Managing COVID-19 and HVAC in Buildings for Emerging Economies

Fundamentals of COVID-19 Risk Management

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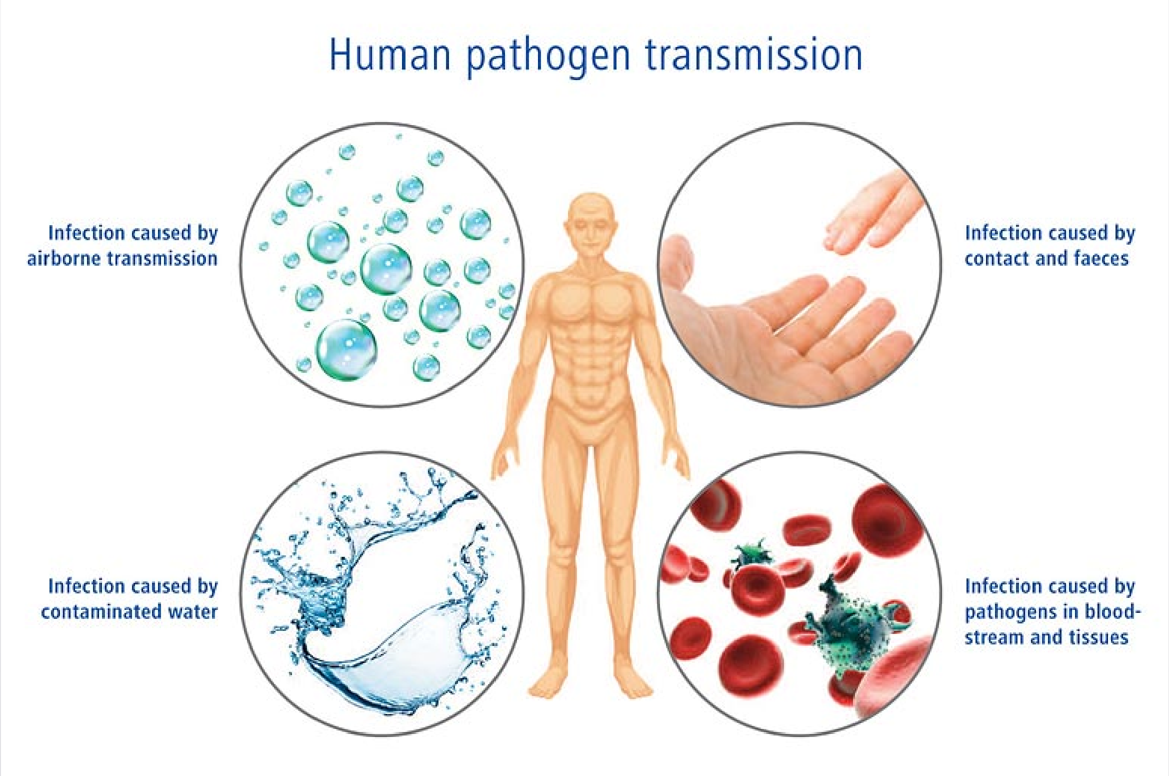
Infectious Disease Transmission Modes

- Airborne
  - Large droplet/short range
  - Aerosol
- Fomite – intermediate surface
- Water/food
- Physical contact
- Insect/animal vector

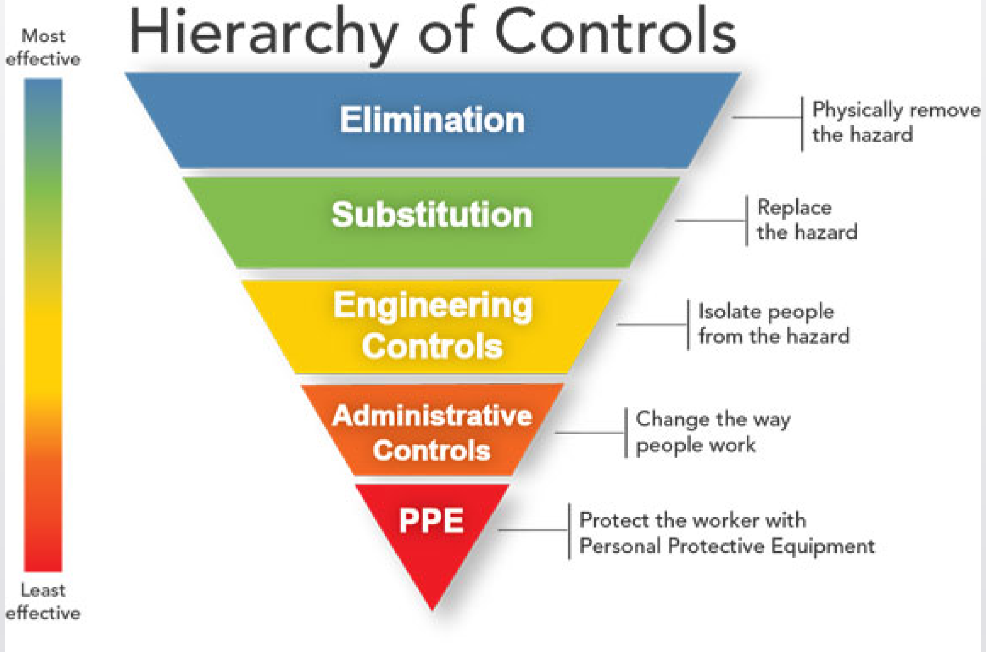
…HVAC mainly impacts aerosol and fomite transmission – only part of a solution



bode-science-center.com

Risk Management

- Multiple modes of transmission → multiple controls
- Collaboration gives best results
  - Designers
  - Owners
  - Operators
  - Industrial hygienists
  - Infection control specialists
- Focus here on engineering controls for aerosols

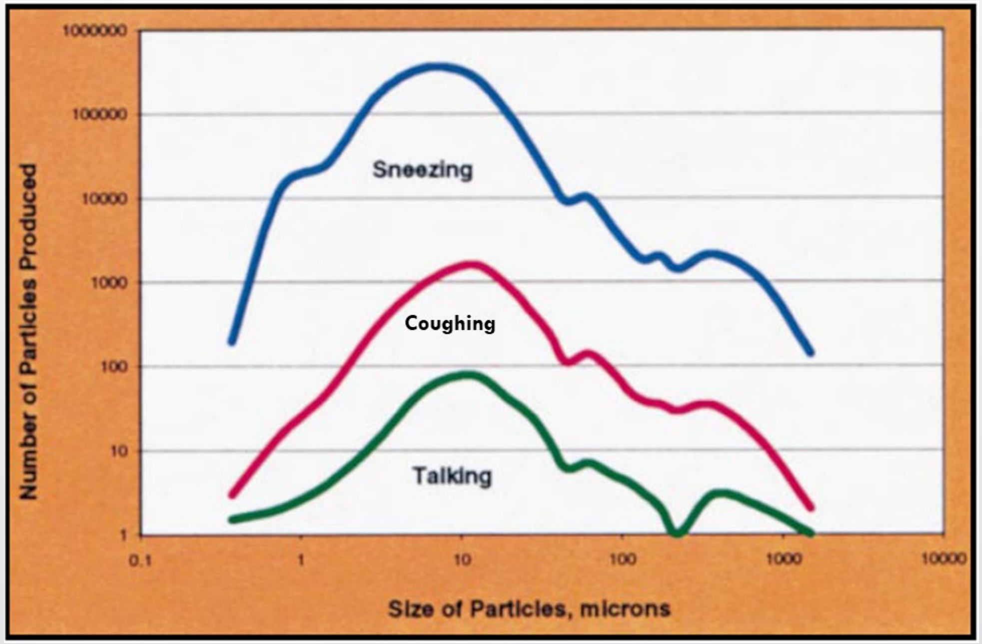


Sources of Infectious Aerosols

- Humans – breathing, talking, singing, coughing, sneezing
- Plumbing – toilet flushing, splashing in sinks
- Medical procedures – dentistry, endotracheal intubation, and others

