PennState College of Engineering | ARCHITECTURAL ENGINEERING

PRACTICAL CONSIDERATIONS FOR USING PORTABLE AIR CLEANERS TO PREVENT TRANSMISSION OF INFECTIOUS AEROSOLS: BACKGROUND

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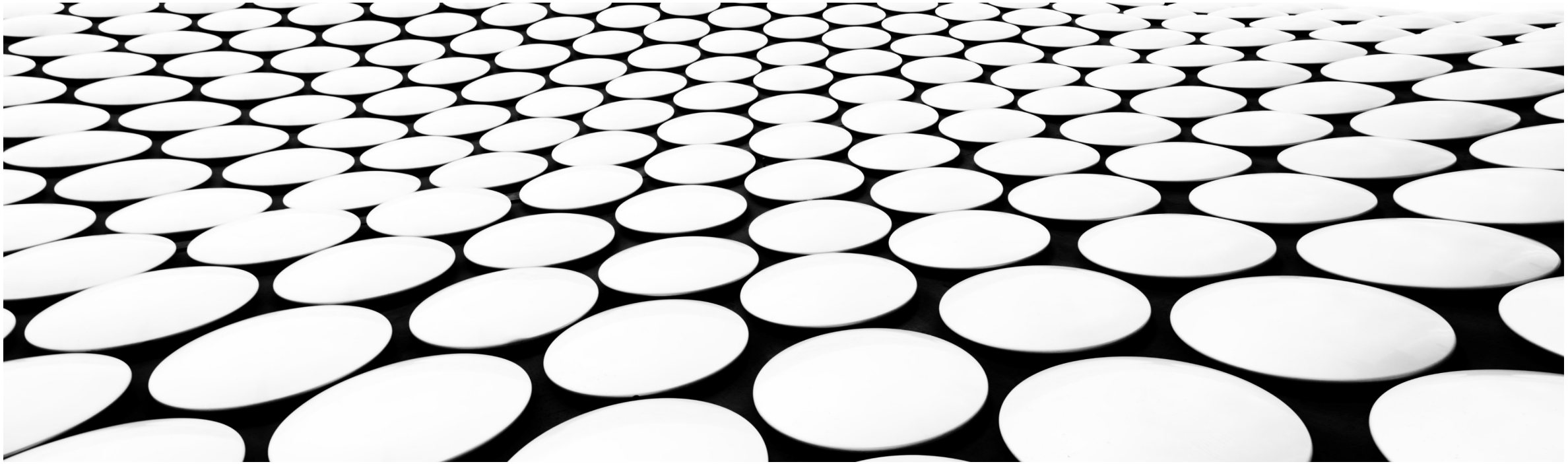
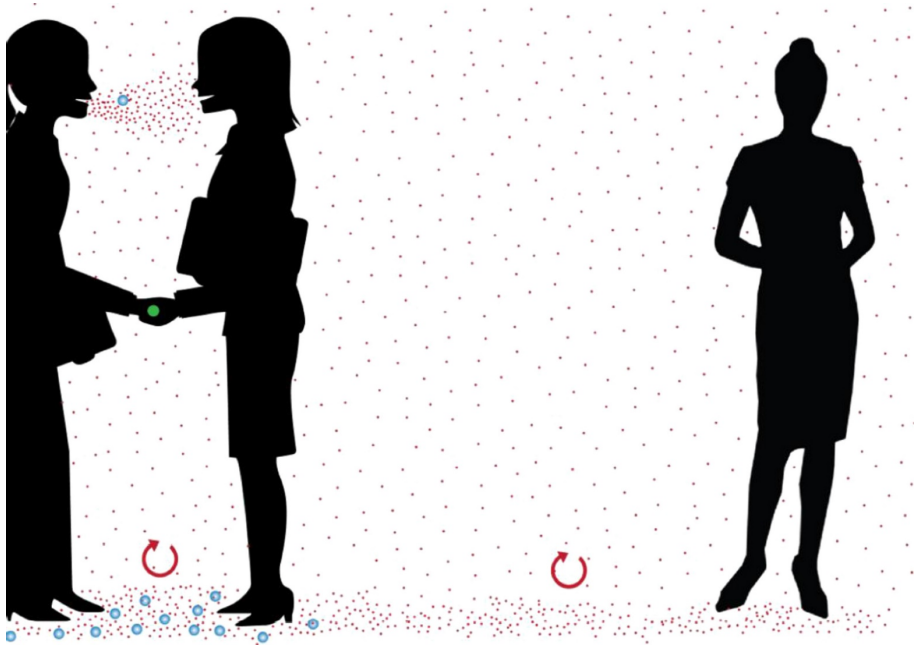


TOPICS

- How are communicable diseases transmitted?
- Infection risk management
- Engineering controls for airborne transmission
- Portable air cleaner basics

COMMUNICABLE DISEASE TRANSMISSION MODES

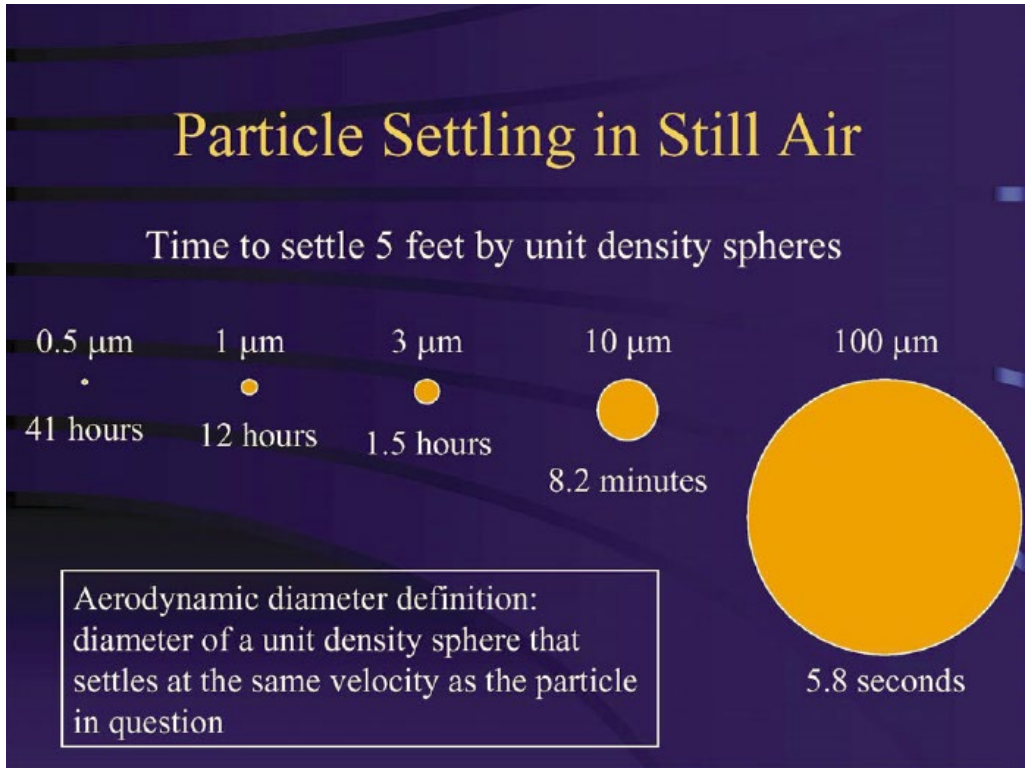
- Inhalation – fine respiratory droplets and aerosol particles
- Deposition – splash or spray of respiratory droplets onto mucous membranes (mouth, nose, eyes)
- Touching – with hands directly contaminated or indirectly by touching contaminated surfaces (fomites)



