PennState College of Engineering | ARCHITECTURAL ENGINEERING

AIR CONDITIONING AND INFECTION RISK: KNOWNS, UNKNOWNS, AND SUSPICIONS

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ASHRAE®

Does air conditioning spread Covid-19?

CDC Centers for Disease Control and Prevention
CDC 24/7: Saving Lives, Protecting People™

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Volume 26, Number 7—July 2020

Research Letter

COVID-19 Outbreak Associated with Air Conditioning in Restaurant, Guangzhou, China, 2020

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Research Letter

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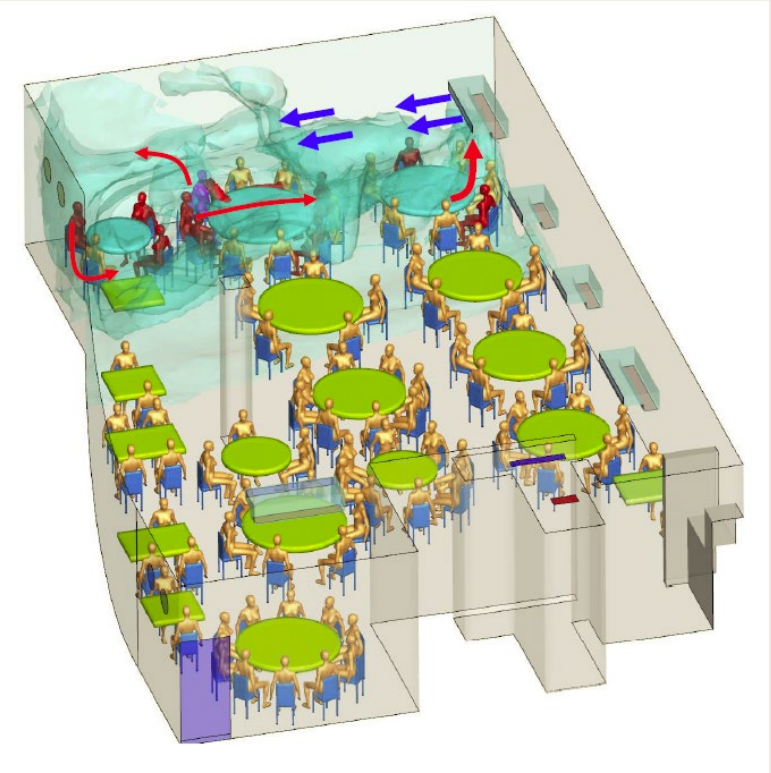
"We conclude that in this outbreak, droplet transmission was prompted by air-conditioned ventilation."

"Conclusions: Aerosol transmission of SARS-CoV-2 due to poor ventilation may explain the community spread of COVID-19."

Li, et al. analysis of Guanzhou restaurant incident

- Ductless mini-split air-conditioning
- No ventilation air supply
- Four exhaust fans, none running
- No close range/fomite transfer opportunities observed on video
- Measured ventilation rate ~0.75 – 1 L/s per patron (very low!)



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

William Bahnfleth posted this

Should I run my air-conditioning system during the pandemic? What does the Guangzhou restaurant incident really tell us?

William Bahnfleth on LinkedIn

May 1, 2020

"If shutting off air-conditioning means that ventilation and filtration functions will be disabled, it is quite possible that risk of infection will increase, but if there is no ventilation or filtration, circulation of air in a space may contribute to risk."

"The main way (air conditioning) can contribute to spreading coronavirus is by creating strong air currents that can move the droplets … and contribute to increased risk," said William Bahnfleth, chair of the American Society of Heating, Refrigerating and Air-Conditioning Engineers' Epidemic Task Force (ASHRAE) and professor at Penn State University."

Willis Carrier's definition of air-conditioning

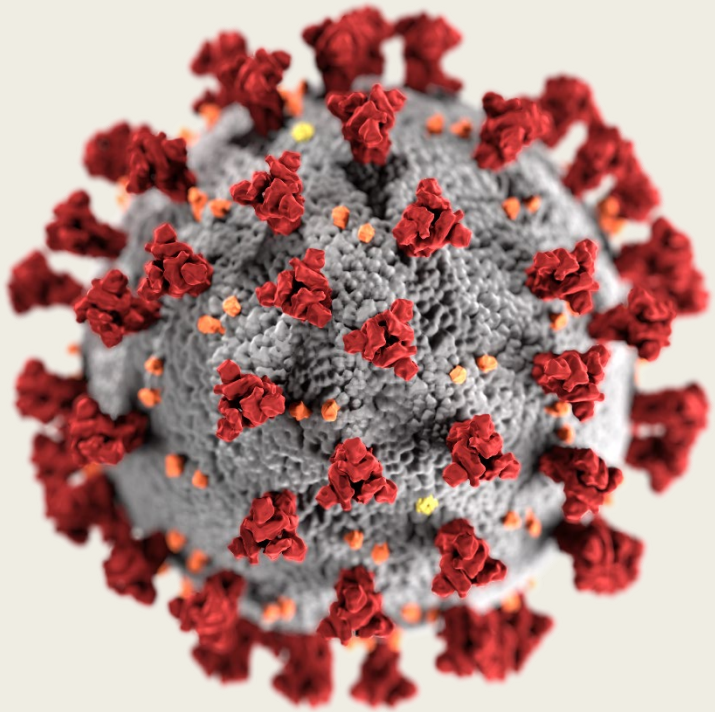
"The control of temperature, moisture content, cleanliness, quality, and air circulation as required by occupants, a process, or a product"

Air Conditioning per Carrier and Infection Risk

- Temperature and moisture control – may reduce risk
- Cleanliness/air quality
  - *Ventilation with outdoor air – reduces risk*
  - *Filtration and air cleaning – reduces risk*
- Air motion – situationally increases or decreases risk
  - *Characteristics of pathogen*
  - *Ventilation/Filtration/Air cleaning in place*

