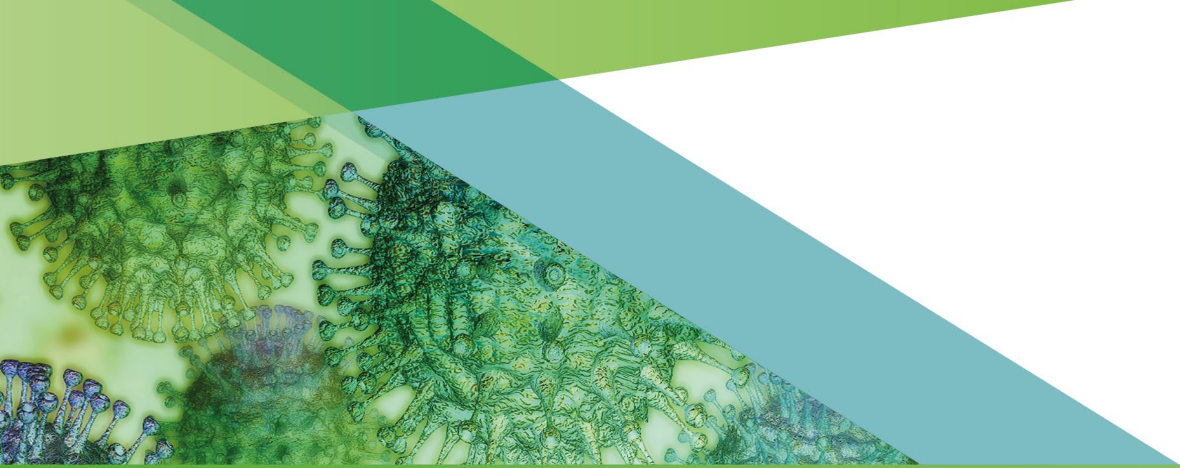

Heating, ventilation and air-conditioning systems in the context of COVID-19: first update

10 November 2020

Key messages

- It is now well-established that COVID-19 transmission commonly occurs in closed spaces;
- If well-maintained and adapted for use in the COVID-19 pandemic, heating, ventilation and air-conditioning (HVAC) systems may have a complementary role in decreasing potential airborne transmission of SARS-CoV-2;
- Four bundles of non-pharmaceutical interventions (NPIs) should be considered to reduce potential airborne transmission of SARS-CoV-2 in closed spaces: the control of COVID-19 sources in closed spaces; engineering controls in mechanically ventilated (by HVAC systems) and naturally ventilated closed spaces; administrative controls; and personal protective behaviour.

Scope of this document

This document provides guidance on heating, ventilation and air-conditioning (HVAC) systems in closed spaces in the context of the COVID-19 pandemic.

Changes to the current update

The first update of the ECDC ventilation guidance document contains:

- key new findings that emphasise four bundles of NPIs to reduce the risk of SARS-CoV-2 transmission in closed spaces;
- updated references on the evidence of transmission in closed spaces;
- recommendations based on the new evidence and on national and international guidance; and
- an overview of national guidance ventilation documents in the context of COVID-19 based on an inquiry sent to ECDC's National Focal Points (NFPs) for Preparedness and Response and NFPs for Influenza and other respiratory diseases.

Target audience

Public health authorities in the European Union and European Economic Area (EU/EEA) and the United Kingdom (UK).

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Heating, ventilation and air-conditioning (HVAC) systems

HVAC systems are used to provide comfortable environmental conditions (temperature and humidity) and clean air in indoor settings such as buildings and vehicles. HVAC systems can be configured in a variety of ways, depending on their application and the functions of the building or vehicle [1,2]. Ventilation systems provide clean air by exchanging indoor and outdoor air and filtering. Air-conditioning systems can be part of integrated HVAC systems or stand-alone, providing air filtering and/or cooling/warming and dehumidification. Stand-alone systems usually recirculate the air without mixing it with outdoor air.

Poor ventilation in confined indoor spaces is associated with the increased transmission of respiratory tract infections such as influenza, tuberculosis and rhinovirus infection [3]. Similarly, SARS-CoV-2, there transmission is particularly effective in closed spaces, including from pre-symptomatic COVID-19 cases [4-6]. Although the role of ventilation in preventing SARS-CoV-2 transmission is not currently well-defined (i.e. by preventing the dispersal of infectious particles to minimise the risk of transmission or preventing the transfer of an infectious dose to susceptible individuals, it is thought to be primarily transmitted via large respiratory droplets; however, several reports point to aerosols playing a role in COVID-19 outbreaks [7-13]. Aerosols consist of small droplets and droplet nuclei that remain suspended in the air for longer than large droplets [14,15]. There is a debate in the scientific community over the long-standing terminology that defines droplets as having an average particle size ≥5 μm and aerosols as having an average particle size <5 μm [16,17]. Nonetheless, there is consensus that coughing, shouting, singing, and even speaking produce a mixture of both droplets and aerosols in a range of sizes [18]. Scientific groups have undertaken environmental investigations in hospital rooms in which COVID-19 patients were admitted and detected viral RNA in air samples and air outlet fans, therefore inferring the possibility of aerosols in those areas [19-23]. Two studies strongly suggest that transmission through aerosols probably occurs in closed spaces (short-range aerosol) in which many people stay for longer periods of time [11,13]. In two studies, low concentrations of cultivable SARS-CoV-2 were detected in air samples from a hospital room in which COVID-19 patients resided [11,13]. The relative roles of large droplet, aerosol and fomite transmission for SARS-CoV-2 and the transmissibility of the virus at different stages of the disease remain unclear.

