National Tribal Air Association
IAQ Considerations to Assist Tribes in Re-opening Tribal Buildings During COVID: *Winter is Coming*

Combining Ventilation, Filtration, And Air Disinfection: A Systems Approach To Effective Airborne Risk Reduction

William P. Bahnfleth, PhD, PE, FASHRAE, FASME, FISIAQ

Professor of Architectural Engineering, Penn State

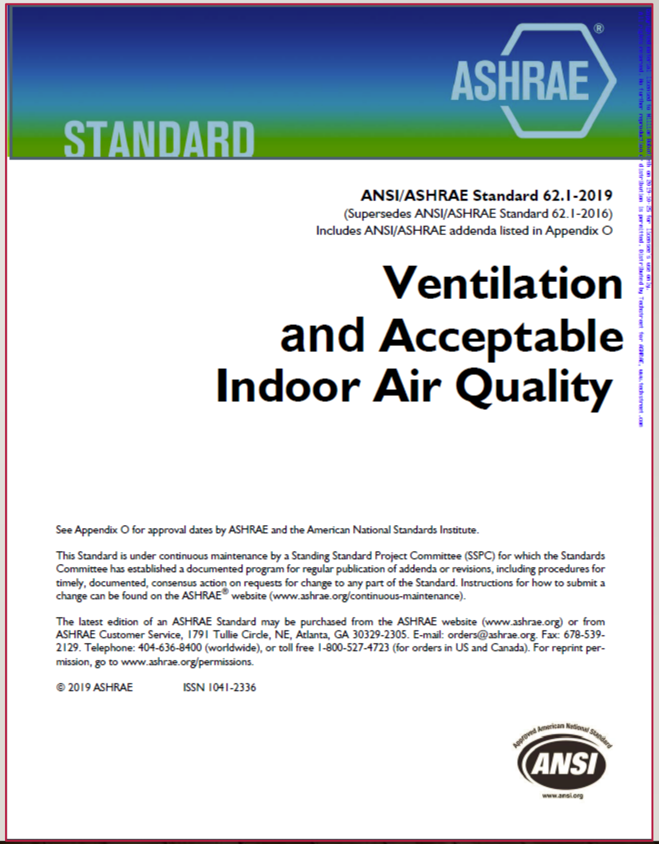
Chair, ASHRAE Epidemic Task Force

PennState College of Engineering | ARCHITECTURAL ENGINEERING

ASHRAE®

2 The current definition of indoor air quality for most buildings is safety + acceptability, not infection prevention

- ***acceptable indoor air quality (IAQ):*** air in which there are no known contaminants at harmful concentrations, as determined by cognizant authorities, and with which a substantial majority (80% or more) of the people exposed do not express dissatisfaction.


STANDARD

ASHRAE

ANSI/ASHRAE Standard 62.1-2019
(Supersedes ANSI/ASHRAE Standard 62.1-2016)
Includes ANSI/ASHRAE addenda listed in Appendix O

Ventilation and Acceptable Indoor Air Quality

See Appendix O for approval dates by ASHRAE and the American National Standards Institute.

This Standard is under continuous maintenance by a Standing Standard Project Committee (SSPC) for which the Standards Committee has established a documented program for regular publication of addenda or revisions, including procedures for timely, documented, consensus action on requests for change to any part of the Standard. Instructions for how to submit a change can be found on the ASHRAE® website (www.ashrae.org/continuous-maintenance).

The latest edition of an ASHRAE Standard may be purchased from the ASHRAE website (www.ashrae.org) or from ASHRAE Customer Service, 1791 Tullie Circle, NE, Atlanta, GA 30329-2305. E-mail: orders@ashrae.org. Fax: 678-539-2129. Telephone: 404-636-8400 (worldwide), or toll free 1-800-527-4723 (for orders in US and Canada). For reprint permission, go to www.ashrae.org/permissions.

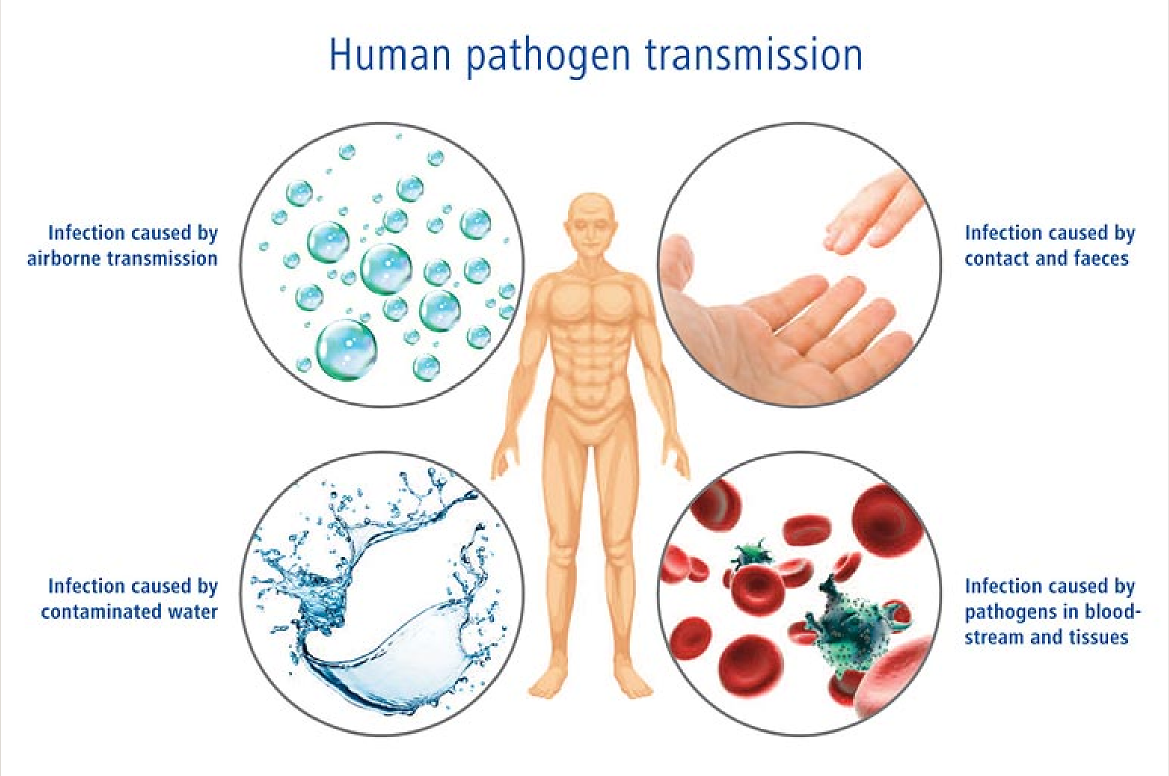
 ISSN 1041-2336

Approved American National Standard
ANSI
www.ansi.org

3 INFECTIOUS DISEASE TRANSMISSION MODES

- Airborne
  - Droplet
  - Aerosol
- Fomite – intermediate surface
- Direct contact
- Vehicle borne (water, food, blood)
- Vector (insect, animal)

