

FOCUS ON

Heating, Ventilation and Air Conditioning (HVAC) Systems in Buildings and COVID-19



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Introduction

This document replaces and builds upon the previously-published document titled *Frequently Asked Questions (FAQ) on COVID-19: Heating, Ventilation and Air Conditioning (HVAC) Systems in Buildings*. This version incorporates additional evidence and discussion on the role of HVAC systems, humidity, air flow and CO₂ on COVID-19 transmission. New sections have been added, some of which give added detail on particular components of previous questions, to help with readability and accommodate new references.

Background

COVID-19 is primarily transmitted via close (<2 metres) contact with an infected individual.¹ Although close contact is the dominant way COVID-19 is transmitted, it can be transmitted over longer distances by aerosols under favourable conditions. The risk is increased in crowded, inadequately ventilated

settings, and with increasing time spent under these circumstances. Activities such as exercising which can lead to heavy breathing, shouting and singing may also increase the risk, especially indoors.

Key measures to reduce transmission risk include limiting contacts, screening and self-isolation of people with symptoms, physical distancing, hand hygiene and masking (respiratory source control). In addition, indoor air quality improvement through ventilation and filtration supports this mitigation strategy by removing and diluting virus laden particles from indoor air. However, ventilation and filtration are not sufficient on their own to control the risk of transmission, and particularly from close contact exposures. Thus, while ventilation and filtration are important for overall indoor air quality as well as COVID-19 risk reduction, they must be used in conjunction with all other public health measures to minimize transmission risk.

Regular inspection and maintenance are also necessary for HVAC systems. Assessment and adjustments to a HVAC system is best managed by a professional, as there are usually building specific issues and potential unintended effects to consider.

Methods

A library search was done on MEDLINE, Inspec, Environment Complete, and Scopus databases as well as the NIH COVID-19 Portfolio for peer-reviewed and preprint publications on COVID-19 transmission related to HVAC, air, or indoor settings. The full search results are available upon request. Results were screened for key articles relevant to the topics covered in this document for the update.

Key terms defined in this document are based on the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) glossary of terms.

Key issues related to ventilation and COVID-19

Filtration, ventilation and a HVAC system

Filtration and ventilation are important components in an indoor air quality improvement strategy to exhaust or capture gases, vapours and airborne particles including virus-containing dust and aerosols.² Removal of these matter dilutes their concentration in indoor air and can reduce occupant exposures. These terms, and HVAC system are described below.

Mechanical filtration involves the use of different types of fibrous media designed to remove particles from the airstream. A portion of the particles in air entering a filter attach to the fibrous media and are removed from the air as it passes through the filter. The particle removal efficiency of the filter, the rate of air flow through the filter, location of the filter, and size of the particles filtered by the filtration system contribute to the reduction of indoor particle concentrations.³

Ventilation is the supply/distribution or removal of air from a space by mechanical or natural means.⁴ Ventilation can be for the purposes of controlling air contaminant levels, humidity, or temperature within the space. It can be achieved through natural means, such as through openings (e.g., windows, doors) and by passive infiltration.⁵ Mechanical ventilation is the active process of supplying air to or removing air from an indoor space by powered equipment such as motor-driven fans and blowers.⁵ Examples include HVAC systems, and bathroom or cooking exhaust fans. This document focuses on ventilation in the context of building spaces in the community, but not local exhaust ventilation used in certain occupational and industrial settings to control air contaminants at or near their source.⁶

A **HVAC system** is the equipment, distribution systems, and terminals that provide, either collectively or individually, the processes of heating, ventilating, or air conditioning to a building or portion of a building.⁵ Note, most HVAC systems also incorporate the use of filtration, as do guidelines and standards on these systems.³

HVAC systems and risk of COVID-19

Measures such physical distancing, reduced occupancy, masking, and cleaning and hygiene are critical components of a comprehensive strategy against COVID-19. Well-functioning HVAC systems support this strategy by removing and diluting aerosols that may contain viruses from indoor spaces, but they will not eliminate the risk from COVID-19 transmission during close contact exposures.⁷

Building ventilation and air movement within buildings have been associated with transmission of various infectious diseases, such as tuberculosis and measles.⁸ A multidisciplinary review focused on COVID-19 and HVAC systems in public spaces found that more evidence is needed to provide recommendations about the potential role HVAC systems play in spreading and/or mitigating the risk of transmission.⁹ However, the review acknowledged its role in air distribution, and thus impact on transmission of airborne infectious diseases and dilution of particles in air, particularly in closed spaces.⁹ Few studies to date specifically examine the role of HVAC systems in COVID-19 transmission, and no evidence was found associating transmission with central HVAC systems. However, there are many studies on ventilation related factors that demonstrate the risk from inadequately ventilated indoor spaces, as well as studies that have documented transmission under circumstances of likely inadequate ventilation, as discussed below.

