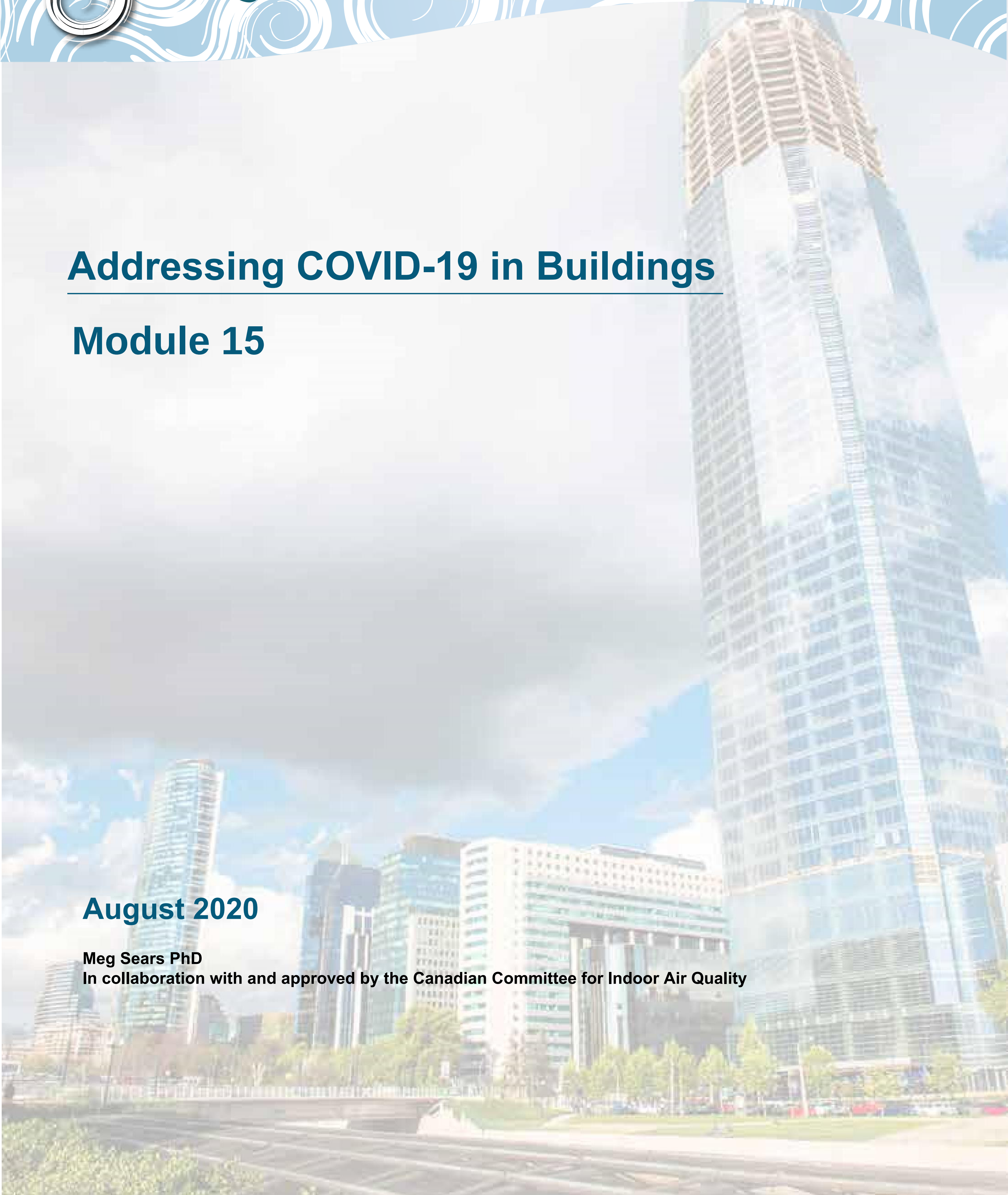
Canadian Committee on Indoor Air Quality



Addressing COVID-19 in Buildings

Module 15

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In collaboration with and approved by the Canadian Committee for Indoor Air Quality

Canadian Committee on Indoor Air Quality (CCIAQ)

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Indoor air quality is a very complex issue and there is currently a significant gap between knowledge of the effects of indoor air quality on the health of occupants and the effectiveness of various air quality technologies and solutions. User discretion is advised.

Preamble

The objective of the CCIAQ is, ultimately, to improve indoor air quality (IAQ) for all Canadians in every type of building. The CCIAQ has decided that its initial focus should be on buildings where many Canadians spend time outside their home, working, learning, shopping, being entertained, etc. For the most part, these buildings have relatively complex heating, ventilating and air conditioning systems that are operated and managed by knowledgeable persons. Documents produced by the CCIAQ are primarily intended for the use of building operators and facility managers, but the information contained in the guides can be helpful to anyone seeking a general understanding.

Module 15 – Addressing COVID-19 in Buildings is a response to the important need to support endeavours to reduce the spread of the SARS-CoV-2 in buildings. As knowledge about evidence-based intervention and mitigation strategies to reduce the risk of virus transmission are evolving rapidly, the CCIAQ plans updates to this document.

The Committee welcomes feedback about all documents and invites the submission of suggestions for their improvement. The Committee is also soliciting ideas for new topics for discussion.

Please feel free to contact the CCIAQ at https://iaqresource.ca/contact-us/ or register on the website at www.IAQResource.ca

The Canadian Committee on Indoor Air Quality Module 15 – Addressing COVID-19 in Buildings, is available online at: https://iaqresource.ca/en/iaq-guides/

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1. Purpose of this Module

Curbing transmission of the novel Severe Acute Respiratory Syndrome Coronavirus (SARS-CoV-2) responsible for the Coronavirus Disease (COVID-19) pandemic led to buildings being closed or minimally occupied for extended periods of time, starting March 2020 in Canada. Learning to live with this virus includes re-opening safely, and reoccupying spaces in different ways, and with different behaviours.

The purpose of this guide is to assist building owners, managers and operators, maintenance workers, educational authorities, employers, occupants and visitors with measures in preparation for building re-occupancy and to minimize disease transmission as Canadians return to workplaces and educational facilities. Written in the context of rapidly advancing knowledge, this module relies on scientific literature (including some in pre-print) and authoritative sources from governments, professional groups, and health organizations. Precautionary approaches to uncertainties regarding the transmission of SARS-CoV-2 are highlighted.

Other Canadian Committee on Indoor Air Quality (CCIAQ) modules address numerous relevant, related indoor air quality topics, and can be accessed at: https://iaqresource.ca/en/iaq-guides/

2. Introduction

The COVID-19 pandemic sweeping the globe resulted in rapid shutdown of buildings as on-site work was halted, schools were closed and some people transitioned to telework and e-learning, with directives to physically distance and to venture away from one's residence as infrequently as possible. Curtailing the rapidly increasing transmission of SARS-CoV-2 entailed lockdown of populations and restrictions on economies.

As understanding improves about strategies to limit viral transmission, plans are evolving for staged return to more pre-pandemic activities. *Contingent upon case numbers being low and stable in the community*, an effective suite of measures for buildings, activities, occupants and visitors can be put in place to maintain low, or to reduce SARS-CoV-2 infection rates and associated COVID-19. Individually these "non-pharmaceutical interventions" are all imperfect,[1,2] but together they may be used to contain COVID-19 sufficiently to start to return safely to workplaces, schools, child-care programs and public venues.

The waxing and waning of COVID-19 cases as public health measures change over time create incentives and pose challenges to: minimize viral transmission; support health to minimize the number of cases who develop severe illness; remain prepared to swiftly, safely and effectively scale back activities on-site and shift to more telework, e-learning, etc.; and to return safely and efficiently when case numbers fall again. As knowledge, innovation and experience related to COVID-19 evolve, being attentive to this emerging science and knowledge will enable nimble adaptation to minimize the virus in indoor spaces, and to maximize opportunities for workers, students and all Canadians to engage in less protected interactions. Finally, lessons learned and improvements in resilience must acknowledge that there are further risks in addition to

COVID-19 that may also require control and management, such as the impacts of the pandemic on food supplies and other essential supplies and services, as well as concurrent risks such as worsening severe weather and fires with climate change.

2.1. How to use this guide

This guide introduces a variety of considerations and measures for re-occupying buildings that have had few if any occupants for several months, along with measures to minimize transmission of SARS-CoV-2. Various options will be applicable and feasible to varying degrees for various activities in different buildings as they are re-opened, and during ongoing operations.

Prevention of SARS-CoV-2 transmission via inhalation of small particles (larger droplets from coughs, to finer aerosols from breathing) is discussed with a focus on buildings with ducted heating/ventilation systems that may remove, dilute and disperse infectious particles with outdoor air, and filter and disinfect recirculated air. Ducted heating systems may or may not include an outdoor air supply with a heat-recovery ventilator (HRV) or energy-recovery ventilator (ERV) to eliminate or minimize recirculation of air, as in modern heating, ventilation and air conditioning or HVAC systems. Some older buildings including institutional buildings (some schools, care homes, places of worship, community centres, etc.) may rely upon radiant heat and have limited or no forced-air heating or cooling. In these cases with only natural or room-specific ventilation (e.g., windows and vents, if they are maintained and operable), local options for air cleaning may reduce airborne viral loads.