…HVAC mainly impacts aerosol transmission



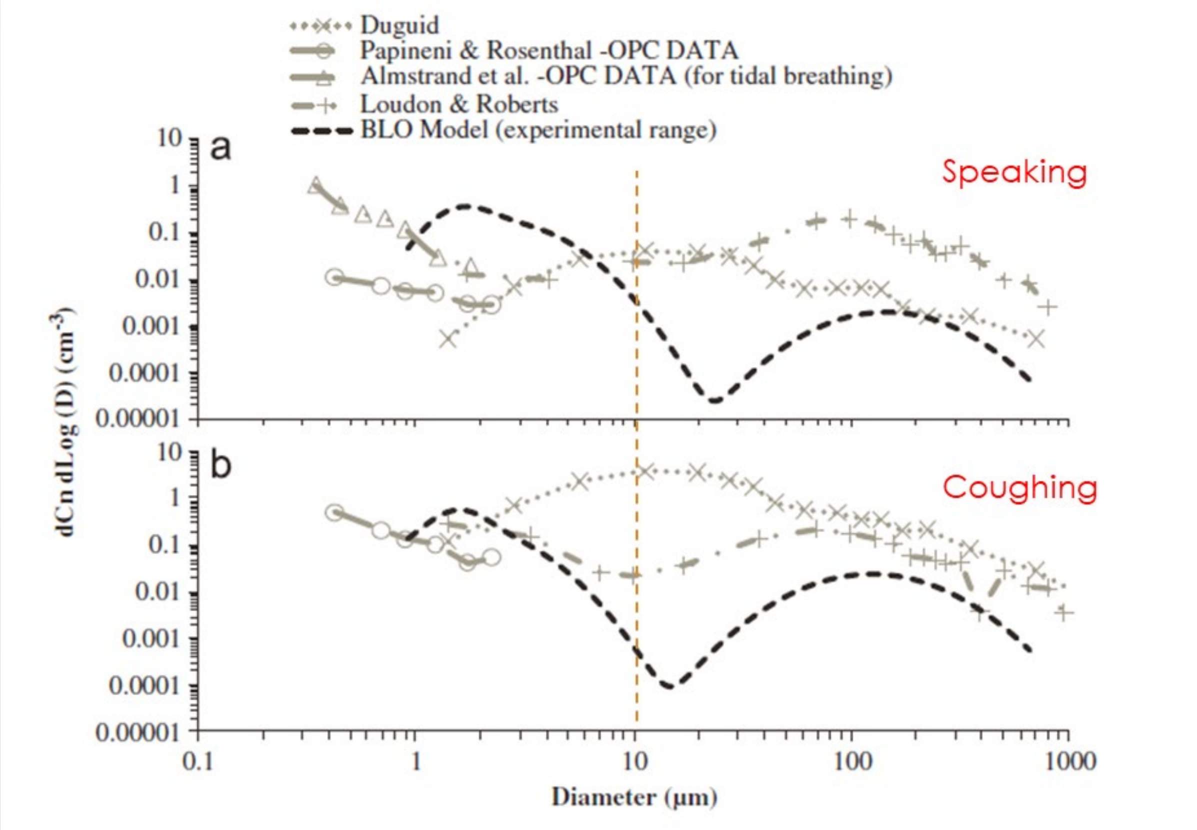
bode-science-center.com

4 SOURCES OF INFECTIOUS AEROSOLS

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

5 RESPIRATORY DROPLET CHARACTERISTICS

- Droplets contain proteins and salts, dry to 20-40% of initial size
- Pathogens are incorporated in particles
- Similar size distribution but varying output for different activities
- Half or more of infectious load is in particles < ~5 μm
- Small particles can stay airborne for long periods of time



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

6

US CDC and WHO recognize possible indoor airborne transmission of covid-19

(10/5/2020)

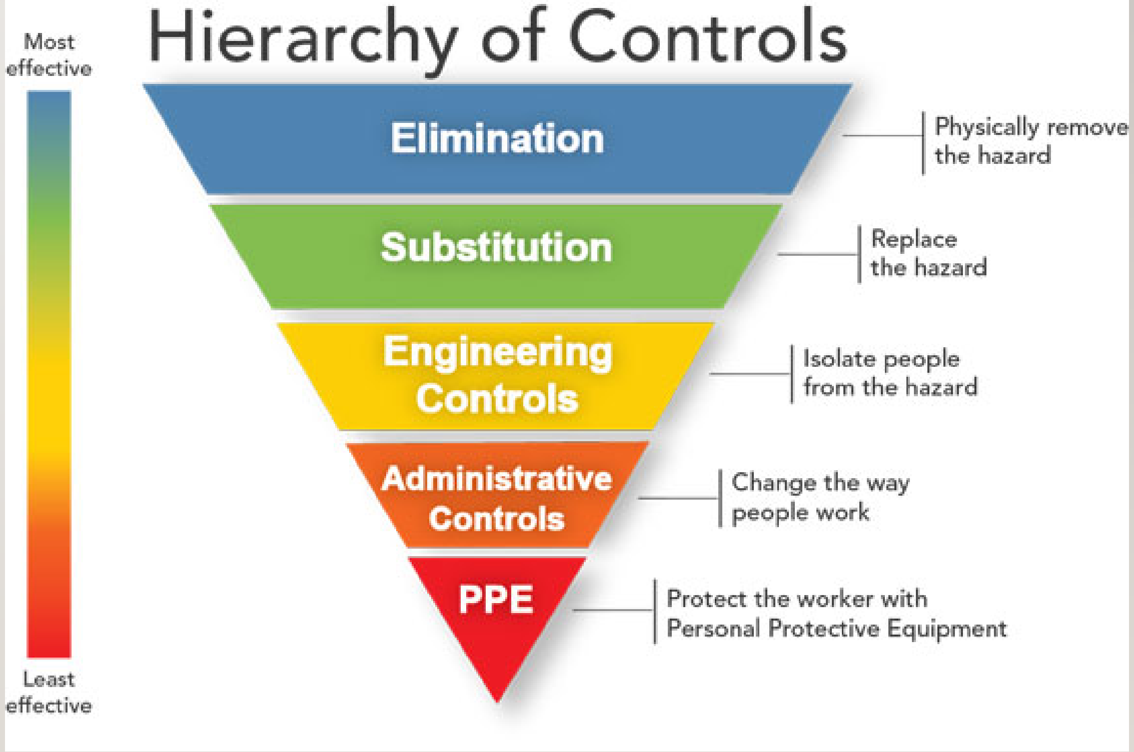
- *COVID-19 most commonly spreads during close contact*
  (cdc.gov/coronavirus/2019-ncov/prevent-getting-sick/how-covid-spreads.html)
- *COVID-19 spreads less commonly through contact with contaminated surfaces*
  (cdc.gov/coronavirus/2019-ncov/prevent-getting-sick/how-covid-spreads.html)
- *Airborne transmission of SARS-CoV-2 can occur under special circumstances*
  (cdc.gov/coronavirus/2019-ncov/more/scientific-brief-sars-cov-2.html)
  - Enclosed spaces
  - Prolonged exposure to respiratory particles
  - Inadequate ventilation and air-handling

"Ventilation represents a very important aspect, a very important factor to prevent the virus from spreading indoors."