Reviews by Institut National de Santé Publique du Québec (INSPQ) and Leclerc et al report COVID-19 outbreaks and clusters in various indoor spaces, including homes, means of transportation, as well as religious, elder care, meal and office settings.¹⁰⁻¹³ Few clusters are reported in exclusively outdoor settings where ventilation is not an issue.¹¹ Various studies and reviews cite inadequately ventilated spaces and high occupant density as possible contributors for transmission via inhalation.^{10,14-17} Experimental and modeling studies show respiratory aerosols during breathing and speech, droplet dispersion in air and suggest the plausibility of transmission through inhaled virus in air.¹⁸⁻²¹ There are also environmental sampling studies that demonstrate viral genetic material (ribonucleic acid, or RNA) in air and surfaces where COVID-19 patients have been,²²⁻²⁵ including HVAC systems.²⁶ These studies suggest inhaled virus as a likely route of transmission in some outbreaks, mainly in the same room or space.¹⁴

Evidence from outbreak investigations include Lu et al's and a further pre-print analysis by Li et al, regarding transmission of COVID-19 between families at three tables in a densely occupied restaurant (Table A with the index case was between Table B and Table C).^{27,28} A wall air conditioner with no fresh air intake may have dispersed infectious particles from the infected customer; none of the other diners or staff in the restaurant were infected.^{27,28} The three tables involved were also directly in the line of the likely air flow of the unit to the opposite wall and back to the unit – i.e., there appears to have been little mixing with the air in the rest of the room.²⁸ Exposure time to droplets may also have been a factor; diners at Table A and Table B overlapped for 53 minutes and diners at Table A and Table C overlapped for 75 minutes.²⁸ Tracer gas experiments showed that the index case's droplets would have been elevated at Tables A, B and C and another adjacent table. However, this table only had 18 minutes of exposure to Table A. The pre-print analysis concluded that the adjacent table and servers were likely uninfected due to the relatively short exposure time to exhaled droplets from the index patient.²⁸

Another report documents a cluster in Slovenia in early 2020 when there was no community spread of COVID-19.²⁹ The match partner of a squash player who became symptomatic in the evening after their Heating, Ventilation and Air Conditioning (HVAC) Systems in Buildings and COVID-19

game and two subsequent pairs that used the same court became ill three to six days after the matches, four of whom tested positive for COVID-19. The first pair left the facility before the subsequent pair entered the facility. While transmission via fomites was possible, this investigation supports transmission through persistence of aerosols in a poorly ventilated space.²⁹ The restaurant and squash investigations represent situations where poor ventilation and exposure time likely contributed to transmission.

Other reports of outbreaks in fitness dance classes,³⁰ a call centre in South Korea,³¹ choir practices in Washington State,³² and recreational hockey,³³ as well as non-peer-reviewed reports of outbreaks in settings of intense exercise^{34,35} are examples where inadequate ventilation may have contributed to transmission, but specifics on ventilation are not available from these reports and transmission through close contact and fomites was also plausible.

These observations along with experimental and modelling studies indicate that inadequate ventilation, activities that generate high levels of respiratory aerosols, limited physical distancing or crowding and longer duration of exposure increase the risk of aerosol transmission.¹ Ventilation reduces this risk by removing or diluting virus laden particles in indoor air, but will not eliminate the risk from COVID-19 transmission during close contact exposures.

Relevance of air flow (e.g., from room AC units and fans)

There is evidence that air flow e.g., fans moving air from an infected individual to others nearby, can be an important factor in transmission. Avoiding direct air flow around people's breathing zones will reduce respiratory droplets being dispersed from person to person. Rather than air flow at head level, options would be to direct the air upwards or to exhaust room air out of an open window while other open windows draw fresh air in.

