Managing HVAC Systems to Reduce Infectious Disease Transmission

Better Buildings Space Conditioning Technology Research Team
National Renewable Energy Laboratory

May 4, 2020
2:30 – 3:30 pm EDT

Agenda

- Introductions
- HVAC Research Team
  - Marcus Bianchi, NREL – Senior Research Engineer
  - Miles Hayes, NREL – Research Engineer
  - Michael Deru - Senior Research Engineer



- US Department of Energy
  - David Nemtzow, Buildings Technology Office Director
- Speaker
  - Bill Bahnfleth, Penn State University

Better Buildings Virtual Summit 2020

https://betterbuildingssolutioncenter.energy.gov/summit

- Series of timely webinars & peer exchanges
- The full schedule can be viewed here
- Register for individual sessions, meet-ups, and workshops here
- Registration and all sessions **free**

David Nemtzow

- Building Technologies Office Director of the Office of Energy Efficiency and Renewable Energy (EERE).
- He previously served as the team's senior strategist.
- Was president of the Alliance to Save Energy.
- M.S. in public policy, Harvard University and a bachelor's in environmental policy from Brown University.

Dr. Bill Bahnfleth

- Professor of architectural engineering at the Penn State, since 1994.
- Was President of ASHRAE
- Author of more than 170 technical papers and articles and 14 books and book chapters.
- Fellow of ASHRAE, ASME, and the International Society for Indoor Air Quality and Climate (ISIAQ).
- Chair of the ASHRAE Epidemic Task Force

MANAGING HVAC SYSTEMS TO REDUCE INFECTIOUS DISEASE TRANSMISSION

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PROFESSOR OF ARCHITECTURAL ENGINEERING, PENN STATE

CHAIR, ASHRAE EPIDEMIC TASK FORCE

2 OUTLINE

- Infectious disease transmission
- Respiratory aerosols
- Controversy over airborne transmission of COVID-19
- ASHRAE Guidance – general/Covid-19
- REHVA Covid-19 Guidance summary
- ASHRAE Epidemic Task Force

3 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

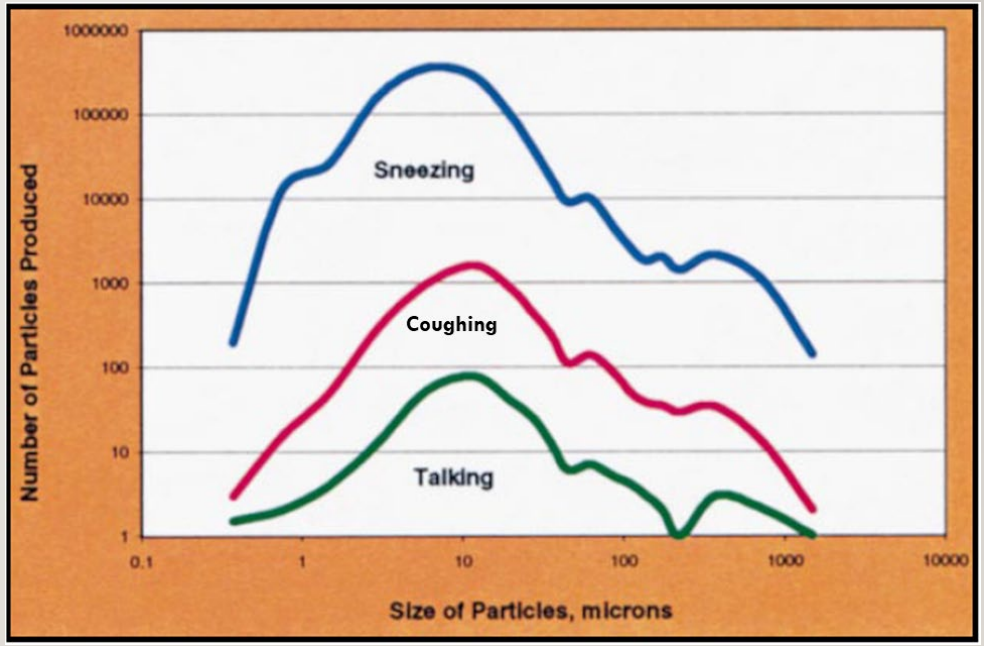
bode-science-center.com

4 SOURCES OF INFECTIOUS AEROSOLS

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

5 RESPIRATORY AEROSOL PROPERTIES

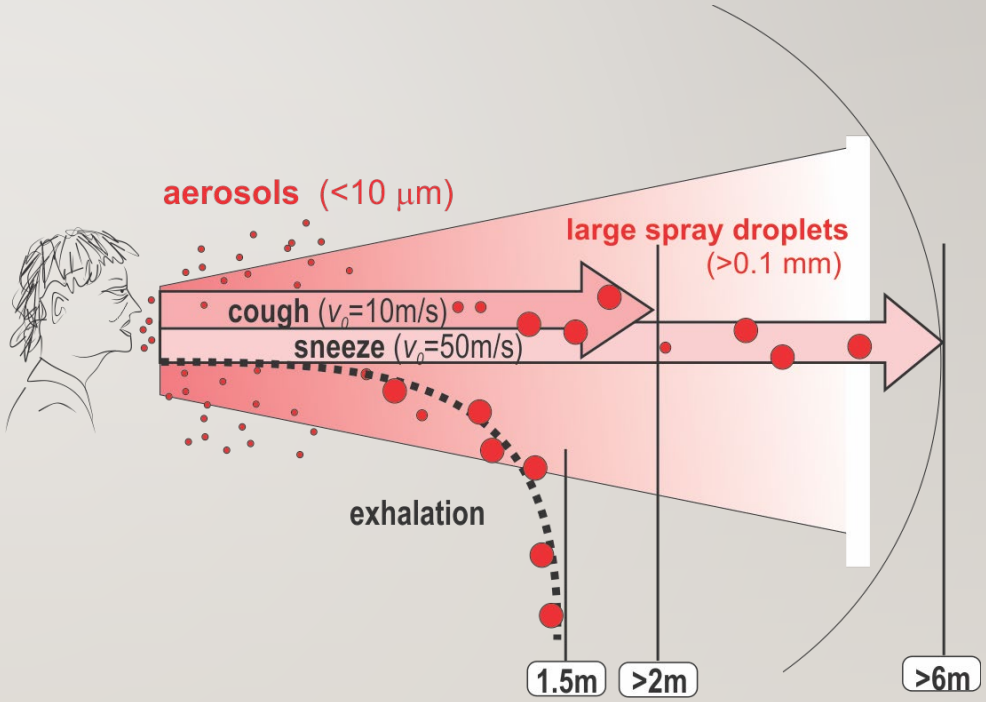
- Emitted as droplets
  - Water, proteins, salts…
  - Dehydrate to smaller sizes
  - Process dependent on relative humidity
  - Initial diameter < 1 µm to > 1000 µm
- Infected persons shed viruses in droplets
- Studies of influenza have found > 50% of viral load is in particles < ~5 µm