Respiratory Aerosol Properties

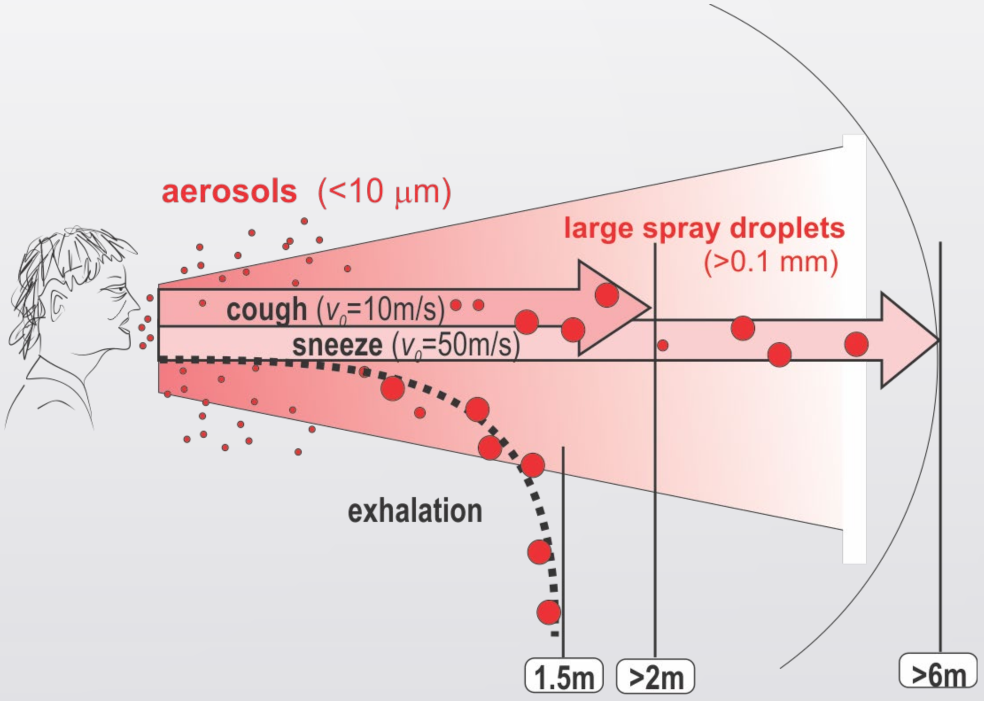
- Emitted as droplets
  - Water, proteins, salts…
  - Dehydrate to smaller sizes
  - Process dependent on relative humidity
  - Initial diameter < 1 μm to > 1000 μm
- Infected persons shed viruses in droplets
- Studies of influenza have found > 50% of viral load is in particles < ~5 μm



Duguid, et al. 1945

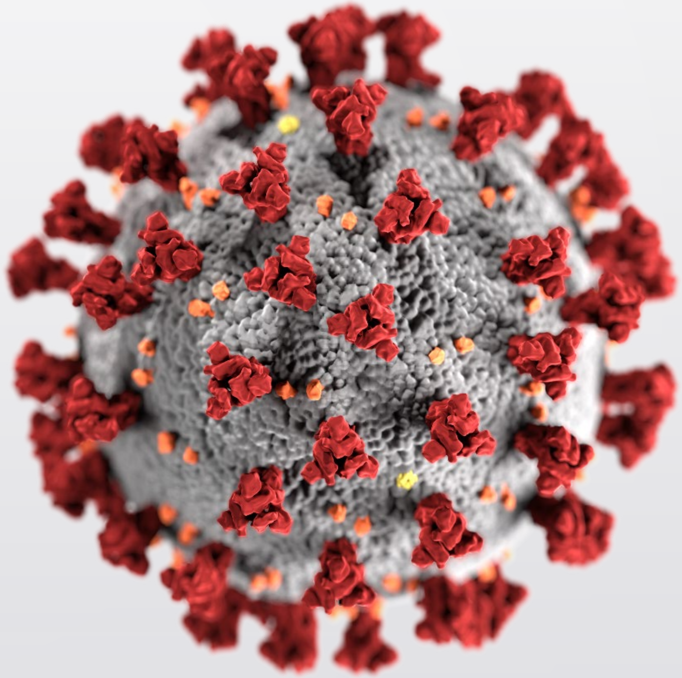
Respiratory Aerosol Dynamics

- "Large" droplets settle before travelling long distances
- "Small" droplets/aerosols remain airborne longer, may travel significant distances
- Various definitions of boundary between small and large –~ 60 μm initial diameter, 10 μm final diameter



SARS-CoV-2, The virus that causes Covid-19

- Coronavirus related to the one that causes SARS
- RNA virus with lipid envelope
- Diameter $\approx$ 120 nm (0.12 µm)
- Not determined
  - Shedding rate
  - Infectious dose
- Survival of hours in air, days on surfaces



Controversy Over COVID-19 Transmission

- Health organizations (WHO, CDC)
  - Evidence points to predominantly large droplet transmission at short range
  - Other modes not ruled out
  - Tend to rely on evidence from healthcare environments
- Possible explanations
  - Virus mostly in large droplets
  - Infectious dose is large
  - Exposure reduced by environmental factors

- Unexplained COVID-19 "community spread" incidents cast doubt on claimed insignificance of airborne transmission, e.g.
  - Skagit Valley, WA choir rehearsal - 47 of 60 participants infected despite following distancing and hygiene guidelines
  - Guangzhou, CHN restaurant – 10 of 21 diners at three adjacent tables infected by one person at distances of up to 5 m
- Documented airborne transmission of SARS also suggests possibility for COVID-19

Controversy Over COVID-19 Transmission

- Some feel strongly that airborne transmission is clear
    - Aerosol science – behavior of respiratory aerosols
    - Behavior of other coronaviruses
    - Interpretation of community spread events

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Airborne transmission of SARS-CoV-2: The world should face the reality

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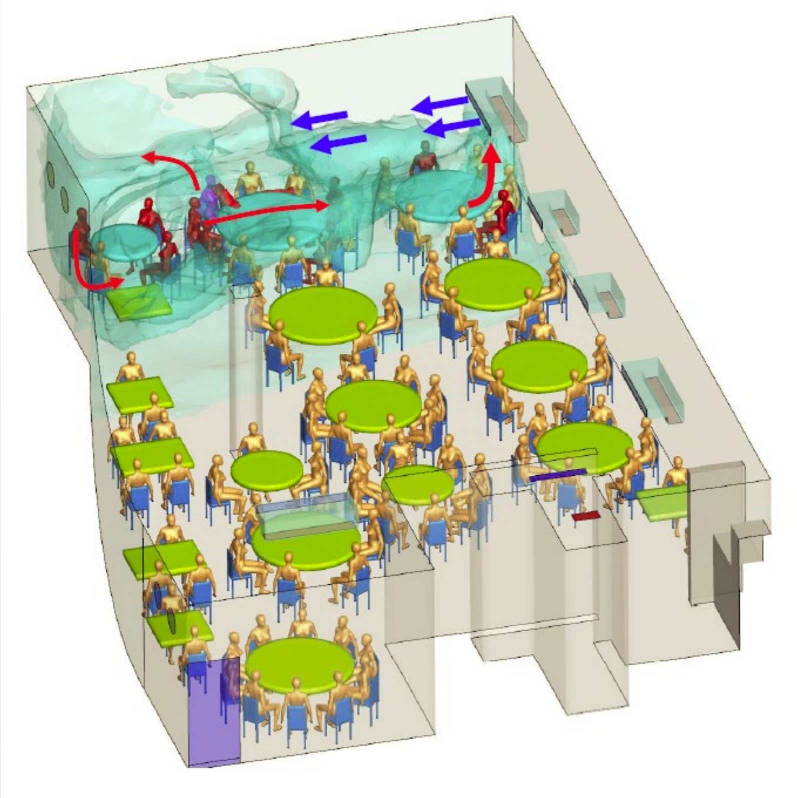
ABSTRACT

Hand washing and maintaining social distance are the main measures recommended by the World Health Organization (WHO) to avoid contracting COVID-19. Unfortunately, these measured do not prevent infection by inhalation of small droplets exhaled by an infected person that can travel distance of meters or tens of meters in the air and carry their viral content. Science explains the mechanisms of such transport and there is evidence that this is a significant route of infection in indoor environments. Despite this, no countries or authorities consider airborne spread of COVID-19 in their regulations to prevent infections transmission indoors. It is therefore extremely important, that the national authorities acknowledge the reality that the virus spreads through air, and recommend that adequate control measures be implemented to prevent further spread of the SARS-CoV-2 virus, in particularly removal of the virus-laden droplets from indoor air by ventilation.

