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Support Document for the Advisory Committee on COVID-19 Transmission in School and Healthcare Environments and on the Role of Ventilation

Québec

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Direction de la santé environnementale et de la toxicologie

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Note to the reader

This support document was written at the request of the Ministère de la Santé et des Services sociaux (MSSS) to support the work of the members of the group of scientific and technical experts focusing on the use of ventilation in healthcare and educational institutions during the current COVID-19 pandemic. The purpose of this document is, more specifically, to take stock of the current knowledge on the transmission of SARS-CoV-2 in building interiors and to develop a portrait of the role that ventilation in indoor environments may play in a pandemic context. As the situation and knowledge surrounding SARS-CoV-2 (COVID-19) are rapidly developing, the information provided in this document is subject to updates. This document is not an exhaustive review of the scientific literature. The technical terms used herein are those generally used by the cited authors, and the terminology used is adapted to the conventions for use defined by the Ventilation Working Group of the Institut national de santé publique du Québec (INSPQ). It is important to note that some scientific publications on COVID-19 cited in this document were published without peer review. Complete information on the methodology used to create this document is presented in Appendix 1.

Foreword

This document includes a summary of current knowledge on SARS-CoV-2 transmission, the environmental parameters that contribute to maintaining the viability of the virus indoors (temperature and relative humidity), and survival time on various surface types. The document also discusses the link between transmission of the virus and indoor air ventilation and filtration systems. The data in the scientific literature make it possible to establish key takeaways to inform occupants, users, and managers of public and private buildings of the practices to adopt in indoor spaces to minimize the risk of transmitting COVID-19. Finally, the section on SARS-CoV-2 transmission summarizes the main points of the INSPQ document entitled *SARS-CoV-2 transmission: Findings and Proposed Terminology*.

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Glossary

Note: The following definitions are intended to promote uniform language across all disciplines at the INSPQ.

Aerosols

Particles suspended in the air whose movement is primarily governed by the particle size, typically smaller than 100 µm (usually called droplets when > 5 µm), and which are inhalable and can be classified according to the anatomical location where they are deposited in the respiratory tract (Figure 1):

- Nasopharyngeal particles, which are deposited in the nose or throat (≤ 100 µm)
- Tracheobronchial particles, which are deposited in the bronchi (≤ 15 µm)
- Alveolar particles, which reach the pulmonary alveoli (≤ 5 µm), typically called droplet nuclei or microdroplets.

Asymptomatic

The state of an infected person who secretes virus and who will not develop symptoms.

Culturable

The quality of a virus being able to reproduce itself on appropriate cell cultures under the right conditions. A virus being culturable does not necessarily mean that it is infectious.

Droplets

Formerly defined as particles typically measuring more than 5 µm, now included in the definition of *aerosols*.

Drops

Particles larger than 100 µm which may be deposited directly on the mucosa (mucus membranes) of the nose, mouth, or eyes, and on surfaces or objects, following a ballistic trajectory (therefore not inhalable).

HEPA (high-efficiency particulate air)

High-efficiency air filter capable of filtering at least 99.97% of particles with a diameter of 0.3 µm or larger in one pass.

HVAC (heating, ventilation, and air conditioning system)

A system that manages air exchange between indoor and outdoor environments while heating or air conditioning as needed.

Infectivity

The ability of a pathogenic agent (such as a virus) to enter, survive in, and multiply in a host

MERV (Minimum Efficiency Reporting Value)

Scale for measuring the particle removal performance of a filter.

Particles

Small pieces of solid or liquid matter.

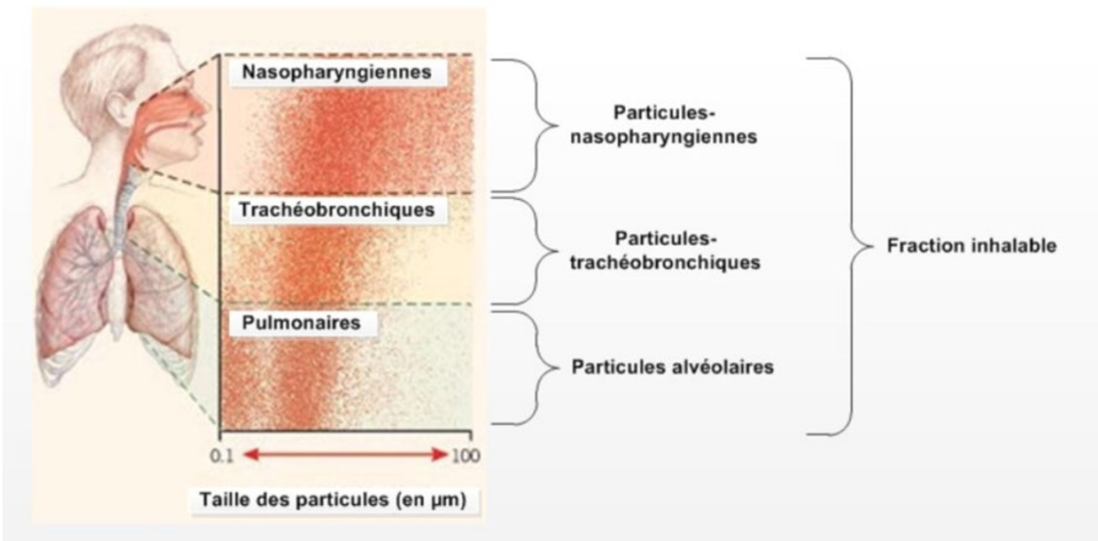
Presymptomatic

The state of an infected person who secretes virus but who has not yet developed symptoms.

Transmission The process by which a pathogenic agent is issued from a source in such a way to cause an infection in a host.

Tropism The propensity of an infectious or parasitic agent to target an organ, tissue, or type of cell.

Figure 1 Deposition regions in the respiratory tract for the various particle sizes



Adapted from Roy and Milton (2004) by the Government of Canada (2017).

Note: The figure is available in French only.

1 SARS-CoV-2 Transmission

KEY TAKEAWAYS

- SARS-CoV-2 is mainly spread through close (less than 2 metres) and prolonged (over 15 minutes) person-to-person contact.
- The available experimental and epidemiological data support transmission by aerosols in close proximity (less than 2 metres).
- The risk of SARS-CoV-2 transmission increases in closed, crowded, and inadequately ventilated spaces, and with prolonged exposure. The data show that transmission during close contact is still the main transmission route. Data also suggest that aerosol transmission can occur at some distance. The maximum distance is still unclear, but it is unlikely to exceed a few metres.
- The presence of SARS-CoV-2 RNA and of infectious virus in the air does not always imply that there has been airborne transmission, as is described for tuberculosis. At present, there is no direct proof that clearly demonstrates airborne transmission of SARS-CoV-2.

Current prevention and control recommendations for infections associated with droplet and airborne modes of transmission are based on a dichotomous approach. While this approach has proved effective in preventing and controlling transmission of infections such as influenza and tuberculosis, SARS-CoV-2 requires an approach that is better adapted to the growing body of knowledge on the dynamic aspect of aerosols, which suggests that transmission occurs on a continuum (see the model and definitions in the glossary).

1.1 The process of SARS-CoV-2 transmission and infection

For SARS-CoV-2 infection to occur, a set of close, complex connections must occur between the source of the infectious agent (microorganism), the host, and the environment. Not all exposures result in infection. Based on previous observations, the main factors in transmission and development of infection are described below. They have been grouped into the three main constituents: the emitter, the transmitter, and the receiver.

1.1.1 EMITTER

When an infected and contagious person breathes, speaks, coughs, sneezes, or sings, particles of various sizes are emitted in variable quantities. Several studies which have found viral RNA in these particles indicate that SARS-CoV-2 is excreted by the airways (Chia et al., 2020; Dumont-Leblond et al., 2020; Guo et al., 2020; Lei et al., 2020; Liu et al., 2020; Razzini et al., 2020; Zhou et al., 2020). Several studies have also found viral RNA in stool (Cheung et al., 2020), confirming that the virus can be found in the gastrointestinal system. No cases of transmission by aerosolization of fecal matter have been reported in the available data but this element remains to be clarified.