SARS-CoV-2

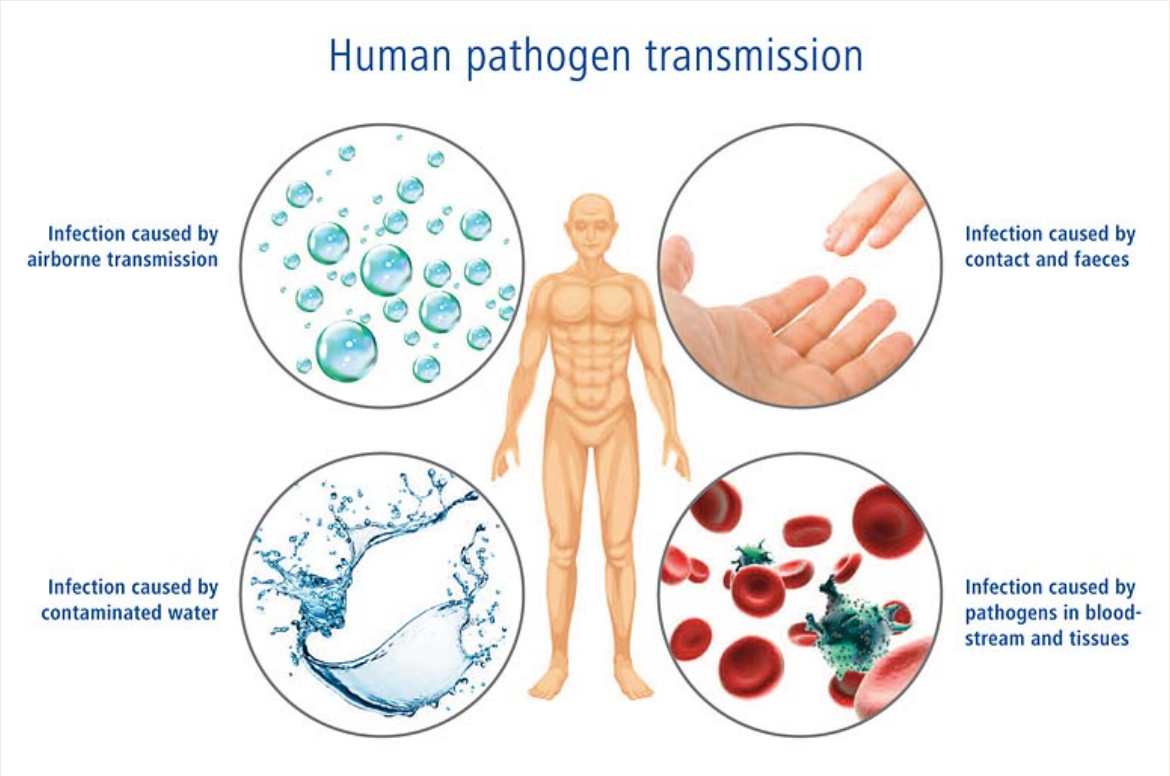
- Known
  - *Size…but rides on/in respiratory droplets and other aerosols*
- Not accurately determined
  - *Shedding rate of infectors*
  - *Infectious dose*
  - *Partitioning in aerosols*
- Debated
  - *Aerosol transmission*