Tang, J.W., et al., 2021. Dismantling myths on the airborne transmission of severe acute respiratory syndrome coronavirus (SARS-CoV-2). *Journal of Hospital Infection*.

PARTICLE SIZE IS IMPORTANT IN TRANSMISSION AND CONTROL

- Aerosols are fine particles that can stay in the air for some period of time
- Particles 5 micrometers or smaller are important for intermediate range inhalation transmission
- At close range, larger particles also contribute to inhalation and deposition
- The smaller a particle is, the longer it is likely to stay airborne
- Investigations of influenza and Covid-19 transmission found that most of viral load is in particles smaller than 5 micrometers



5 ft = 1.52 m

INFECTION RISK IS A FUNCTION OF EXPOSURE (DOSE)

- Inhaled Dose = Concentration × Volume Inhaled
- Factors affecting concentration
  - Number of infectors
  - Emission rate per infector
  - Removal rate – controls + natural mechanisms
- Factors affecting volume inhaled
  - Age
  - Activity level
  - Duration of exposure

AIRBORNE INFECTION RISK – WELLS-RILEY MODEL

$$P = 1 - \exp\left(-\frac{Iqpt}{Q}\right)$$

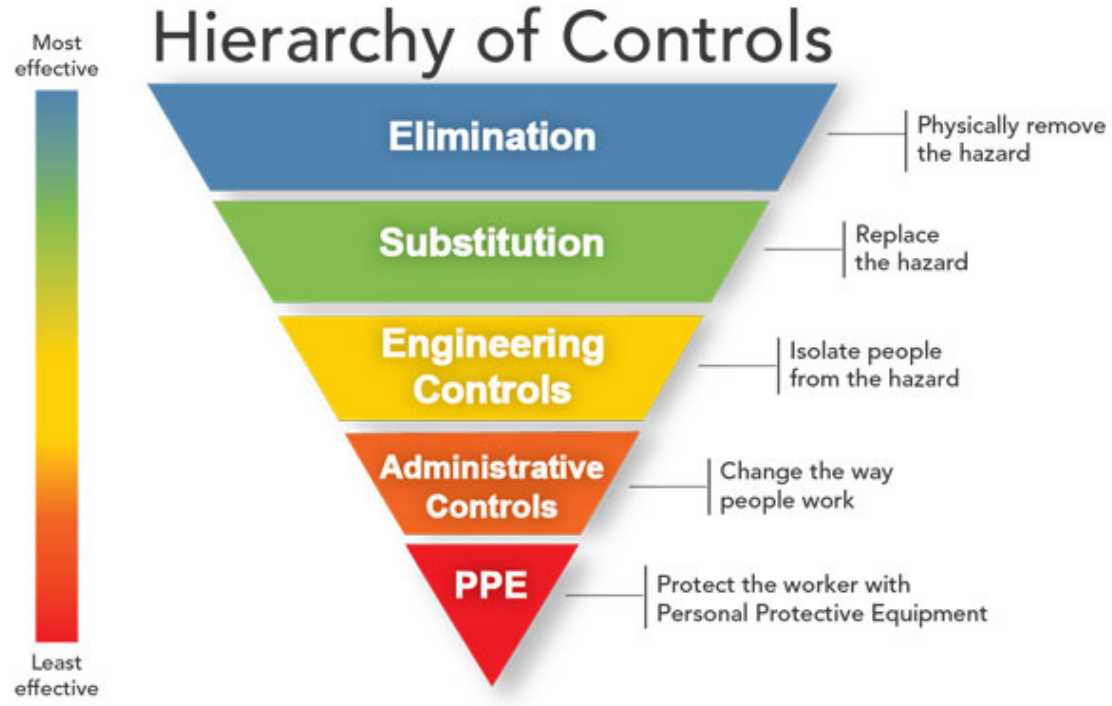
- Steady-state conditions
- Time-dependent risk
- Quanta determined from data

- P = probability of new infections
- I = number of infectors
- q = quanta (infectious dose) emission rate [1/hr]
- p = pulmonary ventilation rate per susceptible [m^3/h]
- t = exposure time [hr]
- Q = flow rate of uncontaminated air [m^3/h]

Given source and occupancy characteristics, can calculate required uncontaminated air flow rate

INFECTION RISK MANAGEMENT – HIERARCHY OF CONTROLS

- Source elimination
  - Testing, contact tracing
- Substitution – NA
- Engineering controls
  - HVAC interventions to control aerosol concentration
- Administrative controls
  - Rules and procedures
- Personal protective equipment
  - Face coverings
  - Respirators

