CADTH COVID-19 PANDEMIC

COVID-19 CADTH HEALTH TECHNOLOGY REVIEW

Heating, Ventilation, and Air Conditioning Systems in Public Spaces

This report was published on September 22, 2020.

To produce this report, CADTH used a modified approach to the selection, appraisal, and synthesis of the evidence to meet decision-making needs during the COVID-19 pandemic. Care has been taken to ensure the information is accurate and complete, but it should be noted that international scientific evidence about COVID-19 is changing and growing rapidly.

Version: 1.0
Publication Date: September 2020
Report Length: 24 Pages

CADTH COVID-19 PANDEMIC

Cite As: *Heating, Ventilation, and Air Conditioning Systems in Public Spaces*. Ottawa: CADTH; 2020 September. (CADTH Health Technology Review).

Acknowledgements: Implementation Support and Knowledge Mobilization, CADTH COVID Taskforce, and Research Information Services. Multidisciplinary expert panel members are listed in Appendix A.

About CADTH: CADTH is an independent, not-for-profit organization responsible for providing Canada's health care decision-makers with objective evidence to help make informed decisions about the optimal use of drugs, medical devices, diagnostics, and procedures in our health care system.

Funding: CADTH receives funding from Canada's federal, provincial, and territorial governments, with the exception of Quebec.

Questions or requests for information about this report can be directed to **requests@cadth.ca**.

Table of Contents

Key Messages

- Heating, ventilation, and air conditioning (HVAC) systems are a common and important part of building operations for both health care and non-health care settings, including schools and workplaces.
- More robust, published, peer-reviewed evidence is needed in order to provide recommendations about the potential role HVAC systems play in spreading and/or mitigating the risk of transmission of Severe Acute Respiratory Syndrome Coronavirus 2 (SARS-CoV-2).
- Therefore, until the evidence base suggests otherwise, the most substantial risk of transmission of SARS-CoV-2 is from close personal contact. As such, public health recommendations regarding hand hygiene, respiratory etiquette, physical distancing, wearing non-medical masks or face coverings when physical distancing is not possible, and cleaning and disinfecting surfaces and objects with appropriate and safe products and methods remain critical.

Summary

- HVAC systems are an important and common part of building operations in indoor workplaces, schools, and other health and non–health care settings.
- Air quality is important to health and wellness.
- HVAC systems impact the distribution of air and can therefore impact the transmission of airborne infectious diseases, while simultaneously decreasing risk through particle dilution, particularly in closed spaces such as elevators and "dead zones" in room corners, atria, or hallways.
- Adding air purification strategies to ventilation can further decrease risks. Natural ventilation, ultraviolet light, and photocatalytic oxidation and ionization may have roles in air purification. However, more research is needed to ensure emerging air purification options do not include harmful by-products with unintended health effects.
- A decision to alter or invest in ventilation and/or air purification systems must also consider the long-term financial and human resource commitment necessary to operate and maintain these systems in accordance with accepted standards.
- SARS-CoV-2 is found concentrated in large droplets and dispersed in small droplets or aerosols. The larger the droplet, the greater the response to gravity, falling near their source, and are then infectious to others through close contact and surface contact. Aerosols may travel farther distances and stay diluted and suspended in the air for a period of time, and the significance of their role is an active area of study and debate.
- Evidence about SARS-CoV-2 specifically and modes of transmission is evolving and still only measurable in months. More robust, published, peer-reviewed evidence will help clarify the potential role that HVAC systems play in mitigating the risk of the virus's transmission and provide more concrete evidence-based recommendations. A significant amount of the available evidence comes from studies in experimental laboratories and may not necessarily mimic what is seen in clinical practice or for infectious disease pathways. Moreover, many studies are being published as preprints that are awaiting peer-reviewed publication.

- Until the evidence base suggests otherwise, the most substantial risk of transmission of SARS-CoV-2 is from close personal contact. As such, public health recommendations regarding hand hygiene, respiratory etiquette, physical distancing, wearing non-medical masks or face coverings when physical distancing is not possible, and cleaning and disinfecting surfaces and objects with appropriate and safe products and methods remain critical.

Question 1: Airflow Transmission of COVID-19 From HVAC Systems

- Transmission via aerosols remains unproven but theoretically possible. The primary means of transmission is through large respiratory droplets in short range, with aerosol transmission only a small possibility outside of experimental models.
- SARS-CoV-2 is found concentrated in large droplets and dispersed in small droplets or aerosols. Droplets respond to gravity, falling near their source and are known to be infectious to others primarily through close contact and surface contact. Aerosols may travel farther distances and stay diluted and suspended in the air for a period of time. Several studies of SARS-CoV-2 support aerosol and large droplet airborne transmission and one study conducted in an experimental setting documented virus components at a distance of four metres (approximately 13 feet). Further research is needed.
- There is a need for ongoing research to better evaluate and understand conditions that affect airborne horizontal transmission of infectious diseases in order to inform physical distancing recommendations.
- The question of how heat stress impacts personal and social behaviours such as mask wearing and face touching remains unaddressed but is relevant to HVAC systems.
- To date, there is no clear evidence of SARS-CoV-2 transmission associated with HVAC systems in hospitals or health care facilities.
- Studies that have identified the presence of viral ribonucleic acid (RNA) in air samples have not conclusively demonstrated that this route of transmission would be capable of infecting susceptible hosts.
- Both large droplets and aerosols are influenced by air currents. Therefore, HVAC systems may influence the spread of the virus, but are more likely beneficial as they would dilute the concentration of SARS-CoV-2.

Question 2: Airflow Transmission of Non–SARS-CoV-2 Pathogens Associated With HVAC Systems

- There is limited evidence available to determine minimum ventilation standards in either hospital or non-hospital environments. This review was based on non-SARS-CoV-2 infections; thus, external validity may come into question.
- There have been associations drawn between the transmission of infectious diseases (i.e., measles, tuberculosis, chickenpox, influenza, smallpox) and airflow ventilation patterns in indoor environments.

Question 3: Ventilation of Indoor Spaces

- HVAC systems are highly complex and integrated. Careful consideration of evidence from experts in engineering, structural systems, and other essential utility technical components is important in determining their use in public indoor settings.

- Based on other infectious disease models such as tuberculosis, there is a lower risk of the transmission of airborne particles (specific to SARS-CoV-2) in outdoor settings versus indoor settings.
- Air movement, in general, in public spaces caused by walking, physical movement, door opening, and so forth may play a role in the spread of some infectious diseases.
- Closed environments with limited or no airflow may be more conducive to the spread of airborne infectious diseases.

