MINUTES

BOARD OF DIRECTORS MEETING

Tuesday, April 14, 2020

Note: These draft minutes have not been approved and are not the official record until approved by the Board of Directors.

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Board of Directors Meeting

Tuesday, April 14, 2020

PRINCIPAL APPROVED MOTIONS

Board of Directors Meeting

Tuesday, April 14, 2020

No. - Pg.	Motion
1 - 2	That the Board approve the reaffirmed *Infectious Aerosols* Position Document as presented in ATTACHMENT A.
2 - 4	Motion 23 (*That ASHRAE engage an association secretariat service to continue the function of the European Office in SY 2021. This effort is to be supported by ASHRAE staff resource(s) with priorities defined by the Board of Directors for the European Office. The staff resource (s) for the European Office shall be phased-in based on recommendation from the Executive Vice President by the 2020 Annual Meeting.)* from the Wednesday, February 5, 2020 BOD meeting be reconsidered.
3 - 4	That Motion 2 be postponed until the May 5, 2020 BOD meeting.

MINUTES
BOARD OF DIRECTORS MEETING
Tuesday, April 14, 2020

MEMBERS PRESENT:
Darryl Boyce, President
Chuck Gulledge, President Elect
Mick Schwedler, Treasurer
Bill Dean, Vice President
Dennis Knight, Vice President
Bill McQuade, Vice President
Farooq Mehboob, Vice President
Jeff Littleton, Secretary
Chris Phelan, Region I DRC
Jeff Clarke, Region II DRC
Dunstan Macauley, Region III DRC
Steve Marek, Region IV DRC
Doug Zentz, Region V DRC
Rick Hermans, Region VI DRC
Michael Cooper, Region VII DRC
Jon Symko, Region VIII DRC
Trent Hunt, Region IX DRC
Marites Calad, Region X DRC
Russell Lavitt, Region XI DRC
Robin Bryant, Region XII DRC
Apichit Lumlertpongpana, Region XIII DRC
Costas Balaras, Region XIV DRC
Ahmed Alaa Eldin Mohamed, RAL DRC
Kelley Cramm, DAL
Van Baxter, DAL
Don Brandt, DAL
Katherine Hammack, DAL
Jaap Hogeling, DAL
Sarah Masaton, DAL
Tim McGinn, DAL
Chandra Sekhar, DAL
Ashish Rakheja, DAL

GUESTS PRESENT:
Chris Gray
Randy Schrecengost
Tyler Glesne
Devin Abellon
Adrienne Thomle
Andres Sepulveda
Ken Fulk
Wade Conlan
Wayne Stoppelmoor
Larry Schoen
Bill Bahnfleth

STAFF PRESENT:
Candace DeVaughn, Mgr. of Board Services
Chandrias Jacobs, Coord. of Board Services
Alice Yates, Director - Govt. Affairs
Joyce Abrams, Director - Member Services
Vanita Gupta, Director - Marketing
Kim Mitchell, Chief Development Officer
Mark Owen, Director - Pub & Education
Stephanie Reiniche, Director - Technology
Craig Wright, Director - Finance & Admin. Services

CALL TO ORDER

Mr. Boyce called the meeting to order at 9:00 am.

CODE OF ETHICS

Mr. Boyce read the Code of Ethics commitment and encouraged members to become familiar with the full Code of Ethics.

ROLL CALL/INTRODUCTIONS

Roll call was conducted, and guests introduced themselves.

REVIEW OF MEETING AGENDA

The agenda was reviewed. There were no changes or additions.

INFECTIOUS AEROSALS POSITION DOCUMENT

Mr. Knight expressed thanks for the monumental efforts of the PD Committee, with special thanks to PD Committee Chair Erica Stewart and EHC Chair Wade Conlan. An unprecedented number of comments were received, and the committee has spent a tremendous amount of time and effort.

Mr. Knight moved that

1. The Board approve the reaffirmed *Infectious Aerosols* Position Document as presented in ATTACHMENT A.

It is the intent that the two statements specific to SARS COV2, recently approved by ExCom, be added to this document. The introductory text needs to be updated as well; it will be an informative statement, pointing out the relevance of SARS COV2.

There was discussion of whether the statements should be published together.

Mr. Conlan reported that the position document and two statements will be packaged together for the foreseeable future. The PD is general in nature, but the majority of people will be reviewing it primarily because of current SARS COV2 crisis. The PD and statements will be packaged together until it no longer makes sense to do so.

MOTION 1 PASSED (Voice Vote, 1 Abstention, CNV). Mr. Sekhar abstained.

EPIDEMIC TASK FORCE UPDATE

Mr. Knight reported that the task force has worked tirelessly - with several 16-hour days, countless emails, weekly web meetings, and interim meetings as necessary.

The group has revamped the webpage and it is now much easier to navigate by user type and get to the exact ASHRAE guidance proposed for building/occupancy/use type.

Mr. Bahnfleth reported that all the work of the task force has happened in the last two weeks; and it has taken a lot of effort and work to get to this point. It is important to get guidance out and the appearance of the webpage is something that will be improved on an ongoing basis.

Bahnfleth expressed thanks to members of the task force and staff for the terrific effort thus far.

Mr. Boyce thanked all of the task force members and expressed appreciation of their efforts.

Mr. Knight reported that a specific email address has been created for governmental requests. Emails sent to the address go directly to staff who work with Mr. Bahnfleth to identify an appropriate expert. Almost all requests are being answered within 24 hours.

2020 ANNUAL CONFERENCE

Mr. Littleton reported that staff is moving forward with making plans for the virtual conference. There will be a full technical program, with all the presentations recorded in advance. There will also be a live question and answer session with each of the technical program authors. Each of the four days of the conference will begin with a traditional leadership presentation - President's update, Secretary's report, BOD inauguration, and the 2020-21 Society theme update.

There will be a rolling schedule of technical committee, standing committee, and council meetings. Staff is creating a master schedule.

The presentation of awards will likely be postponed until the January 2021 Conference.

In terms of hotel contracts, staff has successfully negotiated all hotel contracts and there are no further obligations apart from one, which is currently in process.

Staff is working on the Bylaw's requirement of the 100 meeting of the members. New York state law does not allow the meeting to be conducted virtually. The meeting could take place in July or August depending on how the pandemic unfolds. Until the in-person meeting happens, the existing BOD will remain intact.

When someone registers for the Annual Conference, they will have access to the virtual conference. The cost to access just the virtual conference has been $250 in the past. There has been ongoing discussion of what the cost should be.

There was discussion of what the cost for registration should be as well as a timeline for making the final decision. It was also suggested that CEC be engaged to help set pricing.

COVID-19 REGIONAL AND CHAPTER OPERATIONS

Mr. Boyce reported that several requests have been received from regions and chapters, requesting guidance on regional and chapter operations in the current environment. A document has been drafted and the goal is to distribute the final document to the chapters and regions along with a letter from Mr. Boyce.

FINANCE COMMITTEE RECOMMENDATION ON ASHRAE PRESENCE IN BRUSSELS

Mr. Schwedler reported that the Finance Committee had a meeting earlier in the week. From that meeting, the Committee reached consensus on the following recommendation: *Finance Committee advises the Board of Directors to reconsider the decision to appoint an Association Management Company in Europe for the 20-21 Society Year and defer that decision until the 21-22 Society Year.*

Finance has reduced projections for dues revenue and has been discussing the possibility of a reduction in Expo revenue. Schwedler reported that there has also been discussion of adjusting the RP matching funds that Society contributes.

The current budget projections show a $460,000 deficit beginning July 1st. Recommendations from the previous lean assessment are being revisited and additional expense reductions and revenue sources are being explored.

Mr. Cooper moved and Mr. Hunt seconded that

2. Motion 23 (*That ASHRAE engage an association secretariat service to continue the function of the European Office in SY 2021. This effort is to be supported by ASHRAE staff resource(s) with priorities defined by the Board of Directors for the European Office. The staff resource (s) for the European Office shall be phased-in based on recommendation from the Executive Vice President by the 2020 Annual Meeting.)* from the Wednesday, February 5, 2020 BOD meeting be reconsidered.

Mr. Macauley stated that in order for Society to play an instrumental role in the current critical issues in Europe, a physical presence in Europe is required. There is the possibility of changing the start date for the association management firm or engaging in a smaller contract so that the cost is reduced but allows Society to still have a voice and influence. Postponing the transition to an association management firm for a year could be very detrimental.

Mr. Macauley moved and Mr. Hermans seconded that

3. Motion 2 be postponed until the May 5, 2020 BOD meeting.

MOTION 3 PASSED (Voice Vote, 5 Nays, CNV).

EXECUTIVE SESSION

Executive session was called at 10:25 am.

The open session meeting reconvened at 10:34 am.

