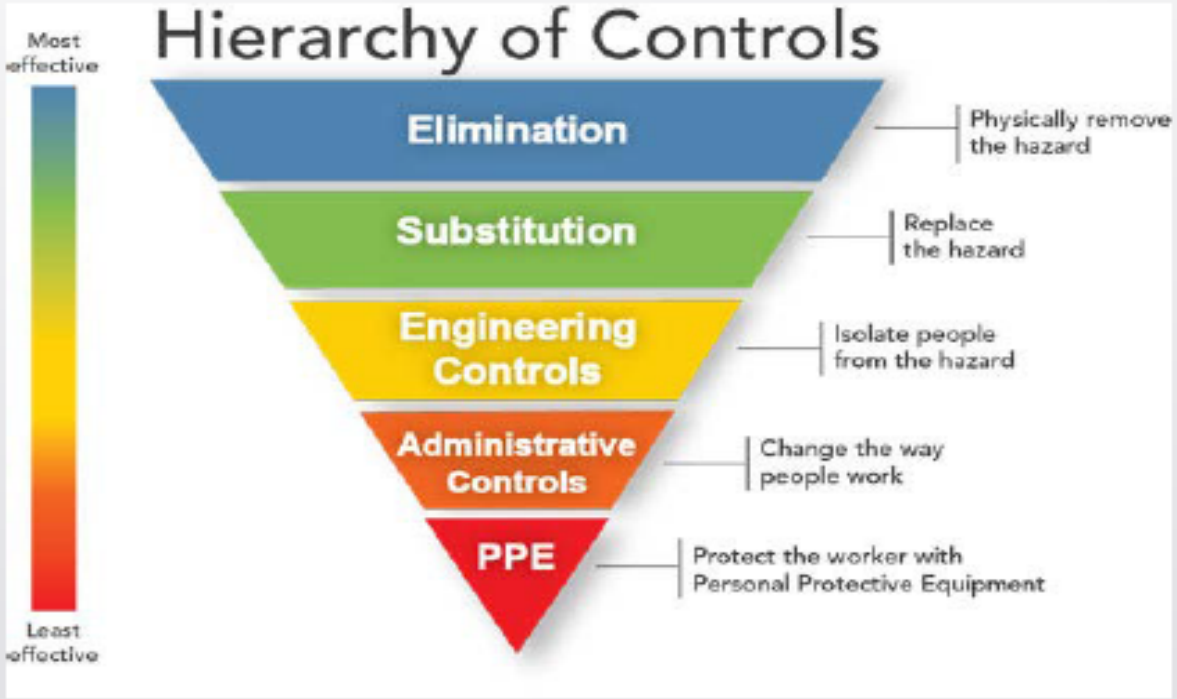
ASHRAE

PennState College of Engineering | ARCHITECTURAL ENGINEERING

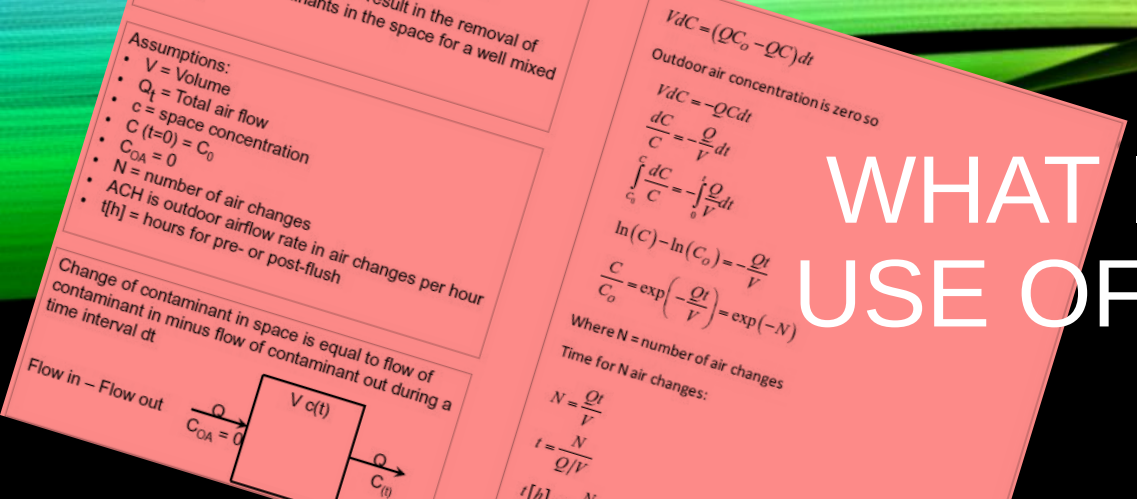
HOW CAN IMPROVED VENTILATION REDUCE THE RISK OF AEROSOL EXPOSURE?

Risk Management – HVAC is one layer of an effective mitigation strategy

- Source elimination
  - Testing, contact tracing
- Substitution – NA
- Engineering controls
  - HVAC interventions to control aerosols
- Administrative controls
  - Rules and procedures
- Personal protective equipment
  - N95 mask – mainly protects wearer
  - Surgical/cloth masks mainly protect others



WHAT IS POSSIBLE WITH BETTER USE OF EXISTING VENTILATION IN HIGH-RISK SETTINGS?



