Canadian Committee on Indoor Air Quality

Addressing COVID-19 in Buildings

Module 15 - Version 2

June 2021

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

Module 15

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First Update, including risk estimation modelling for SARS-CoV-2 variants

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Canadian Committee on Indoor Air Quality (CCIAQ)

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Indoor air quality is a broad issue, and there are gaps in 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 goal of the Canadian Committee on Indoor Air Quality and Buildings is to improve indoor air quality in buildings and, ultimately, the health of occupants, by providing a national forum and clearinghouse for “best-of-knowledge” information on the design and operations of buildings as they affect indoor air quality.

Its mandate is to:

- solicit and review relevant information;
- identify gaps and issues;
- provide a discussion forum;
- recommend studies;
- develop “best-of-knowledge” positions and best practices;
- disseminate knowledge;
- promote adoption of uniform requirements, best practices and guidelines for the design and operation of buildings; and
- provide guidance for evaluation of solutions and technologies.

The CCIAQ’s initial focus was on non-specialist (e.g., not health care nor industrial) buildings, such as offices, schools, commercial spaces and residences. Many larger buildings have complex heating, ventilating and air conditioning systems that are operated and managed by knowledgeable persons; however, some buildings lack sophisticated systems. Documents produced by the CCIAQ are intended for use by building operators and facility managers, but the information contained in the Guides is meant to be helpful to anyone seeking understanding. CCIAQ’s modules are not intended to substitute for releases by Federal and Provincial/Territorial health organizations, but to support and to complement them with background, technical expert information and related insights on actionable technical solutions, backed by scientific and peer-reviewed scientific literature, and releases of cognizant authorities.

This first update of *Module 15 – Addressing COVID-19 in Buildings* includes scientific releases since version 1 (Aug. 2020), for meaningful endeavours to limit the spread of SARS-CoV-2. This update retains much of the original content and is expanded to include:

1. options for buildings with limited or no mechanical ventilation; and
2. risk estimation modelling of SARS-CoV-2 transmission, estimating the extent to which non-pharmaceutical interventions (e.g., masks, ventilation and limits on occupancy) must be improved to counter virus variants.

This is the CCIAQ's first module addressing contagious disease. As knowledge of evidence-based interventions and mitigation strategies to reduce the risk of virus transmission are evolving rapidly, the CCIAQ may further update this document.

The Committee welcomes feedback on all documents and invites submission of suggestions for their improvement. The Committee is also soliciting ideas for new topics for discussion. Please contact the CCIAQ at https://iaqresource.ca/contact-us/

The Canadian Committee on Indoor Air Quality *Module 15 – Addressing COVID-19 in Buildings*, and the COVID-19 risk estimation modelling spreadsheet are available online from the list of CCIAQ modules at https://iaqresource.ca/en/iaq-guides/

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Executive Summary

Over more than a year into the global pandemic, understanding of Severe Acute Respiratory Syndrome Coronavirus-2 (SARS-CoV-2) transmission and Coronavirus Disease-2019 (COVID-19) infection prevention and control has advanced. Consensus that most transmission occurs via airborne particles has increased attention to inhalational exposures. New challenges are emerging, however, as SARS-CoV-2 evolves, and as preventive measures such as vaccination and prophylaxis are not uniformly available and accepted globally. Effective, safe measures to prevent disease transmission indoors remain a high priority.

This is the first update of *Addressing COVID-19 in Buildings,* building on the 2020 publication. It summarizes findings from over 250 carefully selected publications by scientists, medical experts, engineers and cognizant authorities; incorporates expertise of the Canadian Committee on Indoor Air Quality (CCIAQ); and benefited from review by external experts. The CCIAQ invites feedback and new information for future updates, or recommendations of topics for review (https://iaqresource.ca/en/contact-us/).

This update is intended to assist building owners, managers, operators and engineers, maintenance workers, educational authorities, employers, occupants and visitors to minimize disease transmission in buildings, including workplaces, educational facilities and public spaces. Understanding will support implementation of measures to prevent transmission of SARS-CoV-2, via infectious respiratory droplets, and smaller particles that remain airborne (aerosols). Although vaccines, treatments and prophylaxis are crucial, prevention of transmission is essential, because SARS-CoV-2 strains ("variants of concern") are evolving that are more transmissible and virulent, and not as susceptible to current immunity.[1,2,3,4] Checklists and resources for building re-opening and ongoing operations are also included.

This update is written in the context of the need for more stringent measures to counter variants of concern.[5] Preventing transmission of a virus that is airborne[6,7,8] and that can be spread by asymptomatic individuals who do not know they have the disease[9] poses a challenge that can only be addressed with multiple layers of protective measures, per public health guidance.[10,11] Exposure pathways are comparable to those for second-hand and third-hand smoke.[12]

Properly wearing a well-fitting, well-constructed, effective mask[13,14,15] reduces emissions from infectious individuals and helps to protect susceptible individuals from inhaling an infectious dose of virus particles (virions).[14]

Addressing airborne SARS-CoV-2 in buildings requires adequate, optimized clean air supply with ventilation (outdoor air supply) via HVAC, and/or air cleaning/disinfecting (e.g., by filtering and/or possibly with ultraviolet light); verification of clean air delivery; consideration of retrofit or replacement of poorer and dated systems or components; use of ancillary equipment; and strategies to maximize ventilation via windows and doors even during inclement weather. Attention to fans and pressure adjustments should ensure that air from more-occupied or potentially contaminated areas (e.g., washrooms) is exhausted and does not flow to less-occupied or contaminated areas.

Variants of concern causing renewed surges of COVID-19 require more stringent responses. Risk estimation modelling of transmission of virions in well-mixed air (Annex 2 - Section 7) illustrates the substantial scale of necessary improvements in ventilation, mask wearing, and limiting of occupant numbers and time spent in shared spaces. Universal, proper wearing of well-fitting and well-constructed (and therefore effective) masks offers a low-cost, rapidly implemented option with substantial potential impact. To attain acceptable risk levels, outdoor and clean air supply ventilation exceeding recommendations of the American Society for Heating, Refrigerating, and Air-conditioning Engineers (ASHRAE) may be necessary, depending on the venue, mask efficiency and adherence, and occupancy rate (numbers and length of stay).

Alternative ventilation strategies such as displacement ventilation [16] reduce horizontal (and therefore interpersonal) airflow and increase vertical airflow. It is potentially an efficient and effective alternative strategy to limit airborne transmission, and merits investigation.[16]

Many older buildings, including schools and care homes, lack HVAC systems, or even mechanical ventilation or air handling. In these cases, possible options for mitigation include:

- Opening of windows (with cross-flow), and possibly use of high-capacity fans and innovative attention to detail for ventilation, such as rapid, intermittent air exchange to flush out building air and to reduce viral loads;
- Air cleaners deployed to intercept and clean air that is potentially more infectious, while avoiding directing potentially infectious plumes towards susceptible individuals and improving mixing of the air;
- When buildings are occupied, carbon dioxide (CO_2) measurement has been used to detect "dead zones" indicative of poor air distribution or insufficient outdoor air supply. Since poorly ventilated space could be associated with high infectious risk, high CO_2 levels could correspond to "hotspots" of airborne virus-laden particles. This association would be unlikely, however, when using air cleaners (that remove virions but not CO_2), or if other sources such as gas appliances or pets emit CO_2.
- Upgrading ventilation system or installation of new systems.

Hand hygiene and environmental cleaning, particularly of frequently touched surfaces and objects, can interrupt transmission of SARS-CoV-2 via hands, and can help to limit re-suspension and transmission of virions in particles. SARS-CoV-2 is readily inactivated and removed with soap/detergent,[17] or with alcohol when washing is not an option. Health Canada recommends that fragrance not be included in sanitizers[18] due to risks of allergic reactions (notably asthma) and other adverse effects.[19,20] Use of lower toxicity products protects vulnerable populations, such as those who experience chemical sensitivities and respiratory or dermal irritation as well as the development of these conditions in others.[19] Safer alternatives are also less likely to promote antimicrobial resistance.

Caveat emptor (buyer beware) with novel anti-SARS-CoV-2 measures. Caution is merited with space-spraying or "fogging" services because devices must be registered by the Pest Management Regulatory Agency within Health Canada,[21,22] and no products are currently approved for fogging against viruses in Canada.[23] Some products originally promoted for deodorizing may risk damaging belongings. Long-acting surface treatments were disclaimed by expert buildings groups in a joint statement, saying that antimicrobials should only be used as preservatives in building materials, but not for disease prevention;[24] no product or surface treatment has been registered in Canada to provide long-term protection against viruses. As well, ultraviolet and ozone-producing air cleaning devices must be approved by the Pest Management Regulatory Agency (PMRA).[21,25]

Evolving scientific knowledge and results of pragmatic precautionary approaches to COVID-19 merit systematic data collection, to answer current research questions and for future pandemic preparedness.[26]

When COVID-19 is in the community, SARS-CoV-2 will be in buildings. Until a large majority of individuals are immune (currently unpredictable given SARS-CoV-2 variants of concern[4,27,28]) and case numbers are very low, multiple measures, taken together, can minimize the potential exposure of individuals, transmission of the virus, and the numbers of severe cases and deaths.

Attention to indoor air for pandemic response must consider energy use and wildfire response, in the context of the rapidly changing climate.

Addenda to this update include:

- a scientific summary regarding COVID-19 transmission, to aid in understanding challenges; and
- risk estimation modelling, comparing risks of infection with original and more transmissible SARS-CoV-2 variants with: masks of various efficiencies; well-mixed ventilation; occupancy numbers and exposure duration; and number of infectious individuals.

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1. Purpose of this Module

This is the first update of the August 2020 CCIAQ guidance on transmission of the novel Severe Acute Respiratory Syndrome Coronavirus (SARS-CoV-2) responsible for the Coronavirus Disease (COVID-19) in buildings. The purpose of this module is to assist building owners, managers, operators and engineers, maintenance workers, educational authorities, employers, occupants and visitors to minimize disease transmission in buildings, including workplaces, educational facilities and public spaces. It also describes measures in preparation for building re-occupancy following lockdown. Written in the context of rapidly advancing knowledge, this module is based 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, as the virus evolves.[5]

The module outlines options to counter variants of concern; to reap the cumulative benefits of multiple preventive measures, including mask wearing, physical distancing, limiting occupancy and in-person interactions, improving ventilation and air distribution, air cleaning/disinfecting,[11] as well as washing hands, cleaning and disinfecting.[29,30] The scale of efforts to minimize airborne transmission via infectious droplets, aerosols and particles can be informed by risk estimation modelling.

Sections 3 and 4 address specific measures for pandemic responses to reduce SARS-CoV-2 in buildings, and Section 5 summarizes measures for ongoing operations. Section 6 provides context, with an overview of the COVID-19 disease, evolution and challenges; while Section 7 describes necessary improvements in preventive measures to counter variants of concern, estimated using a COVID-19 risk calculator.

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

2. Introduction

The COVID-19 pandemic poses historic challenges to counter infectious disease. The 2020 year-end World Health Organization (WHO) briefing described emerging SARS-CoV-2 variants, emphasized that natural selection will bring additional variants and that COVID-19 will not end soon.[31] The European Centre for Disease Prevention and Control (ECDC) detailed risks and responses to emergence of variants,[32] and a Canadian Public Health Association editorial lauded scientific progress but cautioned, "No, we are not going into the home stretch of the pandemic."[33] In April 2021, Canadians who should be immune were being re-infected with a variant of concern (British Columbia became the largest hotspot outside of Brazil of the gamma variant of concern[34]). In May 2021, the even more infectious delta variant arose in India, and in June a Canadian Medical Association Journal commentary, "Mitigating airborne transmission of SARS-CoV-2"[35] advocated for greater recognition of airborne transmission, upgraded ventilation and greater access to N95 respirators.

It is now clear that although other routes are plausible, the predominant route of transmission of SARS-CoV-2 is inhalation.[11,36]

2.1. How to use this guide

No single measure will reliably prevent SARS-CoV-2 transmission in everyday indoor spaces, 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.[11]

This Guide details measures during ongoing operations to minimize transmission of SARS-CoV-2 in buildings with and without mechanical ventilation, discusses principles for consideration, design and implementation of diverse solutions to minimize SARS-CoV-2 exposure in buildings, and lists recommended measures and considerations for re-occupying buildings which have had few or no occupants for a period of time.

Addenda include:

- an overview of the developing understanding of COVID-19, to understand context, challenges and potential time frames for public health measures (Annex 1 – Section 6); and
- estimation of COVID-19 risk reduction depending upon mask efficiency, room ventilation, and/or occupancy, for original and more transmissible variants (Annex 2 – Section 7).

2.2. Limiting transmission

Multiple, complementary actions, together, can limit transmission of COVID-19. These include:

- **Source removal or control**

  SARS-CoV-2 originates in people, so "source removal" includes properly wearing an effective mask (both source control and some personal protection, Section 3.1), staying home when sick, rapid detection and isolation of COVID-19 cases, and tracing and quarantining of contacts (Section 5.1). "Control" includes reducing airborne transmission within a facility (Sections 3 and 7), and cleaning, sanitizing and disinfecting (Section 4.2).
- **Engineering controls**

  Maximizing outdoor air supply (ventilation); optimizing air distribution, filtration and disinfection; retrofits such as local air purifiers for disinfection, and shields/barriers and dividers to intercept droplets and to redirect potentially contaminated airflow, all help to minimize levels of infectious aerosols in occupant breathing zones (Section 3);
- **Administrative controls (policies and protocols to limit the spread of COVID-19)**

  Some examples include: telework/e-learning; detailed onsite measures (Section 5) such as physical distancing with 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 and testing; schedules to reduce and to stagger occupancy; smaller cohorts for in-person encounters; paid sick leave; and cooperation with site-specific knowledge for backward contact tracing by Public Health (with COVID-19 testing of potential cases and contacts, quarantine if at risk of disease and isolation if ill), as well as outbreak response and deciding when to close facilities temporarily; and

- **Personal protection and preventive practices**

  Proper use of effective respirators/face masks, plus (as appropriate) eye protection (goggles, glasses or face shields) (Section 3.1), physical distancing while keeping personal encounters brief, hand hygiene, respiratory etiquette, seeking testing as indicated, ensuring quarantine and isolation as necessary, and mutual support to cooperate in good faith (Section 5).

Pandemic response is multi-faceted. Cleaning and sanitizing hands and disinfecting surfaces were targeted early to curb the community spread,[37] whereas transmission of SARS-CoV-2 via airborne particles (droplets and aerosols) is now recognized as a key pathway that must be addressed.[13,15] For context, further responses beyond the immediate scope of this document would include: government-mandated restrictions of commerce, school attendance, gatherings and travel; public health surveillance, screening, testing, tracing, isolation and quarantine; paid sick leave for workers; and medical responses such as treatment and prophylaxis (e.g., vaccines).

Some buildings have been closed or operated with low occupancy. Section 4 details guidance for re-occupancy. Flushing/cleaning and re-commissioning of water and air handling systems are top priorities to limit health impacts, by removing at source non-SARS-CoV-2 infectious and toxic biological and chemical hazards. Air handling equipment that is appropriately sized may be operated in different ways, or be newly deployed for ventilation and/or air cleaning.

2.3. SARS-CoV-2 transmission and COVID-19 infection

Reducing transmission of SARS-CoV-2 requires understanding how transmission occurs. Key points are summarized here, and Annex 1 – Section 6 covers in greater detail scientific knowledge underlying imperatives for successful (re)occupancy of buildings.

COVID-19 begins with SARS-CoV-2 transmission to mucous membranes (respiratory tract, eyes and/or gastrointestinal tract). Risks are heightened indoors if there is inadequate ventilation, and worsened when not properly wearing an effective mask, being in crowded spaces, having frequent or prolonged (several minutes) close encounters, and/or engaging in activities that increase respiratory emissions such as singing, shouting, exercising, or even just talking.[38,39]

Risk estimation modelling (Annex 2 – Section 7) is used to compare effects of non-pharmaceutical interventions (NPIs) on risks of infection indoors with either wild type (original) SARS-CoV-2 or a more infectious variant. The infectious dose of SARS-CoV-2 is unknown, but "quanta" represent the infectious load emitted by an infected individual, according to activities.[40] The concept was calibrated using data from earlier spreading events,[41,42] successfully applied to built environments[43] and mass transit vehicles,[44] and further developed in the context of variants in several additional scenarios.[45] Risk estimation modelling illustrates that details of and adherence to NPIs must improve substantially, to counter variants. The risk estimation modelling terms [in square brackets] capture public health advice as follows:

- **Virus quanta exhaled into shared spaces depend on:**
  - the number of infectious people [sources], the quantity and infectivity of virus exhaled by each source [variant], [mask wearing] and [activities] (e.g., singing, exercising, loud or quiet speech, sitting quietly). Quanta are derived from observed spread of the virus.