Question 4: Evidence Specific to Ventilation Fans and Air Conditioning

- Although not SARS-CoV-2 specific, exhaust air should be discharged directly to the outdoors and not recirculated to other areas in health care facilities.
- Office and public space humidity values should be maintained to within a range that limits microbial growth.
- Decreased ventilation rates are associated with increased infectious illnesses.
- These recommendations may be applied to non–health care facilities.

Question 5: Other Guidance — Fans, Filters, and HVAC

- Several national and international guidelines have provided recommendations for reducing airborne transmissions in business operations.
- Ventilation alone is likely not enough to eliminate all risk; there is a need for a combination of ventilation and air purification to obtain significant assured prevention of the spread of SARS-CoV-2.
- Natural ventilation, ultraviolet light, and photocatalytic oxidation and ionization may have roles in air purification, although the extent of the impact on the potential transmission of SARS-CoV-2 is uncertain.
- The extent to which temperature, humidity, and air flow patterns (including wind) affect transmission is uncertain.

Purpose and Context

In May 2020, CADTH received a request for evidence on airflow transmission of SARS-CoV-2 and the risks associated with the use of HVAC systems.

Questions

1. What is known about airflow transmission of SARS-CoV-2 and risks of transmission attributable to HVAC systems?
2. What is known about airflow transmission of coronaviruses and risks of transmission due to air cooling, air heating, and air circulation from HVAC systems?
3. Is there a scientific evidence basis for actively encouraging the ventilation of indoor spaces?
4. Is there a scientific evidence basis for actively encouraging or discouraging the use of fans or air conditioners?
5. What guidance is being provided in other jurisdictions with respect to HVAC systems?

Methods

CADTH examined the evidence pertaining to these five questions using three approaches:

- a targeted literature review
- multidisciplinary expert panel–recommended evidence
- a multidisciplinary panel discussion.

Targeted Literature Review

A limited literature search was conducted by an information specialist in the following resources: MEDLINE, PubMed, Cumulative Index to Nursing and Allied Health Literature (CINAHL), Scopus, and websites of selected Canadian and international health resources on COVID-19, as well as a focused internet search. Preprints (preliminary reports, not peer reviewed) were also searched. The search strategy was comprised of both controlled vocabulary, such as the National Library of Medicine's MeSH (Medical Subject Headings), and keywords. The main search concepts were "HVAC systems" and "coronavirus." The search was completed on June 3, 2020. No filters were applied to limit the retrieval by study type. The search was limited to English- and French-language documents, but it was not limited by publication date.

Key literature from scientific evidence, clinical guidelines, recommendations, national standards, and guideline groups that were directly relevant to the requestor's questions were included. Bibliographic searches were not conducted. After de-duplicating search results from the four databases, 214 unique articles were retrieved, as well as 131 grey literature links.

Members from CADTH's Implementation Support and Knowledge Mobilization team screened the literature and selected those deemed to be of high quality and relevant to the questions posed for this report. Literature was reviewed but not critically appraised. Members from CADTH's Implementation Support and Knowledge Mobilization team and CADTH's COVID-19 taskforce provided a brief interpretation for each source to assist the reader. A draft report was then produced, which identified key messages and evidence to respond to the questions.

Multidisciplinary Expert Panel — Recommended Evidence

Given the complexity of the current evidence base, and the need to evaluate literature and expertise from a variety of disciplines, including fluid dynamics and engineering, CADTH convened a multidisciplinary ad hoc panel to provide additional context and insight. This panel included individuals with expertise in mechanical engineering, fluid dynamics, infectious diseases, epidemiology, public health, medical microbiology, and policy. Its members were identified from published evidence and reports, as well as recommendations from organizations and leaders in the topic areas. To be considered as a panel member, individuals had to be working or volunteering at a leadership level in a Canadian academic institution or organization; and have published or have demonstrable insight into the science of transmission, use of HVAC systems, and/or implementation of measures to potentially mitigate transmission risk through HVAC systems. The final slate of panel members reflected the intent for balance in representation across a range of relevant disciplines, Canadian geography, and gender, and consisted of individuals with expertise in fluid dynamics (N = 3), engineering (N = 3), medical microbiology (N = 1), infectious diseases (N = 1), and public health (N = 1). Additional members in the latter three categories, as well as those with expertise in epidemiology and policy, were unable to participate. The final multidisciplinary expert panel was formed in July 2020 and provided input up to August 10, 2020.

Panel members were asked to provide feedback on the CADTH draft report through each discipline's lens of expertise to verify or challenge the observations and conclusions in the report, recommend additional essential literature, and to identify any risk-mitigation strategies that had not been addressed in the draft report. The draft report was revised to incorporate any appropriate references provided by the expert panel. A full list of supplemental references is available upon request.

Multidisciplinary Panel Discussion

Panellists were asked to identify issues they wished to raise for consideration during a single interactive two-hour panel teleconference held on August 21, 2020. The panel teleconference was structured to allow each individual panel member to present pre-identified issues, and then all panel members engaged in a discussion. A summary of the key discussion points raised during this meeting can be found in Appendix B.

A summary of the input received, merged with the original report, is outlined, by question, in the tables that follow (updated August 28, 2020).

Results

Question 1: Airflow Transmission of COVID-19 From HVAC Systems

Scientific evidence	• A systematic review by Bahl of original research published in English in science, medical, and non-medical journals examining the horizontal spread of respiratory droplets was conducted.[1] • In that review, 10 out of 393 initially identified papers met the inclusion criteria, of which nine were published in or after 2006 (note that an open data strategy was used in the search); seven used experimental or modelling approaches to determine horizontal spread, and all included horizontal distances of six to 26 feet. • Results indicated that there was limited scientific data to inform spatial separation guidelines, which are current assumed physical distance guidelines for SARS-CoV-2. Some data indicate that SARS-CoV-2 can travel at least four metres (13 feet), which is twice the generally assumed safe physical distance, although this is solely through a theoretical model and has not been humanized. • Given the likelihood that transmission may be affected by large droplets and airborne routes, the authors support a precautionary approach to minimize horizontal transmission. • The limitations of the evidence base include both insufficient epidemiologic and simulation studies in the area of infections generally and with respect to transmission of SARS-CoV-2 specifically, inconsistent classification of relevant terms and measures (e.g., “droplet”), lack of evidence, and lack of focus on the effects of ventilation, humidity, and temperature are also acknowledged by the authors as limitations of the evidence base. • Correia and colleagues recognize that studies are warranted to confirm their hypotheses regarding airborne transmission of the virus in HVAC systems.[2] **Interpretation: Several studies of SARS-CoV-2 hypothesize airborne transmission. Evidence suggests infections cannot neatly be separated into the dichotomy of droplet versus aerosol transmission routes. Available studies show that SARS-CoV-2 can be detected in the air for as long as three hours post-aerosolization. Authors suggest the need for ongoing research to better evaluate and understand conditions that enhance the possibility of airborne horizontal transmission in order to inform physical distancing recommendations.**
Guidelines and standards	Four national societies (including one in engineering and one in filtration) have provided guidelines on HVAC and virus transmission. • The American Society of Heating, Refrigerating and Air-Condition Engineers (ASHRAE) is a membership-based organization with a presence in more than 132 nations. Its focus includes building resilient buildings and communities and addressing indoor environmental quality by providing standards and guidance in the areas of heating, ventilation, air conditioning and refrigeration. • In a 2020 Emerging Issues brief about the COVID-19 pandemic and airborne transmission, ASHRAE reinforces the importance of identifying and understanding the effectiveness of engineering interventions to minimize the spread of COVID-19.[3] The brief highlights the organization’s position on the airborne transmission of SARS-CoV-2: • Airborne exposure to SARS-CoV-2 is likely and therefore should be controlled. Specific recommendations regarding control are not documented in this reference but are discussed in other ASHRAE technical and training documents. • Changes to building and HVAC operations can reduce airborne exposure risk. • ASHRAE has also created a position paper on infectious aerosols.[4]