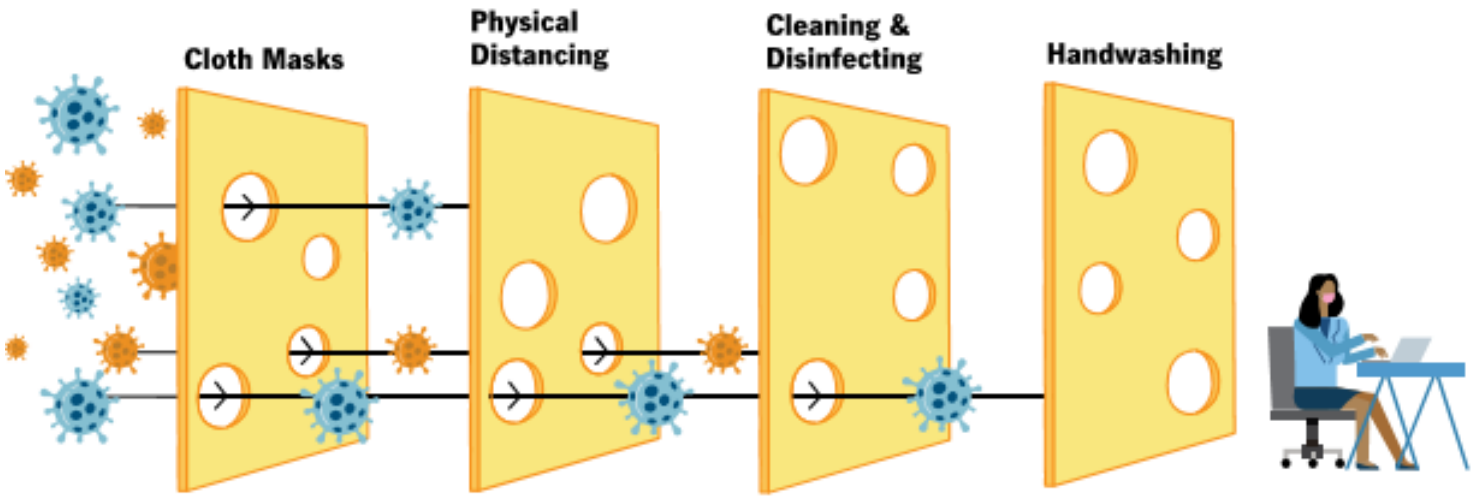


ENGINEERING CONTROLS

- Ventilation – dilute contaminants with outdoor air/exhaust contaminated air
- Air Distribution – use airflow to prevent exposure/enhance removal of contaminants
- Mechanical Filtration – capture infectious particles
- Disinfection – inactivate infectious particles
- Humidity – influence natural inactivation rate of infectious particles (viruses)

INFECTION RISK MANAGEMENT – SWISS CHEESE MODEL

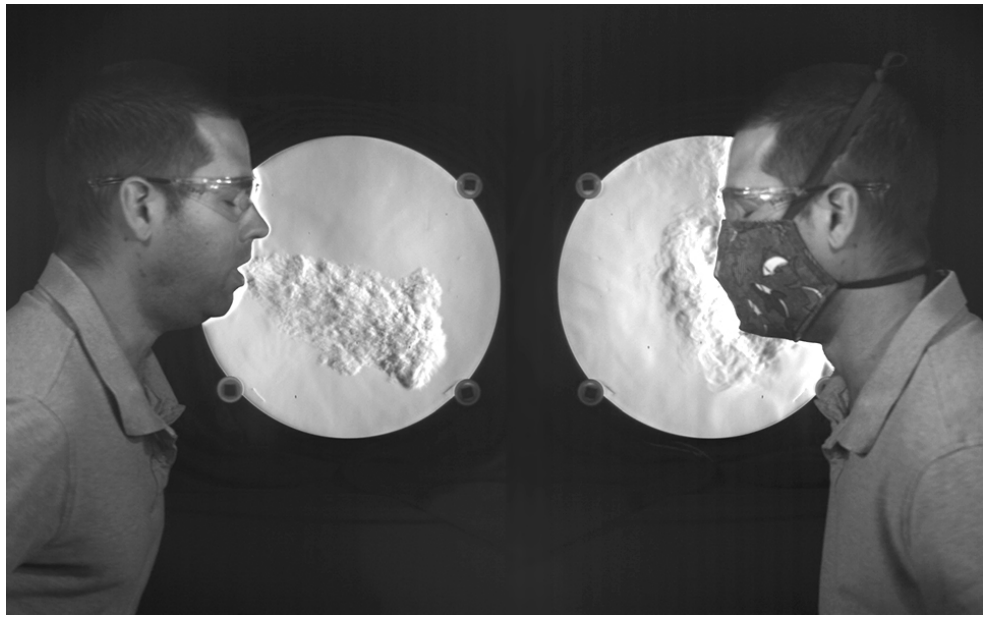
- Objective – minimize dose
  - Lower concentration
  - Reduce inhaled air volume
  - Protect against short range transmission and touching
- Multilayered approach is best
  - No single control is perfect
  - Different controls target different risk factors



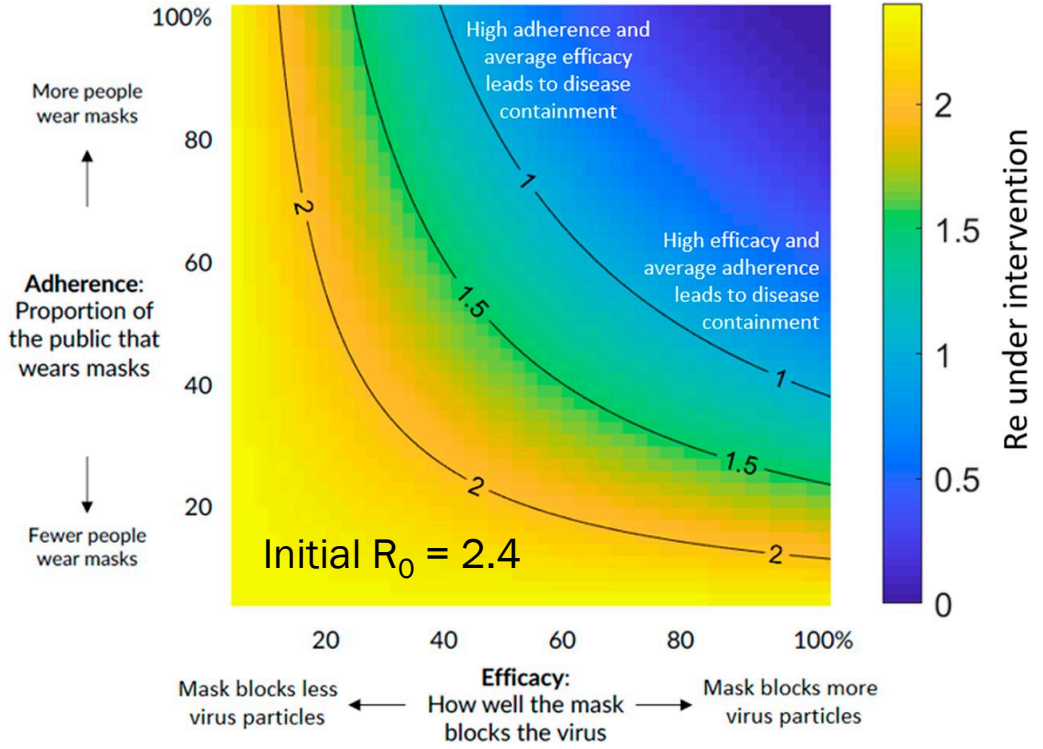
Source: Cleveland Clinic

MASKS AND RESPIRATORS ARE BOTH PPE AND SOURCE CONTROLS

- Reduce inhalation of infectious aerosols by susceptible persons/emission by infected persons
- Limit spread of concentrated infectious jets



