JAMA Insights

Indoor Air Changes and Potential Implications for SARS-CoV-2 Transmission

Joseph G. Allen, DSc, MPH; Andrew M. Ibrahim, MD, MSc

Buildings have been associated with spread of infectious diseases, such as outbreaks of measles, influenza, and *Legionella*. With SARS-CoV-2, the majority of outbreaks involving 3 or more people have been linked with time spent indoors, and evidence confirms that far-field airborne transmission (defined as within-room but beyond 6 feet) of SARS-CoV-2 is occurring.[1]

Controlling concentrations of indoor respiratory aerosols to reduce airborne transmission of infectious agents is critical and can be achieved through source control (masking, physical distancing) and engineering controls (ventilation and filtration).[2] With respect to engineering controls, an important flaw exists in how most buildings operate in that the current standards for ventilation and filtration for indoor spaces, except for hospitals, are set for bare minimums and not designed for infection control. Several organizations and groups have called for increasing outdoor air ventilation rates, but, to date, there has been limited guidance on specific ventilation and filtration targets. This article describes the rationale for limiting far-field airborne transmission of SARS-CoV-2 through increasing outdoor air ventilation and enhancing filtration, and provides suggested targets.

+ Supplemental content

To reduce far-field airborne transmission of SARS-CoV-2 in small-volume indoor spaces (eg, classrooms, retail shops, homes if guests are visiting), the suggestions include targeting 4 to 6 air changes per hour, through any combination of the following: outdoor air ventilation; recirculated air that passes through a filter with at least a minimum efficiency rating value 13 (MERV 13) rating; or passage of air through portable air cleaners with HEPA (high-efficiency particulate air) filters.

Despite the dose-response for SARS-CoV-2 being unknown, and continued scientific debate about the dominant mode of transmission, evidence support these suggestions. First, SARS-CoV-2 is primarily transmitted from the exhaled respiratory aerosols of infected individuals. Larger droplets (>100 μm) can settle out of the air due to gravitational forces within 6 feet, but people emit 100 times more smaller aerosols (<5 μm) during talking, breathing, and coughing. Smaller aerosols can stay aloft for 30 minutes to hours and travel well beyond 6 feet.[1] Second, high-profile and well-described SARS-CoV-2 outbreaks across multiple space types (eg, restaurants, gyms, choir practice, schools, buses) share the common features of time indoors and low levels of ventilation, even when people remained physically distanced.[3]

Third, these suggestions are grounded in the basics of exposure science and inhalation dose risk reduction. Higher ventilation and filtration rates more rapidly remove particles from indoor air, thereby reducing the intensity of exposure and duration that respiratory aerosols stay aloft inside a room. Fourth, this approach is consistent with what is used in hospitals to minimize risk of transmission (eTable in the Supplement). Fifth, reviews on the relationship between ventilation and infectious diseases found that the weight of evidence indicates ventilation plays a key role in infectious disease transmission, citing observational epidemiological studies showing low ventilation associated with transmission of measles, tuberculosis, rhinovirus, influenza, and SARS-CoV-1.[4-6] All 3 reviews note the limited number of research papers on this topic and limitations of observational data. Sixth, more recently, the National Institute of Allergy and Infectious Diseases cited the importance of adequate ventilation in the suite of COVID-19 control measures,[2] and the Centers for Disease Control and Prevention and the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) support higher ventilation rates and enhanced filtration as components of holistic risk reduction strategies.

Current Indoor Air Ventilation Measures and Standards

Current ventilation standards for most indoor spaces are established by ASHRAE.[7] These standards have been designed with the goal of diluting bioeffluents (such as odors from people) and achieving basic levels of acceptable indoor air quality, rather than infection control.[8]

While multiple conventions exist to describe ventilation rate (eg, total volumetric flow, volumetric flow per person and area, outdoor air ventilation rates), air exchange rate is frequently used in health care settings and commonly expressed in units of air changes per hour (ACH).