	• The National Air Filtration Association (NAFA) published a 2020 COVID-19 and Air Filtration FAQ document which indicates that HVAC systems can be part of an overall strategy to mitigate the risk of COVID-19.[5] • The document notes a potential difference in effectiveness to remove viruses and other particles based on the efficiency of the filter. Though current evidence does not allow for specific recommendations, the report suggests that low-efficiency filters are unlikely to affect transmission while properly installed higher efficiency filters may. The type of filter is critical to risk reduction. • Public Services and Procurement Canada has created a report on minimum HVAC requirements.[6] The document provides guidance on operating and maintaining HVAC systems to ensure healthy work environments. **Interpretation: Appropriate installation and maintenance are required to ensure that HVAC systems operated optimally in order to decrease the impact of air filtration on the transmission of airborne infectious diseases. Multiple engineering controls (e.g., reducing airborne concentration), whether used alone or in combination, are discussed, as well as the limited evidence to support their effectiveness in reducing risks of infection from pathogens such as SARS-CoV-2. Disabling HVAC systems is not recommended to reduce the transmission of SARS-CoV-2, as low-ventilated air space can allow the concentration of the virus to increase.**
Additional evidence and resources	• A May 2020 Rapid Evidence Report produced by Alberta Health Services (AHS)[7] provides a set of expert committee observations and recommendations about the transmissibility of SARS-CoV-2 or similar viruses through HVAC systems. • The review identified 80 abstracts, of which 24 were retrieved and reviewed. Among those articles included three guidance documents from US-, European-, and UK-based HVAC or engineering groups; two systematic reviews of the literature relating to ventilation and airborne transmission of airborne infectious diseases indoors; one study measuring levels of viral RNA in two Wuhan hospitals during the pandemic; three surface testing studies conducted in a Wuhan hospital, 25 sites in Singapore, and at the US National Quarantine Unit in Nebraska, US; as well as three studies conducted in a restaurant and municipalities in China and a call centre in South Korea. • The report, which was subject to an expert committee discussion and external expert review, offers key messages and practical considerations, identifies research gaps, and offers three specific recommendations. **Interpretation: Based on their reviews to date, authors reported no clear evidence of transmission of SARS-CoV-2 associated with HVAC systems in hospitals or health care facilities, although the mechanistic possibility of this occurring cannot be dismissed. The studies that were included in the AHS review and that have identified the presence of viral RNA have not demonstrated that the virus would be capable of infecting susceptible hosts; however, viral culture may be relatively insensitive. The report noted that there is a lack of data on viable virus in air samples in different HVAC systems as studies have not considered and evaluated all HVAC configurations and their potential for infection transmission. The authors report that epidemiologic studies have not measured the role of ventilation systems, ventilation rates, and their effect on viral load.**

AHS = Alberta Health Services; ASHRAE = American Society of Heating, Refrigerating and Air-Conditioning Engineers; FAQ = frequently asked questions; HVAC = heating, ventilation, air conditioning; NAFA = National Air Filtration Association; RNA = ribonucleic acid.; SARS-CoV-2 = severe acute respiratory syndrome coronavirus 2.

Question 2: Airflow Transmission of Non–SARS-CoV-2 Pathogens Associated With HVAC Systems

Scientific evidence	
	• Li and colleagues[8] examined the role of ventilation in the airborne transmission of infectious agents in buildings based on a review of the scientific literature from 1960 to 2005. • The main goals were to determine whether there was an association between the spread of airborne infections and airflow patterns AND whether there was any good evidence or data supporting ventilation requirements that could minimize the transmission of airborne infectious diseases in different environments. After screening, 40 original studies were eligible for the review. • A multidisciplinary panel of experts in epidemiology, medicine, and engineering reviewed the studies on quality of the design, parameters, and outcomes. They focused on ventilation rates and airflow patterns. • A total of 25% of the studies supported a direct relationship between airflow and transmission, 30% were inconclusive, and 45% showed no relationship. • Expert input from CADTH's HVAC panel indicated that most filters become more efficient the longer they are used ensuring the flow is not compromised. **Interpretation: Based on the review, the authors report an association between the transmission of infectious diseases (i.e., measles, tuberculosis, chickenpox, influenza, smallpox) and airflow ventilation patterns in indoor environments. There was, however, limited evidence available to determine minimum ventilation standards in either hospital or non-hospital environments. This review was based on non-SARS-CoV-2 infections; thus, external validity may come into question.** • Liu and colleagues[9] conducted a literature review examining methods for controlling contamination of HVAC systems. • The investigators critically reviewed studies with characteristics around antimicrobial distribution, growth, and reproduction, and their impact on aerosol transmission. • The authors identified possible contamination risks related to filters (e.g., humidity, thickness, water retention) and airducts (e.g., materials, composition, particle weight), and provided information on characteristics. • Other possible contamination sites included heat exchangers, fan coils, and cooling water systems. • Evidence on purification technologies, such as microwave sterilization, UV sterilization, or adsorption, were reviewed and evidence showed that they should be used as adjuncts to HVAC systems. • The study also identified specific environmental conditions around temperature ranges and humidity levels, which play a role in controlling contamination. • This study provided many recommendations related to purification and contamination risks. **Interpretation: Some air purifiers were reported to reduce the exposure to infectious aerosols, thereby reducing the overall household infection risk. When used, filters should be thoroughly disinfected, or collected and disposed of as medical waste. The optimal frequency of replacing filters is unknown but suggested to be higher than in ordinary use. Air purifiers should be used as adjunct to other HVAC mitigation strategies.**