As cited above, both ventilation and air movement within buildings have been associated with transmission of various infectious diseases, including tuberculosis, influenza, and Severe Acute Respiratory Syndrome (SARS).²⁸ Air currents created by fans or air conditioning systems could affect the dispersion of respiratory droplets in the air, hence assessing and directing air flow to avoid blowing air from one person to another may reduce risk. The Centers for Disease Control and Prevention (CDC) supports avoidance of contaminated air flow from one person to another and suggests that a window fan can be used to exhaust room air out while other open windows draw air in.³⁶

The restaurant outbreak discussed above is one where air flow moving droplets to adjacent tables may have contributed to transmission.²⁷ Kwon et al also reported on transmission of COVID-19 in a restaurant which was associated with transmission due to air currents produced by ceiling air conditioning units.³⁷ Two patrons were infected out of a total of 11 patrons and two staff who were present while the index case was in the restaurant. One patron was 6.5 m from the index case for five minutes with a maximum air current of 1.0 m/s; the other patron was 4.8 m from the index case for 21 minutes with a maximum air current measured of 1.2 m/s. Two other patrons located closer to the index case for a longer duration but not in the path of direct air flow from the index case were not infected. In addition, three other patrons sitting at tables with the two secondary cases but facing away from the index case were not infected. It was noted that the restaurant was located on the first floor of a building without windows or a ventilation system so recirculation of air was likely.³⁷

When they are used, manufacturer's guidance should be followed for cleaning, disinfecting and maintaining fans and air conditioners on a routine basis. More detailed guidance on the positioning, use, and maintenance of fans and air conditioning units can be found in Public Health Ontario's report titled "The Use of Portable Fans and Portable Air Conditioning Units during COVID-19 in Long-term Care and Heating, Ventilation and Air Conditioning (HVAC) Systems in Buildings and COVID-19

Retirement Homes”, found [here](#).³⁸ Portable air cleaners as a potential source of strong currents is also discussed in Public Health Ontario’s [FAQ](#) on portable air cleaners.³⁹

Recirculation of indoor air

There is limited information on recirculated air as a cause of COVID-19 transmission, and no reports have been identified of centralized HVAC systems contributing to a building wide outbreak. However, in general limiting recirculation and bringing in fresh air would lower the concentration of any viral particles present in indoor air.

Recirculation in the context of HVAC systems usually refers to indoor air returned to and filtered in the central system, then redistributed within the building. Some degree of recirculation in HVAC systems may be necessary to maintain humidity and temperature goals and control energy costs, but redistribution of building air would still dilute the concentrations of viral particles. Nonetheless, to the extent possible, limiting recirculation of indoor air would serve to exhaust more potentially infectious indoor air and bring in fresh air, reducing transmission risk.

There is limited information on recirculated air specifically as the cause of COVID-19 transmission. Lu et al’s reported cluster in a restaurant, described above, may have been facilitated by a wall air conditioner in the room.²⁷ The pre-print analysis, in addition to demonstrating a zone around the three tables where air was somewhat contained based on air currents from the AC, also reported that there was no outdoor air supply and that ventilation was only achieved by infiltration of air through occasional door openings and an exhaust fan in the restroom.²⁸

Shen et al also reported on two groups of bus riders in China, one of which had a case of COVID-19.³⁹ Infections were spread throughout the bus with the index case; there were no cases on the other bus (60 individuals). Twenty-three out of 67 susceptible individuals were reported to be infected, however six of the passengers had incubation periods greater than 14 days. The ventilation on the affected bus was reported to be in heating and recirculation mode which may have contributed to the high attack rate. At the outdoor religious event where all passengers and other participants attended, the only other people infected were those who had been in close contact with the index case.³⁹

These accounts describe situations of recirculation with little to no ventilation with outdoor air and minimal dilution, in contrast to how air would be recirculated (with dilution and usually filtration) in building HVAC systems.

HVAC measures to minimize the risk from infectious aerosols

Enhancing outdoor air ventilation and/or enhancing filtration where possible, and a well-functioning HVAC system should complement other public health measures by removing and diluting virus from indoor air, thereby lowering exposure to COVID-19.

COVID-19 prevention depends on a combination of interventions which vary in effectiveness and practicality day to day. The key is to always practice as many measures, as consistently as possible. Exposure to virus can be reduced by minimizing occupancy in a space, particularly where it is not possible to increase outdoor air ventilation.⁷ Avoiding confined spaces, close contact and being in the way of another person’s direct air flow (e.g., via a fan’s air flow) are other measures to reduce exposure.^{10,14,16,42} In addition, air quality improvement strategies can reduce the concentration of virus particles in the air. Thus, most guidance encourage ventilation with outdoor air (i.e., avoiding recirculation) as far as practically possible and ensuring clean filters.^{10,15,16,40,43,44} Assessment and

adjustments to a HVAC system are best managed by a professional, as there are usually building specific issues to consider.