- **Avoidance (distancing) and protection:**
    - minimizing non-essential in-person interactions with others outside of one's immediate household [modelled as occupancy – the number of people and size of space]
    - ensuring that interactions that must occur are:
        - from the greatest physical distance possible [for a given room size, lower occupancy means greater spacing between individuals]
        - as few and as brief as possible [minimizing exposure time]
    - avoiding poorly ventilated and/or crowded spaces [ventilation, room size and occupancy]
    - properly wearing a well-fitting, well-constructed, efficient mask, to protect oneself and others [modelled in terms of both the fraction of occupants wearing masks, and the efficiency of masks when inhaling and exhaling]
- **Virus removal:**
    - ventilation and cleaning of air, as well as deposition of droplets and inhalation [all these modes are estimated; cleaning of surfaces and hands are not]
- **Time:**
    - longer or repeated exposures even to low levels may amount to an infectious dose [46] [occupancy time]

Minimizing the presence and transmission of infectious agents must address challenges with SARS-CoV-2 that are different from some previous epidemics such as SARS.[47] As detailed in Annex 1 – Section 6, working assumptions that have evolved since the beginning of the pandemic include:

- **Recognition of pre-symptomatic and asymptomatic transmission** [9,48]
    - Contact tracing to identify the source or previous carrier of infection can be unsuccessful outside of outbreak settings (e.g., Ontario data[49]); this is in part due to asymptomatic carriers,[50] including children.[51] During early infection, individuals exhale millions of SAR-CoV-2 virions per hour;[52]
- **Transmission by children deserves attention** [51,53,54,55,56,57]
    - Children may carry high infectious loads without symptoms,[58] and are more susceptible to variants.[59] When the virus is active in the community high numbers of asymptomatic cases have been measured among Canadian students,[60,61] and it was noted in the *Canadian Medical Association Journal* that, "schooling in crowded, poorly ventilated classrooms could result in students being significant drivers of COVID-19." [57] In June 2021, Ontario cited projected increases in cases, particularly of variants of concern, as the reason not to re-open schools before greater vaccine coverage.[62]
- **Transmission over distances greater than two metres**
    - Virus-laden respiratory particles range from large droplets from a cough or sneeze, to finer secretions and infectious aerosols exhaled when shouting, singing, talking and breathing, that in turn dry into smaller particles that can remain airborne and infectious for hours.[41,63,64,65] SARS-CoV-2 has been transmitted via indoor air currents from one infectious diner to several others sitting more than two metres away in a restaurant,[66] through a poorly ventilated, crowded call centre[67] and nursing home,[68] from an infectious singer to several others at a choir practice,[69] and through an

apartment building via plumbing vents.[70] Airborne transmission is cited among reasons that the disease has persisted at much higher levels in districts with doubts of the merits of public health measures and with less stringent NPIs, while COVID-19 has been more successfully suppressed in jurisdictions with stringent public health measures, particularly requiring and even providing high quality masks.[71,72,73,74,75,76]

The "light at the end of the tunnel" – results of vaccination – are eagerly anticipated,[59] and evident in vaccinated seniors.[77] On a cautionary note, however, mutations of coronaviruses can alter transmission, the course of disease, and efficacy of pre-existing immunity.[78] Current vaccines are at least partially effective against emerging variants of concern,[79,80] but with ongoing mutations and evolutionary pressure during vaccine rollout, the initial high efficacy may wane. Fortunately, advanced vaccine platforms are being adjusted to address variants.[81] Importantly, use of multiple personal protective practices, physically intercepting virions with masks and air cleaning, are inherently effective even if challenged with increased transmissibility.

Inconsistent and limited adherence globally to public health advice related to mask wearing and physical distancing,[82] alongside challenges to vaccine rollout and increasing rates of COVID-19 with more transmissible variants, make efforts to reduce transmission all the more important. Although some provinces and international jurisdictions, particularly those that are more isolated, are carefully achieving and maintaining very low numbers of cases, "living with" COVID-19 may be more likely in other locales. This is expected to become easier with vaccinations, but it is possible that the disease will be a long-term reality, at least seasonally. Measures to minimize disease transmission are important to reduce both infections and opportunities for mutations. This is especially so in buildings, particularly those that are poorly ventilated and where physical distancing and cleaning/disinfecting are more challenging (e.g., care homes, emergency housing and some schools).

3. Addressing airborne transmission

SARS-CoV-2 moves from infectious to susceptible individuals mostly via small infectious airborne particles including "aerosols."[8,41,83,84] While masks, barriers and physical distancing are effective to reduce exposure to droplets that settle to the floor, this section addresses how inhalation of particles that were initially smaller than 100 µm, that shrink as they dry out and can remain suspended in air for hours, can be reduced with effective masks, ventilation and air cleaning.

Ventilation (exchange of indoor with outdoor air) continuously moves some infectious particles outdoors and dilutes the remainder with outdoor air. In buildings lacking mechanical ventilation (e.g., with radiators or forced air with no air exchange – i.e., 100% recirculation) the options include exploiting "natural ventilation" via windows, doors and vents, on top of uncontrolled infiltration (leaky buildings). When ventilation is insufficient, in-duct or stand-alone equipment may be used to filter/disinfect recirculated air.

Strategies to reduce SARS-CoV-2 in indoor air are discussed for:

1. buildings with forced-air (ducted) heating, ventilation and air conditioning (HVAC) systems;
2. buildings with forced-air heating and perhaps cooling, but without mechanical ventilation systems to exchange indoor air for outdoor air; and

3. older buildings, including some institutional buildings (e.g., schools, care homes, places of worship, community centres, motels) that rely upon local radiant heat (e.g., baseboard heaters or hot water/steam radiators) and have limited (e.g., window-mounted) or no forced-air heating, cooling or ventilation.

3.1. Masks

A mask is the first (when exhaling) and final (when inhaling) air filter and layer of protection for others as well as for yourself against SARS-CoV-2.[75] Evidence is clear of benefits of community-wide use of properly worn, well-constructed, well-fitting (i.e., effective) masks.[85] Only a mask can intercept virions from close range.

Recommendations for ventilation and widespread use of multi-layer, well-fitting masks are made by Canada[86] and the WHO,[87] and mask wearing is required in shared indoor spaces (e.g., work, school, shopping) and occupied outdoor spaces, especially when physical distancing is not feasible. A letter to the medical community and to the relevant national and international bodies from 239 scientists laid out the science and urged recognition of airborne transmission of COVID-19.[88] In support of public health, Masks4Canada.org is helping to build awareness and provides detailed information about proper wearing of masks that fit and filter well.

Risk estimation modelling of COVID-19 can be helpful to predict trends. In November 2020 (prior to widespread recognition of more transmissible variants), the International Institute for Health Metrics Evaluation COVID-19 Forecasting Team estimated that universal mask use would prevent more than 700,000 deaths by March 1, 2021.[89] In response to variants, along with improvements in adherence to other layers of guidance addressing inhalational exposures (ventilation, physical distancing, limiting encounters), improved mask efficiency and use could substantially reduce the dose of inhaled virions. Risk estimation modelling of SARS-CoV-2 transmission in well-mixed air (Section 3.3, and Annex 2 – Section 7) indicates that along with physical distancing, universal wearing of masks that are at least 80% efficient could independently and substantially reduce risks of contracting COVID-19.

In industrial workplaces or occupational settings with potentially high or extended duration exposures to hazardous particulates, workers typically wear eye protection and a fit-tested rubber respirator with high-efficiency filter cartridges, or an N-95 (or equivalent) respirator. Protection against infectious particles such as SARS-CoV-2, however, is two-way and the following protective equipment is **not recommended against SARS-CoV-2:**

- powered air-purifying respirators (PAPRs) – these do not protect others from an infected wearer and may further spread infectious particles. They are also expensive, noisy to the extent that they can hamper communication, and difficult-to-maintain;[90]
- respirators with exhalation valves (to ease breathing), because exhaled air is not filtered; and
- N-95 masks with exhalation valves, used to protect against dust in the trades.

Valve-less N-95 masks are used during intensive and invasive care of COVID-19 patients, rather than procedure/surgical masks according to risk level.[91] Essential workers have struggled with N-95 shortages in the workplace, while doctors and nurses seeing disease among colleagues argue that higher quality personal protective equipment (PPE) is essential during the pandemic, and if supplies are limited they should be prioritized for these workers.[92] Fortunately, shortages seen early in the pandemic are not a problem in this second year.

Cloth masks are not subject to the same quality criteria as respirators, but well-constructed, well-fitting, properly worn masks can also offer suitable protection both for the wearer and for others.[13,14,85] Small particles are captured as they encounter or impact fibres, and by electrostatic attraction. High thread count, multi-layer masks containing a filtering layer such as non-woven polypropylene or cotton (e.g., padding or interfacing fabric) can protect the wearer from inhaling infectious particles.[14,86,93] Air bypassing the mask poses significant, unnecessary risk, so masks must not overly restrict airflow, and be properly worn to cover the nose, mouth and chin with attention paid to close fit around the edges.[94,95,96] Better mask fit to eliminate gaps may be achieved using a metal strip to shape the mask over the nose and cheeks, tightening head ties or adjustable ear loops, and possibly using a mask fitter or brace, elastics across the back of the head rather than only ear loops, joining ear loops with a hair clip in back, improving fit with a section of hosiery over the mask and lower head/neck, or even "doubled" or "layered" masking. Masks4Canada.org and the US Centers for Disease Control and Prevention (CDC) detail options to improve "face covering" fit and filtration,[96,97] and an ASTM consensus standard has been published for "reusable barrier face coverings," addressing capture of particles, air resistance or "breathability," and fit.[98]

Eye protection and face shields cannot replace masks, but they may offer incremental, complementary protection of the mucous membranes in eyes.[73] Indeed, eye protection has been postulated as a significant gap in intercepting SARS-CoV-2 transmission.[99] Medical style face shields that fit well at the top and extend to the ears and below the chin, can intercept droplets from a cough and limit touching of the face with potentially contaminated hands. Compared with masks, however, face shields offer little protection for general inhalational exposures.[100,101] 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."[102]

Consistent information and requirements are necessary to overcome confusion about the roles of masks of varying effectiveness, including guidance for proper usage and care.[13,93] Some jurisdictions, such as Hong Kong,[103] with stricter attention to public health measures including high mask wearing compliance, supply effective, multi-layer, well-fitting masks to citizens.[104]

Well-constructed and well-fitting, efficient masks should be worn indoors at school, work, play, in public spaces and in the company of those outside your household, according to public health advice. Masks are also necessary outdoors where numbers of people may make physical distancing difficult, and during any encounter even outdoors where a minimum of 2 metres distancing might not be maintained. A mask should not be worn by individuals incapable of tolerating or removing it, nor by children under the age of two.

3.1.1. Masks Summary

Measures against COVID-19 must be deployed as layers of protection, including properly wearing well-fitting, multi-layer efficient masks. When worn in public or communal areas and during interactions with people from outside one's immediate household, by all who are able, masks are a direct, readily implemented, effective measure against SARS-CoV-2. Mask design and construction has advanced to achieve sufficient efficiency necessary to counter variants.[14,98] This knowledge is applied in Section 3.7 and Annex 2 – Section 7.

3.2. Heating, ventilation and air conditioning (HVAC) systems

Increasing the ventilation rate (i.e., increasing the supply of outdoor air) above typical levels, as well as careful attention to airflow patterns and exhaust(s) are recommended by authoritative groups, such as the American Society of Heating, Refrigerating and Air-conditioning Engineers (ASHRAE)[105] and the Federation of European Heating, Ventilation and Air Conditioning Associations (REHVA),[106] to dilute and to exhaust viral loads. Ventilation cannot intercept virions during close encounters (closer than approximately 2 metres) so minimizing interactions, physical distancing and wearing of masks remain essential to reduce risk of transmission.

Ventilation is to achieve the maximum degree of virion exhaust, and dilution with outdoor air. The potentially infectious viral load in a room is not precisely quantified (or quantifiable), and is expected to vary among individuals and across variants, with a dose response for severity.[107] Occupancy numbers and frequency, proximity of individuals and duration of interactions should be limited, and scaled according to mask wearing and ventilation and air disinfection capacity.

High-efficiency heat recovery ventilators (HRVs) and energy recovery ventilators (ERVs), when present, can assist to maximize outdoor air supplies, control humidity and conserve energy. Heat/energy recovery systems are, however, vulnerable to cross-contamination of incoming air with potentially infectious exhaust; ASHRAE and REHVA have published detailed guidance for HRVs/ERVs during an epidemic, addressing design, evaluation, inspection, remediation and repair, and re-commissioning after shutdown.[106,108]Measures to maximize flow separation include preventing leaks in systems utilizing energy recovery wheels, careful pressure adjustment, additional filtration, and other measures to help to prevent cross-contamination. If feasible (e.g., if dampers are in place to redirect flow), temporarily bypassing the energy exchanger/condenser components may be indicated, pending cleaning, inspection and completion of refurbishment and maintenance.

Potential upgrades to HVAC systems are summarized in Section 3.2.1 and further technical resources are catalogued in Section 9.

To mitigate risk of transmission, the central HVAC system should be operated to utilize as many strategies as feasible to achieve:

- ✓ maximum outdoor air supply for optimum indoor air replacement, with as little recirculation as possible (i.e., disable demand-control systems and recirculation, and open outdoor dampers);
- ✓ clean air delivery through efficient filtration for air purification/disinfection to meet or exceed disinfection levels necessary to limit the risk of an occupant receiving an infectious dose of virions ("quanta") from one or more infectious individuals. Risk estimation can indicate the relative scale of improvements necessary for more transmissible variants. Variables include room size, ventilation rate, the number and location of sources of virus (infected individuals), use of masks and the occupancy rate. (see Section 3.7 and Annex 2 – Section 7); [106,109,69]
- ✓ ventilation systems operating beyond the hours of occupancy (at least two hours before and after occupancy of the building, or three total air changes, whichever is longer), or around-the-clock (possibly at lower fan speed when unoccupied), as necessary to flush buildings completely (ASHRAE provides a calculator for air exchange and cleaning[110]);
- ✓ washroom exhaust fans operating continuously;
- ✓ for recirculating air, to the extent that the system permits upgrading to use higher-performance filters (minimum efficiency reporting value [MERV] 13, or better, high-efficiency particle arrestor [HEPA]), with attention to sealing around the edges to prevent bypass;[105,111,112,113]

- ✓ ensure that at least the minimum quantities of clean air supply and exhaust recommended by ASHRAE are being provided.[114] Pressure differential measurements and/or smoke testing can be useful to ensure that air is exhausted from riskier areas and that distribution is protective;[115]
- ✓ check, adjust, correct and optimize air movement in occupied spaces, particularly where layouts are modified to accommodate distancing, and barriers are installed to intercept airborne particles. To ensure proper air distribution and circulation with elimination of "dead zones" related to eddies and stagnant layers from temperature stratification:
    - o check air diffuser placement and adjustment, and remove any blockage;
    - o check air exhaust/return registers and adjustment, and remove any blockage;
    - o ensure that barriers to intercept potentially infectious droplets have at least 30 centimetres open space at floor level, and have sufficient clearance between the top of the barriers and the ceiling to allow for adequate air movement;
    - o consider adjusting or removing partitions or furniture that interfere with air circulation and contribute to "dead zones;" and
    - o consider the possibility that potentially infectious and susceptible individuals may be upstream and downstream, so local fans or air cleaners should be placed and adjusted to the extent possible not to blow air directly from one person to another in breathing zones. It is preferred to move air vertically/diagonally through breathing zones, with horizontal movement predominantly above or below breathing zones (for further discussion, see Section 3.2.2).

Continue routine cleaning and disinfecting of the HVAC system cooling coils, heating coils, condensate drain pans and drains, and humidifiers, to prevent mould and bacterial growth. If present, ultraviolet disinfection bulbs should be maintained to remove dust that would reduce effectiveness (see Section 3.5).

Depending upon outdoor air conditions, greater ventilation may require additional humidification or dehumidification, to supplement existing capacity to maintain comfortable humidity, or to prevent moisture and biological contaminants, respectively.

3.2.1. HVAC upgrades

Currently, while 100% outdoor air supply is a design goal for some areas in healthcare facilities and is a requirement for laboratories that handle airborne hazards,[116] there are challenges with broad scale implementation. Nevertheless, while 100% supply air ventilation would be desirable for epidemic preparedness for all buildings,[113] with current building designs the temperature, humidity and energy operational demands typically require significant levels of air recirculation, except during certain times in spring and fall when 100% recirculation can be possible.