Studies indicate that SARS-CoV-2 particles can remain infectious on various materials, as well as in aerosols in indoor environments, with the duration of infectivity depending on temperature and humidity [24]. To date, transmission through fomites has not been documented, but it is considered possible.

Evidence for SARS-CoV-2 transmission in closed spaces and the role of HVAC systems

SARS-CoV-2 transmission is particularly effective in crowded, confined indoor spaces such as workplaces (offices, factories) and other indoor settings, such as churches, restaurants, gatherings at ski resorts, parties, shopping centres, worker dormitories, dance classes, cruise ships and vehicles [25]. There are also indications that transmission can be linked to specific activities, such as singing in a choir [10] or during religious services characterised by the increased production of respiratory droplets and including aerosols through loud speech and singing. However, there is as yet no evidence of human infection with SARS-CoV-2 caused by air distributed through the ducts of HVAC systems [8].

In a study of 318 outbreaks in China, SARS-CoV-2 transmission occurred in indoor spaces in all but one of the outbreaks [12]. The only case of outdoor transmission identified in this study involved two people. However, outdoor events have also been implicated in the spread of COVID-19, typically those associated with crowds, such as carnival celebrations [26] and football matches [27], highlighting the risk of crowding even at outdoor events. Nevertheless, outdoor events often have adjacent closed spaces, such as bars, food areas and restrooms, which can be crowded.

The length of time that people stay in indoor settings appears to be associated with the attack rate. For example, in a 2.5-hour choir practice in Washington State in the United States, there were 32 confirmed and 20 probable secondary COVID-19 cases among 61 participants (85.2%) [10]. In an epidemiological investigation at a call centre in South Korea, there was an attack rate of 43.5% among 216 employees on the ninth floor of the call centre, indicating extensive transmission in a crowded indoor workplace environment [28]. Nearly all the infected employees were sitting on the same side of the ninth floor, and there was no obvious relationship between the risk of transmission and the distance from the index case on this side of the floor. The authors also concluded that the length of time people were in contact played the most important role in the spreading of COVID-19, since the cases were limited almost exclusively to the ninth floor despite interactions with colleagues in other settings such as in elevators and in the lobby.

Several studies have addressed the role of ventilation in COVID-19 outbreaks. In a COVID-19 outbreak in a restaurant in Guangzhou, China, there were 10 cases across three families [29]. They developed symptoms between 26 January and 10 February 2020, having eaten lunch on 23 January at the same five-floor restaurant, in which windows could not be opened and ventilation was only provided by the air-conditioning system. Their tables were more than one metre apart. The index case was pre-symptomatic and developed a fever and cough the same evening after leaving the restaurant. The secondary cases were sitting along the line of airflow generated by the air-conditioning system, while diners sitting elsewhere in the restaurant were not infected. The authors of the report attributed transmission to the spread of respiratory droplets carrying SARS-CoV-2 via the airflow generated by the air-conditioning.

The investigation of two other outbreaks from China in January 2020 considered air-conditioning systems using a re-circulating mode as a probable aid to transmission [30,31].

The first outbreak was associated with a 150-minute event at a temple [30]. The index case, who had previously visited Wuhan, was pre-symptomatic until the evening after the event. The attack rates in the outbreak were the highest among those who shared a 100-minute bus ride with the index case (23 out of 67 passengers; 34%). Passengers sitting closer to the index case did not have a statistically higher risk of COVID-19 than those sitting further away. However, all passengers sitting close to a window remained healthy, with the exception of the passenger sitting next to the index case. This supports the hypothesis that the airflow along the bus facilitated the spread of SARS-CoV-2. In contrast, there were seven COVID-19 cases among 172 other people who attended the same 150-minute temple event, all of whom described having had close contact with the index case.

The second outbreak was associated with a training workshop that took place between 12 and 14 January 2020 in Hangzhou city, Zhejiang province [30]. It had 30 attendees from different cities, who booked hotels individually and did not eat together at the workshop facility. The workshop had four group sessions lasting four hours each, which were in two closed rooms of 49 square metres and 75 square metres, respectively. An automatic timer on the central air-conditioners circulated the air in each room for 10 minutes every four hours, using 'an indoor re-circulating mode'. No trainees were known to be symptomatic during the workshop. Between 16 and 22 January 2020, 15 of the trainees were diagnosed with COVID-19.

Several outbreaks have also occurred among workers in meat-processing facilities [7,9]. Poor ventilation has been one factor implicated in such outbreaks.

Adaptations of HVAC systems to reduce the risk of SARS-CoV-2 transmission in closed spaces

Ventilation with outdoor air is deemed to dilute contaminants in closed spaces and increase the time required for exposure to an infectious dose. This process is energy-consuming, but automatically controlled HVAC systems usually lower the air exchange just before and after the use of closed spaces depending on room occupation and can even be switched off during certain periods, e.g. overnight.