WHI Science in 5
https://www.youtube.com/watch?v=XJC1f7F4qtc

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 protect others (mainly)



8 Quantifying airborne risk – the Wells-Riley model

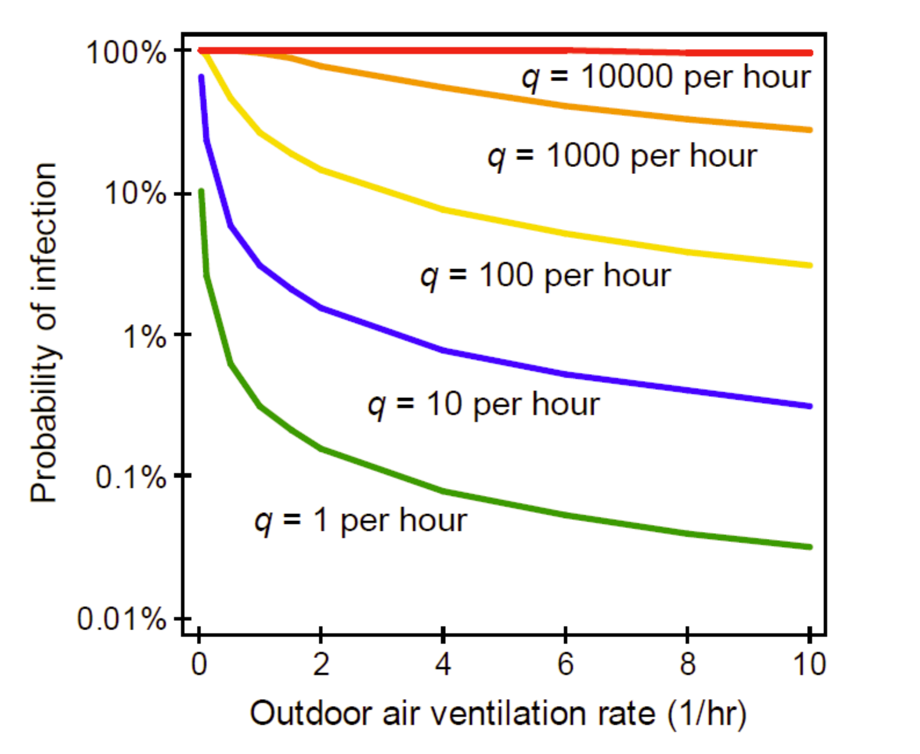
$$P = 1 - \exp\left(-\frac{Iqpt}{Q} \right)$$

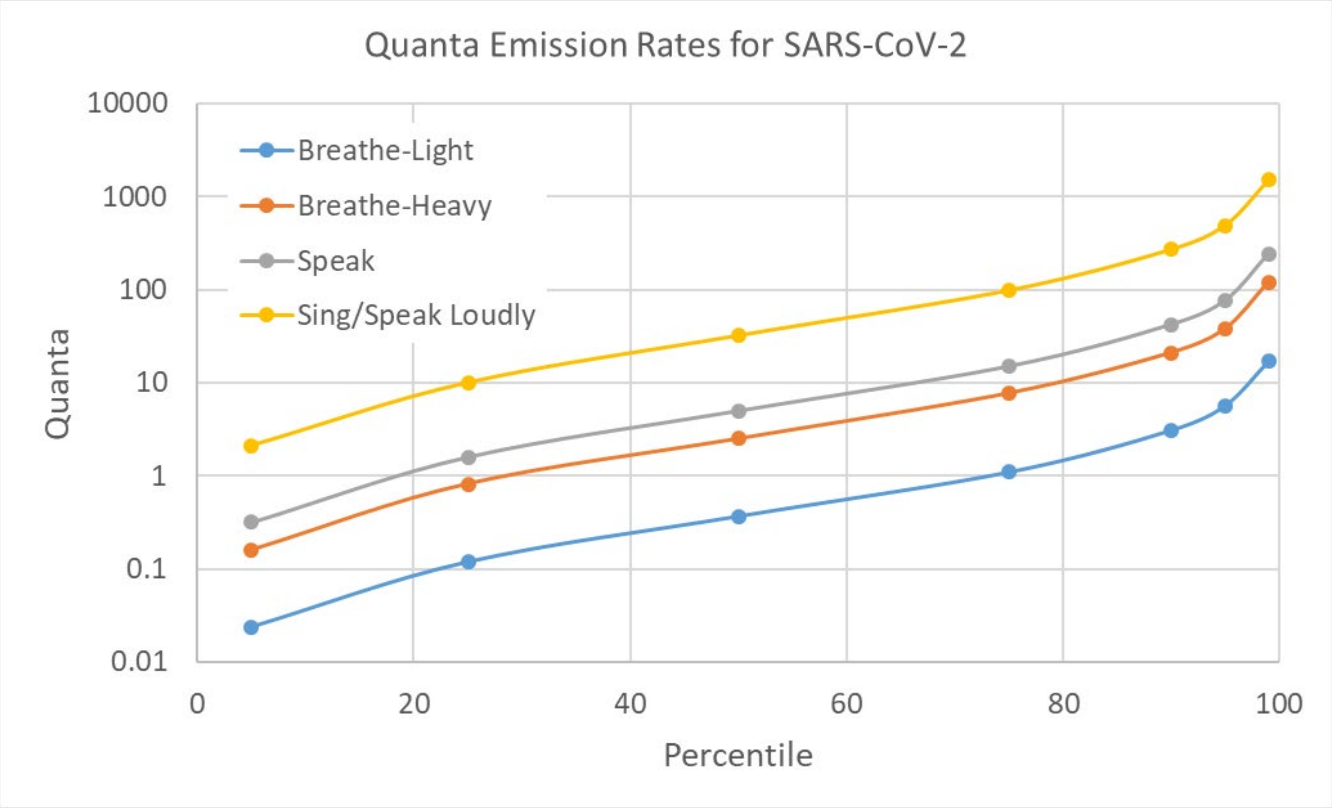
- Steady-state conditions
- Time-dependent risk
- Quanta determined from data

- 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 (1/hr)

9 If quanta emission rate is known, risk can be estimated …but not very accurately for COVID-19

Office, 8-hr occupancy





Stephens. 2012. HVAC filtration and the Wells-Riley approach to assessing risks of infectious airborne diseases. Final report to NAFA.