NEW BUSINESS

CAPITAL CAMPAIGN FOR MEMBERS

Mr. Boyce reporting that the Development Committee is considering postponing any further communication of the capital campaign to members because of the COVID-19 crisis.

Companies will continue to be contacted, only communication to individuals will be stopped at this time.

Ms. Mitchell reported that at this time, there has been no mention of changes to pledged contributions from major donors.

UPCOMING MEETINGS

The next BOD meeting will be a conference call on May 5. The primary agenda item for this call will be an update from the Finance Committee.

ADJOURNMENT

The meeting adjourned at 10:41 am.

Jeff H. Littleton, Secretary

ATTACHMENTS:

A. Infectious Aerosols Position Document

1791 Tullie Circle,

ASHRAE Position Document on

INFECTIOUS AEROSOLS

Approved by ASHRAE Board of Directors (*completed by ASHRAE staff*) Month day, 20YR

Reaffirmed by ASHRAE Technology Council *(if applicable, completed by ASHRAE staff)*
Month day, 20YR

Expires (*completed by ASHRAE staff*) Month day, 20YR

ASHRAE

COMMITTEE ROSTER

The ASHRAE Position Document on "Infectious Aerosols" was developed by the Society's Environmental Health Position Document Committee formed on April 24, 2017, with Erica Stewart as its chair.

Kenneth Mead
CDC/NIOSH
Cincinnati, OH, USA

Russell N. Olmsted
Trinity Health
Livonia, MI, USA

Jovan Pantelic
University of California at
Berkeley, CA USA

Lawrence J Schoen
Schoen Engineering Inc
Columbia, MD, USA

Chandra Sekhar
National University of Singapore
Singapore, Singapore

Erica J Stewart (chair)
Kaiser Permanente
Pasadena, CA, USA

Walter Vernon
Mazzetti
San Francisco, CA, USA

Former members and contributors

Yuguo Li
The University of Hong Kong
Hong Kong, China

Zuraimi M Sultan
Berkeley Education Alliance for
Research in Singapore (BEARS) Ltd
Singapore, Singapore

Cognizant Committees

The chairpersons of Environmental Health and Healthcare Facilities also served as ex-officio members.

Wade Conlan, Environmental Health Chair, Hanson Professional Services Maitland, FL, USA

HISTORY

of

REVISION / REAFFIRMATION / WITHDRAWAL DATES

The following summarizes the revision, reaffirmation or withdrawal dates:

6/24/2009—BOD approves Position Document titled Airborne Infectious Diseases

1/25/2012—Technology Council approves reaffirmation of Position Document titled Airborne Infectious Diseases
1/19/2014—BOD approves revised Position Document titled Airborne Infectious Diseases

1/31/2017 - Technology Council approves reaffirmation of Position Document titled Airborne Infectious Diseases

2/5/2020 - Technology Council approves reaffirmation of Position Document titled Airborne Infectious Diseases

4/14/2020 – BOD approve revised Position Document titled Infectious Aerosols

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

CONTENTS

ASHRAE Position Document on

“Infectious Aerosols”

ABSTRACT

The pathogens that cause infectious diseases are spread from the host to secondary hosts via several different routes. For example, some diseases are known to spread by infectious aerosols; for other diseases, the route of transmission is uncertain. The risk of pathogen spread and therefore the number of people exposed can be affected, both positively and negatively, by heating, ventilating, and air-conditioning (HVAC) and local exhaust ventilation (LEV) systems and airflow patterns in a space. ASHRAE is the global leader and foremost source of technical and educational information on the design, installation, operation and maintenance of these systems. Although the principles discussed in this document apply primarily to buildings, they may also be applicable to other occupancies, such as planes, trains, and automobiles.

ASHRAE will continue to support research that advances the knowledge-base of indoor air management strategies aimed to reduce occupant exposure to infectious aerosols. Chief among these ventilation-related processes are dilution, airflow patterns, pressurization, temperature and humidity distribution and control, filtration, and other strategies such as ultraviolet germicidal irradiation (UVGI). While the exact level of ventilation effectiveness will vary with local conditions and the pathogens involved, ASHRAE believes that these techniques, when properly applied, can reduce the risk of transmission of infectious disease through airborne aerosols.

To better specify the levels of certainty behind the ASHRAE policy positions stated in this document, we have chosen to adopt the Agency for Healthcare Research and Quality (AHRQ) rubric for expressing the scientific certainty behind our recommendations. (Burns et al. 2011) These levels of certainty are as follows:

Grade of Research	Description
A	Strongly Recommend; good evidence
B	Recommend; at least fair evidence
C	No recommendation for or against. Balance of benefits and harms too close to justify a recommendation
D	Recommend against; fair evidence is ineffective or harm outweighs the benefit
E	Evidence is insufficient to recommend for or against routinely; evidence is lacking or of poor quality; benefits and harms cannot be determined.

ASHRAE’s position is that facilities of all types should follow, as a minimum, the latest published standards and guidelines and good engineering practice. ANSI/ASHRAE Standards 62.1 and 62.2 (ASHRAE 2019a, 2019b) includes requirements for outdoor air ventilation in most residential and non-residential spaces, and Standard 170 (ASHRAE 2017) covers both outdoor and total air ventilation in healthcare facilities. Based upon a risk assessment or owner project requirements,

designers of new and existing healthcare facilities could go beyond the minimum requirements of these documents, using techniques covered in ASHRAE's publications including ASHRAE Handbooks, ASHRAE research reports, published papers and articles, and design guidelines to be even better prepared to control the dissemination of infectious aerosols.

EXECUTIVE SUMMARY

With infectious diseases transmitted through aerosols, HVAC systems can have a major effect on the transmission from a primary host to secondary hosts. Designers of mechanical systems should be aware that ventilation is not capable of addressing all aspects of infection control.

HVAC systems [1] , however, impact the bio-burden and distribution of infectious aerosols and droplets to airborne and aerosol pathogens. Small aerosols may persist in the breathing zone, available for inhalation directly into the upper and lower respiratory tract, or settling onto surfaces where they can be indirectly transmitted by resuspension or fomite [2] contact. Clearly, decreasing exposure of secondary hosts is an important step in curtailing the spread of infectious diseases.

Infectious aerosols can pose an exposure risk, regardless of whether or not a disease is classically defined as an "airborne infectious disease". This document covers strategies through which HVAC systems modulate aerosol [4] distribution and can therefore increase or decrease exposure to infectious droplets [3], droplet nuclei [5], surfaces [6], and intermediary fomites [7] in a variety of environments.

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[1] These are described in the *ASHRAE Handbook—HVAC Systems and Equipment* (ASHRAE 2020). [2] An object (such as a dish or a doorknob) that may be contaminated with infectious organisms and serve in their transmission

[3] In this document, droplets are understood to be large enough to fall to a surface in 1-2 meters (3-7 feet) and thus not become aerosols.

[4] An aerosol is a system of liquid or solid particles uniformly distributed in a finely divided state through a gas, usually air. They are small and buoyant enough to behave much like a gas.

[5] Droplet nuclei are formed from droplets that become less massive by evaporation and thus may become aerosols.

[6] Direct contact refers to bodily contact such as touching, kissing, sexual contact, contact with oral secretions or skin lesions, and additional routes such as blood transfusions or intravenous injections

[7] Indirect contact is an exposure that occurs through touching a contaminated inanimate object such as a doorknob, bed rail, TV remote and bathroom surfaces.

This position document (PD) provides recommendations on the following:

- the design, installation, and operation of heating, ventilating, and air- conditioning (HVAC) systems, including air cleaning and local exhaust ventilation (LEV) systems to decrease the risk of infection transmission;
- non-HVAC control strategies to decrease disease risk; and
- strategies to support facilities management for both everyday operation and for emergencies.

Infectious diseases can be controlled by interrupting a transmission route used by the pathogen. HVAC professionals have an important role in protecting building occupants by interrupting the indoor dissemination of infectious aerosols with HVAC and LEV systems.

1. THE ISSUE

The potential for airborne dissemination of infectious pathogens is widely recognized, although there remains uncertainty about the relative importance of the various disease transmission routes, such as airborne, short range droplets, direct or indirect contact, or by multimodal means (a combination of mechanisms). Transmission of disease will vary by pathogen infectivity, reservoirs, vectors and secondary host susceptibility (Shaman and Kohn 2009; Roy and Milton 2004; Li 2011) . The variables which are the most relevant for HVAC design and control are decreasing the reservoirs and transmission pathway of infectious aerosols.

Infection control professionals describe the chain of infection as a process in which a pathogen (microbe which causes disease) is carried in an initial host, gains access to a reservoir and a route of ongoing transmission, and with sufficient virulence finds a secondary susceptible host. Ventilation, filtration and air distribution systems, and disinfection technologies have the potential to limit airborne pathogen transmission through the air and thus break the chain of ongoing infection.