	• Luongo and colleagues[10] conducted a literature review of the role of mechanical ventilation in the airborne transmission of infectious agents. The quantity and quality of epidemiological studies and interventional studies on airborne exposure (e.g., ventilation rates) and clinical outcomes in diseases transmitted by aerosolized infections was evaluated. A total of 172 publications were found and, after a review, 13 were found to have both exposure variables and outcomes. The most common exposure variable was ventilation rate. Different building types were included (e.g., schools, correction facilities, hospitals, army barracks). • Most studies showed increased transmission of airborne pathogens with closer proximity to the infected patient with transmission of SARS; low outdoor ventilation was associated with more respiratory infections in different groups and environments (e.g., crowded college dormitories, increased respiratory illness in crowded army barracks). **Interpretation: Results showed that decreased ventilation rates were associated with increased infectious illnesses. There was insufficient evidence to determine how mechanical ventilation affects airborne transmission.**
Guidelines and standards	ASHRAE recently published (April 14, 2020) a position statement on mitigation strategies for airflow transmission.[4] • This position statement provides a comprehensive assessment of the strategies and quality of evidence assessment for hospitals, health care settings, and non–health care settings. • Overall, the document includes information on how to reduce the risk of infection through design, installation, and operation of HVAC and Non-HVAC systems across different building types and in environments. Recommendations are rated by ASHRAE by quality of the evidence. ASHRAE provided several high-quality, strongly rated recommendations across a number of building types and environments. For hospitals: • Provide effective flow paths for airborne articles and appropriate cleaning systems (buildings and transportation vehicles). • Include anterooms in the design of airborne infection isolation rooms, when there is a significant risk of transmission (hospital setting). • Single-space high-efficiency filtration units have been shown to be highly effective in lowering infectious aerosol concentrations and controlling airflow to the bedside (hospital setting). Filtration will not stop all transmission. • UVGI light that inactivates or kills microorganisms has been approved as an adjunct to filtration in the reduction of tuberculosis (hospital setting). Some general strategies for non–health care buildings highlighted in the report include: • continuous running of systems; increasing outdoor air ventilation • temperature and humidity maintenance based on infectious aerosol • improve filtration to the highest level achievable (e.g., MERV 13) • add portable room air cleaners with filters (e.g., high-efficiency particulate air [HEPA] or high Minimum Efficiency Reporting Values [MERV]) • add adjunct UVGI devices to high-density spaces (e.g., shelters, waiting rooms, prisons).

	Finally, ASHRAE opposes advice to stop running residential or commercial HVAC systems. The previously noted proper mitigation strategies mentioned can help control the spread of the virus in different environments. **Interpretation: HVAC, if properly managed and operated, and used in conjunction with filtration, can reduce the airborne concentration of certain pathogens; this could possibly be extrapolated to SARS-CoV-2 and the risk of aerosolized transmission. Mitigation strategies include ventilation, filtration, temperature and humidity control, air distribution, and disinfection.**

ASHRAE = American Society of Heating, Refrigerating and Air-Conditioning Engineers; HEPA = high-efficiency particulate air; HVAC = heating, ventilation, air conditioning; MERV = Minimum Efficiency Reporting Values; SARS = severe acute respiratory syndrome; SARS-CoV-2 = severe acute respiratory syndrome coronavirus; UVGI = ultraviolet germicidal irradiation.

Question 3: Ventilation of Indoor Spaces

Scientific evidence guidelines and standards	• A 2005 Ontario Health Technology policy assessment[11] focused on the administrative option (i.e., engineering methods such as HVAC) to modify the concentration of breathable infectious pathogens in room air with the then new technology: in-room air cleaner. Among others, it aimed to answer for in-room air cleaners: when to use, how effective they are, and whether adding UVGI to HEPA is more effective than HEPA alone. • On the question of "When" to use, the authors rationalized that for airborne transmission (e.g., spread of infectious pathogens) consideration of the relative size of the vehicle is key (i.e., small drops [droplet nuclei: remains suspended in the air for hours and are carried on currents over distances] versus large drops [droplet: larger than droplet nuclei, therefore travel shorter distance before falling out of the air onto the ground]) as those pathogens spread by droplet (e.g., influenza and SARS) will not be impacted by in-room air cleaners as compared to those spread by droplet nuclei (e.g., chicken pox, measles, disseminated herpes zoster). • On the question of how effective adding UVGI to HEPA is versus HEPA alone: A total of 59 identified studies were ultimately all excluded with one publication (four reported experiments) identified and included from a guidelines reference list. • Expert input from CADTH HVAC Panel indicated that the use of UVGI is not required as a properly installed and maintained HEPA filter will prevent all viruses from getting through and being circulated. **Interpretation: Uncertainty remains regarding any benefit of adding UVGI to HEPA for in-room air cleaners due in part to the low-grade quality assigned to the evidence. Therefore, it is unclear if adding UVGI to HEPA filters for in-room air cleaners decreases transmission.** • NAFA (2020): A Frequently Asked Questions document confirms there is no scientific evidence that HVAC systems are a benefit, but that some reduced exposure to SARS-CoV-2 may be assumed due to some filters removing the pathogen; however, it does not make recommendations on the filter type due to the currently unknown nature of SARS-CoV-2.[5] **Interpretation: Limited evidence is available, but adjunct filtration for airborne particles may decrease transmission.**
Additional evidence and resources	• Qian and colleagues conducted a review to determine what key elements of ventilation influence airborne infection (namely rate, flow direction, and airflow pattern). The article also notes that "natural ventilation" can deliver a large ventilation rate as noted by authors. Higher ventilation rates are preferred as they are reported to reduce risk of airborne infection; however, there is a lack of scientific evidence on the minimum ventilation rate.[12] • Wei and Li conducted a review of literature that focuses on the airborne spread of infectious agents indoors and introduces other impacts to indoor airflows. It starts with presence in mucus and follows the impact of airflows generated from bodily functions (breathing, coughing, sneezing), to room airflow, walking, and others in the environment.[13] • In a preprint article/modelling study, Nishiura and colleagues examined secondary transmission of COVID-19. In their analysis of 110 COVID-19 cases, of the 24.6% reported primary cases, the authors conclude that there were 18.7 times odds that a primary case transmitted SARS-CoV-2 in a closed versus an open-air environment.[14] • One study reported on the transport of saliva droplets produced by coughing in a calm indoor environment.[15]