Duguid, et al. 1945

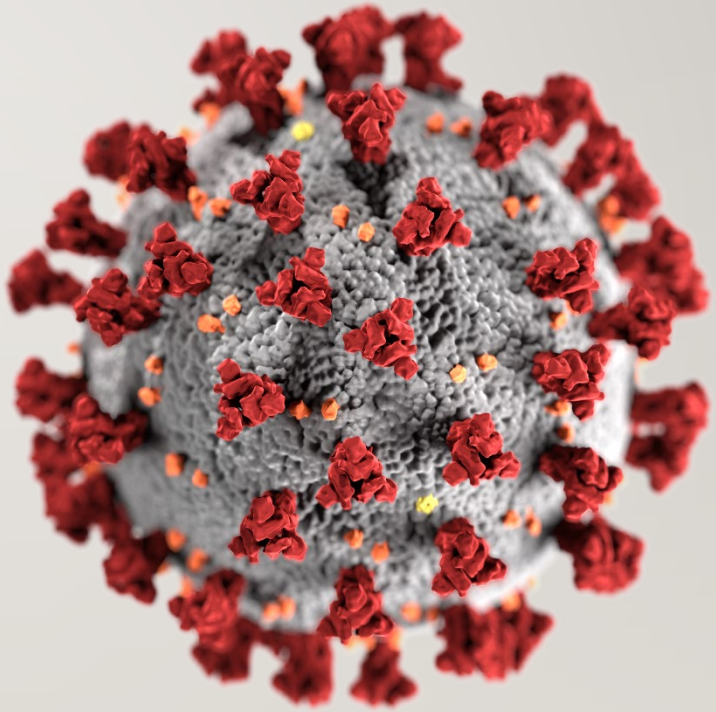
6 RESPIRATORY AEROSOL DYNAMICS

- "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



7 SARS-CoV-2, THE VIRUS THAT CAUSES COVID-19

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

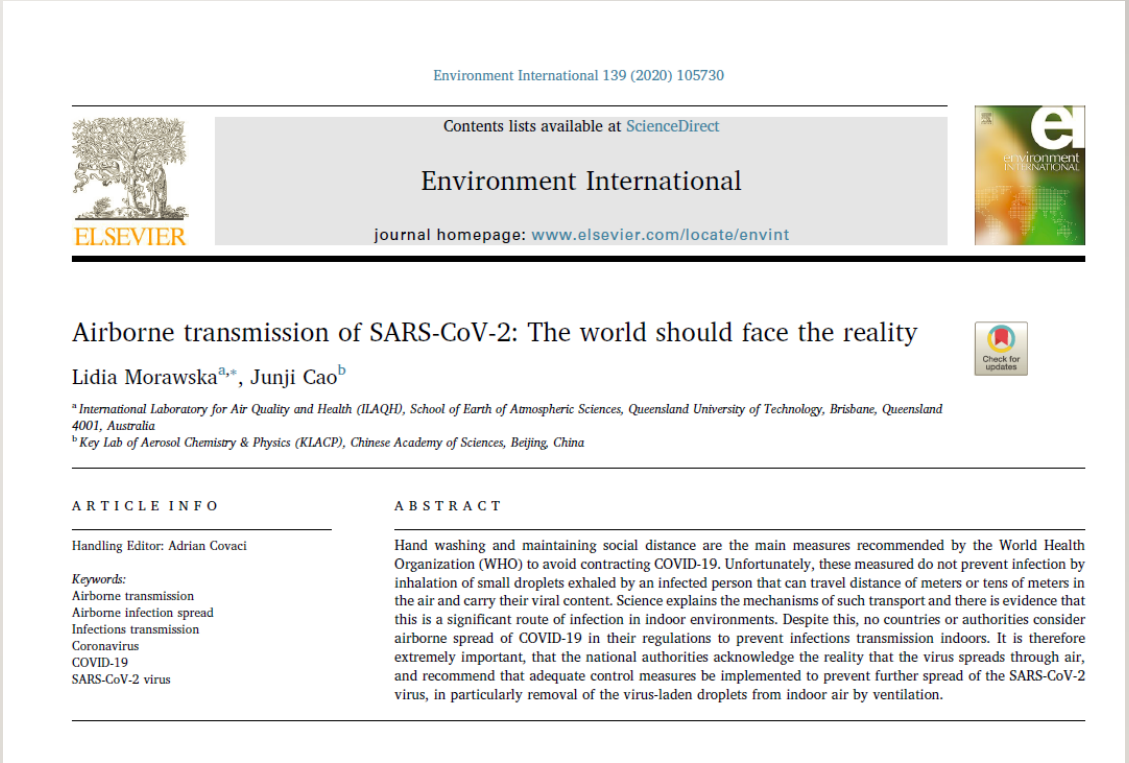


CONTROVERSY OVER COVID-19 TRANSMISSION

- Health organizations (WHO, CDC)
  - Evidence points to predominantly large droplet transmission at short range
  - Possible fomite transmission
  - 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 - 28 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

9 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.

HVAC ORGANIZATIONS HAVE TAKEN CONSERVATIVE POSITIONS

ASHRAE

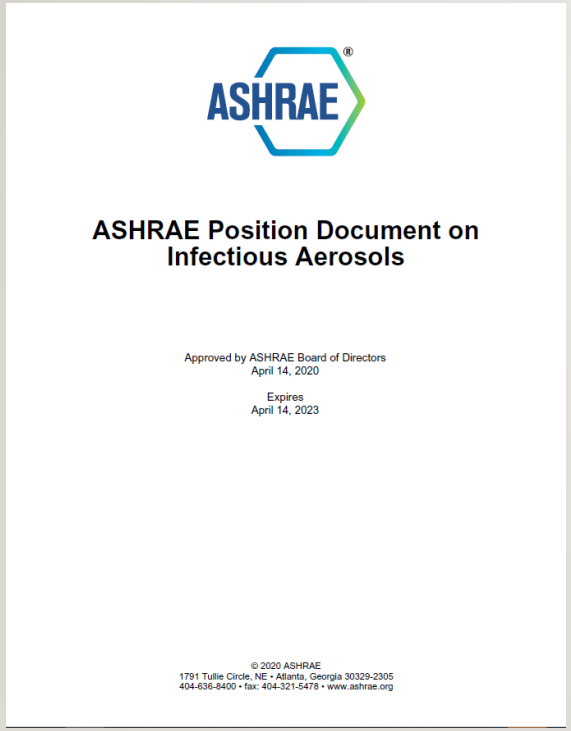
Transmission of SARS-CoV-2 through the air is *sufficiently likely* that airborne exposure to the virus should be controlled. Changes to building operations, including the operation of heating, ventilating, and air-conditioning systems, can reduce airborne exposures.

