SCIENCE AND TECHNOLOGY ORGANIZATION
CENTRE FOR MARITIME RESEARCH AND EXPERIMENTATION

Special Publication **CMRE-SP-2020-001**

Airborne transmission risk: ventilation and filtration in occupied buildings during the SARS-CoV-2 pandemic

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March 2021

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CMRE–SP-2020-001

Airborne transmission risk: ventilation and filtration in occupied buildings during the SARS-CoV-2 pandemic

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This document, which describes work performed under the Programme Covid 19 task force of the STO-CMRE Programme of Work, has been approved by the Director.

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Abstract: During the SARS-CoV-2 pandemic, many mitigation strategies have been employed to reduce the risk of transmission between individuals, including hygienic practices such as washing hands and objects frequently, wearing face masks, maintaining social distance between people, reducing room occupancy and tracking the health status of individuals. This document examines mitigation strategies related to airborne transmission of the SARS-CoV-2 virus inside occupied buildings. Topics covered include the impact of air conditioning and ventilation systems on the potential spread of SARS-CoV-2, recommendations for best practices, and the effectiveness of filtration on mitigating the risk of contagion.

Keywords: Covid-19 ○ MVHR ○ HEPA ○ SARS-CoV-2 ○ transmission risk ○ ventilation ○ filtration

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Contents

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Acronyms

ACH: Air Changes per Hour

ASHRAE: American Society of Heating, Refrigerating and Air-Conditioning Engineers

CADR: Clean Air Delivery Rate

CDC: Centers for Disease Control and Prevention

CFM: Cubic Feet per Meter

ECDC: European Centre for Disease Prevention and Control

HEPA: High-efficiency particulate air

HVAC: Heating, Ventilation and Air Conditioning

ISS: Istituto Superiore di Sanità

MERV: Minimum Efficiency Reporting Value

MPPS: Most Penetrating Particle Size

MVHR: Mechanical Ventilation Heat Recovery

REHVA: Federation of European Heating, Ventilation and Air Conditioning Associations

RH: Relative Humidity

SARS-CoV-2: Severe Acute Respiratory Syndrome coronavirus 2

ULPA: Ultra Low Particulate Air

VOCs: Volatile Organic Compounds

1 Introduction

During the SARS-CoV-2 pandemic, mitigation strategies include many that aim to reduce the risk of transmission between individuals, by means of hygienic practices (washing hands and objects frequently), wearing face masks, maintaining distance between people, reducing room occupancy and tracking the health status of individuals. This document examines mitigation strategies related to airborne transmission inside occupied buildings.

1.1 Airborne transmission

Airborne transmission of the SARS-CoV-2 virus occurs through respiratory droplets and aerosols expectorated from infected individuals. There is extensive evidence of airborne transmission of respiratory viral illness, but little is known about estimating the absolute risk of transmission for SARS-CoV-2 from airborne exposure.

A study on influenza transmission [1] suggests that the probability of infection is primarily a function of cohabitation time and ventilation of the room. Figure1 shows the probability of transmission as a function of time and ventilation for a poorly ventilated room. The solid line is the mean estimate, the dashed and dotted lines are the 90th and the 10th percentile estimates, respectively. Note the exceptionally large variance between the 90th and the 10th percentile estimates. On this basis, strategies to reduce exposure to airborne particles include reducing exposure time, and increasing the rate of air change for the room. This does not account for other factors such as social distancing, use of masks and eye protection, and the number of room occupants.

The role of Heating, Ventilation and Air Conditioning (HVAC) in SARS-CoV-2 transmission must be given serious consideration. From a document published 22 June 2020 on European Centre for Disease Prevention and Control (ECDC) website [2]:

In a restaurant outbreak in Guangzhou, China, there were 10 cases across three families [3]. They developed symptoms between 26 January and 10 February 2020, having eaten lunch on 23 January at the same restaurant, which is a five-floor building without windows. Their tables were more than a metre apart. The index case was pre-symptomatic, developing a fever and cough that evening. The secondary cases were sitting along the line of airflow generated by the air-conditioning, while diners sitting elsewhere in the restaurant were not infected. The authors of the report attribute transmission to the spread of respiratory droplets carrying SARS-CoV-2 via the airflow generated by the air-conditioning.