	• In addition, some very recent studies in Belgium and the Netherlands deal directly with COVID-19 on fluctuations in concentrations of the virus.[16 17] • Some questions and answers on this topic are available.[18] • A number of books, reports, and opinion pieces provide guidance and reflections regarding filtration for air-cleaning systems, and have been created to protect and understand building environments for airborne pathogens.[19-32] **Interpretation: Additional articles support the importance of airflow on airborne pathogen spread and the idea of increased airborne pathogen transmission indoors versus outdoors, including global recommendations and information on protecting building environments.**
Emerging guidance documents	The National Collaborating Centre for Environmental Health recently provided guidance on air and surface disinfection measures.[33] In a recent preprint, Horve and colleagues identified SARS-CoV-2 RNA in health care HVAC settings. Investigators studied whether SARS-CoV-2 was detectable in different health care settings. Results showed that SARS-CoV-2 RNA was present in 25% of samples from nine HVAC locations. Samples were not evaluated for viral infectivity.[34] **Interpretation: SARS-CoV-2 RNA has been shown to be found in HVAC systems in health care settings. However, samples were not evaluated for viral infectivity and more research is needed to evaluate the risk of SARS-CoV-2 transmission via HVAC systems.**

HEPA = high-efficiency particulate air; HVAC = heating, ventilation, and air conditioning; NAFA = National Air Filtration Association; RNA = ribonucleic acid; UVGI = ultraviolet germicidal irradiation; SARS-CoV-2 = severe acute respiratory syndrome coronavirus 2.

Question 4: Evidence Specific to Ventilation Fans and Air Conditioning

Scientific evidence	There are several papers examining the potential re-ingestion of exhaust into the HVAC system of a building or an adjacent building. A critical parameter seems to be, for design purposes, observing the minimum distance between HVAC outlets and inlets.[16,17]
Guidelines and standards	• A review of the CSA (2019)[35] found no SARS-CoV-2 or coronavirus-specific information on evidence related to ventilation fans and air conditioning. However, there is guidance on technical requirements that are specific to health care facilities. The combination of CSA standards (Z317.2:19 and Z8000-18) as they apply to HVAC requirements for single-bedded patient rooms has been shown to significantly reduce the transmission of infectious elements. • Technical requirements to reduce the risk of infection transmission among patients, staff, and visitors described in this report include design requirements, construction guidance, and continuity of systems. • ASHRAE offers COVID-19 building readiness and re-opening guidance that was created by the ASHRAE Epidemic Task Force in 2002.[36] This document provides guidance on mitigating potential health risks that could develop when re-opening buildings, such as operating exhaust fans and using HVAC programming to provide air flushing two hours before and after occupancies. • Expert input from CADTH's HVAC panel noted that HEPA filters need to be verified annually for laboratories and other settings. Filter replacement is to occur when the conditions of the air and filter dictate; for example, a pressure drop increase above the limit, with 10 years as the maximum lifespan. **Interpretation: Although not SARS-CoV-2 specific, recommendations for health care facilities are that exhaust air should be discharged directly to the outdoors and not be recirculated to other areas. HEPA filters, when necessary, must be located downstream of the containment source and must be monitored for pressure drop for replacement; office and public space humidity values should be maintained within a range that does not encourage microbial growth.** **These recommendations may be applied to non–health care facilities, as well.**
Additional evidence and resources	• On June 18, 2020, ASHRAE hosted a webinar on managing SARS-CoV-2 and HVAC.[37] It included technical information on HVAC systems and how to manage SARS-CoV-2, and was targeted specifically for government officials and policy-makers. This webinar provided technical information on risk assessment, management, and commercial building design to decreased transmission. It also focused on how to navigate HVAC system operations in several environments, including health care facilities. • Recent reports discuss topics and solutions for indoor sports. Blocken and colleagues discuss whether and how indoor sports could be continued during COVID-19, provide some guidance on how and when to open these facilities,[38,39] and provide a questions and answers document.[18]

ASHRAE = American Society of Heating, Refrigerating and Air-Conditioning Engineers; CSA = Canadian Standards Association; HEPA = high-efficiency particulate air; HVAC = heating, ventilation, and air conditioning; SARS-CoV-2 = severe acute respiratory syndrome coronavirus 2.

Question 5: Other Guidance — Fans, Filters, and HVAC

Guidelines and standards	
	• Ontario's Occupational Health and Safety Act is a key piece of legislation meant to protect the health and safety of workers. It establishes procedures for ensuring protection against workplace hazards and provides enforcement mechanisms for when voluntary compliance with the Act cannot be achieved. The provisions of the Act not only apply during COVID-19, and are of paramount importance for the health and safety of workers.[40] • The US Department of Labour Guidance for Preparing Workplaces for COVID-19 recommends several specific engineering controls to protect workers from SARS-CoV-2 infection. These include "installing high-efficiency air filters, increasing ventilation rates in the work environment, installing physical barriers such as clear plastic sneeze guards, installing drive through windows for customer service, and use of specialized negative pressure ventilation in some settings, such as for aerosol generating procedures."[41] • A European Federation of Heating, Ventilation and Air Conditioning Association's interim living guidance document is designed to help prepare workplaces in areas with a COVID-19 outbreak.[42] It is designed to supplement WHO guidance on the same topics and is intended for use in public and commercial buildings where exposure to individuals infected with SARS-CoV-2 is occasionally possible. The report addresses: routes of transmission (including fecal-oral) and recommendations to limit transmission (e.g., avoiding dried-out floor drains and potential exposure to droplets when fecal matter is flushed), and provides eight practical building maintenance and operations recommendations (e.g., increasing air flow and ventilation, potential use of in-room air-cleaning systems, maintaining standard humidification and air conditioning settings, and avoiding air recirculation during COVID-19 outbreaks) and 14 additional practical measures. • In one of several Annexes to the WHO interim guidance document regarding the management of public health and social measures, developed in consultation with a branch of the International Labour Organization, workplace prevention of COVID-19 in non–health care workplaces is addressed. This specific annex proposes a categorization of low (e.g., minimal occupational contact with coworkers or public), medium (e.g., close and frequent contact with coworkers or public), and high (close contact with known or suspect COVID-19 patients or contaminated occupational settings) exposure risk roles and tasks; specific strategies by exposure category; and expectations of workers and employers.[43] • The US Centers for Disease Control and Prevention guidance document for businesses and employers in non–health care settings (most recently updated on May 6, 2020) includes recommendations for employers, including resumption of normal or phased-in business operations. The report includes practical recommendations for employers to reduce the transmission of SARS-CoV-2 among employees (e.g., regular hazard assessment, daily in-person or virtual health checks, prompt separation of sick and well employees) and options to address business continuity and healthy business policy (e.g., policies to support sick employees to stay home, staggered hours to accommodate commutes during less busy transit times), as well as engineering, administrative, and individual PPE controls (e.g., select, provide, and train workers on appropriate use of PPE) to minimize the risk of virus transmission in the workplace.[44] **Interpretation: Several national and international guidelines have provided recommendations for reducing transmissions in business operations. These recommendations include engineering and administrative controls, as well as universal measures for good infection prevention and control (e.g., social distancing, hand hygiene).**

Additional evidence and resources	• A peer-reviewed column in the ASHRAE Journal highlights several building operation infection prevention and control measures, as well as additional HVAC-specific modifications, including to increase the degree of outdoor air ventilation, disable outdoor air dampers, increase the degree of central air filtration (MERV 13 or the highest compatible with the filter rack), and consider portable room air cleaners with HEPA filters.[45]

ASHRAE = American Society of Heating, Refrigerating and Air-Conditioning Engineers; HEPA = high-efficiency particulate air; HVAC = heating, ventilation, and air conditioning; PPE = personal protective equipment; SARS-CoV-2 = severe acute respiratory syndrome coronavirus 2.