Other options for contaminant removal from recirculated air include higher-efficiency filtration and potentially ultraviolet germicidal irradiation (UVGI, discussed below), when 100% outdoor air supply is not feasible such as during the heating and cooling seasons. High-efficiency filtration and/or contaminant removal of outdoor air may also be necessary to remove airborne particles and chemicals, including 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:

- ✓ local/zonal exhaust systems from locations of greater risk; examples include washrooms (that should be continuously exhausted to maintain lower pressure) 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;

- ✓ stand-alone or portable high-efficiency air cleaning systems, pending ventilation upgrades, to supplement or in the absence of mechanical ventilation (Section 3.5). These must be approved by the Pest Management Regulatory Agency;[21,25]
- ✓ additional humidification or dehumidification may be necessary seasonally to accommodate increased ventilation rates;
- ✓ 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, ease of maintenance and filter replacement or installation, and effective seals to eliminate filter bypass are important considerations;
- ✓ upgraded fan/filter units to include ideally MERV 13 or better, such as HEPA filters. Retrofits may also include pre-filters to ease the burden on the finer filters that may require more frequent replacement; higher-powered fans; and other design changes may be required such as reinforcement to handle the higher pressure-drop across the filter bank;
- ✓ upgraded systems to provide more outdoor air than the current maximum; preferably 100% outdoor air with exhaust. Upgrades must also include capacity to recirculate and filter/clean air, to be used during extreme weather and in the case of high levels of outdoor air pollution such as wildfire smoke.

More extensive options for HVAC systems would typically be expensive and require significant capital budgets; however, in addition to added resilience during the pandemic there can be other long-term benefits from increasing ventilation and improving indoor air quality, including reducing other infectious diseases such as influenza, reducing allergies and improving productivity.[117] A wide range of options and systems to improve building HVAC system(s) are available. Buildings that are known to have poor ventilation and/or aging systems may be especially good candidates for upgrades. In some cases, capital works or deferred maintenance programs may already have identified and estimated costs of the needed replacements or improvements. Pandemic recovery funding may also aid with building, ventilation and air cleaning improvements.

HVAC engineers and operators can identify airflow patterns and air movement within a space or between spaces or zones in a building. Zonal pressures (differential pressures between indoor zones, and between indoors and outdoors) and negative-pressure hoods and rooms for containment in laboratories must be maintained, and noted when addressing potential viral transmission. Relative pressures and airflows under various operating conditions should be verified with pressure measurements and testing (e.g., smoke testing).

Building ventilations systems should be designed, and pressures checked, to ensure that air is exhausted or flows from “cleaner” to “dirtier” spaces, according to pressure zones and exhaust rates.[105,118] 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 always be the case. Options for ventilation via stairwells and other vertical shafts may contribute to passive or mixed ventilation,[119] but ventilation via these conduits 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 (Section 3.5).

3.2.2. Stratified ventilation and displacement ventilation

No one wants to be directly downwind of an infectious individual, so a common goal of HVAC systems (also reflected in risk estimation modelling) is to maximize ventilation and mixing. Preferably this is accomplished without feeling overly draughty. Mixing means, however, that everyone is to some extent rebreathing air with infectious particles. Moreover, the goal to completely mix the air may also be thwarted by eddies or "dead zones" resulting from intricacies of airflow in occupied spaces with furniture and barriers. Hotspots of virus accumulation in indoor spaces have been demonstrated using experimentation and modelling,[120] and under some circumstances may be detected by measurement of carbon dioxide (Section 3.7).

Apart from adjustments of ventilation controls and furnishings, innovative potential solutions to develop and consider over the longer term include displacement ventilation.[16] This minimizes horizontal air movement (from one person to another) and moves exhaled air away from breathing zones, thereby reducing virion transfer from an infected to a susceptible individual. Infection prevention as well as energy efficiencies occur because in displacement systems, stale, contaminated air is not continuously mixed with fresh, conditioned (heated or cooled, and dehumidified or humidified) air.[121,122] Displacement ventilation may be designed to operate upwards or downwards.[123,124]

Upward displacement ventilation is the more common design, with low-velocity delivery of conditioned air through supply diffusers (wall or corner diffusers) located at or close to floor level. Perimeter heating may be provided during cold weather to compensate for cooling of outdoor walls and windows. Heat sources (e.g., occupants, equipment) create thermal buoyancy and spatial stratification, as the warming air flows upward to the ceiling, where it is exhausted. Canada's National Research Council found that upward displacement ventilation, including during cold weather, performs well and is more efficient than a conventional mixed-air ventilation system with overhead air supply. Air distribution was more effective, leading to superior IAQ in the occupied zone (up to 1.8 metres from the floor).[121]

Heating and contaminant-removal advantages with upward displacement ventilation were demonstrated in a machining shop, where infrared heating was used for comfort. Particle capture was improved by 70%, during cold weather that necessitated heating. Cooler air supplied near the floor was warmed by occupants and equipment (that had been warmed by the infrared heating), and oil mist was entrained to upper exhaust.[125]

Further research may clarify the impacts of well-mixed versus slow upward air flows on: settling of particles and accumulation of infectious particles below the breathing zone; importance of cleanliness of flooring/carpeting and possible entrainment of dried infectious particles; and the role of distance from the floor of air supply diffusers located on walls, and possibly pillars.

Downward displacement ventilation is presently installed in areas where biological containment or infection control is essential, such as some specialized laboratories and operating theatres, and it could be more broadly applied for cooling in any building. Air that is cooler than the bulk of the room air is introduced at ceiling level, and falls to low-level air-return vents. This obviates concerns regarding re-entrainment, and again, horizontal movement is minimized.

A downward mixed-air distribution system with high induction supply diffusers in the ceiling and exhaust at floor level presents similar advantages of supplying fresh air directly to breathing height. It could improve contaminant removal effectiveness by entraining contaminants from the occupied zone toward the floor to be exhausted.

3.3. Buildings with limited or no mechanical ventilation

Some older Canadian buildings, built under old codes in different times, are not served with HVAC systems. Those with forced-air heating (but no A/C) should also upgrade filter banks and possibly fans, and may utilize in-duct UV air disinfection (Section 3.5.2).

Some older buildings rely upon radiative heating (e.g., hot water or baseboard heaters), with no forced-air heating or cooling, including schools and care homes. Some options include:

- **Opening windows** can be an effective, often readily available means to supplement ventilation, to dilute and exhaust aerosols, although the overall value is contingent upon the quality of the outdoor air (e.g., smog, smoke), wind direction, need for cross-flow and resulting airflows. As well, since warm air rises, the "chimney effect" can cause cooler air to flow in on lower floors and, as it is warmed, to exit upstairs. Fans may assist to direct and enhance airflow, while minimizing potential for plumes of infectious particles to be directed at others.
  Strategies: In buildings with only natural or room-specific ventilation, windows and vents should be maintained and operable, and may be employed even in colder weather. Leaving windows open continuously may be the more common practice, but with no control over pressure zones or airflows in the building it is hard to predict the results, particularly when windows open only on one side of the building (potentially windward, or leeward). An alternative that building operators and workers might consider (e.g., in schools) during colder weather is to use temporary fans to exhaust air, and for rooms to be exhausted each in turn, with windows and perhaps doors wide open over brief periods. The energy to heat air is much less than to heat the structure and furnishings, so there is potential for this to be a more energy-efficient as well as effective strategy, depending upon the site and operational details.

Caution: Open windows can provide substantial ventilation and are encouraged; however, some thoughtfulness is warranted. Airflow through windows is not well controlled, and although the first priority is to maximize ventilation and dilution of infectious particles, rare potential pitfalls have been identified. There is potential transmission of viruses via plumbing vents and through open windows, as observed at Amoy Gardens during the SARS epidemic.[126] As well, transmission via windows of potentially infectious airborne particles above an infectious source in a high-rise, in warm buoyant air against a sunny outdoor wall, has been demonstrated with tracer gas and modelled mathematically.[127,128]

- **Mixed ventilation** strategies utilize windows, doors, vents and local fans to enhance other means (e.g., HVAC) for air exchange between indoors and outdoors. For example, mixed ventilation may exploit the "chimney effect" whereby warm air rises indoors and may be exhausted (e.g., this can be quite effective in stairwells). When implemented in design and construction, mixed ventilation may offer money-saving and energy-saving means to provide greater outdoor air supplies, as well as heating or cooling according to the weather.[119,129]

Caution: When using mixed ventilation, the local and overall airflows in complex buildings must be assessed for different scenarios of temperature and wind direction,[130] as well as risks of contagion, to protect cleaner areas from higher-risk potential sources of contagion.

3.4. Air disinfection

In buildings without a ventilation system, and when aerosols cannot adequately be exhausted outdoors, airborne virions may be removed by filtration or destroyed with ultraviolet (UV) light. Attention must be paid to deployment of standalone units as particulates move in small scale turbulent clouds.[131] Not only sneezing and coughing, but also activities that generate fine aerosols (e.g., exercise, singing and talking, and even just regular breathing) can cause an infectious viral load,[132] according to the volume and direction of airflow.[67,126,133,134]

3.4.1. Filtration

Air filtration or cleaning may be provided by local stand-alone air cleaners,[111] where ventilation is limited, in adapted workspaces, classrooms, congregate care and housing, and other venues. The clean air delivery rate (CADR) of units must be sufficient for the size of the room; multiple units may be required. Effective filters (MERV 13+ or HEPA) may be attached to local fans.[135] Units must be:

- ✓ regularly maintained and filters changed according to manufacturer's instructions; and
- ✓ deployed to minimize the potential for plumes of infectious particles to be carried from an infectious to a susceptible individual.

Options to improve local airflow, to be more protective against transmission, include stand-alone air filtration. This may be deployed along with barriers to direct clean air to individuals or to intercept airflows with potentially higher viral load, as has been illustrated in health care for multi-bed rooms.[136] Candidate areas in non-healthcare settings would include spaces with poor ventilation, such as where staff is working behind new barriers that may hinder airflow, poorly-ventilated or enclosed spaces such as offices or meeting rooms, or areas that are offset for privacy or architectural interest.

Some air-cleaning technologies utilize electrostatic attraction, but these are not recommended – ASHRAE's review of filtration and air cleaning systems noted potentially harmful generation of ozone.[137] ASHRAE identified the greatest body of evidence regarding benefits and risks for ultraviolet germicidal irradiation (UVGI) and filtration of airborne virus-bearing airborne particles, and recommends only these two technologies.[137]

Ozone is a potent oxidizing agent that kills viruses, but ozone-based treatments (originally promoted to deodorize indoor spaces) may be harsh for indoor surfaces, carpets, furniture, window coverings and equipment, and would be inappropriate for routine application. At time of writing, these have not been approved or registered for disease prevention in Canada; neither have fogging nor vapour treatment with other chemicals, nor substances meant to provide long-term protection. See Section 4.2.4. Disinfection devices incorporating UV and/or that have potential to generate ozone (intentionally or as a side-effect of UV or electrostatic systems) must be assessed and registered by the Pest Management Regulatory Agency (the PMRA is within Health Canada).[21,25]

3.4.2. Ultraviolet light and ozone

Ultraviolet germicidal irradiation (UVGI) has a long history of deployment to kill microbes and to inactivate viruses, and coronaviruses are quite sensitive to UV light.[138,139] Conventionally, 254 nanometre (nm) wavelength light generated by mercury lamps has been used to inactivate airborne viruses.[45,105,113,141]

UV light is hazardous, so to reduce risks of cataracts the bulbs must be shielded (not in plain sight), and the glass of the lamp must filter shorter wavelength light to minimize generation of harmful ozone,[142] which is in itself a hazard. The PMRA notes, "depending on the UV wavelength, intensity, and duration of radiation exposure, exposure to ultraviolet light from these devices can result in serious injuries, including severe burns to the skin and eyes. Similarly, inhaling ozone can lead to decreased lung function, irritation of respiratory pathways, and inflammation of pulmonary tissues, as well as irreversible lung damage leading to higher susceptibility of respiratory infections."[25]

Ozone also reacts with volatile organic compounds (VOCs) from scents, and cleaning and renovation products, to form toxic degradation products. Nevertheless, high intensity UV-C sources may be installed in plenums with reflective interiors, or weaker sources may be situated high on walls or ceilings, shielded from direct sight, and with appropriate warning labels for maintenance personnel.[137,143,144]

An alternative to older mercury lamps is filtered excimer bulbs that emit ultraviolet light of 222 nm wavelength. The slightly shorter wavelength is said to limit ozone generation and risks of skin and eye damage,[145] and can be effective against coronaviruses.[144] There is very limited evidence on health effects, and eyes have no blood flow so are very vulnerable, so it is prudent to continue to shield the eyes from direct view.

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.[105,111]

UVGI devices that are assessed and registered for use[21,25] may be especially suitable 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 within elevators and stairwells.

Training and cautionary notices are necessary to ensure that bulbs are turned off before maintenance to remove dust (that reduces efficacy) and to replace bulbs.

UVGI is a further potential layer of protection against SARS-CoV-2 that complements but does not replace the need to wear masks, minimize interactions, maintain physical distance, or for proper ventilation and other public health measures.

3.5. Climate and Relative Humidity

Temperature affects the rate of inactivation of coronaviruses. Experimentally, SARS-CoV-1 remained infectious for days at temperatures and relative humidity commonly encountered outdoors and in air-conditioned environments in Canada, but rapidly diminished at 38°C and very high relative humidity.[146] Heating to 56°C is being used for rapid (15 minute) non-toxic disinfection of vehicles, such as for police.[147] High temperatures may be used in new construction to decrease rapidly the levels of volatile organic compounds, but this technique may be damaging to items in inhabited spaces (e.g., foods, personal care products and some plastic items).

Relative humidity may affect the response of airways to the virus and vulnerability to infection, 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.[148] Moreover with low relative humidity, exhaled virus-bearing particles dry and shrink more rapidly, and so may remain airborne longer than at higher humidity when particles remain hydrated and heavier.[149]

With respect to COVID-19, it is recommended that humidity be maintained at 40% to 60%,[105] not for any effect on virus activity but to avoid mould growth. While higher humidity levels might be feasible in some cases during the summer, condensation of excessive humidity in basements and cold walls will cause mould growth, which will impact health and damage structures. Buildings with poor or no vapour barriers can suffer structural damage from excessive humidity. Thus, the lower end of this range (40% in winter) is recommended in Canada.[150] Fragility of SARS-CoV-2 under warmer, very humid conditions has been proposed possibly to contribute to efficacy of masks,[151] although there is little direct evidence to support this hypothesis.

Depending upon outdoor air conditions, increasing ventilation may require additional (perhaps stand-alone) humidification or dehumidification equipment, to supplement existing capacity to maintain comfortable humidity, or to prevent moisture and biological contaminants, respectively.

Climate in context. 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). More robust physiological response against contagious respiratory disease with higher Vitamin D levels from greater sun exposure, diet or supplements is noted by the WHO[152] and others, specifically regarding SARS-CoV-2.[153,154,155,156,157,158]

Latitude (and thereby sun exposure) was previously plausibly linked to COVID-19 incidence and severity,[159] but this is a complex aspect of public health and health equity.[160]

The bottom line is that SARS-CoV-2 continues to be transmitted throughout the seasons, as evidenced by 2020 summertime surges of infections particularly in some countries with limited adherence to NPIs such as masks and physical distancing. This has experts concluding that non-pharmaceutical interventions are central to curtailing SARS-CoV-2 transmission.[161,162]

3.6. Carbon dioxide

Minimum air exchange rates have historically been developed to keep carbon dioxide (CO_2) levels below target values; these also keep the related bioeffluent contaminants from occupants below levels that would cause indoor air quality complaints. Ventilation to maintain a lower CO_2 level is beneficial for health and productivity,[117] and pandemic response recommendations are to increase ventilation with outdoor air as much as possible.[105] Lower occupancy will of course also result in lower CO_2 levels.

Increasing outdoor air supply will bring CO_2 levels closer to outdoor levels, with some recommending a range of 800 to 1000 parts per million (ppm). This precise target is not substantiated in the context of virus variants, and "as low as achievable" would obviously be preferred from a health perspective. Low levels have been achieved and found to curtail disease transmission; for example, increasing ventilation in under-ventilated buildings, reducing CO_2

levels from 3200 ppm to 600 ppm, was sufficient to halt ongoing transmission of tuberculosis (an airborne disease) in university buildings.[163]

When occupants are the only indoor source of CO_2, the level tracks the total exhaled breath and the ventilation in the space, and logically would be proportional to virions emitted by an infectious individual.[164] A study of three Montreal classrooms, including two with no HVAC system, found that CO_2 tracked occupancy over time. Knowing occupancy and activity levels, the scientists estimated air exchange.[165] The two classrooms with no HVAC systems had extremely low air exchange rates, which would pose high risks of SARS-CoV-2 transmission if an occupant was infectious and there was no accessory air cleaning equipment. One classroom is used in the example of risk estimation for SARS-CoV-2 wild type and variant (Section 3.7 and Annex 2 – Section 7) according to ventilation, masks, and occupancy over time.