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.

https://www.ashrae.org/file%20library/technical%20resources/covid-19/core-recommendations-for-reducing-airborne-infectious-aerosol-exposure.pdf

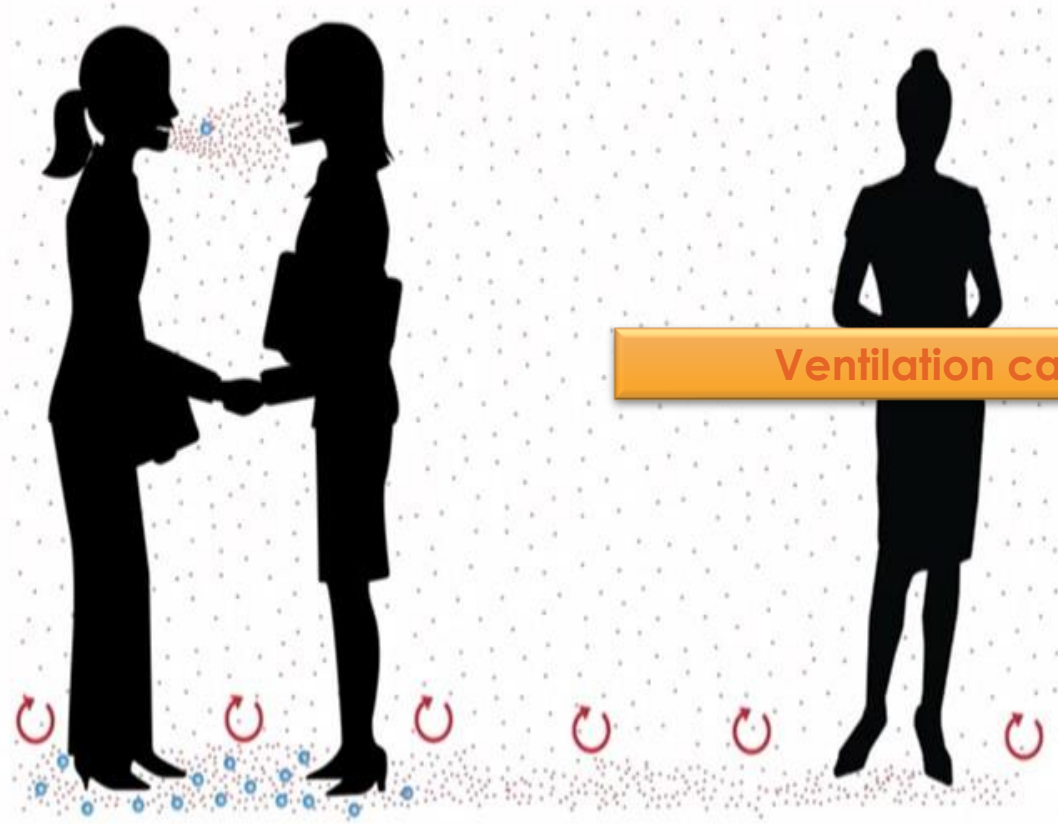
https://www.ashrae.org/file%20library/technical%20resources/covid-19/ashrae-covid19-infographic-.pdf

Below are some general parameters for non-COVID emergency surge spaces outside of a licensed hospital

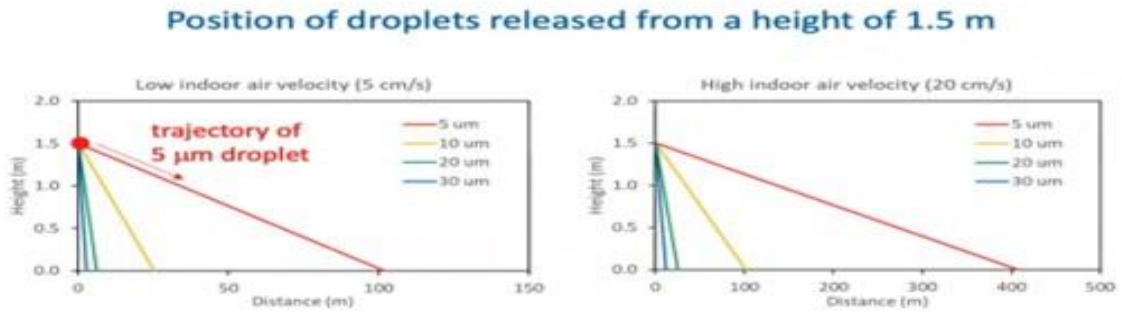
- Minimum 2 ACH Outdoor air and 2 ACH Total air, though higher total air is desired
  - for large volume spaces with high ceilings, such as conference rooms, minimum OA and total ACH may be calculated as 2ACH Outdoor divided by 0.8 ACH, or 2.5 Total air, (ASHRAE 62.1 ventilation effectiveness) and supply air temperatures kept no more than 8.3°C (15 °F) above room temperature to minimize stratification and short circuiting of air within the space.
- No less than MERV 13 and MERV 14 preferred for systems that are not serving specialized environments that may require even higher efficiency filtration.
- Temperature 21-24°C (70–75 °F)
- Humidity – – consider maintaining 40-60% RH.

WHAT IS POSSIBLE WITH BETTER USE OF EXISTING VENTILATION IN HIGH-RISK SETTINGS?