Infectious Disease Transmission Modes

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

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



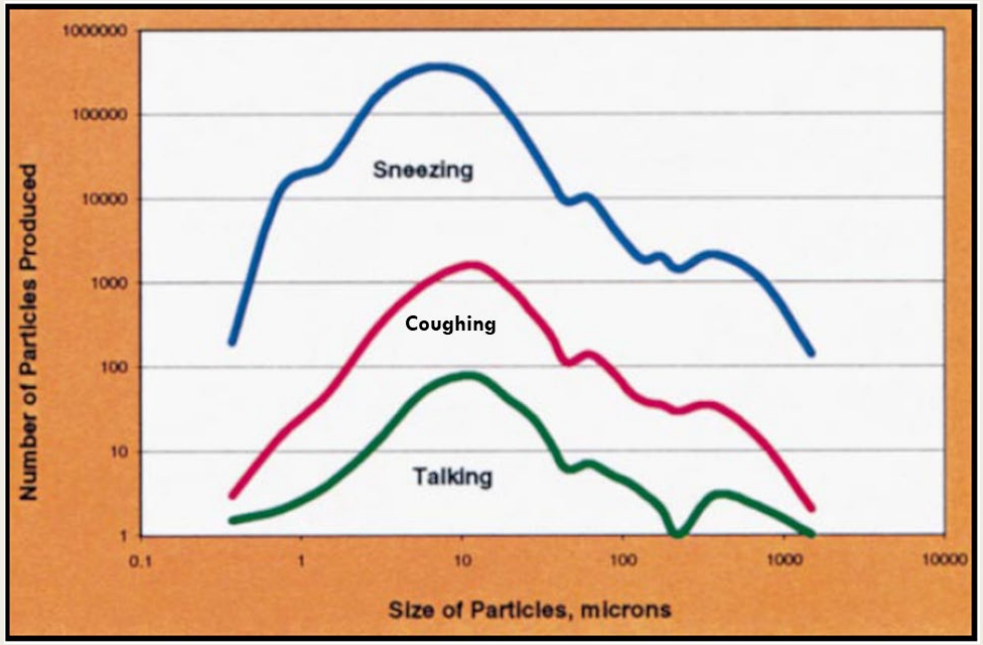
bode-science-center.com

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

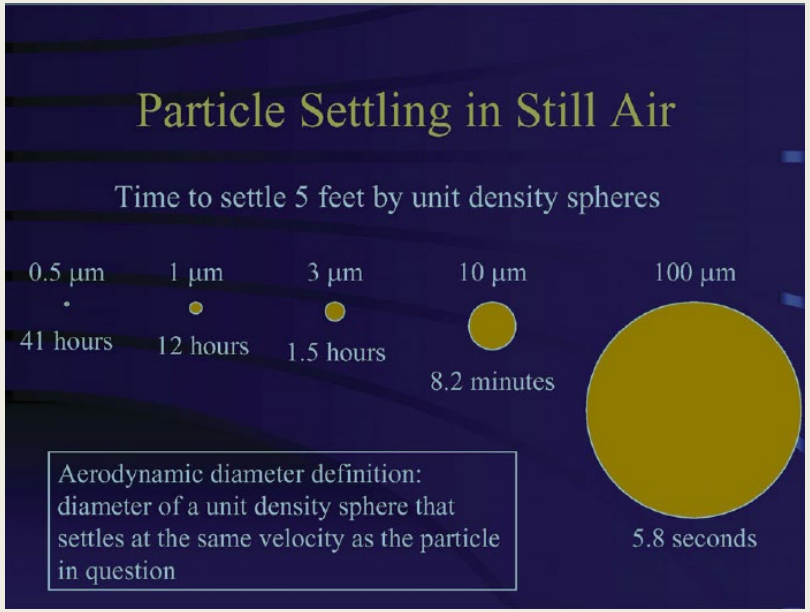
- Emitted as droplets
  - *Water, proteins, salts…*
  - *Dehydrate to smaller sizes*
  - *Process dependent on relative humidity*
  - *Initial diameter < 1 µm to > 1000 µm*
- Infected persons shed viruses in droplets
- Studies of influenza have found > 50% of viral load is in particles < ~5 µm

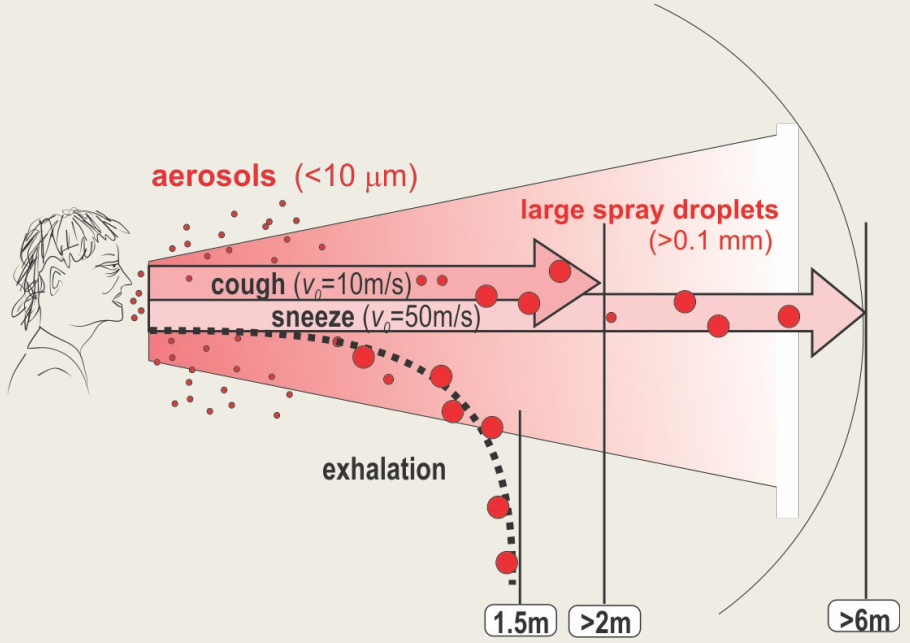


Duguid, et al. 1945

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





COVID-19 Transmission

- Public health authorities (WHO, national organizations like CDC in US)
  - *Transmission is mainly close contact/large droplet*
  - *Admit some evidence of aerosol transmission*
- ASHRAE, REHVA, and other HVAC societies
  - *HVAC systems mainly impact aerosol transmission*
  - *Take evidence of possible aerosol transmission as justification for applying the precautionary principle*

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.

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.

ashrae.org/covid19

Ventilation and filtration provided by heating, ventilating, and air-conditioning systems can reduce the airborne concentration of SARS-CoV-2 and thus the risk of transmission through the air. Unconditioned spaces can cause thermal stress to people that may be directly life threatening and that may also lower resistance to infection. In general, disabling of heating, ventilating, and air-conditioning systems is not a recommended measure to reduce the transmission of the virus.

ashrae.org/covid19

Bottom line

- We know ways to reduce the probability of infection
- We do not know precisely how far we need to go with engineering controls
- Distancing and masks are effective source control/personal protection
- Engineering controls – HVAC
  - *Increased outdoor air*
  - *Increased filter efficiency*
  - *Improved air distribution*
  - *Air-cleaners: UV-C and other*