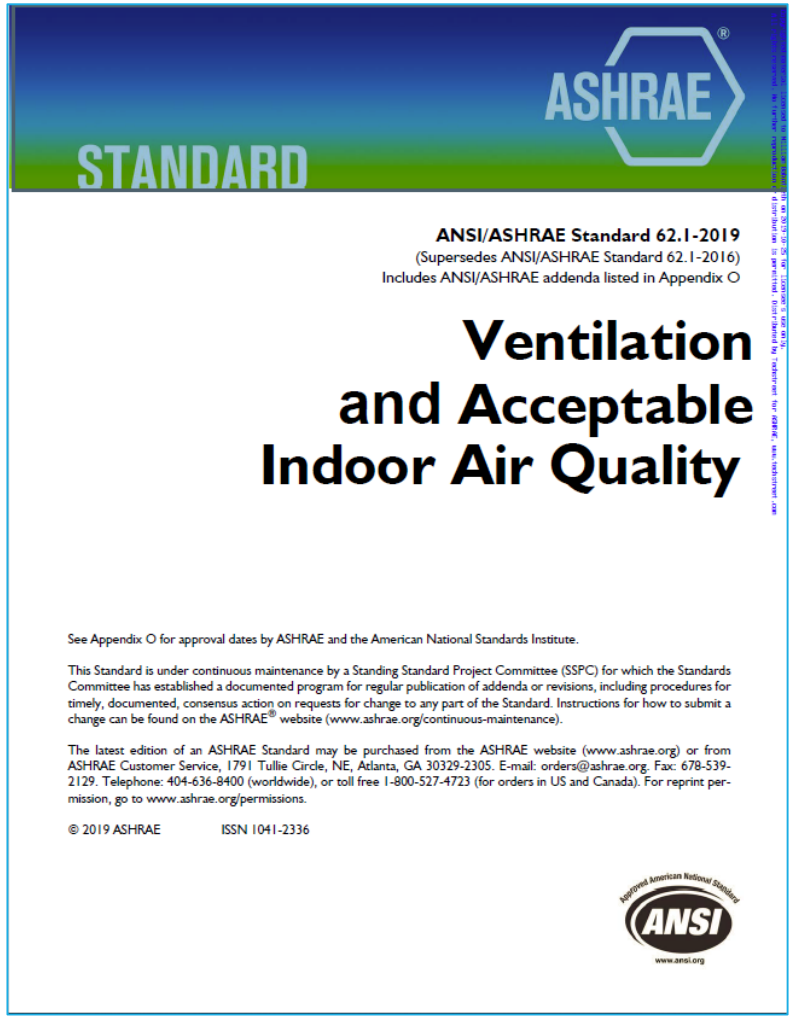
Credit: M. Staymates/N. Hanacek/NIST
www.nist.gov/blogs/taking-measure/my-stay-home-lab-shows-how-face-coverings-can-slow-spread-disease



Howard, J., et al. An evidence review of face masks against COVID-19. Proc. National Academy of Sciences. 118(4). doi.org/10.1073/pnas.2014564118

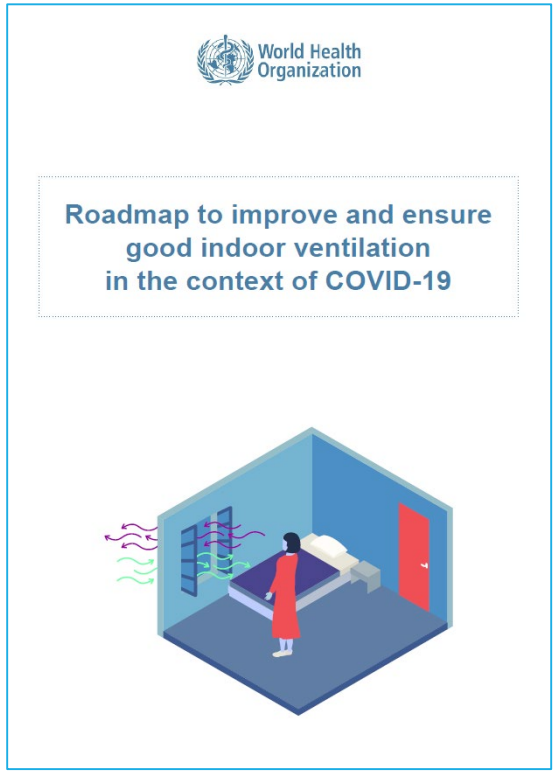
VENTILATION

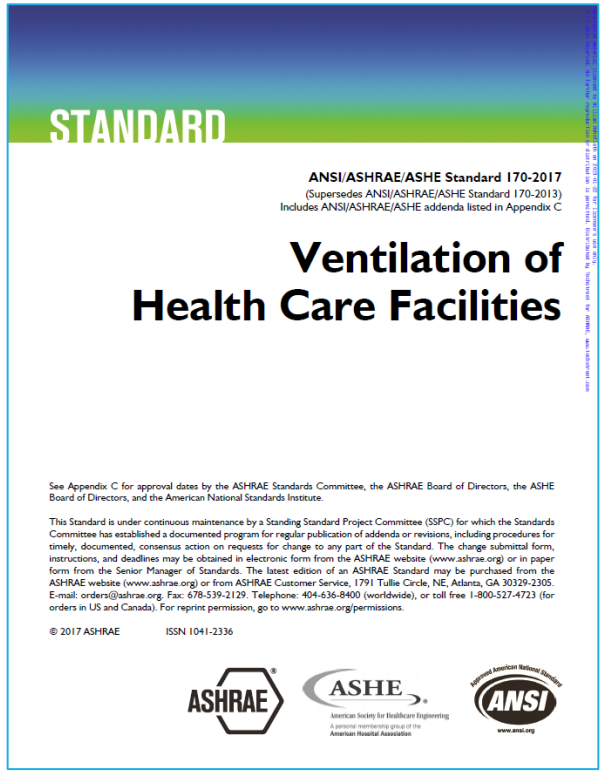
- Remove contaminated indoor air/replace with outdoor air
- Required by code for most buildings
- In US, requirements for non-residential buildings come from ASHRAE Standard 62.1
- Typically, ~15 cubic feet per minute/person
- Not sufficient for effective infection control



WHO RECOMMENDATIONS FOR COVID-19

- Healthcare facilities
  - 60 liters/second-person (127 cfm/pers)
  - Alternatively 6 air changes per hour
  - Similar to ASHRAE lower range in ASHRAE Standard 170
- Non-healthcare
  - 10 liters/second-person (21 cfm/pers)





AIR CHANGES PER HOUR (ACH)

