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HVAC Source Strength and Air Distribution

Designing for Airborne Infection Control

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The estimated total annual cost of hospital-acquired infections in the United States, is ~$7 billion, with airborne transmission contributing 10% to 20%.[1] This is a significant issue and these numbers increase when we consider commercial and transportation indoor environments. However, the proper design of the HVAC system can mitigate airborne infection transmission and help to control these costs. This article reviews ASHRAE's *HVAC Design Manual for Hospital and Clinics* and HVAC from the perspective of infectious source strength and air change rate, one of the key parameters in healthcare design.

Transmission occurs when infectious aerosols are emitted in the environment and expose the susceptible person. Exposure has to be above the disease specific infectious dose to cause an infection. HVAC systems can help to control airborne transmission by influencing dilution, exposure time and airflow patterns.[2] At the moment, air change rates for different environments are designed per ANSI/ASHRAE/ASHE Standard 170-2017, *Ventilation of Health Care Facilities,* considering thermal requirements and necessary air exchange rates, but without considering the emission of infectious aerosols, nor concentration of infectious aerosols in respect to the infectious dose. Knowledge about the emitted quantity of infectious aerosols combined with well-mixed environment assumption enable calculation of airflow rate that can sufficiently dilute infectious aerosols and reduce exposure below the infectious dose. Studies that quantify infectious source strength used epidemiological data to deduce information about infectious source emissions from the epidemiological outcomes in terms of quanta or using known dose-response relationships.[3] Both of these approaches based on epidemiological outcomes have inherent uncertainties, and beyond research papers, the developed methods did not find their way into the design guideline.

One challenge in conducting this research and using it to make design recommendations is that accurate estimation of the infectious source strength requires an aerosol sampling device that does not restrict respiratory activities, collects aerosol with high efficiency, and preserves virus culturability.[4] The device with these characteristics was not available until the development of the G-II aerosol sampler. The G-II enables

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direct estimation of infectious source strength and was used to quantify influenza aerosol shedding rates in the United States, Hong Kong and Singapore.[5,6] One hundred forty two cases with confirmed influenza infection were part of the study with a total of 218 samples collected.[6] Each case was sampled for 30 minutes to include different naturally occurring unrestricted expiratory activities to better reflect real emissions. Results showed that, on average, influenza infected people emit 4×10^4 virus particles in droplets smaller than 0.5 μm, with 40 of them culturable and 4.13×10^4 virus particles in droplets larger than 0.5 μm. Since the aerosol infectious dose is one culturable virus particle, the average amount emitted in 30 minutes can potentially infect 40 people.

With information about the source strength, it is possible to design the air supply flow rate to target reduction in the propagation of secondary infection cases. A full database of source strengths for the infectious diseases that are primarily or only transmitted via airborne route, including tuberculosis, measles, smallpox and chickenpox, is needed. Such a database does not exist at the moment, but recent developments in sampling technology have removed many previous technical limitations.

Currently, airflow rates cited in Standard 170-2017 are based on choosing the maximum between the air requirements for cooling load, air change rate and makeup air. The largest of the three values will determine the supply air requirements for the air handler. Recommended air change rates are not based on the information about the source strength, therefore we can determine if they are correct, too low or too high. At the moment, evaluation of these air change rates can be performed for one type of influenza virus.

The *HVAC Design Manual*[2] bases the calculation of the supply flow rates on the assumption of a well-mixed environment. This approach shows that the supply flow rate increase creates a higher level of dilution and reduces exposure to infectious droplets. Recent studies have shown that in some cases when the supply flow rate increases the generated airflow patterns will cause increased exposure to the infectious aerosols aerosolized by breathing[8] or coughing.[9] Movement of people also plays a role in the transport of infectious aerosols. The wake generated behind the moving person or object entrains infectious droplets and can transport them to the adjacent space.[10] Complex flow interactions between expiratory activity flow and the convective boundary layer around the human body (the background flow generated by the air supply system) determines the dispersion of infectious aerosols. It's still not fully understood if in the design process all these complexities need to be accounted for. One potential solution can be the use of advanced air delivery systems[11] that supply clean air effectively to the user's breathing zone.

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