Buonanno, et al. 2020. Quantitative assessment of the risk of airborne transmission of SARS-CoV-2 infection: Prospective and retrospective applications. Environment International, 145

10

The purpose of engineering controls is to reduce airborne exposure

- Ventilation
- Air distribution
- Filtration
- Inactivation
  - Disinfection
  - Humidification and temperature control

VENTILATION WITH OUTDOOR AIR

- Dilute/exhaust contaminants
- Effective, but energy intensive, even with energy recovery
- Minimum required (e.g., ASHRAE 62.1) is a good baseline – but not sufficient without other controls
- 7-10 L/s-pers ≈ 15-20 cfm/pers

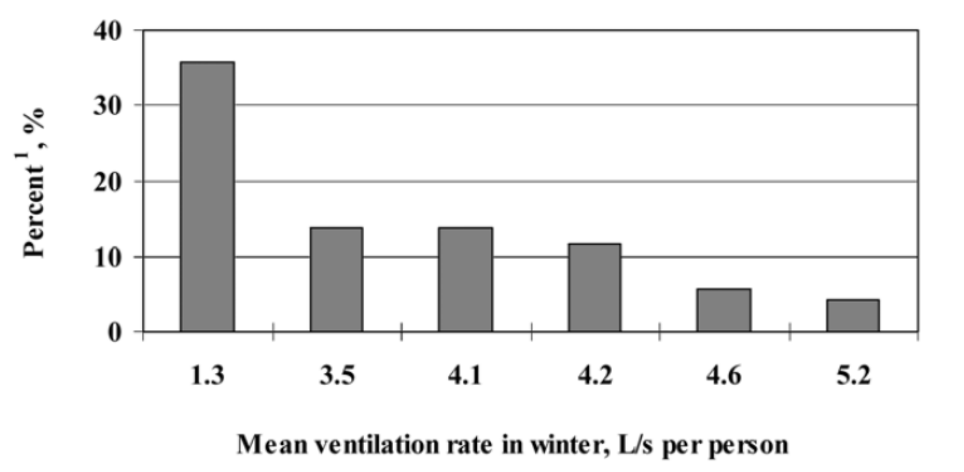
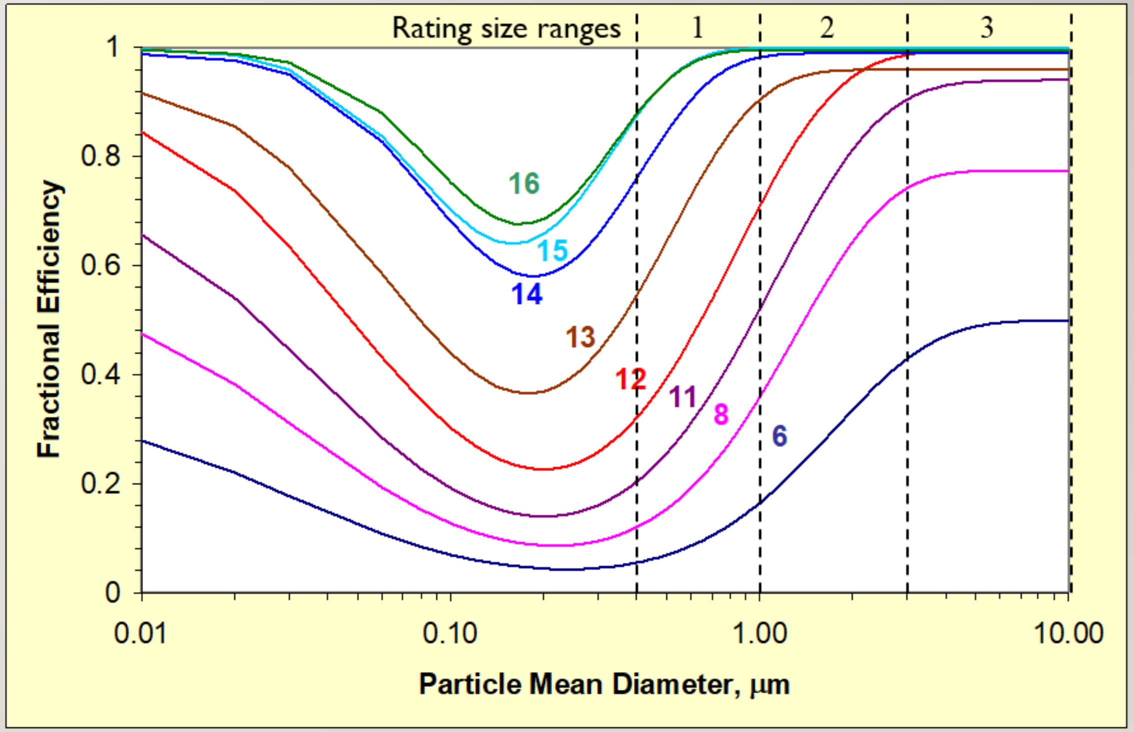


Figure 4. Associations between common cold infection rates and mean ventilation rate in winter in buildings constructed after year 1993. [1] Proportion of occupants with ≥6 common colds in the previous 12 months.

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

12 FILTRATION

- High efficiency filters can remove respiratory aerosols efficiently
- For indoor sources, must have recirculate indoor air through filters
- Effective if clean air delivery rate (efficiency × flow rate) is high enough
- ASHRAE Standard 52.2 Minimum Efficiency Reporting Value (MERV) rating prevalent in US