REHVA

At this date we *need all efforts* to manage this pandemic from all fronts…

(T)ake a set of measures that help to also control the airborne route in buildings

ASHRAE GUIDANCE – POSITION DOCUMENT ON INFECTIOUS AEROSOLS



- The Issue
- Background
- Practical Implications for Building Owners, Operators, and Engineers
- Conclusions and Recommendations
- References
- Bibliography

First approved 2009, last revision April 2020

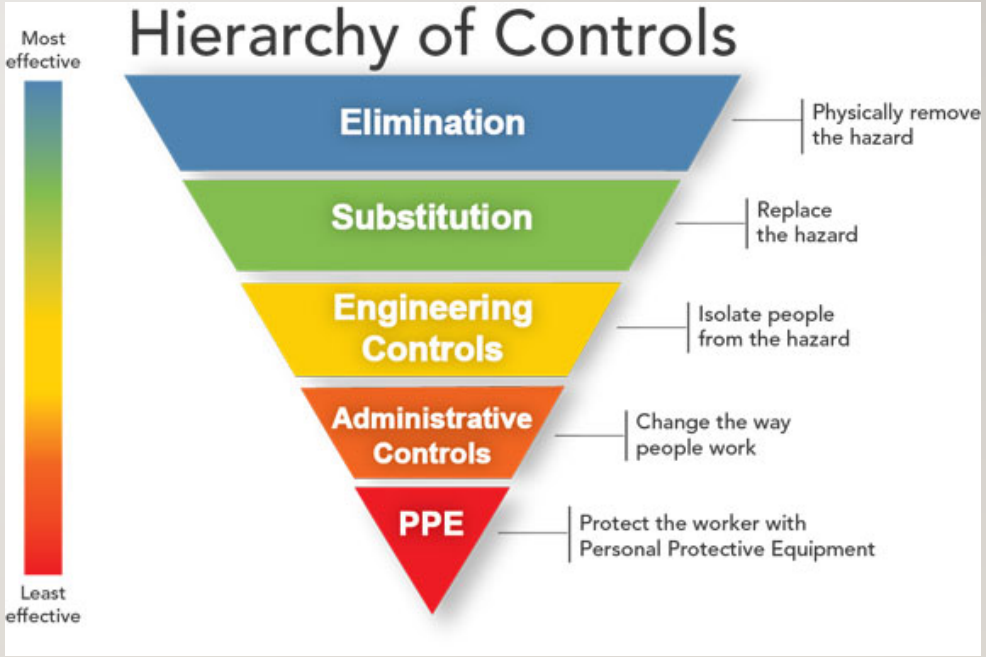
https://www.ashrae.org/file%20library/about/position%20documents/pd_infectiousaerosols_2020.pdf

ISSUE

- Diseases may be transmitted from person to person by air as infectious aerosols – particles or droplets
- HVAC system design and control can disrupt transmission pathways
- Non-HVAC measures are also important
- Owners, operators, designers need to understand how HVAC systems contribute to risk management along with non-HVAC measures

PRACTICAL IMPLICATIONS: GENERAL

- HVAC – focused measures can't eliminate all risk
  - Need to consider multiple approaches
  - Collaborate to develop best overall strategies
    - Designers
    - Owners
    - Operators
    - Industrial hygienists
    - Infection control specialists



PRACTICAL IMPLICATIONS: SPECIFIC TO FACILITY TYPE

- Follow applicable standards and beyond-code guidance
- Most infections transmitted in non-health care facilities (but currently no non-healthcare infection control standards)
- "Infection control bundles" for health care facilities
  - Administrative controls (rules and procedures)
  - Environmental controls (e.g., HVAC)
  - Personal protective equipment
- Proper installation, commissioning and maintenance!

PRACTICAL IMPLICATIONS: GUIDANCE DOCUMENTS

- Comprehensive
  - Facility Guideline Institute Guidelines (healthcare – adopted in 39 states, alternate compliance path in 4 states)
- Ventilation
  - ASHRAE Standards 62.1 and 62.2 for non-health care
  - ASHRAE Standard 170 for health care facilities National Institutes of Health guidelines for laboratories
- Beyond-code
  - CDC Tuberculosis control guidelines
  - ASHRAE IAQ Guide

ASHRAE INDOOR AIR QUALITY GUIDE – BEST PRACTICES FOR DESIGN, CONSTRUCTION, AND COMMISSIONING

- Eight objectives with detailed guidance
  - Manage the design and construction process to achieve good IAQ
  - Control moisture in building assemblies
  - Limit entry of outdoor contaminants
  - Control moisture and contaminants related to mechanical systems
  - Limit contaminants from indoor sources
  - Capture and exhaust contaminants from building equipment and activities
  - Reduce contaminant concentrations through ventilation, filtration, and air-cleaning
  - Apply more advanced ventilation approaches

Free download:
http://iaq.ashrae.org

PRACTICAL IMPLICATIONS: VENTILATION AND AIR CLEANING

- Reduce aerosol load → Reduce exposure → Reduce risk
- Approaches
  - Supply clean air to susceptible occupants
  - Contain and exhaust contaminated air to outdoors
  - Dilute indoor air with cleaner outdoor or filtered air
  - Clean air in the space

18 VENTILATION AND AIR-CLEANING STRATEGIES

- Means shown to be effective
  - Ventilation (including pressurization)
  - Particulate filtration
  - Inactivation by ultraviolet germicidal irradiation (UVGI)
- Evidence in literature
  - Reduced aerosol loads/inactivation – Yes
  - Controlled interventions demonstrating clinical effectiveness – No
  - Field studies indicating effectiveness - Some

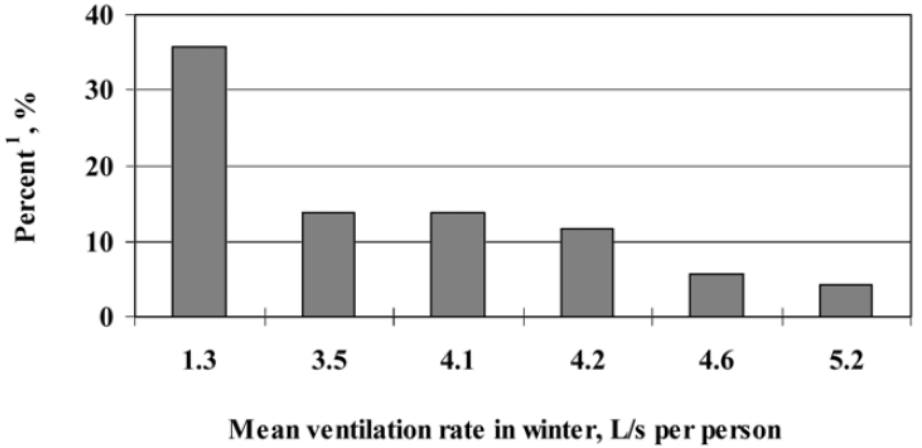
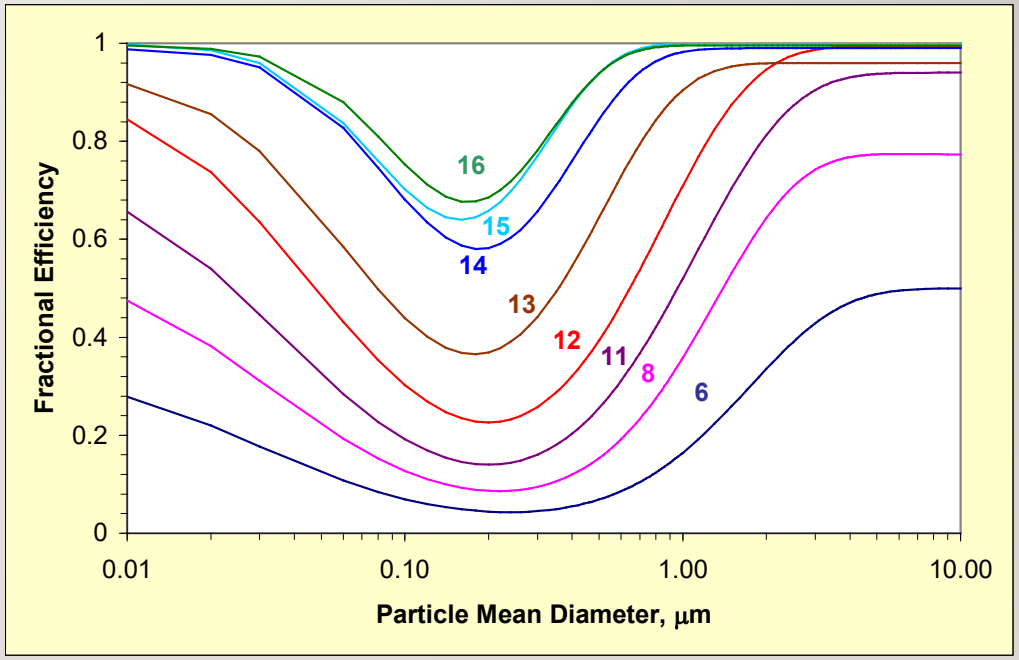