A 2006-2007 study in crowded dormitories for students at Tianjin University in China showed an inverse association between common cold infection rates and mean air exchanges in winter [32]. Baseline numbers of required air exchanges during customary use are proposed by the American Society of Heating Refrigerating and Air-Conditioning Engineers (ASHRAE) as 7-10 L/s per person [33]. The Federation of European Heating, Ventilation and Air Conditioning Associations (REHVA) recommends ensuring the minimum number of air exchanges per hour, following the applicable building regulations[2].

In addition to the ventilation itself, air filtration could be another way of reducing the risk of transmission of SARS-CoV-2 compared to only increasing the air exchange rate in closed spaces. A study using a case study of airborne transmission of influenza for modelled estimates of relative influenza risk reduction showed, for a hypothetical office, a positive association between risk reductions and the use of higher filter quality according to the MERV (Minimum Efficiency Reporting Value) filter classifications of ASHRAE. The greatest risk reduction at the lowest costs was shown for MERV 13 filters [34].

The filters commonly used in HVAC systems (see Table A3 in the Annex) are capable of retaining large droplets but not aerosols (small droplets and droplet nuclei). High Efficiency Particulate Air (HEPA) filters have demonstrated good performance with particles of the size of SARS-Cov-2 (approximately 70–120 nm) and are used in aeroplanes and in healthcare settings [15]. The role of HEPA filters in buildings outside of healthcare settings in preventing the transmission of infectious diseases is unclear. For SARS-CoV, the virus causing SARS ,a modelling study of how the infection risk was modified by three types of ventilation systems in relatively large commercial aeroplanes showed that, among the three systems, the mixing ventilation system had the highest risk and the conventional displacement system had the lowest risk.

A relative humidity of 40–60% may help to limit the spread and survival of SARS-CoV-2 within a closed space [24,33]. Humidity levels in this range could therefore be considered for HVAC systems. However, even new buildings with state-of the art HVAC systems cannot usually exceed more than 40% relative humidity, especially in winter, and older systems often cannot exceed much lower relative humidity levels because of the risk of damaging the HVAC system as well as room structures due to the risks of condensation and mould development [2,33].

Complementary decentralised air cleaning methods or stand-alone HEPA filter devices

These include ion generators, ozonation and ultraviolet germicidal irradiation (UVGI) [1,35-38], as well as stand-alone HEPA-filter devices. These methods are usually relatively costly, require special maintenance, and can only treat a relatively small volume of air. The potential benefits in reducing the levels of particles that induce allergic reactions are not considered in this document [37].

Negative ion generators or air ionizers disperse charged ions, which attach to particles in the air, including those containing bacteria or viruses, which are subsequently trapped in the filters of the device. [35,36]. No data are currently available regarding the capacity of negative ion generators to reduce the amount of droplets or aerosols containing SARS-CoV-2. Filters can generate charged particles, such as ozone or volatile organic compounds (VOCs), which are detrimental to health, particularly if they are insufficiently dispersed [1,36,37]. Ozonators generate the ozone from oxygen. Ozone is toxic to bacteria and viruses at concentrations that exceed public health standards for ozone concentrations [1,36]. There are no standardised testing procedures to determine the conditions for use of this method in indoor air spaces that exclude health hazards linked to ion and ozone generators [1,35-37].

UVGI causes decomposition through ultra-violet C (UVC) radiation of bacteria and viruses [36]. However, UVC can generate ozone and free radicals, which are hazardous in closed spaces. Its surface disinfection effects are hindered by physical obstacles to direct UVGI [1,36]. Standardised testing procedures to determine conditions to exclude the health hazards of UVGI, for potential use to reduce SARS-CoV-2 in indoor air spaces, are very limited [1,36].

International professional societies for HVAC have produced guidelines on the principles and operation of ventilation in indoor spaces as a means to decrease the risk of transmission of SARS-CoV-2 [1,2,33,39-41]. In the context of the COVID-19 pandemic, available national guidelines from EU/EEA countries and the UK and from Canada and the US (see Table A1 in the Annex) consistently recommend an increase of air exchange compared to the pre-pandemic phase, the avoidance of re-circulation of air wherever possible, round-the-clock operation of HVAC systems, and for naturally ventilated closed spaces to create frequent air exchange through the opening of windows.

In summary, the available evidence indicates that:

- Transmission of SARS-CoV-2 commonly occurs in closed indoor spaces.
- HVAC systems may have a complementary role in decreasing transmission in closed indoor spaces by increasing the rate of air exchange, decreasing recirculation of air and increasing the use of outdoor air, and using adequate types of filter.
- The risk of human infection with SARS-CoV-2 caused by air distributed through the ducts of HVAC systems is rated as very low.
- The air flow generated by air-conditioning units may facilitate the spread of droplets excreted by infected people over long distances within closed indoor spaces.
- Well-maintained HVAC systems, including air-conditioning units, securely filter large droplets containing SARS-CoV-2. It is possible that aerosols (small droplets and droplet nuclei) containing SARS-CoV-2 spread through HVAC systems within a building or vehicle and through stand-alone air-conditioning units if air is recirculated. However, the extent to which such potential aerosol route contributes to COVID-19 transmission is unknown and rated as very low for well-maintained, central HVAC systems.
- There is limited evidence regarding the effect of stand-alone air filtration and other air cleaning technologies on the transmission of SARS-CoV-2.