The existing minimum standards for ACH vary based on building type (eTable in the Supplement). For example, according to ASHRAE, the predominant standard-setting organization for ventilation rates, the minimum required total ACH that occur in most households is 0.35 ACH of outdoor air, and schools should be designed for approximately 10 times higher rates, although most schools do not meet this in practice.[9] The suggestion for increasing the target to 4 to 6 ACH is more consistent with rates set in hospitals, where the higher ACH requirements underscore the potential role of air change rates as an infection control strategy.

Current Air Filtration Measures and Standards

In addition to air ventilation from outdoor air, respiratory aerosols can also be removed through air filtration. Filtered air can therefore be considered in terms of equivalent air changes per hour (ACHe) and added to the ACH from outdoor air.

Clean air delivery rate (CADR) is a term used to describe the amount of clean air delivered to a space as determined by filtration effectiveness and the amount of air moving through that filter. Portable air cleaners commonly use CADR to describe their effectiveness. For example, if a portable air cleaner has a high-efficiency particulate air (HEPA) filter, it will capture 99.97% of aerosols at 0.3 μm. Filter efficacy is commonly reported based on the aerosol size against which the filter performs most poorly (0.3 μm), although a HEPA filter will capture an even greater percentage of aerosols larger (and smaller) than 0.3 μm.

The CADR metric is valuable because it can be used to estimate the ACH of virus-free air being delivered to the room. The estimated

ACHe is calculated as [CADR in ft^3/min × 60 min] divided by the room volume in ft^3. A device with a CADR of 300 in a 500-square-foot room with 8-foot ceilings will therefore deliver 4.5 ACH.

This same filtration concept can be applied to air that is recirculated through a central mechanical ventilation system or within-room ventilation system. However, most central mechanical systems were not designed for HEPA filters. Instead, these systems use filters on a different rating scale, minimum efficiency reporting value, or MERV, and typically use a low-grade filter (eg, MERV 8) that captures only approximately 15% of 0.3- to 1-μm particles, 50% of 1- to 3-μm particles, and 74% of 3- to 10μm particles.[4] For infection control, buildings should upgrade to MERV 13 filters when possible, which could capture approximately 66%, 92%, and 98%, of these sized particles, respectively. These MERV values can be applied to the estimate of the overall clean air delivery rate for the room as with HEPA filters, but, instead of using near 100% capture efficiency for HEPA, the calculation has to be adjusted for the lower capture efficiencies of whichever MERV filter is used. Upgrading filters in mechanical systems is particularly important in buildings that use systems that recirculate air within the same room or same local ventilation zone.

Practical Design Considerations When Increasing Air Exchange and Filtration

Implementing changes to air ventilation and filtration to any building will have several important and practical design considerations.

First, increasing air exchange rates involves trade-offs including the added costs of moving more air as well as heating or cooling this larger volume of air. These added costs could be limited by using energy-efficient systems and “smart” systems that deliver air when the space is occupied. In addition, when appropriate, natural ventilation (eg, open windows) also could minimize the costs of achieving increased ventilation.

Second, improving indoor air ventilation and filtration only accounts for far-field (ie, beyond 6 feet) aerosol transmission and does not significantly influence close contact transmission. Wearing masks is still important indoors for source control and for close contact with individuals even when high air exchange rates are achieved.

Third, the utility of air changes per hour over a volumetric flow approach to ventilation is most useful in small rooms with ceiling heights generally less than 12 feet. In rooms with higher ceilings (eg, gymnasiums, atria), aerosols will dilute into the larger space and volumetric flow per area or per person would be a more appropriate measure that takes into account occupant density and activity level, which also influence aerosol emission rates.

Fourth, air exchange rates are useful under typical or low-occupant-density scenarios, as should be happening during a pandemic. In places with large occupancy limits, or if more people are added to a smaller space than it is designed for, ventilation needs to scale up accordingly.

Fifth, in locations where masks are not worn all of the time, like restaurants, additional strategies are needed including increasing to higher air change per hour targets, workers wearing high-efficiency masks, patrons wearing masks at all times other than while actively eating or drinking, and everyone inside physically distancing at least 6 feet.

