ASHRAE Position Document on

Airborne Infectious Diseases

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American Society of Heating, Refrigerating and Air-Conditioning Engineers

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Executive Summary

This position document has been written to provide the membership of the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) and other interested persons with information on the health consequences of exposure to airborne infectious disease and on the implications of this knowledge for the design, installation and operation of heating, ventilating, and air-conditioning (HVAC) systems. In this paper three methods of transmission of Airborne Infectious Diseases are discussed, namely through direct contact, large droplet contact, and inhalation of droplet nuclei. The practice of the HVAC&R professional is likely limited to reduction of disease transmission to those diseases transmitted by droplet nuclei. The conclusions regarding needed research and advice for the practitioner are listed in Table 1.

ASHRAE's sole objective is to advance the arts and sciences of HVAC&R to serve humanity and promote a sustainable world through research, standards writing, publishing and continuing education. Therefore, the health effects of airborne infectious disease transmission are relevant to ASHRAE.

ASHRAE's position at the present is:

- Many infectious diseases are transmitted through inhalation of airborne infectious particles termed droplet nuclei,
- Airborne infectious particles can be disseminated through buildings including ventilation systems,
- Airborne infectious disease transmission can be reduced using dilution ventilation, specific in-room flow regimes, room pressure differentials, personalized and source capture ventilation, filtration, and UVGI.

ASHRAE should commit to improving the health of individuals who occupy buildings and should support further research on engineering controls to reduce infectious disease transmission.

1.0 Issue

The potential for airborne transmission of disease is widely recognized although it generates much controversy and discussion for example which diseases are spread via the airborne route or via other mechanisms of dissemination. Three issues are pertinent for engineers:

- the impact of ventilation on disease transmission,
- the disease for which ventilation is important for either transmission or control,
- the control strategies are available for implementation in the buildings of interest.

This position paper addresses each of these.

2.0 Background

2.1 Introduction to Infectious Disease Transmission

Infectious diseases are typically transmitted based on certain characteristics and spread through populations in predictable ways. Diseases can be spread from a single source, i.e., a "point source" such as an individual with active tuberculosis in a restaurant, or in an ongoing way, in a person-to-person pattern. The relationship of the incubation period (the time period between acquisition of the infection and its clinical appearance) to the pattern of onset of illness ("epidemic curve") identifies whether something arises from a single source or represents ongoing transmission (Sartwell 1995). As the shape of the epidemic curve deviates from a normal or log-normal distribution, ongoing person-to-person or ongoing point source transmission becomes more likely than transmission from a single source at a given point in time. Successive waves of epidemic transmission are usually assumed to represent person-to-person transmission.

Infectious diseases are transmitted through three primary routes: (1) direct contact and fomites, which are inanimate objects that transport infectious organisms from one individual to another; (2) large droplets (generally with a mass median aerodynamic diameter (MMAD) of >10 micrometers - μm); and (3) particles with MMAD <10 μm sometimes termed droplet nuclei. Recent work by Xie and colleagues (2007) indicate that large droplets are those larger than 5-100 μm at the original time of release. Nicas and colleagues (2005) show by modeling that emitted large droplets will evaporate to 50% of their initial value and that if the initial diameter is < 20 μm this process will happen instantaneously. These three primary routes each require different control strategies, evolved over many years of infectious disease practice. They have generated standards of practice for infectious disease and hospital epidemiology (APIC 2008). This classification represents a fundamental belief among infectious disease physicians and infection control professionals (Mandell 1999). Additional transmission routes, such as blood transfusions, intravenous injections, or injuries are not of concern here.

Direct contact implies the passage of the infectious agent through surface contact. For example, the infectious agent resides on the skin or in secretions on hands is left on doorknobs, bed rails and surfaces; and is picked up by the next victim. This form of transmission requires the implementation of barrier precautions, such as gloving, handwashing, and cleaning of contaminated surfaces. Prototypical diseases transmitted in this way are rhino virus-induced upper respiratory tract illness, the common cold, and hepatitis C, a cause of viral liver disease.

Some infectious agents are secreted in large droplets, such as may be coughed or sneezed. These droplets usually fall to the ground within three feet, and transmission via the airborne route to persons greater than three feet distant is considered unlikely so that a six-foot protection ring is considered needed. Many diseases transmitted from person-to-person follow this pathway. Infectious pneumonias like pneumococcal disease (Hogue et al. 1994), or plague

(CDC 2001) are thought to be transmitted in this way. Humidity affects survival of the infectious agent although not always in predictable ways.