Real-time measurements of CO_2 levels, and spot CO_2 measurements can be helpful to identify locations indoors with poorer ventilation or air circulation. In the absence of other CO_2 sources (e.g., a flame) or air cleaning (that does not remove CO_2), CO_2 could prove to be a useful flag for higher risk of COVID-19 transmission in a communal space.[165] While CO_2 levels might correlate with airborne viral loads,[105] transmission risks may occur even with small increases of CO_2.[166]

Exhalation of respiratory particles also contribute to water vapour and particles indoors. With many other indoor sources, the monitoring of neither relative humidity nor particulates is recommended as a potential surrogate to track virion levels.

3.7. Estimating necessary improvements in measures against airborne virion-bearing particles

With multiple layers of protections against airborne transmission, including infrastructure (e.g., ventilation), personal behaviour (e.g., mask wearing) and situation (e.g., avoiding crowding and ensuring that encounters are as few and brief as possible) to reduce SARS-CoV-2 transmission, it might be tempting to rationalize trade-offs (e.g., "I'm wearing a mask …" or "The window is open, so I can stay in this crowded situation.").

SARS-CoV-2 variants of concern may be more transmissible, result in more severe disease in younger age groups and be less susceptible to immunity from previous infection or vaccination.[167] When a new variant of concern emerges it may spread rapidly and overwhelm health care systems. Until COVID-19 immunity is widespread globally and the disease becomes endemic rather than a pandemic, curtailing infection requires applying every protective measure in a united front.[168] Building owners and operators, businesses, educational institutions, workers and visitors think back to the summer of 2020 and wonder, "How much better must efforts be to counter more transmissible variants?"

An established transmission risk estimation model[45] was used to compare build-up of airborne virions in a room and risk of disease, for a "summer of 2020" or wildtype SARS-CoV-2 and a more transmissible variant (Annex 2 – Section 7). The risk estimation spreadsheet is available on the CCIAQ website (https://iaqresource.ca) along with this module, for those wishing to adjust modelling according to their situation. Similar alternatives include an online version by Jimenez et al.,[102] while REHVA makes a somewhat simplified version available [109] (see Resources, Section 8). The CCIAQ modelling was executed by the Concordia Urban Buildings Environment (CUBE) group.

Please see Annex 2 – Section 7 for the full description, figures, interpretation and limitations, that are summarized here.

Brief background:

- When infection may spread, the average number of susceptible people who become infected by one infectious occupant is the reproduction number (R_0). When R_0 is more than one, the case numbers climb; when R_0 is less than one the epidemic declines. The lower R_0, the steeper the decline of both transmission and case numbers.
- Individuals become infected when they inhale an infectious dose of virus, so risk depends upon both the infectivity of the virus (variant) and rate of release of viruses from an infectious individual. Although these two values are uncertain, empirically they are combined as infectious "quanta."
- The infectious dose of SARS-CoV-2 is unknown, but "quanta" represent the infectious load emitted by an infected individual, according to activities.[40] A classic model (Wells-Riley) was applied to risk of COVID-19 from airborne particles.[41] This modelling was calibrated by Jimenez et al. using data from earlier spreading events[41,42] and then successfully applied to estimations of SARS-CoV-2 transmission in built environments[43] and mass transit vehicles[44] and further developed in the context of variants in several additional scenarios.[45]
- Risk estimation modelling illustrates how details of and adherence to NPIs must improve substantially, to counter variants. In the present work, the method was used to compare infection risk estimations for a variant virus that is 1.7-fold more transmissible, such as that identified in the United Kingdom.[1]
- The modelling simulates how, with one or more infectious individuals in an initially clean room with perfectly mixed air, the airborne quanta change over time as they mix in the air, and are also continuously depleted by ventilation (dilution and exhaust), air cleaning, settling out and being inhaled by occupants. This modelling of *perfectly mixed* air does not address details of airflow such as around partitions, or during close encounters.
- An individual's quanta dose is affected by: the number of infectious people present; room size (dilution volume); clean air delivery (ventilation plus air cleaning); mask wearing and efficiency; activity level (affecting breathing rate and volume); and time spent in the venue.

The risk estimation scenarios' base case is a poorly ventilated classroom (0.3 air changes per hour [ACH]) with 18 students, identified in a study of Montreal schools.[116] Other base case parameters were set to 100% wearing of masks with 50% efficiency, 19 occupants (one infectious), and medium activity level. The model permits adjustment of susceptibility of individuals, but given uncertainties of asymptomatic disease and potential reinfections, zero pre-existing immunity was investigated as a conservative case.

R_0 was compared for different values for ventilation, mask efficiencies, occupancy and numbers of infectious occupants. This reveals situations that pose risks of escalating disease transmission, and can be informative to scope the scale of interventions (e.g., increasing clean air, improving mask quality and adherence, and decreasing occupancy numbers and time) necessary to lower risks of transmission.

3.7.1. Risk estimation comparing previous SARS-CoV-2 with a more transmissible variant: Key findings

Please see Annex 2 – Section 7 for the full methods, results and figures, conclusions and limitations. While the numerical values are derived from the particular scenario of a poorly ventilated classroom, the trends and scale of differences in mask efficiency, ventilation rates and occupancy times to maintain R_0 below 1.0 indicate the scale or magnitude of improvements necessary to contain a more infectious variant of concern.

Examples of key findings include:

- To maintain R_0 below 1.0, with 50% efficient masks universally worn, and with one infectious individual ("source"), the maximum occupancy time would be less than 4 hours with the original SARS-CoV-2, and roughly halved to be less than 2.5 hours with the variant.
- To maintain R_0 below 1.0 over a 7-hour stay, compared with measures necessary for the original virus, with the variant it is necessary to double the ventilation rate (exceeding ASHRAE guidance), and/or increase mask efficiency from 62% to at least 72%.
- Over a 7-hour stay with 4 infectious individuals in the room, R_0 reaches 3-4 with the original virus and 9-10 with the variant.
- With two rather than one infectious individuals in the room, clean air delivery must be increased three-fold, to maintain R_0 at or below 1.0.

Improving ventilation does not remove risks from close encounters. Along with other protective measures, universal proper wearing of effective masks that arrest 80% of virions, during both inhaling and exhaling, may be effective to curb a more infectious SARS-CoV-2 variant of concern.

4. Building operations

Individuals' actions – such as staying home when sick, properly wearing a well-constructed, well-fitting, efficient (i.e., "effective") mask, maintaining physical distance, limiting interactions, avoiding closed spaces (with poor ventilation) and crowded places, washing hands and practicing respiratory etiquette – reduce the probability of transmission, but greater successes also depend upon the built environment. As knowledge advances of longer-term needs to limit contagion, complementing improving air quality directly, the following are considerations for re-opening, and for ongoing operations.

4.1. Re-opening

During shutdown and re-opening, 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 re-opening 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 with plastic barriers); and
- ✓ planning for ongoing operations, and for cleaning and disinfecting to limit viral transmission.

Administrative/organizational measures to achieve good productivity while respecting and supporting public health may entail multi-partner collaboration to:

- lay out and to communicate detailed logistics of occupancy; and
- to establish decision-trees for when employees or close contacts test positive for COVID-19.

The unique re-opening preparation time during and following COVID-19 shutdown is an opportunity to re-examine and to improve practices, operations, equipment and the facility itself. It is also the time to ground proof and establish protocols for the future.

4.1.1. Water systems

During periods of low or no occupancy water lies stagnant in plumbing and antimicrobial additives (e.g., chlorine or chloramine) from water utilities dissipate. This 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.[169]

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.[169] Fixtures, systems supplying hot and cold water, equipment (e.g., distillation units or ice machines), and systems for greywater (wash water 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.[170]

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.[171]

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 necessary.

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.[172,173] If a toilet lid is fitted, a sign should remind users to lower it before flushing.

Fill all traps with water. A small amount of oil may be added to slow evaporation.

As COVID-19 restrictions change over time, periods of low occupancy may result in recontamination of water, so routine flushing of toilets (with lids lowered, if available[173]) and running of taps may need to continue, and retesting may be advisable. It is essential to continue routine daily flushing of pipes to minimize lead levels in schools' drinking water.

Wastewater surveillance at sewage treatment plants for SARS-CoV-2 genetic material provides early warning of increasing cases,[174,175] including of variants.[176] New-build and retrofit sampling access may permit finer-grained sampling of "sewer-sheds," or even facilities for infections with markers excreted in sewage.[177]

4.2. Cleaning, sanitizing and disinfecting

The objective is to minimize viral transmission from objects, surfaces or dust (fomites) via the hands, to the mouth, nose or eyes where infection may be initiated.

Products registered with Health Canada that are expected to be effective against SARS-CoV-2 for sanitizing and for disinfecting surfaces are listed online[178] and identified on the packaging with a Drug Identification Number (DIN) or Health Product Number (HPN). Approved sanitizers and disinfectants require a wet contact time to ensure efficacy. This contact time may be several minutes – much longer than the 20 seconds recommended for washing with soap.[178] Government of Canada research found that virus reduction is much more efficient and rapid (5 seconds) when surfaces are wiped, compared with several minutes for spray-on chemicals that must penetrate surface residues, called fomites.[145]

4.2.1. Cleaning

Cleaning is the removal of contaminants from surfaces. It is necessary for successful sanitizing or disinfecting to inactivate potentially infectious materials including SARS-CoV-2, and living organisms such as bacteria, fungi (e.g., moulds), algae and spores.

SARS-CoV-2 is enveloped by a lipid (fatty) coat that makes it very susceptible to surfactants such as soap or detergent, so washing with soap and water is the preferred method to clean and sanitize hands. Soap removes contaminants and inactivates SARS-CoV-2, without any need for additional antimicrobial chemicals to sanitize most surfaces in buildings.[179,180,181]

4.2.2. Sanitizing and disinfecting

Sanitizing, less stringent than disinfecting, is used in non-healthcare settings and for hand cleaning. In these settings, gloves are used to protect the skin from cleaning agents; SARS-CoV-2 can be readily and safely inactivated and removed with soap and water, or inactivated with alcohol. 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 were permitted, to bridge supply constraints,[182] although certain alcohol-based hand sanitizers with unacceptable contaminant levels have been recalled.[183]

Disinfection to achieve sterile environments is necessary in key areas of healthcare, where gloves are used for protection and sterility of hands.

4.2.3. Safer choices for sanitizing and disinfecting

There are many options to eliminate SARS-CoV-2 on surfaces, with available products on the market posing a range of toxicities, including virtually non-toxic options. An important example is soap and water as used for hand washing, which has been shown in the scientific literature to be highly effective for eliminating SARS-CoV-2.[184] The use of lower-toxicity, or preferably non-toxic products is encouraged, because higher-toxicity products are problematic for vulnerable and sensitive populations. Use of safer products also protects against the development of sensitivities among those who do not presently experience the condition.[185]

To determine the potential impacts of a product, it can be helpful to consider the ingredients.

Active ingredients. In some users, bioactive chemicals in disinfectants can cause harmful effects, which may be immediate (e.g., allergies or sensitivity reactions) or delayed (e.g., developmental, hormone- or endocrine-related problems).

Some of the more concerning ingredients in disinfection products available on the market today include the widely used quaternary ammonium compounds (QACs or "quats"),[186] sodium dichloroisocyanurate and a few others contained in small numbers of products, as well as triclosan and chlorhexidine gluconate.[18,187]

The common antimicrobial triclosan, which is contained in many hand sanitizers and disinfectant products, has been reported in the scientific literature to disrupt the endocrine system (e.g., thyroid) which in turn affects early brain development,[188] harms the liver and poses risks to aquatic organisms as it enters waterways via wastewater.[189] Prior to COVID-19, triclosan was being released into the environment at levels that were potentially harmful,[190,191] and the human risk assessment has not been updated.[189] Health Canada notes that triclosan-containing products must be labelled, and offers advice to minimize exposure and to protect the environment. This advice includes: properly washing hands with plain soap and water (noting that antimicrobial ingredients are not necessary); reading labels to identify if triclosan is present; choosing alternatives; following safety warnings and directions; and disposing of products responsibly.[189]

Chlorhexidine and its salts are used in Canada as broad-spectrum antiseptics and antimicrobial preservatives in products such as cosmetics, natural health products, prescription and non-prescription drugs for human or veterinary uses, and hard-surface disinfectants. Chlorhexidine and its salts are recommended to join triclosan on the list of toxic substances, Schedule 1 of the *Canadian Environmental Protection Act* (CEPA).[192]

High-alcohol preparations are flammable and may pose risks during pregnancy and to children, and some other chemicals also pose proximate, immediate risks.[18]

A final concern is that routine use of sanitizers and disinfectants in general, and especially now with their increased usage during the pandemic, can contribute to the slower-moving global infectious hazard of antimicrobial-resistant organisms.[193,194,195,196] The pandemic has highlighted the importance of antimicrobial policies and improving wastewater treatment.[197]

As part of making environmentally preferable and healthier choices, it is recommended that sanitizing and disinfecting products be chosen that do not contain ingredients of concern, such as those designated or recommended to be listed as toxic under CEPA, especially when safer and more environmentally friendly alternatives are available.

Safer disinfectant options. To help consumers make safer product choices, the U.S. Environmental Protection Agency (EPA) has a list of disinfectants under its Safer Choice Program.[198] Some ingredients that are also approved in Canada include L-lactic acid, citric acid and peroxyacetic acid.[199] During the pandemic, dedication to healthcare of limited supplies of safer disinfectants containing alcohol (for hand sanitizers and wipes) or peroxides[200] may result in more higher-risk disinfectants being used in new applications and spaces. Safer disinfectant choices can be important particularly to protect those who are more vulnerable – e.g., children, women of childbearing age, pregnant women, the elderly, people who are exposed to hazardous substances in their homes, communities and work, and those whose health is compromised.

Disinfectants against more robust, non-SARS pathogens may be desired for higher risk applications such as medical care and food preparation, where peroxides can be effective. Although peroxides can pose acute risks during disinfection if not used according to manufacturers' directions, once dissipated they do not pose longer term risks.

Fragrance. Health Canada recommends that fragrance not be included in sanitizers,[18] as chemicals in fragrances pose risks of allergic reactions (notably asthma) and other adverse effects.[19,20] Over four thousand substances, including hazardous volatile chemicals of concern and phthalates, are potential ingredients in fragrance mixtures.[201] Fragrance-free policies are common in healthcare, and workplaces are increasingly self-designating as fragrance-free for the health of workers and clients, and to welcome and accommodate individuals identifying themselves as having sensitivities to these products. Occupants of multi-unit buildings and workplaces have noted infiltration of odours from neighbours' enthusiastic usage of products for cleaning, sanitizing and disinfecting. As well as communicating with the neighbours and/or landlord/building manager,[202] technical solutions to infiltration between units can include sealing of cracks with a tolerated filler (caulking, filler or plaster of Paris) or tape (metallic or paper-based, which may off-gas less volatile organic compounds) are possible remedies.

If products beyond soap/detergent and water are required for vulnerable groups, then safer products should be preferred. When possible, disinfection should be conducted when spaces are not occupied; residues may be washed or wiped off. Optimizing indoor air quality with attention to cleaning details is further discussed in Module 13, Addressing Multiple Chemical Sensitivities.[19]

4.2.4. Products with anti-viral claims

Times of uncertainty and fear are unfortunately occasions for marketing of products with possibly overblown claims or undisclosed hazards, to solve the "problem of the day." Promises of novelty, extended action and absolute safety merit close examination. Ineffective and/or risky actions inspired by misinformation and vested interests highlight the importance of regulatory requirements, and possible loopholes. Canada legally requires regulatory assessment and approval of anti-viral treatments such as disinfectants, sanitizers and fumigants. This is to protect human and environmental health, and to ensure that purported solutions actually work.

Viruses are inanimate, so must be damaged physically or chemically 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 tend to have lower activity against viruses than microbes, and may themselves pose risks when they transfer to the skin or enter the environment. As described below, heat and UV light offer non-chemical means to inactivate SARS viruses.

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[203]). This approach might possibly have some merit, but it is not yet a validated option against viruses and may pose risks.

Plastics embedded with antimicrobial chemicals are marketed, but these are only effective to the extent that they leach hazardous chemicals to their surface[204] so are subject to the same limitations as other dry residual chemicals. Another example, testing of a nanotechnology surface using liquid virus samples[205] could over-estimate effectiveness against dry particles settling from the air. Catalytic surfaces that dismantle bacteria and viruses have been researched in air filtration[206] and liquid systems,[207] but have uncertain feasibility and risks for use on touched surfaces.