The goal is to minimize transmission to the extent that susceptible individuals are not exposed to infectious viral loads (infectious doses). SARS-CoV-2 transmission by asymptomatic individuals means that as long as the virus is present in the community, it *is highly likely* to be present in workplaces, schools and other venues. No single measure will prevent COVID-19, so cooperation of building owners, operators, managers, occupants and visitors is essential to implement as many options as feasible, that offer layers of protection against viral transmission.

This introductory guidance document provides overviews of topics to be considered when devising detailed site-specific plans during reopening and re-occupancy timeframes:
1. addressing and preventing hazards caused by buildings and building systems having been shut down for an extended period as systems are safely restarted, and various air handling systems are adjusted and retrofitted to minimize airborne transmission, as well as re-commissioning water systems and planning enhanced cleaning (Section 3); and
2. actions, measures, policies and plans to minimize the transmission of SARS-CoV-2 as buildings become re-occupied and activities progress to more normal levels of operation (Section 4). Authoritative guidance documents are referenced, and resources are catalogued in Section 8.

Please note that the science is developing rapidly so some of the information may become outdated.

2.2. Hierarchy of actions to limit transmission

Occupational and public health authorities employ a logical hierarchy of actions to prevent injury or contagion, from the most preferable and effective, to more onerous and potentially less effective.[3]

Prior to re-occupancy, the cleaning and re-commissioning of water and ducted air handling systems are at the top of the hierarchy to limit health impacts, removing at source infectious and toxic chemical hazards.

In the context of COVID-19, these complementary actions include:

- **Source removal or control.** SARS-CoV-2 originates in people, so "source removal" includes staying home when sick, rapid detection and isolation of COVID-19 cases, and quarantining and follow-up for contacts of cases (Section 4.4). "Control" includes measures to reduce airborne transmission within a facility (Section 3.1), as well as cleaning and sanitation (Section 3.3). Individual measures are also essential, and are included under personal protection, below;
- **Engineering controls** vary according to the facility. These may include maximizing outdoor air supply, air filtration and disinfection to minimize levels of infectious aerosols, retrofits such as local air purifiers or disinfection, and shields and dividers to intercept droplets and to direct potentially contaminated airflow away from occupant breathing zones (Section 3.3);
- **Administrative controls** may include continued telework/e-learning, or detailed onsite measures (Section 4.4). Stemming from administrative measures, personal protection includes physical distancing such as modified on-site physical layout (e.g., of seating/work stations) and site navigation (e.g., one-way halls or stairwells, limited ridership in elevators), pre-work and post-work health screening, schedules to reduce and to stagger occupancy and smaller "bubbles" or "cohorts" of in-person encounters, paid sick leave, and (in collaboration with Public Health) detection and tracking of COVID-19 testing, cases, contact tracing, quarantine, isolation, and deciding when to close facilities temporarily; and
- **Personal protective behaviours and equipment** such as use of masks (Section 4.1.1), physical distancing, good faith participation in administrative measures, hand hygiene, cough etiquette when not wearing a mask (sneeze or cough into the elbow or a tissue), seeking out testing as indicated, engaging in quarantine and isolation as necessary, and mutual support.

2.3. SARS-CoV-2 transmission and development of COVID-19

Intercepting and reducing transmission of SARS-CoV-2 requires understanding how transmission occurs. Section 6 summarizes in greater detail the medical scientific knowledge underlying key imperatives for any successful plan for return to work or school. This knowledge is advancing rapidly.

COVID-19 begins with SARS-CoV-2 transmission, which occurs via a number of pathways. These include inhalation of virus-laden particles (droplets and smaller aerosols) that reach mucous membranes in the respiratory and digestive systems; and hand-to-face transfer to the mouth, nose or eye. During infection, well before symptoms manifest, SARS-CoV-2 is shed from the respiratory tract[4] and digestive tract (in feces).[5,6] This results in environmental contamination and possible infection transmission, especially in indoor environments with lower rates of ventilation and higher occupancy.[7,8]

Sanitation of the hands and environment was recognized early as being important to curb the spread of SARS-CoV-2,[9] and airborne transmission is now recognized as another key pathway that must be addressed.[10] A letter to the World Health Organization (WHO) by 239 scientists outlined the scientific evidence and importance of airborne transmission and urged widespread use of good quality non-medical masks[11] – a recommendation that is now made by Canada [12] and the WHO,[13] and is increasingly required in indoor spaces, transit vehicles and in highly occupied outdoor spaces, especially when physical distancing is not feasible.

The duration of exposure and the viral load that an individual encounters are the two key determinants of transmission of sufficient SARS-CoV-2 to result in COVID-19. These offer potential independent opportunities for mitigation strategies. Longer exposures even to relatively low levels of virus particles, cumulative exposures to multiple infectious individuals and virus particles in the environment (in air or on surfaces) all increase the risk of an individual receiving an infectious dose of the virus.

Measures to minimize the presence and transmission of infectious agents must address important challenges with SARS-CoV-2 that are different from some previous epidemics such as SARS.[14] Working assumptions that were reasonable at the beginning of the COVID-19 pandemic, but have since evolved, include:

- recognition of pre-symptomatic and asymptomatic transmission.[15] Contact tracing back in time to identify the source or previous carrier of infection is frequently unsuccessful; this may be due to transmission from asymptomatic carriers,[16] including children;[17]
- transmission by children.[18] Children may have 10 to 100 times higher viral loads compared with adults according to swabs of the nose and throat.[19] With low community levels of COVID-19, Rhode Island found that virus transmission in child care facilities was limited with adherence to public health measures, while clusters were associated with lack of adherence.[20] Re-opening of schools and colleges has met with mixed success and shifts to online learning, while at a summer camp with little attention to COVID-19 prevention, roughly half of the children and councillors rapidly became infected;[21] and
- transmission over distances greater than the two metre physical distancing standard via virus-laden respiratory droplets from a cough or sneeze, as well as smaller infectious aerosols of secretions exhaled when breathing, talking, singing and shouting.[22,23,24,25] Airborne transmission is cited as the reason that the virus has persisted at higher levels in districts without wide-spread use of masks.[26,27,28,29,30,31]

A study using modelling that is interactive and available online[26] of reopening of colleges indicates that in addition to sanitation, masks and physical distancing, that frequent, regular testing for the virus among asymptomatic individuals is essential for COVID-19 control.[26,32]

Cleaning of potentially contaminated surfaces is important to break transmission of the virus via hands. SARS-CoV-2 has been shown to linger on all surfaces in spaces occupied by infectious individuals, even air vents,[15] and was observed to remain active for more than four days on indoor smooth surfaces, and in one sample up to a week on a mask.[33] Under experimental conditions SARS-CoV-2 persisted in fine aerosols throughout three hours of observation, over 73 hours on plastic and stainless steel, less than 24 hours on cardboard and less than four hours on copper.[34]

Maintaining physical distancing and limiting contacts at work and in school reduce the probability of transmission, and directly translate into limiting the number of individuals who must stay home when a case is identified. Defining an administrative decision-tree for scenarios of COVID-19 case identification should be an important component of planning for re-opening.

3. Preparations before reopening buildings

Following months of being shut down, workplaces, schools and other buildings require careful reopening and re-commissioning of air (Section 3.1) and water (Section 3.2) supply systems.

In addition to pre-reopening cleaning, limiting viral transmission requires multi-pronged collaboration and investments to update:

- systems for air ventilation, heating and cooling, distribution and cleaning, and strategies to minimize overall and localized airborne virus-laden particles (Section 3.1);
- building-specific reopening strategies to address microbial and chemical contamination of water supplies that have been stagnant (Section 3.3);
- details of physical layout and retrofits to enhance physical distancing and to introduce barriers to virus transmission (e.g., interception of droplets); and
- planning for ongoing operations and cleaning to limit viral transmission.

Administrative/organizational measures to achieve good productivity while respecting and supporting public health measures may entail multi-partner collaboration to delineate and communicate detailed logistics of occupancy, and to establish decision-trees for occasions when employees or close contacts test positive for COVID-19.

This unique re-opening time following the initial COVID-19 shutdown is an opportunity to re-examine, and to make improvements in practices, operations, equipment and the facility itself. It is also the time to ground proof and establish protocols for the future.

3.1. Heating, ventilation and air conditioning (HVAC) maintenance, configuration and retrofit in preparation for re-occupancy

Stopping a virus that is airborne and that can be spread by individuals who do not know they have the disease poses a challenge that can only be addressed with multiple layers of protective measures.[35] This requires understanding how particulates move in small scale turbulent clouds [36] because not only sneezing and coughing, but also activities that generate fine aerosols (e.g., singing and talking, and even just breathing) cause an infectious airborne viral load,[37] and the volume and direction of airflow all feature in spreading SARS coronaviruses.[38,39,40,41] Exposure pathways – exhalation by unsuspecting carriers, airborne transport, and exposure via air and contaminated surfaces – are comparable to those for second-hand and third-hand smoke.[42] Ventilation and air filtration are key features in a multi-pronged approach to reduce viral loads by exhausting or capturing airborne particles, including virus-laden aerosols and dust.[43]

Prior to re-occupancy, HVAC systems should be inspected, cleaned, and verified to ensure they maintain sufficient airflow and distribution, avoid recirculation of stale air and maximize outdoor air supply. The use of high quality filters and other air disinfection should also be considered.