- Measure of flow rate in number of room volumes supplied in an hour
- Used in healthcare ventilation standards
- Has been used to describe air flow requirements for Covid-19
- For a space with volume V in cubic feet (L×W×H), and ventilation rate Q in cubic feet per minute

$$ACH = \frac{Q \cdot 60}{V}$$

- Example -ASHRAE Standard62.1 office space
  - 5 cfm/person + 0.06 cfm/sf
  - Typical density - 5 persons/1000 sf
  - For 1000 sf, need 85 cfm = 17 cfm/pers
  - For 9 foot ceiling height, V = 9000 cubic feet

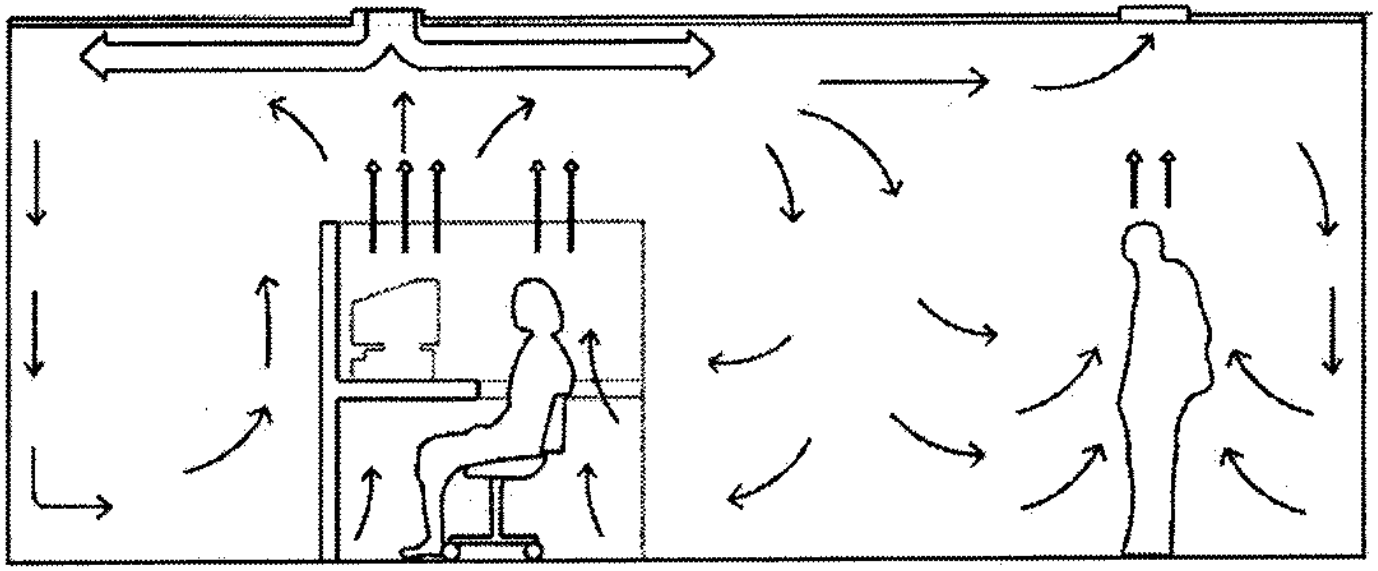
$$ACH = \frac{Q \cdot 60}{V} = \frac{85 \cdot 60}{9000} = 0.47$$

LIMITATIONS OF VENTILATION

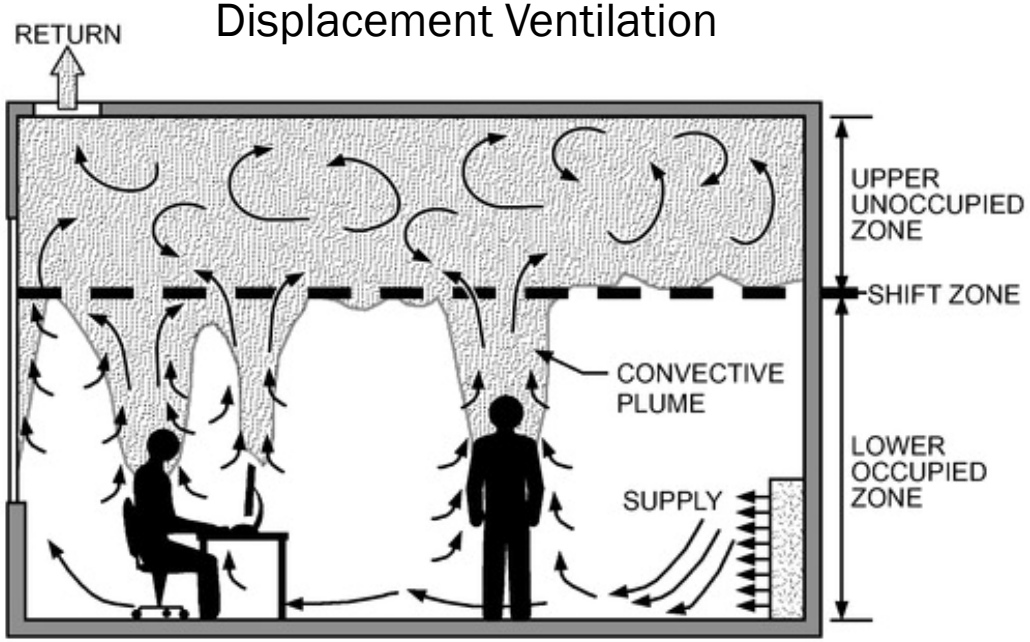
- Outdoor air must be conditioned to indoor temperature and humidity – large energy requirement
- In existing systems, increasing outdoor air may not be feasible due to equipment capacity limitations