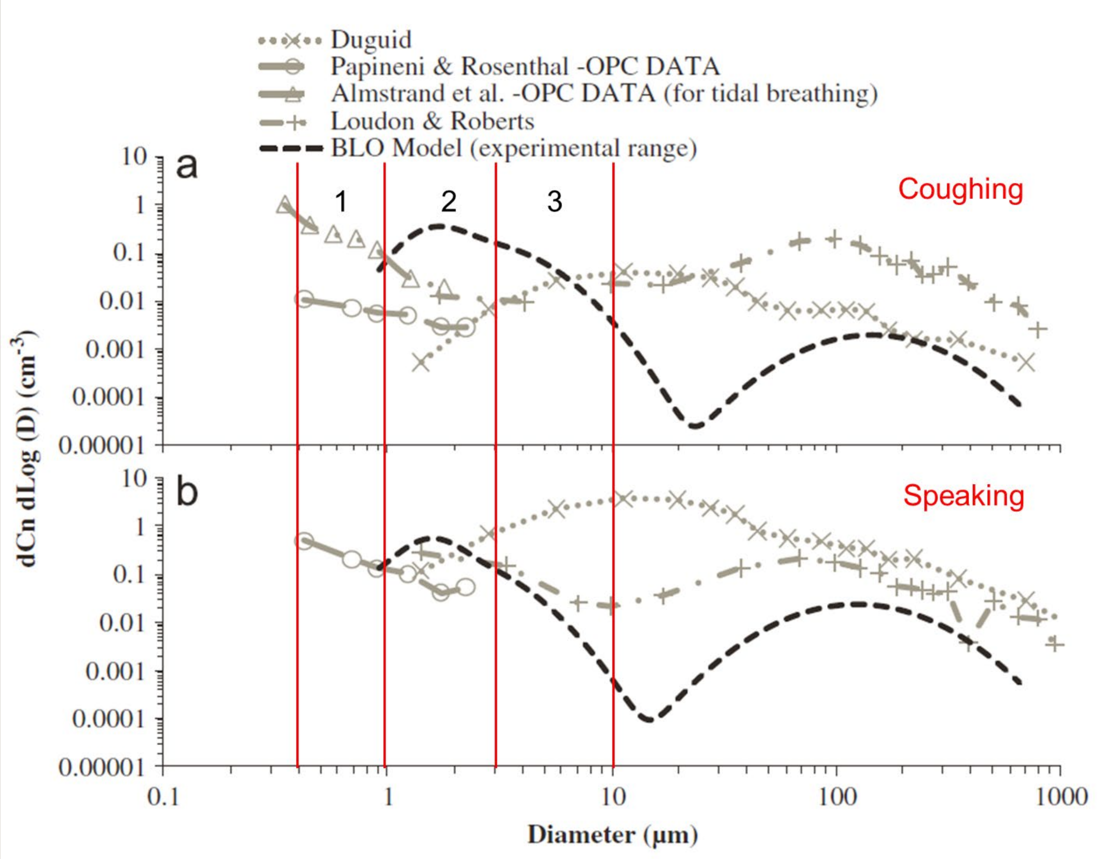


Representative MERV rated filter performance

Kowalski, W.J. and Bahnfleth, W.P., 2002. MERV filter models for aerobiological applications. Air Media, Summer, 1.

13

Respiratory droplets that carry infectious disease pathogens are not captured by minimum standard (MERV 6, 8) filters – MERV 13 recommended



	MERV 6	MERV 8	MERV 13
1 (0.3-1µm)	N/A	N/A	≥ 50%
2 (1-3 µm)	N/A	≥ 20%	≥ 85%
3 (3-10 µm)	≥ 35%	≥ 70%	≥ 90%

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

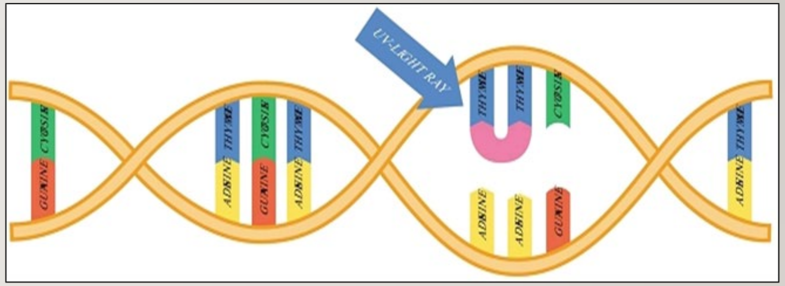
14 INACTIVATION - AIR CLEANERS

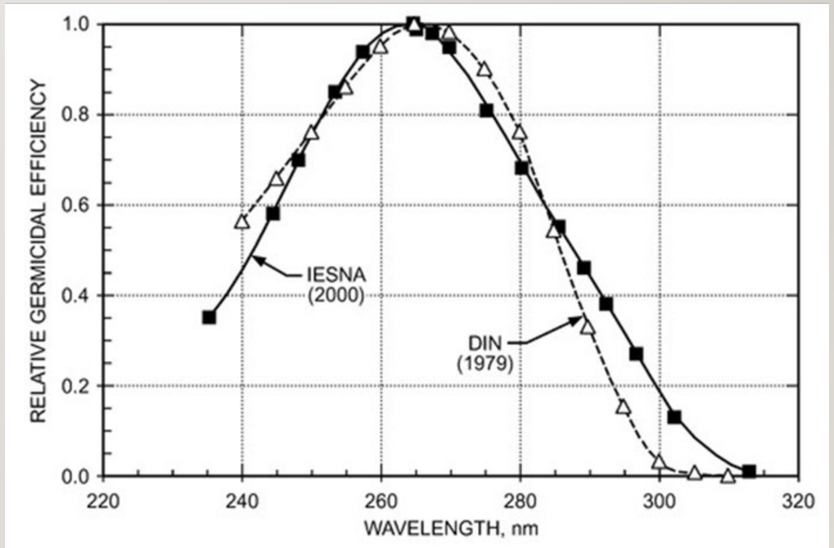
- Ultraviolet Germicidal Irradiation
- Alternative particulate filters
  - Electrostatic
  - Thermal
- Air cleaners that create reactive species
  - Photocatalytic Oxidation (PCO)
  - Dry Hydrogen Peroxide (DHP)
  - Bipolar Ionization (BPI)

- Key questions –
  - Effective in this application?
  - Safe for use?
    - Direct exposure
    - Byproducts
  - Better than alternatives?

15 Germicidal ultraviolet light is a well-validated technology

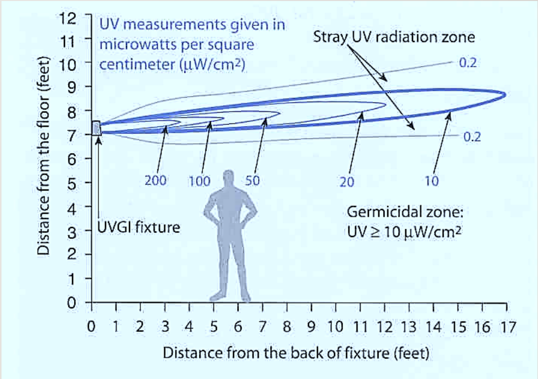
- Ultraviolet light in UVC band
- 265 nm ideal, 254 nm produced by low pressure Hg vapor lamps is standard
- Disrupts microbial DNA/RNA, prevents reproduction
- Coronavirus susceptibility is good
- CDC approved for tuberculosis control as adjunct to filtration
- Upper room systems measured > 10 ACH equivalent clean air supply