References

1. Bahl P, Doolan C, de Silva C, Chughtai AA, Bourouiba L, MacIntyre CR. Airborne or droplet precautions for health workers treating COVID-19? *J Infect Dis.* 2020.
2. Correia G, Rodrigues L, Gameiro da Silva M, Gonçalves T. Airborne route and bad use of ventilation systems as non-negligible factors in SARS-CoV-2 transmission. *Med Hypotheses.* 2020;141:109781.
3. ASHRAE Environmental Health Committee. Pandemic COVID-19 and airborne transmission. *Environmental Health Committee (EHC) Emerging Issue Brief*. Atlanta (GA): The American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE); 2020 Apr 17: https://www.ashrae.org/file%20library/technical%20resources/covid-19/eiband-airbornetransmission.pdf. Accessed 2020 Jun 22.
4. ASHRAE position document on infectious aerosols. Atlanta (GA): The American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE); 2020 Apr 14: https://www.ashrae.org/file%20library/about/position%20documents/pd_infectiousaerosols_2020.pdf. Accessed 2020 Jun 22.
5. National Air Filtration Association (NAFA). COVID-19 (corona virus) and air filtration frequently asked questions (FAQs). [2020]; https://www.nafahq.org/covid-19-corona-virus-and-air-filtration-frequently-asked-questions-faqs/. Accessed 2020 Jun 22.
6. Heating ventilation and air conditioning (HVAC) minimum requirements – (COVID-19). Ottawa: Public Services and Procurement Canada (PSPC); 2020 Apr 22: https://wiki.gccollab.ca/images/5/56/PSPC_Communique_-_Heating_Ventilation_and_Air_Conditioning_System_Requirements_-_COVID-19_-_April_22_2020.pdf. Accessed 2020 Aug 21.
7. COVID-19 Scientific Advisory Group. Risk of transmission from HVAC systems. *(Rapid evidence report)*. Edmonton (AB): Alberta Health Services; 2020 Jun 5: https://www.albertahealthservices.ca/assets/info/ppih/if-ppih-covid-19-sag-risk-transmission-hvac-systems-rapid-review.pdf. Accessed 2020 Jun 22.
8. 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.
9. Liu Z, Ma S, Cao G, Meng C, He B. Distribution characteristics, growth, reproduction and transmission modes and control strategies for microbial contamination in HVAC systems: a literature review. *Energy Build.* 2018;177:77-95.
10. Luongo JC, Fennelly KP, Keen JA, Zhai ZJ, Jones BW, Miller SL. Role of mechanical ventilation in the airborne transmission of infectious agents in buildings. *Indoor Air.* 2016;26(5):666-678.
11. Medical Advisory Secretariat. Air cleaning technologies: an evidence-based analysis. *Ont Health Technol Assess Ser.* 2005;5(17):1-52. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3382390/pdf/ohtas-05-52.pdf. Accessed 2020 Jun 22.
12. Qian H, Zheng X. Ventilation control for airborne transmission of human exhaled bio-aerosols in buildings. *J Thorac Dis.* 2018;10(Suppl 19):S2295-S2304.
13. Wei J, Li Y. Airborne spread of infectious agents in the indoor environment. *Am J Infect Control.* 2016;44(9 Suppl):S102-108.
14. Nishiura H, Oshitani H, Kobayashi T, et al. Closed environments facilitate secondary transmission of coronavirus disease 2019 (COVID-19) **[non peer-reviewed preprint]**. *medRxiv.* 2020:doi: 10.1101/2020.1102.1128.20029272. https://www.medrxiv.org/content/10.1101/2020.02.28.20029272v2. Accessed 2020 Jun 22.
15. Zhu S, Kato S, Yang J-H. Study on transport characteristics of saliva droplets produced by coughing in a calm indoor environment. *Build Environ.* 2006;41(12):1691-1702.
16. Tominaga Y, Stathopoulos T. Steady and unsteady RANS simulations of pollutant dispersion around isolated cubical buildings: Effect of large-scale fluctuations on the concentration field. *Journal of Wind Engineering and Industrial Aerodynamics.* 2017;165:23-33.
17. Tominaga Y, Stathopoulos T. Ten questions concerning modeling of near-field pollutant dispersion in the built environment. *Build Environ.* 2016;105:390-402.
18. Blocken B, Marchal T. Towards aerodynamically equivalent COVID-19 1.5m social distancing for walking and running: questions and answers. [unknown place]: [unknown publisher]; [2020]: http://urbanphysics.net/Questions_and_Answers.pdf. Accessed 2020 Aug 21.
19. Anderson EL, Turnham P, Griffin JR, Clarke CC. Consideration of the Aerosol Transmission for COVID-19 and Public Health. *Risk Anal.* 2020;40(5):902-907.
20. Institut National de Sante Publique du Quebec. COVID-19: Indoor Environment. *(Version 1.1)* 2020 May 6; https://www.inspq.qc.ca/en/publications/2992-indoor-environment-covid19. Accessed 2020 Aug 21.
21. Environmental Health (EH) Research Scan: COVID-19 Special Issue. Vol 4 (5). Vancouver (BC): National Collaborating Centre for Environmental Health; 2020 May 9-Jun 3: https://ncceh.ca/sites/default/files/NCCEH%20Research%20Scan%20-202005%20May%209-Jun%203%20Covid-19%20Issue.pdf. Accessed 2020 Aug 21.
22. Guidance for filtration and air-cleaning systems to protect building environments from airborne chemical, biological, or radiological attacks. Cincinnati (OH): National Institute for Occupational Safety and Health; 2003 Apr: https://www.wbdg.org/FFC/HHS/NIOSH/NIOSH_2003_136.pdf. Accessed 2020 Aug 21.
23. Morawska L, Tang JW, Bahnfleth W, et al. How can airborne transmission of COVID-19 indoors be minimised? *Environ Int.* 2020;142:105832.
24. United States Environmental Protection Agency. Indoor Air and Coronavirus (COVID-19). [2020]; https://www.epa.gov/coronavirus/indoor-air-and-coronavirus-covid-19. Accessed 2020 Aug 21.