The authors of a pre-print manuscript describing two other outbreaks from China in January 2020 attribute air conditioning systems using a re-circulating mode as a probable aid to transmission [4].

In addition to ECDC citations, as reported in [5], on June 17, 2020 there was a new confirmed COVID-19 case in Jeonju, Korea, considered as transmitted by droplets at 6.5 m

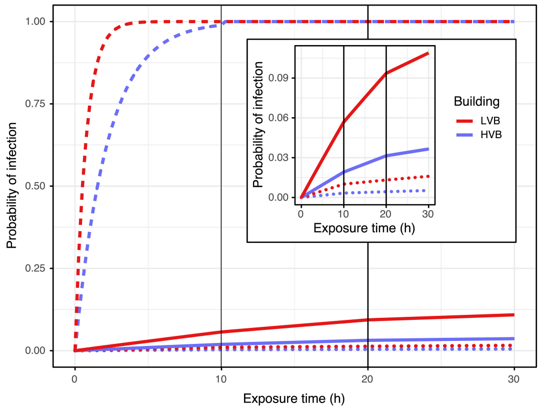

Figure 1: Probability of influenza infection for low ventilated rooms (retrieved from [1])

away from the infector and 5 minutes exposure in a restaurant with air conditioning.

In the same document, ECDC concludes the following:

- Transmission of SARS-CoV-2 commonly occurs in closed indoor spaces.
- There is currently no evidence of human infection with SARS-CoV-2 caused by infectious aerosols distributed through the ventilation system ducts of HVACs. The risk is rated as very low.
- Well-maintained HVAC systems, including air-conditioning units, securely filter large droplets containing SARS-CoV-2. It is possible for COVID-19 aerosols (small droplets and droplet nuclei) to spread through HVAC systems within a building or vehicle and stand-alone air-conditioning units if air is recirculated.
- Air flow generated by air-conditioning units may facilitate the spread of droplets exhaled by infected people over longer distances within indoor spaces.
- HVAC systems may have a complementary role in decreasing transmission in indoor spaces by increasing the rate of air change, decreasing recirculation of air and increasing the use of outdoor air.

Reference [6], published 10 July 2020, by JASON, the independent group of scientists which advises the United States government on science and technology, is a comprehensive analysis with recommendations for return to on-site work at universities and national laboratories in the US following the "first wave" of the COVID-19 pandemic in March and April 2020. The report is highly relevant to CMRE.

Non-HVAC related factors are:

- **Physical distancing**

  Physical distancing of 1-2 m between people is stressed as a valuable risk mitigation. But the risk depends on the circumstances and increases with the total number of people in a room, how long they are together and whether they are speaking or silent.

- **Number of occupants**

  The relative risk of adding more persons to a room increases roughly as the square of the number of persons.

- **Masks**

  Masks are effective in reducing risk, provided that they have good filtration characteristics.

- **Reducing droplet-generating activities**

  Speaking loudly produces more than four times as many droplets than speaking softly. Even if masks stop only some of the droplets, it is important not to remove the mask when speaking, and to limit speaking volume in order to minimize aerosol/droplets production.

The JASON report also addresses HVAC considerations. Relevant findings from the report can be summarized as follows:

- **Air change**
  - 4 ACH provides removal of pollutant concentration by more than 50%
  - 15 ACH provide 90% removal

  The first case is the lower end, typical for commercial spaces, while the second is the high end which could be recommended for medical or laboratory spaces where risk of exposure is greater, or people share the same space for a longer period of time than in commercial spaces.