Guidance

From outbreak reports and research studies published to date, it is not yet possible to clarify whether aerosols result in transmission through close proximity (airborne transmission), direct contact (aerosol contamination of hands, etc.) or through indirect contact (aerosol contamination of objects/surfaces). In addition, there is a potential for publication bias, with fewer communications of negative findings; and confirmation bias, with published studies re-confirming known science. However, the current body of evidence on COVID-19 more generally demonstrates the high risk of transmission in crowded indoor settings and the importance of combining bundles of prevention measures. The prevention measures proposed below are based on the scientific evidence shown above or, where evidence does not exist, derived from the technical regulations and current recommendations of international professional societies [1,2,39] [42]. They are mostly in line with the recommendations from existing national guidelines in EU/EEA countries and the UK (see Table A1 in the Annex).

In closed spaces and in the context of COVID-19, there are four groups of non-pharmaceutical interventions (NPIs) that include measures to reduce the risk for airborne transmission of SARS-CoV-2 [33,42]. These are:

1. The control of COVID-19 sources;
2. Engineering controls in mechanically ventilated and naturally ventilated closed spaces;
3. Administrative controls to reduce occupancy; and
4. Personal protective measures (see Table A2 in the Annex).

Organisers and administrators responsible for gatherings and critical infrastructure settings in confined spaces should ensure that all relevant measures and controls are in place or followed, and also provide guidance material to participants regarding the application of the preventive measures

1. Control of COVID-19 sources in closed spaces

To avoid the direct transmission of SARS-CoV-2 and subsequent potential airborne transmission in closed spaces in which people are present for significant durations, it is essential that the guidance is followed, which are outlined in documents such as ECDC's guidance for discharge and ending of isolation of people with COVID-19 [43]. These include that COVID-19-positive people, people with COVID-19-related symptoms and people in quarantine must not stay in closed spaces together with other people.

In the enclosed spaces of vehicles, it is also essential to adhere to the guidance as outlined in guidance documents from ECDC in collaboration with other relevant EU agencies:

- COVID-19 Rail Protocol: Recommendations for safe resumption of railway services in Europe, 21 July 2020 [44];
- COVID-19 Aviation Health Safety Protocol: Guidance for the management of airline passengers in relation to the COVID-19 pandemic, issue 2, 1 July 2020 [45];
- EU guidance for cruise ship operations, 27 July 2020 [46].

2. Engineering controls in mechanically ventilated (by HVAC systems) and naturally ventilated closed spaces

Building administrators should review, maintain (including the upgrade of filters where appropriate), and monitor HVAC systems according to the manufacturer's current instructions, particularly in relation to the cleaning and changing of filters [2]. There is no benefit or need for additional maintenance cycles in connection with COVID-19.

The minimum number of air exchanges per hour, in accordance with the applicable building regulations, should be ensured at all times. Increasing the number of air exchanges per hour will reduce the risk of transmission in closed spaces. This may be achieved by natural or mechanical ventilation, depending on the setting [1,6,32,33,34].

Specific recommendations for natural ventilation through opening windows and doors should be developed on an individual basis, taking into account the characteristics of the room (volume, size and function of openings, occupancy rates), the activities taking place in the room, the climatic and weather conditions, as well as energy conservation and the comfort of the users. Advice on these topics can be found in the documents referenced in this guidance [2,33,38].

When it is not possible to measure the ventilation rate, measuring carbon dioxide air levels can be considered, especially in naturally ventilated rooms, as a surrogate of the sufficiency of ventilation. Technical guidelines recommend that the carbon dioxide concentration is kept below 800 to 1 000 ppm to ensure sufficient ventilation [2].

Energy-saving settings, such as demand-controlled ventilation in central HVAC systems controlled by a timer or CO_2 detectors, should be assessed for their possible impact on risks of transmission. Consideration should also be given to extending the operating times of HVAC systems before and after the regular period [1,2,39].

Direct air flow should be diverted away from groups of individuals to avoid the dispersion of SARS-CoV-2 from infected persons and transmission to other persons. For example, in supermarkets, cashiers and customers have different levels of mobility and durations of occupancy. As a general principle, mechanical ventilation should be arranged so that it minimises the direction of sustained air flow towards stationary persons.

Building administrators should, with the assistance of their technical/maintenance teams, explore options to avoid the use of air recirculation as much as possible [1,2,39]. They should consider reviewing their procedures for the use of recirculation in HVAC systems based on information provided by the manufacturer or, if unavailable, seeking advice from the manufacturer.

It is not recommended to change heating set points, cooling set points and possible humidification set points of HVAC systems as a measure to reduce potential SARS-CoV-2 transmission [2,33].

The use of stand-alone air cleaning devices equipped with an HEPA filter or a filter with comparable efficiency level can be considered, especially in spaces in which optimal ventilation is impossible. Such 'room air cleaners', however, usually only cover small areas and need to be placed close to the people occupying the room [2]. UVGI devices, either in the ducts of HVAC systems or placed sufficiently high in rooms, can also be considered, but they should be shielded from direct vision due to the risk of causing cataracts [47]. Stand-alone air cleaning devices and UVGI devices can have a role in settings where central HVAC systems are not capable of increasing the air exchange or reducing the re-circulation of air.