Finally, some diseases are transmitted through the airborne route in particles with a MMAD of <10 µm. These particles are typically generated by coughing and sneezing, and to a lesser extent, singing and talking. Such particles remain airborne for hours at a time and can be transported far distances. There is thought to be a large range in the rate of production of these airborne infectious particles, depending on differences in patients and diseases (Riley and Nardell 1989). Tuberculosis represents the prototypical airborne transmission disease although a few outbreaks of small pox have been documented (Wehrle et al. 1970) and even recently of SARS (Chu et al. 2005) appear to have followed this pathway. As these particles remain airborne for some period of time, HVAC system operation affects the concentration in several ways.

2.2 Mathematical Model of Airborne Droplet Nuclei Infection

Riley and Nardell (1989) present a standard model of airborne infection usually referred to as the Wells-Riley equation. This equation is useful for understanding the relationship between the number of new infections, C, and the number of susceptibles (S) and infectors (I), the number of doses of airborne infection (q) added to the air per unit time by a case in the infectious stage, the pulmonary ventilation per susceptible (p) in volume per unit time, the exposure time (t), and the volume of fresh or disinfected air into which the quanta are distributed (Q):

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

In this equation, the exponent represents the degree of exposure to infection and $(1 - e^{-Iqpt/Q})$ is the probability of a single susceptible being infected. The parameter q is derived from the term quantum, which Wells used to indicate an infectious dose, whether it contains a single organism or several organisms (Wells 1955). 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 (Catanzaro 1982; Riley et al. 1962), and 5480 qph for measles (Riley et al. 1978). Fennelly and colleagues (2004) measured cough aerosol directly from tuberculosis patients. The patients generated infectious aerosol that contained 3-4 colony-forming units (cfu) to a maximum of 633 colony-forming units (cfu is a direct measure of infectiousness using culturing techniques). Also the size distributions that were measured in this study suggest that most of the viable particles in the cough-generated aerosols were immediately respirable.

Equation 1 is useful for understanding 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 ultraviolet germicidal irradiation, as discussed below.

2.3 For which Diseases is the Airborne Transmission Route Important?

Standard textbooks of infectious diseases and of infection control classify agents by primary transmission route. Tables 1 and 2 present the standard beliefs in the field on how each of these diseases is transmitted. Table 1 presents those infections widely considered likely to be transmitted through the air; those for which airborne, i.e., droplet nuclei, transmission has been documented are identified with an *. Recent controversy, primarily focused on small pox and influenza transmission, is worth acknowledging. The theoretical basis and the implications are important for engineers as they have major consequences for air handling. Table 2 presents those infections that are not transmitted through the air, but through other routes. This is included in order to clarify those infections that *cannot* be influenced by ventilation.

Only in the 1950s did the relationship of particle size, airborne suspension and transmission implications begin to become clear. Particle size distributions of coughed materials are thought to encompass a broad range of diameters, from very small to large airborne droplets and macroscopic elements. There is not, however, enough data to describe the particle size distributions of cough-generated aerosols or to predict these distributions based on the infected person's viscosity of secretions, anatomical structures in the oropharynx (roughly meaning throat) and airways, and disease characteristics. Research is needed to better characterize cough-generated aerosols.

Although small pox was assumed to result from fomite and large droplet transmission, two outbreaks documented that airborne transmission could occur (Gelfand and Posch 1971; Richter 1971). It remains unclear whether this resulted from peculiarities of the source patients, who might have had anatomic abnormalities that generated smaller particles; some characteristics of the infection with wetter secretions and therefore small particles; or whether the local clinical staff was more observant about true transmission and this route had simply been missed elsewhere.

Similarly the Severe Acute Respiratory Syndrome (SARS), a corona virus, like the common cold, was assumed to result from large droplet transmission although many health-care workers preferred to rely on respirators effective against droplet nuclei. In general, no major difference was seen in protection capabilities between devices with protection against very small particles (N95 respirators, according to current standard classifications) and those without such protection (surgical masks). Still in one dramatic outbreak, in the Amoy Gardens high-rise apartment, airborne transmission through droplet nuclei most likely represented the primary mode of disease spread, likely due to the dried-out floor drain, through airborne dissemination by the toilet exhaust fan and winds (Yu et al. 2004, Li et al., 2005).