AIR DISTRIBUTION METHODS

Mixing Ventilation

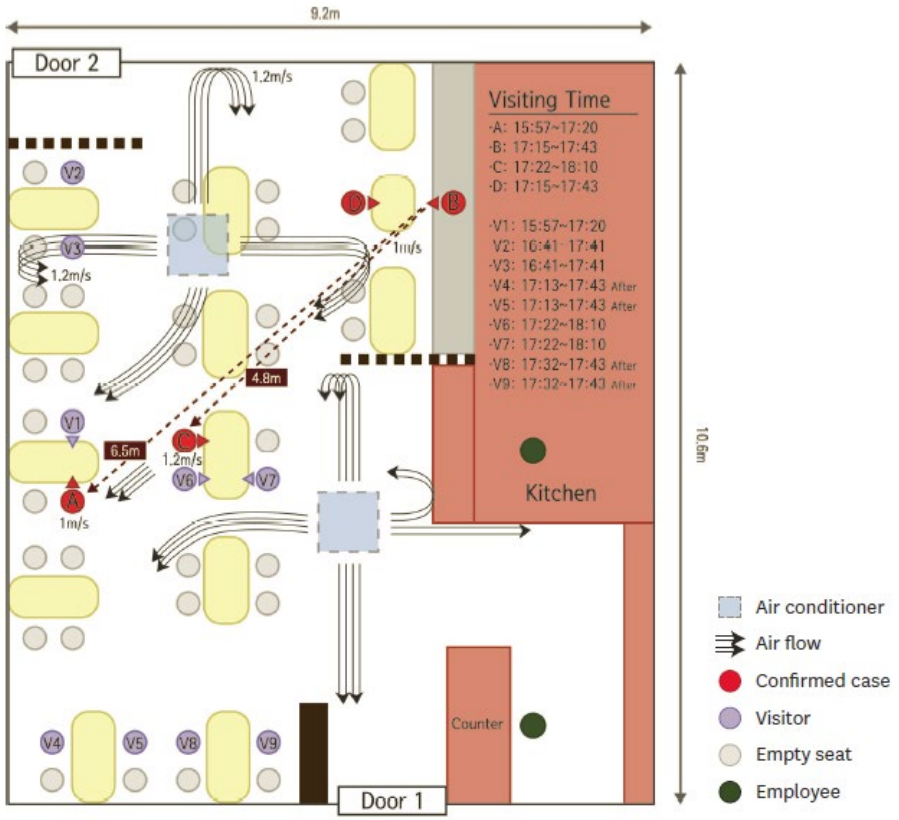


Displacement Ventilation



Performance of in-room air cleaners is affected by existing air distribution

POOR AIR DISTRIBUTION CAN INCREASE INFECTION RISK



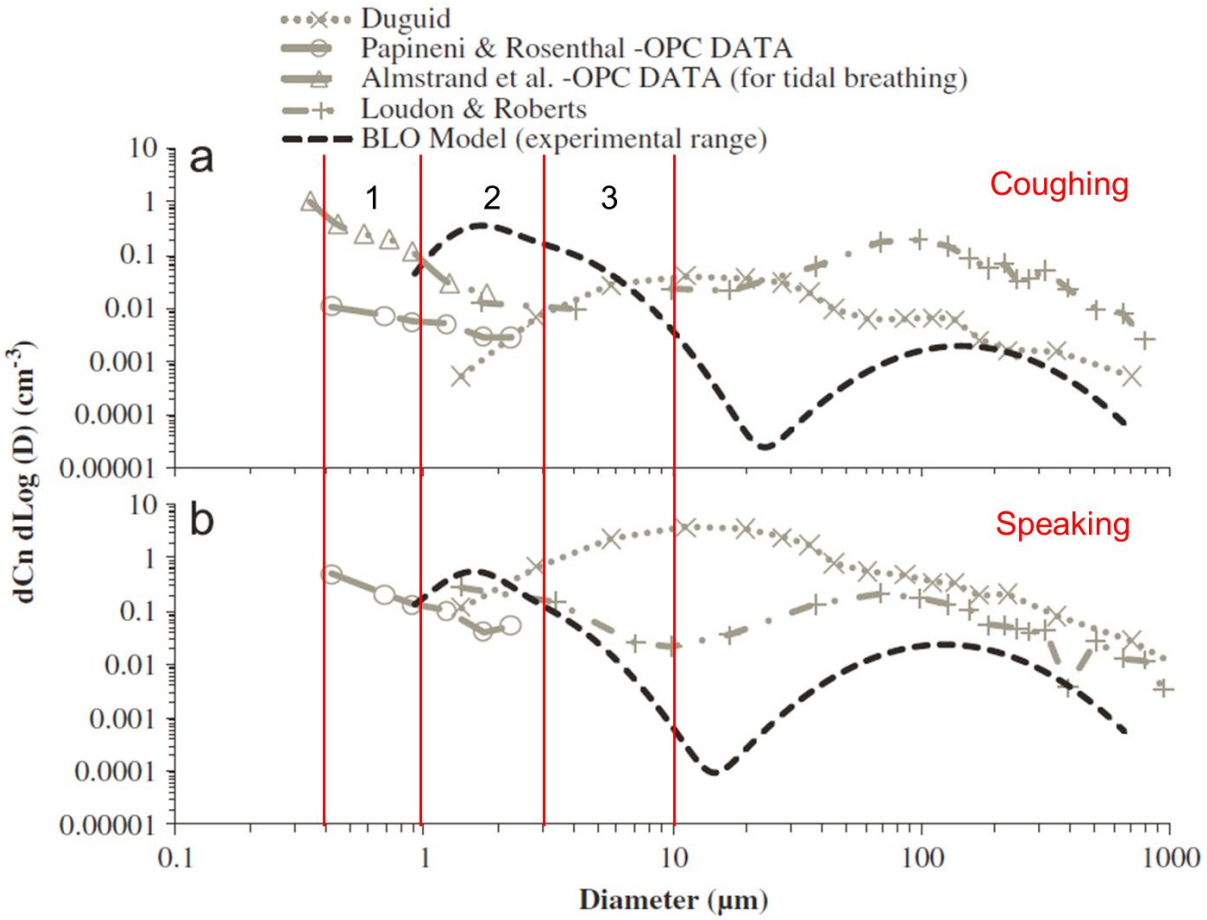
J Korean Med Sci. 2020 Nov 30;35(46):e415
https://doi.org/10.3346/jkms.2020.35.e415

Li, Y., P. Nielsen, M. Sandberg. 2011. ASHRAE J. 53(6): 86-88

MECHANICAL FILTRATION

- Removal of particles from the air by fiber filters
- Rated using ASHRAE Standard 52.2
- MERV – minimum efficiency reporting value
  - Ranges from 1 – 16
  - Larger numbers are more efficient, especially for smaller particlews
- ASHRAE Standard 62.1 requires MERV 8 or better
- ASHRAE Standard 170 requires MERV 14 or HEPA for sensitive environments

MERV-13 RECOMMENDED FOR INFECTION CONTROL



	MERV 8	MERV 13
1 (0.3-1μm)	N/A	≥ 50%
2 (1-3 μm)	≥ 20%	≥ 85%
3 (3-10 μm)	≥ 70%	≥ 90%

Johnson, et al. 2011. Modality of human expired aerosol size distributions. Journal of Aerosol Science 42:839-851.