Building science professionals must recognize the importance of facility operations and ventilation systems in interrupting this step of disease transmission. Other measures such as effective surface cleaning, contact and isolation precautions mandated by employee and student policies, as well as vaccination regimens are effective strategies that are beyond the scope of this document.

Dilution and extraction ventilation, pressurization, airflow distribution and optimization, mechanical filtration, UVGI and humidity control are effective strategies for reducing the risk of dissemination of infectious aerosols in buildings and transportation environments.

Although this position document is primarily applicable to viral and bacterial diseases that can use the airborne route in transmission from person to person, the principles of containment may also apply to infection from building reservoirs such as water systems with *Legionella spp.* and organic matter containing spores from mold to the extent that the microorganisms are spread by the air. The first step in control of such diseases is to eliminate the source before it becomes airborne.

2. BACKGROUND

ASHRAE provides guidance and develops standards intended to mitigate the risk of infectious disease transmission in the built environment. These documents provide engineering strategies for reducing the risk of disease transmission and therefore could be employed in a variety of other spaces.

This position document covers the dissemination of infectious aerosols but not direct contact routes of transmission. Direct contact generally refers to bodily contact such as touching, kissing, sexual contact, contact with oral secretions or skin lesions, and routes such as blood transfusions or intravenous injections. Indirect transmission by resuspension is covered.

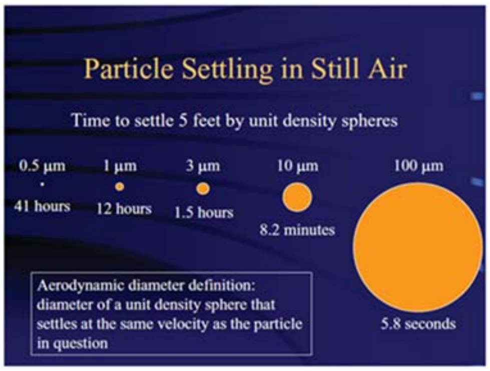
2.1 Airborne Dissemination

Pathogen dissemination through the air occurs through droplets and aerosols typically generated by coughing, sneezing, shouting, breathing , toilet flushing, some medical procedures, singing and talking (Bischoff 2013, Yan et al. 2018). The majority of larger emitted droplets are drawn by gravity to land on surfaces within about 3-7 feet (1-2 m) from the source (See Figures 1a and 1b)[1]. General dilution ventilation and pressure differentials do not significantly influence short range transmission. Conversely, dissemination of smaller infectious aerosols including droplet nuclei resulting from desiccation can be affected by airflow patterns in a space in general and airflow patterns surrounding the source in particular. Of special interest are small aerosols (< 10 µm), which can stay airborne and infectious for extended periods (several minutes, hours or days), and thus can travel longer distances and infect secondary hosts who had no contact with the primary host.

Many diseases are known to have high transmission rates through larger droplets when susceptible individuals are within close proximity, about 3-7 ft (1-2 m) (Nicas 2009; Li 2011) Depending upon environmental factors, these large (100-micron diameter) droplets may shrink

[1] Figure 1a depicts the 5-ft (1.5 m) settling time for particles settling in still air. Figure 1b illustrates the theoretical aerobiology of transmission of droplets and aerosols produced by an infected patient with an acute infection.

by evaporation before they settle, thus becoming an aerosol (approx. $\leq$10 µm). The term *droplet nuclei* has been used to describe such desiccation of droplets into aerosols (Siegel et al. 2007). While ventilation systems cannot interrupt the rapid settling of large droplets, they can influence transmission of droplet nuclei infectious aerosols. Directional airflow is employed to create flow by the micro-environment created by localized airflow patterns followed by direct capture through local exhaust ventilation or HEPA filtration.



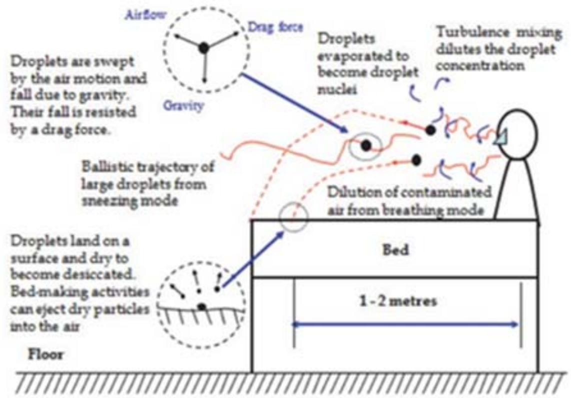


Figure 1. (1a) Comparative settling times by particle diameter (Baron 2017)**.**
(1b) Aerobiology of droplets and small airborne particles produced by an infected patient. (Courtesy of Yuguo Li)

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

Even the most robust HVAC system cannot control all airflows and completely prevent dissemination of an infectious aerosol or disease transmission by droplets or aerosols. The HVAC system's impact will depend upon source location, strength of the source and distribution of the released aerosol, droplet size, air distribution, temperature, relative humidity, and filtration. Furthermore, there are multiple modes and circumstances under which disease transmission occurs. Thus, strategies for prevention and risk mitigation require collaboration among designers, owners, operators, industrial hygienists and infection prevention specialists.

3.1 Varying Approaches for Facility Type

Healthcare facilities have criteria for ventilation design to mitigate airborne transmission of infectious disease (ASHRAE 62.1-2019, 170-2017; HVAC Design Manual for Hospitals and Clinics, 2013, 2018 FGI Guidelines for Design and Construction of Hospitals). Yet, infections are also transmitted in ordinary occupancies in the community and not in industrial or healthcare occupancies. General ventilation and air quality requirements are included in Standards 62.1-

2019, 62.2-2019 and 170-2017 and the ASHRAE IAQ Guide. ASHRAE does not provide specific requirements for infectious disease control in homes, offices, schools, retail environments, prisons, shelters, transportation, and other public facilities.

In healthcare facilities, most infection control interventions are geared to reduce direct or indirect contact transmission of pathogens. These emphasize personnel education and surveillance of behaviors such as hand hygiene and compliance with checklist protocols. These interventions for limiting airborne transmission (Aliabadi et al. 2011) are largely restricted to a relatively small list of diseases from pathogens which only spread through the air. Now that microbiologists understand that many pathogens can travel through both contact and airborne routes, the role of indoor air management has become critical to successful prevention efforts. In view of the broader understanding of flexible pathogen transmission modes, healthcare facilities now use multiple modalities simultaneously, known as "infection control bundles". (Apisarnthanarak et al. 2009, et al. 2010a, et al. 2010b; Cheng et al. 2010). For example, in the case of two diseases that clearly utilize airborne transmission such as tuberculosis and measles, bundling includes administrative regulations, environmental controls and personal protective equipment protocols in healthcare settings. This more comprehensive approach is needed to control pathogens, which can utilize both contact and airborne transmission pathways. Similar strategies may be appropriate for non-healthcare spaces such as public transit and airplanes, schools, shelters and prisons, that may be subject to close contact of occupants.

Many buildings are fully or partially naturally ventilated. They may use operable windows and rely on intentional and unintentional openings in the building envelope. These strategies create different risks and benefits. Obviously, the airflow in these buildings is variable and unpredictable, as are the resulting air distribution patterns, and so the ability to actively manage risk is much reduced. Naturally ventilated buildings can go beyond random opening of windows and be engineered intentionally to achieve ventilation strategies and thereby reduce risk from infectious aerosols. Generally speaking, designs that achieve higher ventilation rates will reduce risk. On the other hand, such buildings will be more affected by local outdoor air quality, including the level of allergens and pollutants within outdoor air, varying temperature and humidity conditions, and flying insects. The World Health Organization has published Guidelines for naturally ventilated buildings, which should be consulted in such projects. (Atkinson et al. 2009)

3.2 Ventilation and Air-Cleaning Strategies

The design and operation of HVAC systems can affect infectious aerosol transport, but they are only one part of an infection control bundle. The following HVAC strategies have the potential to reduce the risks: air distribution patterns, differential room pressurization, personalized ventilation, source capture ventilation, filtration (central or local) and controlling indoor temperature and relative humidity. ~~ee~~While UVGI is well researched and validated, many new technologies are not (ASHRAE 2018). (Evidence Level B)

Ventilation with effective airflow patterns (Pantelic and Tham, 2013) is a primary infectious disease control strategy through dilution of room air around a source and removal of infectious agents (CDC 2005). However, it remains unclear by how much infectious particle loads must be reduced (infectious dose varies widely among different pathogens) to achieve a measurable reduction in disease transmissions and whether these reductions warrant the associated cost (Pantelic and Tham, 2012; Pantelic et al., 2011). (Evidence Level B)

Room pressure differentials and directional airflow are important for controlling airflow between zones in a building (Siegel et al. 2007; CDC 2005) (Evidence Level B). Some designs for Airborne Infection Isolation Rooms (AIIRs) incorporate supplemental dilution or exhaust/capture ventilation (CDC 2005). Interestingly, criteria for AIIRs differ substantially between regions and countries in several ways, including air supply into anterooms, exhaust from space, and required amounts of ventilation air (Subhash et al. 2013; Fusco et al. 2012). A recent ASHRAE Research Project found convincing evidence that a properly configured and operated anteroom is an effective means to maintain pressure differentials and create containment in hospital rooms (Siegel et al. 2007; CO-RP-03). Where a significant risk of transmission of airborne aerosols has been identified by infection control risk assessments, design of AIIRs should include anterooms (Evidence Level A).