3.1.1. Ventilation strategies

Establishing a higher rate of air exchange to reduce viral loads, as well as careful attention to air flow patterns and exhaust are recommended by authoritative groups such as the American Society of Heating, Refrigeration and Air-conditioning Engineers (ASHRAE).[44] These measures may not all be feasible for many existing buildings, but to limit infection transmission, the central HVAC system should be operated to utilize as many of the strategies below as feasible, such that:

- there is complete air replacement with no recirculation to the maximum extent possible (disabling of demand-control systems and recirculation, and opening of outdoor dampers);
- increase the amount of air exchanged per hour;
- ventilation systems operate beyond the hours of occupancy (two hours before and after occupancy of the building) or around the clock, as necessary to achieve complete flushing of buildings;
- higher performance (minimum efficiency reporting value [MERV] 13 or better; ideally high efficiency particle arrestor [HEPA]) filters are used, with attention to sealing around the edges to prevent bypass;[44,45,46,47] and
- air flow in occupied spaces, with modified layouts to accommodate distancing, is checked, adjusted, corrected and optimized to ensure that the proper quantities of air supply and exhaust are being provided, in the correct locations. Ensure proper air distribution and circulation with elimination of dead zones related to eddies and stagnant layers from temperature stratification by
    - checking diffuser placement and adjustment, and removing any blockage,
    - ensuring that barriers to intercept potentially infectious droplets have at least 30 cm open space at floor level, and have sufficient clearance between the top of the barriers and the ceiling to allow for adequate air movement, and
    - considering altering or removing partitions that interfere with air circulation and contribute to “dead zones.” Consider upstream and downstream airflow when placing local fans or air cleaners.

The goal is to achieve the maximum degree of ventilation with optimal air exchange that building systems can achieve. Where ventilation is not sufficient to reduce viral loads below infectious levels, then options to upgrade or augment existing ventilation and disinfection may be implemented. In the interim, building occupancy and/or occupant density should be restricted accordingly, as long as SARS-CoV-2 is in the community.

Currently, 100 percent outdoor air supply is a design goal for healthcare facilities and a requirement for laboratories that handle airborne hazards.[48] This capacity is noted as being a desirable design consideration for epidemic preparedness for all buildings.[47] High ventilation rates may not be possible through all seasons without major upgrades, depending on the existing HVAC system (e.g., fans, humidity control, filter banks) and the building envelope capacity to address outdoor temperatures and humidity.

High efficiency heat recovery ventilators (HRVs) and energy recovery ventilators (ERVs), when present, can assist to maximize outdoor air supplies and control humidity. Heat/energy recovery systems are, however, vulnerable to cross-contamination of incoming air with potentially infectious exhaust. ASHRAE has published detailed guidance for ERVs during an epidemic, addressing design, evaluation, inspection, remediation and repair, and re-commissioning after shutdown.[49] With measures to ensure complete flow separation, for example stopping and preventing leaks in systems utilizing energy recovery wheels, ERVs may be made sufficiently safe for continued operation. In these systems, careful pressure adjustment is required, and additional filtration and other measures may be required to prevent cross-contamination. If feasible, temporarily bypassing the energy exchanger/condenser components may be indicated, pending cleaning, inspection and completion of refurbishment and maintenance as required.

Minimum air exchange rates have historically been developed to keep carbon dioxide (CO_2) levels below target values, and thereby also keep the related bioeffluent contaminants from occupants below levels that would cause indoor air quality complaints. Lower occupancy will of course also result in lower CO_2 levels. Ventilation to maintain a lower CO_2 level is beneficial for health and productivity,[50] and pandemic response recommendations are to increase ventilation with outdoor air as much as possible.[44] This will bring CO_2 levels closer to outdoor levels. It is possible that real-time measurements of CO_2 levels may prove to be a useful indicator of the risk of COVID transmission where infectious individuals are present as occupancy increases, in which case CO_2 levels may correlate with airborne viral loads.[44] For example, increasing ventilation in under-ventilated buildings, reducing CO_2 levels from 3200 parts per million (ppm) to 600 ppm, was sufficient to halt ongoing transmission of tuberculosis in university buildings.[51] Relative humidity and particulates may also be monitored in buildings to protect health; while merited, these parameters would be less closely related to potential infection transmission.

Measures to eliminate viruses in the HVAC system would not be necessary with zero recirculation during moderate weather, but filtration and potentially ultraviolet germicidal irradiation (UVGI, discussed below) of recirculated air should be available when 100 percent outdoor air is not feasible, such as during extreme temperatures. High efficiency filtration for particles as well as removal of airborne chemicals is necessary to address outdoor air quality, to remove pollen, transport related or industrial air pollutants, and smoke during emergencies such as wildfires.

In addition to adjusting existing ventilation systems, more extensive options could include:

- Installation of special exhaust systems from locations of greater risk. Examples include washrooms (that should be continuously exhausted) or a room that is designated for individuals who are developing symptoms while on the premises, until such time as they are able to leave the facility safely;
- Use of stand-alone or portable systems if upgrades aren't possible. Stand-alone filtration, humidification or dehumidification equipment may be needed to accommodate increased ventilation rates, depending on outdoor air conditions;
- Installation of high capacity air exchange ventilation systems in buildings where there is currently limited or no mechanical ventilation or air conditioning (e.g., some schools, institutional and multi-residential buildings). HVAC capacity requirements, and ease of maintenance and filter replacement and installation are important considerations;
- Upgrading of fan/filter units to include MERV 13 or better, or HEPA filters. Retrofits may also include pre-filters to ease the burden on the finer filters, and filters may require more frequent replacement. More powerful fans may be required to handle the higher pressure drop across the filter bank;
- Upgrading of systems to provide more outdoor air than the current maximum; preferably 100 percent outdoor air and exhaust. Upgrades must also include optional recirculation and

cleaning of indoor air, to be used during extreme weather and in the case of high levels of outdoor air pollution.

More extensive options for HVAC systems would typically be expensive and require significant capital budgets; however, owners should be aware that improvements are possible, and assessment of options should be considered. A wide range of different systems is available, and it may be incorrect to assume that upgrades are not feasible. Buildings that are known to have poor ventilation and/or aging systems may be especially good candidates. In some cases, capital works or deferred maintenance planning programs may already have identified and estimated costs of the needed replacements or improvements.

HVAC engineers and operators can identify unique features and behaviours of airflow within a particular building, while specific features must be respected in planning such as negative-pressure rooms for containment in laboratories. Relative pressures and airflows under various operating conditions must be verified with measurements and testing (e.g., smoke testing).

Even with a high rate of air exchange, the intricacies of airflow in variously configured occupied spaces with furniture and barriers, can result in eddies. Using a combination of experimentation and modelling, it was demonstrated, that “hotspots” of virus accumulation may occur in indoor spaces.[52] Several solutions are discussed by the authors, such as displacement ventilation, which delivers conditioned fresh air through supply outlets located at or near floor level and relies upon temperature stratification to draw the air upward, where it is exhausted at ceiling level. Canada’s National Research Council researched displacement ventilation, including during cold weather. They found that it was feasible and more efficient than conventional mixed air ventilation supplied from ceiling diffusers or from perimeter units 1 m above the floor, because in displacement systems, stale air is not continuously mixed with fresh air.[53] Displacement ventilation works in combination with the convective air currents, by which warm air from occupants rises, and thereby reduces the horizontal transfer of exhaled air from one occupant to another. It is unclear, however, the extent to which infectious particles may be re-entrained from surfaces, including the floor, with conventional mixed or with displacement ventilation systems.

Building ventilations systems should ideally be designed and pressures checked to ensure that air flows from “cleaner” to “dirtier” spaces, according to pressure zones and exhaust rates.[44,54] For example, areas with lower occupancy and lower risks (e.g., workstations that are well distanced and with good ventilation) should not be jeopardized with air from riskier areas where greater viral loads might occur (e.g., washrooms, entrances, corridors by elevators, stairwells that may be poorly ventilated and where breathing may be heavier, or occupied meeting rooms). While elevators can potentially have high levels of ventilation, this may not be the case in many buildings. Options for ventilation via stairwells and other vertical shafts are discussed in the context of mixed ventilation,[55] but they may be limited by fire codes that require the capability to pressurize these vertical spaces during emergency situations and for fire doors to remain closed. Such situations may be candidates for air disinfection (see S. 3.1.2).

Supplementing ventilation by opening windows may provide effective, inexpensive dilution of aerosols, although the overall value is contingent upon the quality of the outdoor air and resulting airflows. Mixed ventilation strategies in design and construction offer many money-saving and energy-saving means to provide greater outdoor air supplies, as well as heating or cooling according to the weather.[55,56] When using mixed ventilation, consideration must be given to overall airflows in complex buildings.[43] Modern buildings may have windows that do not open (and some older building may have windows that do not function well), so opening windows to increase ventilation is not always an option.

3.1.2. Air disinfection

Ultraviolet germicidal irradiation (UVGI), conventionally 254 nm wavelength light generated by mercury lamps, may be used to inactivate airborne viruses.[44,47,57,58] Fixtures must not be in plain sight to reduce risks of causing cataracts, and the glass must filter shorter wavelength light to minimize generation of harmful ozone,[59] which is in itself a hazard. Ozone also reacts with volatile organic compounds (VOCs) from scents, and cleaning and renovation products, to form toxic degradation products. Nevertheless, UV-C sources may be installed in plenums with reflective interiors, or weaker sources may be situated high on walls, shielded from direct sight and with appropriate warning labels for maintenance personnel.[60,61,62]

An alternative to conventional mercury lamps is filtered excimer bulbs, that emit ultraviolet light of 222 nm wavelength. The slightly smaller wavelength is said to limit ozone generation and risks of skin and eye damage,[63] and can be effective against coronaviruses.[61]

UVGI fixtures have been used in healthcare, and use of upper-room installations along with ceiling fans for mixing, to avoid stagnant air, is supported by high level scientific evidence.[44,45]

UVGI may be considered for washrooms, poorly ventilated spaces and areas with intermittent but potentially higher numbers of people breathing heavily such as entrances/exits, corridors by elevators, and elevators and stairwells.

