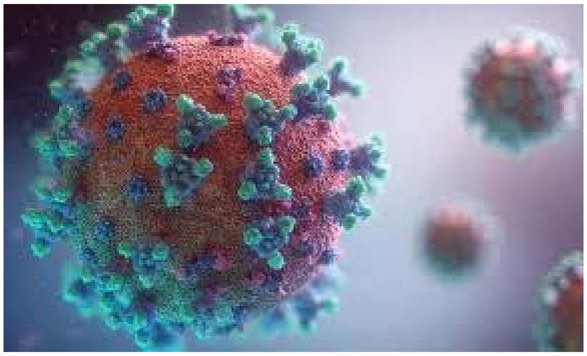
IAQ & Airborne Infectious Diseases

Indoor Air Quality or IAQ is a fundamental concern in modern HVAC design. Historically, the focus on indoor air quality has shifted from concerns such as tobacco smoke, moisture, and odors to encompass a holistic view of indoor environmental quality with the focus on sick building syndrome. This interest has expanded to include the impact of indoor air quality on asthma, allergies, and infections. The ASHRAE Fundamentals handbook notes that with respect to agents that cause disease, "Over a 70-year lifespan in a developed region, indoor air (in homes, schools, day cares, offices, shops, etc.) constitutes around 65% of the total lifetime exposure (in mass), whereas outdoor air, air during transportation, food, and liquid makes up the rest. For more vulnerable populations, such as newborns, the elderly, and the homebound ill, indoor air in homes makes up around 80% of the exposure."



ASHRAE identifies four classes of environmental hazards: chemical hazards, biological hazards, physical hazards, and ergonomic hazards. In this white paper, we are going to narrow that focus much more tightly to biological hazards. At the time of the writing of this paper, airborne infectious diseases are an enormous focus of concern and research, as SARS-CoV-2 is circulating around much of the world. However, this pandemic is only the most severe of the recent impacting the world. The 1918 flu virus is often cited when thinking about severe pandemics, but there have been several others throughout the last century of varying degrees of severity including an H2N2 flu virus in 1957-1958, an H3N2 flu virus in 1968-1969 (with one million deaths globally), an H5N1 flu virus in 1997, SARS-CoV in 2003, and an H1N1 flu virus in 2009. And it's not just pandemics that exact a toll on society; according to a report published by researchers at the US Centers for Disease Control in 2007, the annual flu epidemic costs the United States nearly $90 billion dollars, including 44 million working days lost due to illness.

Pandemic threats and the potential for bio-terrorism constitute emergencies for facilities, but the built environment can contribute to the circulation of more common pathogens such as rhinitis/common cold virus as well. Good building design practices can place HVAC engineers on the frontlines in mitigating the social and economic costs of disease in the United States.

Common Pathogens & Routes of Transmission

The follow is a list of some common & well known pathogens that can be spread via airborne means. This list is not exhaustive and many of these diseases may be spread by more than one route:

- Chickenpox/shingles – Droplet or airborne spread of vesicle fluid or respiratory tract secretions.
- Coronaviruses – Airborne transmission was the primary means of transmission of SARS-CoV (the virus responsible for the SARS outbreak in 2003) and many pre-print journal articles indicate this may hold true for SARS-CoV-2 (the virus that causes COVID-19)
- Influenza – Airborne spread is the predominant means
- Measles – Airborne by droplet spread
- Meningitis – Respiratory droplet spread
- Mumps – Airborne spread or droplet spread
- Pneumonia – Droplet spread, including potential airborne spread
- Rhinitis/Common Cold – Inhalation of airborne droplets
- Rubella – Droplet Spread
- Tuberculosis – Exposure to tubercle bacilli in airborne droplet nuclei

This is by no means an exhaustive or conclusive list. For many pathogens, the relative importance of transmission routes remains uncertain and a topic demanding further research. What is known for the HVAC engineer is this: there will be sick people in the spaces we design and we can select our systems to help mitigate the spread of disease.

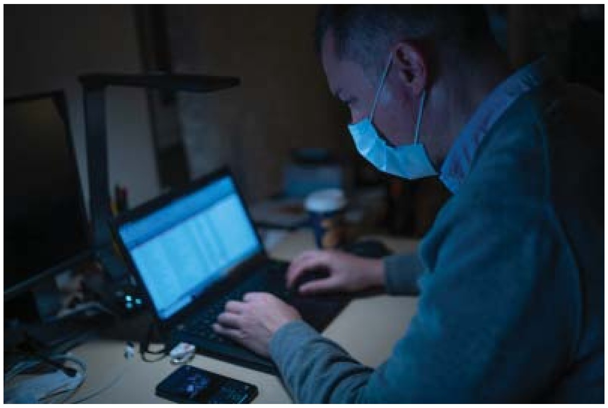
Infectious Dose

To ground this discussion in a little bit of mathematical analysis, we can take a look at a mathematical model developed to look at the probability of new infections. The Wells-Riley equation considers the number of new infections, *C*, as a function of several factors. *S* is the number of individuals susceptible to infection. I is the number of individuals shedding infectious material. The number of infectious doses added to the air per unit time by each *I* is given by *q*. Pulmonary ventilation, *p*, is given in volume per unit time. The exposure time is given by *t* and the volume of fresh air is given by *Q*. The totality of the term in parentheses may be thought of as a probability that each susceptible individual is infected.