The use of highly efficient particle filtration in centralized HVAC systems reduces the airborne load of infectious particles (Azimi and Stephens 2013). This strategy reduces the transport of infectious agents from one area to another when these areas share the same central HVAC system through supply of recirculated air. When appropriately selected and deployed, single-space high efficiency filtration units (either ceiling mounted or portable) can be highly effective in reducing/lowering room air concentrations of infectious aerosols in a single space. They also achieve directional airflow source control that provides exposure protection even at the patient bedside (Miller-Leiden et al. 1996, Mead et al. 2004, Kujundzic et al. 2006, CDC 2012, Dungi et al. 2015). Filtration will not eliminate all risk of transmission of airborne particulates because many other factors besides infectious aerosol concentration contribute to disease transmission. (Evidence Level A)

The entire UV spectrum can kill or inactivate microorganisms, but UV-C energy, in the wavelengths from 200 nm to 280 nm, provides the most germicidal effect, with 265 nm being the optimum wavelength. The majority of modern UVGI lamps create UV-C energy at a near-optimum 254 nm wavelength. UVGI inactivates microorganisms by damaging the structure of nucleic acids and proteins with the effectiveness dependent upon the UV dose and the susceptibility of the microorganism. The safety of UV-C is well known. It does not penetrate deeply into human tissue but it can penetrate the very outer surfaces of the eyes and skin, with the eyes being most susceptible to damage. Therefore, shielding is needed to prevent direct exposure to the eyes. While ASHRAE's Position Document on Filtration and Air Cleaning does not make a recommendation for or against the use of ultraviolet energy in air systems for minimizing the risks from infectious aerosols (ASHRAE 2015), the US CDC has approved UVGI as an adjunct to filtration for reduction of tuberculosis risk and has published a guideline on its application (CDC citation) (Evidence Level A). [Note: Optical radiation in longer wavelengths as high as 405 nm is an emerging disinfection technology that may also have useful germicidal effectiveness.

Personalized ventilation systems that provide local exhaust source control and/or supply 100% outdoor, highly filtered, or UV disinfected air directly to the occupant's breathing zone (Bolashikov et al., 2009; Cermak et al. 2006; Pantelic et al., 2009. Pantelic et al, 2015; Licina et al., 2015) may offer protection against exposure to contaminated air in the breathing zones of occupants. Personalized ventilation may be effective against aerosols that travel both long distances as well as short-ranges (Li 2011). Personalized ventilation systems, when coupled with localized or personalized exhaust devices, further enhance the overall ability to mitigate exposure in the breathing zones, as seen from both experimental and CFD studies in healthcare settings (Yang et al. 2013, 2014, 2015; Bolashikov et al., 2015; Bivolarova et al., 2016). However, there are no known epidemiological studies that demonstrate a reduction in infectious disease transmission. (Evidence Level B).

Advanced techniques such as Computational Fluid Dynamics (CFD) analysis, if performed properly with adequate expertise, can predict airflow patterns and probable flow path of airborne contaminants in a space. Such analyses can be employed as a guiding tool during the early stages of the design cycle. (Khankari, 2016, Khankari 2018a, Khankari 2018b, Khankari, 2018c).

Other factors, such as a) relative humidity, b) UV source to target distance, c) total pathogen and organic load, and d) surface type, also have impacts on overall disinfection efficiency.

3.3 Temperature and Humidity

HVAC systems are typically designed to control temperature and humidity, which can in turn influence transmissibility of infectious agents. Although HVAC systems can be designed to control relative humidity (RH), there are practical challenges and potential negative effects of maintaining certain RH setpoints in all climate zones. While the weight of evidence at this time suggests that controlling RH reduces transmission of certain airborne infectious organisms, including some strains of influenza, this PD encourages designers to give a careful consideration to temperature and relative humidity issues. Recent evidence using metagenomic analysis shows that controlling relative humidity (RH) can effectively reduce the transmission of infectious aerosols as well as inhibit the viability of many viral and bacterial pathogens. In addition, immuno-biologists have correlated mid-range humidity levels with improved mammalian immunity against respiratory infections. ASHRAE CO-RP-03 reports that the scientific literature generally reflects the most unfavorable survival for micro-organisms when RH is between 40%-60% (Evidence Level e). Introduction of water vapor to the indoor environment to achieve the mid-range humidity levels associated with decreased infections requires proper selection, operation and maintenance of humidification equipment. Cold winter climates require proper building insulation to prevent thermal bridges which can lead to condensation and mold growth. (ASHRAE, 2009). Other recent studies (Lax et al. 2015, 2017, Taylor 2018) identified RH as a significant driver of patient infections. These studies showed that RH below 40% is associated with three factors that increase infections. First, infectious aerosols emitted from a primary host shrink rapidly to become droplet nuclei. These dormant, yet infectious pathogens remain suspended in the air and are capable of travelling great distances. When they encounter a hydrated secondary host, they are re-hydrated and able to propagate the infection. Secondly, many viruses and bacteria are anhydrous resistant (add citation), and actually have increased viability in low RH conditions. And finally, immuno-biologists have now clarified the mechanisms through which ambient RH below 40% impairs mucus membrane barriers and other steps in (add citation) immune system protection. (Evidence Level B). This PD does not make a definitive recommendation on indoor temperature and humidity setpoints for the purpose of controlling infectious aerosol transmission. Practitioners may use the information above to make building design and operation decisions on a case-by-case basis.

3.4 Emerging Pathogens and Emergency Preparedness

Disease outbreaks (i.e. epidemics, pandemics) are increasing in frequency and reach. Pandemics of the past have had devastating effects on affected populations. Novel microorganisms that can be disseminated by infectious aerosols necessitate good design, construction, commissioning, maintenance, advanced planning and emergency drills to facilitate fast action to mitigate exposure. In many countries, common strategies include naturally ventilated buildings and isolation. Control Banding is a risk management strategy that should be considered for applying the hierarchy of controls to emerging pathogens, based on the likelihood and duration of exposure and the infectivity and virulence of the pathogen (Sietsema 2019) (Evidence Level B). Biological agents that may be used in terrorist attacks are addressed elsewhere (USDHHS 2002, 2003).

4. CONCLUSIONS AND RECOMMENDATIONS

Infectious aerosols can be disseminated through buildings by pathways that include air distribution systems and interzone airflows. Various strategies have been found to be effective at controlling transmission, including optimized airflow patterns, directional airflow, zone pressurization, dilution ventilation, in-room air cleaning systems, local exhaust ventilation, personalized ventilation, local exhaust ventilation at the source, central system filtration, UV-C and controlling indoor temperature and relative humidity. The design engineer can contribute an essential contribution to reducing infectious aerosol transmission through the application of these strategies. Research on the role of airborne dissemination and resuspension from surfaces in pathogen transmission is rapidly evolving. Managing indoor air to control infections is an exciting and effective intervention which adds another strategy to medical treatments and behavioral interventions in disease prevention.

4.1 ASHRAE Positions

4.1.1 The HVAC design team should follow, as a minimum, the latest ASHRAE practice standards and guidelines and, based upon risk assessment or owner project requirements, go beyond the minimum requirements of these documents, using techniques covered in ASHRAE's publications including ASHRAE Handbooks, ASHRAE research reports, and papers and articles published by ASHRAE to be even better prepared to control the dissemination of infectious aerosols.

4.1.2 Mitigation of infectious aerosol transmission should be a consideration in the design of all facilities. The appropriate mitigation design should be incorporated in those identified as high-risk facilities.

4.1.3 The design and construction team, including HVAC designers, should engage in an integrated design process in order to incorporate the appropriate bundle of infection mitigation strategies in the early stages of design.