Figure 4. Associations between common cold infection rates and mean ventilation rate in winter in buildings constructed after year 1993. [1] Proportion of occupants with ≥6 common colds in the previous 12 months.

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

19 FILTRATION

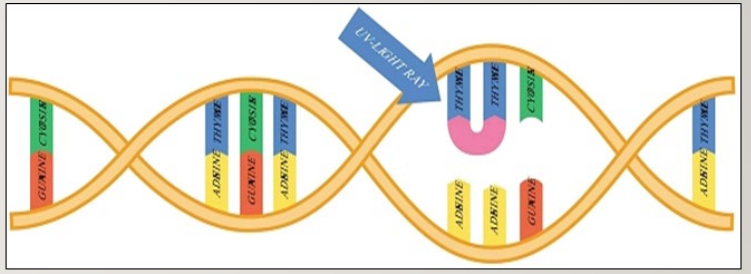
- Can remove any aerosol contaminant (but not all with 100% certainty)
- For indoor sources, requires recirculation in space or system
- Effective if
  - Contaminants of concern are airborne
  - Clean air delivery (efficiency + recirculation) is high enough

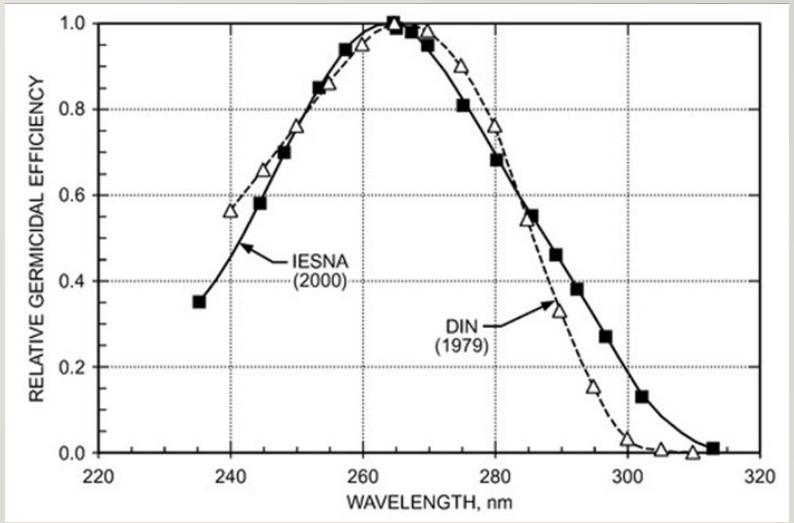


Representative MERV rated filter performance (Kowalski and Bahnfleth 2002)

20 ULTRAVIOLET GERMICIDAL IRRADIATION

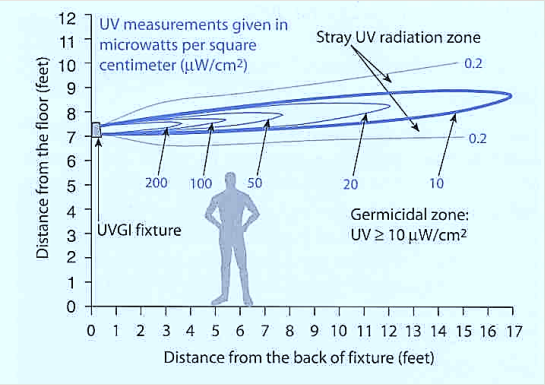
- Ultraviolet light in UVC band
- 265 nm ideal, 254 nm produced by low pressure Hg vapor lamps
- Disrupts microbial DNA/RNA, prevents reproduction
- Treats air in-room, in air-handling units, disinfects surfaces
- Effective if contaminant is airborne, viable, susceptible





21 ULTRAVIOLET GERMICIDAL IRRADIATION

Upper Air UVGI



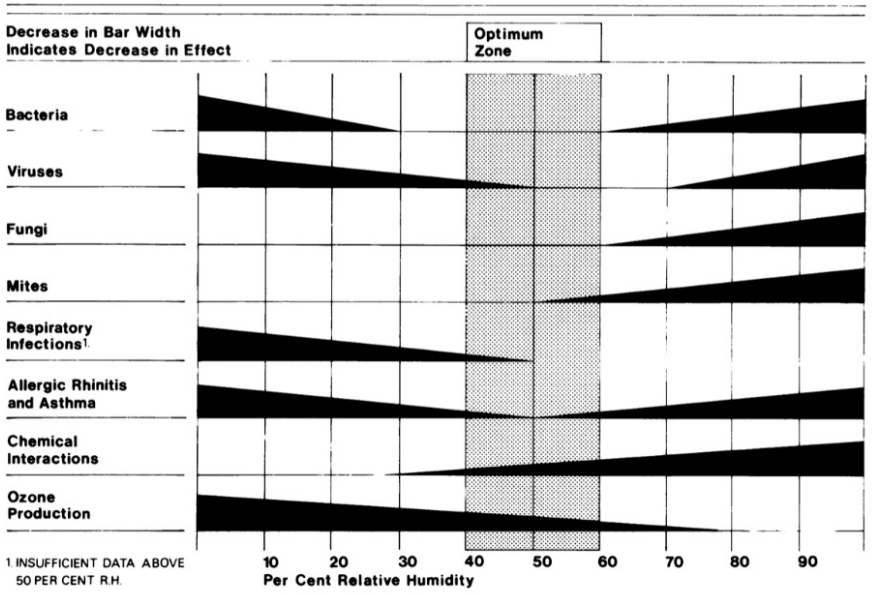
In-Duct/Coil UVGI

Portable Surface Treatment UVGI

PRACTICAL IMPLICATIONS: TEMPERATURE AND HUMIDITY

- 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.