Work by Dick and colleagues suggest that the common cold may in fact be transmitted through the same airborne droplet nuclei route (Dick et al. 1967, 1987). Experimental studies (Dick et al. 1987) document the possibility of transmission beyond three feet under controlled conditions in experimental chambers and strongly suggest airborne transmission as at least one

component even of rhinoviral infection. A recent field study (Myatt 2004) supports that result and documents its likely importance in a field investigation.

Care of patients with seasonal influenza has for decades relied upon (large) droplet precautions. The sparse older epidemiologic literature suggests this as adequate. Nevertheless there is some evidence suggesting a far greater importance for airborne transmission by droplet nuclei. A 1959 study of influenza prevention in a Veterans Administration nursing home (ARRD) 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 less infective 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 1979). This outbreak is widely thought to represent a second piece of evidence for airborne transmission and it is also thought that the high attack rate was due in part to the ventilation system not being in operation (Moser 1979). A recent review (Tellier 2006) acknowledges the importance of these papers and suggests including consideration of airborne transmission in pandemic influenza planning. Older literature, too, acknowledges the potential importance though it suggests that droplet transmission is far more important than airborne droplet nuclei transmission, at least for other common viral diseases such as the common cold (Gwaltney and Hendley 1978). At present, planning for pandemic influenza in the U.S. relies on "social distancing," i.e., maintaining at least three feet of distance between individuals to reduce the likelihood of transmission, on minimizing public contact (work at home, closure of schools, etc), and on both respiratory hygiene (coughing into tissue or towels) and hand cleanser use (USDHHS 2008).

2.4 Implications for Engineers

ASHRAE has a long tradition of relying on United States public health agencies as the cognizant authorities on public health, more recently including international health agencies and following those recommendations. It dos not generally rely on its own interpretations of the health literature. ASHRAE's role and the purpose of this Position Document is to use the health science, combined with engineering principles and practices to identify how ASHRAE programs, publications and research can better address the proper design and operation of HVAC system to prevent the spread of disease through airborne transmission.

Considering the three main transmission routes (direct contact, large droplets > 10 μm and droplet nuclei < 10 μm) it is clear that ventilation has no influence on direct contact transmission. Control strategies for large droplet transmission include respiratory hygiene, i.e., coughing into handkerchiefs or putting masks on ill individuals to prevent dissemination of particles (CDC 2001). Because such particles are quite heavy and drop quickly, general dilution and even enclosures and exhaust ventilation will not significantly influence airborne particle concentrations and the potential for transmission. Although some of the moisture content may evaporate, this does not happen quickly enough to change large droplets into droplet nuclei,

especially as 95% of the content must evaporate for the MMAD to decrease by 50%. Droplet nuclei particles may be transported through ventilation systems, as has been documented for tuberculosis, Q-fever, and measles (Li et al., 2007). 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. In the absence of controlled intervention trials, this remains of great interest but of undetermined value.

Some biological agents potentially used in terrorist attacks may be purposefully transmitted through HVAC systems, such as small pox, plague pneumonia, and hemorrhagic viruses.

The following technical solutions 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 ultraviolet germicidal irradiation (upper room, in-room and in the air stream).

Ventilation represents a primary infectious disease control strategy through dilution of room air around a source (CDC 2005). Directed supply and/or exhaust ventilation such as laminar flow and displacement is important in several settings including operating rooms (AIA 2006).

Room pressure differentials are important for controlling airflow between areas in a building (Garner et al. 1996). For example, TB isolation rooms are kept at negative pressure with respect to the surrounding areas to keep potential infectious agents within the rooms; hospital rooms with immuno-compromised individuals are kept at positive pressure to keep potential infectious agents out of the rooms.

Another strategy from an exposure control perspective could be the use of personalized ventilation systems that supply 100% outdoor air, highly-filtered, or UV disinfected air, (i.e., the ventilation provision per person) directly to the occupant-breathing zone (Cermak et al. 2006; Sekhar et al. 2005). Additionally, providing supplemental (either general dilution or exhaust/capture in a specific location) ventilation in locations in which infectious sources are located will reduce exposure potential, such as what is done in TB isolation rooms (CDC 2005). The value of these strategies is unproven and individual case study may be required to justify their application.