Some air cleaning technologies utilize electrostatic precipitation, but these are not recommended. ASHRAE's review of filtration and air cleaning systems noted that these devices generate ozone and may be harmful overall.[62] ASHRAE identified less evidence regarding benefits and risks of technologies other than UVGI and filtration for airborne viruses, and only these two technologies are presently recommended.

3.1.3. Local (stand-alone) air cleaning and moisture control

Ventilation capabilities vary across different buildings, and seasonally with changing heating/cooling loads. Given that air recirculation will be required in many buildings while COVID-19 remains in the community, attention to filtration may move beyond the HVAC system to include local stand-alone HEPA filtration air cleaners [45] in adapted workspaces. Within constraints of the building system, airflow may potentially be adjusted to be more protective against transmission. For example, stand-alone air filtration may be deployed along with barriers to direct clean air to individuals, to intercept airflows with potentially higher viral load (e.g., near a washroom or meeting space, or in an isolation room). This is illustrated in healthcare, where stand-alone air cleaners may feature along with barriers in the provision of clean air to patients in multi-bed rooms.[64] Candidate areas in non-healthcare settings would include areas with poor ventilation, such as where staff are working behind new barriers that may hinder airflow. In order to be effective in mechanically ventilated buildings, these units need to be properly sized and located to direct airflow in a manner expected to minimize exposure from potential sources of virus, and be regularly maintained according to manufacturer's instructions.

It is possible for virus-laden dust to be re-suspended in air from carpets or soft furnishings. Thus HEPA filtration should be installed and maintained on vacuum cleaners, according to manufacturers' instructions. Cleaning staff must use appropriate personal protection equipment (PPE – mask and eye protection) and wash hands regularly. Vacuuming during off-hours (a common practice already) is recommended.

Depending upon outdoor air conditions, stand-alone humidification or dehumidification equipment may also be needed supplement existing capacity, to prevent moisture and biological contaminants, or to maintain comfortable humidity (see Section 4.2).

3.2. Water systems

Periods of low or no occupancy, when water lies stagnant in plumbing and antimicrobial additives (e.g., chlorine or chloramine) from water utilities dissipate, can lead to growth of diverse pathogens such as *Legionella*, or to elevated levels of metals such as lead and copper that may leach from building plumbing and supply pipes. Return to use requires cooperation between building owners and operators, the water utility and public health.[65]

In a review of water supply re-commissioning focused on post-COVID-19 re-occupancy of buildings, Purdue University scientists and engineers describe considerations for inspection, testing, flushing, cleaning and verifying safety for washing and drinking water following extended stagnation.[65] Fixtures, and systems supplying hot and cold water, equipment (e.g., distillation units or ice machines), and systems for greywater (washwater and rainwater) should they exist, all require attention.

Large buildings may have complex plumbing interconnections, risking dead zones or areas where sufficient flushing of lines may be dependent upon the strategy employed. Guided by the detailed layout of plumbing systems, systematic approaches involve starting close to the water supply, and possibly flushing zones separately to achieve effective flow rates.[66]

Biological films and solids are expected when flushing plumbing, so aerators should be removed prior to flushing, and diligently cleaned then reinstalled prior to sampling. Baseline microbial and chemical testing of representative samples will assist to identify the extent of problems and sections of plumbing at risk of poor water quality. Sampling plans according to details of the plumbing layout, with smaller first-run samples as well as samples following specific volumes of flushing, may differentiate contributions of plumbing fixtures versus sections of pipes with microbial biofilm, in water contamination.[67]

In cooperation with public health, testing after flushing of plumbing will verify the suitability of water quality for flushing toilets, for washing hands, and finally for drinking once safety is established. Additional disinfectant may be required to clear plumbing. During this time, clear signage and provision of clean drinking water are strongly recommended.

In preparation for re-opening, the feasibility of installing lids on toilets may be considered, as viral fecal contamination may be spread via droplets and aerosols generated with flushing.[46,68]

3.3. Cleaning and disinfection

Re-occupancy should be preceded by thorough cleaning, and development of area-specific cleaning schedules. The objective is to minimize viral transmission from objects, surfaces or dust that may carry infection (fomites), via the hands, to the mouth, nose or eyes where infection may be initiated.

"Cleaning" is the removal of contaminants from surfaces, whereas "disinfection" is the destruction of all potentially infectious materials including SARS-CoV-2 and living organisms such as bacteria, fungi (e.g., moulds), algae and spores. Disinfection to achieve sterile environments is necessary in key areas of healthcare, where gloves are used for sterility of hands. "Sanitizing," less stringent than disinfection, is used in non-healthcare settings and for hand cleaning.

3.3.1. Sanitizing

Washing with soap and water is the preferred method to sanitize hands. Soap removes contaminants and inactivates SARS-CoV-2, without any need for additional antimicrobial chemicals such as triclosan.[69,70] SARS-CoV-2 is enveloped by a lipid (fatty) coat, that makes it very susceptible to inactivation. Surfactants such as soap or detergent are sufficient to sanitize most surfaces in buildings.[71,72,73] Approved sanitizers and disinfectants require a wet contact time to ensure efficacy – times that may be similar to, or frequently much longer than, the 20 seconds recommended for washing with soap.[70]

Alcohol-based hand rubs may be used when facilities to wash hands are not available. Health Canada has published recommended formulations for alcohol-based hand sanitizers containing alcohol (ethanol or isopropanol), glycerol, and small quantities of hydrogen peroxide and water. Temporarily during the pandemic, lower quality ethanol with limited contaminants may be used to bridge supply constraints,[74] although certain alcohol-based hand sanitizers with unacceptable contaminant levels were recalled.[75] Health Canada recommends that fragrance not be included, because of allergic reactions (often asthma).[74,76,77] Nevertheless, occupants of multi-unit buildings have noted infiltration of odours from neighbours' enthusiastic use of cleaning products. As well as communicating with the neighbours and/or landlord/building manager,[78] sealing of cracks with a tolerated filler (caulking, filler or plaster of Paris) or tape (metallic or paper based may present lower VOCs) are possible remedies.

3.3.2. Disinfection

Products registered with Health Canada for sanitizing hands and for disinfection of surfaces that are expected to be effective against SARS-CoV-2 are listed online[70] and identified on the packaging with a Drug Identification Number (DIN) or Health Product Number (HPN). While surfactants (soap or detergent) inactivate SARS-C0V-2 and are sufficient for non-healthcare use, some other potential ingredients pose a number of risks.

Routine use of disinfectants contributes to the slower-moving global infectious hazard of antimicrobial-resistant organisms,[79,80] while high-alcohol preparations are flammable and chemical toxicities pose proximate risks.[76] Some of the more concerning ingredients include quaternium ammonium compounds or "quats,"[81] sodium hypochlorite (chlorine bleach), triclosan, chlorhexidine gluconate, sodium dichloroisocyanurate and a few others contained in small numbers of products.[76,82] Harmful effects may be immediate (e.g., allergies or sensitivity reactions) or delayed. For example, the common antimicrobial triclosan disrupts the endocrine system (specifically thyroid), affects early brain development,[83] and harms the liver. Triclosan also poses risks to aquatic organisms as it enters waterways via wastewater,[84] and thus is listed on Schedule 1 of the *Canadian Environmental Protection Act* (CEPA). Even prior to COVID-19, triclosan was being released into the environment at levels that were potentially harmful,[85,86] so it is important to read labels to avoid ingredients of concern.

Although a surfactant (soap or detergent) is effective against SARS-CoV-2, disinfectants against more robust, non-SARS pathogens may be desired for higher risk applications such as medical care and food contact surfaces. Safer disinfectant options listed by the U.S. Environmental Protection Agency (EPA) Safer Choice Program [87] that are also approved in Canada include L-lactic acid, citric acid and peroxyacetic acid.[88] During the pandemic, dedication to healthcare of limited supplies of safer disinfectants containing alcohol (for hand sanitizers and wipes) or peroxides[89] may result in more higher-risk disinfectants being used in new applications and spaces. There are concerns over exposing children, pregnant women and anyone whose health is compromised to excessive quantities of volatile organic compounds from alcohol-based and other sanitizers, and to many potential disinfectants.

If products beyond soap/detergent and water are required for vulnerable groups, then safer products should be preferred, disinfection should be conducted when spaces are not occupied, and residues should be washed off. Optimizing indoor air quality with attention to cleaning details is further discussed in Module 13, Addressing Multiple Chemical Sensitivities.[77]

3.3.3. Choice of validated, regulated cleaning and disinfection products

Times of uncertainty and fear are unfortunately occasions for marketing of products with overblown claims to solve the problem of the day. Ineffective and risky actions inspired by misinformation and vested interests highlight the importance of attention to regulatory requirements, and possible loop-holes. Canada's laws require assessment of anti-viral treatments, cleaning products and products claiming to inactivate viruses, as well as chemicals to disinfect large spaces. Regulations for disinfectants and pesticides underlie legally required approvals, to protect health and to ensure efficacy of purported solutions for COVID-19. Promises of novelty and extended safety merit close examination.