ASHRAE Assumes Possibility of Airborne/Aerosol Transmission

- Transmission of SARS-CoV-2 through the air is *sufficiently likely* that airborne exposure to the virus should be controlled. Changes to building operations, including the operation of heating, ventilating, and air-conditioning systems, can reduce airborne exposures.



Li, et al. (2020) https://doi.org/10.1101/2020.04.16.20067728

Engineering Controls

- Ventilation
- Air distribution
- Filtration
- Disinfection
- Temperature and humidity control

Ventilation and Pressurization

- Ventilation dilutes contaminants, increases exposure time required for exposure to an infectious dose
- Effective, but energy intensive, even with energy recovery
- Works in conjunction with exhaust and pressurization to isolate or contain

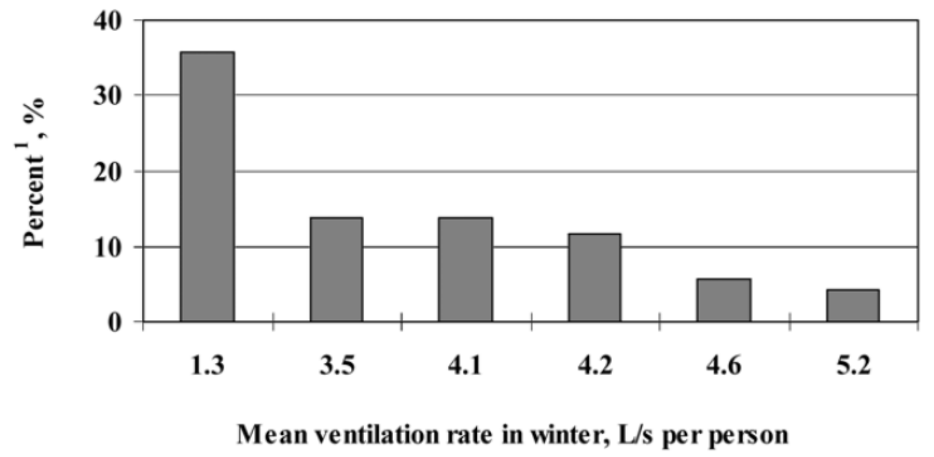
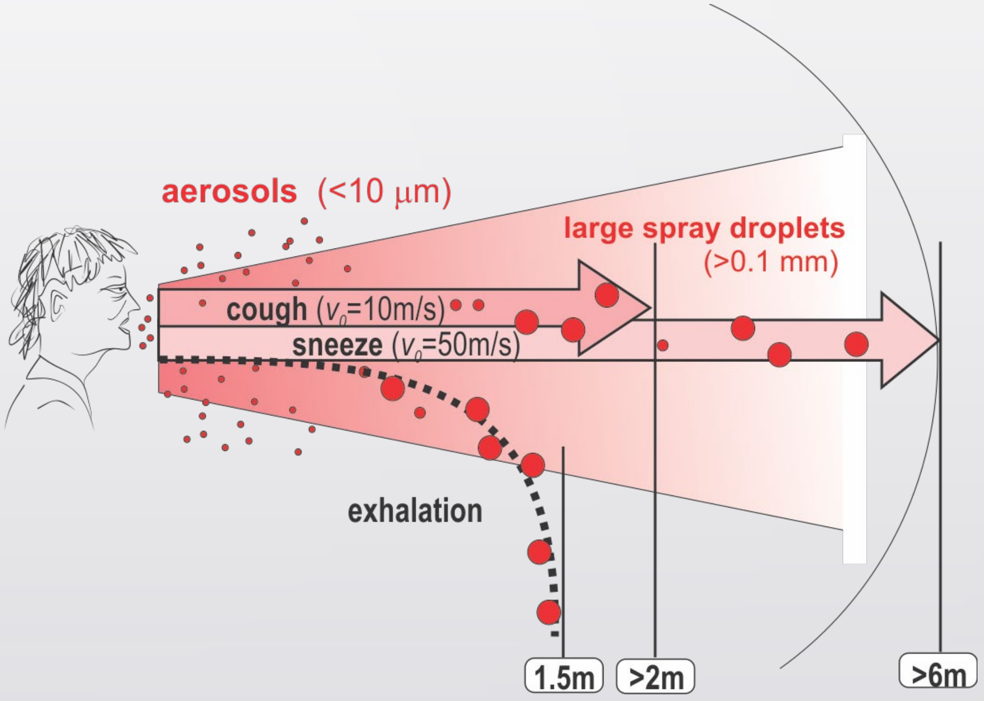


Figure 4. Associations between common cold infection rates and mean ventilation rate in winter in buildings constructed after year 1993. [1] Proportion of occupants with ≥6 common colds in the previous 12 months.

Sun, et al. (2011)
https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3217956/

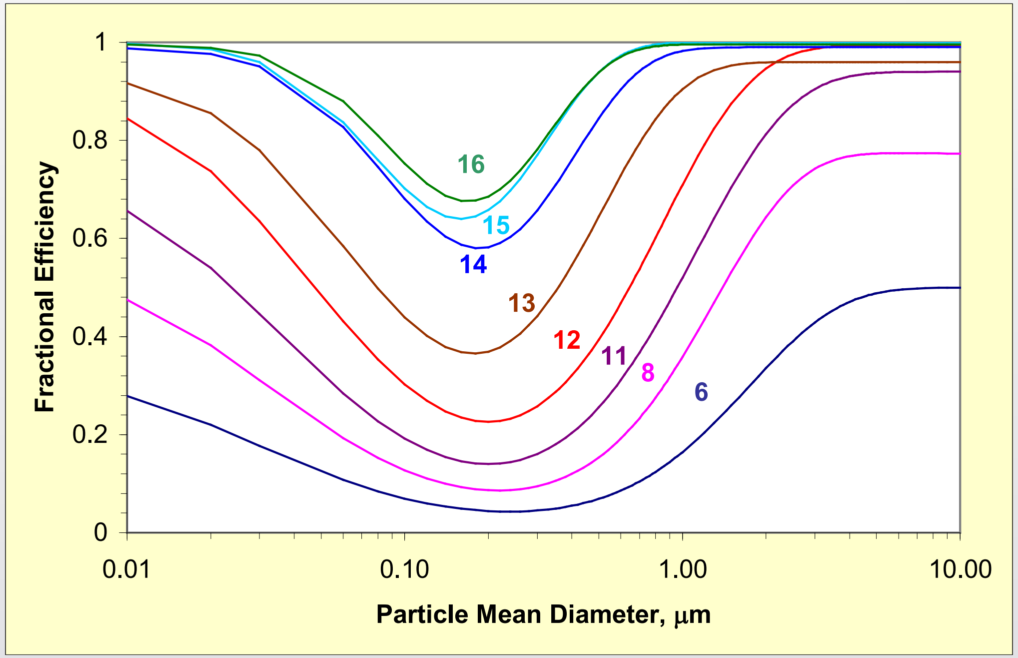
Air Distribution

- Room air distribution may contribute to risk if it extends distance travelled by large droplets – avoid high velocity discharge in breathing zone
- Lower velocity mixing may be preferable to displacement
- Personalized ventilation/exhaust are options in some cases



Filtration

- Can remove any aerosol contaminant (but not with 100% certainty)
- For indoor sources, requires recirculation in space or system
- Effective if
    - Contaminants of concern are airborne
    - Clean air delivery (efficiency + recirculation) is high enough