C=S*(1- e^((-Iqpt)/Q))

The term q in the preceding equation is very difficult to estimate and doesn't hold much value for us to consider except in the abstract for the engineer. Likewise, exposure time is somewhat outside the domain of the engineer: an office or retail worker will be in that space for their shift. There are several takeaways for the HVAC engineer in looking at the equation:

- The probability of infection increases with the density of infected individuals. While we can't control close contact or how many people share a space, we can use zoning solutions to provide some isolation.
- The probability of infection decreases with the volume of fresh air, Q. In other words, the same amount of infectious agent is more dilute and less likely to infect any individual.
- There are some solutions available such as filtration or engineered deactivation, to help minimize the amount of infectious agent in the air. This is effectively a reduction in the infectious doses in the air per unit time and is not neatly accounted for in this equation.



Disease Mitigation Strategies for HVAC

The range of mitigation strategies ASHRAE has identified that may be employed to minimize the risk of disease transmission through HVAC systems, minimize the economic impact of productivity lost to disease, and maximize the ability of building owners and facilities personnel to react to emergencies is as follows:

Dilution ventilation: Dilution ventilation is achieved by introducing outdoor air into the building. By increasing the volume of air free from pathogens into the space, the overall concentration of infectious particles can be reduced. Demand control ventilation schemes reduce the effectiveness of this mitigation strategy overall and while they may be desirable from the standpoint of maximizing energy efficiency, there is a trade-off in indoor air quality. Where this balance falls in the future remains to be seen as the industry adjusts to the 2019 pandemic and is forced to look more seriously at the risk of future pandemics. Airside economizers, conversely, are great systems for both energy savings and dilution ventilation; by maximizing outdoor airflow during suitable ambient conditions, both dilution and energy savings may be achieved.

A compact VK-OA® solution for delivering outdoor air in spaces with limited mechanical space.

Temperature & Humidity Control: Some viruses such as influenza are inactivated relatively quickly at higher humidity levels. Conversely, when humidity is allowed to drift too low (as happens frequently during the winter), the size of respiratory droplets are rapidly reduced; these smaller droplets are subsequently able to stay aloft in the air much longer. Unfortunately, allowing humidity levels to drift too high can promote the growth of fungi and molds. Maintaining relative humidity in the range of 40-60% is typically an optimal zone not just for comfort, but to minimize bacterial and viral transmission and avoid fungal growth.

Personalized ventilation: Dedicated systems delivering air directly to the occupant's breathing zone may be an effective control strategy to prevent aerosol movement.

Local exhaust: Contaminated air is directly removed from the space and exhausted to the outside.

Central system filtration: A well-maintained and designed central HVAC system will always incorporate air filtration. Higher efficiency filtration can reduce the spread of infectious agents between zones and may reduce the airborne load of infectious particles.

Local air filtration: Dedicated filtration units may be mounted in spaces in specific zones where additional filtration may be desirable.

Upper-room UVGI: Ultraviolet germicidal irradiation or UVGI refers to using UV-C light to kill or inactivate microorganisms such as bacteria, molds, viruses, and other pathogens. Upper-room UVGI is used to irradiate an entire room. Exposure to UV-C is harmful to humans, though, so there are two strategies for this: (1) Running the UVGI while the space is unoccupied or (2) running the UVGI in a space where all of the occupants are wearing PPE (i.e. potentially in a surgical suite).

Duct & Air- Handler UVGI: When used in HVAC equipment, UVGI is most effective when it's placed in the air handling unit in the coil section. This typically does not impose any additional pressure drop on the unit and irradiates the drain pan and coil as well as disinfecting the air passing through the coil section. In-room flow regimes: Operating theaters will frequently use laminar air flow to direct air streams away from the operating field and prevent bacterial inoculation of the surgical area.

Differential pressurization: Differential pressurization is commonly used in healthcare and laboratory facilities. In laboratory environments, airflow typically is routed from low hazard areas to high hazard areas via space pressurization. Likewise, hospitals utilize pressurization to isolate medical/surgical rooms or ICUs treating infectious disease. Pressurization is also an important consideration in multifamily residential buildings and hotels.

Recommendations

ASHRAE recommends employing a range of mitigation strategies in tackling the threat posed by infectious diseases rather than focusing on a singular option. When designing your equipment, AboveAir in particular recommends the following when specifying our equipment:

- If space and budgetary concerns allow, utilize parallel dedicated outdoor air systems with primary space control systems. Dedicated outdoor air systems ensure that every zone is getting the minimum code-required outdoor air flow.
- Where DOAS does not fit the space or budget constraints, specify AboveAir's HPOA equipment. Select features and options support operation of our equipment from 30%-100% outdoor air at all ambient conditions in North America.
- If you need to use demand control ventilation to meet code requirements, make sure you specify a flush cycle. The ventilation system should be turned on and run prior to building occupancy to flush all of the zones served with fresh air.
- Always specify an airside economizer when possible. This maximizes the outdoor air to your space during the unit's regular service life. This also maximizes the amount of air that can be used for dilution in the event of an emergency.
- Make sure you consider what level of filtration is right for your application: high efficiency filters (MERV 13 or higher) are becoming a requirement in more applications and are desirable from a global IAQ standpoint. HEPA filters (approximately MERV 17-20) may be required for some applications or by some owners. In order to maximize the life of your MERV 13 or higher filter, specify a MERV 8 pre-filter as well.
- Consider specifying humidification for your space to maintain relative humidity during the winter.
- Take a close look at specifying UVGI in your air handling unit. This is a cost-effective mitigating feature for biological agents that does not impact the performance of your unit.

Further information of interest may be found in ASHRAE's position papers and the ASHRAE design manuals.