16 GERMICIDAL UV APPLICATIONS

Upper Air UVGI



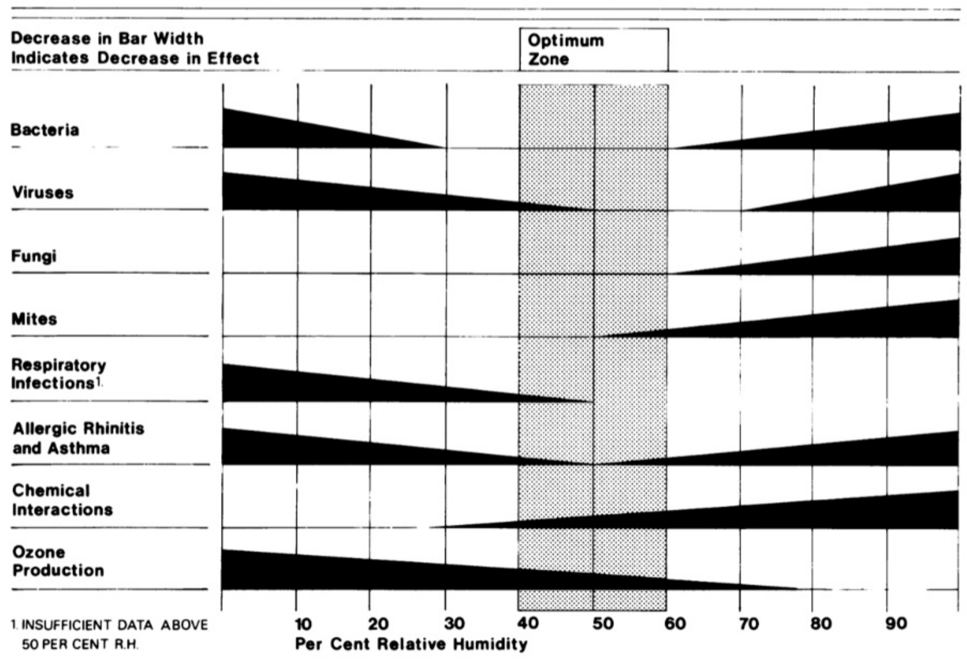
Airstream UVGI

Surface Treatment UVGI

17 INACTIVATION TEMPERATURE AND HUMIDITY

- 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
- Good to do if feasible
- Difficult to humidify many existing buildings safely
- Significance for COVID-19 needs further investigation

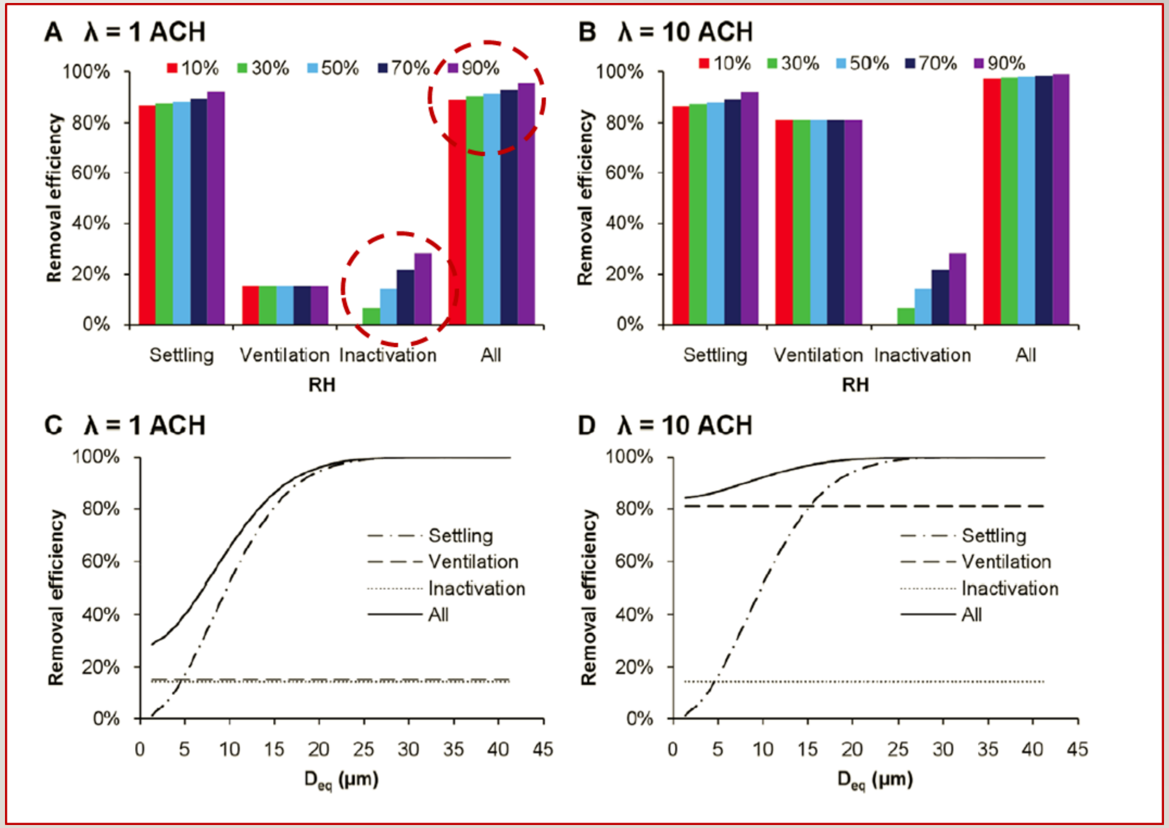
Arundel AV, Sterling EM et al. *Indirect Health Effects of Relative Humidity in Indoor Environments*, Environmental Health Perspectives Vol 65, 351-61, 1986.



Optimum relative humidity range for minimizing adverse health effects.

18 TEMPERATURE AND HUMIDITY CONTROL

- Humidity has a large impact on rate of inactivation
- Settling is affected by humidity, but not much
- If ventilation and filtration are at recommended levels, impact of RH on exposure is secondary
- Not clear – effect of RH on susceptibility



Yang W, Marr LC (2011) Dynamics of Airborne Influenza A Viruses Indoors and Dependence on Humidity. PLoS ONE 6(6): e21481.

19 Comparing controls

- Ventilation
  - Limited by temperature and humidity control constraints
  - Expensive
  - Low first cost impact
- Filter upgrades
  - Limited by flow resistance effects
  - Possible increase in fan energy use
  - Variable first cost impact
- Inactivation - Air cleaners
  - Wide range of cost – and performance
  - Don't affect comfort
  - Moderate/low energy use and cost
  - Claims vs. evidence
- Inactivation – Temperature and humidity
  - Clear evidence to change set points is lacking

All reduce airborne exposure – need an approach to application that is effective, efficient, economical

20 Equivalent clean air flow for other removal factors can be included in wells-riley

$$P = 1 - \exp\left[-\frac{ipqt}{Q}\right] = 1 - \exp\left[-\frac{ipqt}{\cancel{V}} \Big/ \alpha_{OA}\right]$$