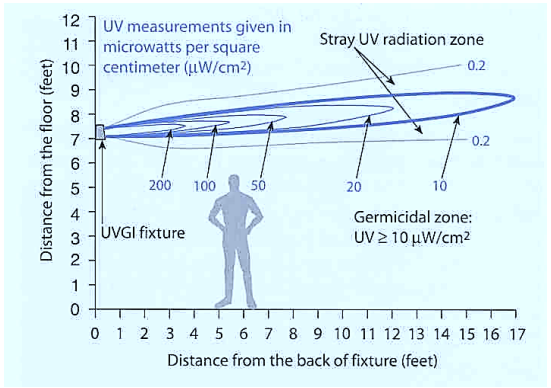
DISINFECTION

- Destroy or inactivate or destroy microorganisms
- Many technologies in the marketplace
  - Germicidal ultraviolet light (GUV) - damages microbial DNA/RNA
  - Additive air cleaners – add oxidants to air
    - Bipolar ionization
    - Dry hydrogen peroxide
    - Photocatalytic oxidation
    - Triethylene glycol

- GUV is well understood, accepted technology, approved by CDC for tuberculosis control
- Additive air cleaners lack strong evidence basis for effectiveness and safety, do not have consensus methods of test
- Some technologies produce ozone

GERMICIDAL UV APPLICATIONS

Upper Air UVGI



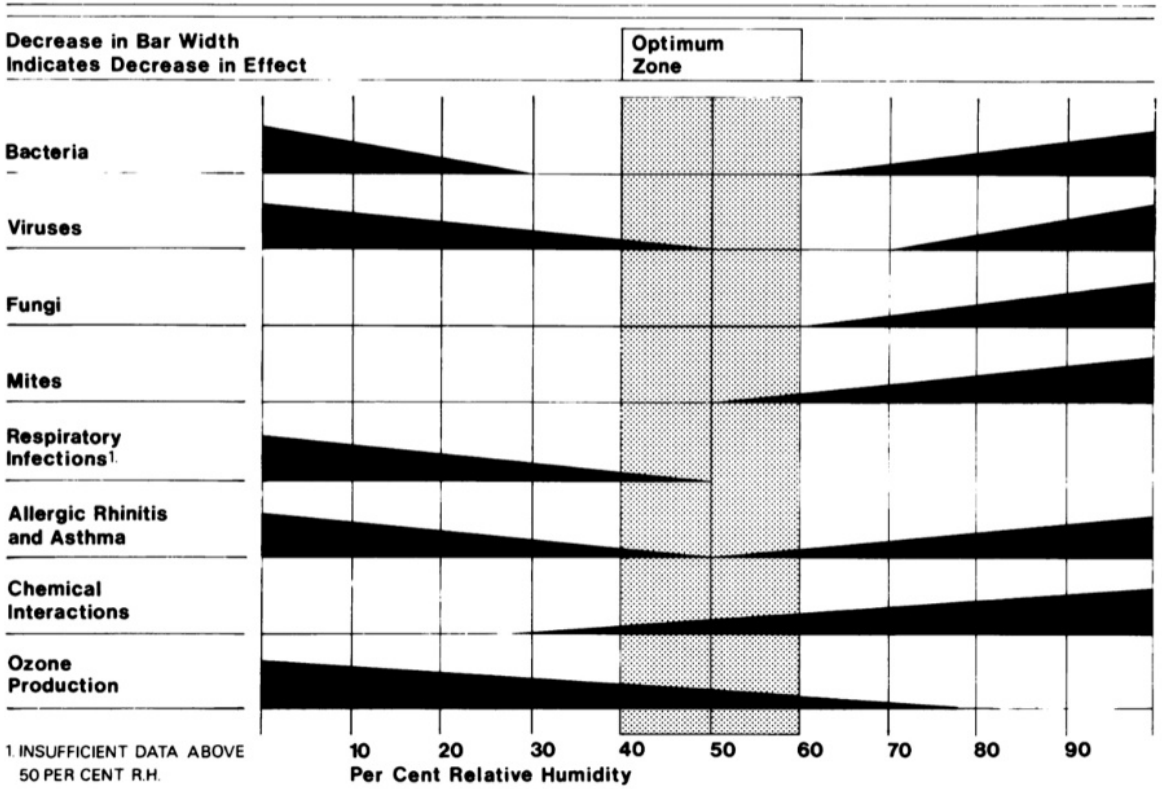
In-Duct/Coil UVGI

Portable Surface Treatment UVGI

HUMIDITY

- Evidence exists that viruses survive longer in air at low relative humidity
- Susceptibility to respiratory infection lower at low relative humidity
- Maintaining humidity in ~30-60% range is recommended by ASHRAE
- Impact is lower than other engineering controls, so not considered highest priority for Covid

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



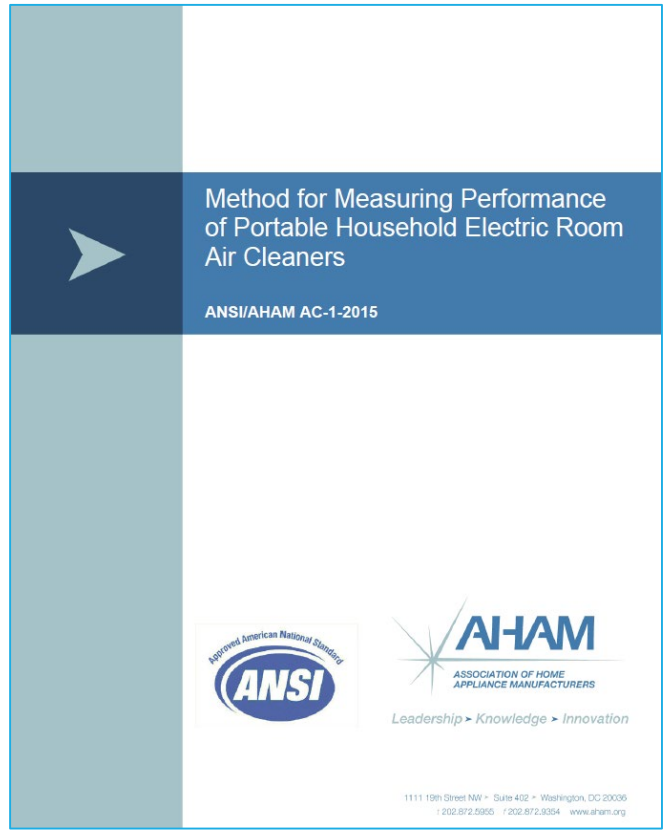
Optimum relative humidity range for minimizing adverse health effects.

PORTABLE AIR CLEANERS

- Standalone engineering controls
- Can incorporate filtration, disinfection technologies for microorganisms
  - HEPA filter – 99.97% efficient for 0.3 micron particles
- May include other technologies to remove gases from air
  - Activated carbon
- Wide range of costs and capacities

RATING PORTABLE AIR CLEANERS

- Few consensus standards or certifications exist
- AHAM AC-1 rates performance for particles
  - Chamber test
  - “Clean Air Delivery Rate” CADR
  - CADR is the flow rate of clean air that would have the same effect on particles
- UL 2998 rates ozone emissions
  - Chamber test
  - 5 part per billion limit
  - Required by ASHRAE Standard 62.1
- Manufacturer ratings can be misleading!
- Standards organizations are working on improved standards –but that will take time



ISSUES WITH PERFORMANCE AS DESCRIBED IN ADVERTISING

- Chamber tests in volumes that are much smaller than advertised capacity
- Pull-down test with impressive sounding results but no comparison with control (air cleaner off) test
- Portland State tool ACE-IT converts typical manufacturer performance results into CADR

  https://www.pdx.edu/healthy-buildings/ace-it

- Example
  - 98% inactivation in 1 hour
  - 100 cubic ft chamber
  - 82% natural loss in control test
  - Equivalent air change rate:
    - Total – 3.9 ACH
    - Natural – 1.7 ACH
    - Air cleaner – 2.2 ACH
  - Equivalent CADR: 3.7 cfm

HOW MUCH CAPACITY IS NEEDED?

