ASHRAE Position Document on Airborne Infectious Diseases

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Note: ASHRAE's Technology Council and the cognizant committee recommend revision, reaffirmation, or withdrawal every 30 months.

Note: ASHRAE position documents are approved by the Board of Directors and express the views of the Society on a specific issue. The purpose of these documents is to provide objective, authoritative background information to persons interested in issues within ASHRAE's expertise, particularly in areas where such information will be helpful in drafting sound public policy. A related purpose is also to serve as an educational tool clarifying ASHRAE's position for its members and professionals, in general, advancing the arts and sciences of HVAC&R.

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ABSTRACT

Infectious diseases spread by several different routes. Tuberculosis and in some cases influenza, the common cold, and other diseases spread by the airborne route. The spread can be accelerated or controlled by heating, ventilating, and air-conditioning (HVAC) systems, for which ASHRAE is the global leader and foremost source of technical and educational information.

ASHRAE will continue to support research that advances the state of knowledge in the specific techniques that control airborne infectious disease transmission through HVAC systems, including ventilation rates, airflow regimes, filtration, and ultraviolet germicidal irradiation (UVGI).

ASHRAE's position is that facilities of all types should follow, as a minimum, the latest practice standards and guidelines. ASHRAE's 62.X Standards cover ventilation in many facility types, and Standard 170 covers ventilation in health-care facilities. New and existing health-care intake and waiting areas, crowded shelters, and similar facilities should go beyond the minimum requirements of these documents, using techniques covered in ASHRAE's *Indoor Air Quality Guide* (2009) to be even better prepared to control airborne infectious disease (including a future pandemic caused by a new infectious agent).

EXECUTIVE SUMMARY

This position document (PD) has been written to provide the membership of ASHRAE and other interested persons with information on the following:

- the health consequences and modes of transmission of infectious disease
- the implications for the design, installation, and operation of heating, ventilating, and air-conditioning (HVAC) systems
- the means to support facility management and planning for everyday operation and for emergencies

There are various methods of infectious disease transmission, including contact (both direct and indirect), transmission by large droplets, and inhalation of airborne particles containing infectious microorganisms. The practice of the HVAC professional in reducing disease transmission is focused primarily on those diseases transmitted by airborne particles.

1. THE ISSUE

The potential for airborne transmission of disease is widely recognized, although there remains uncertainty concerning which diseases are spread primarily via which route, whether it be airborne, short range droplets, direct or indirect contact, or multimodal (a combination of mechanisms).

Ventilation and airflow are effective for controlling transmission of only certain diseases. Several ventilation and airflow strategies are effective and available for implementation in buildings.

Although this PD is primarily applicable to diseases that spread from person to person, the principles also apply to infection from environmental reservoirs such as building water systems with *Legionella* spp. and organic matter with spores from mold (to the extent that the microorganisms spread by the airborne route).[1] The first step in control of such a disease is to eliminate the source before it becomes airborne.

2. BACKGROUND

2.1 Introduction to Infectious Disease Transmission

This position document covers the spread of infectious disease from an infected individual to a susceptible person, known as *cross transmission* or *person-to-person transmission*, by small airborne particles (an aerosol) that contain microorganisms.

This PD does not cover direct or indirect contact routes of exposure. Direct contact means any surface contact such as touching, kissing, sexual contact, contact with oral secretions or skin lesions, or additional routes such as blood transfusions or intravenous injections. Indirect contact involves contact with an intermediate inanimate surface (fomite), such as a doorknob or bedrail that is contaminated.

Exposure through the air occurs through (1) droplets, which are released and fall to surfaces about 1 m (3 ft) from the infected and (2) small particles, which stay airborne for hours at a time and can be transported long distances. The aerobiology of transmission of droplets and small particles produced by a patient with acute infection is illustrated in Figure 1.

Because large droplets are heavy and settle under the influence of gravity quickly, general dilution, pressure differentials, and exhaust ventilation do not significantly influence droplet concentrations, velocity, or direction, unless they reduce diameter by evaporation, thus becoming an aerosol. The term *droplet nuclei* has been used to describe desiccation of large droplets into small airborne particles (Siegel et al. 2007).