- **Air purifiers**

  If the HVAC system is not equipped with external air intake, an alternative or complementary method to clean the air would be to use HEPA filter-equipped air purifiers which typically provide 100 CFM for 10 W of power consumption. As a rule of the thumb, a 100 CFM unit provides 1 ACH for a $25x25x10$ ft^3 room (176 m^3).

- **Air circulation**

  Some HVAC systems may circulate air between rooms, which is very dangerous and should be avoided as it could potentially cause high viral loads to be carried from one room to another.

1.2 Droplets and aerosols

It is important to define droplets and aerosols as both may play a role in the spread of SARS-CoV-2 infection. Droplets are $> 5\,\mu m$ in diameter and are rapidly pulled downwards by gravity. Aerosols are $< 5\,\mu m$ in size and can remain suspended in the air for one hour or more [7].

In the scientific community there is no general agreement on the role of aerosols in spreading SARS-CoV-2. According to the CDC, most SARS-CoV-2 infections are spread through close contacts, not airborne transmission. This implies that the primary vector of transmission is droplets, not aerosols.

In October 2020, the CDC published the following on its website:

Available data indicate that SARS-CoV-2 has spread more like most other common respiratory viruses, primarily through respiratory droplet transmission within a short range (e.g., less than six feet). There is no evidence of efficient spread (i.e., routine, rapid spread) to people far away or who enter a space hours after an infectious person was there.

However, on the same page CDC indicates that among the interventions to prevent the spread of the virus, hand hygiene, and surface cleaning and disinfection, ventilation and avoidance of crowded indoor spaces are especially relevant for enclosed spaces, where circumstances can increase the concentration of suspended small droplets and aerosols carrying the virus.

A recent review paper [8] concludes that several studies support that aerosol transmission of SARS-CoV-2 is plausible, and the plausibility score (weight of combined evidence) is 8 out of 9. Precautionary control strategies should consider aerosol transmission for effective mitigation of SARS-CoV-2. Another study [9] came to a similar conclusion: even if epidemiological evidence for aerosol transmission is lacking, it has been demonstrated that SARS-CoV-2 can remain viable in aerosols for 3 hours or longer; therefore, future efforts at prevention and control must consider the potential for airborne spread of SARS-CoV-2 in closed environments through air recirculation. The key point is that even if droplets are the main vector of SARS-CoV-2 infection, the management of air circulation and exchange in buildings must be designed to reduce the spread of aerosols.

2 Effectiveness of air purifiers in risk mitigation

As we have seen, some references recommend the usage of air purifiers equipped with HEPA filters. This section contains some findings and investigations about their use during the pandemic.

2.1 How do HEPA filters work, and can they stop viruses?

By definition high-efficiency particulate air (HEPA) filters remove 99.95% of particles of 0.3 µm diameter and remove larger and smaller particles with even greater efficiency. The HEPA standard is regulated by ISO29463 / EN 1822 in the EU and by ASHRAE (52.2) in the US. The Minimum Efficiency Reporting Value (MERV) is a metric developed by ASHRAE that rates the effectiveness of air filters. A MERV rating of 17-19 is similar to HEPA filters and MERV 20 is similar to the Ultra Low Particulate Air (ULPA) filtration standard.

Figure 2 shows characteristic size ranges of common airborne contaminants. We are interested in the effectiveness of HEPA filters in removing aerosols smaller than 5 µm that could carry the SARS-CoV-2 virus. The size range of the aerosols could conceivable extend down to near the size of individual viruses.

To understand the effectiveness of HEPA filters against particles in this size ranges, we need to explore how HEPA filters work. The following description is mostly derived from Ref. [10]. HEPA filters are manufactured by pleating microfiber glass or other fibrous media with multiple layers of randomly arranged fibers, with diameters ranging from 2 to 500 nm. Particles flowing through are trapped by three mechanisms: impaction, interception, and