The addition of highly efficient particle filtration to central ventilating systems is likely to reduce the airborne load of infectious particles. [1] This control strategy may prevent the transport of infectious agents from one area, such as patient rooms in hospitals or lobbies in public access

[1] Filter efficiency varies with particle size, so the type of filtration required in order to be effective will vary with the type of organism and the aerosol that carries it. ASHRAE Standard 52.2 describes a minimum efficiency reporting value (MERV) for filter efficiency at various particle sizes and HEPA filtration may not be necessary. Specific personnel safety procedures may be required when changing filters, depending on the types of organisms and other contaminants that have been collected on the used media.

buildings, to other occupied spaces, when these areas share the same central ventilation system. Such systems are common in buildings in the U.S. Additionally, local efficient filtration units (either ceiling mounted or portable) reduce local airborne loads and may serve purposes in specific areas such as healthcare facilities or high-traffic public occupancies (Miller-Leiden et al 1996; Kujundzic et al. 2006).

There are three general UVGI strategies: installation into ventilating ducts, irradiation of the upper zones of occupied spaces, and in-room irradiation after one occupant and before the next. All depend upon inactivation of viable agents carried in droplet nuclei. In both the duct and in-room UVGI, the amount of radiation applied can be much higher compared to what can be used for upper-zone UVGI, resulting in higher exposures and quicker inactivation. When effectively applied, duct-mounted UVGI functions similarly to filtration. Upper-zone UVGI, when effectively applied, inactivates infectious agents locally and can be considered in public access and high-traffic areas such as cafeterias, waiting rooms, and other public spaces. In-room UVGI can be considered as a kind of disinfection between successive occupants of a room. There is research that shows UVGI in both the upper-room and in-duct configuration can inactivate some disease transmitting organisms (Riley et al. 1962; Ko et al. 2002; CDC 2005; Kujundzic et al. 2007; VanOsdell and Foarde 2002; Xu et al. 2003, 2005) and that it can affect disease transmission rates (McLean 1961). Additional research is needed showing clinical efficacy specifically in occupancies with high-risk sources (such as jails, homeless shelters, and health-care facilities) and facilities where high-risk susceptible individuals congregate, such as nursing homes and healthcare facilities. Such research may lead to other recommended changes in HVAC system design. More research is also needed to document intrinsic (specific to microorganism) airborne virus and bacteria inactivation rates. See Table 3 for a summary of occupancy categories in which various strategies may be considered and priorities of research needs.

The *2006 Guidelines for Design and Construction of Health Care Facilities* (AIA 2006) describe criteria including ventilation rates, filtration and pressure relationships among rooms that can guide HVAC designers of these facilities. ASHRAE's ANSI/ASHRAE Standard 170-2008, *Ventilation of Health Care Facilities*, covers similar requirements (ASHRAE 2008).

When outbreaks occur in the workplace, transmission through HVAC systems must be considered. Although there is currently inadequate information to suggest the need for or benefits from the control strategies discussed above, engineers should consider their possible application. As other routes are blocked by more efficient prevention strategies, the airborne route is likely to become relatively more important. It is unclear by how much infectious particle loads must be reduced to achieve a measurable reduction in disease transmissions and whether the cost-benefit implications or efficiencies warrant use of these controls. Societal disruption from epidemics and the unexpected transmission of disease in workplaces, public access facilities, and transportation warrants both modeling and field research of engineering controls.

3.0 Recommendations

ASHRAE holds a strong position that engineers play a key role in reducing disease transmission that occurs in buildings.

ASHRAE recommends that

- a strategic research agenda be developed to address the role of HVAC systems in the spread of infectious disease;

- this topic be included in ASHRAES future strategic plans;

- further research be conducted to understand how reducing the energy footprint of buildings will impact infectious disease transmission;

- further research be conducted on engineering controls to reduce infectious disease transmission. Table 3 summarizes the control strategies available and the occupancy categories in which these controls can be used. The research priority for each control is provided. Filtration and UVGI controls research are given top priority because less is known about how these controls can be applied in buildings and HVAC systems to decrease disease events.

ASHRAE should commit to improving the health of individuals that occupy buildings and to reduce the risk of airborne infectious disease transmission.