Of the modes of transmission, this PD's scope is limited to aerosols, which can travel longer distances through the airborne route, including by HVAC systems. The terms *airborne*, *aerosol*, and *droplet nuclei* are used throughout this PD to refer to this route. HVAC systems are not known to entrain the larger particles.

The size demarcation between droplets and small particles has been described as having a mass median aerodynamic diameter (MMAD) of 2.5 to10 µm (Shaman and Kohn 2009; Duguid 1946; Mandell 2010). Even particles with diameters of 30 µm or greater can remain suspended in the air (Cole and Cook 1998). Work by Xie and colleagues (2007) indicates that large droplets are those of diameter between 50 and 100 µm at the original time of release. Tang and others (2006) proposed a scheme of large-droplet diameter $\geq$60 µm,

[1] For ASHRAE's position concerning *Legionella*, see ASHRAE (2012a). Readers are referred to other resources that address mitigation of transmission of this waterborne pathogen (ASHRAE 2000; CDC 2003; the forthcoming ASHRAE Standard 188; OSHA 1999; SA Health 2013, and WHO 2007). For ASHRAE's position concerning mold and moisture, see ASHRAE (2013d).

small droplet diameter < 60 µm, and droplet nuclei with a MMAD of <10 µm. The exact size demarcation is less important than knowing that large droplets and small particles behave differently and that the latter can remain airborne.

Small particles that can become airborne are typically generated by coughing, sneezing, shouting, and to a lesser extent by singing and talking. Even breathing may generate such particles in sick and highly infectious individuals (Bischoff 2013). Particle size distributions of coughed materials are thought to encompass a broad range of diameters, from very small to large droplets, depending on differences in patients and diseases (Riley and Nardell 1989).

Fennelly et al. (2004) measured cough aerosol emanating directly from tuberculosis patients. The patients generated infectious aerosol that contained from three to four colony-forming units (CFU, a direct measure, using culturing techniques, of the number of viable, growing, and infectious organisms) to a maximum of 633 CFU. The size distributions that were measured in this study suggest that most of the viable particles in the cough-generated aerosols were immediately respirable, ranging from 0.65 to 3.3 µm. Wainwright et al. (2009) also measured cough aerosols from cystic fibrosis patients and documented that 70% of viable cough aerosols containing *Pseudomonas aeruginosa* and other Gram-negative bacteria were of particles ≤ 3.3 µm. Positive room air samples were associated with high total counts in cough aerosols.

There are not, however, enough data to fully describe or predict cough particle size distributions[2] for many diseases, and research is needed to better characterize them (Xie et al. 2009).

In the 1950s, the relationship among particle size, airborne suspension, and transmission implications began to become clear. The different routes require different control strategies, which have evolved over many years of infectious disease practice, and there are now standards of practice for infectious disease and hospital epidemiology. See the Professional Practice documents available from the Association for Professionals in Infection Control and Epidemiology at www.apic.org.

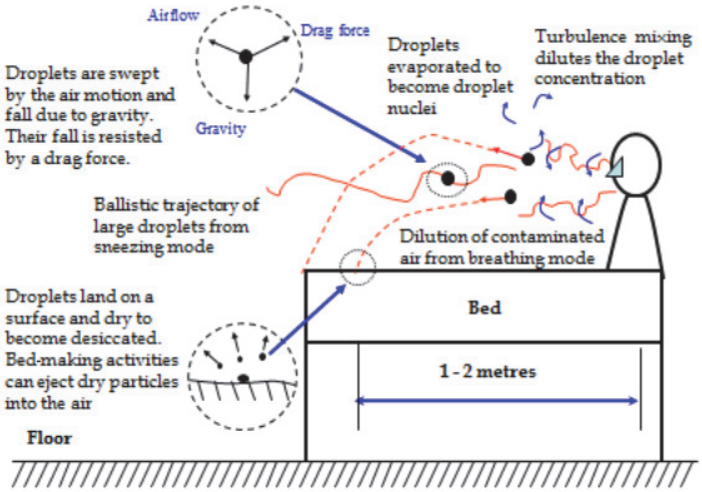

Figure 1 Droplet suspension: illustration of the aerobiology of droplets and small airborne particles produced by an infected patient.