Representative MERV rated filter performance (Kowalski and Bahnfleth 2002)

Filtration – Infections Aerosol Size

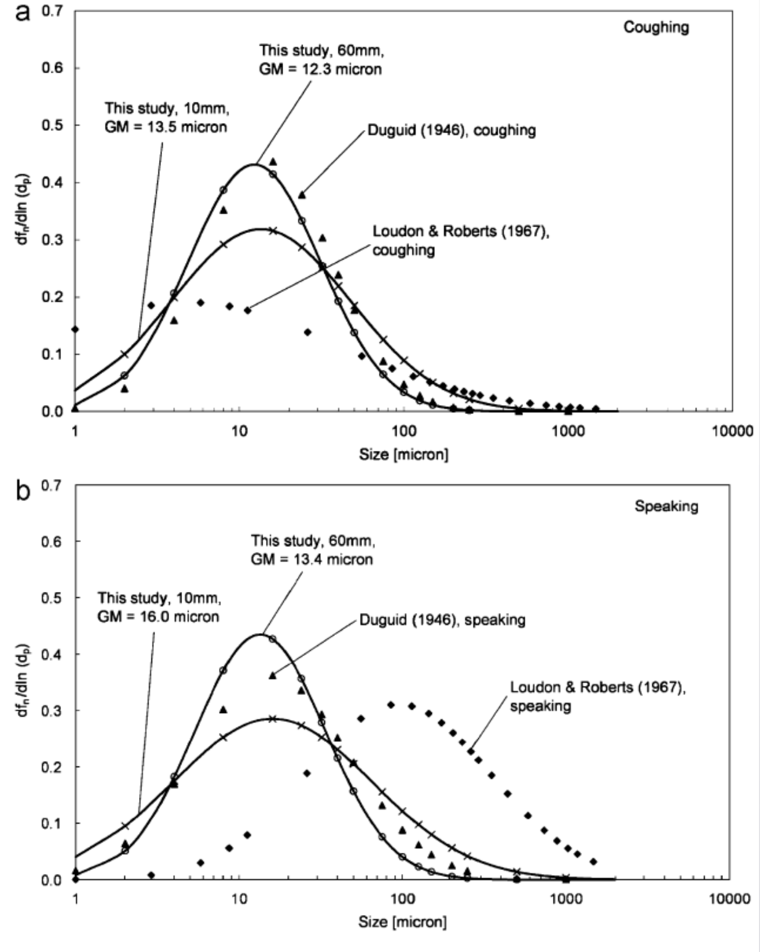
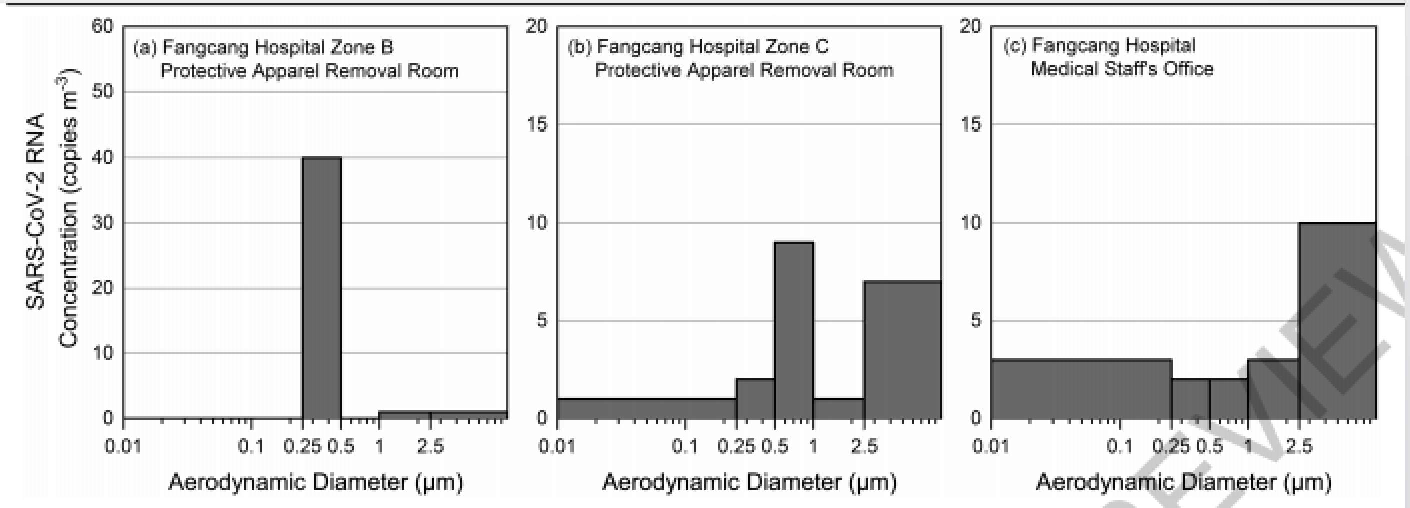


Fig. 3. (a) Droplet size distribution for coughing and (b) droplet size distribution for speaking.

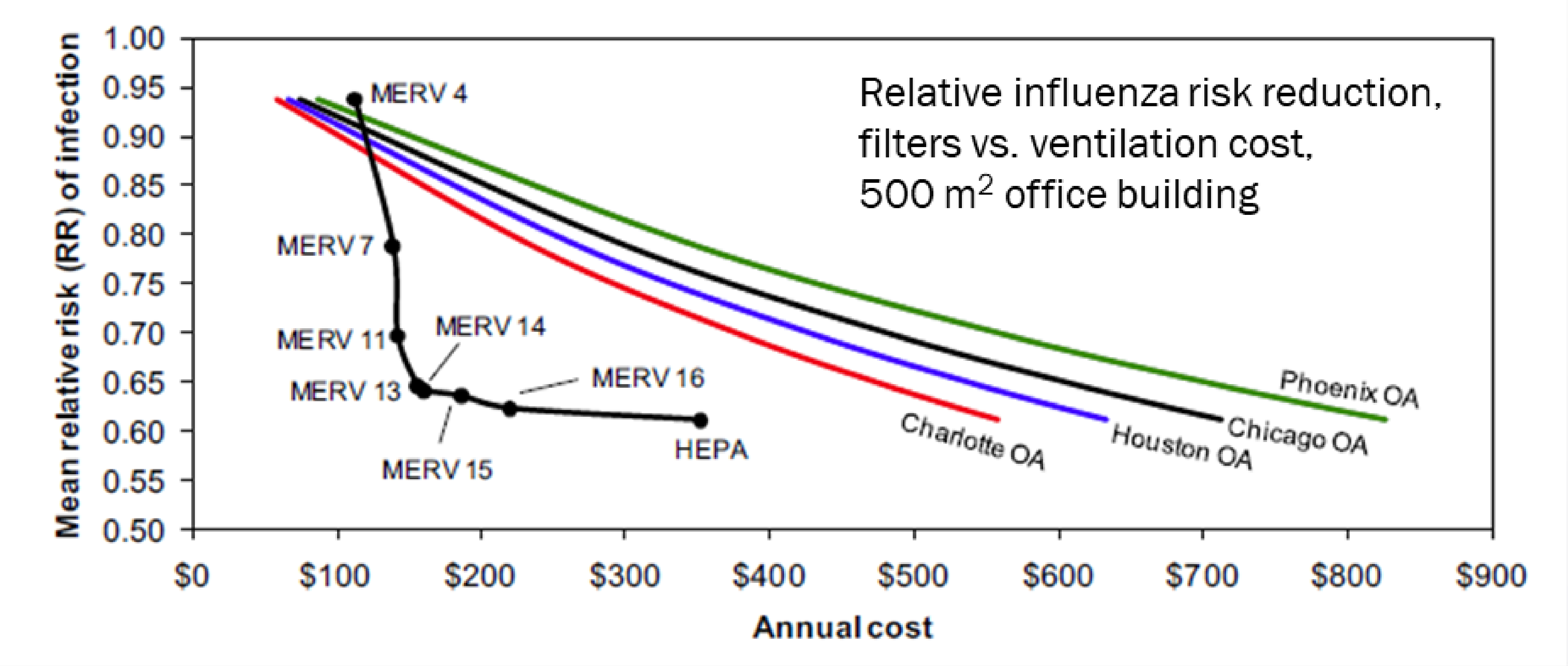
- SARS-CoV-2 size O(100nm)
- Contained in respiratory droplet residues of larger size
- Sub-HEPA media filters can collect particles with high efficiency