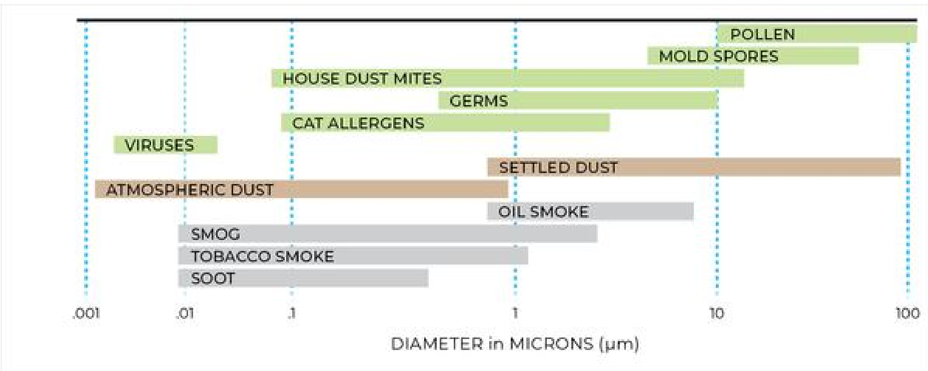

Figure 2: Particle size ranges for common airborne contaminants (from alen.com)

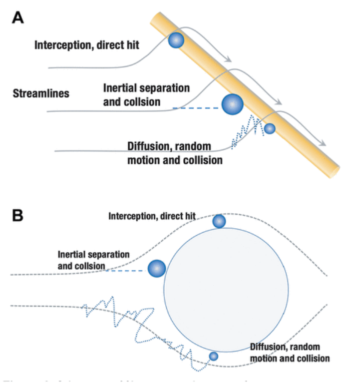

Figure 3: Particle size ranges for common airborne contaminants (from [10])

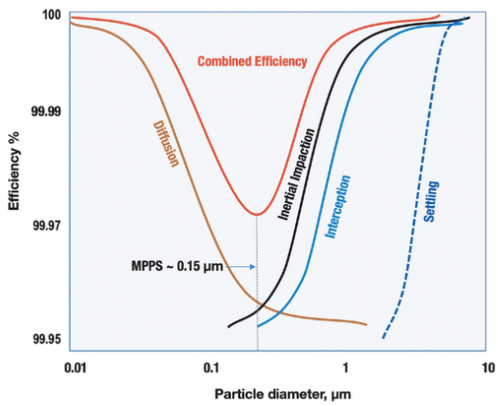

Figure 4: HEPA efficiency (from [10])

EN1822 Classification

Filter Group	Class	MPPS Integral Values		MPPS Local Values	
		Efficiency (%)	Penetration (%)	Efficiency (%)	Penetration (%)
EPA	E10	85	15	-	-
	E11	95	5	-	-
	E12	99,5	0,5	-	-
HEPA	H13	99,95	0,05	99,75	0,25
	H14	99,995	0,005	99,975	0,025
ULPA	U15	99,9995	0,0005	99,9975	0,0025
	U16	99,99995	0,00005	99,99975	0,00025
	U17	99,999995	0,000005	99,9999	0,0001

Figure 5: filters classification (from atri-tech.com)

diffusion. For particles larger than about 1 µm the particles simply get stuck in the filter because they are larger than the holes in the net or because they are too heavy to get through. Smaller particles tend to move around with Brownian movement, hitting the fibers many times thus increasing the probability of adhesion, which happens by means of Van de Waals forces, electrostatic attraction or capillary action (figure 3).

The efficiency curve of HEPA filters is U-shaped (figure 4), with a minimum at 0.3 µm the Most Penetrating Particle Size (MPPS), due to the combination of the effects described above. This is the size for which the filter efficiency threshold is defined. Therefore, HEPA filters can effectively stop aerosols over their entire size range all the way down to the size of individual viruses on the order of 10 nm.

ULPA filters are a step beyond HEPA; they stop 99.999% of particles in the 0.1-0.2 µm size range. They are more expensive that HEPA and might have shorter lifespans which translates into higher operational costs. Both HEPA and ULPA filters are used in clean rooms, depending on clean room class. The classification of filters is shown in figure 5.