Products registered to clean/disinfect surfaces include specific label instructions to spray from a close distance, that legally must be followed.[23] Electrostatic sprayers that apply disinfectants without a need to wipe are advertised to require much lower quantities of product, so their use may not result in adequate wet contact times, particularly on harder to reach surfaces (e.g., furniture surfaces that are under and behind the surface sprayed).[208,209]

Products that are applied to surfaces or sprayed more broadly to control infectious agents must be registered as a drug (with a Drug Identification Number or DIN) or a pesticide (with a *Pest Control Products Act* (PCPA) number). The use of a previously unregistered product with the intention to provide prolonged protection against SARS-CoV-2 in Toronto trains was subject to PMRA intervention. The product has since been registered (PCPA#15133) against bacteria, fungi and algae, but it is not labelled for anti-viral applications. As of writing, no space-spraying or “fogging” products or devices were registered for SARS-CoV-2 decontamination in Canada – instructions specify “direct application” or small distances for spray (confirmed via label search[23] [June 2021], personal communication with the PMRA [May 2021], and January 2021 personal communication during Health Canada Science Forum 2021). Health Canada has reported research on health care surface decontamination using peracetic acid fogging.[210] Internet searches reveal fogging services using peroxide, ozone or both combined, discussed in Section 3.5.

4.2.5. Cleaning/sanitizing/disinfecting plan

Surfaces/items that are touched frequently by multiple people may provide sites for virus transfer, and thus require frequent cleaning 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 must be accessible, including for children and those in wheelchairs. This requires:

- ✓ soap (with neither disinfectant nor fragrance ingredients) and water;
- ✓ towels to dry hands, such as laundered towelling or paper towels with dedicated disposal to permit recycling or composting (ensure air dryers are disabled to prevent a potential source of airborne virus[211]);
- ✓ authorized alcohol-based, fragrance-free hand sanitizer in dispensers (consider touchless devices) at entrances, exits, elevators and other places where there may be interactions or commonly touched surfaces, and no ready access to hand washing; and
- ✓ signage at hand sanitizing stations, and how-to-wash-hands with soap, at sinks.

Vacuuming, at best, results in "cleaning." To minimize re-suspension of virus-laden dust from carpets or soft furnishings, maximally efficient, ideally HEPA filtration should be installed in the machine, and maintained according to manufacturers' instructions. Cleaning staff must use appropriate personal protection equipment (PPE: mask for airway protection, eye protection, and gloves for protection against chemicals) and wash hands frequently with soap and water. Vacuuming during off-hours (a common practice already) is recommended. Ventilation and air cleaners should continue running during and following maintenance periods.

4.3. Adaptation, modifications, new equipment and new procedures

Beyond upgrading ventilation and air cleaning for air quality (Section 3), other innovative means to reduce SARS-CoV-2 levels in the environment and viral transmission are being investigated, proposed, tested and implemented.

Physical barriers (e.g., dividers or shields) installed to separate staff from the public (e.g., at service desks), and staff, students and other occupants/visitors from one another, may intercept droplets. Aerosols will still transfer via the airflow. Barriers may affect and direct air flow, and could decrease local ventilation, so removal of infectious aerosols might be limited in a space that is meant to be protected.[120] Local air cleaning may help. As well, barriers to intercept infectious droplets require frequent cleaning.

Voice-activated or touchless equipment – from faucets to assistants – is gaining attention during the pandemic. Advantages are unclear as speaking may increase exhalation of virions, and transmission via fomites is now considered to be uncommon and can be mitigated by cleaning. 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.[212] 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.

Pulse oximeters are finger-clips that measure pulse and blood oxygen saturation may detect "silent hypoxia" that can be experienced in COVID-19 infections. This is used to screen visitors to community health services. Hypoxia is typically not the first symptom of COVID-19, so pulse oximetry, although important in clinical settings, is unlikely to identify otherwise asymptomatic infections.[213]

The above is not to cast aspersions on use of handheld thermometers or pulse oximeters as they are deployed in high-risk settings such as dental clinics. In combination, screening that includes education and querying of symptoms and risks of exposure can improve awareness and adherence to public health protocols, potentially contribute to epidemiology, improve public health measures such as isolating and quarantining, and might affect willingness of ill people to avoid travel or to stay home from workplaces, schools or non-essential appointments. Thus, comprehensive screening has potential to provide another helpful layer of protection.[214] These activities, along with identifying and following cases and contacts, require honest participation by staff, occupants, visitors and management, and public health support.

5. Ongoing response

It can be difficult and stressful to keep up with details of evolving advice and requirements according to federal,[215] provincial and local public health, as well as site-specific requirements (e.g., occupancy limits, and one-way aisles and stairs). Successfully minimizing disease transmission will depend upon ongoing adherence to multiple layers of protection in locations such as offices, laboratories, meeting rooms, classrooms, washrooms, workshops, cafeterias, shipping and handling, corridors, elevators and stairways. Guidance and requirements for individuals are based on straightforward public health principles:[11]

- ✓ Staying home and away from others when experiencing COVID-19 symptoms (even if mild), if have been diagnosed with or exposed to COVID-19, or when awaiting a test result
- ✓ Minimizing interactions (i.e., few contacts, with brief interactions from the greatest distance possible)
- ✓ Avoiding closed spaces (with poor ventilation) and crowded places
- ✓ Proper wearing of well-constructed, well-fitting, efficient (i.e., “effective”) masks
- ✓ Hand hygiene and respiratory etiquette
- ✓ Cleaning / disinfecting of frequently touched surfaces and objects

Employers and building managers can assist with clear, consistent instructions, and on-the-spot signage can avoid confusion, encourage compliance and, hopefully, ease frustration and anxieties. Navigating the pandemic requires open channels of communication such as between management, staff and unions, or educational staff, students and parents’ groups, along with public health and other experts for consistent measures.

If COVID-19 is present in the community it will emerge in places where people come together, so it is important 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 available from public and occupational health and union organizations (see Resources, Section 9).

Engineering controls alone are unlikely to prevent SARS-CoV-2 transmission between individuals in relatively close proximity, especially over an extended period of time, so measures to encourage and enforce physical distancing, mask wearing and limiting the number of interpersonal contacts (e.g., “cohorting” to restrict interpersonal contact to a consistent small group of people) must be included in strategies for ongoing operations, while COVID-19 risks remain.

5.1. COVID-19 detection and public health measures

Public health requirements and guidance determine measures adopted in workplaces. These will change according to the level of risk in the community (number and rate of change of COVID-19 cases, including of variants) and scenario (e.g., workplace, school, community or commercial space, outdoor facility). SARS-CoV-2 variants' prevalence and transmission in the community determines transmission risks within buildings, and hence need for restrictions on opening and services. Wastewater surveillance, including of variants, can inform early actions before contagion outstrips public health and healthcare capacities and lockdowns become necessary.[174,175] Importantly, children and adolescents may be significant, silent carriers of infection. This may be detected with asymptomatic testing in regions with high incidence of disease.[61,216]

The following lists detail potential measures.

COVID-19 screening and followup

Emergence of extremely contagious variants heightens the risk of rapid spread. Screeners must wear personal protective equipment, and the person being screened must wear a mask.

- ✓ Rapid testing of symptomatic individuals for SARS-CoV-2, isolation, contact tracing and quarantine, and testing and isolation of positive cases. Consider testing of close contacts. Establish roles of public health and others, when an individual who was in the building has a positive test;
- ✓ Routine testing (preferably rapid testing) to detect pre-symptomatic or asymptomatic carriers;
- ✓ Screening before and following work/school with a questionnaire/app to report symptoms, and exposure to potential or known cases;
- ✓ In conjunction with questionnaires, screening for elevated temperature using a handheld no-touch thermometer, and possibly pulse oximetry, have been implemented. This is practiced in healthcare, carried out for sports teams, and was proposed for successful return to college/university.[71,217] As with all non-invasive screening, these will miss pre-symptomatic and asymptomatic cases; and
- ✓ In particular instances, for example when cases are surging, or for people interacting with potentially infected individuals, consider targeted strategies for SARS-CoV-2 testing of asymptomatic/pre-symptomatic individuals.

Wearing of masks

- ✓ Proper, consistent wearing of well-constructed, well-fitting, efficient (i.e., "effective") masks is a very important strategy among the layered approaches to reduce COVID-19. See Section 3.1 and Annex 2 – Section 7;
- ✓ Wash/sanitize hands frequently, especially after contact with high-touch surfaces/objects or other individuals, and before and after putting on and taking off one's mask;
- ✓ Change masks when soiled or damp, and wash (with scent-free soap or detergent) and dry reusable masks when soiled, damp or after several hours of use; and
- ✓ Well-fitting, multi-layer masks provided by employers both protect employees and the public, and contribute positively to public perception.

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

- ✓ Voluntary use of an ethical[218] validated phone app for COVID-19 contact notification (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, following significant exposure to an infected individual, or to care for family members (as defined by public health);
- ✓ In partnership with public health, wastewater facilities and researchers, testing of sewage for SARS-CoV-2 virus may provide an early indication that the virus is active in a building, community or region[219] (the Canadian Water Network COVID-19 Wastewater Coalition is advancing "wastewater epidemiology" for SARS-CoV-2,[220] including of variants.[221]); and
- ✓ Testing for SARS-CoV-2 (including variants) and immunity, as applicable and available.

5.2. 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.

Public health measures may include:

- ✓ Telework as appropriate for employees when their presence onsite is not essential, and particularly for employees with chronic medical conditions or living with someone with chronic medical conditions (e.g., heart disease, hypertension, chronic respiratory disease, diabetes, obesity, cancer and immune suppressive treatments[222]) that put them at greater risk of severe disease or outcomes from COVID-19;
- ✓ Physical distancing and personal protective practices (e.g., proper wearing of effective masks, hand washing and respiratory etiquette);
- ✓ Education outdoors (small groups, with masks and physical distancing) and remote learning;
- ✓ Minimizing size and diversity of groups meeting in person (i.e., form and enforce small cohorts rather than continuously changing members of groups onsite);
- ✓ Staggered work hours to minimize crowding, such as at entrances, elevators and food outlets;
- ✓ Masks and other PPE for cleaning and maintenance staff, as appropriate for chemical (e.g., disinfectants) and potential infectious exposures (e.g., while vacuuming), and adequate supplies to change PPE as needed;
- ✓ Cleaning and disinfecting of high-touch surfaces/objects; and
- ✓ Procedural changes such as the use of electronic signatures and files.

5.3. 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., one-way corridors, aisles and staircases; 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 provided for washrooms in some commercial spaces);
- ✓ In washrooms, consider retrofitting lids on toilets,[172] providing towels rather than air dryers for drying hands,[211] and ensuring frequent cleaning and substantial, continuous exhaust (i.e., 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; and
- ✓ Clean reusable drink containers and other items may be used safely in retail settings.[223]

5.4. Surveillance, continuous learning and preparedness

The COVID-19 health emergency is requiring rapid and ongoing adaptation. Site-specific as well as broader lessons learned while re-opening buildings and resuming operations will be important as SARS-CoV-2 mutates and COVID-19 continues, as well as for subsequent emergencies. Systematic data collection, including details of testing and cases of COVID-19 as well as environmental indicators (e.g., wastewater[174]), are essential for coordinated, evidence-based rapid responses, and development of preparedness plans. Site-specific protocols should be developed and made available, including building operations during low occupancy, shut-down and re-opening, to maintain safe and adequate ventilation, air cleaning and water supplies.

Learning during staged re-opening can result in iterative adjustments, to reduce potential transmission of the contagion as increasing numbers of people return to workplaces, schools and public places, and as transmissibility and severity of COVID-19 evolve. 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 has the additional benefit of reducing the spread of other viruses such as influenza.[224,225]

When COVID-19 cases occur among groups such as workers or students, whether contracted at home, play, work, school or elsewhere, all parties aim for the earliest possible detection of cases, and rapid, efficient contact tracing and quarantine to intercept the chain of transmission. Examining circumstances of transmission may yield additional recommendations to further dampen the spread. Protocols and decision-trees for response should be established, communicated to occupants and visitors, and all review/revision communicated regularly and clearly. Changing and unclear “rules” contribute to additional stress and “covid fatigue,” and affect adherence.

Going forward, facilities should be designed, built and retrofitted with versatile capabilities to adapt to diverse emerging threats. For example, beyond ventilation with outdoor air to counter contagious disease, other threats, such as climate-related hotter and more extreme weather, and smoke from wildfires, require different capabilities. These include 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 all to ensure that data is collected and experience acted upon for continuous improvement and better outcomes for the population, economy and environment in the near term and for the next time.[226]

6. Annex 1: SARS-CoV-2 transmission and COVID-19

Addendum to Addressing COVID-19 in Buildings, first update

Intercepting and reducing transmission of SARS-CoV-2 requires understanding the disease process. COVID-19 begins with inhalation of virus-laden particles that reach mucous membranes in the respiratory and digestive systems, and/or via hand-to-face transfer to the mouth, nose or eye. Viruses themselves are not actually alive, which has implications for methods to inactivate them. SARS-CoV-2 enters susceptible cells in the respiratory and/or digestive tract, where host cells' resources, structures and enzymes replicate the virus, and many copies are released. During infection with SARS-CoV-2, even before symptoms manifest, the virus is shed from the respiratory tract[227] and digestive tract (in feces),[228,229] contaminating the environment and thus potentially transmitting infection to susceptible hosts.[38,39]

Given that zero viral transmission – perfection – is unlikely in workplaces and schools while SARS-CoV-2 is circulating in the community, how much viral load might be tolerated? Although this is expected to differ among individuals and across variants, it is a perspective to 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 defences 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 the person has 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 inhaled dose of virions depends upon both the duration and intensity of exposure. Exposure in turn relates to the infectious individual(s) shedding virus (volumes and concentration of virions in air exhaled while breathing, talking, singing, exercising, sneezing and coughing, or even just breathing quietly), proximity to the source, and protective factors such as wearing of masks and ventilation (encounters outdoors are safer, but being close is always higher risk). 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/objects) may all culminate in an individual becoming infected, then infectious and possibly (not always) developing symptoms. These considerations support risk estimation modelling of relative, if not absolute, risks to prioritize mitigation measures to limit airborne transmission[15] (Annex 2 – Section 7).

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 masks without compromising medical supplies[15] – a recommendation that is now made by Canada [86] and the WHO,[87] and is increasingly required in indoor spaces, transit vehicles and even highly-occupied outdoor spaces, especially when physical distancing is not feasible. In support of public health, Masks4Canada.org provides further scientific overview and detailed guidance for an essential element to address this pandemic.[230]

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.[47]

Working assumptions that were reasonable at the beginning of the COVID-19 pandemic included under-estimations of pre- and asymptomatic transmission, transmission by children, and transmission via airborne particles over distances much greater than the two metre physical distance suggested as a minimum; separation between individuals should be as large as feasible.

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,"[48] while people who never develop symptoms cause "asymptomatic transmission."[51] Estimates vary, and the US Centers for Disease Control and Prevention (CDC) models consider that 10 to 70% of infectious cases may be silent, and never develop symptoms.[231] 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 testing for case detection, contact tracing, isolation (of cases) and quarantine (of contacts) are essential to limit disease spread. Modelling using an interactive, online resource[232] applied to re-opening of colleges indicates that in addition to sanitation, masks and physical distancing, the frequent testing of apparently healthy individuals for the virus is essential.[71,217]

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 and ongoing operations. In some jurisdictions, however, once students returned to school – either distance- or in-person learning – small classes were merged and physical distancing was no longer feasible, creating a need for further caution to limit contacts and to increase surveillance. Workplaces, restaurants, bars and shops may become more crowded as well.

Contact tracing is commonly forward-looking to identify contacts who may have been infected by a newly-identified case – it is a staple of Canada's public health response. Contact tracing to identify the source or previous carrier of infection (i.e., backward contact tracing) may be thwarted by anonymous, silent, covert or cryptic transmission from asymptomatic carriers,[50,233] including children,[51] and can frequently be unsuccessful outside of outbreak settings (e.g., Ontario data[49]).