4.1.4 Buildings and transportation vehicles should, based on risk assessment, consider a design that promotes cleaner airflow patterns for providing effective flow path for airborne particulates to exit the space to less clean zones and uses appropriate air-cleaning systems. (Evidence Level A)

4.1.5 Where a significant risk of transmission of airborne aerosols has been identified by infection control risk assessments, design of AIIRs should include anterooms. (Evidence Level A)

4.1.6 Based on risk assessment, consider the use of specific HVAC strategies supported by the evidence-based literature including:
(i) enhanced filtration (higher MERV filters over code minimum in occupant-dense and/or higher-risk spaces) (Evidence Level A);

(ii) upper-room UVGI (with possible in-room fans) as a supplement to supply airflow (Evidence Level A);
(iii) local exhaust ventilation for source control (Evidence Level A);
(iv) personalized ventilation systems for certain high-risk tasks (Evidence Level B);
(v) portable free-standing HEPA filters (Evidence Level B); and
(vi) temperature and humidity control (Evidence Level B).

4.1.7 Design and build inherent capabilities (as outlined in 4.1.6 and 4.1.8) to respond to emerging threats and plan and practice for them. (Evidence Level B)

4.1.8 Non healthcare buildings should have a plan for an emergency response. Modifications to building HVAC system operation should be considered:
(i) Increase outdoor air ventilation (disable demand-controlled ventilation (DCV)) and open outdoor air dampers to 100% as indoor and outdoor conditions permit;
(ii) Improve central air and other HVAC filtration to MERV-13 (cite 52.2) or higher level achievable;
(iii) Keep systems running longer hours (24/7 if possible);
(iv) Add portable room air cleaners with HEPA or high MERV level filters with due consideration to CADR (AHAM 2015);
(v) Add duct/AHU mounted UVGI, upper room and portable UVGI in connection to in-room fans in high-density spaces such as waiting rooms, prisons and shelters;
(vi)–Maintain temperature and humidity as applicable to the infectious aerosol of concern; and
(vii) Bypass energy recovery ventilation systems that leak potentially contaminated exhaust air back into the outdoor air supply.

Hospital buildings should consider design and operation to:
(i) capture expiratory aerosols with headwall exhaust, tent or snorkel with exhaust, floor to ceiling partitions with door supply and patient exhaust, local air HEPA grade filtration;
(ii) exhaust of toilet and bed pan (essential);
(iii) Maintain temperature and humidity as applicable to the infectious aerosol of concern;
(iv) deliver clean air to caregivers;
(v) maintaining negatively pressurized ICUs where infectious aerosols may be present;
(vi) maintain rooms with infectious aerosol concerns at negative pressure;
(vii) provide 100% exhaust of patient rooms;
(viii) use UVGI;
(ix) increase the outdoor air change rate (for example patient rooms from 2 ACH to 6 ACH); and,
(x) establish HVAC contributions to patient room turnover plan before re-occupancy.

4.2 ASHRAE Commitments

4.2.1 Address research gaps with future research projects including:
(i) investigate and develop source generation variables for use in an updated ventilation rate procedure;
(ii) understanding the impacts of air change rates in operating rooms on patient outcomes;
(iii) determine effectiveness of location of supply, return and exhaust registers in patient rooms;
(iv) conduct controlled interventional studies to quantify the relative airborne infection control performance and cost-effectiveness of specific engineering strategies, individually and in combination, in field applications of high-risk occupancies;
(v) evaluate and compare options to create surge airborne isolation space and temporary negative pressure isolation space and the impacts on overall building operation; and
(vi) understanding the appropriate application of humidity and temperature control strategies across climate zones on infectious aerosol transmission.
(vii) Investigate how Control Banding techniques can be applied to manage the risk of infectious aerosol dissemination.

4.2.2 Partner with infection prevention, infectious disease, occupational health experts and building owners to evaluate emerging control strategies and provide evidence-based recommendations.

4.2.3 Educate stakeholders and disseminate best practices.

4.2.4 Create a database to track and share knowledge on effective, protective engineering design strategies.

4.2.5 Update standards and guidelines to reflect protective evidence-based strategies.

5. REFERENCES (Note - ASHRAE will include references cited in text in this section. Others to be deleted or moved to a bibliography)

ANSI/AHAM. AC-1-2015 (AHAM AC-1)

Apisarnthanarak, A., T.M. Uyeki, P. Puthavathana, R. Kitphati, and L.M. Mundy. 2010b. Reduction of seasonal influenza transmission among healthcare workers in an inten- sive care unit: A 4-year intervention study in Thailand. *Infection Control and Hospital Epidemiology* October 31(10):996–1003. doi: 10.1086/656565.

ASHRAE. 2000. ASHRAE Guideline 12-2000, *Minimizing the Risk of Legionellosis Associated With Building Water Systems*. Atlanta: ASHRAE.

ASHRAE. 2008. ANSI/ASHRAE/ASHE Standard 170-2008*, Ventilation of Health-Care Facilities*. Atlanta: ASHRAE.

ASHRAE. 2009. *Indoor Air Quality Guide: Best Practices for Design, Construction and Commissioning*. Atlanta: ASHRAE.

ASHRAE. 2010. ASHRAE 2010–2015 Research Strategic Plan. www.ashrae.org/standards -research--technology/research. Atlanta: ASHRAE.

ASHRAE. 2012a. *Legionellosis*, Position Document. Atlanta: ASHRAE.

ASHRAE. 2012b. ASHRAE Standard 52.2-2012, *Method of Testing General Ventilation Air-Cleaning Devices for Removal Efficiency by Particle Size*. Atlanta: ASHRAE.

ASHRAE. 2013a. ASHRAE Standard 55-2013, *Thermal Environmental Conditions for Human Occupancy*. Atlanta: ASHRAE.

ASHRAE. 2013b. ANSI/ASHRAE Standard 62.1-2013, *Ventilation for Acceptable Indoor Air Quality*. Atlanta: ASHRAE.

ASHRAE. 2013c. ANSI/ASHRAE Standard 62.2-2013, *Ventilation and Acceptable Indoor Air Quality in Low-Rise Residential Buildings*. Atlanta: ASHRAE.

ASHRAE. 2013d. *Minimizing Indoor Mold Problems through Management of Moisture in Building Systems*, Position Document. Atlanta: ASHRAE.

ASHRAE. 2018. Position Document on Filtration and Air Cleaning. Atlanta: ASHRAE.

Atkinson J., Chartier, Y., Pessoa-Silva, C.L., Jensen, P., and Seto, W.H. 2009. *Ventilation for Infection Control in Health-Care Settings*, WHO available at https://www.who.int/water_sanitation_health/publications/natural_ventilation/en/.Azimi, P. and B. Stephens. 2013. HVAC filtration for controlling infectious airborne disease transmission in indoor environments: Predicting risk reductions and operational costs. *Building and Environment* 70:150e160.

Baron 2017 - (2017), Generation and Behavior of Airborne Particles (Aerosols), Presentation published at CDC/NIOSH Topic Page: Aerosols, National Institute for Occupational Safety and Health, Centers for Disease Control and Prevention, Public Health Service, U.S. Department of Health and Human Services, Cincinnati, OH: https://www.cdc.gov/niosh/topics/aerosols/pdfs/Aerosol_101.pdf assessed 04/07/2020.

Belongia, E.A., B.A. Kieke, J.G. Donahue, R.T. Greenlee, A. Balish, A. Foust, S. Lindstrom, D.K. Shay. 2009. Marshfield Influenza Study Group. Effectiveness of inactivated influenza vaccines varied substantially with antigenic match from the 2004–2005 season to the 2006–2007 season. *Journal of Infectious Diseases*, January, 15;199(2):159–67. doi: 10.1086/595861.

Bischoff, W.E., K. Swett, I. Leng, T.R. Peters. 2013.Exposure to influenza virus aerosols during routine patient care. *Journal of Infectious Diseases* 207(7):1037–46. doi: 10.1093/ infdis/jis773. Epub 2013, Jan 30.

Bivolarova, M. P., Melikov, A. K., Mizutani, C., Kajiwara, K., & Bolashikov, Z. D. (2016). Bed-integrated local exhaust ventilation system combined with local air cleaning for improved IAQ in hospital patient rooms. Building and Environment, 100, 10-18.

BOMA: *Emergency Preparedness Guidebook: The Property Professional's Resource for Developing Emergency Plans for Natural and Human-Based Threats*. Washington, DC: Building Owners and Managers Association International. 2012.

Bolashikov, Zhecho D., Maria Barova & Arsen K. Melikov (2015) Wearable personal exhaust ventilation: Improved indoor air quality and reduced exposure to air exhaled from a sick doctor, Science and Technology for the Built Environment, 21:8, 1117-1125.

Bolashikov, Z. D., Melikov, A. K., & Krenek, M. (2009). Improved Performance of Personalized Ventilation by Control of the Convection Flow around Occupant Body. ASHRAE Transactions, 115(2), 421-431.