There is interest in surfaces that have "self-disinfecting" properties with either: 1) residual activity of a chemical application; or 2) by virtue of the innate characteristics of the surface (e.g., SARS-CoV-2 has a shorter half-life on copper than on other surfaces[34]). This approach may have some merit, but it is not yet a validated option against viruses, and can pose risks.

Viruses are inanimate, so must be damaged physically in order to be inactivated (bacteria and other living microbes that may contaminate surfaces can be killed via additional biological toxicity mechanisms). The lipid-containing capsule of SARS viruses are disrupted by wet contact with a surfactant; dry or residual disinfectants have low anti-viral activity and may themselves pose risks when transferred to the skin or enter the indoor environment. As described elsewhere, heat and UV light are effective against SARS viruses.

Plastics embedded with antimicrobial chemicals are marketed, but these are only effective to the extent that they leach hazardous chemicals to their surface[90] so are subject to the same limitations as other dry residual chemicals. Similarly, testing of a nanotechnology surface using liquid virus samples[91] might over-estimate effectiveness against drier particles. Catalytic surfaces that dismantle bacteria and viruses have been researched in air filtration[92] and liquid systems,[93] with uncertain feasibility and risks for use on touched surfaces.

Products that are sprayed broadly to control infectious agents must be registered as pesticides in Canada. The use of a previously unregistered product with the intention to provide prolonged protection against SARS-CoV-2 in Toronto trains was subject to Pest Management Regulatory Agency intervention (the PMRA is within Health Canada). The product has since been registered (PCPA#15133) against bacteria, fungi and algae, but is not labelled for anti-viral applications. As of August 21, 2020, no space-spraying or "fogging" products were registered as pesticides for application in Canada against human viruses (some products are registered for surfaces, with very specific label instructions that legally must be followed).[94] A related uncertainty is the use of electrostatic sprayers, which are said to require much lower quantities of product; however it is unclear how adequate wet contact times will be ensured, or the veracity of claims to coat harder to reach surfaces.[95,96]

3.4. Adaptation, modifications and new equipment and procedures

Beyond cleaning and air quality, other innovative means to reduce SARS-CoV-2 levels in the environment and viral transmission are being investigated, proposed, tested and implemented.

Dividers or shields installed to separate staff from the public (e.g., at service desks) and staff or students from one another (e.g., barriers on desks) may intercept droplets, though aerosols can still transfer via the airflow. Barriers may affect and direct air flow, and decrease ventilation in areas, so removal of infectious aerosols might be limited in a space that is meant to be protected.[52] Local air cleaning may help. Regardless, in situations such as these, wearing masks becomes an essential part of the strategy. As well, just as with all protective equipment, barriers require frequent cleaning.

The future may bring more use of voice-activated or touchless equipment. To protect against failure of voice-activated components, particularly in critical applications such as elevators, designs must also include conventional controls such as push buttons.

Handheld temperature measurement devices are being used to detect fevers in air travellers and in workplaces abroad, as one aspect of broader screening efforts. A review of the technology by the Canadian Agency for Drugs and Technologies in Health (CADTH) concluded, based on limited evidence, that infrared temperature screening methods were ineffective for detecting infected staff or visitors entering health care facilities or for screening travellers.[97] Infrared temperature testing on its own has inaccuracies (potential fevers must be verified with a tympanic measurement), will miss afebrile cases and may be defeated with anti-fever medication.

"Silent hypoxia" may be experienced in COVID-19 infections, and can be detected using a finger-clip that measures pulse and blood oxygen saturation or "pulse oximeters." but is typically not the first symptom. Thus, although pulse oximetry is important in clinical settings it is unlikely to identify otherwise asymptomatic infections.[98]

In combination, screening that includes education and querying of symptoms and contacts can improve awareness, potentially contribute to epidemiology, improve public health measures such as quarantining, and might affect willingness of ill people avoid travel or going to workplaces or schools. Thus, comprehensive screening has potential to provide another helpful layer of protection.[99] These activities, along with identifying and following cases and contacts, will require honest participation by staff, and occupant, management and public health support.

4. Ongoing Operations

As workplaces open up in phases, initial low occupancy rates could make it easier to enable physical distancing, and are expected to result in low average concentrations of viral particles in the air (higher concentrations will nevertheless occur in the vicinity of infectious individuals). As occupancy increases, additional measures may be required to protect occupants, such as additional cleaning of surfaces, installation of protective barriers, increased ventilation, filtration and disinfection of air if sufficient ventilation is not possible, and wearing of masks for extended times.

Even after reopening, initial periods of low occupancy may result in recontamination of water, so routine flushing of toilets (with lids lowered, if available[68]) and running of taps may need to continue, and retesting may be advisable. It is essential to continue routine daily flushing of pipes to reduce drinking water lead levels in schools.

Engineering controls are less likely to prevent SARS-CoV-2 transmission between individuals in relatively close proximity, especially over an extended period of time, so measures to improve physical distancing, requirements to wear masks, and limiting the number of interpersonal contacts (e.g., "cohorting" to restrict interpersonal contact to a consistent small group of people) should be included in strategies established for ongoing operations.

4.1. Minimizing airborne infectious particles

Following the implementation of measures in section 3.1, ongoing operations will entail enhanced cleaning/maintenance to accommodate increasing numbers of occupants over time. Furthermore, to facilitate continuous improvement, lessons learned from incidents of suspected or actual transmission in a particular situation should be carefully noted, including observations and recommendations from occupants.

4.1.1. Masks

The first (when exhaling) and final (when inhaling) air filter and layer of protection against SARS-CoV-2 is a mask.[30] Early in the pandemic medical and public health representatives facing shortages of personal protective equipment (PPE) did not recommend masks for the general public, but knowledge has advanced and that advice has changed. In industrial workplaces or occupational settings with high and longer duration exposures to hazardous particulates, workers typically wear a fit-tested rubbery respirator with high-efficiency filter cartridges, while N-95 respirators or surgical masks are used in health care, according to risk level.[100] Cloth masks are not subject to the same quality criteria as respirators, but will capture droplets from coughs and sneezes. Indeed, small particles are captured to some extent as they encounter fibres and by electrostatic attraction, so multi-layer cloth masks offer protection from airborne infectious particles as well.[101] Air bypassing the mask poses significant, unnecessary risk, so masks must be properly worn to cover both the nose and mouth, and attention should be paid to close fit around the edges.[102,103]

Eye coverings and face shields also offer incremental, complementary protections.[28] Medical style face shields with no gap at the top, extending to the ears and below the chin, can intercept droplets from a cough and stop touching of the face with potentially contaminated hands, but do not offer protection equivalent to masks for inhalational exposures.[104] Face shields are used in medical settings as a further layer of protection along with masks, and were encouraged early in the pandemic against droplets.[105] Face shields do not protect against finer aerosols and are described by occupational and public health organizations such as the Public Health Agency of Canada as “eye protection.”[106] (SARS-CoV-2 may infect the eye.[107])

Consistent information and requirements are necessary to overcome confusion about the roles of face coverings such as multi-layer masks and face shields to reduce SARS-CoV-2 infections, including guidance for proper usage and care.[101]

4.2. Climate and Relative Humidity

Some viruses, and related flus and colds are more common at particular times of the year, as persistence of some viruses is affected by the environment (e.g., humidity, temperature and sunlight) and there may be a better, more robust physiological response to contagions with higher vitamin D levels from greater sun exposure.[108] Relative humidity may affect the response of airways to the virus, as low humidity dries airways, reduces trapping of dust and pathogens by the mucous layer and reduces transport via ciliary action to the upper airway to be expelled,[109] thereby increasing vulnerability to infection. With respect to COVID-19 it is recommended that humidity be maintained at 40 percent to 60 percent,[44] but while higher humidity levels might be feasible in the summer, excessive humidity may condense in basements and cold walls, causing mould in buildings, that will impact health and damage structures.[110]

All else being equal, summer-time relief from viruses is not always the case.[111] Although some small studies suggest that COVID-19 might abate over the summer in Canada, the 2020 summertime surges of infections in the U.S.A. and elsewhere, and evidence of effective transmission in all climates globally, has experts concluding that SARS-CoV-2 transmissibility will be maintained throughout the seasons.[112] Surges of infections in congregate housing during initial lockdowns, and then from socializing subsequent to loosening of lockdowns, demonstrate clearly that individuals’ circumstances and actions are among over-riding determinants of SARS-CoV-2 transmission.

Temperature is important in inactivation of coronaviruses. Experimentally, SARS-CoV-1 persistence was rapidly diminished at 38°C and very high relative humidity, but the virus remained infectious for days at temperatures and relative humidity commonly encountered outdoors and in air-conditioned environments in Canada.[113] Heating to 56°C is being used for rapid (15 minute) non-toxic disinfection of vehicles, such as for police.[114]

4.3.Cleaning

The choice of cleaning products is discussed in Section 3.3. Surfaces that are touched frequently by multiple people may provide sites for virus transfer, and thus require repeated cleaning throughout each day with soap/detergent and water, or wiping with alcohol if soap and water are not feasible. Examples include door handles, light switches, bathroom fixtures, banisters, push buttons (for doors, elevators, intercom, etc.), and shared equipment or devices (e.g., photocopiers, drink dispensers or payment devices). Personal frequently touched surfaces also merit cleaning, including: electronics, drink containers and unshared equipment in the workspace (e.g., desk, chair, computer, office supplies).