2.2 Caveats about HEPA filters

Are HEPA filters the right solution? In filter efficiency classification, ULPA and HEPA have the highest efficiency, and work well if appropriately installed. In practice, there is no better choice.

If we look at recommendations from the WHO, ASHRAE, CDC and ECDC, none indicate air purifiers provided with HEPA filters as a solution to infection risk. This may be because there are no studies quantifying the risk reduction obtained by using these units. Filtering air certainly helps in mitigating the risk, but it should be used as complementary to other countermeasures.

When choosing HEPA and ULPA equipped air purifiers, it should be kept in mind that:

- the better a filter is, the more it will cause resistance to air flow resulting in more power consumption;
- periodical filter replacement and maintenance is required, and efficiency will decrease with time;
- if not properly maintained, a filter can become contaminated and a health risk;
- there are no visual indications of a contaminated filter, so people in the room have no perception of a potential infection risk;
- replacing a potentially contaminated filter requires the operator to wear appropriate PPE, the filter must be sealed, removed and disposed of with great care;
- labels such as True HEPA, HEPA like or HEPA type generally do not meet recognized standards. They are marketing names with no technical meaning;
- HEPA and ULPA filters are expensive.

In an appendix of Environmental Infection Control Guidelines [11], CDC reports:

A7. Recirculating devices with HEPA filters may have potential uses in existing facilities as interim, supplemental measures to meet requirements for the control of airborne infectious agents. Limitations in design must be recognized. The design of either portable or fixed systems should prevent stagnation and short-circuiting of airflow. The supply and exhaust locations should direct clean air to areas where health-care workers are likely to work, across the infectious source, and then to the exhaust, so that the healthcare worker is not in position between the infectious source and the exhaust location. The design of such systems should also allow for easy access for scheduled preventative maintenance and cleaning.

A11. The verification of airflow direction can include a simple visual method such as smoke trail, ball-in-tube, or flutterstrip. These devices will require a minimum differential air pressure to indicate airflow direction.

2.3 Beware of CADR ratings

Commercial air purifiers often have an effectiveness rating called Clean Air Delivery Rate (CADR). It is a figure of merit expressed in CFM of air that has had all the particles of a given size distribution removed. CADR is defined as the product of the air flow and filter efficiency. For example, if the filter has an efficiency of 80% and the ventilation has a flow of 200 CFM, the resulting CADR will be 160. For HEPA and ULPA filters, that have very high efficiencies close to 100%, the CADR rating is not meaningful and therefore not usually used for these types of filters.

The CADR is biased towards air purifiers that circulate a higher rate of semi-clean air, rather than air purifiers that can clean the air well, but circulate air at a lower rate.

To measure CADR, the unit is placed in an enclosed room that is then filled with airborne contaminants. After running the unit for 20 minutes, the air quality is tested and the CADR calculated. This is a relatively short time, as many higher-end air purifiers require at least an hour to circulate air and improve air quality, especially if the filtration efficiency is high. Therefore, air purifiers that circulate more air tend to have higher CADR, despite the fact they removed a smaller amount of contaminants. Because a high CADR is often used as a marketing tool, many manufacturers design their units to circulate air at the fastest rate possible, even though this allows for only the largest size particles to be removed from the air.

Many companies selling higher-end air purifiers do not use CADR ratings for their product, as their units are evaluated against filtration efficiency and do not use faster air flow to compensate for poor filtration. Air purifiers should be selected with a critical eye if they use CADR rating; this does not necessarily mean that if a company uses the CADR rating the air purifier is not good, but care must be taken to be sure that the air purifier uses HEPA filters. Some companies choose not to use CADR ratings. These include Austin Air Systems, Dyson, Alen and AllenAir.

2.4 How much air do we need?

The average breathing frequency of an adult human is 15 breaths per minute and the average volume of each breath is 0.5 l. Therefore the air flow for an individual is approximately

0.5 m^3/h (0.3 CFM). The concentration of SARS-CoV-2 that can be exhaled by an infected individual, is unknown. As an example, ASHRAE recommends ventilation of 15 CFM per person, but standards vary across the US and EU.