The technical specifications regarding the logistical arrangement of closed spaces, including the physical placement of HVAC systems, need to be informed by scientific evidence and technical expertise, so as to minimise the risk of transmission of SARS-CoV-2. These specifications also need to take into account the expected number of users, the different types of user, and the users' activity.

3. Administrative controls

As a general principle, it is recommended to limit the maximum number of people in closed spaces (e.g. office buildings, schools, universities, shops, buildings for leisure activities) and the maximum duration of stay in them, to reduce the risk of transmission of SARS-CoV-2 [42].

Other non-pharmaceutical measures include continued teleworking/e-learning, as outlined in, for example, ECDC's guidelines for the implementation of non-pharmaceutical interventions against COVID-19 [48].

4. Personal protective behaviour

Even the best COVID-19-related adaptations of HVAC systems and engineering measures for naturally ventilated spaces are jeopardised in the absence of personal protective behaviour to reduce potential direct SARS-CoV-2 transmission. Personal preventive measures with proven evidence of reducing the risk of SARS-CoV-2 transmission should therefore be emphasised [48]. Organisers and administrators responsible for gatherings and critical infrastructure settings should provide guidance material to participants and personnel regarding the application of personal preventive measures, including:

- Physical distancing;
- Meticulous hand hygiene;
- Respiratory etiquette;
- The appropriate use of face masks, if required for staff, and in areas where physical distancing cannot be maintained due to structural or functional impediments.

The application of the above guidance should be in accordance with national and local regulations (e.g. building regulations, health and safety regulations) and appropriate to local climatic conditions.

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The ECDC National Focal Points (NFPs) for Preparedness and Response and NFPs for Influenza and other respiratory diseases are acknowledged for providing links to national guidelines on ventilation in the context of COVID-19.

Annex

Table A1. National guidelines for heating, ventilation and air-conditioning (HVAC) systems in EU/EEA countries and the UK in the context of COVID-19, complemented by guidelines from other countries and from international professional associations

- All cited guidelines collectively emphasise that HVAC systems must be examined and adapted where necessary and maintained according to the respective national technical recommendations. Measures concordantly include an increase of air exchange compared to the pre-pandemic phase, the avoidance of re-circulation of air wherever possible, round-the-clock operation of HVAC systems, and for naturally ventilated closed spaces frequent air exchange through opening of windows.
- The list of national guidelines in EU/EEA countries below is based on an inquiry (October 2020) sent to all ECDC National Focal Points (NFPs) for Preparedness and Response and NFPs for Influenza and other respiratory diseases.

Specific points of these guidelines are mentioned below as examples.

EU/EEA countries and the UK	
Belgium	
[49], [50]	• Ensure that outside air is drawn from place(s) where contamination is as low as possible. • Options for increasing ventilation include: adjustment of pipes, motor, pulleys, pressure changes, end grilles, regulators, etc.); however, it depends on the system and may not be possible. • Potentially contaminated air from waiting areas or conference rooms should not be evacuated to parking garages, which also need ventilation with fresh air. • Attention to toilet ventilation (negative pressure) and flush toilets with closed lid. • Turn off the recirculation flaps; operate HVAC systems at least two hours before the start of work and continue function two hours after the end of work. • The use of ozone and other technologies (UV, biocides) is not recommended. There is no direct clinical evidence for the benefit of portable air purifiers. • If possible, windows should be kept opened for at least 15 minutes at least three times a day, especially after space occupancy.

Setting	Air changes per hour (ACH)*	Time to decrease contamination by 90%
Closed windows without mechanical ventilation	0.1-0.5	5-25 hrs
Window tilted (one side)	1-2	1 h15 min-2hrs
Windowless room with mechanical ventilation	4	37 min
Windowless room with increased mechanical ventilation	8	20 min
Windows wide open	± 10	15 min
Windows wide open, in opposite walls	± 40	5 min

* At least 2.5 ACH are needed to change at least 90% of the air in a room

Cyprus	
[51]	• Recommend proper maintenance, particularly at re-opening previously closed buildings, filters should be changed with appropriate personal protective equipment (PPE). • Recommend continuous operation of HVAC system even at times when the premises are not in use at lower speed. • Increase recirculation and increase amount of incoming fresh air. • Fresh air should blow diagonally in a space.