Hand cleaning requires:

- provision of soap with no disinfectant or fragrance ingredients;
- towels to dry hands, such as laundered towelling or paper towels with dedicated disposal to permit recycling or composting (disabling blowing air dryers will eliminate a potential source of airborne virus[116]);
- alcohol-based, fragrance-free hand sanitizer in dispensers at entrances, exits, elevators and other places where there may be interpersonal interactions or commonly touched surfaces, and no ready access to hand washing;
- signage for hand sanitizing stations and how-to-wash hands where sinks are present.

If toilets are fitted with lids, a sign should remind users to lower the lid before flushing.[68]

4.4. Considerations for ongoing detailed response

After months of telework or layoffs, the evolution of new standards and practices to maintain the necessary physical distancing, sanitation, health and wellness activities (e.g., mask use, contact tracing and testing, and symptom and possibly temperature screening) and follow-up will present initial challenges. These principles have been publicized by health authorities and media during recent times. Successfully minimizing disease transmission will depend upon layers of protection in many locations such as offices, laboratories, meeting rooms, washrooms, workshops, cafeterias, shipping and handling, corridors, elevators and stairways. Clear, consistent expectations and instructions, and on-the-spot signage are essential to avoid confusion, to encourage compliance and hopefully to ease frustration and anxieties.

If COVID-19 is present in the community, it will most probably emerge in the workplace. It is important to consult, and to establish and communicate a decision-tree and action plan for when an occupant or visitor develops symptoms or tests positive for COVID-19. Resources and templates are becoming available from occupational health and union organizations (see Resources, Section 8). At the same time, in this uncharted COVID-19 journey, it is important to maintain open channels of communication between management, unions, staff and parents' organizations for schools, for continuous improvement. Health and wellness measures need be consistent with guidance from public health authorities, and executed in consultation and cooperation with public health.

4.4.1. COVID-19 detection and public health measures

The following measures may be used in workplaces and in cooperation with public health as part of a layered approach, and as appropriate according to the level of risk in the community (number and rate of change of COVID-19 cases), type of building (e.g., single-story to high-rise) and scenario (e.g., workplace, school, commercial space). Measures in place that affect the potential for SARS-CoV-2 transmission among segments of society also affect potential transmission within buildings, such as restrictions on opening and services of businesses and facilities. Importantly, it is increasingly clear that children and adolescents may be significant, silent carriers of infection.

Screening

- Screening for COVID-19 before and following work with a questionnaire/app to report symptoms, and exposure to potential or known cases;
- In conjunction with questionnaire results, screening for elevated temperature using a handheld no-touch thermometer, and less frequently pulse oximetry, have been implemented in some places, albeit with little evidence of significant marginal benefit for the level of effort and resources. Checking of suspect cases would include a tympanic (in the ear) measurement. As with all non-invasive screening measures, temperature checks will miss pre-symptomatic and asymptomatic cases. If utilized, during this close encounter, the screener must wear personal protective equipment, and the person being measured should wear a mask;
- Rapid testing of symptomatic individuals for SARS-CoV-2, isolation, contact tracing, and testing and quarantine of positive cases. Testing of close contacts may be considered. Determine roles of public health and others, when an individual who was in the building has a positive test;
- In particular instances when cases are surging, in the context of interactions of people including potentially infected individuals, or to assess community level infection, beyond routine screening for symptoms, temperature, consider SARS-CoV-2 testing in targeted strategies for asymptomatic/pre-symptomatic cases. This is practiced in healthcare, carried out for sports teams, and proposed to be essential for successful return to college/university.[26,32]

Wearing of masks

The wearing of masks is emerging as one of the most important strategies that can be employed to reduce COVID-19 transmission, and should be advised or required in conjunction with other measures listed herein.

- While high-quality cloth masks are less effective than reusable cartridge respirators or N95 masks, they are readily available to the public, tend to be more comfortable to wear, and will capture large droplets and to some extent lessen aerosol exposure. There is a wide range of quality and fit of reusable cloth masks, including some better ones for protection against air pollution while cycling, and with or without inserts. Hands must be washed/sanitized before and after donning or doffing, and masks should be changed when soiled or damp and washed frequently;
- Workplaces could consider providing well-fitting, multi-layer masks.

Tracking cases and contacts, isolation and quarantine, and indicators of infection

- Voluntary use of an ethical[115] phone app when it is validated in the workplace context for contact notification in case of COVID-19 (Canada's app is available at: https://www.canada.ca/en/public-health/services/diseases/coronavirus-disease-covid-19/covid-alert.html);
- Clear policies and compensation to stay home when sick or following significant exposure to an infected individual (as defined by public health);
- In partnership with public health and researchers, testing of sewage for SARS-CoV-2 virus may provide an early indication that the virus is active in a building or region[116] (the Canadian Water Network COVID-19 Wastewater Coalition is advancing "wastewater epidemiology" for SARS-CoV-2[117])
- Testing for antibodies/immunity to SARS-CoV-2 might be warranted, once interpretation of results is understood, and testing is reliable and available.

4.4.2. Measures in workplaces and educational settings

Each workplace, school or other building should be inspected and assessed for potential risks (points of vulnerabilities) using a standardized checklist. Administrative measures may include:

- Requiring physical distancing and protections (e.g., mask wearing and hand washing);
- Cleaning and maintenance staff should wear masks and other PPE as appropriate for chemical and potential infectious exposures, and have adequate supplies to change them as needed;
- Minimize size and diversity of groups meeting in person (i.e., form and enforce cohorts or "bubbles" rather than continuously changing members of groups on-site);
- Continue telework as appropriate for employees when their presence onsite is not necessary, and particularly for employees with chronic conditions or living with someone with chronic conditions that put them at greater risk of severe disease (e.g., heart disease, hypertension, chronic respiratory disease, diabetes, obesity, cancer and immune suppressive treatments[118]);
- Modify the work to limit exposures such as the use of electronic signatures and files rather than photocopying papers;
- Stagger work hours to minimize crowding of entrances, elevators and food facilities if operating.

4.4.3. Physical arrangements in the workplace and educational settings

- Locate furnishings (e.g., desks, tables, chairs) to limit and spread out seating; restrict occupancy in open-plan offices (e.g., use alternate corrals); reconfigure open-plan offices that previously had small footprints for individuals. The new layout should not compromise health and safety practices;
- Retrofit plastic barriers where staff interact with the public or with numerous employees (e.g., desks at entrances), and in close quarters. Of note, placement of barriers should include consideration of airflow and possible remedial measures such as stand-alone air cleaners, while ensuring that potentially contaminated air is not inadvertently directed to a potentially cleaner, occupied area.
- Post signage for directions (e.g., staircases that are for going only up, or only down; maximum number of people in the elevator or particular rooms; markings on floors delineating separation distances);

- When possible, leave doors physically open, and where feasible devise doorless entrances (e.g., as have been provided for washrooms in some commercial spaces);
- For washrooms, consider retrofitting lids on toilets,[119] using towels rather than air dryers after washing hands,[120] and ensuring frequent cleaning and substantial, continuous exhaust from washrooms (washrooms are maintained at a lower pressure);
- Enclosed waste containers may have foot-activated lids. Containers should have adequate capacity and be emptied frequently due to potentially higher volumes of paper towels and other pandemic-related trash. Consider composting or recycling of paper;
- Clean reusable drink containers may be used, with appropriate sanitation and hands-free or limited-touch refilling.

4.5. Surveillance, continuous learning and preparedness

The COVID-19 health emergency is requiring rapid and ongoing adaptation. Lessons learned while reopening buildings and resuming operations will be important as this disease ebbs and flows, and for subsequent emergencies. Systematic data collection will aid this learning and development of preparedness plans. Site-specific protocols should be developed and made available, including building operations during very low occupancy and shut-down, and for reopening to maximum occupancy, to maintain safe and adequate ventilation and water systems.

Learning during staged reopening is expected to result in iterative adjustments, to reduce potential transmission of contagion as increasing numbers of people return to workplaces, schools and public places. Minimizing transmission of SARS-CoV-2 is very challenging, and innovation in the necessary multi-pronged approaches should be evaluated and shared. Blunting COVID-19 will have the additional benefit of reducing the spread of other viruses such as influenza.[121,122]

When COVID-19 cases occur among workers, whether contracted at work or elsewhere, both management and public health aim for the earliest possible detection of cases, and rapid efficient contact tracing and quarantine to intercept the chain of transmission and to reduce the number of subsequent cases. Examination of circumstances of transmission may yield additional recommendations to further dampen the spread. The protocols and decision-trees for response should be established, communicated to occupants and visitors, and reviewed/revised regularly and as needed.

Going forward, facilities should be designed, built and retrofitted with versatile capabilities to adapt to diverse emerging threats. For example, beyond contagious disease, other threats such as climate-related hotter and extreme weather, and smoke from wildfires require different capabilities, including reduced ventilation with outdoor air, and high-quality, high-capacity air filtration/cleaning for chemicals and particles.