Chao, et al., Aerosol Science 40 (2009) 122-133

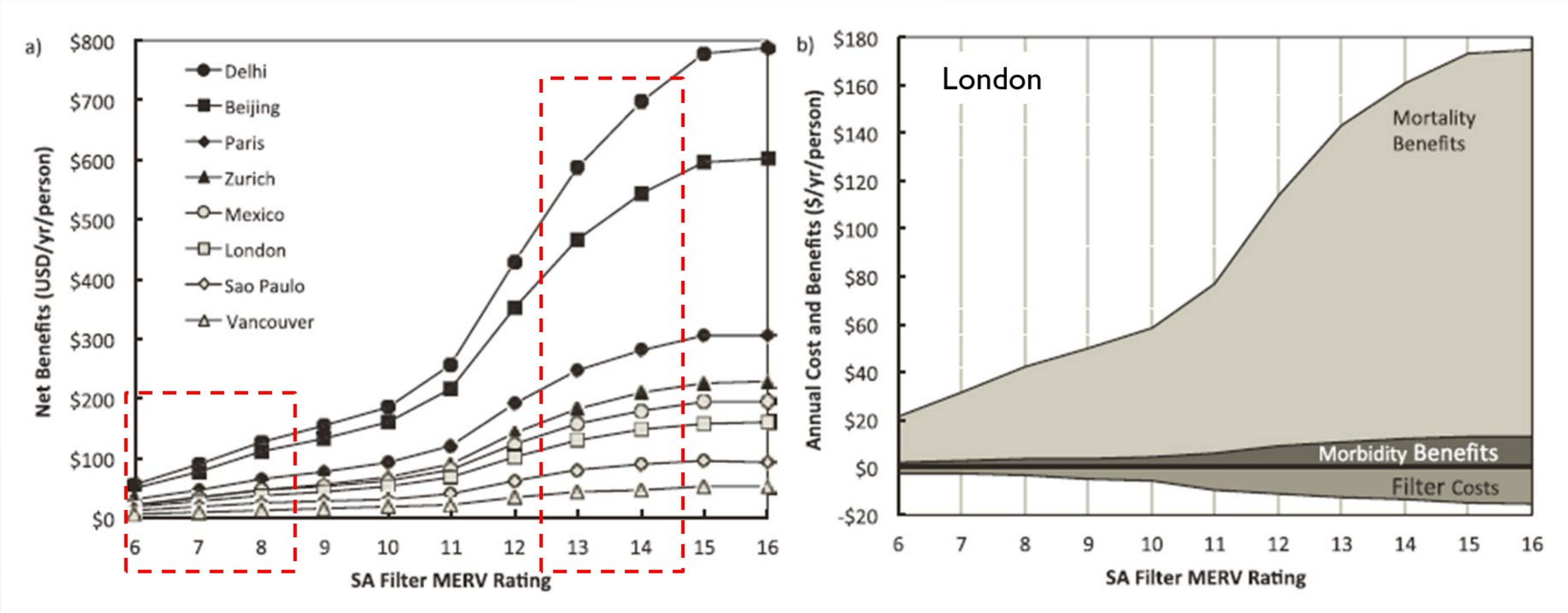
Liu, et al., Nature 40 (2020) https://doi.org/10.1038/s41586-020-2271-3

Filtration can be a lower energy way to reduce aerosol/airborne infection risk



Azimi and Stephens, Building and Environment 70 (2013) 150-160

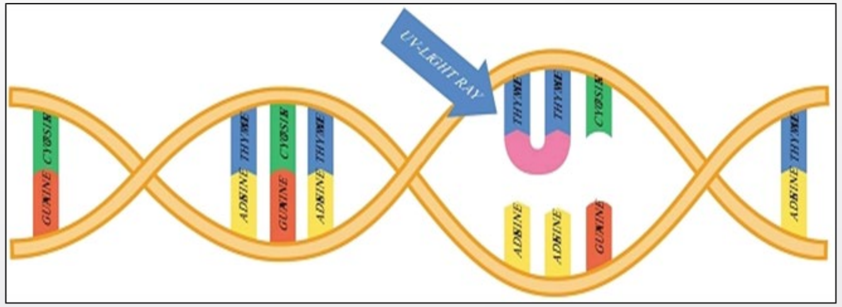
Filtration has benefits other than infection control

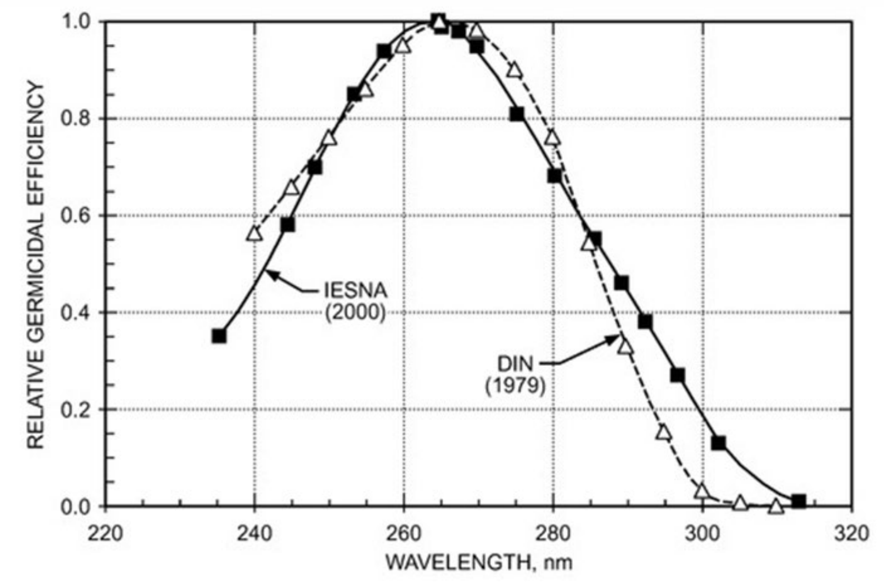


(Montgomery, J., C. Reynolds, S. Rogak, S. Green. 2015. Financial Implications of Modifications to Building Filtration Systems. Building and Environment 85:17-28.)

Air disinfection – germicidal UV light

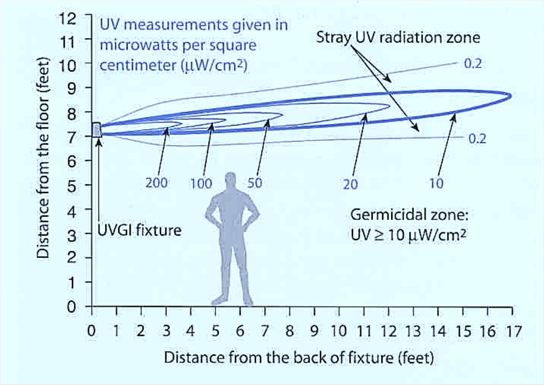
- Ultraviolet light in UVC band
- 265 nm ideal, 254 nm produced by low pressure Hg vapor lamps is standard
- Disrupts microbial DNA/RNA, prevents reproduction
- Exponential dose response
- Coronavirus susceptibility is good
- Long record of application, CDC approved for tuberculosis control as adjunct to filtration
- Emerging technology – LEDs, far UV (222 nm) from Kr-Cl excimer lamps





Germicidal UV applications

Upper Air UVGI



In-Duct/Coil UVGI

Portable Surface Treatment UVGI

System Effects – Combining Ventilation, Filtration, and Air Cleaning

- Combinations of controls can be synergistic
  - MERV rated filter + UV can approach HEPA performance
- Some combinations of controls are mutually exclusive
  - DOAS + central filtration for indoor contaminants
- Some are additive but trade off
  - Ventilation + air cleaning