Viral shedding

The viral shedding depends on the phase of the illness. For SARS-CoV-2, a meta-analysis suggests that the viral load in the upper respiratory tract is highest when symptoms appear and for about a week thereafter, then decreases gradually over the following weeks (Walsh et al., 2020). The amount of virus excreted by the airways seems to be associated with the time when the disease is most contagious, that is, around the time symptoms appear (Cheng, et al. 2020) and two days before their onset (INSPQ, 2020c). The exact correlation between viral excretion measured by diagnostic RT-PCR and contagiousness, however, remains unclear.

Contagiousness

Asymptomatic and presymptomatic people are contagious. The exact role of particle size in contagiousness has not been determined for SARS-CoV-2. While smaller particles can better penetrate alveoli, current data does not associate this with higher SARS-CoV-2 contagiousness.

1.1.2 Transmitter

Larger particles measuring greater than 100 µm (drops) can be directly deposited on the mucus membranes of the nose, mouth, or eyes. They can also be deposited on surfaces and objects and contribute to transmission by direct contact (e.g., during a handshake) or indirectly via fomites (e.g., with a door handle as an intermediate object), although this form of transmission seems to be of little significance. Aerosols of various sizes can move around according to their aerodynamic diameter (maximum range unknown, but likely several metres).

1.1.3 Receiver

The development of an infection in an individual is influenced by many factors, several of which are introduced here.

Host

For an infection to develop, the host must be receptive. The exposed person's immunity status is thus a key factor in whether an infection occurs after an exposure. For the time being, since this is a new virus, those who have not been vaccinated and who have not contracted the disease are considered to be susceptible. The severity of the illness is influenced by the host's age as well as by any comorbidities they may have.

Tropism

Tropism of an infectious agent is defined as the preferred entryway (target tissue or cells) that will be used by the agent to infect a host. It is clear that coronaviruses need to connect to angiotensin-converting enzyme 2 (ACE2) receptors to enter the host's cells and multiply. Some cells in the nose produce a large amount of ACE2, which suggests that the nasopharyngeal mucosa could be an initial infection site. As a result, the upper respiratory tracts (nasopharynx and oropharynx) also contain the highest viral load at the onset of the illness. It seems that the virus is less inclined to colonize the distal bronchioles and the alveoli (Zhang et al., 2020).

Infectious dose

The dose required to cause an infection is currently unknown and may vary among individuals. Aerosols of various sizes can contribute to the infectious dose of COVID-19. Based on data reported by Bao et al. (2020), the United States Department of Homeland Security (DHS, 2020) reported an average equivalent of 630 to 756 culturable viral units in mice when inhaled with aerosols of less than 5.7 µm. According to a narrative literature review published by the DHS (2020), it probably takes less than 1,000 plaque-forming units (PFU) (or 1,000 culturable viral units) to infect a human. That said, the lack of a human study on the subject means that there is significant uncertainty in the estimate of the infectious dose for human beings.

As a result, transmission of the infection from a contagious individual to a susceptible one and the development of an infection in the susceptible individual are influenced by these factors combined, the contribution of which may vary from one case to the next.

2 Control measures for indoor environments

KEY TAKEAWAYS

- Applying a series of control measures regarding the transmission of SARS-CoV-2 in indoor environments at all times is recommended as a preventive measure.
- These control measures, listed in hierarchical order, are embedded in reference frameworks used by professionals in the fields of infection prevention, public health, and occupational health to establish infection-fighting measures.
- The goal of this hierarchy is to reduce the risk of transmission while organizing control methods by their applicability in population-based environments.
- This type of reference framework assumes that the measures at the top of the hierarchy are generally more effective than those on the lower levels.
- None of these categories were intended to be used alone. The various components work as a whole and offer a multi-tiered system of protection.
- This reference framework includes, in this order:
  - Measures for limiting the number and duration of contacts and for promoting physical distancing
  - Technical and engineering measures
  - Administrative measures
  - Individual protection measures

Beyond being transmitted by symptomatic individuals, COVID-19 can also be spread by asymptomatic and presymptomatic people. Since these people don't have symptoms and are difficult to identify, it is recommended to apply preventive control measures at all times in indoor environments. It's important to specify that indoor environments have environmental conditions that are typically more stable and more favourable to virus survival and are where transmission occurs most of the time. All control measures should therefore be applied simultaneously in occupied indoor environments (e.g., schools, healthcare facilities, shops, institutions, offices, etc.) to reduce the risk of COVID-19 transmission.

The "hierarchy of control" is a reference framework used by professionals in infection prevention, public health, and workplace health and safety to develop anti-infection measures (CCA, 2007). The purpose of this hierarchy is to reduce the risk of transmission by organizing control methods according to the potential efficacy of using them in certain categories (INSPQ, 2018). This kind of reference framework also maintains that the measures at the top of the hierarchy are generally more effective than those on the lower levels (Public Health Agency of Canada [PHAC], 2020; National Collaborating Centre for Environmental Health [NCCEH], 2020b; Occupational Safety and Health Administration [OSHA], 2016; Rivers et al., 2020). However, "[n]o one category is intended to be used alone; rather, each component works in conjunction with the others to provide a system of multi-layered protection" (CCA, 2007).

An example of a reference framework for the control of COVID-19 in indoor environments (for the general population) is described in Appendix 2. Likewise, a summary of the application of the hierarchy tailored to healthcare environments is presented in Appendix 3. In the reference framework that applies to managing COVID-19 in the general population, measures for minimizing the number and duration of contacts as well as distancing are at the highest level of measures against SARS-CoV-19 followed by technical and engineering measures, administrative measures, and personal protection measures. It's important to note that a certain amount of overlap is inevitable in this example of a hierarchical model given that physical distancing measures, for example, can also be applied in the implementation of technical and administrative measures (PHAC, 2020).

2.1 Measures for minimizing contacts and for physical distancing

In this reference framework, measures for minimizing the number and duration of contacts as well as promoting physical distancing are at the top of the hierarchy of control for transmission of the COVID-19 virus. Close contacts are currently considered to be the main way COVID-19 is transmitted. Close contacts in this case refers to physical, person-to-person contact with infectious particles being expelled by the contagious person (Heffernan, 2020; Federation of European Heating, Ventilation and Air Conditioning Associations [REHVA], 2020a). This is why minimizing the frequency and the duration of contacts and practicing physical distancing (reducing proximity of contacts) is proving particularly effective (PHAC, 2020; INSPQ, 2020a). Of course, entirely avoiding contact with people who may be infected (e.g., staying at home with no visitors, working remotely) is the most effective measure. When contact is unavoidable, reducing the crowding of the area so as to keep 2 metres between users is recommended. The particular characteristics of each indoor environment, particularly its dimensions, configuration, and vocation, sometimes make distancing measures difficult to implement.

2.2 Technical and engineering measures

Technical and engineering measures include measures that may, in theory, also be effective. Suggested technical measures include installing physical barriers (Plexiglas enclosures) to separate workers from one another and from customers in order to reduce transmission from the expectoration of infectious particles despite close proximity. These measures must not prevent the ventilation system from circulating air.

Furthermore, increasing air exchange using natural or mechanical ventilation is among the recommended engineering measures. Proper ventilation of the premises prevents the accumulation of potentially infectious particles in indoor environments (REHVA, 2020c). This engineering measure must be applied in conjunction with technical measures (American Society of Heating, Refrigerating, and Air Conditioning Engineers [ASHRAE], 2020f; CADTH, 2020; Haut Conseil de la santé publique [HCSP], 2020c; Morawska & Cao, 2020; REHVA, 2020c). In some situations (e.g., insufficient airflow, recirculation of a large percentage of indoor air), air purification devices (e.g., filtration using a HEPA filter) could be a complementary way of reducing the infectious load in indoor air. Despite their theoretical efficacy, there is not enough proof to demonstrate that these devices either reduce or increase the transmission of respiratory illness. Furthermore, the constraints of installing, using, and maintaining such devices must be considered (NCCEH, 2020b).