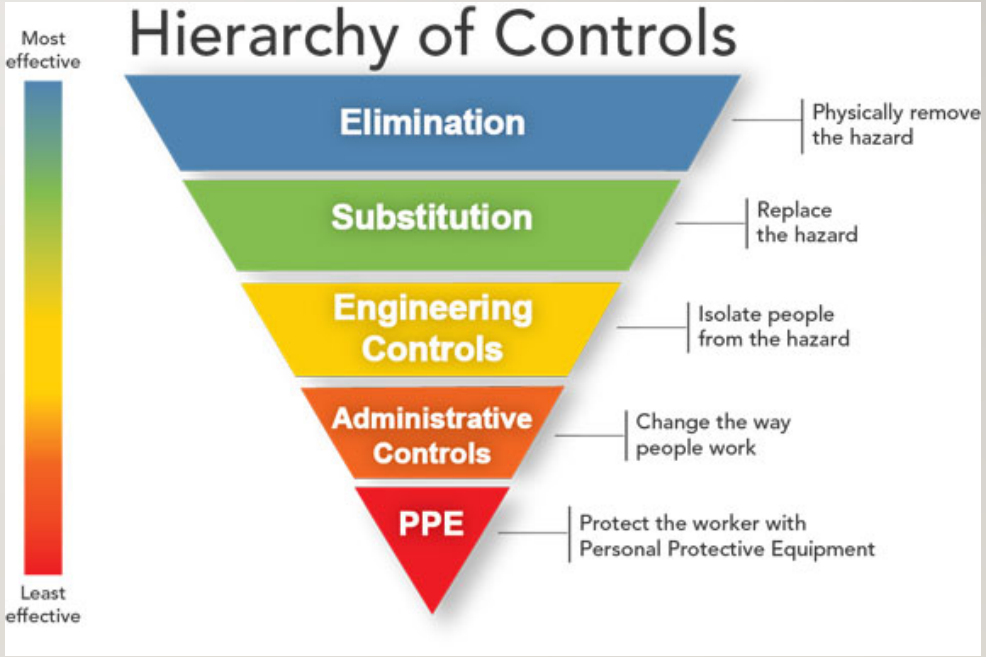
Optimum relative humidity range for minimizing adverse health effects.

PRACTICAL IMPLICATIONS: 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 but, practitioners are encouraged to apply the evidence on a case by case basis

24 PRACTICAL IMPLICATIONS: EMERGENCY PREPAREDNESS

- Design/maintain/operate buildings for effective performance during emergencies
- Use "control banding"
  - Risk assessment and management strategy
  - Determine a control measure based on a "band" of hazards and exposure levels
  - Make use of known solutions where possible
  - Use in conjunction with traditional exposure management hierarchy



RECOMMENDATIONS

- Follow latest standards, guidance
- Go beyond minimum when needed
- Consider infectious aerosol mitigation in design of all facilities
- Integrated design to incorporate appropriate infection control bundles
- Incorporate air flow direction control, use air cleaning systems based on risk assessment

RECOMMENDATIONS HVAC STRATEGIES TO CONSIDER

- General
  - Enhanced installed filtration
  - Portable filtration
  - UVGI
  - Local exhaust, personalized ventilation where needed and feasible

RECOMMENDATIONS HVAC STRATEGIES TO CONSIDER

- Healthcare
  - Exhaust toilets and bed pans
  - Temperature and humidity control based on pathogen
  - Clean air supply for caregivers
  - Negative pressure to ICUs with infectious patients
  - 100% exhaust of patient rooms
  - UVGI
  - Increase outdoor air changes from 2 to 6 ACH
  - Consider HVAC in room turnover plan

RECOMMENDATIONS HVAC STRATEGIES TO CONSIDER

- Non-healthcare – emergency response plan
  - Increase outside air to 100% or highest level possible
  - Improve filter efficiencies to MERV 13 or higher, as possible
  - Operate systems 24/7 to maximize effect of ventilation and air treatment
  - Add portable HEPA or high-MERV air filters
  - Add UVGI
  - Control temperature and humidity based on pathogen
  - Bypass ERVs
  - Practice!

RECOMMENDATIONS

- Address research needs…there is a lot we don't understand well yet
  - Source generation
  - Effect of air change rates in healthcare facilities
  - Effectiveness of patient room air distribution configuration
  - Controlled interventional studies – performance and cost-effectiveness
  - Healthcare surge capacity design
  - Temperature and humidity control strategies
  - Application of control banding to infection control

RECOMMENDATIONS

- Build interdisciplinary expert partnerships
  - Engineers
  - Infectious disease
  - Occupational health
  - Building owners
- Stakeholder education
- Knowledge sharing
- Update standards and guidelines