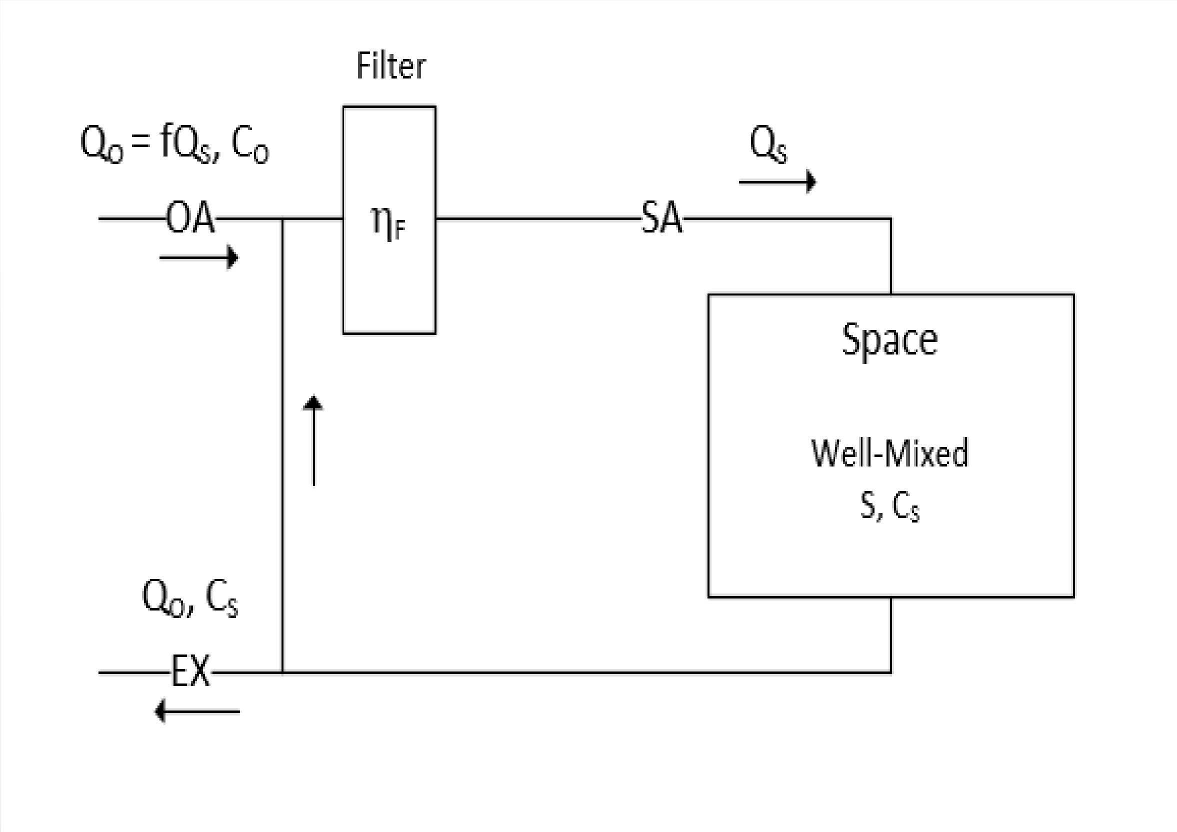
- Air cleaner effectiveness – describes incremental effect of a control

$$\varepsilon = \frac{C_{uncontrolled} - C_{controlled}}{C_{uncontrolled}}$$

Nazaroff, W. 2000. Effectiveness of Air Cleaning Technologies. *Proc. of Healthy Buildings 2000.*

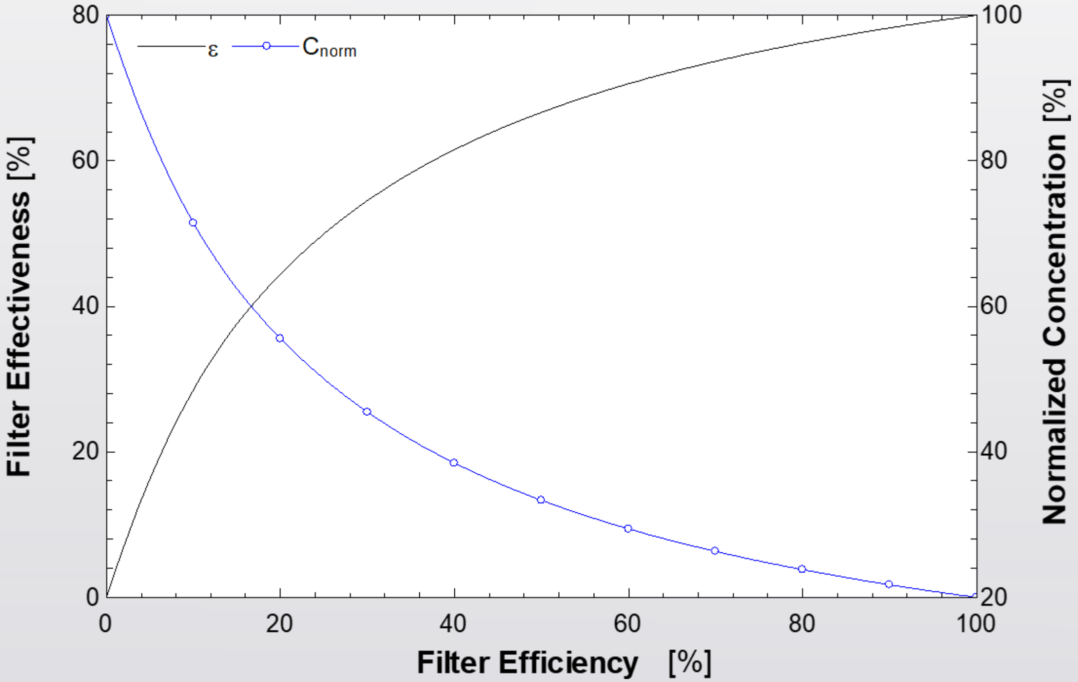
Ventilation/Filtration Trade Off

- Simple example: Ventilation + Filtration
  - Well-mixed, steady state
  - $Q_S = 100$
  - $S=1$
  - $C_O = 0$
- Scenario 1
  - η_F = variable
  - 20% OA
- Scenario 2
  - η_F = 60%
  - f = variable