Substitute outdoor air changes, α_{OA} [h^{-1}] for Q

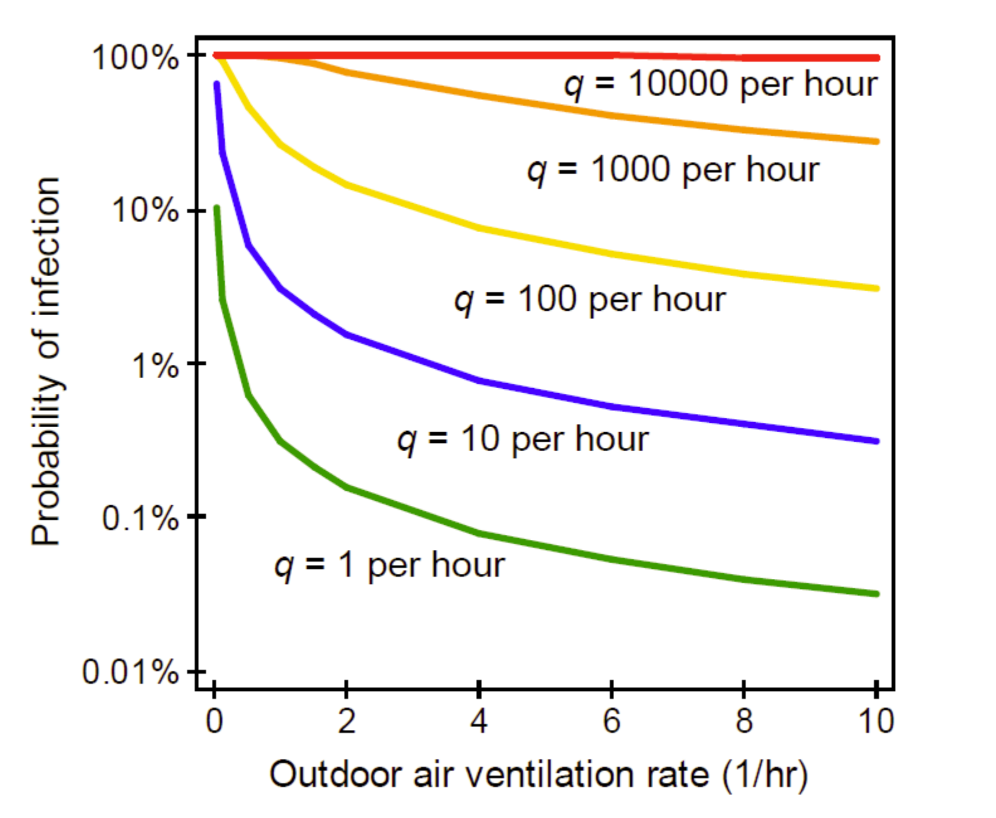
Equivalent uncontaminated air flows rates can be estimated for filters, air cleaners, deposition, and natural inactivation of pathogens

Total equivalent uncontaminated air change rate: $\alpha_{Total} = \alpha_{OA} + \alpha_{Filter} + \alpha_{Clean} + \alpha_{Depo} + \alpha_{Decay}$

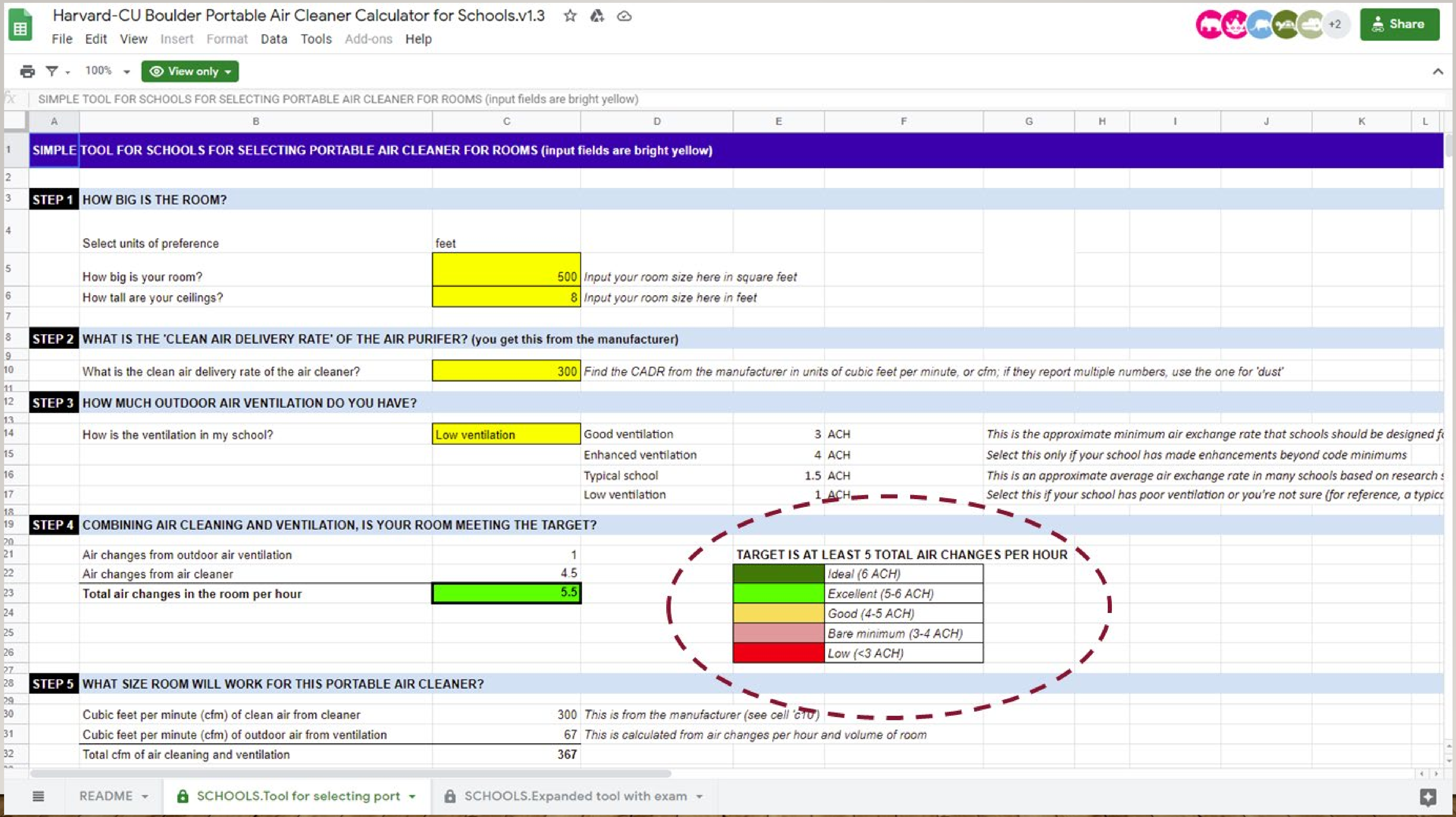
$$P = 1 - \exp\left[-\frac{ipqt}{\cancel{V}} \Big/ \alpha_{Total}\right]$$

21 Recommended equivalent clean air exchange rates

- Based on arbitrary relative risk threshold and occupancy
- Some suggest 3-4 eACH minimally acceptable, 5-6 eACH as excellent
- Comparable to healthcare requirements
  - Patient room minimum, requirements
    - Outdoor air: 2 ACH, total supply air: 4 ACH
    - Pre-filter: MERV 7, Final filter: MERV 14
  - Protective environment
    - Outdoor air: 2 ACH, total supply air: 12 ACH
    - Pre-filter: MERV 7, Final filter: HEPA I



Stephens. 2012. HVAC filtration and the Wells-Riley approach to assessing risks of infectious airborne diseases. Final report to NAFA.