Ventilation/Exhaust/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

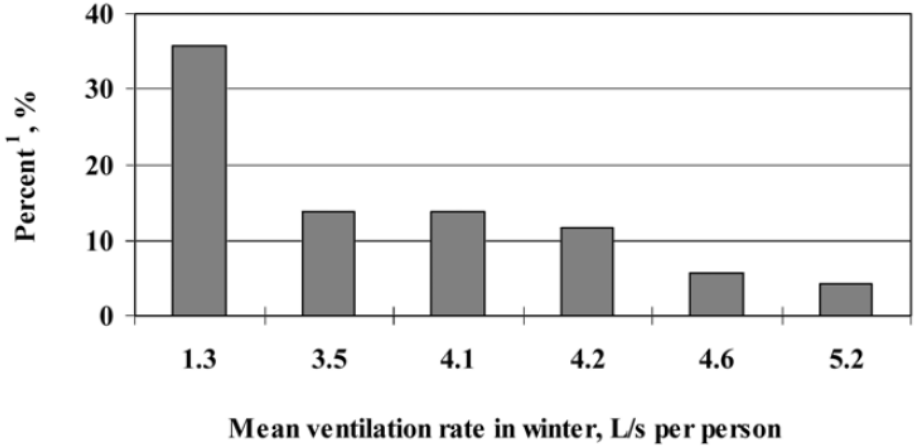
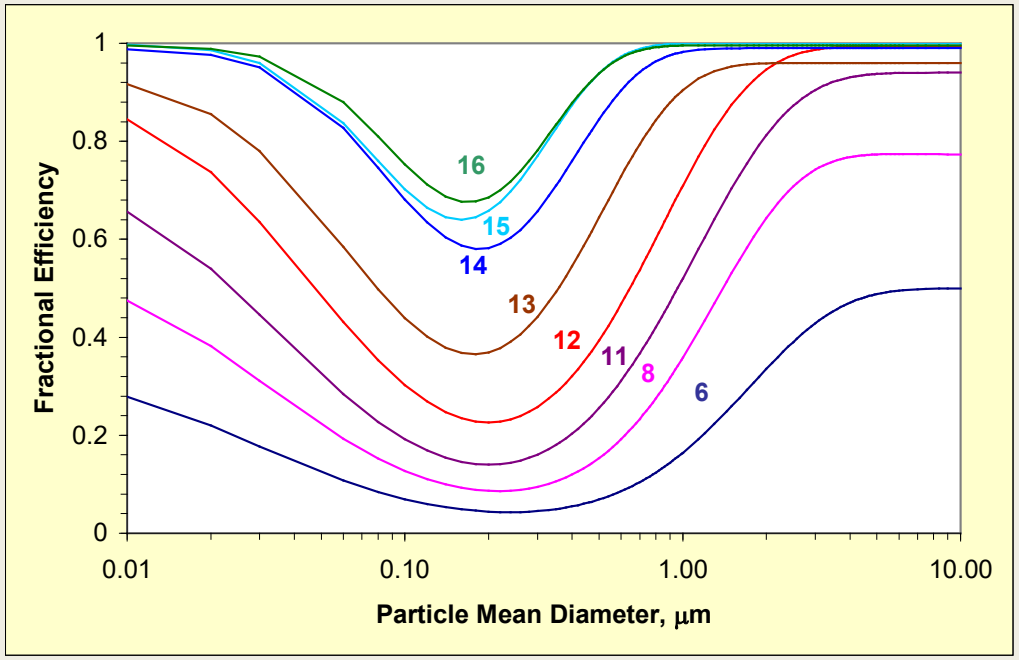


Figure 4. Associations between common cold infection rates and mean ventilation rate in winter in buildings constructed after year 1993. [1] Proportion of occupants with ≥6 common colds in the previous 12 months.

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

Filtration

- Can remove any aerosol contaminant (but not with 100% certainty)
- For indoor sources, must have 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

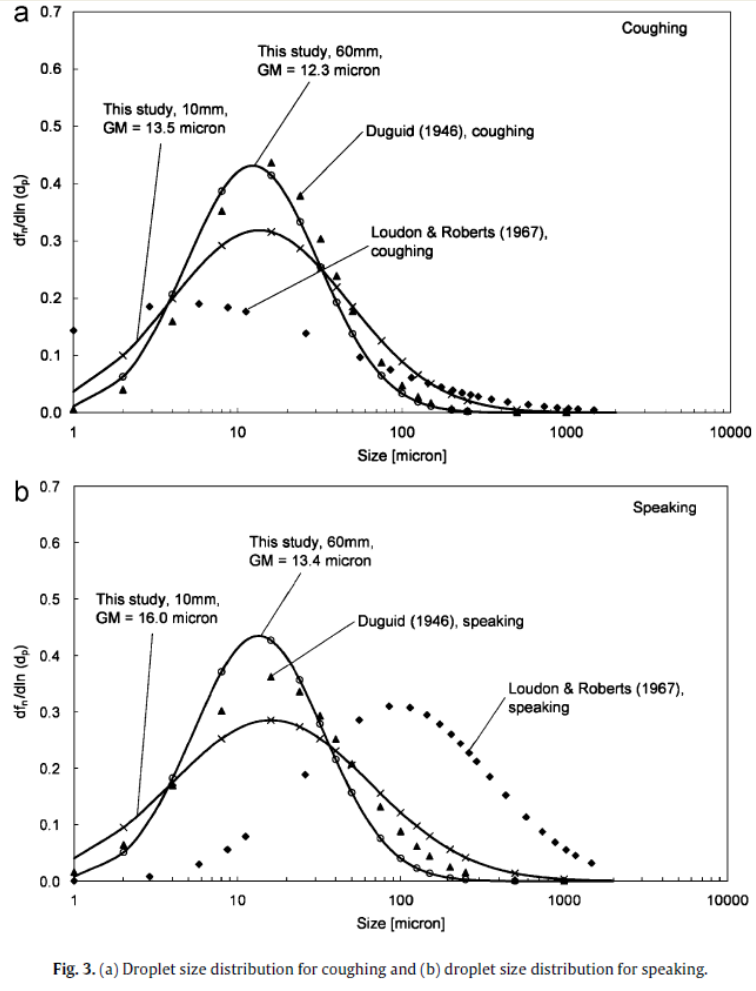
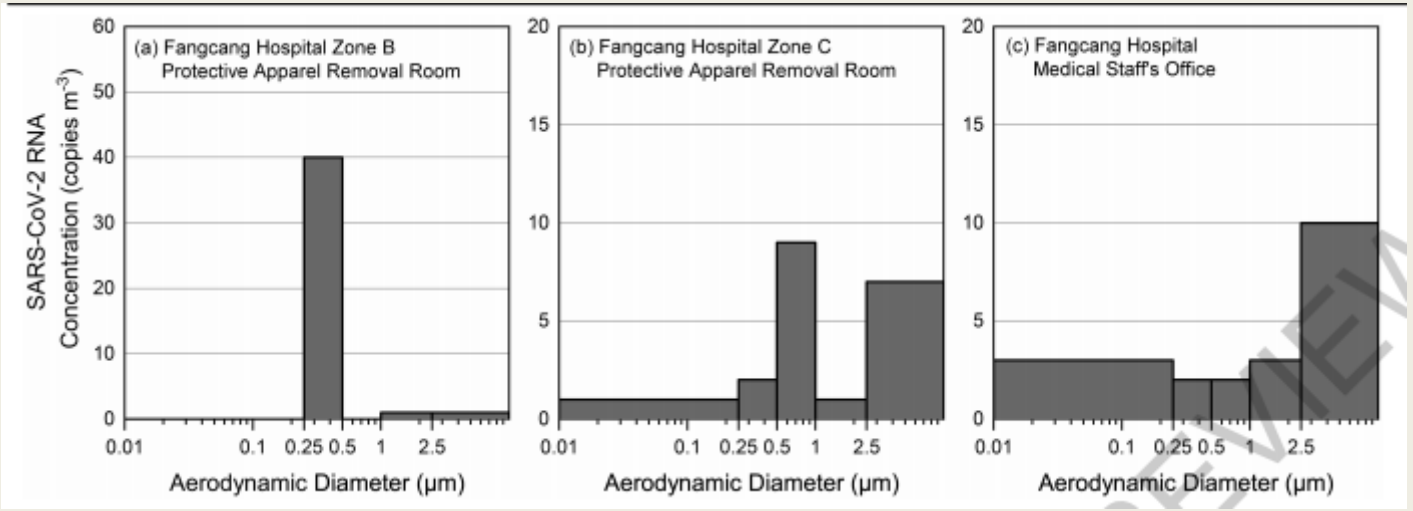