Preparedness requires systematic approaches to planning, detailed documentation, simulations, subsequent adjustments and practice for rapid responses. Most importantly, preparedness requires learning from emergencies. As experiences with COVID-19 unfold it behoves us to ensure that data is collected and acted upon for continuous improvement and better outcomes for the population, economy and environment in the near term and for the next time.

5. Conclusions

Lockdowns suppressed but did not eliminate COVID-19 in Canada, whereas economic factors, impacts on families, and mental and social wellbeing make stay-at-home emergency orders unsustainable. Strong science, collaboration and cooperation are essential for evidence-based and pragmatic precautionary approaches, to co-exist with this threat.

SARS-CoV-2 is a potent, contagious virus that can spread undetected before manifesting as an outbreak of COVID-19 among individuals who are significantly exposed and/or more vulnerable. Interrupting transmission requires multiple layers of protection, including personal practices, environmental controls, public health measures and surveillance. Local public health, building owners and management, workers/unions, and experts in HVAC, infection control, environmental health and other disciplines need to be partners contributing to elements of response.

Reopening buildings will entail extensive cleaning, as well as restarting/re-commissioning and testing air and water systems. COVID-19 response requires maximizing outdoor air supplies via HVAC systems, as well as air cleaning, examining and addressing details of airflow, considering retrofit or replacement of poorer and dated systems, and use of ancillary equipment.

SARS-CoV-2 is primarily transmitted via droplets and micron-sized aerosols emitted by infectious individuals,[10] and development of clinical COVID-19 depends upon the airborne concentration, proximity to the source, time of exposure and characteristics of the susceptible individual. Even with high building ventilation rates, modelling indicates that "hotspots" of virus-laden aerosols may persist due to eddies in airflows. Thus it is important to verify airflows, and to wear masks indoors to limit spread and to provide some protection to the wearer (to the degree offered by the choice of mask, with greater protection from higher quality, multi-layer, well-fitting and properly worn masks, even if not medical grade). Hand hygiene and frequent environmental cleaning, particularly of frequently touched surfaces, can interrupt transmission of SARS-CoV-2 via hands to the mucous membranes of the mouth, nose or eyes.

Only in specialized and healthcare settings is there need for stringent disinfection. SARS-CoV-2 is relatively labile, so washing with soap/detergent is recommended, or wiping with alcohol when washing is not an option. Use of chemicals that have adverse health effects (e.g., fragrance and some disinfectants) is counter-indicated. As of August 21, 2020 no space-spraying or "fogging" products are registered for legal disinfection use in Canada against human viruses.[94] No product or surface treatment has been established to provide long-term protection against viruses.

Successful return to group activities in workplaces, learning institutions and public venues will hinge on clear, consistent guidance detailing protections, expectations and action decision-trees for individuals, organizations and regions. Safety and contingency plans should be developed collaboratively using the most recent data and science, be reviewed regularly as well as following events, and communicated clearly. Rapid, efficient transition to and from telework and e-learning should be planned in advance. There is much still to be learned about this virus, as evolving scientific knowledge guides pragmatic precautionary approaches. For both COVID-19 response as well as pandemic preparedness, it behoves us to document events and actions systematically, and to assemble data to answer research questions, all the while working to suppress COVID-19.[123,124]

When COVID-19 is in the community, SARS-CoV-2 is expected to be present in buildings. For the foreseeable future and until a large majority of individuals are immune (this is currently unpredictable given SARS-CoV-2 mutations[125]), multiple actions, *taken together*, can minimize the potential dose of the virus to individuals, and the number of serious cases.

6. Detailed Annex: SARS-CoV-2 transmission and COVID-19

Intercepting and reducing transmission of SARS-CoV-2 requires understanding how transmission occurs. COVID-19 begins with SARS-CoV-2 transmission via inhalation of virus-laden particles that reach mucous membranes in the respiratory and digestive systems, and/or hand-to-face transfer to the mouth, nose or eye. Viruses themselves are not actually alive, which has implications for methods to inactivate them. Viruses enter susceptible cells in the respiratory and/or digestive tract, where the host cell's resources, structures and enzymes replicate the virus then releases many copies. During infection with SARS-CoV-2, even before symptoms manifest, the virus is shed from the respiratory tract[4] and digestive tract (in feces),[5,6] contaminating the environment and thus potentially transmitting infection to susceptible hosts.[7,8]

Scientific evidence and recommendations have evolved as understanding improves of airborne transmission of SARS-CoV-2. In a letter to the World Health Organization (WHO), 239 scientists outlined the scientific evidence and importance of airborne transmission and urged widespread use of good quality non-medical masks [10] – a recommendation that is now made by Canada [12] and the WHO,[13] and is increasingly required in indoor spaces, transit vehicles and even highly occupied outdoor spaces, especially when physical distancing is not feasible. Addressing airborne viral transmission is essential for any precautionary and successful planning to limit and co-exist with SARS-CoV-2, until effective treatment and/or population (i.e., herd) immunity are achieved.

Given that zero viral transmission – perfection – is unlikely in workplaces while SARS-CoV-2 is circulating in the community, how much viral load might be tolerated? This is expected to be highly individualized and is not quantified, but this perspective can guide prevention strategies. A single virus particle or "virion" may be sufficient to induce infection of cells in a laboratory, but the body's natural defenses mean that an infectious dose is greater in people. Whether viruses replicate to the extent that an individual becomes infectious and sheds the virus, or develops symptoms, depends upon several factors: the dose of virions; the person's age and state of health (pre-existing conditions), nutrition, rest, etc.; whether they have previously been infected or received an effective vaccine; and where the virions deposit in the body (e.g., mouth and upper respiratory tract where some may be expelled, versus in susceptible tissues in the lower lungs).

The received dose of virions depends upon both the duration and intensity of exposure. Intensity of exposure depends upon characteristics of the person shedding virus (volumes and concentration of virions in discharges of breathing, talking, sneezing and coughing), proximity to the source, and protective factors such as wearing of masks and ventilation (encounters outdoors are safer, but being close is always riskier). Longer exposures to lower levels of virions, or cumulative exposures to multiple infectious individuals as well as virions in the environment (e.g., on surfaces) may all culminate in an individual becoming infectious and developing symptoms. These considerations support modelling of relative, if not absolute risks to prioritize mitigation measures to limit airborne transmission.[10]

Measures to minimize the presence and transmission of infectious agents must address important challenges with SARS-CoV-2 that are different from some previous epidemics such as SARS.[14] Working assumptions that were reasonable at the beginning of the COVID-19 pandemic included underestimations of pre- and asymptomatic transmission, transmission by children, and transmission via airborne particles over distances greater than the two metre physical distancing standard.

6.1. Pre-symptomatic and asymptomatic transmission

High SARS-CoV-2 loads in the nose and throat and resultant environmental contamination can occur for multiple days before symptoms onset, resulting in "pre-symptomatic transmission."[15] People who contract the virus and become infectious but never develop symptoms cause "asymptomatic transmission."[17] Estimates vary, but the US Centers for Disease Control and Prevention (CDC) models consider that 10 to 70 percent of infectious cases may be silent, and never develop symptoms.[126] Thus, testing for COVID-19 on the basis of symptoms means that most cases are not detected, and none are detected before there has been considerable opportunity for virus transmission. This is why rapid case detection, contact tracing, quarantine and testing are essential to limit disease spread. Modelling using an interactive, online resource[26] of reopening of colleges indicates that in addition to sanitation, masks and physical distancing, the frequent testing of apparently healthy individuals for the virus is essential.[26,32]

Limiting contacts at work and in school is intended to limit the number of individuals who must stay at home when a case is identified. This administrative decision-tree is an important component of planning for re-opening.

Contact tracing back in time to identify the source or previous carrier of infection is frequently unsuccessful; this may be due to anonymous, silent or "cryptic" transmission from asymptomatic carriers,[16,127] including children.

6.2. Children are likely to be important vectors of SARS-CoV-2

Although a minority of apparently healthy individuals of all ages develop serious cases of COVID-19, children in particular tend to have milder or asymptomatic, unrecognized disease. Children with pre-existing health conditions may present with symptoms that are different from adults, develop serious and life-threatening COVID-19, and uncommonly develop a serious post-viral, autoimmune, inflammatory syndrome.[128]

An optimistic view that viral transmission from and among children is lower than adults arose from low quality studies, milder disease among many children and observations of little transmission from and among children (many in small families) largely during lockdowns, when parent-to-child transmission was more common than vice-versa while children were at home.[129] Analysis of viral loads across age groups found no reason to believe that children are less infectious;[18] indeed a Chicago study of 145 children found that young children had 10 to100 times higher viral loads in swabs.[19] With low community levels of COVID-19, Rhode Island found that virus transmission in child care facilities was limited by adherence to public health measures, while clusters were associated with lack of adherence.[20] Re-opening of schools and colleges has met mixed success and shifts to online learning, such as a large outbreak 10 days after opening a crowded Israeli school.[130] At a summer camp with limited attention to COVID-19 prevention, roughly half of the children and councillors rapidly became infected.[21]

Education and reopening of schools have been identified by prominent Canadian and international public health organizations to be a high priority.[131] Detailed planning, support for changes to ventilation and classrooms, cleaning, and execution and continuous monitoring are necessary to ensure and adapt to maintain safe operations so that vulnerable children are not left behind.[131]