2.3 Administrative measures

Administrative measures essentially include implementing measures by building managers, for example, making occupants aware of certain risky behaviours (e.g., close and extended contact, sharing objects, using common spaces); promoting telework and online communication whenever possible; applying management and compensation measures (policies) to allow symptomatic people, cases, and contacts to stay home from work; markings on the ground or floors; reconfiguring common spaces; etc.

Also, hand hygiene at the entrance to areas as well as the regular cleaning and disinfection of frequently touched objects and surfaces reduces the potential for transmission via contact with contaminated surfaces such as door handles, light switches, counters, handrails, elevator buttons, cell phones, etc. (ASPC, 2020; INSPQ, 2020b).

2.4 Individual protection measures

Finally, using personal protection methods such as medical masks and protective eyewear is an additional measure that could contribute to reducing transmission risk on top of the other measures that are already in place (PHAC, 2020; INSPQ, 2020a). However, individual protection measures must not replace other preventive measures (INSPQ, 2018). For the workplace, refer to: https://www.inspq.qc.ca/sites/default/files/publications/3079-avis-masque-medical-milieux-travail-covid19.pdf [in French only]. It's important to continue, as much as possible, to apply control measures such as physical distancing and hand hygiene along with the other measures.

While reducing the risk of COVID-19 transmission in a given indoor environment naturally depends on the efficacy of the control measures being applied, it also depends on their diversity. Even measures with lower efficacy rates should be considered as important as the others (PHAC, 2020; NCCEH, 2020b; INSPQ, 2018). Accordingly, no category should be implemented in isolation, but rather should be combined with other measures to offer multi-level protection (CCA, 2007). Several recognized organizations including the Public Health Agency of Canada (PHAC) recommend using a number of control measures with various efficacy levels to optimize the potential reduction in transmission risk and to mitigate the difficulty of implementing or maintaining some distancing measures (PHAC, 2020; NCCEH, 2020b; INSPQ, 2018). Also, the control measures don't all target the same transmission methods.

In summary, in a pandemic context, implementing measures lower down on the hierarchy is still pertinent because it is the combination of control measures that makes it possible to lower transmission risk. It therefore seems appropriate to apply various control measures concurrently.

3 Environmental conditions that influence the stability of SARS-CoV-2 in indoor environments

KEY TAKEAWAYS

- According to the available experimental data, the temperature that best supports the presence of coronaviruses in the air and on various surfaces not exposed to sunlight is around 4°C.
- Some experimental studies have shown that SARS-CoV-2's sensitivity to degradation increases with temperature and with the intensity of some forms of radiation (e.g., UVC), while the relationship between virus deactivation and the relative humidity of the ambient air does not appear to be linear (or proportional).
- Under certain controlled conditions, SARS-CoV-2 appears to be stable in the air at generally maintained temperatures and humidity levels for periods of several tens of minutes, while remaining culturable.
- The results of some experiments conducted in controlled environments suggest that SARS-CoV-2 could remain culturable for several days on some surfaces in indoor environments.
- Modifying the generally maintained temperatures and humidity levels in indoor environments is not recommended based on the current knowledge. It is still recommended to keep these environments within the ranges deemed acceptable by recognized bodies.

SARS-CoV-2, in aerosols of all sizes, can survive for some time outside of infected cells, especially in indoor environments (Aboubakr et al., 2020; Carraturo et al., 2020; REHVA, 2020a). Aside from the time factor, the stability of viruses in a given indoor environment can also vary with the air's temperature and relative humidity (RH) as well as with the presence and intensity of some radiation, including UV. Survival time for SARS-CoV-2 in indoor environments also depends on the type of surface (or medium) on which it is deposited.

3.1 Temperature

In their literature reviews, Dietz et al. (2020), Ren et al. (2020), and Aboubakr et al. (2020) highlight that reaching a high temperature may trigger the degradation of coronaviruses' lipid envelope and result in their deactivation. In 2010, Casanova et al. demonstrated in the laboratory that viruses in the SARS-CoV subgroup could remain culturable on stainless steel at 4°C for up to 28 days. Typically, the persistence of human coronaviruses decreases as temperature increases (Kampf et al., 2020). Chin et al. (2020) obtained similar results with SARS-CoV-2. Using tissue cultures, the authors showed the viability of the virus to be optimal at 4°C and that the virus can easily persist for 7 days at 22°C depending on the type of surface. Above 70°C, the time to deactivate the virus was less than 5 minutes.

In a study aiming to determine the effects of relative humidity, temperature, and droplet size on SARS-CoV-2 stability in a simulated matrix and deposited on non-porous surfaces, Biryukov et al. (2020) showed that the virus disintegrates more rapidly when temperature increases. Furthermore, the volume of the liquid (1 to 50 µl) and type of surface (stainless steel, plastic, nitrile) did not have a significant impact on the deactivation rate. Results from other studies have shown that persistence varies depending on the surface, but that it is always lower when temperatures are higher (Harbourt et al., 2020; Fisher et al., 2020). It's important to note that the experimental conditions under which these studies were carried out differ from normal circumstances, which can create variability in the authors' observations.

3.2 Relative humidity

As for relative humidity (RH), Casanova et al. (2010) report that the relationship between deactivation of coronaviruses and RH is not linear, contrary to the observations regarding temperature. Yang and Marr (2012) report that most viruses suspended in air (including coronaviruses) seem to be sensitive to ambient humidity, but that the mechanisms responsible for this phenomenon are unclear (Ren et al., 2020). For example, Ahlawat et al. (2020) note that relative humidity is a factor that may modulate the ability of SARS-CoV-2 to remain suspended in the air. Because humidity can simultaneously affect the kinetics of viral particle evaporation and their growth (by agglomeration), low humidity levels would contribute to aerosolization of larger particles and their ability to remain suspended in the air, and thus contribute to the risk of infection. This is why in relatively dry environments (RH < 40%), the number of suspended particles containing SARS-CoV-2 would be higher than in very humid environments (RH > 90%). In sum, the relationship between the relative humidity of the air and the stability of the virus still raises questions among the cited authors.

3.3 Radiation

Some kinds of radiation, such as the entire UV spectrum (and infrared radiation), have varying virucidal effects that are of interest in the development of disinfection methods (Horton et al., 2020; ACGIH, 2020 [updated in June 2021]; NCCEH, 2020b; Food and Drug Administration [FDA], 2020; International Commission on Non-Ionizing Radiation Protection [ICNIRP], 2020). While the presence of these types of radiation in indoor environments is typically from UV lights, solar radiation that enters indoor environments through windows and glass doors could theoretically be a factor in virus deactivation. In a laboratory study, Ratnesar-Shumate et al. (2020) simulated the solar light spectra at noon, at sea level and 40° north latitude, at various times of year. After exposing samples of aerosolized SARS-CoV-2 to these types of radiation, the authors observed virus half-lives of less than 6 minutes, and 90% of the virus was deactivated within 20 minutes for all the light intensities they tested. These results were corroborated by Schuit et al. (2020). Interested readers are encouraged to see the box on germicidal irradiation by UV rays.

3.4 Surface type

SARS-CoV-2 can survive anywhere from a few minutes to a few days depending on the type of surface it is on. When the other environmental factors are stable, survival tends to be longer on smooth surfaces than on porous surfaces. It’s important to note that these results come from experimental studies conducted under controlled conditions, which are generally more favourable to virus survival than the variable conditions found in real life (Goldman, 2020). In real conditions, the genetic material (RNA) of the virus is most often found in the immediate surroundings of infected people (Jiang et al., 2020; Kanamori et al., 2020; Peyrony et al., 2020; Yamagishi, 2020; Zhou et al., 2020) and on frequently touched objects (Döhla et al., 2020; Tan et al., 2020). The presence of viral RNA on surfaces does not mean that the virus is still infectious. To the knowledge of the authors of this document, no research teams have been able to cultivate viruses present on surfaces in non-experimental settings (Döhla et al., 2020; Zhou et al., 2020; Santarpia et al., 2020; Colaneri et al., 2020; Ong et al., 2020; Moore et al., 2020; Binder et al., 2020). However, for a surface sample, one of these teams did observe intact SARS-CoV-2 virions after 3 days of culturing. That said, it is not presently possible to draw a link between this observation and the infectivity of the virus (Santarpia et al., 2020).