Spread, Dilution, Resuspension

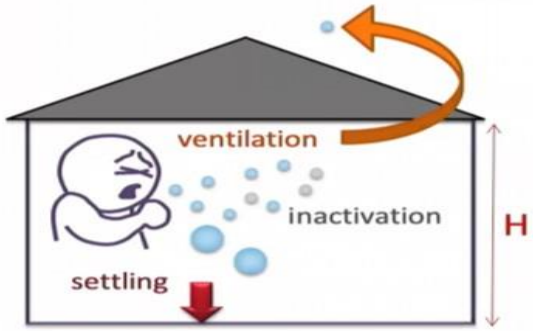


Droplets Can Travel More Than 2 m



Virus Removal in Indoor Air

Ventilation can be improved/optimized to reduce transmission

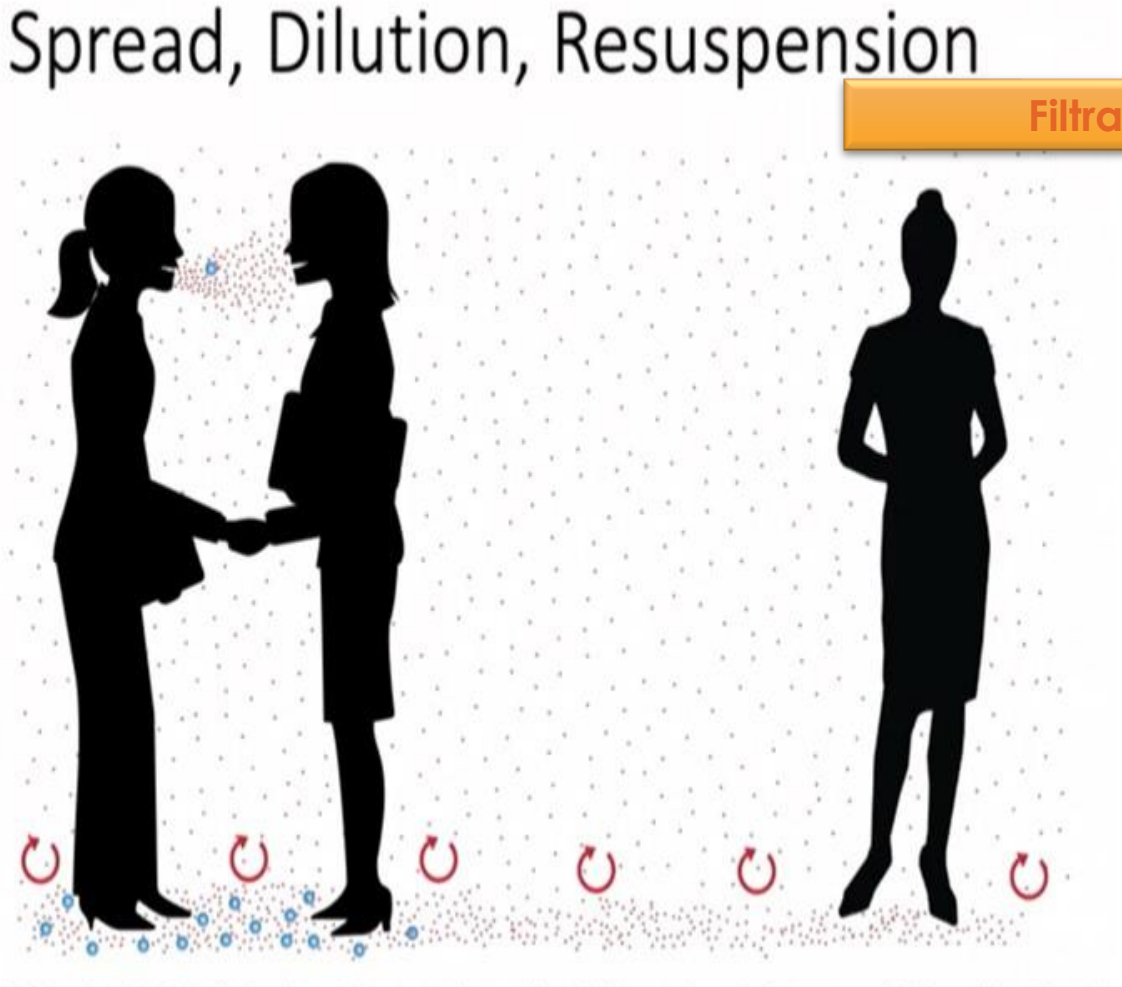


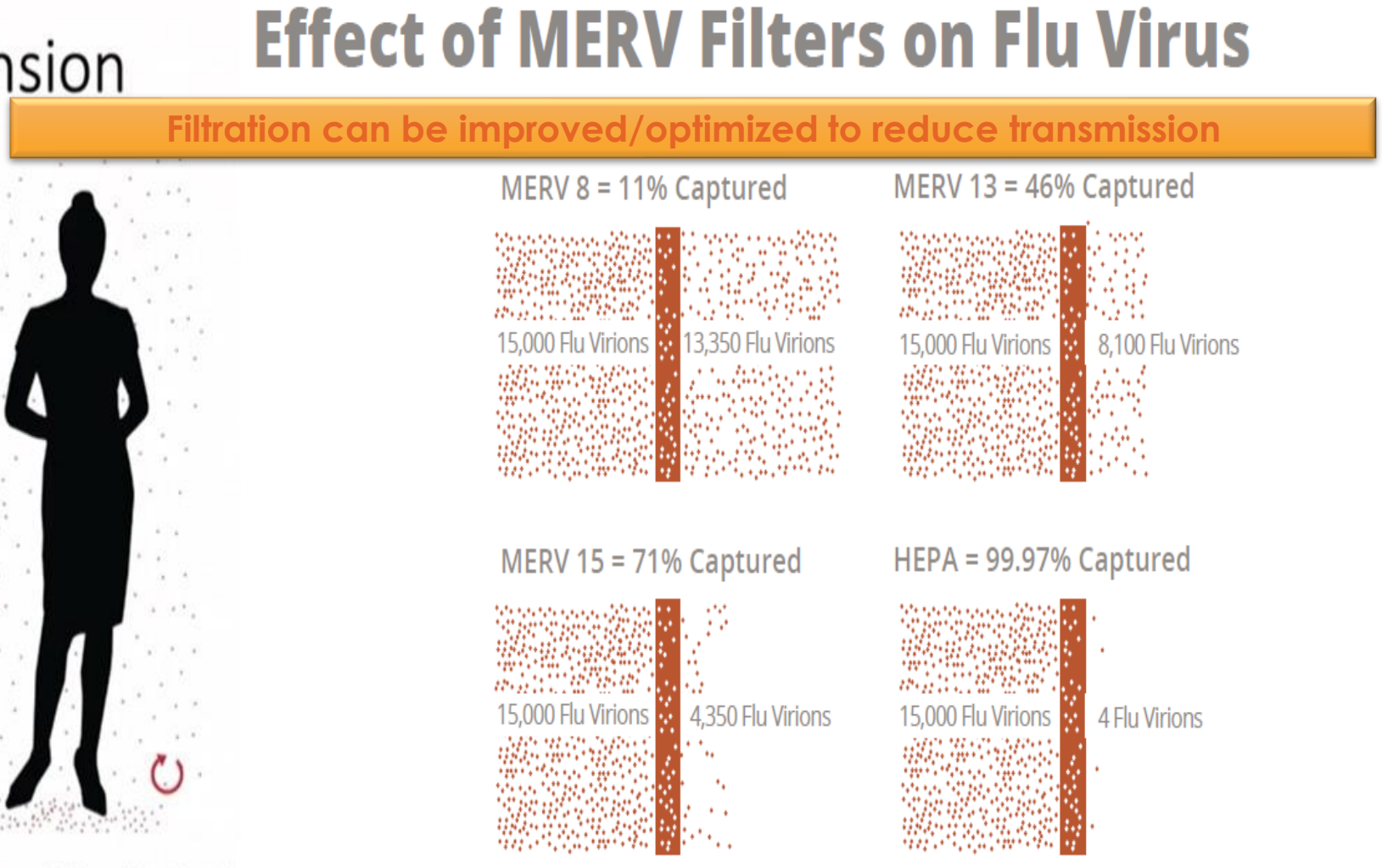
$$\frac{dC_d}{dt} = -\left(\frac{v}{H} + \lambda + k\right)C_d$$

settling · ventilation (air-exchange) · inactivation

C_d: concentration of infectious virus in droplets/aerosols of diameter d

WHAT IS POSSIBLE WITH BETTER USE OF EXISTING VENTILATION IN HIGH-RISK SETTINGS?





- Faster inactivation of SARS-CoV-2 at higher T and RH
- Limited ability to vary T in comfort zone
- 40-60% RH → lower infection rates in some studies

WHAT IS POSSIBLE WITH BETTER USE OF EXISTING VENTILATION IN HIGH-RISK SETTINGS?

Table B.1. Air changes/hour (ACH) and time required for airborne-contaminant removal by efficiency *

ACH § ¶	Time (mins.) required for removal 99% efficiency	Time (mins.) required for removal 99.9% efficiency
2	138	207
4	69	104
6+	46	69
8	35	52
10+	28	41
12+	23	35
15+	18	28
20	14	21
50	6	8

- Liters/s/person is the best indicator (better than ACH)
- Outbreaks of COVID-19 at ~1-3 L/s/p
- Recommend at least 12.5 L/s/p (REHVA), more if possible