Sometimes, particularly when investigating outbreaks, backwards contact tracing is used to identify the source or previous carrier of infection. Spread of COVID-19 is not uniform, as a minority of cases result in a majority of infections – in other words, "super-spreader events." Systematic combination of these methods – identifying individuals who cause many infections and their contacts – may result in more efficient case identification and isolation.[234,235]

6.2. Children may be under-recognized vectors of SARS-CoV-2

A minority of initially healthy individuals of all ages develop serious cases of COVID-19, but children in particular tend to have milder or asymptomatic, unrecognized disease. Children may present with common COVID-19 symptoms, but also tend to have abdominal symptoms, skin changes and/or rashes, as well as symptoms mimicking a cold. Children, particularly those with pre-existing health conditions, may develop serious and life-threatening COVID-19, and uncommonly develop a serious post-viral, autoimmune, inflammatory syndrome.[236,237,238] This issue is evolving, as the alpha variant is affecting young people more severely.[59]

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 (many in small families) largely during lockdowns, when parent-to-child transmission was more common than vice-versa as children were at home.[239] Analysis of viral loads across age groups found no reason to believe that children are less infectious;[53] indeed a Chicago study of 145 children found that young children had 10 to100 times higher viral loads on swabs.[54] 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.[240] Re-opening of schools and colleges has met mixed success and shifts to online learning. For example, a large outbreak occurred 10 days after opening a crowded Israeli school,[241] and roughly half of the children and councillors rapidly became infected at a summer camp with limited attention to COVID-19 prevention.[242]

Education and re-opening of schools have been identified by prominent Canadian and international public health organizations to be a high priority for children's health and development.[243] Detailed planning, support for changes to ventilation and classrooms, cleaning and continuous monitoring are necessary to adapt to and to adopt safe operations so that vulnerable children are not left behind.[243]

Lessons are being learned. During the summer and autumn of 2020 Canadian businesses and then schools re-opened, autumn progressed and COVID-19 cases surged. Many contacts could not be identified, and asymptomatic transmission was investigated. In late November 2020, schools in Windsor[60] and Toronto[61] detected dozens of unsuspected cases, mostly among students.

In the *Canadian Medical Association Journal*, Vogel cautioned that schools may be re-opened safely *as long as community transmission is low*, and appropriate measures are in place, such as reduced class sizes and well-ventilated classrooms.[57]

Modelling of re-opening of colleges indicates that in addition to masks, physical distancing, minimizing frequency and duration of personal interactions, and cleaning/disinfecting, that frequent, regular testing of asymptomatic individuals is essential for COVID-19 control.[71,217] Nevertheless, in June 2021, Ontario cited projected increases in cases, particularly of variants of concern, as the reason not to re-open schools before greater vaccine coverage.[62]

6.3. Airborne transmission is substantial and widespread

SARS-CoV-2 is an airborne coronavirus, transmitted via virus-laden respiratory droplets from a cough or sneeze, as well as smaller infectious aerosols exhaled to increasing degrees when breathing, talking, singing, exercising and shouting.[63,41,64] 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.[64,203] SARS-CoV-2 persists for more than three hours in fine droplets under experimental conditions,[203] and the smallest particles can reach the lower respiratory tract – the most vulnerable tissues of a non-immune or susceptible human host.[88,6]

SARS-CoV-2 has been transmitted via indoor air currents from one infectious diner to several others sitting more than two metres away in a restaurant,[66] through a poorly ventilated, crowded call centre,[67] from an infectious singer to several others at a choir practice,[60] and through an apartment building via plumbing vents.[70] Airborne transmission is cited among reasons that the disease has persisted at much higher levels in districts with doubts of the merits of public health measures and with less stringent NPIs, while COVID-19 has been more successfully suppressed in jurisdictions with different public health measures, including requiring and providing high quality masks.[71,72,73,74,75,76]

Risk estimation modelling of indoor transmission, including of variants (Annex 2 – Section 7) highlights the even greater importance of properly wearing effective masks, ventilation, lower occupancy and limiting time in shared spaces to counter variants.

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

Case identification of an individual who was potentially infectious while at work, school or another venue should trigger quarantine of close contacts, contact tracing and isolation of cases, as well as temporary closure of areas or of the entire building for cleaning and disinfecting and allowing time for thorough ventilation.

The operational assumption during a pandemic is that an asymptomatic source of virions is present regularly, requiring frequent cleaning/disinfecting of often-touched surfaces (including objects) and washrooms.

SARS-CoV-2 persistence ranges from minutes to days, depending upon environmental conditions. Under experimental conditions it persisted in fine aerosols during three hours of observation, and for 72 hours on plastic and stainless steel, but for less than 24 hours on cardboard and for four hours on copper.[203] Studies of spaces occupied by infectious individuals found that SARS-CoV-2 persisted on all surfaces, including air vents,[48] and was observed to remain intact for longer than four days on indoor smooth surfaces, and in one sample up to one week on a mask.[245] Subsequent investigation confirmed that SARS-CoV-2 mRNA detection corresponds to infectious particles, with half-life on common solids (stainless steel, glass, cotton, vinyl and money notes) ranging from 1.7 to 2.7 days at 20^{o}C; but only 1.5 to 3 hours at 40^{o}C.[246]

6.5. COVID-19 evolution

Coronaviruses naturally mutate, which can alter transmission, and the course of disease. “Variants of concern” spread more broadly and quickly, cause more severe disease, evade pre-existing immunity and might not be detected with current tests.[167]

In a laboratory experiment, three spontaneous mutations of SARS-CoV-2 resulted in “immune escape” from highly neutralizing (potent) blood serum from recovered volunteers.[247] Variants of concern that are more transmissible and have resulted in rapid increases in infections, such as those first identified in the UK (alpha; previously B.1.1.7), South Africa (beta; previously B.351), Brazil (gamma; previously P.1) and India (delta; previously B.1.617.2) along with less well understood “variants of interest” [5,248] are spreading globally, including across Canada. Early correlations[249] and strengthening evidence are indicating that some variants may also cause more severe disease with higher mortality in younger people,[1,2] and infect individuals who previously recovered from COVID-19.[3]

Canada’s third wave and ongoing adaptation to COVID-19 was associated with increases in variants (particularly alpha). Canadian wastewater surveillance can provide early warning of COVID-19 surges in communities,[174] including variants of concern, and is being reported by increasing numbers of Canadian Public Health authorities and internationally.[221,176] At time of writing, with increasing immunization, the threats posed by the delta variant and other emerging variants of concern remain uncertain in the context of high levels of vaccination.

Unfortunately, variants are evolving to be more invisible to the immune system. The predominant successful mutations in variants of interest and concern have lower numbers and antigenic potential of sites on the virus spike protein. These sites are recognized by the immune system and are also targeted by vaccines, so this evolution risks decreasing effectiveness of pre-existing immunity.[250]

Results of vaccination are eagerly awaited, but cautionary notes are warranted.

- The incidence or duration of asymptomatic contagion is unknown in the face of emerging variants of concern,[250] so *vaccinated individuals must continue to follow public health guidance*;
- Indications are that available vaccines will be at least partially effective against many emerging variants,[79,80] but with ongoing mutations, and with evolutionary pressure during vaccine rollout, it is unclear how efficacy will evolve.
- The goal to achieve population (or "herd") immunity is being challenged by uneven distribution of vaccines globally, and variants that can cause reinfection.[251,252]
- The success of advanced vaccine platforms being adjusted to address variants remains to be seen.[81]

6.6. One Health

The development of and responses to the COVID-19 pandemic highlight many health and environmental issues. Health issues include vulnerabilities of older populations and of those affected by pollution and modern lifestyles. These overlap with environmental risks from encroachment on natural areas; climate change; antimicrobial pollution and resistance. There are further outfalls of pandemic responses such as health, social and economic consequences of lockdowns, interruption of food and goods, distraction from other activities (e.g., postponement of cancer investigation and treatment) and a pandemic of online misinformation, disinformation and agitation. Interruption of education and entry into the job market will have long-term impacts on the young. Environmental consequences include waste, recycling initiatives and "covid response" rollbacks of environmental protection for essential natural systems and wildlife habitat.

Until safe and effective vaccination is widely achieved with capabilities to adapt to emerging variants, and public and environmental health and social measures improve Canada's resilience, the best hope for return to safe in-person interactions rests in adhering to clear, calm planning and actions, based on advice from competent, broad-based medical, scientific and engineering authorities. People in Canada must continue to use multiple personal preventive practices in a layered approach to protect themselves and others, regardless of individual vaccination status. The simplest, effective, readily implemented action for individuals is to wear effective masks consistently and properly. As COVID-19 joins other endemic respiratory infections, investments and eventual Building Code amendments to improve environmental performance reconciling ventilation and energy efficiency improvements could bear many long-term benefits.

7. Annex 2: COVID-19 modelling, and cumulative benefits of measures to address airborne transmission

Addendum to Addressing COVID-19 in Buildings, first update

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for the Canadian Committee on Indoor Air Quality

7.1. Introduction

Mutated SARS-CoV-2 viruses, particularly more contagious variants that may also cause more severe illness in younger people and may be less susceptible to natural immunity (called variants of concern),[1,253,254] are causing surges in COVID-19 around the world. As vaccines roll out, boosters to better protect against variants are developed, and SARS-CoV-2 mutates to evade immune response,[250] it remains essential to improve the execution of every single non-pharmaceutical intervention (NPI) that offers a layer of protection, particularly against airborne contagion.[15,88,230] Risk estimation modelling may be used to understand the scope and scale of necessary improvements.

The risk of contracting COVID-19 is reduced by physical distancing, properly wearing well-constructed, well-fitting efficient (i.e., “effective”) masks, increasing ventilation/clean air delivery indoors, and minimizing the time and number of people in a potentially infectious environment (thereby minimizing interactions). Cleaning hands and surfaces may interrupt transmission via fingers to the eyes, nose and mouth, although transmission via surfaces is thought to be rare.[255]

Risk estimation modelling can illustrate how infection risks vary according to use of and quality of masks, provision of virion-free air with ventilation and air cleaning, and the number of people and time spent together indoors (occupancy). The scale of necessary improvements for a more transmissible variant compared with previous SARS-CoV-2 are illustrated by comparing the scenarios described below. The complete modelling is contained in an Excel file, available on the CCIAQ website. It may readily be applied to other scenarios, although trends would be similar.

This modelling example is built on a base case of a poorly ventilated classroom first reported in a study of ventilation in Montreal schools.[165] Initially the room contains zero virions, such as a classroom or office at the beginning of the day; then infectious particles build up in the air as they are shed by one or more infectious individuals. Some of these particles deposit to room surfaces, while many remain in the air and are exhausted via ventilation, captured by masks, or evade capture and are inhaled by occupants. Susceptible individuals, who are not immune, would be expected to become infected if the inhaled dose is above infectious levels. This modelling of the risk of contracting COVID-19 in indoor spaces assumes well-mixed indoor air,[41,42,109] so it does not account for idiosyncratic, detailed airflow patterns as discussed in Section 3.

The infectious dose of SARS-CoV-2 is unknown, but “quanta” represent the infectious load emitted by an infected individual, according to activities.[40] A classic model (Wells-Riley) was applied to risk of COVID-19 from airborne particles.[41] This modelling was calibrated by Jimenez et al. using data from earlier spreading events,[41,42] then successfully applied to estimations of

SARS-CoV-2 transmission in built environments[43] and mass transit vehicles,[44] and further developed in the context of variants, in several additional scenarios.[45]

The "reproduction number" or R_0 (called R naught) is the average number of people infected by an infectious person. When one person, on average, infects one more person, then the epidemic or pandemic is perpetuated at the same number of cases, and R_0 is equal to one. The farther R_0 is below one, the faster the epidemic dies out, while the farther R_0 is above one, the faster the virus spreads.

The newer, more transmissible variants differ from older variants, thought to be related to stronger binding with cellular receptors and efficient infection of cells,[256] that may result in greater virion production and shedding in the upper airway, and more severe disease. The result is that variants have been reported to be 1.7 (or more) times as infectious as the original SARS-CoV-2,[257] and may cause more severe disease,[258] possibly more quickly.[2]

The quanta value relates the infectiousness of airborne virion-bearing particles to development of disease. In this application, the equivalent rate of quanta generation for a variant that results in a 1.7-fold incidence of disease was back-calculated. R_0 for both variants was estimated for a range of mask efficiencies, ventilation/clean air delivery rates, and occupant numbers and time spent in the room.

7.2. Base Case

Risk estimation modelling compares the risk of contracting COVID-19 in an initially poorly ventilated classroom with 19 occupants (a case identified in a study of Montreal schools[165]), with one or more infectious individuals and the remainder susceptible to infection. The model begins with a clean classroom and instantaneous mixing of virions in the air, so exposure to more concentrated clouds of virions close to an infected individual would increase risks above those modelled.

The modelled classroom volume is 236 cubic metres (m^3), with 100% of occupants wearing masks. Other default values, unless varied within an analysis, are:

- a low baseline ventilation of 0.3 air changes per hour (ACH; measured as 1/h or h^{-1}). This is lower than 1.4 ACH that would be consistent with the American Society for Heating, Refrigerating and Air-conditioning Engineers (ASHRAE)) recommendation of 5 litres per second per person.[114] "Ventilation" refers to the fresh outdoor air plus effective clean air supplied by air-cleaning devices, and not the total supply rate that may include return air;
- 7 hour occupancy;
- 50% mask efficiency (80% efficiency and even greater have been reported for properly worn, well-fitting, well-constructed cloth masks[14,259]); and
- a single infectious individual, with the remaining 18 individuals susceptible to infection.

7.3. Limitations

This risk estimation modelling is intended to illustrate how protective measures must be improved and adhered to consistently, and to estimate the scale of necessary improvements to mask-wearing, ventilation and occupancy, in order to reduce transmission of SARS-CoV-2 variants sufficiently to quell the pandemic (i.e., maintain R_0 below 1.0).

The modelling only pertains to the bulk mixed air, and does not address close encounters where masks may offer the sole protection against any concentrated plumes of virions.

The risk estimation modelling addresses an "average" individual, and does not factor in uncertainties that some people shed substantially more virions than others, or that individuals are not all equally susceptible to infection.[260,261] The real-life heterogeneous transmission, dubbed "dispersion" in epidemiological modelling, results in "super-spreading" when a significant proportion of cases result from a minority of individuals who unknowingly spread COVID-19 in public venues, generally before they feel symptoms.

The modelling was carried out for a school classroom of particular size and occupancy. This exercise could be replicated, for example, for smaller rooms such as in care homes where levels of virions would build up more quickly; congregate settings such as shelters and warming centres for the homeless; offices and workplaces including larger spaces with more visitors coming and going; and scenarios with multiple infectious individuals. The conclusions will differ somewhat numerically, but the underlying message will remain, that variants of concern necessitate substantially stronger measures to address airborne contagion.

7.4. Mask Efficiency

Masks are the first (when exhaling) and last (when inhaling) lines of defence against SARS-CoV-2. Reports of mask efficiencies range from 55% for medical procedure masks, widely range up to 90% for cloth/reusable masks with efforts to improve fit, and 95% for N-95 masks.[14,96, 262] In this work, for simplicity, it was assumed that efficiency was equal for inhalation and exhalation (masks may be more efficient at intercepting moist exhaled droplets than dried droplet nuclei in room air).

Figure 1 illustrates that for the base case, mask efficiency of 50% would not maintain R_0 below 1.0. Mask efficiency of at least 60% with the original variant (red dot in Fig 1A) must increase to at least 70% to maintain R_0 below 1.0 with the variant (red dot in Fig 1B). In this scenario, after 7 hours of wearing 50% efficient masks, almost twice as many individuals would be infected with the variant as would be infected with the original (green dots in Figs 1A and 1B).