Brankston, G., L. Gitterman, Z. Hirji, C. Lemieux, and M. Gardam. 2007. Transmission of influenza A in human beings. *Lancet Infectious Disease* 7:257–65.

Burns, P.B., Rohrich, R.J., Chung, K.C. 2011. Levels of Evidence and their role in Evidence-Based Medicine. *Plast Reconstr Surg*. 128(1):305-310.

Catanzaro, A. 1982. Nosocomial Tuberculosis. *American Review of Respiratory Diseases.* 125:559–62.

CDC. 2001. Recognition of illness associated with the intentional release of a biologic agent. *Journal of the American Medical Association* 286:2088–90. Centers for Disease Control and Prevention.

CDC. 2003. *Guidelines for Environmental Infection Control in Health-Care Facilities*. Atlanta: Center for Disease Control and Prevention.

CDC. 2005. Guidelines for Preventing the Transmission of *Mycobacterium Tuberculosis* in Health-Care Settings. *Morbidity and Mortality Weekly Report* (MMWR), 54 (No. RR-17):1–140. Atlanta: Centers for Disease Control and Prevention.

CDC. 2014. NIOSH-approved N95 particulate filtering facepiece respirators. www.cdc.gov. www.cdc.gov/niosh/npptl/topics/respirators/disp_part/n95list1.html.

CDC
https://www.cdc.gov/mmwr/preview/mmwrhtml/rr5417a1.htm

https://www.cdc.gov/niosh/docs/2009-105/pdfs/2009-105.pdf

Cermak, R., A.K. Melikov, Lubos Forejt, and Oldrich Kovar. 2006. Performance of personalized ventilation in conjunction with mixing and displacement ventilation. *HVAC&R Research* 12(2):295–311.

Cheng, V.C., J.W. Tai, L.M. Wong, J.F. Chan, I.W. Li, K.K. To, I.F. Hung, K.H. Chan, P.L. Ho, and K.Y. Yuen. 2010. Prevention of nosocomial transmission of swine-origin pandemic influenza virus A/H1N1 by infection control bundle. *Journal of Hospital Infection* March, 74(3):271–7. doi: 10.1016/j.jhin.2009.09.009. Epub 2010 Jan 12.

Chu, C.M., V.C. Cheng, I.F. Hung, K.S. Chan, B.S. Tang, T.H. Tsang, K.H. Chan, and K.Y. Yuen. 2005. Viral load distribution in SARS outbreak. *Emerging Infectious Diseases* December, 11(12):1882–6.

Cole, E.C., and C.E. Cook. 1998. Characterization of infectious aerosols in health care facilities: an aid to effective engineering controls and preventive strategies. *American Journal of Infection Control* 26(4):453–64.

D'Alessio, D.J., C.K. Meschievitz, J.A. Peterson, C.R. Dick, and E.C. Dick. 1984. Short- duration exposure and the transmission of rhinoviral colds. *Journal of Infectious Dis- eases* August 150(2):189–94.

Dick, E.C., C.R. Blumer, and A.S. Evans. 1967. Epidemiology of infections with rhinovirus types 43 and 55 in a group of University of Wisconsin student families. *American Journal of Epidemiology* September, 86(2):386–400.

Dick, E.C., L.C. Jennings, K.A. Mink, C.D. Wartgow, and S.L. Inhorn. 1987. Aerosol transmission of rhinovirus colds. *Journal of Infectious Diseases* 156:442–8.

Duguid, J.P. 1946. The size and duration of air-carriage of respiratory droplets and droplet nucleii. *The Journal of Hygiene* (London) 44:471–79.

Fennelly, K.P., J.W. Martyny, K.E. Fulton, I.M. Orme, D.M. Cave, and L.B. Heifets. 2004. Cough- generated aerosols of *Mycobacterium Tuberculosis*: A new method to study infectiousness. *American Journal of Respiratory and Critical Care Medicine* 169:604–609.

FGI. 2010. *2010 Guidelines for Design and Construction of Health Care Facilities*. Dallas: Facility Guidelines Institute.

Fusco, F.M., S. Schilling, G. De Iaco, H.R. Brodt, P. Brouqui, H.C. Maltezou, B. Bannister, R. Gottschalk, G. Thomson, V. Puro, and G. Ippolito. 2012. Infection control management of patients with suspected highly infectious diseases in emergency departments: Data from a survey in 41 facilities in 14 European countries. *BMC Infectious Diseases* January 28:12:27.

Gao, N.P. and J.L. Niu. 2004. CFD study on micro-environment around human body and personalized ventilation. Building and Environment, 39:795–805.

Gao, X., Y. Li, P. Xu, and B.J. Cowling. 2012. Evaluation of intervention strategies in schools including ventilation for influenza transmission control. *Building Simulation* 5(1):29, 37.

Gwaltney, J., and J.O. Hendley. 1978.Rhinovirus transmission: One if by air, two if by hand. *American Journal of Epidemiology* May,107(5):357–61.

Han, K., X. Zhu, F. He, L. Liu, L. Zhang, H. Ma, X. Tang, T. Huang, G. Zeng, and B.P. Zhu. 2009. Lack of airborne transmission during outbreak of pandemic (H1N1) 2009 among tour group members, China, June 2009. *Emerging Infectious Diseases* October, 15(10):1578–81.

Hoge, C.W., M.R. Reichler, E.A. Dominguez, J.C. Bremer, T.D. Mastro, K.A. Hendricks, D.M. Musher, J.A. Elliott, R.R. Facklam, and R.F. Breiman. 1994. An epidemic of pneumococcal disease in an overcrowded, inadequately ventilated jail. *New England Journal of Medicine* 331(10):643–8.

Khankari, K. . 2016. Airflow Path Matters: Patient Room HVAC. ASHRAE Journal, vol. 58, no. 6, June 2016

Khankari, K. 2018. CFD Analysis of Hospital Operating Room Ventilation System Part I: Analysis of Air Change Rates. ASHRAE Journal Vol. 60, no. 5, May 2018

Khankari, K. 2018. CFD Analysis of Hospital Operating Room Ventilation System Part II: Analyses of HVAC Configurations. ASHRAE Journal, Vol. 60, no. 6, June 2018

Khankari, K. 2018. Analysis of Spread Index: A Measure of Laboratory Ventilation Effectiveness. ASHRAE Conference Paper for ASHRAE Annual Conference, Houston, TX.

Klontz, K.C., N.A. Hynes, R.A. Gunn, M.H. Wilder, M.W. Harmon, and A.P. Kendal. 1989. An outbreak of influenza A/Taiwan/1/86 (H1N1) infections at a naval base and its association with airplane travel. *American Journal of Epidemiology* 129:341–48.

Ko, G., M.W. First, and H.A. Burge. 2002. The Characterization of upper-room ultraviolet germicidal irradiation in inactivating airborne microorganisms. *Environmental Health Perspectives* 110:95–101.

Kujundzic, E., F. Matalkah, D.J. Howard, M. Hernandez, and S.L. Miller. 2006. Air cleaners and upper-room air UV germicidal irradiation for controlling airborne bacteria and fungal spores. *Journal of Occupational and Environmental Hygiene* 3:536–46.

Kujundzic, E., M. Hernandez, and S.L. Miller. 2007. Ultraviolet germicidal irradiation inactivation of airborne fungal spores and bacteria in upper-room air and in-duct configurations. *Journal of Environmental Engineering and Science* 6:1–9.

Li, Y. 2011. The secret behind the mask. (Editorial.) *Indoor Air* 21(2):89–91.

Licina, D., Melikov, A., Sekhar, C., & Tham, K. W. (2015a). Human convective boundary layer and its interaction with room ventilation flow. *INDOOR AIR*, *25*(1), 21-35. doi:10.1111/ina.12120

Licina, D., Melikov, A., Pantelic, J., Sekhar, C., & Tham, K. W. (2015b). Human convection flow in spaces with and without ventilation: personal exposure to floor-released particles and cough-released droplets. INDOOR AIR, 25(6), 672-682. doi:10.1111/ina.12177

Li, Y., H. Qian, I.T.S. Yu, and T.W. Wong. 2005a. Probable roles of bio-aerosol dispersion in the SARS outbreak in Amoy Gardens, Hong Kong. Chapter 16. *Population Dynamics and Infectious Disease in the Asia-Pacific*. Singapore: World Scientific Publishing.

Li, Y., X. Huang, I.T.S. Yu, T.W. Wong and H. Qian. 2005b. Role of air distribution in SARS trans- mission during the largest nosocomial outbreak in Hong Kong. *Indoor Air* 15:83–95.