	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

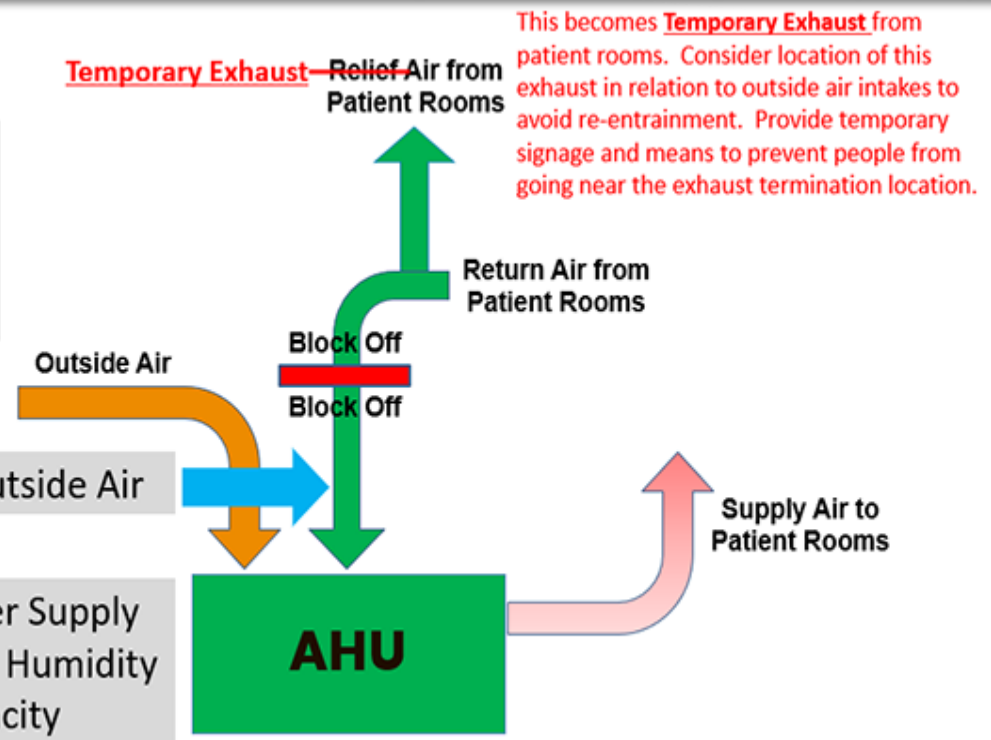
Zhu S, Jenkins S, Addo K, et al. Ventilation and laboratory confirmed acute respiratory infection (ARI) rates in college

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

Temporary adaptation of an existing Air Handling Unit (AHU)

Optional, not required: May want to consider increase of bathroom exhaust airflow.



https://www.ashrae.org/technical-resources/healthcare

Early/easy things to look at:

1. Increasing ventilation (l/s)
2. Better control fresh air intake
3. Invest in CO2 monitoring
4. Improve Temperature and Humidity control
5. Think about a HEPA filter
6. Open windows

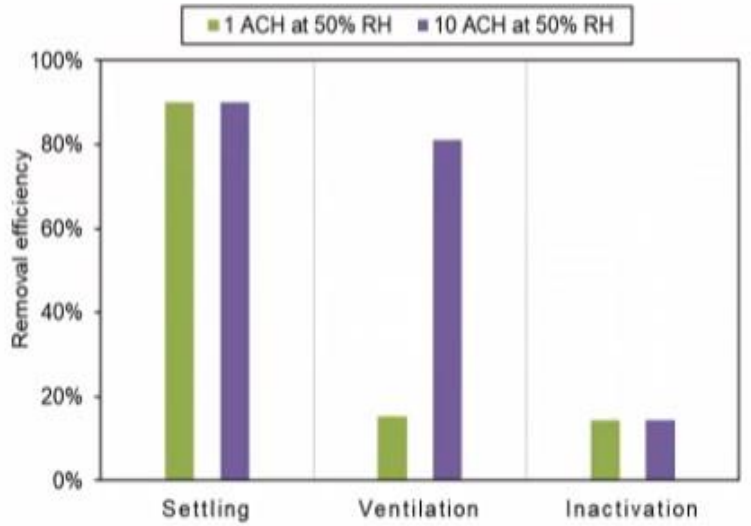
WHAT RETROFITTED SOLUTIONS ARE RECOMMENDED?

Interventions

1. Source control 2. Ventilation and filtration 3. Distance and PPE 4. Hygiene

Removal Mechanisms

- Settling: main removal mechanism, efficient for large but not small droplets
- Ventilation: effective for all sizes, important in public buildings
- Inactivation: depends on the virus, may depend on humidity



(1) Yang, W., Marr, L.C., 2011, Dynamics of airborne influenza A viruses indoors and dependence on humidity, *Plos One*, 6, e21481 (2) Korn
K.A., Lin, K., Prussin II, A.J., et al., 2018, Influenza virus infectivity is retained in aerosols and droplets independent of relative humidity, *J In*
(3) Kormuth, K.A., Lin, K., Qian, Z., et al., 2019, Environmental persistence of influenza viruses is dependent upon virus type and host origi
mSphere