In order to prevent contagion, ECDC recommends increasing the rate of air exchange, but does not give quantitative guidance. CDC gives some indication of the time required for removal of contaminants with 99% efficiency: for example the time needed with 4 ACH is 69 min and goes down to 23 min with 12 ACH. There are specific indications for healthcare facilities (the most recurring recommendation is at least 12 ACH), but not for other work places. These values, however, apply to an empty room with no aerosol-generating source. With a person present and generating aerosols, the values would be higher. There is a reference on the CDC website to appropriate formulas, but it is not clear where they can be found. ASHRAE goes more into more detail, recommending a minimum value of 4 ACH for general interior spaces with different values for specific areas. For example, for classrooms the recommendation is 3-4 ACH while for laboratories 6-12 ACH is recommended. The reasoning behind the recomendations is not given, and the standards are not freely downloadable. It may be that the standards contain the explanation for the recommendations.

The range of recommended ACH values, without explanation from regulatory bodies, makes it difficult to know how to implement air quality improvements at institutions. A particular case is the Visiting Research Professional (VRP) room at CMRE. The volume of the VRP room is 500 m^3, similar to a small conference room. Selecting a cautionary value of 9 ACH would mean having an air change rate of 4500 m^3/h (2650 CFM), while the minimum required would be 2000 m^3/h (1200 CFM). The cost of an air purifier that can deliver 1000 m^3/h is 1-2k USD. Therefore, the cost to provide the minimal recommended air change rate to the VRP room is around 2-4k USD, excluding the cost of maintenance.

3
Ventilation in the SARS-CoV-2 context

We have seen that air purifiers, in order to be effective, need to be equipped with HEPA (or ULPA) filters. However, it is recommended to use them as an interim or complementary solution. We have also seen that enclosed environments with minimal ventilation strongly contribute to a high number of secondary infections [12].

The fact that SARS-CoV-2 is transmitted by aerosols has now been recognized by many scientists. To date, ECDC has also recognized aerosol transmission [2]. The existence of a long-range aerosol-based transmission mechanism implies that maintaining 1-2 m distance from an infected person is not enough, and that ventilation is needed to control the concentration of aerosols in indoor spaces.

Another important issue to be considered in occupied buildings is that the WHO recognizes the aerosol/sewage transmission route for SARS-CoV-2 infections. The WHO proposes as a precautionary measure to flush toilets with the lid closed.

3.1 REHVA recommendations

This subsection is based on the guidance issued in August 2020 [13] about how to operate HVAC systems during SARS-CoV-2 epidemic.

As we have seen, while droplets travel for a short distance, aerosols can stay suspended in air for a long time. Close contact within 1-2 m of an infected person creates high exposure to both droplets and aerosols but the concentration of aerosols from more than 1-2 m can be mitigated with adequate ventilation.

The aerosol-based transmission mechanism of SARS-CoV-2 is now recognized worldwide as is the mitigating effect of ventilation. In hospitals with a ventilation rate of 12 ACH, aerosol transmission is mostly eliminated, while in poorly ventilated spaces it may be dominant. In indoor spaces cross-infection risk may be controlled up to 1-2 m with physical distancing and beyond that distance with ventilation solutions, as illustrated in figure 6.

There has been speculation about the impact of relative humidity (RH) on the infectious potential and lifetime of SARS-CoV-2. According to REHVA, there is little or no effect on SARS-CoV-2 stability by increasing RH up to 65%. It may be pointed out that low RH would allow small droplets to evaporate faster, but nasal system mucous membranes are more susceptible to infection at very low RH so there may be no benefit to reducing RH either. Humidity control, therefore, is not considered a method to reduce the viability of SARS-CoV-2.