Li, Y., G.M. Leung, J.W. Tang, X. Yang, C.Y.H. Chao, J.Z. Lin, J.W. Lu, P.V. Nielsen, J. Niu, H. Qian, A.C. Sleigh, H-J. J. Su, J. Sundell, T.W. Wong, and P.L. Yuen. 2007. Role of ventilation in airborne transmission of infectious agents in the built environment—A multi-disciplinary systematic review. *Indoor Air* 17(1):2–18.
Li, Y. 2011. The secret behind the mask. (Editorial.) *Indoor Air* 21(2):89–91.
Lowen, A.C., S. Mubareka, J. Steel, and P. Palese. 2007. Influenza virus transmission is dependent on relative humidity and temperature. *PLOS Pathogens* 3:1470–6.

Mahida, N., N. Vaughan, and T. Boswell. 2013. First UK evaluation of an automated ultraviolet-C room decontamination device (Tru-D), *Journal of Hospital Infection*. http://dx.doi.org/10.1016/j.jhin.2013.05.005.

Mandell, G. 2010. *Mandell, Douglas, and Bennett's Principles and Practice of Infectious Diseases E-Book,* 7th Edition, Churchill Livingstone Elsevier.

McLean, R.L. 1961. The effect of ultraviolet radiation upon the transmission of epidemic influenza in long-term hospital patients. *American Review of Respiratory Diseases* 83(2): 36–8.

MDH. 2013. Airborne infectious disease management manual: Methods for temporary negative pressure isolation. Minnesota Department of Health. Available at www.health.state.mn.us/oep/training/bhpp/airbornenegative.pdf. Accessed September 13, 2013.

Memarzadeh, F, Olmsted, RM and Bartley, JM 2010. Applications of ultraviolet germicidal irradiation disinfection in healthcare facilities: Effective adjunct, but not stand-alone technology. *American Journal of Infection Control* 38:S13–24.

Memarzadeh, F. 2011. Literature review of the effect of temperature and humidity on viruses. *ASHRAE Transactions* 117(2).

Miller, S.L., J. Linnes, and J. Luongo. 2013. Ultraviolet germicidal irradiation: Future directions for air disinfection and building applications. *Photochemistry and Photobiology* 89:777–81.

Miller-Leiden, S., C. Lobascio, J.M. Macher, and W.W. Nazaroff. 1996. Effectiveness of in-room air filtration for tuberculosis control in healthcare settings. *Journal of the Air & Waste Management Association* 46:869–82.

Moser, M.R., T.R. Bender, H.S. Margolis, G.R. Noble, A.P. Kendal and D.G. Ritter. 1979. An outbreak of influenza aboard a commercial airliner. *American Journal of Epidemiology* 110(1):1–6.

Myatt, T.A., S.L. Johnston, Z. Zuo, M. Wand, T. Kebadze, S. Rudnick, and D.K. Milton. 2004. Detection of airborne rhinovirus and its relation to outdoor air supply in office environments. *American Journal of Respiratory and Critical Care Medicine* 169:1187–90.

Nardell, E.A., S.J. Bucher, P.W. Brickner, C. Wang, R.L. Vincent, K. Becan-McBride,

M.A. James, M. Michael, and J.D. Wright. 2008. Safety of Upper-Room Ultraviolet Germicidal Air Disinfection for Room Occupants: Results from the Tuberculosis Ultraviolet Shelter Study. *Public Health Reports Volume* 123:52-60.

S.J. Bucher, P.W. Brickner, C. Wang, R.L. Vincent, K. Becan-McBride, M.A. James, M. Michael, and J.D. Wright. 2008. Safety of upper-room ultraviolet germicidal air disinfection for room occupants: Results from the tuberculosis ultraviolet shelter study. *Public Health Reports* 123:52–60.

Nicas M, W.W. Nazaroff, and A. Hubbard. 2005. Toward understanding the risk of secondary airborne infection: Emission of respirable pathogens. *Journal of Occupational and Environmental Hygiene* 2:143–54.

Nicas, M., and R.M. Jones. 2009. Relative contributions of four exposure pathways to influenza infection risk. *Risk Analysis* 29:1292–303.

NIOSH. 2009a. *Environmental Control for Tuberculosis: Basic Upper-Room Ultraviolet Germicidal Irradiation Guidelines for Healthcare Settings*. Department of Health and Human Services, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health.

NIOSH. 2009b. Health hazard evaluation report: UV-C exposure and health effects in surgical suite personnel, Boston, MA. By D. Sylvain, and L. Tapp. Cincinnati, OH: U.S. Department of Health and Human Services, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health, NIOSH HETA No. 2007-0257- 3082.

Noti J.D., F.M. Blachere, C.M. McMillen, W.G. Lindsley, M.L. Kashon, D.R. Slaughter, and D.H. Beezhold. 2013. High humidity leads to loss of infectious influenza virus from simulated coughs. *PLOS ONE* 8(2):e57485.

OSHA. 1999. *OSHA Technical Manual*. Washington, DC: Occupational Safety & Health Administration.

Osterholm M.T., N.S. Kelley, A. Sommer, and E.A. Belongia. 2012. Efficacy and effectiveness of influenza vaccines: A systematic review and meta-analysis. *Lancet Infectious Diseases.* January, 12(1):36–44. doi: 10.1016/S1473-3099(11)70295-X. Epub 2011 October 25.

Pantelic, J., Sze-To, G.N., Tham, K.W., Chao, C.Y. and Khoo, Y.C.M., 2009. Personalized ventilation as a control measure for airborne transmissible disease spread. Journal of the Royal Society Interface, 6(suppl_6), pp.S715-S726.

Pantelic, J. and Tham, K.W., 2011. Assessment of the ability of different ventilation systems to serve as a control measure against airborne infectious disease transmission using Wells-Riley approach.

Pantelic, J. and Tham, K.W., 2012. Assessment of the mixing air delivery system ability to protect occupants from the airborne infectious disease transmission using Wells–Riley approach. HVAC&R Research, 18(4), pp.562-574.

Pantelic, J. and Tham, K.W., 2013. Adequacy of air change rate as the sole indicator of an air distribution system's effectiveness to mitigate airborne infectious disease transmission caused by a cough release in the room with overhead mixing ventilation: a case study. HVAC&R Research, 19(8), pp.947-961.

Pantelic, J., Tham, K.W. and Licina, D., 2015. Effectiveness of a personalized ventilation system in reducing personal exposure against directly released simulated cough droplets. Indoor Air, 25(6), pp.683-693.

Peccia, J., H. Werth, S. L. Miller, and M. Hernandez. 2001. Effects of relative humidity on the ultraviolet-induced inactivation of airborne bacteria. *Aerosol Science & Technology* 35:728–40.

Reed, N.G. 2010. The history of ultraviolet germicidal irradiation for air disinfection. *Public Health Reports* January–February, 125(1):15–27.

Riley, R.L., C.C. Mills, F. O'Grady, L.U. Sultan, F. Wittestadt, and D.N. Shivpuri. 1962. Infectiousness of air from a tuberculosis ward—Ultraviolet irradiation of infected air:

Comparative infectiousness of different patients. *American Review of Respiratory Diseases* 85:511–25.
Riley, R.L., and E.A. Nardell. 1989. Clearing the air: The theory and application of ultraviolet air disinfection. *American Review of Respiratory Diseases* 139(5):1286–94.
Riley, E.C., G. Murphy, and R.L. Riley. 1978. Airborne spread of measles in a suburban elementary school. *American Journal of Epidemiology* 107:421–32.
Roy, C.J., and D.K. Milton. 2004. Airborne transmission of communicable infection—The elusive pathway. *New England Journal of Medicine* 350:17.
SA Health. 2013. *Guidelines for Control of Legionella in Manufactured Water Systems in South Australia*. Rundle Mall, South Australia: SA Health.
Schaffer, F.L., M.E. Soergel, and D.C. Straube. 1976. Survival of airborne influenza virus: Effects of propagating host, relative humidity, and composition of spray fluids. *Archives of Virology* 51:263–73.
Shaman, J., and M. Kohn. 2009. Absolute humidity modulates influenza survival, transmission, and seasonality. *Proceedings of the National Academy of Sciences* 106(0):3243–48.
Siegel J.D., E. Rhinehart, M. Jackson, and L. Chiarello. 2007. *2007 Guideline for Isolation Precautions: Preventing Transmission of Infectious Agents in Healthcare Settings.* Atlanta: Centers for Disease Control and Prevention, The Healthcare Infection Control Practices Advisory Committee.
Subhash, S.S., G. Baracco, K.P. Fennelly, M. Hodgson, and L.J. Radonovich, Jr. 2013. Isolation anterooms: Important components of airborne infection control. *American Journal of Infection Control* May, 41(5):452–5. doi: 10.1016/j.ajic.2012.06.004. Epub 2012, October 2.
Sun Y., Z. Wang, Y. Zhang, and J. Sundell. 2011. In China, students in crowded dormitories with a low ventilation rate have more common colds: Evidence for airborne transmission. *PLOS ONE* 6(11):e27140.
Tang J.W., Y. Li, I. Eames, P.K.S. Chan, and G.L. Ridgway. 2006. Factors involved in the aerosol transmission of infection and control of ventilation in healthcare premises. *Journal of Hospital Infection* 64(2):100–14.
Tang, J.W. 2009. The effect of environmental parameters on the survival of airborne infectious agents. *Journal of the Royal Society Interface* 6:S737–S746.
Taylor, S. and M. Tasi. 2018. Low Indoor-Air Humidity in an Assisted Living Facility is Correlated with Increased Patient Illness and Cognitive Decline. IndoorAir2018 Proceedings ISIAQ 744:1–8.
Tellier, R. 2006. Review of aerosol transmission of influenza a virus. *Emerging Infectious Disease*12(11):1657–62.
USDHHS. 2002. *Guidance for Protecting Building Environments from Airborne Chemical, Biological, or Radiological Attacks*. NIOSH Publication No. 2002-139, May. Washington, DC: United States Department of Health and Human Services.
USDHHS. 2003. Guidance for Filtration and Air-Cleaning Systems to Protect Building Environments from Airborne Chemical, Biological, or Radiological Attacks NIOSH