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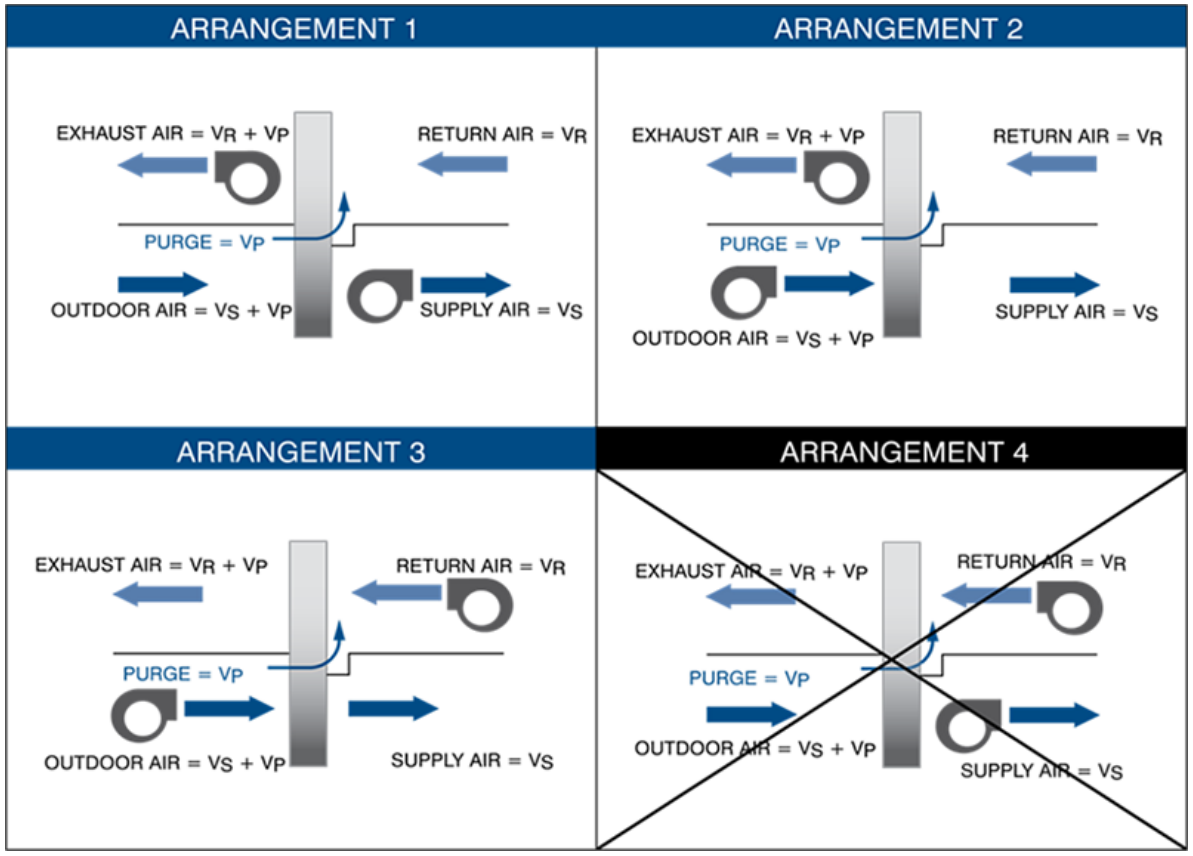
WHAT RETROFITTED SOLUTIONS ARE RECOMMENDED?

Ventilation through Air Exchangers, HRV, ERV



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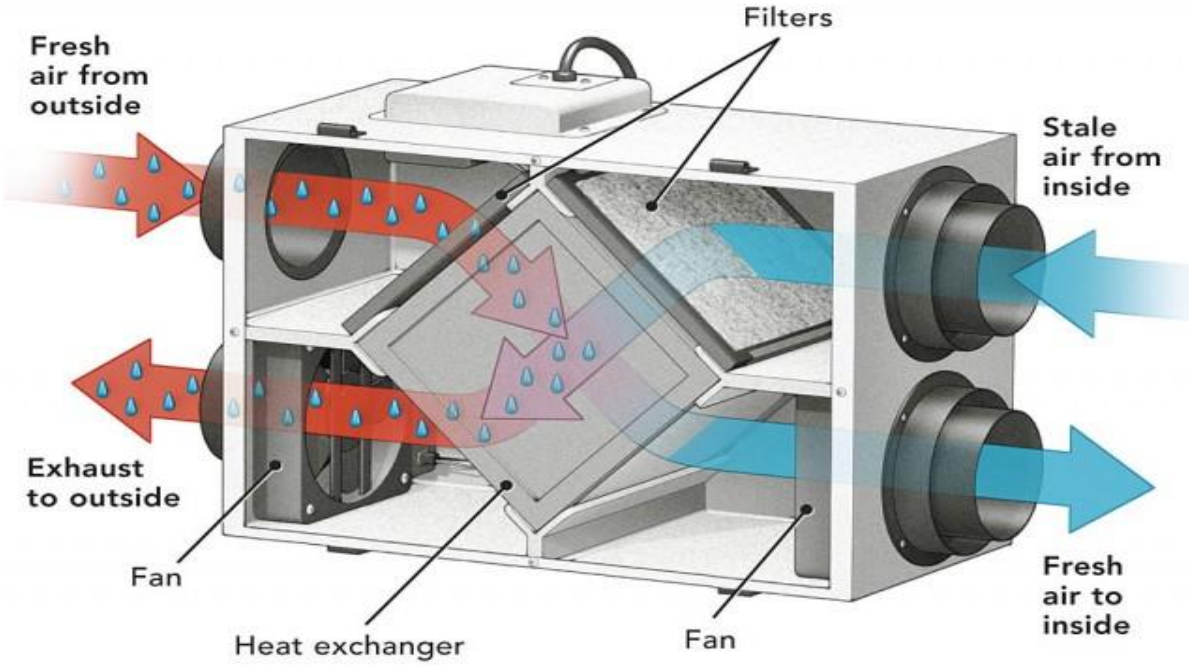

WHAT IS THE VALUE OF AIR PURIFIERS?