Fig. 3. (a) Droplet size distribution for coughing and (b) droplet size distribution for speaking.

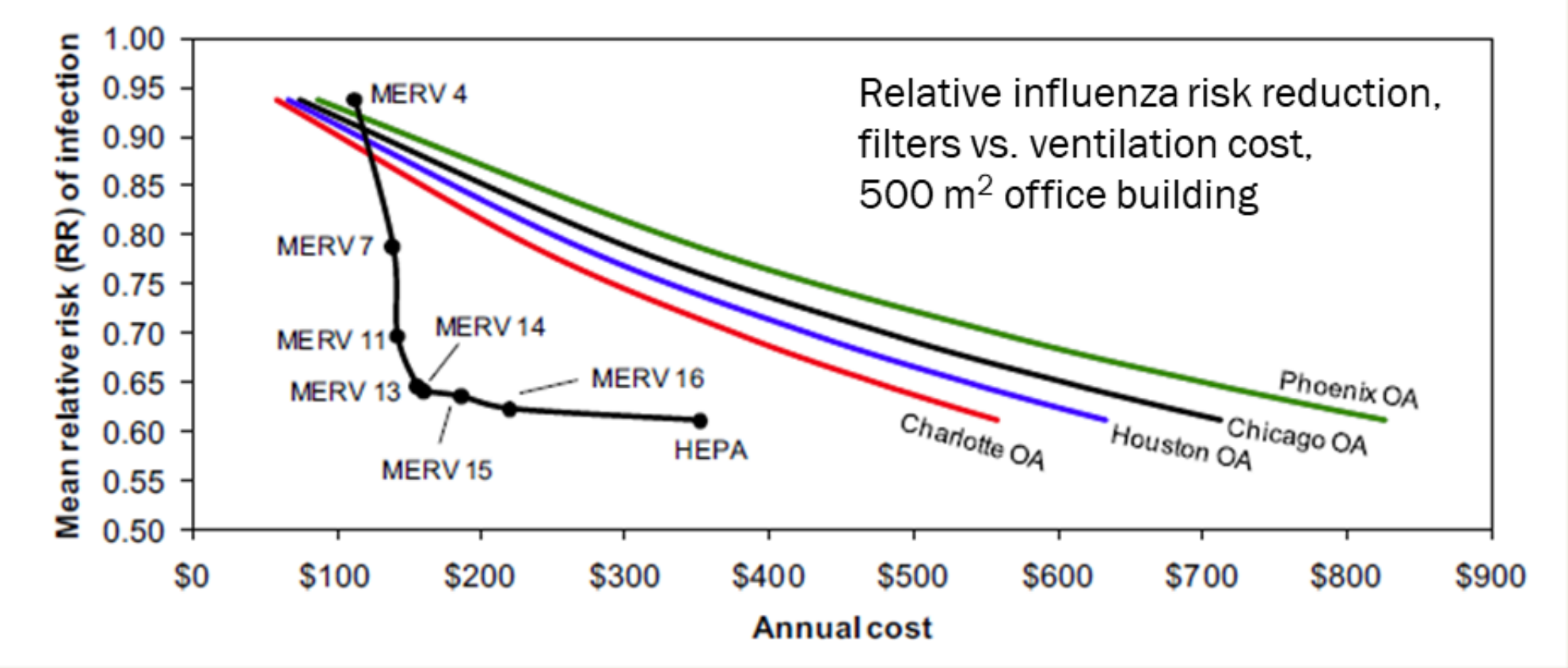
- SARS-CoV-2 size O(100nm)
- Contained in respiratory droplet residues of larger size
- Sub-HEPA media filters can collect particles with high efficiency