4 The role of indoor ventilation in COVID-19 transmission

KEY TAKEAWAYS

- Ventilation consists of extracting the contaminated indoor air of a given environment and diluting its contaminants by introducing outside air.
- Indoor ventilation can be done using mechanical systems or windows (or other kinds of openings which allow for natural aeration such as skylights, doors, air registers, etc.).
- It's generally accepted that proper indoor ventilation is an effective way of managing contaminants in indoor air. Mechanical ventilation systems can help extract and dilute gasses, fine particles, and other contaminants suspended in the air.
- Ventilation systems must be properly designed, installed, maintained, and used in order to be effective.
- In most buildings, the suction power of the ventilation system is not strong enough to capture drops in the indoor environment, which tend to fall to the floor quickly.
- There have been no clearly documented cases of SARS-COV-2 transmission via mechanical ventilation system ducts.[1]
- Engineering-based risk mitigation strategies (including maintaining effective ventilation) should be implemented alongside and as a complement to other protective measures such as physical distancing, minimizing contacts, and practicing respiratory etiquette.

Several studies suggest that increasing ventilation, particularly by using mechanical ventilation systems, can reduce the occurrence of respiratory illness (Corporation des entreprises de traitement de l'air et du froid [CETAF], 2018; Morawska et al., 2020). The literature review done by Qian and Zheng (2018) showed the double role of ventilation systems in fighting respiratory infections such as SARS in 2003 and H1N1 in 2009. According to the authors (Qian & Zhen, 2018), besides helping extract and dilute particles, the stream of fresh air introduced by ventilation systems can be oriented to create directional airflow. Such pressure control may be required when it's advisable to avoid the movement of potentially contaminated air (such as that around an infected person or people) toward an uncontaminated area.

However, there is also a potential connection between ventilation, movement of air in buildings, and the transmission of some airborne diseases such as measles, tuberculosis, and varicella (Li et al., 2007). Various flaws in the design, installation, maintenance, and use of ventilation systems can contribute to conditions that may allow pathogenic agents to accumulate or propagate in indoor environments more easily (Correia et al., 2020). It's important to mention, for example, the theoretical risk of one room contaminating another due to air recirculating in a mechanical ventilation system with inadequate filtration. The Canadian Agency for Drugs and Technologies in Health (CADTH) (2020) also highlights that more robust studies would allow for a better understanding of the potential for ventilation systems to either increase or decrease the risk of infection in interior environments, and the factors involved.

1 A recent article, which has not yet been analysed in detail and which seems to have serious limitations, established that transmission had occurred via ventilation ducts (Hwang et al., 2020).

From a theoretical perspective, the risk of dispersing particles (including viral particles) through a ventilation system recirculating a significant percentage of contaminated air (see Li et al., 2020) cannot be completely discounted (Beggs, 2020; CADTH, 2020; NCCEH, 2020a; Dietz et al., 2020; European Centre for Disease Prevention and Control [ECDC], 2020; National Academies of Sciences, Engineering, and Medicine [NASEM], 2020). However, this possibility seems unlikely (ECDC, 2020; REHVA, 2020a, 2020b, 2020c). The possibility of dispersion is closely linked to the potential for aerosolization of viral agents and the preservation of their infectivity inside ventilation ducts (including the filters). Yet in most residential and commercial buildings, the suction power of ventilation systems is not strong enough to counteract the rapid deposition of drops and aerosols from 10 to 100 µm in indoor environments, which are currently considered to be most significant, along with close contacts, in the process of transmitting COVID-19 (World Health Organisation [WHO], 2020).

Furthermore, CADTH (2020), the Federation of European Heating, Ventilation and Air Conditioning Associations (REHVA) (2020c), and NCCEH (2020c) emphasize that to date there has been no documented case of SARS-CoV-2 transmission via a mechanical ventilation system. NCCEH and CADTH add that, in cases where outbreaks have occurred in areas equipped with ventilation systems (where contribution of the system could be suspected), there has always been an infected person present and near the other occupants who developed the infection afterwards. These circumstances imply that other mechanisms likely contributed to transmission of the infection (CADTH, 2020; NCCEH, 2020c). In France, the HCSP recently examined the risk of SARS-CoV-2 transmission by ventilation systems in institutional buildings, healthcare facilities, and homes, and concluded that there are no studies that demonstrate potential transmission of the virus through these systems (HCSP, 2020b).

Certain technical characteristics of ventilation systems require special attention (see the following section). Additionally, a review of the increasing number of outbreaks occurring in indoor environments (HCSP, 2020c), and confirmation by several trusted organizations that viral particles emitted by infected individuals at close and potentially longer range have infectious potential, appear to support optimizing ventilation as an engineering measure in occupied indoor environments (REHVA, 2020c). According to the ASHRAE, spread of SARS-CoV-2 through indoor air is likely enough to justify the adoption of preventive ventilation measures to limit this kind of exposure to the virus (ASHRAE, 2020a, 2020d, 2020f, 2020g). In the spirit of caution, additional authors and organizations specify that engineering-based risk mitigation strategies (including maintaining effective ventilation) should be implemented in conjunction with physical distancing measures and respiratory etiquette (ASHRAE, 2020f; CADTH, 2020; HCSP, 2020c; Morawska, et al., 2020; REHVA, 2020c).

These recommendations are based on the complementary and coherent conclusions of a growing number of studies on the dynamics of infectious aerosols in crowded indoor environments, which contribute to proximity (see the section SARS-CoV-2 Transmission). The conclusions of the recent quantitative analyses (digital simulations) done by Beggs et al. (2020), Buonanno et al. (2020), Dai and Zhao (2020), Evans (2020), Miller et al. (2020), Melikov et al. (2020), Anghel et al. (2020), and Borro et al. (2020); the laboratory study by Somsen et al. (2020); and the literature reviews by Morawska et al. (2020) and Amoatey et al. (2020) all emphasize the importance of ensuring proper ventilation in this type of environment in order to minimize the risk of COVID-19 transmission.

5 Practical ventilation measures to apply in a pandemic

KEY TAKEAWAYS

- Every building is unique, and all building components must be specifically assessed by qualified professionals to ensure optimized ventilation (mechanical, natural, or both) of the premises in accordance with the building's purpose and occupation type.

Buildings with HVAC systems

- Ensure that a qualified professional assesses the relevant system components before any work is performed on a mechanical ventilation system.
- If the type of ventilation system allows, optimize ventilation of the premises by increasing the intake of fresh air and extraction of exhaust air.
- If a significant proportion of the air is recirculated, it is recommended to add, if possible, a high-efficiency filter with a MERV 13 or higher filtration level to the ventilation system.
- When possible, avoid the use of certain energy-saving strategies (e.g., demand-controlled ventilation regulated by a timer or by CO_2 concentration) to ensure more continuous ventilation of the premises.
- Try to maintain a minimum level of ventilation when the building is unoccupied to ensure a level of continuous indoor air exchange.
- If applicable, ensure that shared central hallways are sufficiency pressurized 24 hours per day.

Buildings without HVAC systems (with operable windows)

- Regularly ventilate occupied rooms by opening the windows (for 10 to 15 minutes, at least twice daily).
- This can be done by choosing strategic times of the day (e.g., at the start and end of the period during which the room is occupied, during breaks, or during meals) to open the windows and doors of the space, even in winter.
- The ways of applying natural, intentional ventilation (e.g., opening windows on opposite walls, with the door open, in combination with fans in the windows, etc.) may vary according to the environment, and their effectiveness depends on a number of architectural, environmental, and human factors (refer to the next box).

Buildings or sections of buildings without HVAC systems or operable windows

- Consider changing the use of rooms and premises that are inadequately ventilated (that do not meet required ventilation requirements) if occupied by multiple individuals.
- Alternatively, consider applying indirect ventilation measures (e.g., forced airflow using bathroom exhaust fans) and using a portable air purifier (see the Filtration section).