[2] Cough particle size distributions are likely to vary based on the infected person's viscosity of secretions, anatomical structures in the oropharynx (roughly meaning throat) and airways, and disease characteristics.

Many diseases have been found to have higher transmission rates when susceptible individuals approach within close proximity, about 1 to 2 m (3 to 7 ft).[3] Over this short range, the susceptible person has a substantially greater exposure from the infected individual to droplets of varying size, both inspirable large droplets and airborne particles (e.g., see Figure 1). Nicas and Jones (2009) have argued that close contact permits droplet spray exposure and maximizes inhalation exposure to small particles and inspirable droplets. Thus, particles/droplets of varying sizes may contribute to transmission at close proximity (Li 2011).

To prevent this type of short-range exposure, whether droplet or airborne, maintaining a 2 m (7 ft) distance between infected and susceptible is considered protective, and methods such as ventilation dilution are not effective.

2.2 Mathematical Model of Airborne Infection

Riley and Nardell (1989) present a standard model of airborne infection usually referred to as the *Wells-Riley equation*, given below as Equation 1. Like all mathematical models, it has its limitations, yet it is useful for understanding the relationship among the variables such as the number of new infections (C), number of susceptibles (S), number of infectors (I), number of doses of airborne infection (q) added to the air per unit time by a case in the infectious stage, pulmonary ventilation per susceptible (p) in volume per unit time, exposure time (t), and volume flow rate of fresh or disinfected air into which the quanta are distributed (Q).

$$C = S(1 - e^{-Iqpt/Q}) \quad (1)$$

The exponent represents the degree of exposure to infection and $1 - e^{-Iqpt/Q}$ is the probability of a single susceptible being infected. Note that this model does not account for varying susceptibility among noninfected individuals. For this and other reasons, exposure does not necessarily lead to infection.[4] The parameter q is derived from the term *quantum*, which Wells (1995) used to indicate an infectious dose, whether it contains a single organism or several organisms. The ability to estimate q is difficult at best and has been reported in the literature to be 1.25 to 249 quanta per hour (qph) in tuberculosis patients (Riley et al. 1962; Catanzaro 1982) and 5480 qph for measles (Riley et al. 1978).

Because of the uncertainty in knowing q, Equation 1 is most useful for understanding the general relationships among the variables, for instance, the impact of increasing the volume of fresh or disinfected air on airborne infection. Increasing Q decreases exposure by diluting air containing infectious particles with infectious-particle-free air. Q can also be impacted through the use of other engineering control technologies, including filtration and UVGI, as discussed in Section 3.2. Therefore, a more complete representation of Q should include the total removal rate by ventilation, filtration, deposition, agglomeration, natural deactivation, and other forms of engineered deactivation.

[3] Infectious pneumonias, like pneumococcal disease (Hoge et al. 1994) or plague (CDC 2001) are thought to be transmitted in this way.

[4] This applies differently to various microorganisms, whether they be fungal, bacterial, or viral. After exposure, the microorganism must reach the target in the body (e.g., lung or mucosa) to cause infection. Some infective particles must deposit on mucosa to result in infection, and if they instead deposit on the skin, infection may not result. Another important element that influences a person's risk of infection is his or her underlying immunity against select microorganisms and immune status in general. For example, individuals with prior *M. Tuberculosis* infection who have developed immunity are able to ward off the infection and a person who had chicken pox as a child or received chicken pox vaccine is not susceptible even if living in the same household as an individual with acute chicken pox. On the other hand, individuals infected with human immunodeficiency virus (HIV) are more susceptible to becoming infected, for instance, with tuberculosis.