25. Morawska L, Milton DK. It is Time to Address Airborne Transmission of COVID-19. *Clin Infect Dis.* 2020:ciaa939.

26. Global Heat Health Information Network. Q&A: do air conditioning and ventilation systems increase the risk of virus transmission? If so , how can this be managed? 2020 May 22; http://www.ghhin.org/heat-and-covid-19/ac-and-ventilation. Accessed 2020 Aug 21.

27. World Health Organization. Q&A: ventilation and air conditioning in public spaces and buildings and COVID-19. 2020 Jul 29; https://www.who.int/emergencies/diseases/novel-coronavirus-2019/question-and-answers-hub/q-a-detail/q-a-ventilation-and-air-conditioning-in-public-spaces-and-buildings-and-covid-19. Accessed 2020 Aug 21.

28. Tellier R, Li Y, Cowling BJ, Tang JW. Recognition of aerosol transmission of infectious agents: a commentary. *BMC Infect Dis.* 2019;19(1):101.

29. Reopening America: strategies for safer buildings. *(Re-occupancy assessment tool v2.0)*. Washington (DC): The American Institute of Architects; 2020 May 28: http://content.aia.org/sites/default/files/2020-06/Reopening-America-Strategies-for-Safer-Buildings_final.pdf. Accessed 2020 Aug 21.

30. Allen J, Marr L. Re-thinking the Potential for Airborne Transmission of SARS-CoV-2 **[non-peer reviewed preprint]**. *Preprints.* 2020:2020050126. https://www.preprints.org/manuscript/202005.0126/v1. Accessed 2020 Aug 21.

31. Eykelbosh A. Role of ventilation in influencing COVID-19 transmission risk. *Vancouver (BC): National Collaborating Centre for Environmental Health;* 2020 Jul 29; https://ncceh.ca/content/blog/role-ventilation-influencing-covid-19-transmission-risk. Accessed 2020 Aug 21.

32. Arav Y, Klausner Z, Fattal E. Understanding the indoor pre-symptomatic transmission mechanism of COVID-19 **[non-peer reviewed preprint]**. *medRxiv.* 2020:2020.2005.2012.20099085. https://www.medrxiv.org/content/medrxiv/early/2020/05/17/2020.05.12.20099085.full.pdf. Accessed 2020 Aug 21.

33. Chen T, O'Keeffe J. COVID-19 in indoor environments — Air and surface disinfection measures. Vancouver (BC): National Collaborating Centre for Environmental Health; 2020 Jul 29: https://ncceh.ca/documents/guide/covid-19-indoor-environments-air-and-surface-disinfection-measures. Accessed 2020 Aug 21.

34. Horve PF, Dietz L, Fretz M, et al. Identification of SARS-CoV-2 RNA in healthcare heating, ventilation, and air conditioning units **[non-peer reviewed preprint]**. *medRxiv.* 2020:2020.2006.2026.20141085. https://www.medrxiv.org/content/medrxiv/early/2020/06/28/2020.06.26.20141085.full.pdf. Accessed 2020 Aug 21.

35. Canadian Standards Association. Special requirements for heating, ventilation, and air-conditioning (HVAC) systems in health care facilities [CSA Z317.2:19]. 2019: https://store.csagroup.org/ccrz__ProductDetails?viewState=DetailView&cartID=&portalUser=&store=&cclcl=en_US&sku=2701348. Accessed 2020 Jun 22.

36. American Society of Heating Refrigerating and Air-Conditioning Engineers (ASHRAE). Building readiness. 2020; https://www.ashrae.org/technical-resources/building-readiness#intent. Accessed 2020 Jun 22.

37. American Society of Heating Refrigerating and Air-Conditioning Engineers (ASHRAE). Managing COVID-19 and HVAC in buildings for emerging economies [webinar]. 2020; https://register.gotowebinar.com/register/5363351057627231504. Accessed 2020 Jun 22.

38. Blocken B, van Druenen T, van Hooff T, Verstappen PA, Marchal T, Marr LC. Can indoor sports centers be allowed to re-open during the COVID-19 pandemic based on a certificate of equivalence? *Build Environ.* 2020;180:107022.

39. Blocken B, Marchal T. Towards aerodynamically equivalent COVID-19 1.5m social distancing for walking and running **[non-peer reviewed preprint]**. [unknown place]: [unknown publisher]; [2020]: http://www.urbanphysics.net/COVID19_Aero_Paper.pdf. Accessed 2020 Aug 21.

40. Occupational Health and Safety Act, R.S.O. 1990, c. O.1 https://www.ontario.ca/laws/statute/90o01#BK9. Accessed 2020 June 22.

41. Guidance on preparing workplaces for COVID-19. Washington (DC): United States Department of Labor, Occupational Safety & Health Administration (OSHA); 2020: https://www.osha.gov/Publications/OSHA3990.pdf. Accessed 2020 Jun 22.

42. REHVA COVID-19 guidance document. Brussels (BE): Federation of European Heating, Ventilation and Air Conditioning Associations (REHVA); 2020 Apr 3: https://www.rehva.eu/fileadmin/user_upload/REHVA_COVID-19_guidance_document_ver2_20200403_1.pdf. Accessed 2020 Jun 22.

43. World Health Organization. Considerations for public health and social measures in the workplace in the context of COVID-19: annex to considerations in adjusting public health and social measures in the context of COVID-19. 2020 May 10; https://www.who.int/publications/i/item/considerations-for-public-health-and-social-measures-in-the-workplace-in-the-context-of-covid-19. Accessed 2020 Jun 22.

44. Centers for Disease Control and Prevention. Interim guidance for businesses and employers responding to coronavirus disease 2019 (COVID-19), May 2020: plan, prepare and respond to coronavirus disease 2019. 2020 May 6; https://www.cdc.gov/coronavirus/2019-ncov/community/guidance-business-response.html. Accessed 2020 Jun 22.

45. Schoen LJ. Guidance for building operations during the COVID-19 pandemic. *ASHRAE Journal.* 2020. https://www.ashrae.org/file%20library/technical%20resources/ashrae%20journal/2020journaldocuments/72-74_ieq_schoen.pdf. Accessed 2020 Jun 22.

Appendix A: Multidisciplinary Expert Panel

Dr. Nasser Ashgriz
PhD
Professor
University of Toronto

Mr. Gordon Burrill
PEng, CCHFM, FASHE,
CHFM, CHC
President
Teegor Consulting Inc.