In buildings without mechanical ventilation systems, it is recommended to open windows as much as possible. Dressing more warmly can ensure occupant's comfort in winter. In buildings with mechanical ventilation systems, REHVA asserts: *extended operation times*

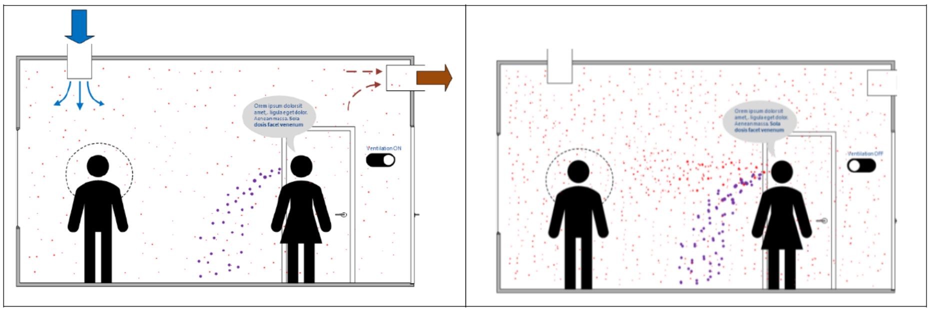

Figure 6: Illustration of how an infected person (speaking woman on the right) leads to aerosol exposure (red dots) in the breathing zone of another person (man on the left). Droplet exhalation is marked with purple dots. When the room is ventilated (left), the amount of virus-laden aerosols in the breathing zone is much lower than when the ventilation system is off (right). Retrieved from [13].

are recommended for these systems. Adjust system timers to start ventilation at the nominal speed at least 2 hours before the building opening time and switch to a lower speed 2 hours after the building usage time. In demand-controlled ventilation systems, change the CO2 setpoint to 400 ppm in order to maintain the operation at nominal speed. Keep the ventilation on 24/7, with lower (but not switched off) ventilation rates when people are absent. [...]

The general advice is to supply as much outside air as reasonably possible. The key aspect is the amount of fresh air supplied per square meter of floor area. If the number of occupants is reduced, do not concentrate the remaining occupants in smaller areas but maintain or enlarge the physical distance (min 2-3 m between persons) between them to improve the dilution effect of ventilation. More information about ventilation rates and risks in different rooms will be provided in the updated version of the document in the following months.

Exhaust ventilation systems for toilets should be operated 24/7 in similar fashion to the main ventilation system. It should be switched to the nominal speed at least 2 hours before the building opening time and may be switched to a lower speed 2 hours after the building usage time. If it is not possible to control the fan speed, then the toilet ventilation should operate 24/7 at full speed.

The disadvantage of fresh air supply in winter is the increase of energy consumption and potential thermal discomfort for room occupants; this is where MVHR comes to our aid.

3.2 What is MVHR?

Mechanical Ventilation Heat Recovery (MVHR) is an energy recovery ventilation system that uses an air-to-air heat exchanger to recover heat that is usually wasted. It works by managing airflows in and out of homes and buildings to ensure better indoor air quality. Heat recovery units can recover up to 90% of normally lost heat depending on the unit and the application. A MVHR system works independently of the heating or cooling system and due to the heat recovery feature, it can provide great savings on energy bills all year round.

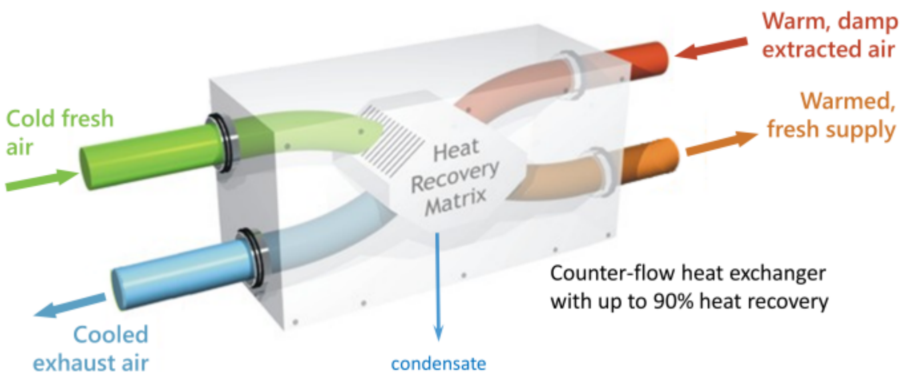

Figure 7: How a MVHR works and saves energy during the cold season (from heatspace-andlight.com)