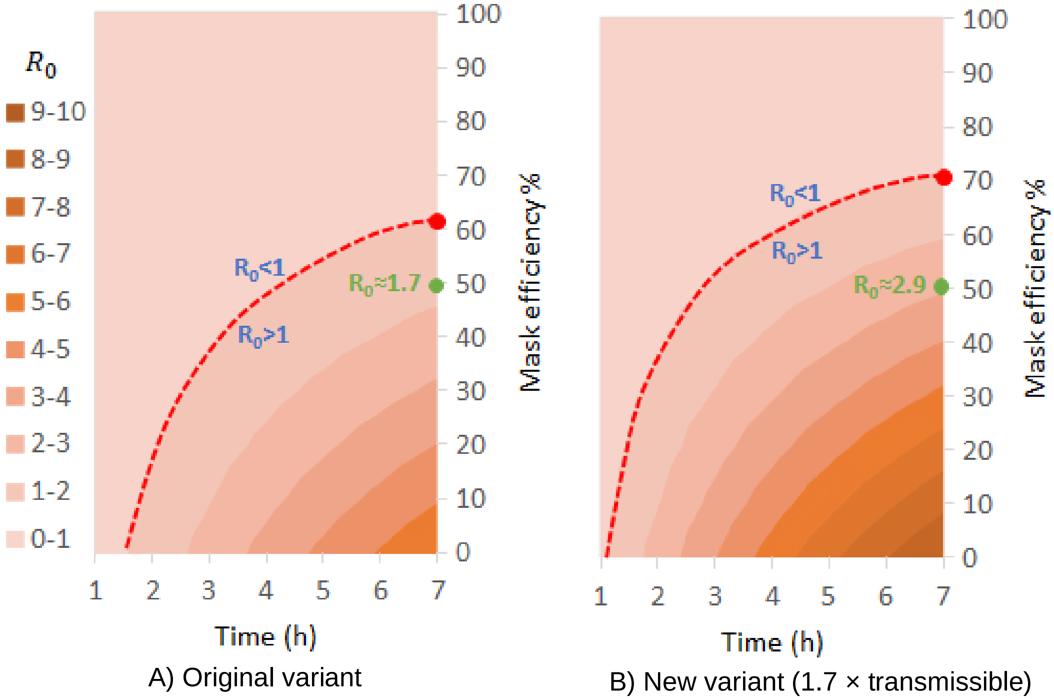


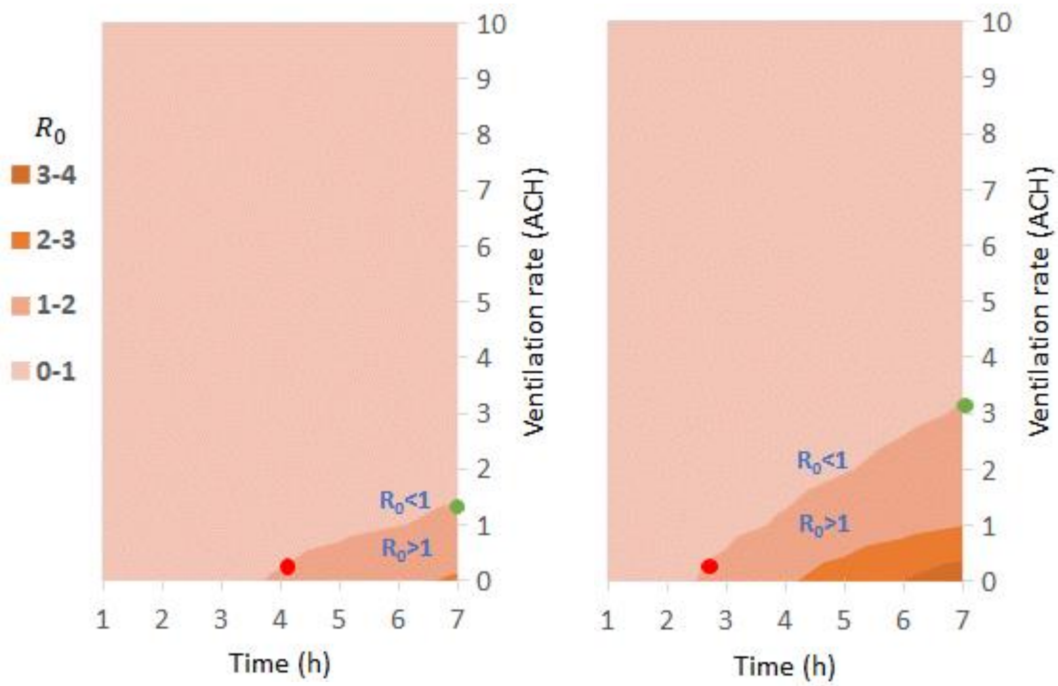
Figure 1. Reproduction number with a single infectious individual, according to mask efficiency and time in the classroom. Other parameters are: 19 occupants (one infectious); ventilation + clean air 0.3 ACH; exposure time 7 h.

7.5.Ventilation rate

Ventilation dilutes indoor air with outdoor air and exhausts virions, extending the time before a susceptible individual will have inhaled an infectious dose.

Based on the base case classroom with an ACH of 0.3, to maintain an R_0 below 1.0, the maximum occupancy time would be less than approximately 4 hours (red dot in Fig 2A) with the original SARS-CoV-2 and less than 2.5 hours (red dot in Fig 2B) with the variant.

Examining a range of ventilation rates, when there is a single infectious individual, and everyone is wearing a mask of 50% efficiency, the ventilation rate to maintain R_0 below 1.0 for the new variant is more than double that for the original SARS-CoV-2 (green dots in Figs. 2A and 2B). This substantial difference may exceed building HVAC capabilities, particularly during temperature extremes.



A) Original variant

B) New variant (1.7 × transmissible)

Figure 2. Reproduction number for a single infectious individual, according to mechanical ventilation rate and time in the classroom. Other parameters are: 19 occupants; mask efficiency 50% for inhalation and for exhalation; exposure time 7 h.

7.6. Number of infectious individuals

Having more infectious individuals in the enclosed space naturally leads to greater transmission and R_0 may exceed 1.0. Figure 3 illustrates this in the poorly ventilated classroom, with 50% efficient masks worn by everyone.

With the original SARS-CoV-2, to maintain R_0 less than 1, the increase from 1 infectious individual to 4 reduces the maximum occupancy time from approximately 4.25 hours to 1.5 hours (red dots in Fig 3A). For the more infectious variant, maximum occupancy time would be reduced from approximately 2.75 hours to just over 1 hour (red dots in Fig 3B).

Another perspective is that with up to four infectious individuals present during the full 7 hour occupancy time, R_0 ranges to 6 for the original virus, while R_0 ranges to 9 with the variant.

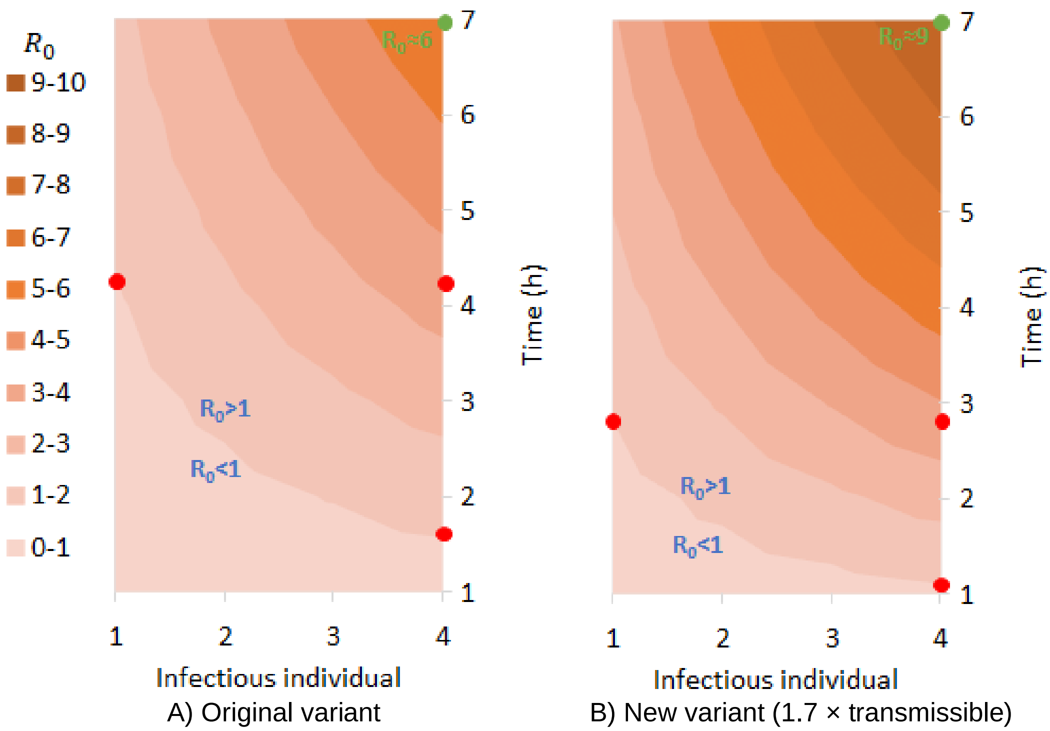


Figure 3. Reproduction number over time, according to the number of infectious individuals. Other parameters are: 19 occupants total; ventilation + clean air 0.3 ACH; mask efficiency 50% for inhalation and exhalation.

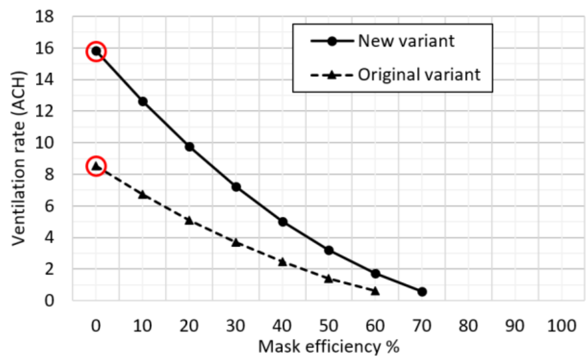
7.7. Maintaining low reproduction number

Figure 4 illustrates that to maintain R_0 below 1.0 in this classroom setting, higher ventilation rates and lower occupancy time and number of people are necessary in the context of the more transmissible variant. As the most proximate form of protection, universal proper wearing of effective masks can mitigate this risk.

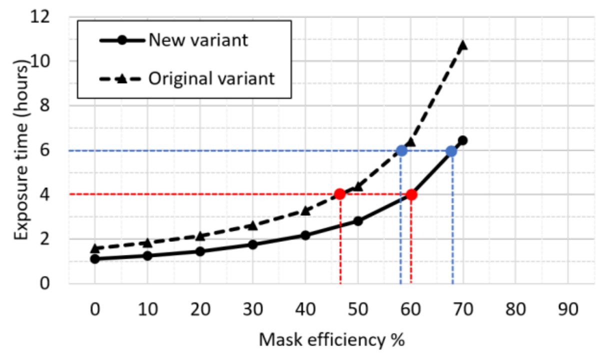
Figure 4A illustrates that with inadequate masks, ventilation rates to maintain R_0 below 1.0 for the new variant are approximately double that for the original SARS-CoV-2 (red circles in Fig 4A). More efficient masks reduce the minimum required ventilation. In this scenario, the universal wearing of masks that are over 70% efficiency would result in low transmission. This is feasible for non-medical masks.[14]

Figure 4B illustrates how more efficient masks are required for longer exposure times to maintain R_0 below 1.0. For example, over a 4-hour exposure time, mask efficiency of 47% and 60% are required for the original and new variants, respectively (red dots in Fig 4B); a 6-hour period in the classroom would require mask efficiencies of 58% and 68%, respectively (blue dots in Fig 4B).

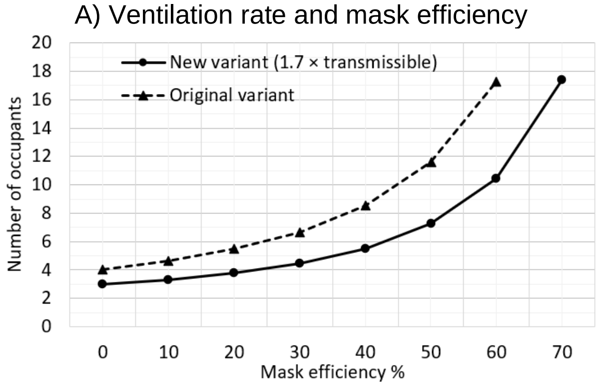
Figure 4C indicates the number of occupants with a given mask efficiency who can be present over a 7-hour period while maintaining R_0 below 1.0.



A) Ventilation rate and mask efficiency



B) Exposure time and mask efficiency



C) Number of occupants and mask efficiency

Figure 4. Ventilation rate, exposure time, and number of occupants in a classroom to maintain R_0 below 1.0, according to mask efficiency. Base case parameters (unless otherwise noted) are: 19 occupants (one infectious); ventilation + clean air 0.3 ACH; exposure time 7 h.

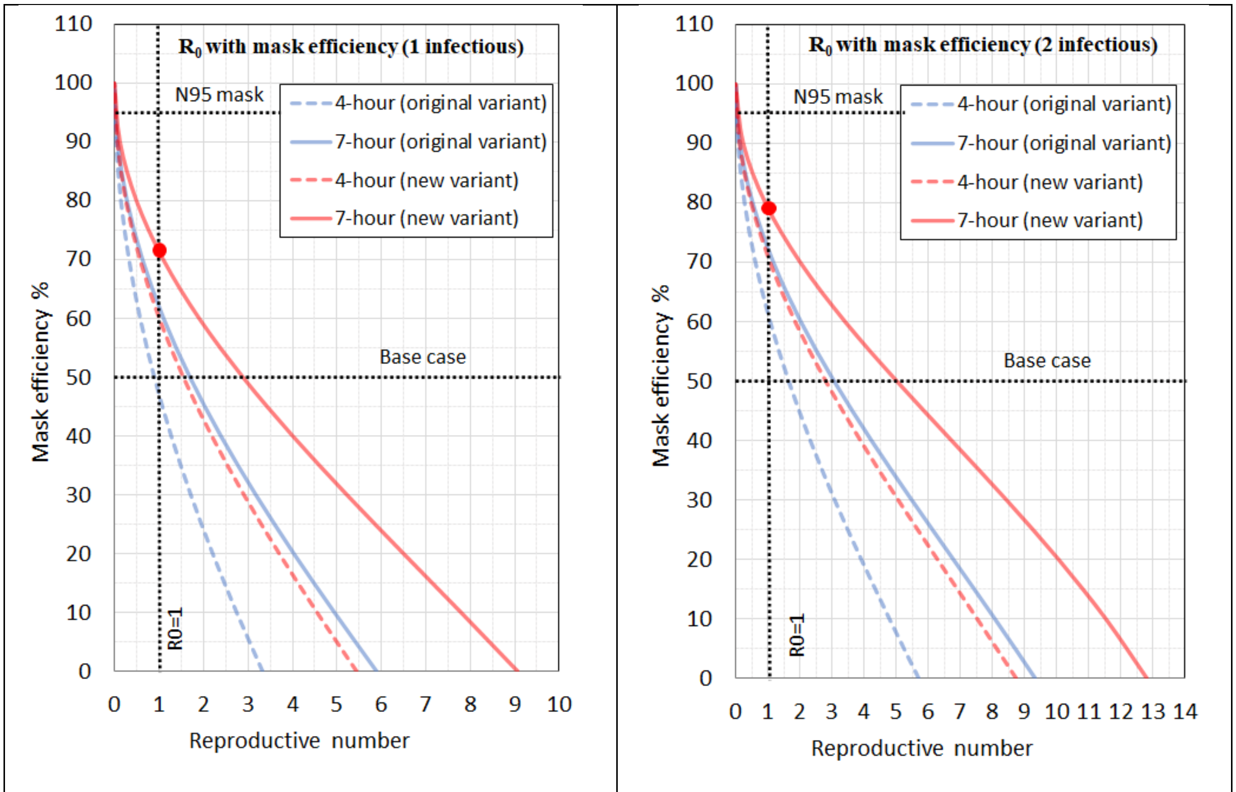
7.8. Effects of number of infectious individuals on reproductive number for non-pharmaceutical interventions (NPIs)

Figure 5 illustrates the effects of NPIs on R_0, over 4 hours or 7 hours, when either one or two individuals are infected with the original or the more transmissible SARS-CoV-2.