Table 1. Diseases Spread by Droplet or Airborne Transmission (*diseases are those where airborne transmission is reasonably certain even if it is not the primary mode)

Disease	Organism	Clinical Manifestations	Healthcare/personal care workers at risk
Adenovirus	Adenovirus	Rhinitis, pharyngitis, malaise, rash, cough	All, especially those in intensive care units, long-term pediatric care facilities and ophthalmology clinics
Influenza*	Influenza virus	Fever, chills, malaise, headache cough, coryza, myalgias	All, especially physicians and nurses
Measles (Rubeola)*	Rubeola virus	Fever, rash, malaise, coryza, conjunctivitis, Koplik's spots, adenopathy, CNS complications	All
Meningococcal disease	Neisseria meningitides	Fever, headache, vomiting, confusion, convulsions, petechial rash, neck stiffness	Emergency medical personnel, emergency department staff
Mumps*	Mumps virus	Painful/swollen salivary glands orchitis, meningoencephalitis	All, especially pediatricians, dentists, daycare workers
Pertussis	Bordetella pertussis	Malaise, cough, coryza, lymphocytosis, "whooping" cough	All
Parvovirus B19	Parvovirus B19	Rash, aplastic anemia, arthritis, myalgias	All, especially nurses
Respiratory Syncitial Virus	RSV	Often asymptomatic; respiratory symptoms	All
Rubella	Rubella virus	Fever, malaise, coryza, rash	All
Tuberculosis*	Mycobacterium species	Fever, weight loss, fatigue, night sweats, pulmonary disease, extra pulmonary involvement including lymphatic, genitourinary, bone, meningeal, peritoneal, miliary	All, especially nurses, pathologists, laboratory workers, housekeeping staff
Varicella	Human Herpesvirus 3	Chickenpox or zoster presentation	All

*Infections for which airborne, i.e., droplet nuclei, transmission has been documented

Table 2. Diseases (Organism) Spread by Routes other than Droplet or Airborne Transmission

Contact with Blood or Body Fluids or via Percutaneous Exposure	**Fecal –Oral Route**	**Skin Contact**
Hepatitis B (Hepatitis B Virus)	Helicobacter pylori (Helicobacter pylori)	Herpetic Whitlow (Herpes simplex)
Hepatitis C (Hepatitis C virus)	Hepatitis A (Hepatitis A virus)	Tinea corporis ringworm (Microsporum, trichophyton species)
AIDS/HIV Infection (Human Immunodeficiency Virus)	Norovirus (Norovirus)	Warts (Papilloma virus)
Viral hemorrhagic fevers-including Lassa fever, Marburg virus, Crimean hemorrhagic fever, Ebola virus (Various viruses)	Polio (Poliomyelitis virus)	
Other diseases that have been transmitted via percutaneous injuries (laboratory, research facilities): Blastomycosis, Brucellosis, Crypotococcosis, Diphtheria, Gonorrhea, Herpes Simplex, Leptospirosis, Malaria, Mycoplasmosis, Rocky Mountain Spotted Fever, Scrub Typhus, Herpes B Virus, Sporotrichosis, Staphylococcal Disease, Streptococcal Disease, Syphilis, Toxoplasmosis, Tuberculosis, Yellow Fever, Creutzfeldt-Jacob disease, Leishmaniasis?	Salmonellosis (Salmonella species)	
	Shigellosis (Shigella species)	
	Enterotoxigenic e. coli (?)	
	Campylobacter (?)	

Table 3. Airborne Infectious Disease Engineering Control Strategies: Occupancy Categories Applicable for Consideration and Research Priorities*

Strategy	**Occupancy Categories Applicable for Consideration****	**Research Priority**
Dilution Ventilation	All	9
Personalized ventilation	1, 4, 6, 9, 10	8
Source capture	1, 2, 8, 14	10
Central system filtration	All	4
Local air filtration	1, 4, 6, 7, 8 10	5
Upper room UVGI	1, 2, 5, 6, 8, 9, 14	1
In-room UVGI	1, 2, 7, 8, 14	3
Duct UVGI	1, 2, 3, 4, 5, 6, 8, 9, 14	2
In-room flow regimes	1, 6, 8, 9, 10, 14	7
Differential pressurization	1, 2, 7, 8 11, 14	6

**Occupancy Categories

1. Health Care (Residential and Outpatient)
2. Correctional Facilities
3. Educational < age 8
4. Educational > age 8
5. Food and Beverage
6. Internet Café / Game Rooms
7. Hotel, Motel, Dormitory
8. Residential Shelters
9. Public Assembly & Waiting
10. Transportation Conveyances
11. Residential Multi-Family
12. Retail
13. Sports
14. Laboratories where infectious diseases vectors are handled.

*Note: In considering going beyond requirements that include codes and standards, planners may use guidance from published sources such as CDC 2005, AIA 2006, APIC 2008, Table 3 above, and discuss risk with the facility user. HVAC system designers can assist closely allied disciplines such as architects and plumbing engineers to understand how 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.

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