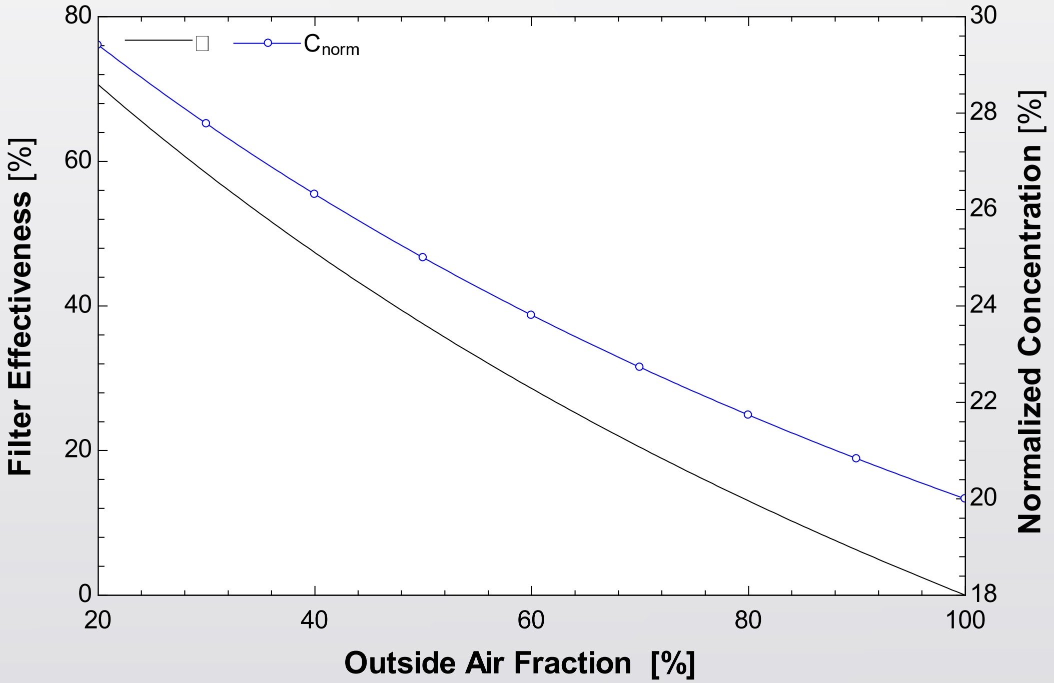


Ventilation/Filtration Trade-Off

20% OA, variable filter efficiency



60% filter efficiency, variable OA

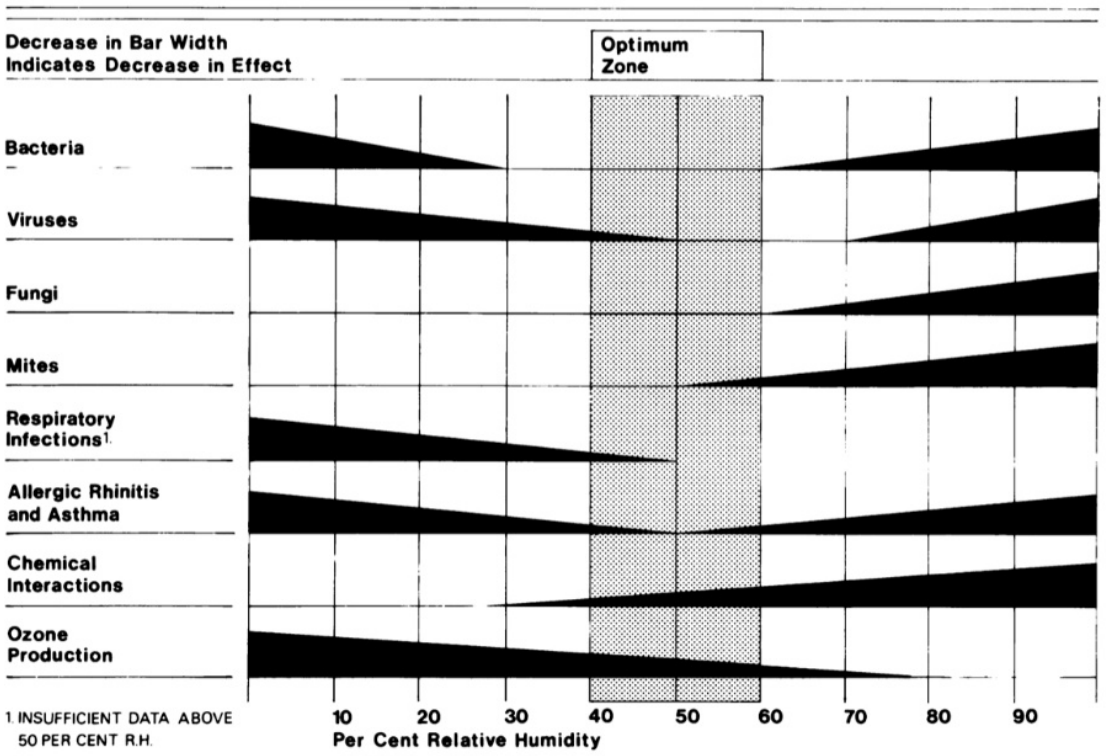


Normalized space concentration is relative to value at 20% OA with no filter

Temperature and Humidity Control

- Air temperature and humidity influence infection risk
- Several recent studies recommend 40 – 60% RH for infection risk, disease specific - and studies on coronavirus suggest they are more resilient than some
- Possible mechanisms
  - Lower RH → faster droplet evaporation, less deposition
  - Lower RH → desiccation of mucosa by dry air increases susceptibility
  - Lower RH → longer survival/higher infectivity of microorganism

Arundel AV, Sterling EM et al. *Indirect Health Effects of Relative Humidity in Indoor Environments*, Environmental Health Perspectives Vol 65, 351-61, 1986.



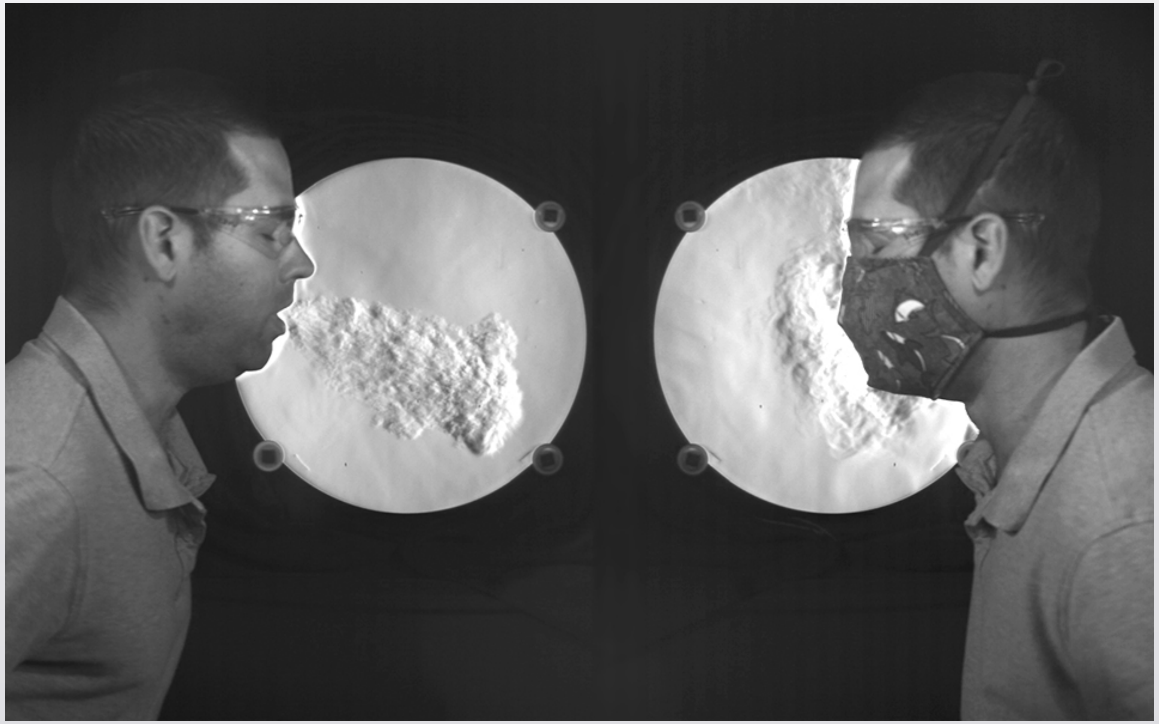
Optimum relative humidity range for minimizing adverse health effects.