Sixth, while these design considerations are important to reducing airborne transmission in the current context of the COVID-19 pandemic, improved air ventilation and filtration is a strategy that should be considered for continued use in buildings going forward because of associations with lower work and school absenteeism, better performance on cognitive function tests, and fewer sick building syndrome symptoms, such as headache and fatigue.[10]

Conclusions

Increasing air changes per hour and air filtration is a simplified but important concept that could be deployed to help reduce risk from within-room, far-field airborne transmission of SARS-CoV-2 and other respiratory infectious diseases. Healthy building controls like higher ventilation and enhanced filtration are a fundamental, but often overlooked, part of risk reduction strategies that could have benefit beyond the current pandemic.

ARTICLE INFORMATION

Author Affiliations: T.H. Chan School of Public Health at Harvard University, Boston, Massachusetts (Allen); Department of Surgery, Taubman College of Architecture & Urban Planning, University of Michigan, Ann Arbor (Ibrahim); HOK Architects, Chicago, Illinois (Ibrahim).

Corresponding Author: Joseph G. Allen, DSc, MPH, Harvard T.H. Chan School of Public Health, 677 Huntington Ave, Boston, MA 02115 (jgallen@hsph.harvard.edu).

Published Online: April 16, 2021. doi:10.1001/jama.2021.5053

Conflict of Interest Disclosures: Dr Ibrahim reports receiving payments from HOK Architects in his role as a senior principal and chief medical officer. Dr Allen owns 9 Foundations Inc, which has provided consulting regarding COVID-19 risk reduction strategies across many sectors, including education, real estate, government, private entities, and faith-based organizations. Dr Allen has also received consulting fees from for-profit organizations, including serving as a scientific advisor for Carrier Corporation.

REFERENCES

1. National Academies of Sciences, Engineering, and Medicine. *Airborne Transmission of SARS-CoV-2: Proceedings of a Workshop—in Brief*. National Academy of Sciences; October 2020.

2. Lerner AM, Folkers GK, Fauci AS. Preventing the spread of SARS-CoV-2 with masks and other “low-tech” interventions. *JAMA*. 2020;324(19):1935-1936. doi:10.1001/jama.2020.21946

3. The *Lancet* COVID-19 Commission Task Force on Safe Work, Safe School, and Safe Travel. Six priority areas. The *Lancet* COVID-19 Commission; 2021.

4. Li Y, Leung GM, Tang JW, et al. Role of ventilation in airborne transmission of infectious agents in the built environment: a multidisciplinary systematic review. *Indoor Air*. 2007;17(1):2-18. doi:10.1111/j.1600-0668.2006.00445.x

5. Sundell J, Levin H, Nazaroff WW, et al. Ventilation rates and health: multidisciplinary review of the scientific literature. *Indoor Air*. 2011;21(3):191-204. doi:10.1111/j.1600-0668.2010.00703.x

6. Luongo JC, Fennelly KP, Keen JA, et al. Role of mechanical ventilation in the airborne transmission of infectious agents in buildings. *Indoor Air*. 2016;26(5):666-678. doi:10.1111/ina.12267

7. American Society of Heating, Refrigerating and Air-Conditioning Engineers. ANSI/ASHRAE standards and guidelines to address COVID-19. Accessed April 9, 2021. https://www.ashrae.org/technical-resources/ashrae-standards-and-guidelines

8. Persily A. Challenges in developing ventilation and indoor air quality standards: the story of ASHRAE Standard 62. *Build Environ*. 2015;91:61-69. doi:10.1016/j.buildenv.2015.02.026

9. Fisk WJ. The ventilation problem in schools: literature review. *Indoor Air*. 2017;27(6):1039-1051. doi:10.1111/ina.12403

10. Allen J, Macomber J. *Healthy Buildings: How Indoor Spaces Drive Performance and Productivity.* Harvard University Press; 2020.