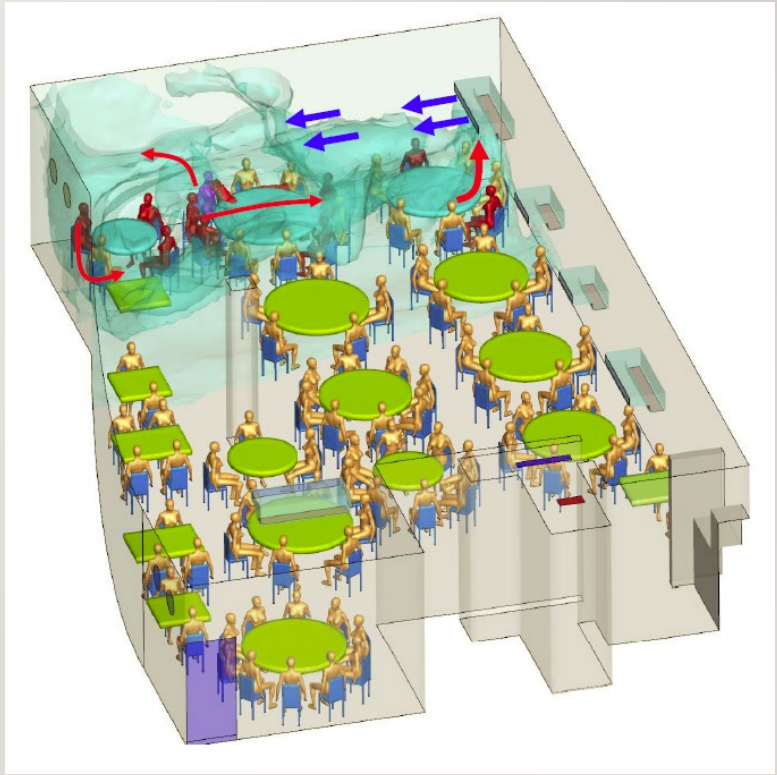
ASHRAE GUIDANCE – COVID-19

Statement on Operation of HVAC Systems During the COVID-19 Pandemic

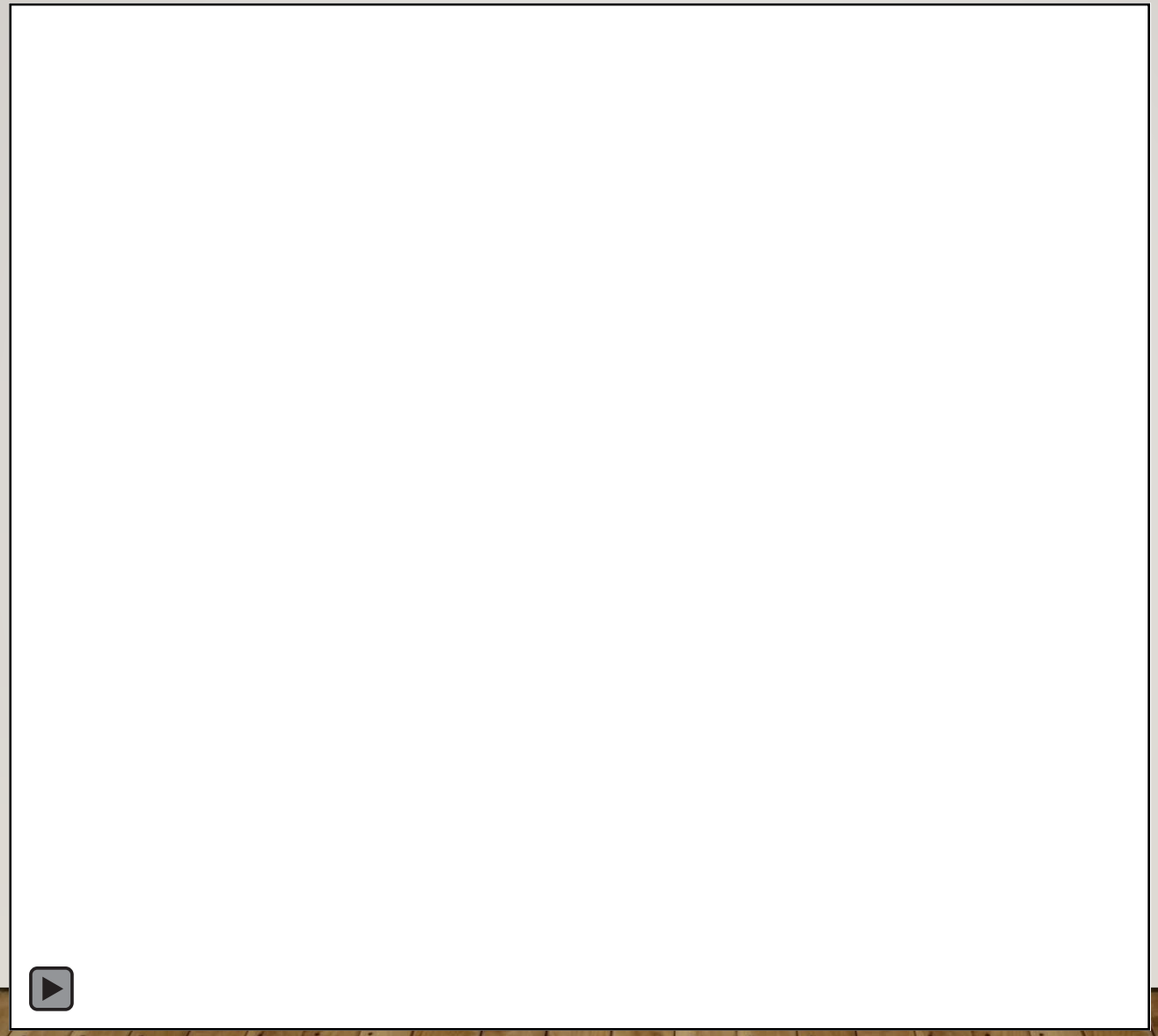
Ventilation and filtration provided by heating, ventilating, and air-conditioning systems can reduce the airborne concentration of SARS-CoV-2 and thus the risk of transmission through the air. Unconditioned spaces can cause thermal stress to people that may be directly life threatening and that may also 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.

CAVEAT – AIR CONDITIONING THAT DOES NOT VENTILATE, FILTER, DOESN'T HELP

- Guangzhou restaurant community spread event
  - No active ventilation
  - Fan coil unit air-conditioning
  - No close range/fomite transfer
  - Measured ventilation rate ~0.75 – 1 L/s per patron (very low!)
- *Conclusions:* "Aerosol transmission of SARS-CoV-2 due to poor ventilation may explain the community spread of COVID-19."