Publication No. 2003-136. Washington, DC: United States Department of Health and Human Services.

VanOsdell, D., and K. Foarde. 2002. *Defining the Effectiveness of UV Lamps Installed in Circulating Air Ductwork—Final Report*. Air-Conditioning and Refrigeration Technology Institute, Arlington, Virginia.

Wainwright, C.E., M.W. Frances, P. O'Rourke, S. Anuj, T.J. Kidd, M.D. Nissen, T.P. Sloots, C. Coulter, Z. Ristovski, M. Hargreaves, B.R. Rose, C. Harbour, S.C, Bell, and K.P. Fennelly. 2009. Cough-generated aerosols of *Pseudomonas aeruginosa* and other Gram-negative bacteria from patients with cystic fibrosis. *Thorax* 64:926–31.

Wang, Y., Sekhar, C., Bahnfleth, W. P., Cheong, K. W., & Firrantello, J. (2016). Effectiveness of an ultraviolet germicidal irradiation system in enhancing cooling coil energy performance in a hot and humid climate. *ENERGY AND BUILDINGS*, *130*, 321-329. doi:10.1016/j.enbuild.2016.08.063

Wang, B., A. Zhang, J.L. Sun, H. Liu, J. Hu, and L.X. Xu. 2005. Study of SARS transmission via liquid droplets in air. *Journal of Biomechanical Engineering* 127:32–8.

Wat, D. 2004. The common cold: A review of the literature. *European Journal of Internal Medicine* 15:79– 88.

Wells, W.F. 1955. *Airborne Contagion and Air Hygiene*. Cambridge: Harvard University Press, 191.

WHO. 2007. *Legionella and the prevention of Legionellosis*. Geneva: World Health Organization 2007. Available at www.who.int/water_sanitation_health/emerging/legionella/en/.

WHO. 2009. *Natural ventilation for infection control in health-care settings*. World Health Organization: Geneva, Switzerland.

WHO. 2014. Influenza: Public health preparedness. www.who.int/influenza/preparedness/en/. www.who.int/influenza/preparedness/en/.

Wong, B.X., N. Lee, Y. Li, P.X. Chan, H. Qiu, Z. Luo, R.X. Lai, K.X. Ngai, D.X. Hui, K.X. Choi, I.X. Yu. 2010. Possible role of aerosol transmission in a hospital outbreak of influenza. *Clinical Infectious Diseases* 51(10):1176–83.

Xie, X., Y. Li, A.T.Y. Chwang, P.L. Ho, and H. Seto. 2007. How far droplets can move in indoor environments—Revisiting the Wells evaporation-falling curve. *Indoor Air* 17:211–25.

Xie, X.J., Y.G. Li, H.Q. Sun, and L. Liu. 2009. Exhaled droplets due to talking and coughing. *Journal of The Royal Society Interface* 6:S703–S714.

Xu, P., J. Peccia, P. Fabian, J.W. Martyny, K. Fennelly, M. Hernandez, and S.L. Miller. 2003. Efficacy of ultraviolet germicidal irradiation of upper-room air in inactivating bacterial spores and mycobacteria in full-scale studies. *Atmospheric Environment* 37:405–19.

Xu, P., E. Kujundzic, J. Peccia, M.P. Schafer, G. Moss, M. Hernandez, and S.L. Miller. 2005. Impact of environmental factors on efficacy of upper-room air ultraviolet germicidal irradiation for inactivating airborne mycobacteria. *Environmental Science & Technology* 39:9656–64.

Xu, P., N. Fisher, and S.L. Miller. 2013. Using computational fluid dynamics modeling to evaluate the design of hospital ultraviolet germicidal irradiation systems for inactivating airborne mycobacteria. *Photochemistry and Photobiology* 89(4):792–8.

Yang, J., Sekhar, S. C., Cheong, K. W. D., & Raphael, B. (2015a). Performance evaluation of a novel personalized ventilation-personalized exhaust system for airborne infection control. *INDOOR AIR*, *25*(2), 176-187. doi:10.1111/ina.12127

Yang, J., Sekhar, C., Cheong, D. K. W., & Raphael, B. (2015b). A time-based analysis of the personalized exhaust system for airborne infection control in healthcare settings. *SCIENCE AND TECHNOLOGY FOR THE BUILT ENVIRONMENT*, *21*(2), 172-178. doi:10.1080/10789669.2014.976511

Yang, J., Sekhar, C., Cheong, D., & Raphael, B. (2014). Performance evaluation of an integrated Personalized Ventilation-Personalized Exhaust system in conjunction with two background ventilation systems. *BUILDING AND ENVIRONMENT*, *78*, 103-110. doi:10.1016/j.buildenv.2014.04.015

Yang, J., C. Sekhar, D. Cheong Kok Wai, and B. Raphael. 2013. CFD study and evaluation of different personalized exhaust devices. *HVAC&R Research*.

Yang, W., S. Elankumaran, and L.C. Marr. 2012a. Relationship between humidity and influenza a viability in droplets and implications for influenza's seasonality. *PLOS ONE* 7(10):e46789. doi:10.1371/journal.pone.0046789.

Yang, W., and L. Marr. 2012b. Mechanisms by which ambient humidity may affect viruses in aerosols. *Applied and Environmental Microbiology* 78(19):6781. DOI: 10.1128/AEM.01658-12.

Yu, I.T., Y. Li, T.W. Wong, W. Tam, A.T. Chan, J.H. Lee, D.Y. Leung, and T. Ho. 2004. Evidence of Airborne Transmission of the Severe Acute Respiratory

Yan J1,2, Grantham M1, Pantelic J1, et al **Infectious virus in exhaled breath of symptomatic seasonal influenza cases from a college community.** Proc Natl Acad Sci U S A. 2018 Jan 30;115(5):1081-1086. doi: 10.1073/pnas.1716561115. Epub 2018 Jan 18.

WELLS WF. On the mechanics of droplet nuclei infection; apparatus for the quantitative study of droplet nuclei infection of animals. Am J Hyg. 1948 Jan;47(1):1-10.

PMID:18921434
DOI:10.1093/oxfordjournals.aje.a119176

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http://www.tandfonline.com/doi/abs/10.1080/08828032.1989.10388568 and https://www.cdc.gov/niosh/docs/hazardcontrol/hc13.html

http://www.tandfonline.com/doi/abs/10.1080/08828032.1989.10388568 and https://www.cdc.gov/niosh/docs/hazardcontrol/hc13.html

[EJS23]Should we be more definitive about the efficacy of HEPA filtration?

[km24]Links to new references:

(1) https://www2a.cdc.gov/nioshtic-2/BuildQyr.asp?s1=mead&f1=AU&Startyear=&terms=3&Adv=1&ct=&Limit=500&Sort=DP+DESC&whichdate=DP&D1=10&EndYear=&PageNo=13&RecNo=129&View=f&

(2) https://www2a.cdc.gov/nioshtic-2/BuildQyr.asp?s1=mead&f1=AU&Startyear=&terms=3&Adv=1&ct=&Limit=500&Sort=DP+DESC&whichdate=DP&D1=10&EndYear=&PageNo=7&RecNo=66&View=f&

(3) https://www2a.cdc.gov/nioshtic-2/BuildQyr.asp?s1=mead&f1=AU&Startyear=&terms=3&Adv=1&ct=&Limit=500&Sort=DP+DESC&whichdate=DP&D1=10&EndYear=&PageNo=3&RecNo=30&View=f&