Harvard-CU Boulder Portable Air Cleaner Calculator for Schools.v1.3

File Edit View Insert Format Data Tools Add-ons Help

Share

100% View only

SIMPLE TOOL FOR SCHOOLS FOR SELECTING PORTABLE AIR CLEANER FOR ROOMS (input fields are bright yellow)

	A	B	C	D	E	F
1	SIMPLE TOOL FOR SCHOOLS FOR SELECTING PORTABLE AIR CLEANER FOR ROOMS (input fields are bright yellow)					
3	STEP 1	HOW BIG IS THE ROOM?				
4		Select units of preference	feet			
5		How big is your room?	500	*Input your room size here in square feet*		
6		How tall are your ceilings?	8	*Input your room size here in feet*		
8	STEP 2	WHAT IS THE 'CLEAN AIR DELIVERY RATE' OF THE AIR PURIFER? (you get this from the manufacturer)				
10		What is the clean air delivery rate of the air cleaner?	300	*Find the CADR from the manufacturer in units of cubic feet per minute, or cfm; if they report multiple numbers, use the one for 'dust'*		
12	STEP 3	HOW MUCH OUTDOOR AIR VENTILATION DO YOU HAVE?				
14		How is the ventilation in my school?	Low ventilation	Good ventilation	3	ACH	*This is the approximate minimum air exchange rate that schools should be designed f*
15				Enhanced ventilation	4	ACH	*Select this only if your school has made enhancements beyond code minimums*
16				Typical school	1.5	ACH	*This is an approximate average air exchange rate in many schools based on research s*
17				Low ventilation	1	ACH	*Select this if your school has poor ventilation or you're not sure (for reference, a typica*
19	STEP 4	COMBINING AIR CLEANING AND VENTILATION, IS YOUR ROOM MEETING THE TARGET?				
21		Air changes from outdoor air ventilation	1			
22		Air changes from air cleaner	4.5			
23		**Total air changes in the room per hour**	5.5			
28	STEP 5	WHAT SIZE ROOM WILL WORK FOR THIS PORTABLE AIR CLEANER?				
30		Cubic feet per minute (cfm) of clean air from cleaner	300	*This is from the manufacturer (see cell 'c10')*		
31		Cubic feet per minute (cfm) of outdoor air from ventilation	67	*This is calculated from air changes per hour and volume of room*		
32		Total cfm of air cleaning and ventilation	367			

TARGET IS AT LEAST 5 TOTAL AIR CHANGES PER HOUR

	Ideal (6 ACH)
	Excellent (5-6 ACH)
	Good (4-5 ACH)
	Bare minimum (3-4 ACH)
	Low (<3 ACH)

README | SCHOOLS.Tool for selecting port | SCHOOLS.Expanded tool with exam

https://docs.google.com/spreadsheets/d/1NEhk1IEdbEi_b3wa6gl_zNs8uBJjlSS-86d4b7bW098/edit#gid=1836861232

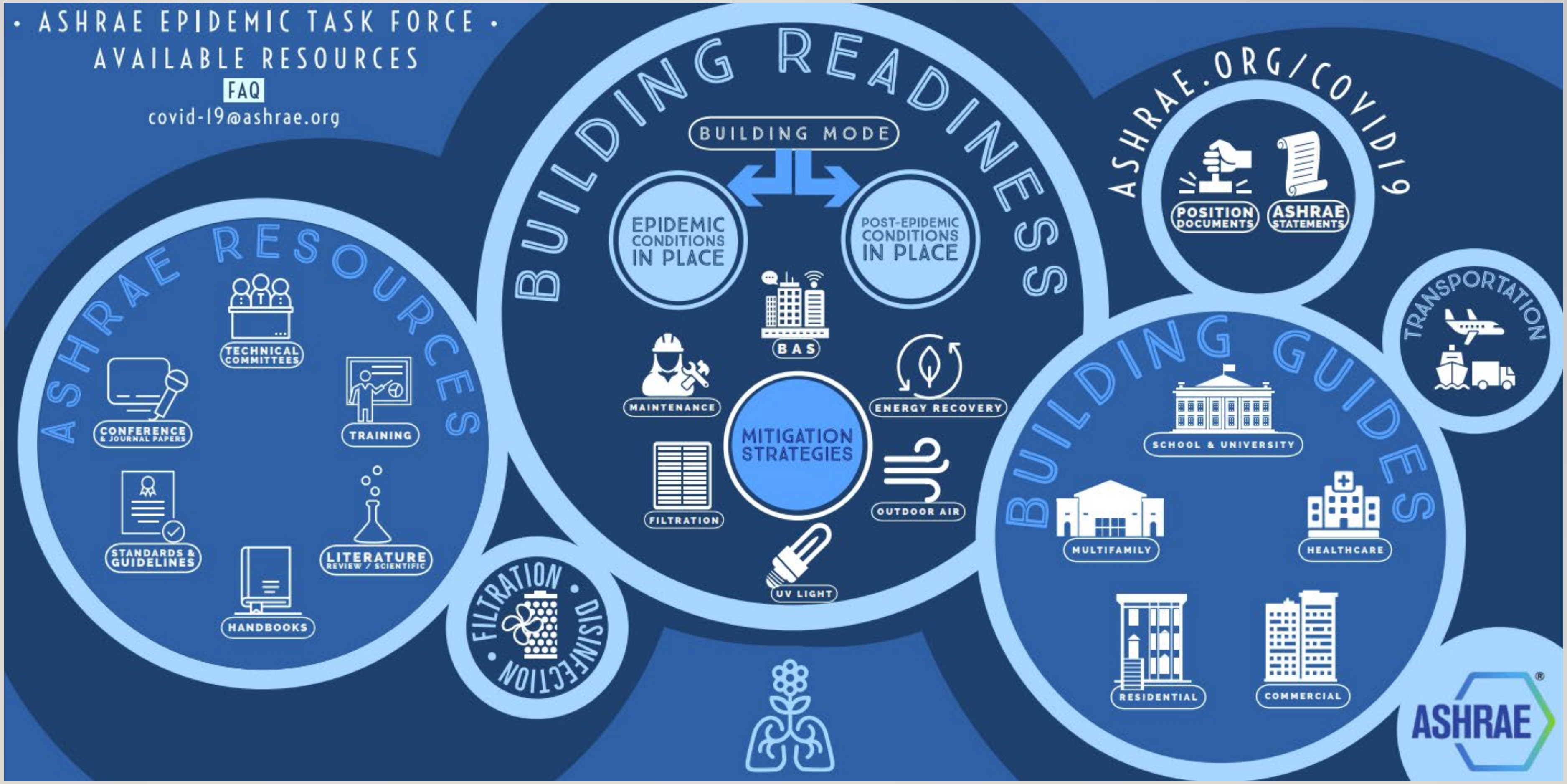
23 Summary

- Most buildings and their HVAC systems are not designed for infection control
- HVAC systems can reduce airborne risk by lowering exposure
- Ventilation, filtration, air cleaners are the primary controls for airborne exposure, humidity control may have secondary benefit
  - All can be effective
  - Great differences in equipment cost, energy use, operating cost
- Equivalent clean air delivery rate provides a basis for optimization
- Current recommendations for COVID-19 are similar to requirements for healthcare

THANK YOU!

Bill Bahnfleth

wbahnfleth@psu.edu



ashrae.org/covid19