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

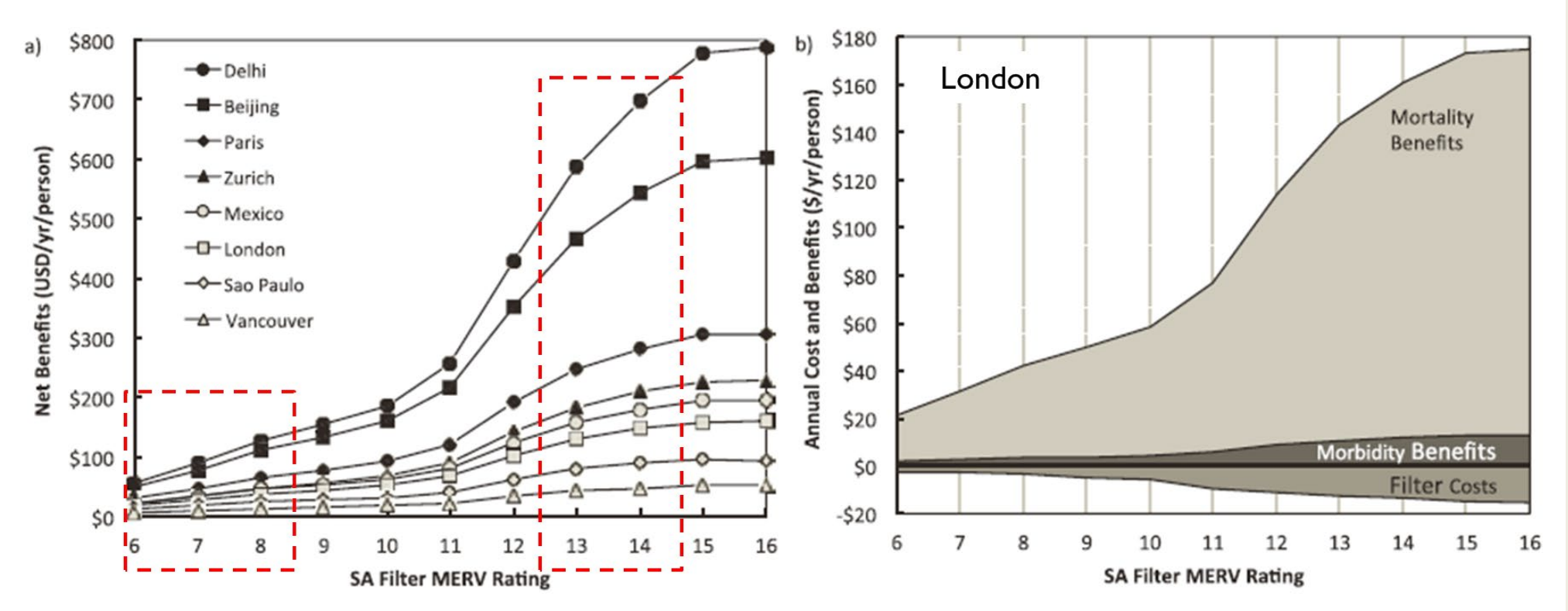
Liu, et al., Nature 40 (2020) https://doi.org/10.1038/s41586-020-2271-3

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



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

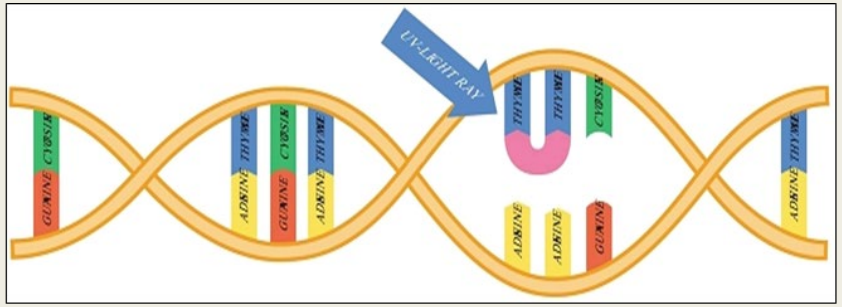
Filtration has benefits other than infection c

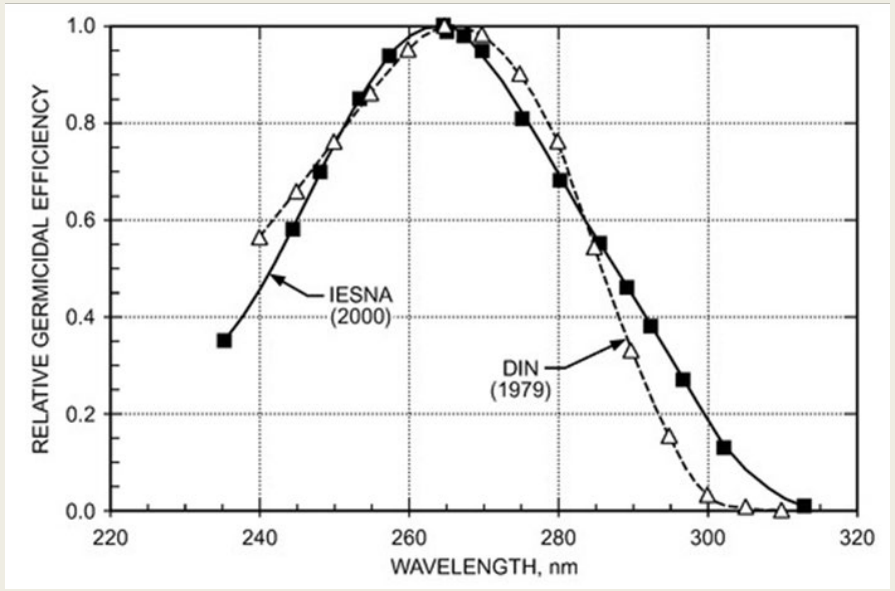


(Montgomery, J., C. Reynolds, S. Rogak, S. Green. 2015. Financial Implications of Modifications to Building Filtration Systems. Building and Environment 85:17-28.)