During a pandemic, sources including NCCEH (2020a, 2020c), REHVA (2020a, 2020b, 2020c), ASHRAE (2020a, 2020b), the Ministère des Solidarités et de la Santé (MSS, 2020), ECDC (2020), the San Francisco Department of Public Health (SFDPH, 2020), ACGIH (2020) [updated in June 2021], Public Health Ontario (PHO, 2020a), the United States Environmental Protection Agency (US EPA, 2020), the World Health Organization (WHO, 2020) and researchers such as Allen and Marr (2020) recommend applying a series of preventative measures in mechanically ventilated buildings. These engineering measures, as a complement to physical distancing measures and other protective measures, aim to reduce COVID-19 transmission in indoor environments, in particular by increasing the air change rate in occupied spaces (see Appendix 4). It is ideally recommended to increase the fresh air intake from outside along with the building's exhaust air extraction. It is also important to avoid creating an unintentional imbalance of air pressure or turbulent directional airflow, which can contribute to the dispersion of viral particles further than 2 metres away from infected individuals. Proper application of these guidelines may mitigate the transfer of exhaust air from a room potentially occupied by infected individuals to another, and reduce the concentration of infectious particles in the building's other habitable rooms. ASHRAE stipulates that a qualified professional must assess all system components, paying particular attention to the automated controller (e.g., timer) before any work is carried out on a mechanical ventilation system.

For buildings without an HVAC system, it is recommended to regularly ventilate the occupied rooms by opening the windows (for 10 to 15 minutes, at least twice daily) when weather permits. Some organizations recommend choosing strategic times of the day (e.g., at the start and end of the period during which it is occupied, during breaks, or during meals) to open the windows and doors of the space, even in the winter (for more information, see the following box and references).

Building managers and administrators, and teams responsible for maintenance and for upgrading ventilation systems should explore optimization options based on the information provided by the manufacturer. It is important to remember that the minimum number of air changes per hour, in accordance with applicable standards (see Appendix 5), should ideally be maintained at all times. This can be accomplished through natural or mechanical ventilation or a combination of the two. In a pandemic, the airflow rates stipulated in the standards should be considered a minimum that needs to be optimized, for example, by performing maintenance on the ventilation system as frequently and quickly as possible, or by using intentional natural ventilation to introduce the most possible fresh outside air.

While physical distancing and other risk management measures remain the priority to reduce the risk of transmission, ensuring good ventilation may reduce the concentration of viral particles suspended in the air, which could theoretically reduce their risk of causing infection. Despite the generic nature of such a recommendation, it is important to emphasize that each building is unique and the application of engineering measures must be specifically assessed by trained individuals. There are different potential avenues for optimizing ventilation, but the choice of which to apply must be made based on the building type and purpose, the way in which it is being occupied, and the prevailing epidemiological situation in the environment.

Further information on intentional natural ventilation

Natural ventilation occurs through the difference in air pressure between a building's interior and exterior, as the air moves from high-pressure areas toward low-pressure areas. This movement of air can be generated by opening the window of a building or by passive infiltration/exfiltration through the building envelope. However, the effectiveness of this ventilation practice varies as the difference in pressure can be modulated by a number of factors, including the difference in temperature between the indoor and outdoor air; the presence or absence and direction of vents; the type, number, and layout of windows; etc.

In the case of some buildings that are not equipped with mechanical ventilation systems or that cannot supply the recommended volumes of fresh air, intentional natural ventilation can be an option worth considering for air exchange or as a complement. However, the effectiveness of this type of approach for exchanging indoor air in a given environment remains conditional on good understanding of the elements that could hinder or facilitate the flow of air in the building (architecture of the premises, presence of obstacles, interaction with different mechanical systems, etc.).

Different options (e.g., a combination of measures) can be considered regarding intentional natural ventilation. These options should ideally be assessed according to the specific characteristics of the building concerned and its occupants. The following references include examples of possible combinations of measures:

- https://www.epa.gov/coronavirus/indoor-air-homes-and-coronavirus-covid-19
- https://apps.who.int/iris/bitstream/handle/10665/44167/9789241547857_eng.pdf;jsessionid=AB83CB5D2D6772AEF579A6A6C88252BE?sequence=1

6 Ventilation system maintenance in a pandemic

KEY TAKEAWAYS

- Mechanical ventilation systems must be regularly maintained.
- It is important to ensure that the ventilation registers and grills (fresh air intake points and exhaust outputs), including the outdoor air intake, are not obstructed by objects, excessive dust accumulation, or other debris.
- All of the system's mechanical and electrical components must be checked to ensure they are functioning properly.
- The filters in place must be kept clean and replaced when applicable.
- It is not considered necessary to apply additional disinfection measures to ventilation ducts.

Most organizations generally recommend properly ventilating all occupied rooms and indoor spaces at all times, and regularly checking that the mechanical ventilation system is functioning properly, as applicable (ASHRAE, 2020a, 2020b; Bahnfleth et al., 2020; NCCEH, 2020a, 2020c; HCSP, 2020b, 2020c; REHVA, 2020c).

During the pandemic, it is also recommended to:

- Conduct regular maintenance of mechanical ventilation systems (referring, as needed, to ASHRAE Standard 180-2018: Standard Practice for Inspection and Maintenance of Commercial Building HVAC Systems; manufacturers' instructions; or the appropriate guides, e.g., the guide for maintaining ventilation systems in school settings (http://www.education.gouv.qc.ca/fileadmin/site_web/documents/education/reseau/qualite_air_reference_s.pdf) [in French only] and the guide for preventing microbial proliferation in ventilation systems (https://www.irsst.qc.ca/media/documents/PubIRSST/RG-088.pdf?v=2020-07-27) [in French only]).
- Ensure that ventilation registers and grills are not obstructed by objects, excessive dust accumulation, or other debris.
- Verify that all of the system's mechanical and electrical components are functioning properly.
- Keep the filters in place clean and replace them when applicable.
- Ensure that the filter is the correct size for the device.
- Ensure that the filter is properly installed (e.g., adjusted to fit flush against the sides of the housing to prevent air from bypassing the filter).

Finally, as the information currently available in the scientific literature indicates low likelihood of the virus maintaining its infectivity through ventilation ducts, it is not considered necessary to apply addition disinfection measures (e.g., UV-light sterilization) to the ventilation ducts (Ezratty & Squinazi, 2008). REHVA (2020a) specifies that while ventilation ducts are not considered a source of contamination, especially if the automated ventilation controllers (such as energy-saving strategies and demand-controlled ventilation controlled by a timer or CO_2 detector) are deactivated and there is little recirculation of exhaust air. The virus present on microparticles will be deposited on duct surfaces or expelled outside of the building. Furthermore, being an obligate parasite, the virus will not multiply on contact with damp surfaces or substrates rich in organic material present in ventilation system ducts the way bacteria and mould can (Lavoie & Lazure, 1994).

7 Filtration as a measure to mitigate the risk of infection

KEY TAKEAWAYS

General information

- Mobile filtration devices (also known as portable units) or devices integrated into mechanical ventilation systems—when properly selected, positioned, maintained, and operated—can help reduce concentrations of viral particles in indoor air.
- Indoor air filtration devices cannot, however, be considered a standalone solution to combat the spread of the virus.
- Filtration devices cannot counter the transmission of SARS-CoV-2 through close contact with infected individuals, which is recognized as the main mode of transmission.
- Other air purification technologies such as UVC irradiation (see box below) could be considered as means of removing pathogenic organisms from indoor air.

Adding filters to HVAC systems

- Adding high-efficiency (MERV 13 and up) or very high-efficiency (HEPA) filters may be an option to consider under certain circumstances (e.g., when a large percentage of indoor air is recirculated), depending on system capabilities.
- This mitigation measure is often difficult to apply in existing ventilation systems and units due, for example, to restrictions it can place on the device. Under such circumstances, the use of additional measures, such as natural ventilation or portable purification devices, could be considered.

Mobile filtration devices

- The effectiveness of mobile or portable air filtration devices depends on multiple factors, which can be constraints to take into account.
- The capacity of filtration devices to reduce concentrations of viral particles in a given volume of indoor air must be considered.
- Filtration device positioning must be carefully determined by a qualified professional (to develop an airflow pattern based on the room perimeter).
- Maintenance of filtration devices and their components, and specifically filters, is a key determinant to monitor in ensuring that the optimal performance of these devices is maintained in the medium and long term.
- It is important to properly manage exhaust airflow rates of filtration devices, and especially to ensure that airflow is not directed toward occupants' faces.
- In certain contexts, such as the education system, the noise generated by filtration devices can be a constraint that must be considered.