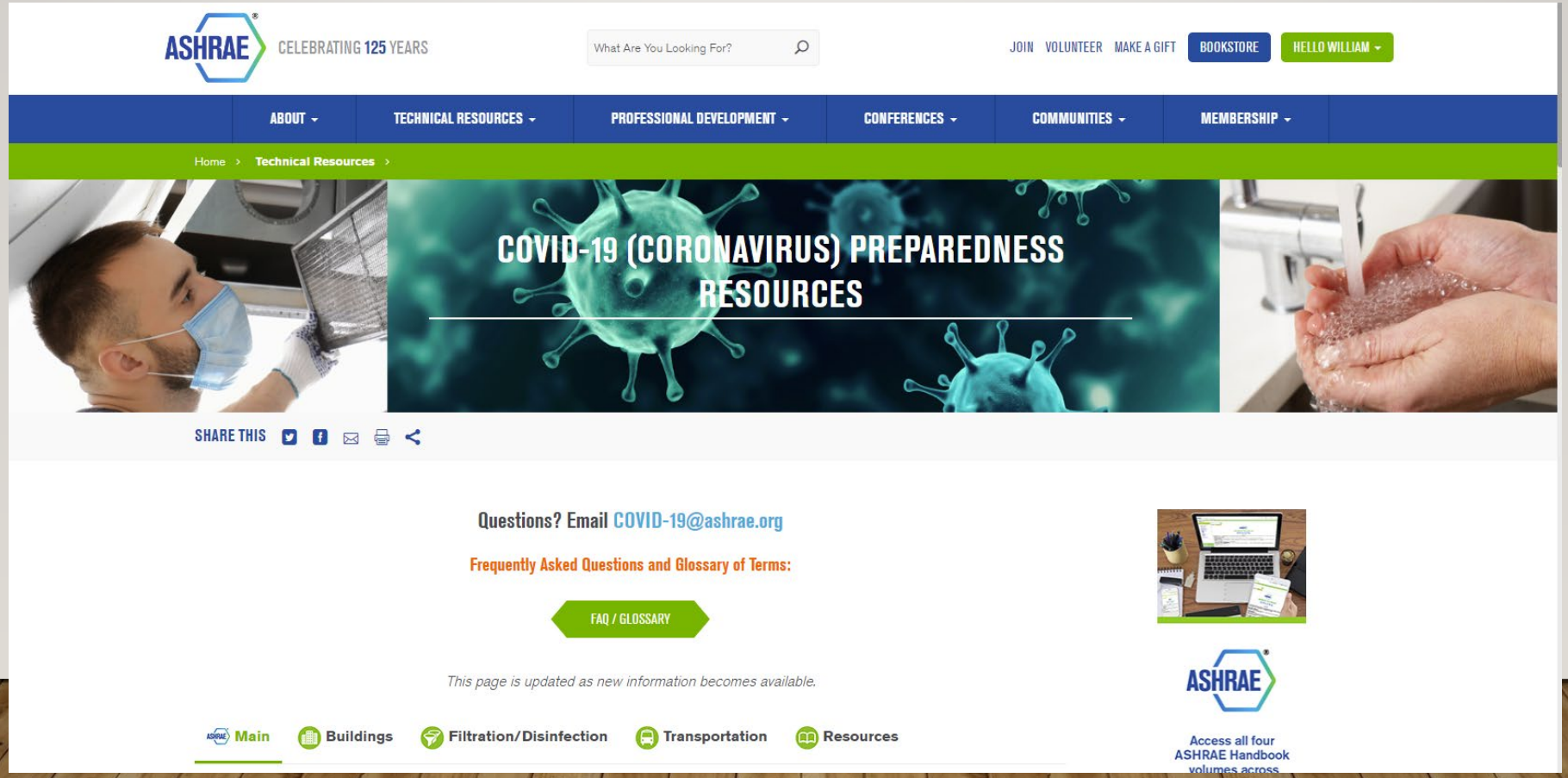


Li, et al. (2020) https://doi.org/10.1101/2020.04.16.20067728



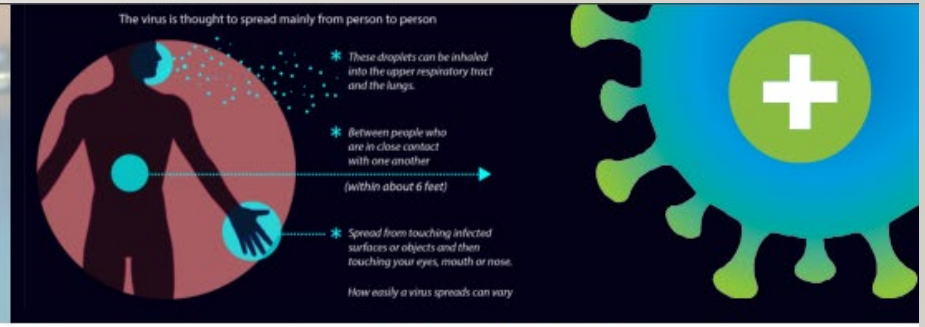
34 DETAILED ASHRAE GUIDANCE COVID-19 RESOURCES PAGE

ashrae.org/covid19



ASHRAE EPIDEMIC TASK FORCE

HEALTHCARE | Updated 4-15-2020



BACKGROUND/CONTEXT

- Modes of Transmission/Aerobiology
- ASHRAE Statements on Airborne Transmission
- CDC recommends Airborne Infection Isolation rooms for aerosol generating procedures (AGPs)
- Committing Airborne Infection Isolation rooms for use as inpatient rooms limits future flexibility. Work with clinical staff to establish use requirements.
- Cohorting – Cautions and current methods.
- See ASHRAE COVID-19
- ASHRAE members have provided input on Disaster Planning and Emergency Management for Healthcare Facilities. Partner on your local professional engineering partners for input and guidance during this time.

GOALS

- Do No Harm
- Protect Healthcare Workers, Family, and Visitors
- Protect Other Patients
- Empower people to make and carry out the best decision they can.
- Work as a team – weigh competing concerns, define key areas, share the plan.
  - Consider the type of HVAC system, the configuration, clinical needs, facility infrastructure capacity, and limited resources available.

LIFE SAFETY

- Confirm that power-consuming equipment is connected to the appropriate branch of the essential power system.
- Maintain Egress
- Consider defend-in-place plans and smoke compartments
- Increased facility oxygen use elevates risk of a fire spreading more rapidly
- First responder protection.
- Develop Interim Life Safety Measures as applicable

SUGGESTED APPROACHES

- Passive Isolation
- Strategically utilize All Rooms
- Airflow from Clean to Less Clean
- Increase Filtration Level if possible
- Eliminate recirculation or minimize to the extent possible
- Maintain relative humidity at 40-60%.
- Deactivate or by-pass heat recovery wheels
- Improve/Consider room airflow direction/patterns
- Utilize portable ante rooms/vestibules with HEPA filtration
- Utilize UV light (see Facilities/Maintenance – Disinfection)
- Areas for non-Covid patients should still be treated with care because someone could be unknowingly infected.

SPECIFIC "HOW-TO" AND UNIQUE AREAS

- Layered approach for normal and small surge operations
- Source Control Options for patient beds
- Operating on COVID-19 positive patient
- Variable Air Volume Adjustments & Modification to economizer or reduced recirc.
- Cautions on Recirculating Room Units (Fan coils, induction units, etc.)
- 2-person patient rooms – creating or managing existing
- Use Operating rooms for inpatient rooms/temp ICU
- Emergency Department
- Warning on Older ICU units
- Transmission through the air in toilet rooms
- Provide areas for safely doffing PPE, such as shoe cover removal followed by "tacky matts" for personnel exiting an area.

SURGE AREAS

- Initial Considerations
- Alternate Care Site Design Concepts
- Single patient room considerations vs. 2-patient rooms
- General Parameters for ACH, Temp, Filtration, and RH

FACILITIES/MAINTENANCE

- PPE basics
- Filter changing
- Room turnover
- Verify performance of critical HVAC systems – airborne infection isolation rooms, Emergency Departments, etc.
- Disinfection: Normal, UV, VHP, Hypochlorous Acid
- See ASHRAE COVID-19 Filtration and Disinfection section for greater detail.
- Considering the possibility of being short-staffed in the future, run-test and re-fuel emergency generator system.
- Submit waivers as required to CMS for inspection, testing, and maintenance under Section 1135. ASHE Template.
- Check to be sure COVID-19 area AHU return air isn't being used to condition mechanical rooms.