Air disinfection – germicidal UV light

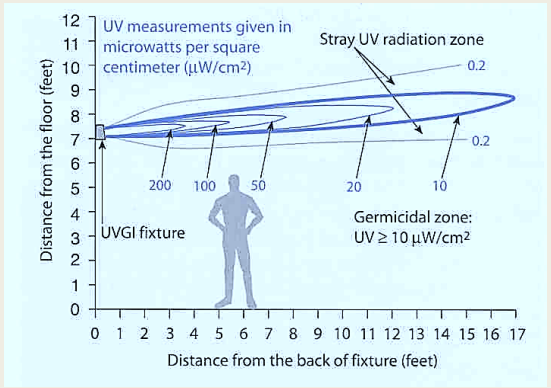
- Ultraviolet light in UVC band
- 265 nm ideal, 254 nm produced by low pressure Hg vapor lamps is standard
- Disrupts microbial DNA/RNA, prevents reproduction
- Exponential dose response
- Coronavirus susceptibility is good
- Long record of application, CDC approved for tuberculosis control as adjunct 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*

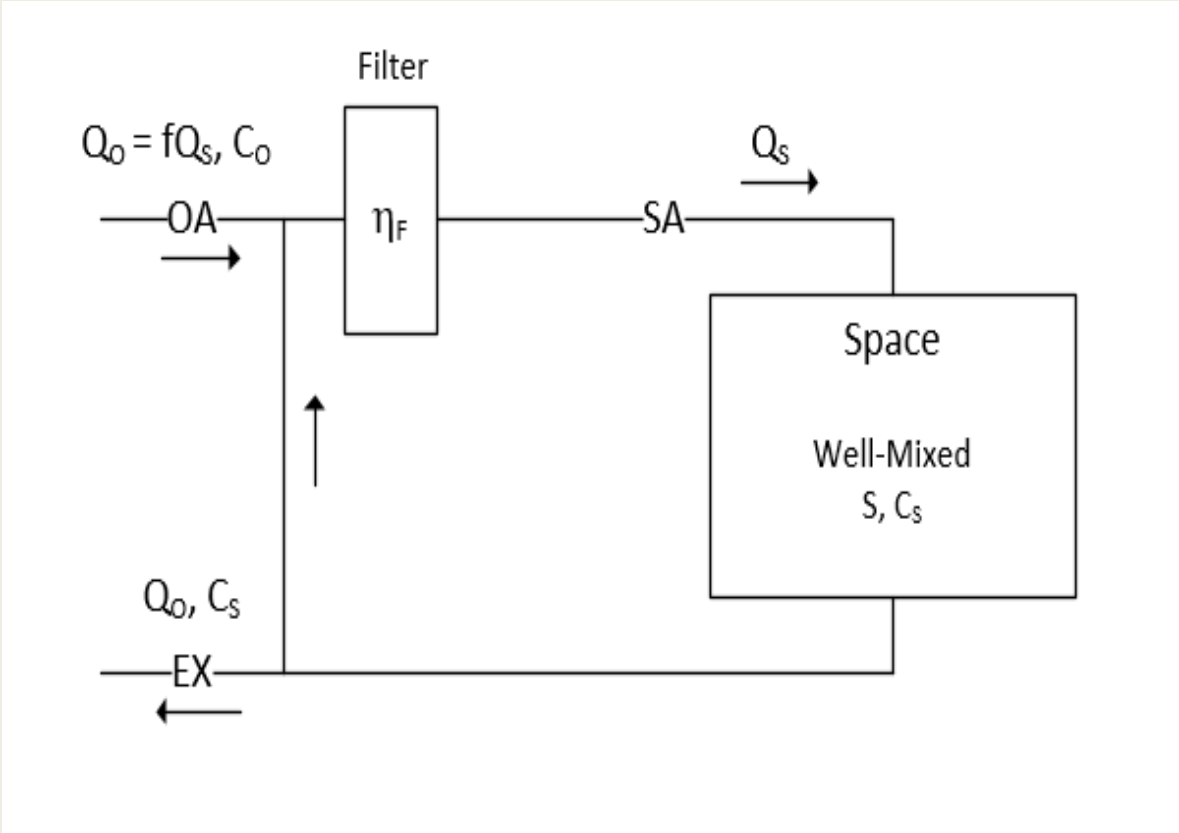
- Air cleaner effectiveness – describes incremental effect of a control

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

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

Ventilation/Filtration Trade Off

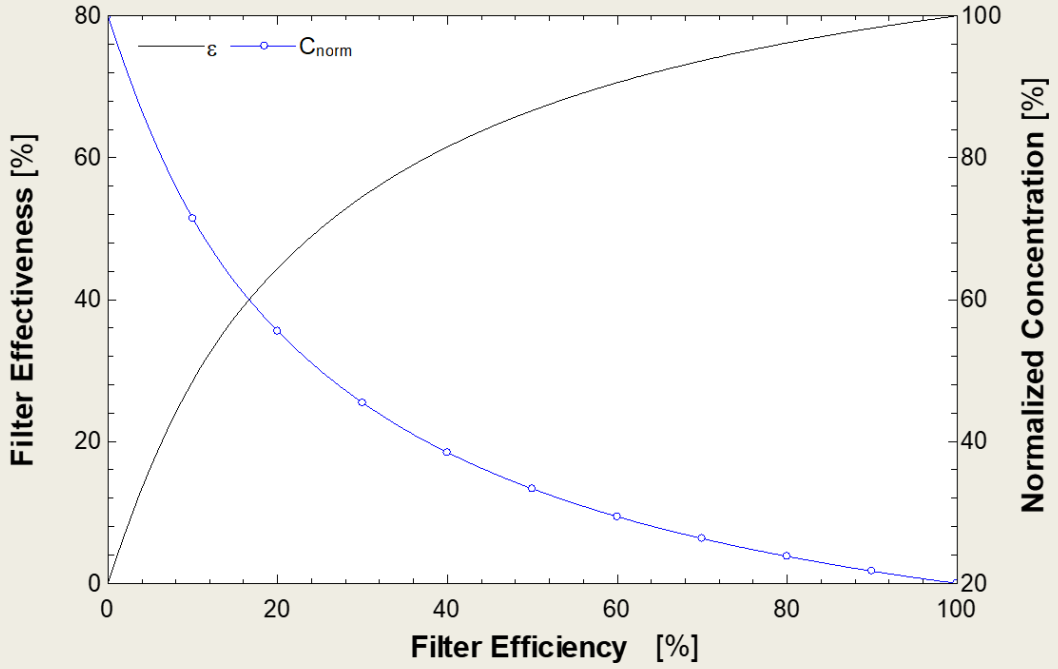
- Simple example: Ventilation + Filtration
  - *Well-mixed, steady state*
  - $Q_S = 100$
  - $S=1$
  - $C_O = 0$
- Scenario 1
  - η_F = variable
  - 20% OA
- Scenario 2
  - $\eta_F = 60\%$
  - f = variable