Increase outdoor air ventilation (minimize recirculation)

For central air handling units at a building level or serving multiple zones, avoiding recirculation is ideal, e.g., operating on as high as possible outdoor air supply. ASHRAE provides guidance on COVID-19 which a HVAC professional can help apply to specific building scenarios.⁴⁵ Some HVAC systems may not allow changes to outdoor air fractions, and opening windows may be a good alternative to bring in outdoor air, however the air flow will be variable (e.g., if there is no breeze or temperature differences).^{16,42,43} Ventilation via open windows may be improved by utilizing a fan facing out to exhaust air and other open windows that bring outside air in.³⁶

Increase filter efficiency

Filtration is another strategy to remove virus and other particles from indoor air. Filters require appropriate maintenance and may also be upgraded where the system allows to maximize effectiveness.^{10,16,40,42,43} The effectiveness of a filter is rated by the Minimum Efficiency Reporting Value (MERV, ranging from 1 to 16), based on the fraction of particles removed from air passing through it under standard conditions.⁴⁵ ASHRAE's COVID-19 guidance suggests using MERV 13 or higher rated filters based on their ability to filter out virus-sized particles (<1 µm).⁴⁵ Higher efficiency filters may not be a viable option for some HVAC systems as they may cause greater resistance to air flow than allowable by design specifications. When central HVAC systems are unavailable and a space is poorly ventilated, portable air cleaning units can be considered to help control concentrations of particles in the air (see PHO's [FAQ on portable air cleaners](#) for considerations).⁴¹

Humidity has uncertain implications

There is some evidence to support that low relative humidity (RH) may enhance survival of COVID-19 on fomites.⁴⁶ As the RH increases, droplets also fall from the air faster onto surfaces, decreasing the fraction of droplets available for conversion to aerosols.⁴⁷ While various organizations⁴⁸⁻⁵⁰ have suggested maintaining a RH level of 40–60% as a supportive measure, there is a lack of evidence on the effectiveness of targeting a particular RH to mitigate COVID-19 transmission. Additionally, maintaining high RH levels risks the build-up of condensation and mould development in the winter season, which may contribute to poor indoor air quality and health problems.⁵¹

Air change rates required

In general, ventilation is improved by more air changes with outdoor air. Standards for air changes are set by various associations for different types of building environments.

The air change rate for a space is the volume of air supplied to and removed from a space, via mechanical systems or through the building enclosure, per unit of time divided by the volume of the space.⁵ Standards for air change rates are available from the Canadian Standards Association (CSA) for HVAC systems in specific zones or areas in healthcare facilities, CSA Z317.2:19.⁵² These air change rate standards for clinical settings account for the potential for airborne infection risks.⁵²

For other indoor settings, ASHRAE Standard 62.1 provides minimum ventilation rates for acceptable indoor air quality according to the type of setting (e.g., correctional facilities, offices, educational settings, hotels, food and beverage settings), occupancy and area.⁵³ Acceptable indoor air quality is defined by ASHRAE as “air in which there are no known contaminants at harmful concentrations, as determined by cognizant authorities, and with which a substantial majority (80% or more) of the people Heating, Ventilation and Air Conditioning (HVAC) Systems in Buildings and COVID-19

exposed do not express dissatisfaction".⁵ It is noted in the standard that recommended outdoor air ventilation rates are not specifically meant to address transmission of airborne viruses, bacteria or other infectious agents.

ASHRAE provides additional guidance for HVAC systems for the COVID-19 pandemic which can be applied with the support of professionals who can assess specific buildings for measures most appropriate and feasible.⁵⁴ Professionals can also assess the outdoor air ventilation rates within a space that has a mechanical HVAC system.⁵⁵ The CSA guidance for workplaces during the pandemic reinforces that air exchange rates should be modified on a building-by-building basis with careful evaluation of the ventilation system because adjustments can lead to issues related to thermal comfort and humidity, and undesired effects on air circulation.⁵⁶

Indoor carbon dioxide (CO₂) measurement as an indicator of ventilation

Indoor CO₂ levels may be used as an indicator of ventilation as part of a professional assessment and are typically evaluated based on time-averaged readings. High indoor CO₂ levels can potentially identify spaces with poor ventilation rates but CO₂ is not an indicator of COVID-19 transmission risk. If CO₂ monitors are being considered for people with no background on their use, then interpretation of levels and corresponding actions are challenges that need careful consideration.

The indoor CO₂ level is an indicator for ventilation. CO₂ is exhaled by people and can build up in indoor spaces compared to normal outdoor ground-level CO₂.⁵⁷ Ventilation can lower indoor CO₂ levels by introducing fresh outdoor air, leading to its use as a proxy for indoor air removal or dilution. There are a variety of ways CO₂ levels can be measured and analysed, but in general measurements are averaged over a period of time to capture the effect of ventilation on CO₂ levels. Measurements are also carried out in the occupied area of a room with the sensors located away from windows, doors, and ventilation grilles.⁴⁹ Follow up measurements can be made if ventilation is increased in a space to verify the effectiveness of the changes. Accuracy of CO₂ sensors used, placement and setting (e.g. large volume spaces) and occupant activity should be considered when reviewing the data. As well, manufacturer's guidance on calibration procedures should be followed.