2.3 For Which Diseases is the Airborne Transmission Route Important?

Roy and Milton (2004) describe a classification scheme of aerosol transmission of diseases as obligate, preferential, or opportunistic[5] on the basis of the agent's capacity to be transmitted and to induce disease. Under this classification scheme, tuberculosis may be the only communicable disease with obligate airborne transmission—an infection that is initiated only through aerosols. For *Mycobacterium tuberculosis*, the aerodynamic diameters of the airborne particles are approximately 1 to 5 µm.

Agents with preferential airborne transmission can naturally initiate infection through multiple routes but are predominantly transmitted by aerosols. These include measles and chicken pox.

There are probably many diseases with opportunistic airborne transmission—infections that naturally cause disease through other routes such as the gastrointestinal tract but that can also use fine-particle aerosols as an efficient means of propagating in favorable environments. The relative importance of the transmission modes for many of these diseases remains a subject of uncertainty (Shaman and Kohn 2009; Roy and Milton 2004; Li 2011).

The common cold (rhinoviruses) and influenza can both be transmitted by direct contact or fomites; there is also evidence of influenza and rhinovirus transmission via large droplets and the airborne route (D'Alesssio et al. 1984; Wong et al. 2010; Bischoff et al. 2013).

Work by Dick and colleagues (1967, 1987) suggests that the common cold may be transmitted through the airborne droplet nuclei route. Experimental studies (Dick et al. 1987) document the possibility of transmission beyond 1 m (3 ft) under controlled conditions in experimental chambers and strongly suggest airborne transmission as at least one component of rhinoviral infection. A recent field study (Myatt et al. 2004) supports this result and documents its likely importance in a field investigation.

Other literature acknowledges the potential importance of the airborne routes while suggesting that droplet transmission is far more important, at least for common viral diseases such as the common cold (Gwaltney and Hendley 1978).

Control of seasonal influenza has for decades relied on large-droplet precautions even though there is evidence suggesting a far greater importance for airborne transmission by small particles. For instance, a 1959 study of influenza prevention in a Veterans Administration nursing home identified an 80% reduction in influenza in staff and patients through the use of upper-room ultraviolet germicidal irradiation (UVGI) (McLean 1961). This suggests that air currents to the higher-room areas where the UVGI was present carried the airborne infectious particles, and they were inactivated. The inactivated (noninfectious) particles were therefore unable to infect staff and patients in control areas with UVGI, as compared to areas without UVGI.

Influenza transmission occurred from one index case to 72% of the 54 passengers aboard an airliner on the ground in Alaska while the ventilation system was turned off (Moser et al. 1979). This outbreak was widely thought to represent a second piece of evidence for airborne transmission, and it was also thought that the high attack rate was due in part to the ventilation system not being in operation (Moser 1979). A review by Tellier (2006) acknowledges the importance of these papers and suggests including consideration of airborne transmission in pandemic influenza planning. However, one systematic review by Brankston et al. (2007) concluded that the airborne transmission route was not important in the same outbreak.

[5] This use of the word *opportunistic* differs from the medical term of art, *opportunistic infection*, which refers to an infection caused by a microorganism that normally does not cause disease but becomes pathogenic when the body's immune system is impaired and unable to fight off infection.

A 1986 outbreak from the H1N1 influenza virus among U.S. Navy personnel was attributed to their having flown on the same airplanes. Many of the infected susceptibles were displaced considerably more than 2 m (7 ft) from the infected individuals (Klontz et al. 1989). This suggests the airborne route of transmission.

A 2009 outbreak of influenza A pandemic (H1N1) developed from a single index case patient in nine tour group members (30%) who had talked with the index case patient and in one airline passenger (not a tour group member) who had sat within two rows of her. None of the 14 tour group members who had not talked with the index case patient became ill. The authors therefore concluded that this outbreak was caused by droplet transmission and that airborne transmission was not a factor (Han et al. 2009).

Chu et al. (2005) documented that airborne transmission of severe acute respiratory syndrome (SARS, a severe form of pneumonia caused by a member of the coronavirus family of viruses—the same family that can cause the common cold) could occur. In one dramatic outbreak of SARS in the Amoy Gardens high-rise apartment, airborne transmission through droplet nuclei seemed to represent the primary mode of disease spread. This was likely due to a dried-out floor drain and airborne dissemination by the toilet exhaust fan and winds (Yu et al. 2004; Li et al. 2005a, 2005b). The observed pattern of disease spread from one building to another, and particularly on the upwind side of one building, could not be explained satisfactorily other than by the airborne route.