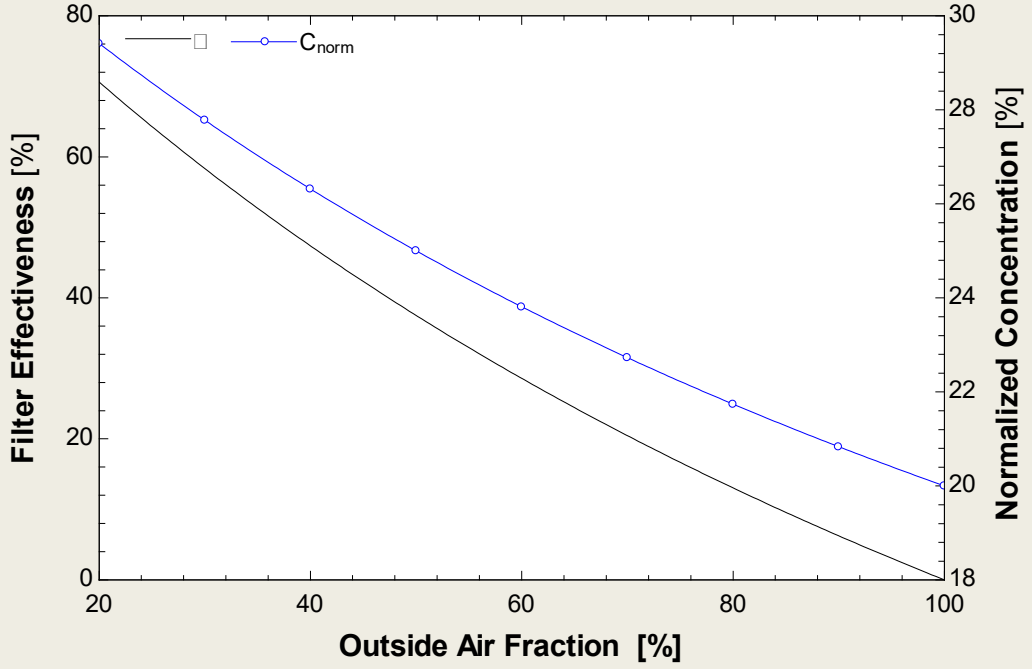
Ventilation/Filtration Trade-Off

Two approaches, same outcome, big energy difference

20% OA, variable filter efficiency



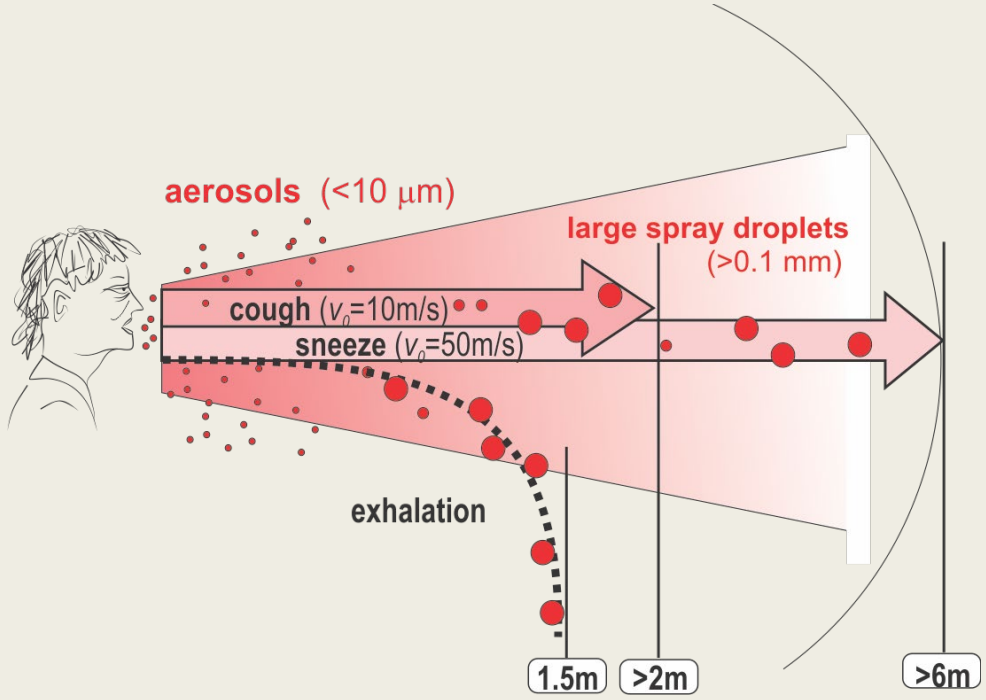
60% filter efficiency, variable OA



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

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 may be options in some cases



Post-Pandemic HVAC

- Changes to standards
  - *Emphasis on health in non-healthcare occupancies*
  - *Higher bar for IAQ that presents challenges with respect to energy goals, system cost*
  - *Resilience as a fundamental design parameter*
- Many research needs
  - *IEQ criteria*
  - *Alternatives to ventilation that are less energy intensive*
  - *Flexible system operation*
  - *Monetization of benefits of infection control measures outside healthcare settings – epidemic response measures have every-day benefits*

Summary

- Overall, well designed and maintained air conditioning systems should not be a major COVID-19 risk factor
- Good outside air supply and filtration are fundamental – without them, factors like air distribution may become important
- The whole truth is complicated and difficult to communicate to a lay audience
- We know how to reduce risk even with incomplete knowledge – more data will lead to better solutions
- Changes in standards and guidance in the future seem likely, particularly increased focus on infection risk and resilience
- ASHRAE COVID-19 guidance: ashrae.org/covid19