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
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 $\approx 120 \text{ nm (0.12 } \mu \text{m)}$
- 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
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.

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. 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

- SARS-CoV-2 size O(100nm)
- Contained in respiratory droplet residues of larger size
- Sub-HEPA media filters can collect particles with high efficiency
Filtration can be a lower energy way to reduce aerosol/airborne infection risk

Relative influenza risk reduction, filters vs. ventilation cost, 500 m² office building
Filtration has benefits other than infection control

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

\[ \varepsilon = \frac{C_{\text{uncontrolled}} - C_{\text{controlled}}}{C_{\text{uncontrolled}}} \]

Ventilation/Filtration Trade Off

• Simple example: Ventilation + Filtration
  • Well-mixed, steady state
    • $Q_s = 100$
    • $S = 1$
    • $C_O = 0$

• Scenario 1
  • $\eta_F =$ variable
    • 20% OA

• Scenario 2
  • $\eta_F = 60$
    • $f =$ 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

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
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!

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