Readers interested in learning more about the technical issues associated with filtration devices may refer to the following references:

- https://www.gov.uk/government/publications/emg-potential-application-of-air-cleaning-devices-and-personal-decontamination-to-manage-transmission-of-covid-19-4-november-2020
- https://www.epa.gov/indoor-air-quality-iaq/air-cleaners-and-air-filters-home
- https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7489049/
- https://schools.forhealth.org/ventilation-guide/

In an INSPQ literature review published in 2019 (https://www.inspq.qc.ca/sites/default/files/publications/2543_dispositifs_epuration_air_interieur_residentiel.pdf) [in French only], the authors highlighted the following points:

- The effectiveness of these devices in preventing health problems has not been well established.
- No purification technology currently on the market can, on its own, provide potential benefits equivalent to applying basic (or fundamental) indoor air quality management methods, i.e., control of contaminants at the source and optimized ventilation.
- Evidence concerning the performance and safety of many air purification technologies currently on the market remains incomplete, and it is risky to make an objective judgement with regard to their relative effectiveness, due notably to the wide range of evaluation specifications used in the studies reviewed.

Available indoor air purification processes (which can be implemented using portable or mobile devices, or integrated into HVAC systems) include mechanical filtration, activated carbon adsorption, electrostatic capture, ionization, ozone generation, plasma, ultraviolet irradiation, and photocatalysis. In their brief descriptions of these technologies and their main characteristics, the authors note that using a number of these technologies can result in collateral exposure to ozone and other co-products of incomplete treatment of air contaminants. These potentially negative impacts on indoor air quality should therefore be evaluated before selecting a given technology. It is also necessary to consider the contaminants targeted by the technologies themselves, since many are designed primarily to attenuate concentrations of volatile organic compounds (VOCs) in indoor air (e.g., adsorption, ozone generation, ionization, photocatalysis).

Among these available technologies, mechanical filtration processes (including those using HEPA filters) are designed to capture suspended particles without generating any potentially harmful contaminants, provided that the filters are replaced regularly. Mechanical filtration is also the most frequently mentioned portable technology described as a preventive measure in the scientific literature on the pandemic. Ultraviolet irradiation systems are also sometimes discussed (in combination with filtration or on their own), but these systems can involve a risk of exposure to ultraviolet radiation, a recognized carcinogen, if preventive measures are not taken in this regard.

As the main recognized modes of transmission of SARS-CoV-2 are close contact (including short-range aerosols), the various types of systems and devices for purifying indoor air (including those using particle filters) cannot be considered a standalone solution to counter the spread of the virus. While a filtration device equipped with a MERV 13 (or higher-efficiency) filter can contribute to reducing the concentration of viral particles in indoor air, it cannot prevent the transmission of SARS-CoV-2 resulting from close contact with an infected individual, as larger particles (e.g., droplets) tend to fall quickly onto nearby surfaces, or constitute a source of exposure for nearby individuals (Heffernan, 2020).

Although the size of SARS-CoV-2 ranges from 0.06 to 0.140 µm (Cascella et al., 2020; Christopherson et al., 2020), virus-laden particles, which disperse in the ambient air, are generally made up of a complex mixture of organic and inorganic constituents (water, salts, lipids, proteins, bacteria, other viruses, etc.), creating virus-laden particles of a size far exceeding the diameter of the virus itself (Dietz et al., 2020; Verreault et al., 2008). The presence of SARS-CoV-2 has been observed in large particles (drops) and aerosols (Dietz et al., 2020).

Filters normally used in mechanical ventilation systems (MERV 5 to 12) are not designed to remove particles measuring 0.3 µm in diameter or less. They still, however, have a certain ability to capture viral particles present in indoor air. Multiple researchers report that using high-efficiency filters (MERV 13 and up) or very high-efficiency filters, (HEPA filters, which can remove more than 99.97% of particles measuring 0.3 µm and larger) could be an option to consider under certain circumstances (e.g., when required fresh airflows cannot be achieved or maintained, or when the proportion of recirculated indoor air is high) to reduce the dispersion of pathogens in the indoor environment (ACGIH, 2020 [updated in June 2021]; Allen et al., 2020; ASHRAE, 2020a, 2020b; Dietz et al., 2020; Evans, 2020).

However, it remains difficult to install better-performing filters in existing ventilation systems and units, due to the high costs (installation, maintenance, energy) of retrofitting and the inherent technical constraints of these types of filters, e.g., additional static load, periodic inspection and replacement (ASHRAE, 2020a; NCCEH, 2020a; Evans, 2020; Ezratty & Squinazi, 2008; Poulin et al., 2019). Precautions must be taken when installing high-efficiency filters in mechanical ventilation systems to ensure the system has sufficient capacity to accommodate these filters without adversely affecting its ability to effectively maintain required ventilation rates, ideal indoor temperatures and humidity levels, and pressure differential pressures needed for the proper movement of indoor air masses (ASHRAE, 2020a).

Despite the constraints associated with the use of high-efficiency filters in the current context, ASHRAE (2020a, 2020b, 2020c), REHVA (2020a, 2020c), SFDPH (2020), the American Conference of Governmental Industrial Hygienists (ACGIH, 2020 [updated in June 2021]), Nardell and Nathavittharana (2020), Morawska et al. (2020), Nazarenko (2020), and Christopherson et al. (2020) note that both mobile filtration devices (portable units) and those integrated into mechanical systems—when properly selected, deployed, and maintained—can be effective in reducing concentrations of infectious viral particles in indoor air. The ACGIH (2020 [updated in June 2021]) and the Harvard School of Public Health (2020) (https://schools.forhealth.org/ventilation-guide) also provide a method to calculate the flows of purified air required in a given room; this is critical information when choosing a device with a filtration capacity that meets the needs of building users.

ASHRAE has published a series of specific recommendations on the installation, use, and maintenance of filters in mechanical ventilation systems or portable ventilation units during a pandemic (ASHRAE 2020a, 2020e, 2020f). Applying these use-related recommendations is essential, as shown in a pilot experiment that simulated the airflow generated by portable filtration devices where such filters may have contributed to dispersing viral particles generated by occupants located in the device’s line of air output (Ham, 2020). This example demonstrates the importance of properly managing the airflows emitted by such devices, and in particular of ensuring that airflows are not directed toward building occupants’ faces (ACGIH, 2020 [updated in June 2021]).

In short, filtration could be considered a complementary protective measure to use alongside ventilation and other methods to reduce the viral load in the air near beds of infected individuals, or in places where it is not possible to achieve required air change rates. Parameters to take into account (e.g., existing ventilation system, type of technology, device capacity, location, etc.) in connection with the installation and use of mobile filtration devices depend on the environment concerned (e.g., dentist's office, patient room, etc.).

Note on germicidal irradiation by UV rays

Ultraviolet sterilization has been used for decades in healthcare settings (and other indoor environments vulnerable to bioaerosol buildup) to control respiratory diseases such as tuberculosis. Studies have found that UVC rays (~254 nm) exhibit greater germicidal efficacy than UVA or UVB rays. The disinfectant effect of UVC radiation results from cellular damage (breakage of DNA and RNA strands) to irradiated bacteria and viruses, which can then no longer multiply. Since UVC radiation can also cause damage to human tissue, such as eyes and skin, protective measures must be taken to limit human exposure.

UV bulbs or lamps can be installed in the ducts of mechanical ventilation systems or in portable or independent devices, which may or may not be combined with fans or other purification technologies. While the effectiveness of disinfection depends on the dose (or intensity) of UV radiation, other factors including general device configuration, exposure time, and the characteristics of the target pathogen must also be considered. Recent scientific literature on the effectiveness of germicidal UV irradiation suggests that this disinfection approach could prove effective with SARS-CoV-2, though its effectiveness is unproven. Broadly speaking, germicidal irradiation should be used with caution and in conjunction with ventilation.