	• Stop use of rotary wheel converters (heat recovery); heat recovery ventilators should be in bypass mode. • Make sure that in-coming air duct openings are away from the out-coming air duct openings • Fan coil units should either be stopped or work round the clock. • Minimum efficiency reporting value (MERV) 13/F7 (EN779) filters recommended. HEPA filters recommended in high risk areas and ultra-violet germicidal irradiation (UVGI), if applicable. • Humidity should be kept at 40-60% in workplace areas. • Windows in toilets should stay closed to avoid interference with central ventilation; toilets' ventilation should stay on round the clock. • Advice against the use of jet air dryers in toilets, but strong reminder to wash hands and use paper towels to all users. • Where there is no HVAC system, then open windows for 15 minutes frequently.
Denmark	
[52]	• Introduce or optimise ventilation in premises with public access (e.g. shops, offices, public transports). • Extend the ventilation time. • Avoid air recirculation. • Avoid the use of energy saving settings or CO_2 sensors control.
France	
[53], **[54]**	• Maintain HVAC systems according to regulations for indoor air quality and manufacturer specifications; ensure correct filters are used; avoid recirculation of air. • For the maintenance staff: recommend full coveralls, filtering face piece (FFP) 2 and strict hygiene rules when changing/cleaning ducts or filters. • Recommend the ventilation of closed spaces before and after cleaning/disinfection. • Recommend the inspection of ventilation openings in all buildings, and ensure they are unobstructed. • Recommend opening windows for a minimum of 10 to15 minutes twice a day. • Air currents: persons in a common room should not feel drafts, i.e. air speed should be kept low about 0.4m/s. • When using split units, only do so if a room is occupied, and do not use plain fans in a common room even if people are wearing masks; plain fans with and without water can be used in single occupancy rooms and should be stopped before another person enters. • Do not use ceiling fans; if absolutely necessary: reduce speed to minimum; increase space between persons in the room and make sure the air is not blowing from one person to the others; consider putting physical barriers between the people.
Germany	
[55], **[56]**	For spaces with capacity for natural ventilation: • Regular full opening of windows (three minutes in the winter and up to 10 minutes in the summer); if necessary, keep windows tilted for permanent ventilation. • Ventilate rooms that are used by many people before and after use. • Adapt the duration between periods of natural ventilation to the number of people using the room, e.g. every 20 minutes for offices. • Consider additional CO_2 measurement ("CO_2 traffic light ") for the purpose of user awareness. Mechanical ventilation: • Increase air volume flow; ensure adequate ventilation at all times and avoid/reduce recirculation and increase the proportion of outside air. • Increase percent of fresh air to decrease the concentration of the virus in the room air (dilution) and therefore decrease the risk of infection. • For energy sparing, ventilation systems are often operating in recirculation mode; decreasing this function as much as possible is recommended. When recirculation cannot be avoided, other methods for air treatment through removal or inactivation of viruses should be applied so that aerosols containing the virus are not released back into the room. • Recommend continuous operation of the ventilation system even when the building is not in use in lower speed; operate the ventilation system in full speed at least two hours before and two hours after the period that the building is in use. • Install air purification devices with HEPA filter. Select air purification devices that are suitable for the size of the room. Use portable devices close to where people gather. • Air purification with UVC radiation can be added to filtering devices.

	• Split units: stand-alone air-conditioning devices, may on one hand decrease the concentration of the virus if operated without recirculation of air, but on the other hand increase the risk of infection by directing air currents containing infectious aerosols towards other occupants of the room.
Greece	
[57]	• Operate at the settings recommended by the manufacturer at least two hours before and two hours after the premises are in use. • Recommend continuous operation of HVAC systems even at times when the premises are not in use at lower speed. Stop/minimise air recirculation; close dampers to guide recirculated air towards outside; increase fresh air provision. • Avoid cleaning ducts in person, prefer robot-mediated cleaning; when removing or cleaning filters use appropriate PPE. • Make sure that in-coming air duct openings are away from the out-coming air duct openings. • The continuous operation of ventilation is recommended in toilets; make sure it is not connected to lighting and disconnect; flushing toilets with the lid closed is also recommended.
Ireland	
[58]	• The continuous function of ventilation systems (i.e. round the clock), is recommended, regardless of building occupancy. • Increase total airflow supply to occupied spaces by increasing number of air exchanges per hour. • Extend the hours of nominal operation of HVAC systems to begin two hours before the building is occupied, and to only reduce to lowest setting two hours after the building has emptied. • Use 100% outdoor air supply, if supported by the HVAC system and compatible with outdoor/indoor air quality regulations. Use HEPA filters if air is recirculated. • Ensure extractor fans in bathrooms are functional and running round the clock. When the building is occupied, they should operate at full capacity. • Disable demand controlled mechanical ventilation, if possible. • In central ventilation systems, install the most efficient filters. • Maintain a relative air humidity of 20% to 60%, if feasible.
Italy	
[59]	• The maintenance of HVAC systems should be performed as usual, with particular care to the correct operation of the filters to guarantee the delivery of the nominal flow rate. Equal care should be taken in the ordinary cleaning and sanitisation of the humidifiers and heat exchange coils. • Before maintenance interventions, HVAC systems must be switched off for 10 minutes, to allow cooling to room temperature, to allow the sedimentation of the larger particles. • When natural ventilation is used, it is essential to keep the internal doors of the building closed in order to limit the diffusion between adjacent rooms. • When accepting visitors to a domestic environment, it is advisable to stop the operation of the HVAC system, or to reduce the speed of the air in the room. After the visitors leave prefer natural ventilation (e.g. by opening windows).
Netherlands	
[60]	• Ventilate by opening windows, or with mechanical ventilation systems. • Air common areas such as a conference room, during breaks or after the meeting when everyone has left the room. • Regular airing of rooms is important. For example, airing is carried out by opening windows and doors wide against each other for 10 to 15 minutes. Do this, for example, after several people have come together. • Ventilate to ensure the sufficient exchange of indoor air with outdoor air. • Recirculation systems where no or too little fresh air is added are not recommended. • Recirculation systems that add fresh air should be adjusted so that enough fresh air is added to the room. • No advice against system with recirculation between room; switching off has consequences for the climate throughout the building; sufficient fresh outside air must be added.