A study of Chinese student dormitories provides support for the theory of the airborne spread of the common cold (Sun et al. 2011). Ventilation rates were calculated from measured carbon-dioxide concentration in 238 dorm rooms in 13 buildings. A dose-response relationship was found between outdoor air flow rate per person in dorm rooms and the proportion of occupants with annual common cold infections $\geq$6 times. A mean ventilation rate of 5 L/(s·person) (10 cfm/[s·person]) in dorm buildings was associated with 5% of self-reported common cold $\geq$6 times, compared to 35% at 1 L/(s·person) (2 cfm /[s·person]).

A literature review by Wat (2004) tabulates the mode of transmission and seasonality of six respiratory viruses, indicating that rhinovirus, influenza, adenovirus, and possibly coronavirus are spread by the airborne route.

The reader of this document should keep an open mind about the relative importance of the various modes of transmission due to the uncertainty that remains (Shaman and Kohn 2009) as illustrated by the studies described above. Disease transmission is complex, and one-dimensional strategies are not suitable for universal application.

3. PRACTICAL IMPLICATIONS FOR BUILDING OWNERS, OPERATORS, AND ENGINEERS

Small particles may be transported through ventilation systems, as has been documented for tuberculosis, Q-fever, and measles (Li et al. 2007). Therefore, when outbreaks occur in the workplace, transmission through HVAC systems must be considered. As disease transmission by direct contact, fomite, and large-droplet routes is reduced by more efficient prevention strategies, the airborne route is likely to become relatively more important.

If influenza transmission occurs not only through direct contact or large droplets, as is the long-standing public health tradition, but also through the airborne route, as newer data suggest, HVAC systems may contribute far more both to transmission of disease and, potentially, to reduction of transmission risk.

There are practical limits to what HVAC systems can accomplish in preventing transmission of infections in large populations. In some cases, infections are transmitted in the absence of HVAC systems.

Owners, operators, and engineers are encouraged to collaborate with infection prevention specialists knowledgeable about transmission of infection in the community and the workplace and about strategies for prevention and risk mitigation.

3.1 Varying Approaches for Facility Type

Health-care facilities have criteria for ventilation design to mitigate airborne transmission of infectious disease (FGI 2010; ASHRAE 2008). Yet most infections are transmitted in ordinary occupancies in the community and not in industrial or health-care occupancies.

ASHRAE does not provide specific *requirements* for infectious disease control in schools, prisons, shelters, transportation, and other public facilities other than the general ventilation and air quality requirements of Standards 62.1 and 62.2 (ASHRAE 2013b, 2013c). However, the *guidance* in this PD does apply to these facilities.

In health-care facilities, many common interventions to prevent infections aim to reduce transmission by direct or indirect contact (for example, directly via the hands of health-care personnel). Interventions also aim to prevent airborne transmission (Aliabadi et al. 2011).

Because of the difficulties in separating out the relative importance of transmission modes, recent work in health-care facilities has focused on "infection control bundles" (i.e., use of multiple modalities simultaneously) (Apisarnthanarak et al. 2009, et al. 2010a, et al. 2010b; Cheng et al. 2010). For two prototype diseases, tuberculosis and influenza, this bundle includes administrative and environmental controls and personal protective equipment in health-care settings. Given the current state of knowledge, this represents a practical solution.

For studies and other publications with specific guidance on air quality and energy in biomedical laboratories, animal research facilities, and health-care facilities, see the National Institutes of Health (NIH) Office of Research Facilities' website (http://orf.od.nih.gov/PoliciesAndGuidelines/Bioenvironmental).

A prerequisite to all of the strategies is a well-designed, installed, commissioned, and maintained HVAC system (Memarzadeh et al. 2010; NIOSH 2009a).