MEDICAL GAS/VACUUM SYSTEMS

- Demand for gasses in ICU rooms
- Demand for gasses in med-surg rooms and OR's
- Accommodating increased demand (flow) in fixed piping systems
- Impact of demand/consumption on existing gas systems
- Consider providing supplementary gas sources

OTHER

- Utilize make up air units or exhaust fans from other facilities (restaurants) that are currently shut down.
- Reduce # of rooms utilized off a single HVAC system to free up AHU capacity to achieve performance goals. 25 beds with desired airflow/temps better than 30 beds with airflow/temp deficiencies.
- Document the Action Plan and Alternations in Place

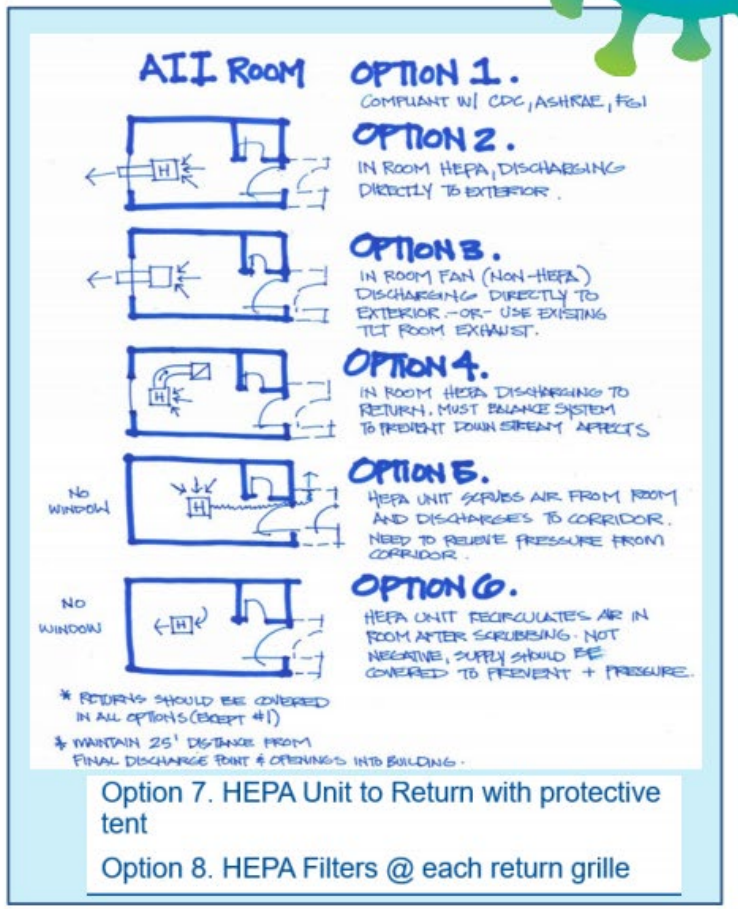
QUESTIONS? COVID-19@ashrae.org

www.ashrae.org/covid19

Layered Approach: A Variety of Options

See overview of options 1-6, plus links below to detailed information on these, plus Options 7 & 8. Evaluate what works best for your condition(s).

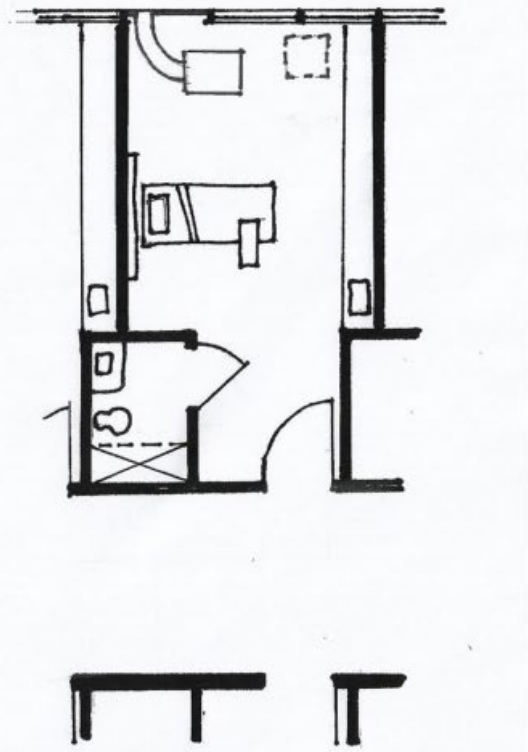
- Normal Operations – Option 1
  - Follow CDC, ASHRAE, FGI Guidelines per your local code.
  - Clinical plan may limit airborne infection isolation room use to aerosol generating procedures.
- Small Surge Option 2
- Small Surge Option 3
- Small Surge Option 4
- Small Surge Option 5
- Small Surge Option 6 – see image
- Small Surge Option 7 (HEPA Unit to return with protective tent)
- Small Surge Option 8 (HEPA filter @ each return grille)



37

Small Surge:
Option 2 Direct to Outside

- Single patient room with dedicated bathroom
- Seal off return air grill in patient room
- Duct through exterior to the outside.
- Remove window and enclose opening
- Keep door to patient room closed
- Verify negative pressure prior to placing room in service and monitor negative pressure while in service
- Limit patient transport and patient transfers
- Terminal cleaning after ACH removes potentially infections particles
- Notify Healthcare workers that HEPA units can not be turned off once in place as this may result in an unsafe condition with the room becoming positively pressurized to the corridor.



The most preferred recommendation is to co-locate all patients to an area served by a single air handling unit and to modify that unit to create negative pressure for the entire area being served. If it is possible the filters on this system should be replaced with HEPA filters. Prior to placing the unit into service the negative pressure of the area should be verified and it should be monitored throughout the time COVID-19 patients are treated within the area.

REHVA GUIDANCE - SUMMARY

- Ventilation and air distribution
  - Increase air supply and exhaust ventilation
  - Use more window airing
  - No use of recirculation
  - Duct cleaning has no practical effect
- Temperature and humidity
  - Humidification and air-conditioning have no practical effect
- Safe use of heat recovery sections
- Filtration and air cleaning
  - Change of *outdoor air* filters is not necessary
  - Room air cleaners can be useful in a specific situation
- Bathroom plumbing
  - Toilet use lid instructions (close them!)
  - Maintain priming of traps

https://www.rehva.eu/activities/covid-19-guidance

ASHRAE EPIDEMIC TASK FORCE

- Objectives
  - Response to COVID-19 pandemic
    - Short term
    - Reopening/2nd wave
  - Future
    - Lessons learned
    - Research
    - Standards and guidance

- 17 core members, including staff liaison and three staff directors
- Steering committee for teams focused on specific areas ~120 team members
- Coordinating with ASHRAE technical and standards committees, other organizations
- Weekly meetings of Task Force, most team leaders have weekly meetings

ASHRAE EPIDEMIC TASK FORCE TEAMS (5/4/2020)

- Communications
- Grassroots
- Advocacy/Developing Economies
- External Organization Partnerships
- Resource Inventory
- Science/Literature Review
- Filtration and Disinfection
- Healthcare (including long-term care)
- Residential
- Commercial/Retail
- Schools
- Transportation
- Building Readiness

ASHRAE EPIDEMIC TASK FORCE – ACTIVITIES SINCE MARCH 29

- Expedited revision of Infectious Aerosols Position Document
- Society statements on SARS-CoV-2
- Emerging Issue Brief "Pandemic COVID-19 and Airborne Transmission"
- Complete update of COVID-19 resources page with guidance developed by teams
- Answered over 220 questions to web site
- Meetings with AIA, NYSERDA, DOE, others
- Participated in AIA charrette
- Healthcare and UVGI webinars
- Reviewed/edited guidance for Florida
- Membership survey
- Working on…
  - Partnership with government on HVAC for alternate care facilities
  - Update to residential IAQ guide
  - Guidance for meat processing plants
  - Reopening plan for ASHRAE HQ
- Beginning to focus on mid-term guidance but continuing to work on guidance already posted

Thank You!

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Q&A

U.S. DEPARTMENT OF ENERGY

Additional Questions?

Please Contact Us

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Thank You!

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