Temperature and Humidity

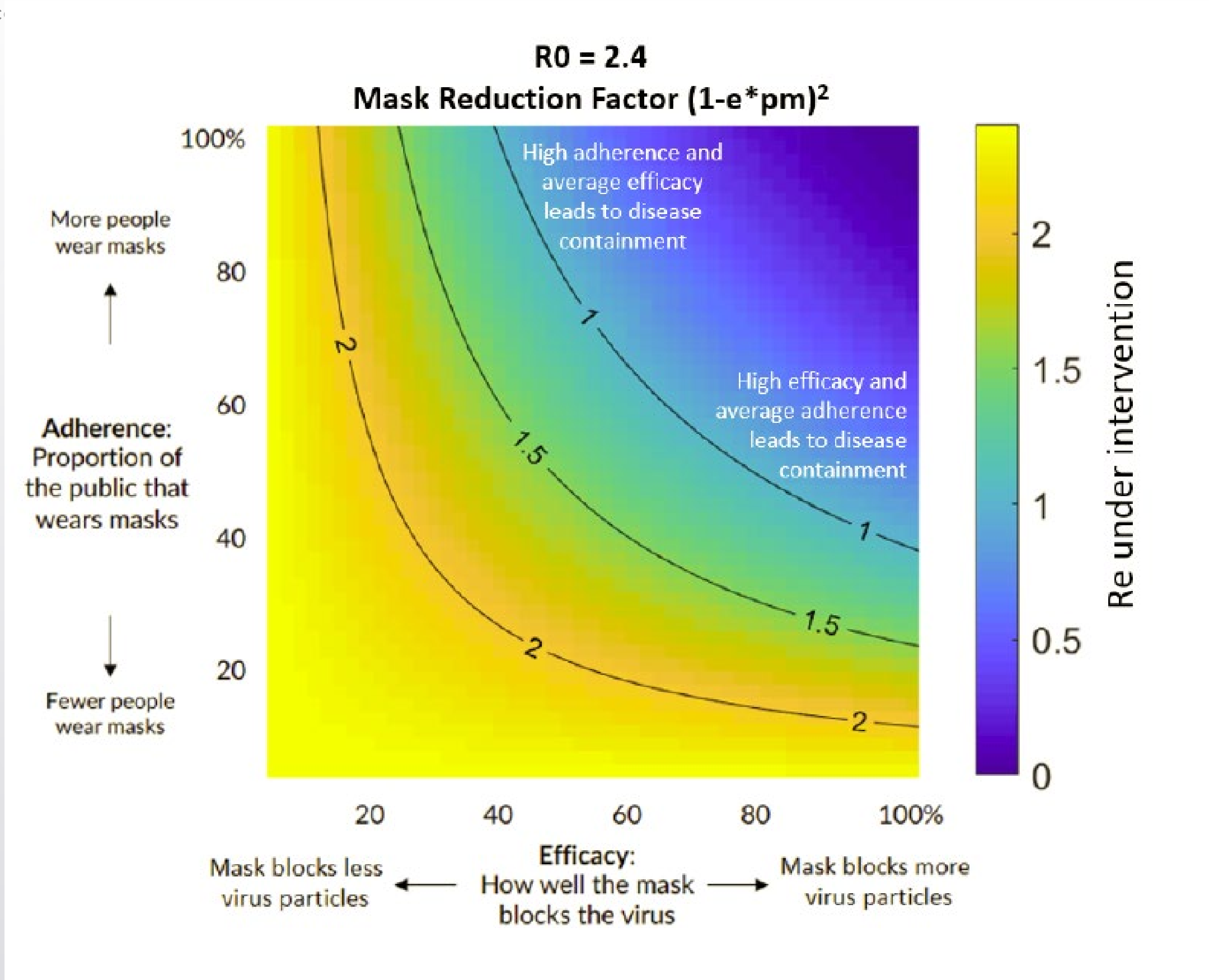
- Possible concerns about humidification and temperature manipulation to control infection risk
  - Different responses for different pathogens
  - Risk of moisture damage/mold growth
  - May reduce effectiveness of UVGI
  - May adversely affect comfort
- No specific recommendation in Infectious Aerosols position document but, practitioners are encouraged to consider on a case by case basis
- ASHRAE Covid-19 guidance for existing buildings bases humidity adjustments on evaluation of system and building limitations
- REHVA Covid-19 guidance – "Humidification and air-conditioning have no practical effect" – based on regional climate and their literature review

Masks - Source Control and PPE

- Well-fitted, high efficiency mask protects wearer and others
- Other masks mainly protect others from large droplet spray/aerosol jets generated by wearer



Credit: M. Staymates/N. Hanacek/NIST
https://www.nist.gov/blogs/taking-measure/my-stay-home-lab-shows-how-face-coverings-can-slow-spread-disease

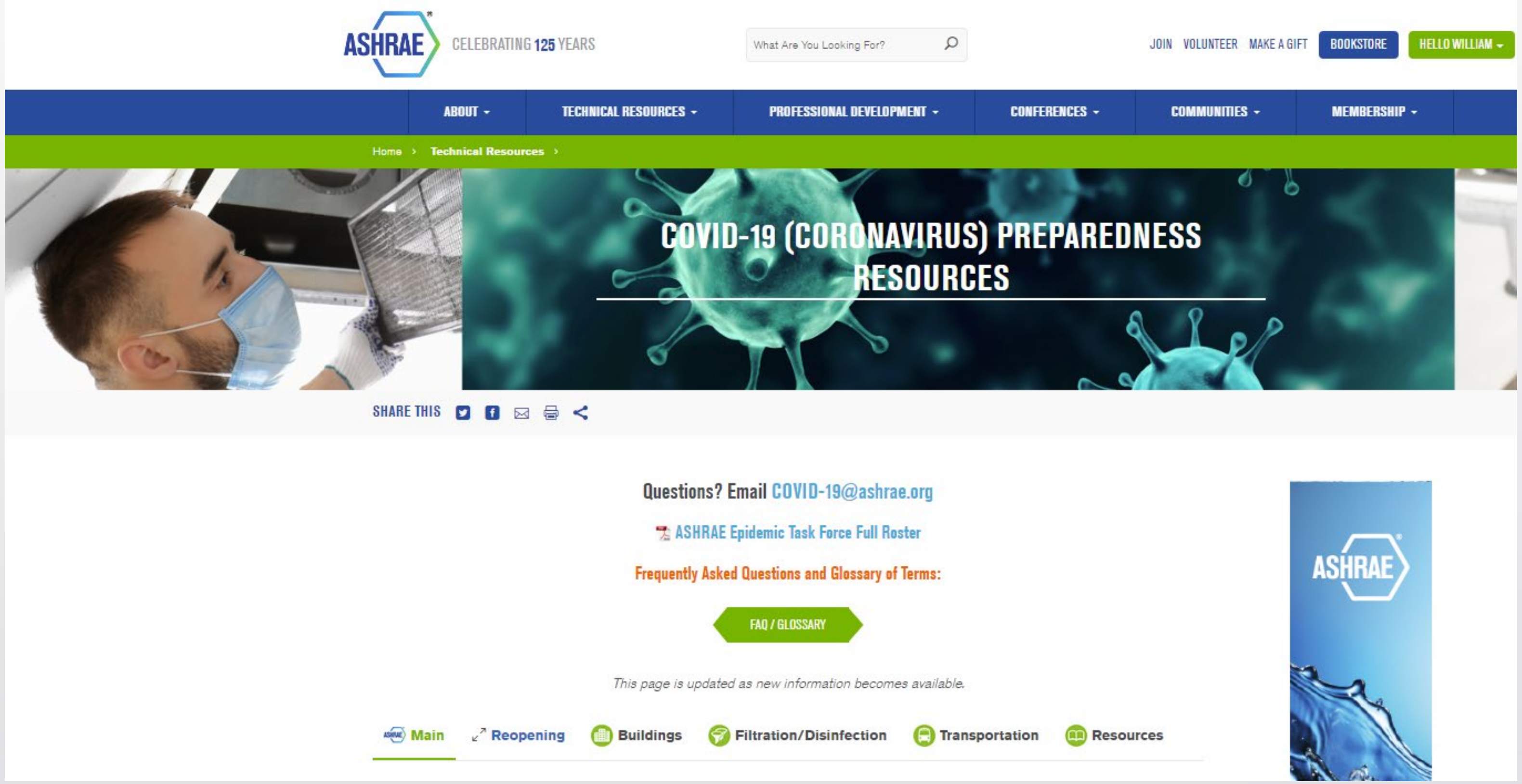


Howard, J., et al. Face Masks Against COVID-19: An Evidence Review
doi:10.20944/preprints202004.0203.v2

Summary

- HVAC systems primarily reduce risk of aerosol and airborne transmission by reducing airborne concentration
- Relatively small repertoire of engineering controls applicable to many building types – with big differences in cost and ease of implementation
- Engineering controls cannot control all infection risk – part of an overall strategy…wear your mask if you have one and follow distancing and hand-washing recommendations!

Thank You!



ashrae.org/covid19

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