To find out more, refer to the links below:

- https://ncceh.ca/documents/guide/covid-19-indoor-environments-air-and-surface-disinfection-measures
- https://www.medrxiv.org/content/10.1101/2020.06.12.20129254v1
- https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7571309/

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Appendix 1

Methodology overview – Checklist

The findings discussed in this document are essentially taken from two brief literature reviews conducted by the INSPQ's nosocomial infections and environmental health teams. They therefore afford a transdisciplinary perspective. The findings apply to a range of indoor environments including healthcare settings, even where the scientific literature reviewed does not specifically target all aspects associated with this type of environment (see the literature review from the environmental health team).

The nosocomial infections team conducted a literature review of knowledge on aerosol transmission of SARS-CoV-2. To do this, the team reviewed scientific articles and preprints available as at September 15, 2020. They consulted bibliographic databases (Medline, Embase by the Ovid search engine), using keywords related to aerosol transmission in the context of COVID-19, as well as COVID-19 scientific monitoring by the INSPQ. Data collected on this subject are drawn primarily from experimental models, observational and epidemiological data, and other literature reviews. For other factors studied (e.g., aerosol dynamics, contagiousness, and infectious dose of SARS-CoV-2), no attempt has yet been made to gather all the scientific publications.

The environmental health team, for its part, reviewed literature on the presence of SARS-CoV-2 in indoor environments and on various measures to mitigate associated infection risks. This team conducted a literature review based on the analysis of articles from the COVID-19 scientific monitoring performed by the INSPQ (whose outputs were shared using Inoreader), and used the snowball method to locate additional studies on the subject. The team used the same method to list studies of COVID-19 outbreaks with cases of long-distance or fomite transmission. In addition, the team reviewed articles written in French and English published as at September 30, 2020, and included in its analysis all articles related to aerosol and fomite transmission identified prior to the drafting of this document. It should be noted that references published after September 30 are included in boxes throughout this document in order to provide the necessary details concerning issues of interest associated with the file (e.g., measuring CO_2 as a ventilation indicator). In addition, the team evaluated both peer-reviewed and non-peer-reviewed articles available on MedRxiv. Studies conducted in the healthcare sector were included where they also discussed the general population or where the results could be transferred to the community at large.

Finally, the document underwent a consultation process involving both INSPQ experts contributing to work on COVID-19 (environmental health, occupational health, nosocomial infections, population measures, and case and contact management teams) and external consultants (four expert reviewers). Authors, members of the scientific committee, and reviewers have duly completed a declaration of interest. No conflict of interest situation was found, although certain reviewers do find themselves in an apparent conflict of interest. No specific measures to manage these conflicts were deemed necessary.

Type of rapid response - RAPID KNOWLEDGE SYNTHESIS

1. Cautionary note on institutional methodology

YES ☐ NO

2. Explicit formulation of the research questions covered or the objectives of the synthesis

YES ☐ NO

3. Literature search strategy

a. Use of the COVID-19 institutional daily scientific monitoring bulletin
b. Use of a COVID-19 institutionnal targeted scientific monitoring bulletin
c. Use of the institutional grey literature monitoring bulletin

Institutional scientific monitoring, up to September 15, 2020

Environmental health scientific monitoring, up to September 30, 2020

d. ☐ Establishment of a a specific literature search strategy (retrospective)
Specify keywords used, databases queried (at least two), sources of grey literature, and search delimiters (e.g., languages, search period start and end dates).

e. Other
Specify.

Grey literature research for positions of recognized organizations

4. **Use of inclusion criteria**

☐ YES ✔ NO

If yes, specify criteria used.

No inclusion criteria, but one exclusion criterion: studies in healthcare settings were not included, except in a few cases where high-quality studies presented valuable data that is transferrable to non-healthcare settings.

5. Treatment of preprints

☐ Their inclusion is noted Their identification is facilitated in the document

Preprint articles were used, but were not identified as such in the document.

6. Data extraction

Inclusion of evidence tables: ☑ YES ☐ NO

Data tables were created only for articles on aerosols and on infected surfaces (fomites), but were not included in this document.

7. Assessment of the quality of the studies or the level of the evidence

NO

☐ YES

If yes, specify the method or approach used.

8. Peer review

a. by the members of the related expert committee
b. by members of other INSPQ COVID-19 thematic units or committees
c. by other reviewers at the INSPQ who did not participate in the work
d. by external reviewers (who are not from the INSPQ and who did not participate in the work
e. ☐ no peer review

Appendix 2

Hierarchy of control adapted to COVID-19

CATEGORY	DESCRIPTION	EXAMPLE MEASURES
Measures to minimize number and duration of contacts and promote physical distancing	▶ Limit the number, frequency, duration, and proximity of contacts between patients/residents ▶ Reorganize premises to permit physical distancing between patients/residents	▶ Minimize contacts: Stay home with no visitors, telework, limit time of social interactions, avoid gatherings, etc. ▶ Physical distancing: Prevent crowding of premises, maintain a minimum distance of 2 metres
Technical and engineering measures	▶ Alter the physical structure, equipment, or layout of spaces to reduce risk of transmission	▶ Install physical barriers (e.g., Plexiglas partitions), modify furniture arrangement or occupants' habits (e.g., tables, chairs, line-ups, foot traffic direction), reduce the need to touch certain objects (e.g., adding automatic doors, automatic hand washing equipment/stations), increase air exchange through natural or mechanical ventilation, add air filtration, etc.
Administrative measures	▶ Change the context in which people interact, work, play, or socialize in a given space to limit close contact and reduce contact with shared spaces, objects, and surfaces.	▶ Establish hand hygiene protocol, disinfect frequently touched surfaces, provide training, display posters, reduce sharing practices (remove objects from waiting rooms, modify employee break schedules to reduce shared use of break room), promote telework and communication over email and by phone, reduce crowding of premises, apply procedures to detect and financially compensate symptomatic people, cases, and contacts to ensure they do not attend work, etc.
Individual protection measures	▶ Adopt individual barriers as an additional method to protect patients/occupants from the virus.	▶ Wear medical masks and protective eyewear (workers), or medical masks or face coverings (population), etc.

Inspired by the following sources: ASPC, (2020); Canadian Centre for Occupation Health and Safety [CCOHS] (2020); CCNSE (2020b); National Institute for Occupational Safety and Health (NIOSH, 2015); OSHA (2016); Rivers et al. (2020).

Appendix 3

Summary: Application of the infection hierarchy of control in healthcare settings

Technical and engineering measures

Technical and engineering measures refer to infrastructure measures that help control risk (infectious agents or infected sources and environments) at the source, especially through:

- Facility design
- Room design (e.g., at minimum, negative pressure emergency rooms)
- Ventilation systems and air circulation in rooms
- Water distribution systems
- Human traffic patterns (e.g., in soiled utility rooms)
- Presence of alcohol-based hand rub (ABHR) distributors and hand washing stations in all types of healthcare settings (hospital centres, CHSLDs, CLSCs, clinics, etc.) to promote the practice of hand hygiene
- Physical barriers to separate patients in multi-bed rooms or increased space between patients in waiting rooms, between emergency stretchers, and in treatment rooms
- Barriers to block droplets when people cough or sneeze (e.g., glass walls in reception areas)

These measures should be included in the design and construction of new healthcare settings, or when renovating existing facilities.

Administrative and organizational measures

These measures include policies, guidelines, protocols, procedures, and rules of care designed to prevent the transmission of an infectious agent to a susceptible host during the delivery of care, including:

- Routine practices and hand hygiene for healthcare workers
- Additional precautions
- Respiratory hygiene and etiquette
- Measures to identify individuals carrying a microorganism or transmissible infection
- Individual protection measures for healthcare workers (e.g., vaccination)
- Education and training measures for all personnel responsible for implementing these measures
- Outbreak management protocols
- Cleaning and disinfecting measures
- Procedural audits

To ensure their effectiveness, these measures must be implemented as soon as a potential source of infection is present, and maintained until the source has left the healthcare setting or is no longer infectious. Ineffective and inconsistent application of administrative measures may result in the transmission of nosocomial infections. In order for administrative measures to prevent the transmission of infectious agents, the necessary resources must be available.