- Effectiveness of HEPA filters
  - Potential impact of HEPA/UV Filters on infection rates for different systems for 2 room configurations (from the SAGE-EMG November report)

The best air purifiers (sometimes known as "air cleaners") help to eliminate dust, pollen, smoke and other irritants from the air, but a good air purifier could also go a long way towards eliminating dangerous airborne threats.

- The CDC says air purifiers "can **help reduce airborne contaminants**, including viruses, in a home or confined space."
- The EPA (Environmental Protection Agency) adds that air purifiers **are helpful** "when additional ventilation with outdoor air is not possible"

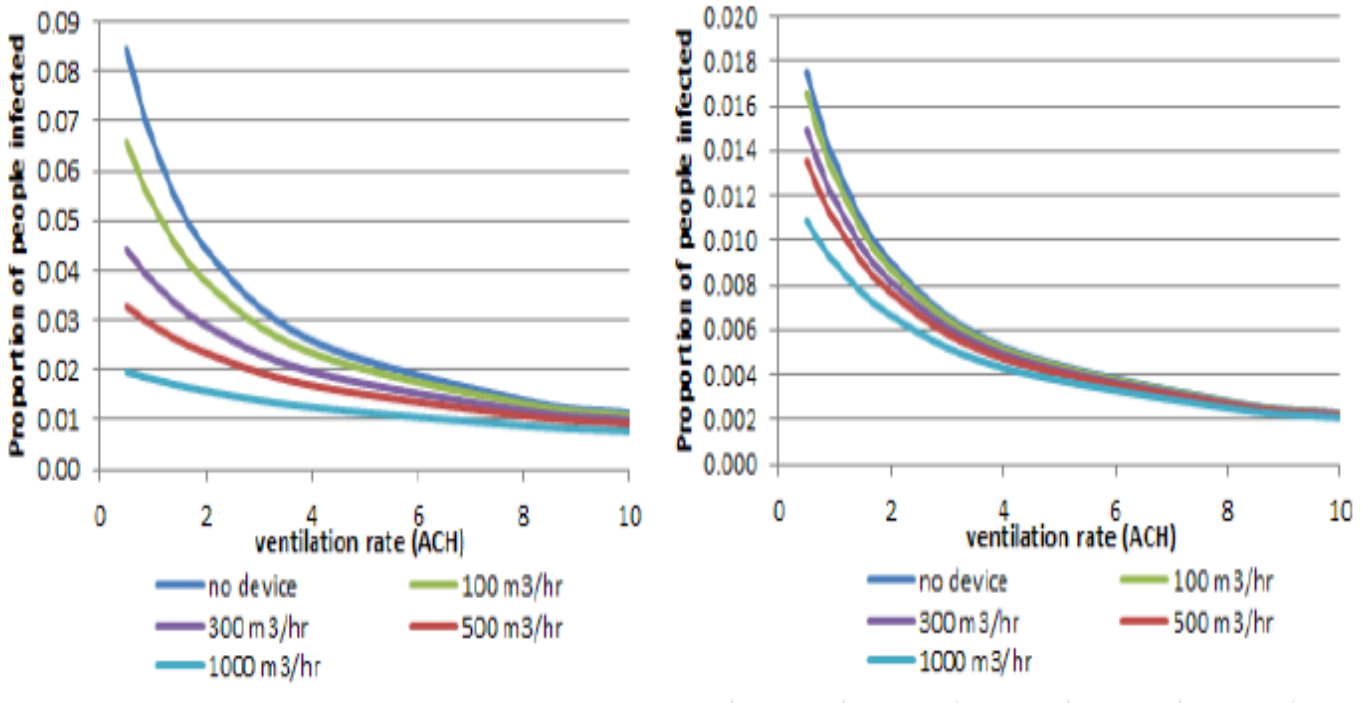

Figure 4: Simulation from Wells-Riley model for airborne transmission over a 2 hour period, , 10 quanta/hr and breathing rate of 10 l/min. Results for device flow rates between 100 and 1000 m3/hr in a 100 m3 room (left) and 500 m3 room (right).

https://www.gov.uk/government/publications/emg-potential-application-of-air-cleaning-devices-and-personal-decontamination-to-manage-transmission-of-covid-19-4-november-2020

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  - One layer in the « Swiss Cheeze » (from Dr. I.Mckay and Dr. J.L Jimenez)