Dr. Zain Chagla
MD, MSc, DTMH
Associate Professor
McMaster University

Dr. Alejandra Dubois
PhD
Senior Policy Analyst
Public Health Agency of Canada

Dr. Jason Kindrachuk
PhD
Assistant Professor
Canada Research Chair
University of Manitoba

Dr. Artem Koronbenko
PhD
Assistant Professor
University of Calgary

Dr. Theodore Stathopoulos
DCE, MESc, PhD
Professor
Concordia University

Mr. Joe Tanelli
BME
Chief Biocontainment Engineer
Public Health Agency of Canada

Dr. Lexuan Zhong
PhD
Assistant Professor
University of Alberta

Appendix B: Key Messages From Panel Discussion

- The science is evolving; the relationship between HVAC and transmission of SARS-CoV-2 is complex and, at present, unclear.
- SARS-CoV2 is found concentrated in large droplets and dispersed in small droplets or aerosols. The larger the droplet, the greater the response to gravity, resulting in collection of the virus near the source and infections spread primarily through close contact and surface contact. Aerosols may travel farther distances and stay diluted and suspended in the air for a period of time, and the significance of their role is an active area of study and debate.
- The extent to which temperature, humidity, and air flow patterns (including wind) affect transmission is uncertain.
- SARS-CoV-2 infection appears to be spread primary by large droplets. Transmission via aerosols remains unproven but theoretically possible. Further research is needed.
- Both large droplets and aerosols are influenced by air currents. HVAC systems impact the distribution of air and can therefore impact the transmission of airborne infectious diseases, while simultaneously decreasing risk through particle dilution, particularly in closed spaces such as elevators and "dead zones" in room corners, atria, or hallways.
- Ventilation alone is likely not enough to reduce all risk; there is a need for a combination of ventilation and air purification to obtain significant assured prevention of the spread of SARS-CoV-2.
- Natural ventilation, ultraviolet light, and photocatalytic oxidation and ionization may have roles in air purification.
- A decision to alter or invest in ventilation and/or air purification systems must also consider the long-term financial and human resource commitment necessary to operate and maintain these systems in accordance with accepted standards.
- The most important way to limit the spread of SARS-CoV-2 is by following public health measures. At the time this report was written, these include hand hygiene, respiratory etiquette, physical distancing, wearing non-medical masks or face coverings when physical distancing is not possible, and cleaning and disinfecting surfaces and objects with the appropriate and safe products and methods.

Panel Discussion Summary

The discussion of fluid dynamics and engineering addressed the standards to which building design and maintenance must adhere. The organizations responsible for setting these standards include the Canadian Standards Association (CSA); the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE); the US Department of Energy; and the recommendations of the World Health Organization (WHO). The Minimum Efficiency Reporting Values (MERVs) of commercial buildings and hospitals were discussed, along with the role of high-efficiency particulate air (HEPA) filters, their installation, monitoring and appropriate replacement schedules, and potential beneficial effects.

Panel members presented thoughts on airflow and its potential effects on the transmission of SARS-CoV-2 both indoors and outdoors. Studies are currently underway to examine the effects of wind and movement on viral transmission, such as the dynamics at play when bicycles pass one another, or when one rider is travelling in another's wake. There was general agreement among panel members as to the role of ventilation as important in preventing the spread of SARS-CoV-2, and the WHO's recommendations to increase ventilation, particularly in closed spaces such as elevators and "dead zones" in room corners, atria, or hallways.

The panellists explored strategies in air purification such as filtering, using ultraviolet light, or photocatalytic oxidation and ionization. Pending further studies, preliminary findings suggest that SARS-CoV-2 may be highly susceptible to ultraviolet light exposure. The best approach remains to be determined, but there is agreement that adding air purification strategies to ventilation systems magnifies the effect of either used in isolation. However, some new and emerging technologies may include risks such as the production of toxic by-products and their unknown impacts to the environment and human health.

There is a need for communication and agreement among designers of adjacent buildings to ensure that one's HVAC system's exhaust does not contaminate another's HVAC system's fresh air intake. This may include variables such as stack size and wind conditions to avoid the phenomenon of re-entrainment. Even within the same building, such as a hospital, there can be competing demands on negative and positive pressure requirements in HVAC flow. For example, positive pressure is used in operating rooms to push microorganisms away from exposed tissues; however, this presents a problem in a patient who is positive for COVID-19 and needs surgery, especially with surgeries often including aerosol-generating procedures.

More research is needed to identify and quantify recommendations on ventilation and purification. For example, the exact recommended value of room air exchanges per hour has not been reached, nor has agreement on the effect of humidity and temperature on viral spread. Some articles have suggested that buoyancy, associated with warmer conditions, may alter the patterns of transmission of viruses. However, evaporation also increases in warm temperatures, which could possibly have a different effect on viral transmission. Recommended MERV values currently vary for different types of buildings, and where HEPA filtration is absolutely necessary remains unclear. Finally, in planning the ideal ventilation and purification system for any building, hospital, lab, and so forth, there is a need to ensure that it is attainable and maintainable both financially and with skilled personnel.

The panel participants with expertise in medical microbiology and infectious diseases addressed several of the high-profile transmission cases and what they have shown in regard to norms and exceptions. There have been both “super spreader” incidents that tend to be highlighted in the media, as well as key cases described in the literature that together show SARS-CoV-2 is spread through large droplets (close contact spread) as well as aerosols and airborne spread. However, the general pattern and most of the data support the large droplet scenario with fairly close and prolonged contact, such as is seen in cohabitating families, as the most significant type of risk. This is further supported by the studies of SARS-CoV-1, which is likely the best comparator. From these studies, it was determined there is usually a need for hundreds to thousands of infectious particles to actually seed an infection, and the aerosol end of the spectrum of transmission has many fewer infectious particles within it.

The final topic of discussion surrounded public health and the recommendations that can be made to health care professionals, facilities engineers, and the public about SARS-CoV-2 transmission risk management. There are specific populations for whom additional precautions are necessary due to procedures or vulnerabilities. There is also the acknowledgement that new and updated information is being released frequently. Based on the currently available evidence, the most substantial risk for transmission of SARS-CoV-2 is close, prolonged exposure. Therefore, public health recommendations remain vital: hand hygiene, respiratory etiquette, physical distancing, wearing non-medical face masks or face coverings when physical distancing is not possible, and cleaning and disinfecting surfaces and objects with the appropriate and safe products and methods.

The convening of the expert panel and the writing of this report has taken place within 8 months of the discovery of SARS-CoV-2. Most of the information is based on the interpretation of preliminary studies in experimental laboratories and some real-world data combined with the panellists’ knowledge of fluid dynamics, engineering, infectious diseases, and microbiology. It is anticipated that further information will be gathered in the coming months leading to a greater understanding of the epidemiology of this virus and provide for more concrete, evidence-based recommendations regarding disease transmission and prevention.