	• Avoid using devices that generate a strong air flow in a common area, especially streams of air going from person to person.
Norway	
[61]	• Ordinary maintenance and operation of ventilation systems is sufficient. • In maintenance, care should be taken when changing filter(s) to use appropriate PPE. • Avoid increasing further ventilation in already well-ventilated rooms; can potentially have negative effects. • Recommend adapting function of HVAC systems to new working hours: turn on around two hours before the start of work and continue function two hours after the end of work. • Work positions should not be located directly under the exhaust(s). • Keeping negative pressure in toilets is recommended, as aerosol formation can occur; flushing toilets with the lid closed is also recommended. • WHO and CDC guidance on ventilation are not practically applicable to Nordic conditions with regards to the recommended degree of ventilation, indoor temperatures and humidity. • The use of a CO_2 sensor can act as an indicator of poor air quality and thus also potential SARS-CoV-2 presence from exhalation. • The number of air changes should be maintained at 7L per second per person in the room and CO_2 should not exceed 1 000 ppm. The limit recommendation in relation to CO_2 must be balanced against humidity (minimum 20% humidity in winter and 30% humidity in summer). • If humidity drops below 15% it may be an indicator that the ventilation speed is too high. • Do not recommend air purifiers, in general, as air purifiers could create air currents. • Ventilation measures do not replace other recommended infection control measures.
Slovenia	
[62]	• Mechanical ventilation should be on at all times. Normal/elevated airflow settings: operate at least two hours before the arrival of people and at least two hours after their departure. For the remaining time, ventilation can operate with a reduced airflow. • When premises are occupied, mechanical ventilation should work with increased air flow. • Where mechanical ventilation cannot be set to increased airflow, simultaneous natural ventilation of the rooms (by opening windows) is advised. • Centralised ventilation systems or air-conditioners must be set so that the air is exchanged only with fresh outside air, without air recirculation. • It is sufficient to set ventilation systems that require the CO_2 value to be set to a lower value at 400 ppm. • In toilets with mechanical ventilation, ventilation must operate round the clock, with vacuum, to prevent transmission via the faecal-oral route. • It is not recommended to use room fans in rooms in which many people are staying.
Spain	
[63]	• Reinforce the maintenance of air-conditioners. Replace air filters according to the maintenance schedule. Regular filter replacement and maintenance work should be carried out with common protective measures, including respiratory protection and taking care when handling dirty filters. • Set ventilation to nominal flow rate at least two hours before building use time and lower flow rate two hours after building closes. At nights and weekends, do not turn off the ventilation. Keep systems running at low settings. • Change the operation of the recirculating air handling units to 100% outside air. Maximise outside air intake and reduce air recirculation as much as possible. • Maintain the ventilation of toilets permanently: round-the-clock days in operation. • Do not open toilet windows to ensure correct ventilation direction. • Instruct building occupants to flush toilets with the lid closed. • Reduce leaks from heat recovery equipment. Modify the control so that the fans are continuously on. • Do not change the heating, cooling and possible humidification set points.
United Kingdom	
[64,65]	• Recommendation to improve ventilation of indoor spaces in general, preferably through fresh air or mechanical systems.

	• Consider ways of maintaining and increasing the supply of fresh air, such as opening windows and doors. • Turn off re-circulation, increase fresh-air supply in HVAC systems. • Advice against adjusting air-conditioning systems. • Advice against portable air-conditioning units because they recirculate 100% of air. • Advice for elevators/lifts by CIBSE.
Other countries	
Canada	
[42,66]	A hierarchical order of four complementary actions to limit transmission in closed spaces: • Source removal or control (includes staying home when sick, rapid detection and isolation of COVID-19 cases, and quarantining and follow-up for contacts of cases. • Engineering controls (engineering measure for HVAC systems). • Administrative controls (reducing maximum number of people, length of stay). • Personal protective behaviours and equipment. HVAC systems: • Paying careful attention to measures recommended by authoritative groups such as the American Society of Heating, Refrigeration and Air-conditioning Engineers (ASHRAE). In addition to adjusting existing ventilation systems, more extensive options could include: • The use of stand-alone or portable filtration, humidification or dehumidification equipment may be needed to accommodate increased ventilation rates, depending on outdoor air conditions. • The installation of high-capacity air exchange ventilation systems in buildings in which there is currently limited or no mechanical ventilation or air-conditioning (e.g., some schools). • The upgrading of fan/filter units to include MERV 13 or better, or HEPA filters. • UVGI fixtures have been used in healthcare, and the use of upper-room installations along with ceiling fans for mixing, to avoid stagnant air, is supported by high level scientific evidence. • Some air cleaning technologies utilise electrostatic precipitation, but these are not recommended.
United States	
[66]	• In general, increasing ventilation and filtration is usually appropriate. • Due to the complexity and diversity of building types, sizes, construction styles, HVAC system components, and other building features, a professional should interpret ASHRAE guidelines for their specific building and circumstances. • Increasing ventilation with all or mostly outside air may not always be possible or practical. In such cases, the effective rate of ventilation per person can also be increased by limiting the number of people present in the building in general, or in specific rooms. Administrative practices that encourage remote participation and reduce room occupancy can help reduce risks from SARS CoV-2.
Professional societies	
Federation of European Heating, Ventilation and Air-conditioning Associations (REHVA)	
[2]	Every space and operation of building is unique and requires specific assessment. Large spaces such as classrooms that are ventilated according to current standards tend to be reasonably safe, but small rooms occupied by a couple of persons show the highest probability of infection even if well ventilated. • Provide adequate ventilation of spaces with outdoor air. • Introduce an indoor air quality (IAQ) sensor network that allows occupants and facility managers to monitor that ventilation is operating adequately.