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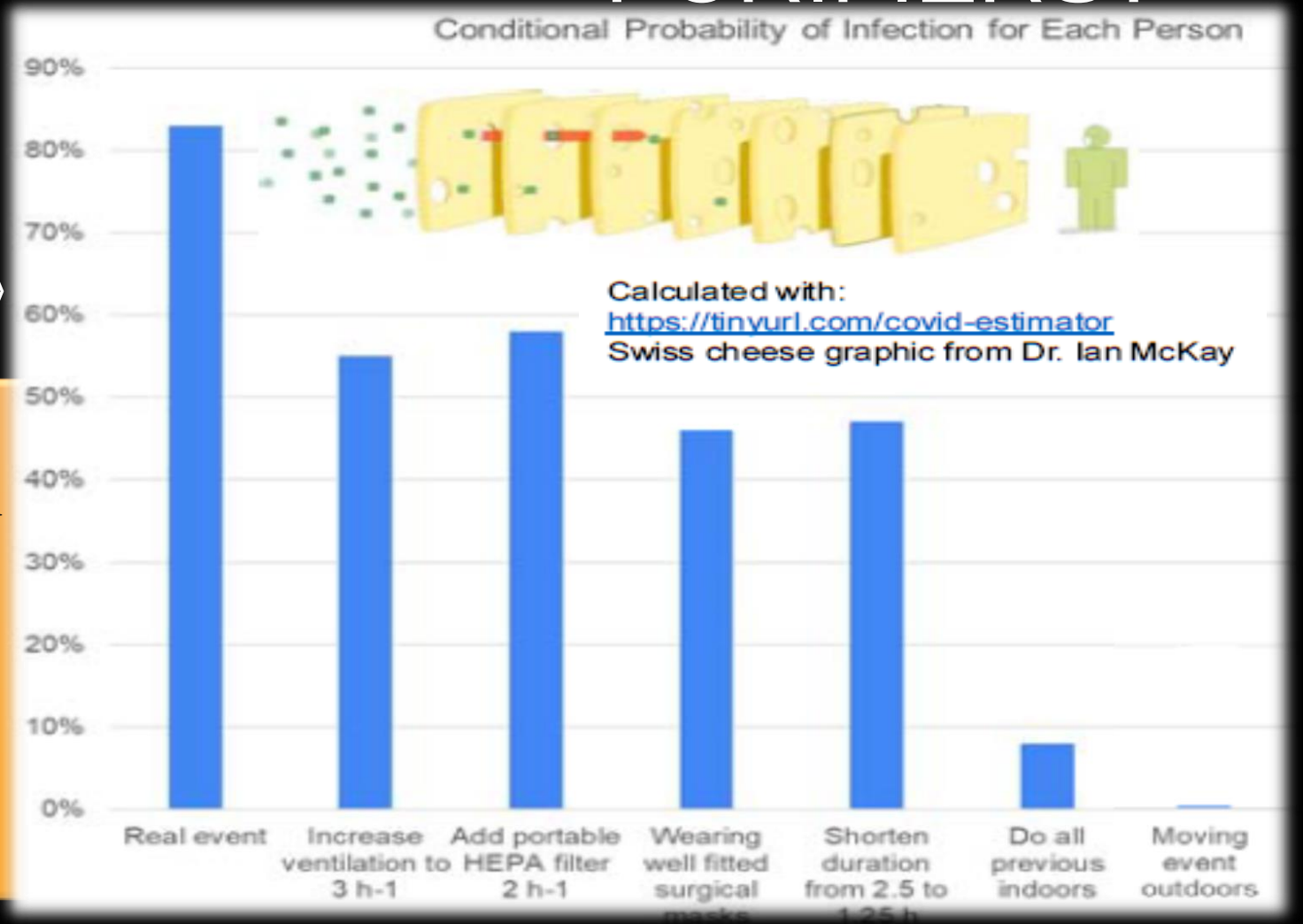

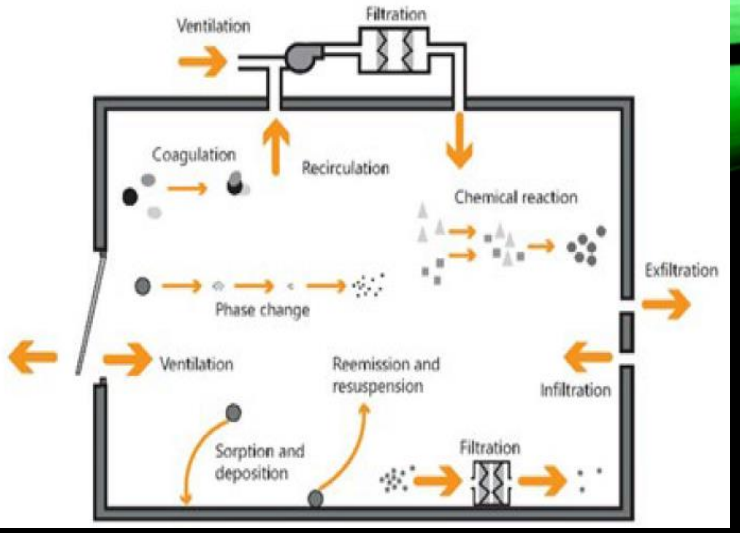

HOW CAN ENGINEERS HELP IDENTIFY SOLUTIONS PROPERLY ADAPTED FOR SPECIFIC FACILITIES?

In a multidisciplinary mindset, Engineering support is important in selecting and implementing devices.

- To properly consider all aspects, not just the potential ability to remove or kill the virus.
- Within a class of devices, some are high quality and likely to be more effective.
- To optimize ventilation and supplement with (effective) air purifiers (where necessary).

To use engineering solutions effectively and safely.

- Advices and guidance to identify appropriate technologies and high quality products.
- Guidance and training for facilities managers and building services practitioners on the selection, design, installation and maintenance of air cleaning devices.

On the longer term:
Further research on the efficacy of devices including more evidence of the technology against SARS-CoV-2 virus, performance in real-world settings, and behavioral responses to the use of such devices.
Standards for device testing and approved facilities with access to independent and verifiable testing

Things to look at:

1. Increasing ventilation (l/s)
2. Better control fresh air intake
3. Invest in CO2 monitoring
4. Improve Temperature and Humidity control
5. Think about a HEPA filter
6. Open windows

Before more complex options