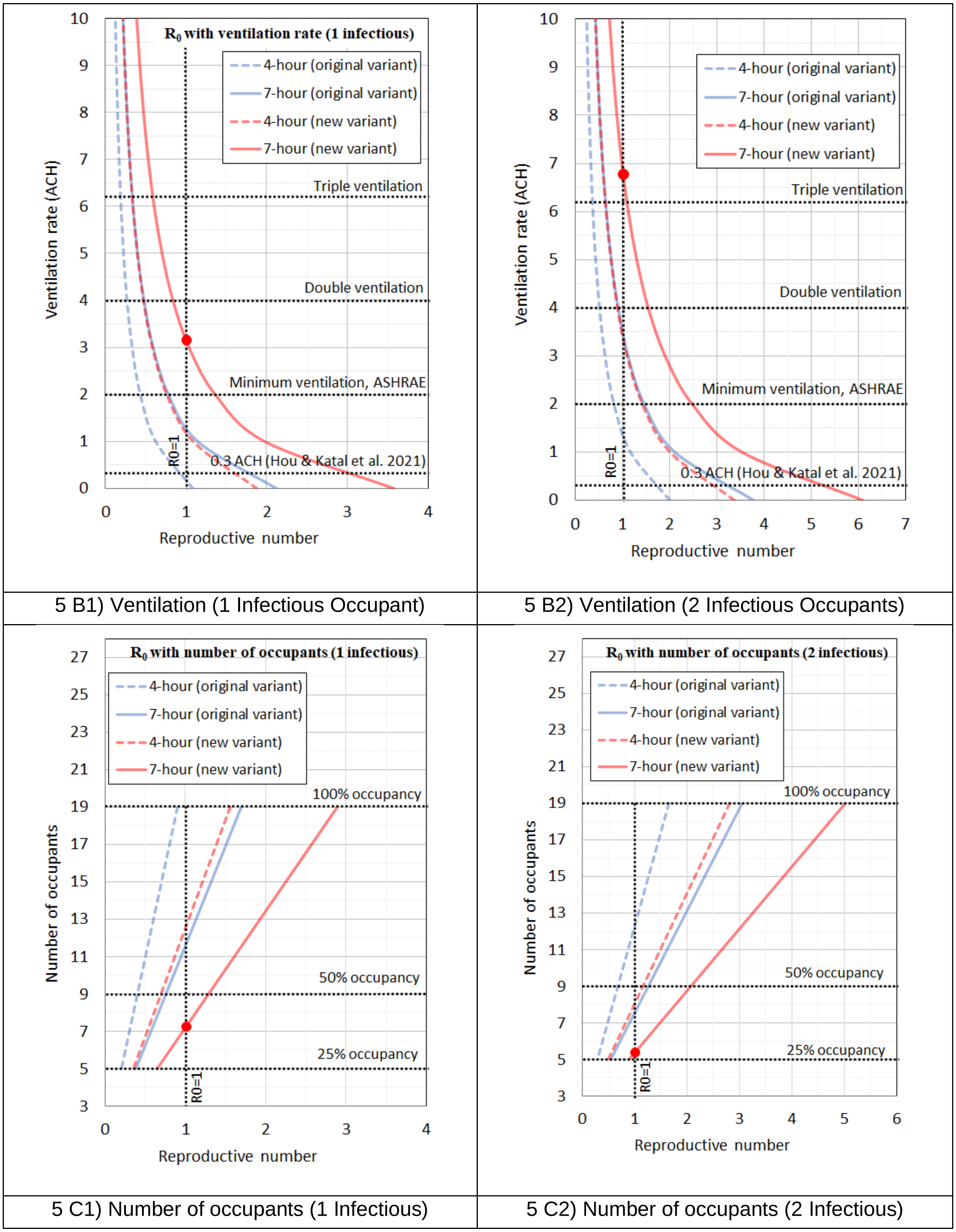
Figure 5A Masks worn universally should be at least 70% (Fig 5A1) and 80% (Fig 5A2) efficient against virions when one or two occupants are infectious, respectively.

Figure 5B Ventilation plus clean air delivery should be increased to at least 1.5 times (with 1 infectious occupant) and 3.5 times (with 2 infectious occupants) that recommended by ASHRAE for acceptable air quality (not infection control).

Figure 5C occupancy must be reduced from 11 to 7 individuals when 1 is infectious (35% reduction) and from 7 to 5 individuals (25%) for the full 7 hours (more people may be present over a briefer period); and every effort must be made to isolate infectious individuals as risks increase with every additional person shedding virions.



5 A1) Mask efficiency (1 Infectious Occupant)	5 A2) Mask efficiency (2 Infectious Occupants)



5 B1) Ventilation (1 Infectious Occupant)

5 B2) Ventilation (2 Infectious Occupants)

5 C1) Number of occupants (1 Infectious)

5 C2) Number of occupants (2 Infectious)

Figure 5. R_0 variation with mask efficiency, ventilation + clean air delivery rate, number of occupants, and number of infectious individuals, at occupancy times of 4 h and 7 h. Base case parameters (unless otherwise noted) are: 19 occupants; ventilation + clean air 0.3 ACH; mask efficiency 50% for both inhalation and exhalation.

7.9. Increases of R_0 with 1 to 4 infectious occupants

Figure 6 illustrates that when the number of infectious individuals increases from 1 to 4 in the classroom with 0.3 ACH, R_0 increases roughly 3-fold.

Over 4 h, R_0 increases from 1 to 3 for the original SARS-CoV-2 and from 1.5 to 4.5 for the variant.

Over 7 h, R_0 increases from less than 2 to 6 for the original SARS-CoV-2 and from 3 to 9 for the variant.

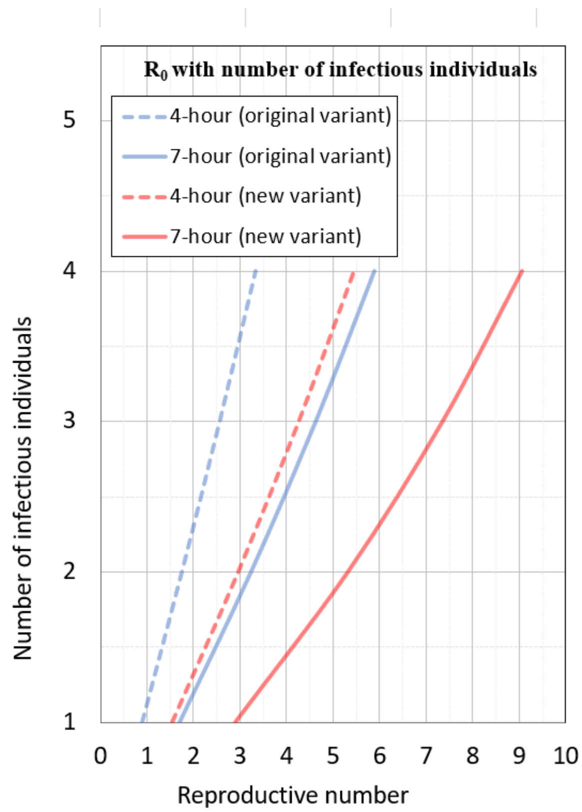


Figure 6. R_0 variation with number of infectious individuals for the base case: 19 occupants; ventilation + clean air 0.3 ACH; mask efficiency 50% for both inhalation and exhalation.

7.10. Conclusion

The scale of necessary improvements in non-pharmaceutical interventions (NPIs) to reduce airborne transmission of a more transmissible SARS-CoV-2 variant is illustrated using the risk estimation modelling of infectious aerosol particles in well-mixed air. All NPIs can be improved, including the proper wearing of effective masks, increasing clean air via ventilation and air cleaning, and reducing occupancy rates. Similar results and conclusions were recently reported using the same modelling concept,[45] that *masks are essential, and that we must significantly improve ventilation for the new variants, relative to what was necessary for earlier SARS-CoV-2.*

The universal wearing of masks of at least 80% efficiency is a highly effective measure both to reduce the source of virions transmitted from infectious individuals and to provide protection to those who could be exposed.

Further improving the air supply is an important strategy to help to counter more infectious variants. Compared with the original virus, a variant that is 1.7-fold more infectious (e.g., B.1.1.7) requires roughly doubling ventilation plus clean air delivery from high-efficiency air-cleaning devices.

Reducing the number of occupants in the room is an effective strategy to stop virus transmission from infectious to susceptible individuals. Summary of required mask efficiencies, ventilation rates, and occupancy percentage to prevent virus transmission for original and new variants are presented in Table 1. Results are provided for different exposure times and the number of infectious occupants.

Table 1. Mask efficiency, ventilation rate, and number of occupants in a classroom required to maintain $R_0 < 1$ (based on Fig 5 results)

Parameters	Exposure Time	One Infectious Occupant		Two Infectious Occupants	
		Original Variant	New Variant	Original Variant	New Variant
Mask Efficiency	4 hours	45%	60%	60%	70%
	7 hours	60%	70%	70%	80%
Ventilation	4 hours	0.3 ACH	1.2 ACH	1.3 ACH	3.5 ACH
	7 hours	1.2 ACH	3 ACH	3.5 ACH	6.8 ACH
Occupancy	4 hours	100%	70%	60%	40%
	7 hours	60%	35%	40%	25%

Viruses mutate, and fitter variants are being naturally selected to bind more tightly with receptor sites on cells, to replicate more rapidly, to be shed in larger quantities, and to evade natural and vaccine-acquired immunity.[263] Thus, more infectious variants will likely continue to become predominant until the contagion is stopped, as every person who is incubating SARS-CoV-2 offers the virus an opportunity to mutate further. "Immune escape" blunts the effectiveness of vaccines and results in re-infections, lending urgency to quenching the pandemic as rapidly as possible, and highlighting the need to employ NPIs that do not rely upon biological response. Recently published research expands upon this methodology, and generalizes findings using a "cumulative exposure time" for occupants as a guideline for occupancy of indoor spaces. This work similarly emphasizes the dramatic reduction in transmission with face masks.[45]

Multiple protective measures to minimize airborne transmission and exposure, along with washing of hands and sanitation, have innate efficacy if assiduously executed. Along with conscientious, proper wearing of highly-effective masks and minimizing interactions with those outside your household, improving IAQ and building operations to curtail COVID-19 transmission should be a high priority. These readily implemented measures have innate effectiveness if well executed. Moreover, investments in better indoor air quality offer long-lasting benefits to health and productivity beyond pandemic preparedness and response,[117] and implementation is readily understood.

Research and renovations, including refining progressive new designs such as displacement ventilation (which would not be modelled as above), are also opportunities to improve energy efficiency and to use ventilation systems and air cleaning to remove contaminants from outdoor air, such as wildfire smoke. This is an essential task to address another key crisis of our times – our changing climate.

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9. Resources

9.1. IAQ Engineering and Science

Authority	Resources	Topics regarding COVID-19	Primary and key links
American Society of Heating, Refrigerating and Air-conditioning Engineers (ASHRAE)	Technical standards Position documents	Infectious Aerosols; COVID-19 Filtration Standards for HVAC	https://www.ashrae.org/technical-resources/resources
Federation of European Heating, Ventilation and Air Conditioning Associations (REHVA)	HVAC guidance and standards	Mathematical modelling of virions in indoor air	https://www.rehva.eu/activities/covid-19-guidance

9.2. Modelling and Calculators

Authority	Resources	Topics regarding COVID-19	Primary and key links
American Society of Heating, Refrigerating and Air-conditioning Engineers (ASHRAE)	Technical standards Position documents	Equivalent Outdoor Air Calculator	https://docs.google.com/spreadsheets/d/1GUCcjAyhzrTATHD8SQvNcF7JnuWKpadSVT6LA_8SUIl/edit#gid=0
Federation of European Heating, Ventilation and Air Conditioning Associations	COVID-19 Ventilation Calculator	Mathematical modelling of virions in indoor air (adapted from Jimenez et al., below)	Guide: https://www.rehva.eu/fileadmin/content/documents/Downloadable_documents/REHVA_COVID-19_Ventilation_Calculator_user_guide.pdf Spreadsheet: https://www.rehva.eu/covid19-ventilation-calculator
Prof. L. Wang, Concordia University Building Environment (CUBE) Lab, Montreal, Quebec	City Reduced Probability of Infection (CityRPI)	Indoor airborne transmission of SARS-CoV-2	https://concordia-cityrpi.web.app/
Prof. Jose L Jimenez, Dept. of Chem. And CIRES, Univ. of Colorado-Boulder, USA	COVID-19 Aerosol Transmission Estimator	More detailed and updated mathematical modelling of virions in indoor air	https://docs.google.com/spreadsheets/d/16K1OqkLD4BjgBdO8ePj6ytf-RpPMlJ6aXFg3PrIQBbQ/edit#gid=519189277

Authority	Resources	Topics regarding COVID-19	Primary and key links
U.S. Department of Homeland Security	Estimated Surface Decay of SARS-CoV-2 Estimated Airborne Decay of SARS-CoV-2	Estimates survival on surfaces under a range of temperatures, relative humidity, and UV Index Estimates survival in air under a range of temperatures, relative humidity, and UV Index	https://www.dhs.gov/science-and-technology/sars-calculator https://www.dhs.gov/science-and-technology/sars-airborne-calculator
U.S. National Institute of Standards and Technology (NIST)	FaTIMA – Fate and Transport of Indoor Microbiological Aerosols	Well-mixed ventilation system with numerous options for infectious particle sources.	https://www.nist.gov/services-resources/software/fatima

9.3. Public Health, Government

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
Public Health Agency of Canada	Coronavirus disease resource page COVID-19: Guidance on indoor ventilation during the pandemic	Epidemiology, vaccines, guidance, supports	https://www.canada.ca/en/public-health/services/diseases/coronavirus-disease-covid-19.html https://www.canada.ca/en/public-health/services/diseases/2019-novel-coronavirus-infection/guidance-documents/guide-indoor-ventilation-covid-19-pandemic.html

Authority	Resources	Topics regarding COVID-19	Primary and key links
Health Canada	Regulatory information	Information for health product manufacturers	https://www.canada.ca/en/health-canada/services/drugs-health-products/covid19-industry.html
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	https://www.canada.ca/en/health-canada/services/drugs-health-products/disinfectants/covid-19.html https://www.canada.ca/en/health-canada/services/drugs-health-products/disinfectants/covid-19/interim-guide-ethanol-hand-sanitizers.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
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: Re-opening Disinfection Masks Day cares Preventing stigma Specific occupations and industries Courses, posters, planning	https://www.ccohs.ca/products/publications/covid19/
Canadian National Collaborating Centre for Environmental Health (NCCEH)	A series of focused science-based discussion / recommendations topic papers and presentations	Many rapid reviews on COVID-19 related topics, including basics, prevention, response, approaches to various venues (e.g., schools and other buildings), wastewater, Indigenous communities, transit, and much more.	https://ncceh.ca/environmental-health-in-canada/health-agency-projects/environmental-health-resources-covid-19

Authority	Resources	Topics regarding COVID-19	Primary and key links
Canadian National Collaborating Centre for Methods and Tools (NCCMT)	Systematic scientific rapid reviews on specific topics, with more focus on medical and mental health topics than environmental health (above)	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, ventilation, sanitation, and many more *Topics may be nominated*	www.nccmt.ca/knowledge-repositories/covid-19-evidence-reviews
Canadian Provinces			
British Columbia	BC COVID-19 Guidance documents	Detailed tools and strategies to operating industries, businesses, child care and education, community services and spaces	http://www.bccdc.ca/health-info/diseases-conditions/covid-19/guidance-documents
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
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	Restart MB Pandemic Response System Restoring Safe Services	Situation and response level COVID-19 public health Roadmap for opening up	https://www.gov.mb.ca/covid19/updates/index.html https://www.gov.mb.ca/covid19/restoring/approach.html

Authority	Resources	Topics regarding COVID-19	Primary and key links
Ontario	COVID-19 response framework: keeping Ontario safe and open	Updates including staging Public health requirements Workplace safety and plan template Workplace-specific guidance	https://www.ontario.ca/page/covid-19-response-framework-keeping-ontario-safe-and-open https://www.ontario.ca/page/resources-prevent-covid-19-workplace
Institute National de Santé Publique du Québec	Numerous FAQs	COVID-19 resources, on Indoor Environment, back to work, temporary foreign workers, various venues, and more	https://www.inspq.qc.ca/en
New Brunswick	Coronavirus disease (COVID-19) resources page	Public health information and resources and updates Guidance 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, 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	Public health data and guidance School toolkit, operational plans, bus safety, and detailed guidelines for every school	https://www.princeedwardisland.ca/en/covid19 https://www.princeedwardisland.ca/en/information/education-and-lifelong-learning/education-toolkit
Yukon	COVID-19 information	Public health, including situation, masks and other measures, testing, isolation and vaccines Health care and essential services Supports and education	https://yukon.ca/en/covid-19-information
Northwest Territories	Government of NWT'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	Status of testing, transmission in Nunavut and neighbours	https://www.gov.nu.ca/health/information/nunavuts-path

Authority	Resources	Topics regarding COVID-19	Primary and key links
International Organizations			
World Health Organization (WHO)	Main Page: Regular updates Country and technical guidance Advice for the public Research and development Strategy and Planning … and more	Emergency response Research - diagnostics, therapeutics, vaccines Public health responses Personal health	https://www.who.int/emergencies/diseases/novel-coronavirus-2019
European Centre for Disease Prevention and Control	Situation reports and resources Heating, ventilation and air-conditioning systems in the context of COVID-19	COVID-19 main page for epidemiology, research Evidence for and response to airborne transmission, and ventilation	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 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
US Centers for Disease Control and Prevention	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	Resources and consensus statements regarding occupational exposures	Aerosol transmission of SARS CoV-2 Re-opening and maintenance guidance	https://www.aiha.org/public-resources/consumer-resources/coronavirus_outbreak_resources
American Industrial Hygiene Association (AIHA)	Back to work safely Job specific back-to-work COVID-19 guidance from the AIHA	Re-opening guidelines for schools, workplaces and many public venues	https://www.backtoworksafely.org/
U.S. Occupational Safety and Health Administration	Guidance on Mitigating and Preventing the Spread of COVID-19 in the Workplace (January, 2021)	Identify risks in workplaces, and identify control measures.	https://www.osha.gov/coronavirus/safework