	• Replace central outdoor air and extract air filters as normal, according to the maintenance schedule. Regular filter replacement and maintenance works shall be performed with common protective measures including respiratory protection. • Carry out scheduled duct cleaning as normal (additional cleaning is not required). • Switch ventilation on at nominal speed at least hours before the building opening time and set it to lower speed two hours after the building usage time. At nights and weekends, do not switch ventilation off, but keep systems running at a lower speed. • Open windows regularly (even in mechanically ventilated buildings). • Keep toilet ventilation in operation round the clock. • Avoid open windows in toilets to maintain the correct direction of ventilation. • Instruct building occupants to flush toilets with closed lid. • Switch air-handling units with recirculation to 100% outdoor air. • Inspect heat recovery equipment to be sure that leakages are under control. • Adjust fan coil settings to operate so that fans are on continuously. • Do not change heating, cooling and possible humidification set points.
American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE)	
[40]	• Outside air for ventilation should be increased to as much as the HVAC system can accommodate. If there are significant energy impacts, use minimum outside air as required by Std 62.1 with MERV-13 filter minimum. • Post warning signs if exhaust outlets are near pedestrian areas; consider diverting to avoid them. • If a space has occupants after hours (e.g. cleaning crew, maintenance workers, construction workers etc.), the space should be operational. As a minimum, the ventilation system, toilet and other relevant exhaust systems should be on, if the space is within the comfort zone. • Consider only operating necessary spaces after hours. • Evaluate building occupied hours, adjust as necessary (have building hours been extended to encourage physical distancing). • Flushing sequence or mode should be implemented to operate the HVAC system with maximum outside air flow for two hours before and after occupied times, or, achieve three air changes of outside air in the space. • Consider UVC light as an enhancement where spaces require additional measures, e.g. spaces serve vulnerable occupants, or, MERV-13 filter or 100% outside air are not possible, etc. • Consider opening windows as an enhancement for outside air, especially when the system cannot accommodate MERV-13 filter or 100% outside air. • In buildings with operable windows, when outside air thermal and humidity conditions and outdoor air quality are acceptable, open windows where appropriate during occupied hours. • Exposure to seasonal and other outdoor allergens (pollen and mould spores) may occur with windows opened.

Table A2. Non-pharmaceutical interventions (NPIs) to reduce potential SARS-CoV-2 transmission in closed spaces (e.g. office buildings, schools, places of worship, shops, facilities for leisure activities, vehicles)*

All four bundles of these NPIs should be implemented and followed as best practices for preventing transmission in closed spaces.

Non-pharmaceutical interventions
1. **Removal and control of COVID-19 source(s)** Hold off persons with COVID-19 or with COVID-19-related symptoms from staying with other people in closed indoor spaces.
2. **Engineering controls in mechanically ventilated (by HVAC systems) and naturally ventilated closed spaces** - Comply with best practice of maintenance and settings of HVAC systems in the context of COVID-19; - Ensure frequently opened windows in naturally ventilated closed spaces.
3. **Administrative controls** Reduce occupancy of closed indoor spaces.
4. **Personal protective behaviour** • Keep physical distance; • Practise respiratory etiquette; • Wear a community face mask.

**Adapted from the Canadian Committee on Indoor Air Quality, Addressing COVID-19 in buildings [42]*

Table A3. **Retention capacity of different filter types used in HVAC systems**

Ventilation system	Typical type of filter	Retention capacity			
		MERV rating[a]	Degree of separation[b]	SARS-CoV-2-containing droplets (≥ 5μm)	SARS-CoV-2-containing aerosol[c] (< 5μm)
Specialised HVAC systems (operating theatres, special laboratories)	H13 -14 [DIN EN]	16–20	99.99%	Yes	
HEPA filter	H13 [DIN EN]	16–20	99.95 %	Yes	
HVAC systems for office buildings, churches, cruise ships, etc.	ePM1 [EN ISO]	9–13	>80 %	Yes	No
Stand-alone air-conditioners (e.g. apartments, shops, restaurants)	- Fiberglass - Polyester/pleated air filters	1–4 8–13	<40% 45%	Yes	No
Pedestal fans	n/a	n/a		No	

a) Minimum Efficiency Reporting Value (MERV), American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE);
b) Minimum separation efficiency for test particles, EN ISO 16890 (particle sizes 0.2 to 1.0 μm, depending on the type of filter);
c) Particles, droplet nuclei of different sizes.

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