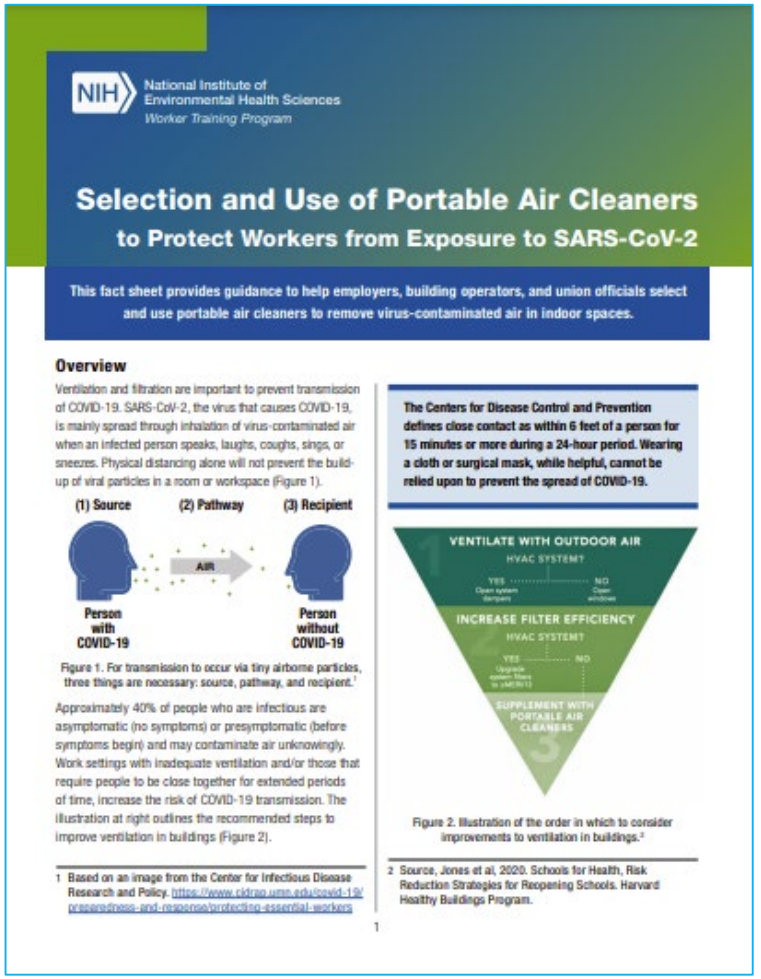
- Risk assessment or standard determines uncontaminated air flow rate required – 5 – 6 ACH is a common recommendation
- Requirement can be met by total of all removal rates – important to understand what HVAC system does!
  - Ventilation
  - Filtration in HVAC systems
  - Deposition
  - Air cleaners
- For general air quality control, AHAM recommends CADR in cfm that is at least 2/3 of floor area in square feet - small air cleaners (relative to space) may not distribute clean air effectively
- Be aware of noise level at highest fan speed/flow rate – may need to operate at less than full speed for acceptable noise level. Many products produce 50 – 60 decibels at full speed.

WHERE TO LOCATE AIR CLEANERS

- Near areas where clean air will have the greatest benefit
- Away from obstructions that interfere with air flow in or out
- Away from windows
- Distribute capacity in large spaces

FINAL THOUGHTS

- Portable HEPA filter units may work as well or better than air cleaners that cost 10X more
- Portable air cleaners often contain multiple technologies that are redundant or not needed for the desired application
- Compare air cleaners on basis of CADR or equivalent ACH
- Ask for proof of safety as well as effectiveness
- Additional information
  - NIEHS factsheet
  - ASHRAE guidance “In-Room Air Cleaner Guidance for Reducing Covid-19 in Air in your Space/Room (www.ashrae.org/technical-resources/covid-19-one-page-guidance-documents)
  - EPA home air cleaner guidance (www.epa.gov/indoor-air-quality-iaq/air-cleaners-and-air-filters-home)



NIH National Institute of Environmental Health Sciences
Worker Training Program

Selection and Use of Portable Air Cleaners to Protect Workers from Exposure to SARS-CoV-2

This fact sheet provides guidance to help employers, building operators, and union officials select and use portable air cleaners to remove virus-contaminated air in indoor spaces.

Overview

Ventilation and filtration are important to prevent transmission of COVID-19. SARS-CoV-2, the virus that causes COVID-19, is mainly spread through inhalation of virus-contaminated air when an infected person speaks, laughs, coughs, sings, or sneezes. Physical distancing alone will not prevent the build-up of viral particles in a room or workspace (Figure 1).

(1) Source (2) Pathway (3) Recipient

AIR

Person with COVID-19

Person without COVID-19

Figure 1. For transmission to occur via tiny airborne particles, three things are necessary: source, pathway, and recipient.[1]

Approximately 40% of people who are infectious are asymptomatic (no symptoms) or presymptomatic (before symptoms begin) and may contaminate air unknowingly. Work settings with inadequate ventilation and/or those that require people to be close together for extended periods of time, increase the risk of COVID-19 transmission. The illustration at right outlines the recommended steps to improve ventilation in buildings (Figure 2).

1 Based on an image from the Center for Infectious Disease Research and Policy. https://www.cidrap.umn.edu/covid-19/preparedness-and-response/protecting-essential-workers

The Centers for Disease Control and Prevention defines close contact as within 6 feet of a person for 15 minutes or more during a 24-hour period. Wearing a cloth or surgical mask, while helpful, cannot be relied upon to prevent the spread of COVID-19.

VENTILATE WITH OUTDOOR AIR
HVAC SYSTEM?
YES NO
INCREASE FILTER EFFICIENCY
HVAC SYSTEM?
YES NO
SUPPLEMENT WITH PORTABLE AIR CLEANERS

Figure 2. Illustration of the order in which to consider improvements to ventilation in buildings.[2]

2 Source, Jones et al, 2020. Schools for Health, Risk Reduction Strategies for Reopening Schools. Harvard Healthy Buildings Program.

1

https://tools.niehs.nih.gov/wetp/public/hasl_get_blob.cfm?ID=13021

Thank You!

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