6.3. Airborne transmission is substantial and widespread

SARS-CoV-2 is an airborne virus; coronaviruses can be transmitted via virus-laden respiratory droplets from a cough or sneeze, as well as smaller infectious aerosols exhaled when breathing, talking, singing and shouting.[22,23,24] Moreover, exhaled droplets can dehydrate, shrink, and along with finer aerosols remain airborne and infectious, drifting distances far beyond the two metres guidance for physical distancing.[24,34] SARS-CoV-2 persists for more than three hours in fine droplets under experimental conditions,[34] and the smallest particles can reach the lower respiratory tract – the most vulnerable tissues of a non-immune or susceptible human host.[11,132]

Examples of transmission of SARS-CoV-2 to downwind tables in a restaurant,[38] throughout a poorly ventilated, crowded call centre,[39] at choir practices,[133] and previously SARS-CoV-1 transmission through an apartment building via plumbing vents and then downwind to other buildings [41] are among increasing numbers of well documented tragic examples of airborne coronavirus contagion. Airborne transmission is cited as a reason why the virus has persisted at higher levels in districts where masks are not widely used.[26,27,28,29,30,31]

6.4. All surfaces may be contaminated in the vicinity of an infectious individual

While frequent cleaning of often-touched surfaces and washrooms is expected to be routine, case identification of an individual who was potentially infectious while at work or school should trigger contact tracing and isolation for the mandated two-week quarantine period, as well as temporary closure of areas or of the entire building for more intensive cleaning and sanitization. Under experimental conditions, SARS-CoV-2 persisted in fine aerosols during three hours of observation, and 72 hours on plastic and stainless steel, but for less than 24 hours on cardboard and for less than four hours on copper.[34] Studies of spaces occupied by infectious individuals found that SARS-CoV-2 persisted on all surfaces, including air vents,[15] and was observed to remain active for longer than four days on indoor smooth surfaces, and in one sample up to one week on a mask.[33]

6.5. One Health

The development of and responses to the COVID-19 pandemic highlight numerous health and environmental issues including wildlife habitat destruction, vulnerabilities of populations affected by pollution and modern lifestyles, overlapping risks from climate change, antimicrobial pollution and resistance, waste, rollbacks of environmental protection, and effects of responses such as health, social and economic consequences of lock-downs, interruption of food and goods, distraction from other activities (e.g., postponement of cancer investigation and treatment), and a pandemic of online misinformation and agitation. Clear, calm planning, communication and actions based on current advice from competent, broad-based medical, scientific and engineering authorities offer the best hope for return to safe in-person interactions.

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8. Resources

There are many resources online. The selected links below lead to additional helpful resources.

Authority	Resources	Topics regarding COVID-19	Primary and key links
Government of Canada	Outbreak update Building management direction for coronavirus disease 2019	Public health data, advice Canada's response Restrictions (e.g., travel) Operations Cleaning Response Return to workplace	https://www.canada.ca/en/public-health/services/diseases/2019-novel-coronavirus-infection.html https://www.canada.ca/en/government/publicservice/covid-19/easing-restrictions/departmental-guidebook/building-management-covid-19.html#a16
Canadian Committee for Occupational Health and Safety (CCOHS)	A series of operationalized sheets, plus extensive resources on ergonomics and office work	COVID-19 resources, including: Reopening Disinfection Masks Day cares Preventing stigma Food service Retail Telework and home office health and safety guide	https://www.ccohs.ca/products/publications/covid19/
Canadian National Collaborating Centre for Environmental Health (NCCEH)	A series of science-based discussion / recommendations topic papers.	Multi-unit residential buildings Outdoor safety	ncceh.ca/documents/guide/covid-19-precautions-multi-unit-residential-buildings

Authority	Resources	Topics regarding COVID-19	Primary and key links
Canadian National Collaborating Centre for Methods and Tools (NCCMT)	Systematic scientific reviews on specific topics	Dozens of reviews on many topics Sponsored by the Public Health Agency of Canada: Aerosolization, face shields, transmission while singing or playing wind instruments, dental care, social bubbles, characteristics of high risk events, ethnicity, outbreaks in the workplace *Topics may be nominated*	nccmt.ca/knowledge-repositories/covid-19-evidence-reviews
Health Canada	Hard-surface disinfectants and hand sanitizers (COVID-19)	Lists of disinfectants and hand sanitizers Information for manufacturers and interim measures to address shortages No list of preferred or least-toxic active ingredients for children	https://www.canada.ca/en/health-canada/services/drugs-health-products/disinfectants/covid-19.html
Pest Management Regulatory Agency (Health Canada)	Searchable database to identify labels for disinfectants that are registered for use against viruses; specifically against SARS-CoV-2. As of August 1, 2020, no label specifically mentioned "SARS."	Disinfectants applied to surfaces may also be considered pesticides. Labels are legal documents that include required composition, application/use instructions, and consumer and worker safety information.	http://pr-rp.hc-sc.gc.ca/ls-re/lbl_detail-eng.php
British Columbia	BC COVID-19 Go-Forward Management Strategy	Detailed rationale and approaches to opening up schools and the economy	https://www2.gov.bc.ca/assets/gov/health/about-bc-s-health-care-system/office-of-the-provincial-health-officer/covid-19/bc_covid-19_go-forward_management_strategy_web.pdf
Alberta	COVID-19 info for Albertans	Cases, testing, severe illness risk Public health requirements Guidelines for travel, gatherings, workplaces, congregate care, etc.	https://www.alberta.ca/coronavirus-info-for-albertans.aspx

Authority	Resources	Topics regarding COVID-19	Primary and key links
Saskatchewan	Re-open Saskatchewan plan	Public health and phased approaches Industry-specific guidelines Workplace information	https://www.saskatchewan.ca/government/health-care-administration-and-provider-resources/treatment-procedures-and-guidelines/emerging-public-health-issues/2019-novel-coronavirus/re-open-saskatchewan-plan
Manitoba			https://www.gov.mb.ca/covid19/restoring/approach.html
Ontario	Reopening Ontario	Updates including staging Public health requirements Workplace safety and plan template Workplace-specific guidance	https://www.ontario.ca/page/reopening-ontario https://www.ontario.ca/page/resources-prevent-covid-19-workplace https://www.ontario.ca/page/develop-your-covid-19-workplace-safety-plan
Institute National de Santé Publique du Québec	Numerous FAQs	COVID-19 resources, on Indoor Environment, back to work and more	https://www.inspq.qc.ca/en
New Brunswick	Coronavirus disease (COVID-19) resources page	Public health information and resources and updates Guidance documents for professionals, businesses and more	https://www2.gnb.ca/content/gnb/en/corporate/promo/covid-19.html
Nova Scotia	Nova Scotia Novel coronavirus (COVID-19) government response	Public health information and resources and updates Guidance documents for workers, businesses, education, childcare	https://novascotia.ca/coronavirus/
Prince Edward Island	In addition to resources similar to others' extensive guidance on schools	School toolkit, operational plans, bus safety, and detailed guidelines for every school	https://www.princeedwardisland.ca/en/information/education-and-lifelong-learning/education-toolkit
Yukon	COVID-19 information	Public health and travel Health care and essential services Supports and education	https://yukon.ca/en/covid-19-information
Northwest Territories	GNWT's Response to COVID-19	Business and Work	https://www.gov.nt.ca/covid-19/en/business-work-0
Nunavut	Nunavut's Path: moving forward during COVID-19	Little on buildings but good philosophy	https://www.gov.nu.ca/health/information/nunavuts-path

Authority	Resources	Topics regarding COVID-19	Primary and key links
American Society of Heating, Refrigeration and Air-conditioning Engineers (ASHRAE)	Technical standards and a series of position documents	Infectious Aerosols Filtration Standards for HVAC	https://www.ashrae.org/technical-resources/resources
World Health Organization (WHO)	Regular updates Country and technical guidance Advice for the public Research and development Strategy and Planning EPI-WIN – infodemic management … and more	Emergency response Research - diagnostics, therapeutics, vaccines Public health responses Personal health	https://www.who.int/emergencies/diseases/novel-coronavirus-2019
US Environmental Protection Agency (EPA)	Disinfectants – 4 categories: all; approved for SARS-CoV-2; "safer"; and for child care	Disinfectants, including contact times, and sublists of safer products	https://www.epa.gov/pesticide-registration/list-n-disinfectants-use-against-sars-cov-2-covid-19
European Centre for Disease Control	Situation reports and resources Heating, ventilation and air-conditioning systems in the context of COVID-19	Evidence for and response to transmission HVAC systems	https://www.ecdc.europa.eu/en/covid-19-pandemic https://www.ecdc.europa.eu/sites/default/files/documents/Ventilation-in-the-context-of-COVID-19.pdf
US CDC	Extensive resources, including public health and research reports	Scientific updates – e.g., disease incidence and prevalence, transmission, outcomes, risks and situational awareness	https://www.cdc.gov/coronavirus/2019-nCoV/index.html
American Industrial Hygiene Association (AIHA) Indoor Environmental Quality Committee	Recovering from COVID-19 Building Closures Workplace Cleaning for COVID-19	Water systems Cooling towers HVAC Cleaning, disinfecting	https://www.aiha.org/public-resources/consumer-resources/coronavirus_outbreak_resources
U.S. Occupational Safety and Health Administration	Guidance on Preparing Workplaces for COVID-19 (March, 2020)	Preparing workplaces Job classifications re. risk Workers' risk characterization Risk reduction	https://www.osha.gov/Publications/OSHA3990.pdf