Personal protective equipment (PPE)

Personal protective equipment (PPE) is considered a "last line of defence" in avoiding exposure to pathogens. However, given that the two previous levels of measures are not always in place or entirely effective, in some situations PPE use will serve as a complementary measure. This level of the infection hierarchy of control encompasses the availability and appropriate use of personal protective equipment: gowns, gloves, masks and other respiratory protection devices, protective eyewear (face shields, safety goggles). Appropriate use of PPE by a susceptible host creates a physical barrier between them and the infectious agent (PHAC, 2014). It is therefore essential that all categories of PPE be made available to healthcare workers and that training in proper PPE use be provided.

Taken from:

https://www.inspq.qc.ca/sites/default/files/publications/2437_prevention_controle_infections_hierarchie_mesures_controle.pdf [in French only]

Appendix 4

Recommended measures in buildings with mechanical ventilation (HVAC) systems during a pandemic

Warning

An in-depth knowledge of HVAC systems is required before any work can be performed. Implementing ad-hoc solutions without an understanding of the limitations of HVAC systems may jeopardize the effectiveness of the system as a whole. A good knowledge of existing systems requires an evaluation of both its initial design and subsequent modifications, based on relevant technical documents. Note that all HVAC tests must be performed by specialists in the field (members of a professional order, engineers, technologists, occupational hygienists, etc.).

- Attempts should be made to optimize ventilation rates of the mechanical ventilation (HVAC) system by increasing fresh air inflows and exhaust air outflows, while avoiding unintentional pressure imbalances, which could generate air transfer and encourage the dispersion of contaminants.
- If the type of ventilation system permits, optimize ventilation of the premises by increasing the intake of fresh air and extraction of exhaust air.
- When a significant proportion of air is recirculated, add a high-efficiency filter to the existing system if possible (e.g., one with a MERV [Minimum Efficiency Reporting Value] rating of 13 or higher).
- Perform periodic maintenance (or replacement) on filters and other HVAC components.
- Use heat or energy recovery devices, ensuring they do not cause cross-contamination.
- When possible, avoid using energy-saving strategies (e.g., demand-controlled ventilation regulated by a timer or by CO_2 concentration).
- Try to keep ventilation rates at low power (low speed) when the building is unoccupied, rather than turning the system off completely, to facilitate full changes of indoor air (24 hours/day).
- If the system must be deactivated, consider extending the system's service hours by up to 2 hours, at normal operating levels, before and after the occupancy period.
- Ensure that positive pressure in shared central hallways, if applicable, is sufficient to prevent air from the living quarters/premises from potentially diffusing into adjacent living quarters. This type of positive pressure should also be maintained 24 hours per day.
- Ensure that negative pressure is maintained in certain rooms (such as bathrooms) to limit the dispersion of aerosols outside the room or space concerned. To do this, extractor fans should be operated 24 hours per day; when this strategy is used, washroom windows should also be closed.
- Maintain the temperature and relative humidity at normal recommended levels for the season (see the recommendations of relevant authorities): https://www.inspq.qc.ca/qualite-de-l-air-et-salubrite-intervenir-ensemble-dans-l-habitation-au-quebec/qualite-de-l-air-et-salubrite/parametres-de-confort [in French only].

Appendix 5

Standards, regulations, and codes specifying required ventilation and minimum airflow rates for various environments

Standard 62.1 – Ventilation for Acceptable Indoor Air Quality, American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE)

ASHRAE standards are often used as guidelines around the world. These guidelines frequently serve as a reference for government regulations, thus becoming legal standards. To read the ASHRAE standards, click on the following link: https://www.ashrae.org/technical-resources/standards-and-guidelines/read-only-versions-of-ashrae-standards

Regulation respecting occupational health and safety

Quebec's *Regulation respecting occupational health and safety* applies to all establishments that are subject to the *Act respecting occupational health and safety*, and is designed to protect workers with organizations in sectors under provincial jurisdiction, which represents the vast majority of Quebec workplaces. The Regulation sets out minimum standards for working environments and the safe performance of various jobs. Division XI - Ventilation and Heating, and Schedule III of this by-law deal more specifically with ventilation. To read the English version of the Regulation, click on the following link: http://legisquebec.gouv.qc.ca/en/showdoc/cr/S-2.1,%20r.%2013

Quebec Construction Code, Chapter I - Building and National Building Code - Canada 2010 (amended)

This purpose of the Code is to regulate the construction of buildings in Quebec. Ventilation for dwelling units, among other things, is covered in Section 9.32 and Article 6.2.2.9. of the Code:

- https://www.rbq.gouv.qc.ca/en/laws-regulations-and-codes/construction-code-and-safety-code.html
- https://www.rbq.gouv.qc.ca/domaines-dintervention/batiment/la-reglementation/chapitre-batiment-du-code-de-construction/entree-en-vigueur-des-modifications-au-chapitre- i-building-du-code-de-construction-du-quebec-including-the-cnb-2010.html [in French only]
- https://nrc.canada.ca/en/certifications-evaluations-standards/codes-canada/codes-canada-publications

Guide to indoor air quality in establishments in the health and social services network

This guide provides a wealth of relevant information on the design, calibration, use, and maintenance of ventilation systems. It specifies that systems must "have rates that are not less than those required under ANSI/ASHRAE-62.1, Ventilation for Acceptable Indoor Air Quality." In some cases, the requirements of establishments in the health and social services network, which are generally expressed as numbers of air changes per hour, exceed the requirements in ASHRAE 62.1. For more information, see Chapter 1, Section 4 – *Critères et normes de conception des systèmes à vocation particulière*, pages 24 to 34 of the guide; this section details ventilation requirements based on room type: https://www.irsst.qc.ca/media/documents/PubIRSST/RG-410.pdf?v=2020-09-16 [in French only].

Special Requirements for Heating, Ventilation, and Air-Conditioning (HVAC) Systems in Health Care Facilities

This is the fifth edition of CSA Z317.2 - Special Requirements for Heating, Ventilation, and Air Conditioning (HVAC) Systems in Health Care Settings; it is one of a series of standards governing the design, construction, and maintenance of HVAC systems in healthcare facilities. It replaces the previous editions (1991, 2001, 2010, and 2015). The standard is designed for architects, engineers, planners, consultants, and healthcare facility staff, to ensure the effective planning, design, construction, and maintenance of HVAC systems. The standard is available at the following link: https://webstore.ansi.org/Standards/CSA/CSAZ3172019?gclid=EAIaIQobChMIor2svJK17QIV0fLjBx31CgpgEAMYASAAEgJ-VvD_BwE

Determining ventilation rates

Various technical means can be used to assess mechanical and natural (intentional and passive) ventilation rates for residential and institutional buildings, which can then be used to check whether recommended ventilation criteria are being met. Depending on specific contexts and needs, the following techniques may be used:

- Anemometers or velometers, using probes in ventilation system ducts to measure incoming or outgoing airflows
- Blower door testing, to evaluate passive natural ventilation (infiltration in the envelope)
- Tracer gas leak testing (e.g., PFTs) to measure air change rates
- CO_2 concentrations as a ventilation indicator

All these techniques have their advantages and disadvantages, and must be applied rigorously in accordance with established protocols in order to provide a reliable assessment of building ventilation. The following references detail methodological issues to consider when such techniques are used:

- ISO - ISO 16000-26: 2012 - Indoor air - Part 26: Carbon dioxide (CO2) sampling strategy
- https://www.astm.org/Standards/D6245.htm
- https://www.irsst.qc.ca/media/documents/PubIRSST/T-16.pdf?v=2021-08-13
- https://www.ecohabitation.com/guides/3455/un-test-dinfiltrometrie-pourquoi-comment-combien/ [in French only]
- https://schools.forhealth.org/ventilation-guide/
- https://www.medrxiv.org/content/10.1101/2020.09.09.20191676v1.full.pdf
- http://www.ic.gc.ca/eic/site/063.nsf/eng/h_98176.html
- https://www.rehva.eu/fileadmin/user_upload/REHVA_COVID-19_guidance_document_V4_23112020_V2.pdf

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