In considering going beyond requirements that include codes, standards, and practice guidelines, use guidance from published sources such as "Guidelines for Preventing the Transmission of Mycobacterium Tuberculosis in Health-Care Settings" (CDC 2005), *Guidelines for Design and Construction of Health Care Facilities* (FGI 2010), *Indoor Air Quality Guide: Best Practices for Design, Construction and Commissioning* (ASHRAE 2009), apic.org, and Table 1 in the Recommendations section, and discuss risk with the facility user. HVAC system designers can assist closely allied professionals such as architects and plumbing engineers to understand how sources of unplanned airflow can impact airborne infectious disease transmission. Examples include wastewater drains (especially if improperly trapped) and wall and door leakage (including the pumping action of swinging doors).

3.2 Ventilation and Air-Cleaning Strategies

Because small particles remain airborne for some period of time, the design and operation of HVAC systems that move air can affect disease transmission in several ways, such as by the following:

- supplying clean air to susceptible occupants
- containing contaminated air and/or exhausting it to the outdoors
- diluting the air in a space with cleaner air from outdoors and/or by filtering the air
- cleaning the air within the room

The following strategies are of interest: dilution ventilation, laminar and other in-room flow regimes, differential room pressurization, personalized ventilation, source capture ventilation, filtration (central or unitary), and UVGI (upper room, in-room, and in the airstream).

ANSI/ASHRAE/ASHE Standard 170-2008, *Ventilation of Health-Care Facilities*, covers specific mandatory HVAC requirements including ventilation rates, filtration, and pressure relationships among rooms (ASHRAE 2008). The *Guidelines for Design and Construction of Health Care Facilities* (FGI 2010) include the Standard 170 requirements and describe other criteria that can guide designers of these facilities.

Ventilation represents a primary infectious disease control strategy through dilution of room air around a source and removal of infectious agents (CDC 2005). Directed supply and/or exhaust ventilation, such as nonaspirating diffusers for unidirectional low-velocity airflow, is important in several settings, including operating rooms (FGI 2010; ASHRAE 2008).

However, it remains unclear by how much infectious particle loads must be reduced to achieve a measurable reduction in disease transmissions and whether the efficiencies warrant the cost of using these controls.

Energy-conserving strategies that reduce annualized ventilation rates, such as demand-controlled ventilation, should be used with caution, especially during mild outdoor conditions when the additional ventilation has low cost. Greater use of air economizers has a positive impact both on energy conservation and annualized dilution ventilation.

Natural ventilation, such as that provided by user-operable windows, is not covered as a method of infection control by most ventilation standards and guidelines. There are very few studies on natural ventilation for infection control in hospitals. One guideline that does address it recommends that natural ventilation systems should achieve specific ventilation rates that are significantly higher than the ventilation rates required in practice guidelines for mechanical systems (WHO 2009).

Room pressure differentials are important for controlling airflow between areas in a building (Siegel et al. 2007; CDC 2005). For example, airborne infection isolation rooms (AIIRs) are kept at negative pressure with respect to the surrounding areas to keep potential infectious agents within the rooms. Some designs for AIIRs incorporate supplemental dilution or exhaust/capture ventilation (CDC 2005). Interestingly, criteria for AIIRs differ substantially between cultures and countries in several ways, including air supply into anterooms, exhaust from space, and required ventilation air (Subhash et al. 2013; Fusco et al. 2012). This PD takes no position on whether anterooms should be required in practice guidelines.

Hospital rooms with immune-compromised individuals are kept at positive pressure in protective environments (PEs) to keep potential infectious agents (e.g., *Aspergillus* sp. or other filamentous fungi) out of the rooms (Siegel et al. 2007; FGI 2010; ASHRAE 2008).

Personalized ventilation systems that supply 100% outdoor air, highly filtered, or UV disinfected air directly to the occupant's breathing zone (Cermak et al. 2006; Sekhar et al. 2005) may be protective as shown by CFD analysis (Yang et al. 2013). However, there are no known field studies that justify the efficacy. Personalized ventilation may be effective against aerosols that travel both long distances as well as short-range routes (Li 2011).