The issues with using CO₂ levels as an estimation of transmission risk have been summarized by others including United Kingdom Scientific Advisory Group for Emergencies Environmental Modelling Group (SAGE-EMG) and the National Collaborating Centre on Environmental Health (NCCEH).^{49,58} For example, CO₂ levels are not affected by mitigation measures such as the use of masks or HVAC system filters or someone who is highly infectious, while combustion devices and pets will increase CO₂.^{57,58} With these limitations in mind, the SAGE-EMG paper suggests CO₂ measurements should only be considered an approximate indicator of ventilation, with high levels potentially identifying poorly-ventilated spaces to prioritize for improvements in ventilation or other mitigation strategies.⁴⁹ Guidelines for indoor CO₂ levels have been proposed by SAGE-EMG and ASHRAE (for schools and universities) to inform ventilation adjustments.^{49,54}

In addition, the Federation of European Heating, Ventilation and Air Conditioning Associates (REHVA) and the German Federal Environmental Agency (Umwelt Bundesamt) have proposed a traffic light-based indicator of continuous CO₂ levels for use by room occupants.^{43,49,58} Although these thresholds are meant to create awareness among room occupants of indoor air quality,⁵⁸ the limitations discussed above are cautions for continuous CO₂ monitoring, particularly if levels are erroneously interpreted as transmission risk. Other questions that arise include what actions would be linked to these levels, when the actions would be triggered, and the recourse if the desired effect is not achieved with the action. The NCCEH review provides a useful summary of this issue.⁵⁸

HVAC systems on partial or limited occupancy modes

Generally, most HVAC guidance recommend against a complete shutdown of the HVAC system, even during a building shutdown. During normal operations, guidance also suggests running the system for longer than usual and maintaining outdoor air ventilation rates when the building has fewer occupants than the allowable capacity.

ASHRAE recommends operating the HVAC system in occupied mode when people are present in the building including periods when the building is occupied by a small portion of the allowable capacity.^{59,60} ASHRAE also recommends continuing to run the HVAC system in occupied mode for additional time pre- and post-occupancy before switching to unoccupied mode and provides more detailed guidance on determining the duration [here](#).⁵⁹⁻⁶¹ ASHRAE and REHVA recommend maintaining normal temperature and humidity setpoints (see previous sections for humidity considerations).^{43,60}

During routine operations, REHVA similarly recommends increasing outdoor air supply and exhaust ventilation and starting ventilation at least two hours before the building is occupied and continuing to run the ventilation for at least two hours after the building has been vacated.⁴³ REHVA recommends lowering the ventilation rate or switching off when people are absent outside of the two hour pre- and post-occupancy period.⁴³

Inspection or maintenance

Routine inspections and maintenance as appropriate for the system are necessary.

Recommended inspection and maintenance measures for air handling systems (including inspection and replacement of filters, if applicable) are essential to follow.^{10,62} Adjustments to ventilation (e.g., increased outdoor air) may require more frequent inspections and filter changes.¹⁰ System humidifiers should be inspected to ensure they are cleaned, maintained and operating properly.⁶² As ventilation systems are complex and changes made have unintended effects, adjustments should be made in consultation with a HVAC specialist to verify intended parameters and appropriate maintenance procedures.

There is a joint standard from the American National Standards Institute (ANSI), ASHRAE and Air Conditioning Contractors of America (ACCA) for HVAC inspection and maintenance. ANSI/ASHRAE/ACCA standard 180-2018 (Standard Practice for Inspection and Maintenance of Commercial Building HVAC Systems) details procedures and establishes minimum HVAC inspection and maintenance requirements that preserve a system's ability to achieve acceptable thermal comfort, energy efficiency, and indoor air quality in commercial buildings.⁶³ This guidance can be considered by facility operators in order to optimize HVAC system operation on a routine basis, regardless of an infectious disease pandemic.

Some buildings may use Energy Recovery Ventilators (ERVs) which are HVAC systems that transfer energy (heat in winter, cold in summer) from indoor exhaust air to outdoor supply air within a building to lower energy costs associated with heating or cooling outdoor air used for ventilation. ERVs should be inspected and properly maintained. Pressure differences and design limitations in some types of ERVs can allow a portion of indoor exhaust air to be transferred into outdoor supply air streams. There are maintenance techniques and modifications that can reduce exhaust air transfer and ASHRAE has provided guidance on operation of ERVs during epidemics.^{61,64}

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