Fresh air is vital for good indoor air quality, providing oxygen, removing smells, reducing moisture, removing volatile organic compounds (VOCs) and CO2. Around 8 l/s/person of fresh air is needed to provide good indoor air quality [14].

MVHR is generally less expensive to operate than air purifiers because it uses clean air from outside and does not require HEPA filters, therefore it requires less maintenance. In MVHR systems filters are used to block pollutants from outside, but do not play a role in air filtration from pollutants generated inside the building. MVHR systems reduce CO2 and reduce contamination risk by diluting the concentration of contaminated interior air.

If only air purifiers are used, and no air is introduced from outside, filter maintenance becomes critical for indoor air quality. Relying only on air purifiers also poses a risk from contaminated filters if the filters are not changed regularly. The disadvantage of MVHR is that installation might require significant modification to the building or room, such as drilling holes on the walls and adding pipe ducts for rooms without external walls.

As an indication, a commercial model that can provide 700 m^3/h costs around 2k USD, without installation costs.

3.3 Is measuring CO2 useful?

As we have seen, a safe method to reduce the risk of infection is having outside air constantly replacing stale inside air. Simply put, the more fresh air from outside is introduced inside a building, the better. Bringing in outside air dilutes contaminants in a building and reduces the exposure of anyone inside. Every time we exhale, we release CO2 into the air. Since the coronavirus is most often spread by breathing, coughing or talking, could we use CO2 levels as an indication of the level of room ventilation?

A recent publication [15] reports on the effect of ventilation on a tuberculosis outbreak at Taipei University. Many of the rooms in the school were under-ventilated and had CO2 levels above 3,000 ppm (fresh air has about 400 ppm CO2). When engineers improved ventilation and got CO2 levels under 600 ppm, the outbreak completely stopped. According to the research, the increase in ventilation was responsible for 97% of the decrease in transmission.

According to [16], it is recommended to keep CO2 levels below about 600-800 ppm. This is consistent with ASHRAE's recommendation of 700 ppm. In practice, in office spaces with large number of occupants and typical ventialtion, it is difficult to achieve this level of CO2 concentration. According to [17], a more realistic target for a room with many occupants would be 1000 ppm.

The above considerations suggest that measuring CO2 is a useful indication of how much fresh air is entering the building to compensate for carbon dioxide generated by the occupant's breath.

4 Conclusions

This report has presented recommendations from agencies in Europe and the United States, as well as recent scientific publications, on the topic of interior air quality and its potential impact on the spread of SARS-CoV-2. All the sources examined stress the importance of renewing the air inside an occupied building either by replacing it with outside air, or by filtering it. However, little explicit guidance was found that expresses how much air we need to replace in order to be safe. This lack of quantitative recommendations may be due to the current incomplete knowledge of SARS-CoV-2 transmission through the air.

Implementation/design of a ventilation or air filtering/conditioning system intended to mitigate the spread of SARS-CoV-2 should be addressed by a specialist. To this end CMRE has engaged a local HVAC expert to analyse the HVAC systems of the Centre's buildings and to make recommendations for short term and long term improvements.

The intent of this report is to make the management and staff of CMRE aware of the technologies and methods available to improve indoor air quality and of the implications for mitigating the risk of SARS-CoV-2 transmission.

In summary, we found that the most important actions we can take to reduce contamination risk in occupied buildings are, in order of priority:

- Improve air quality: the air must be replaced with clean air from outside.
- Mitigate the impact of wasting energy by implementing MVHR.
- If MHVR is not feasible, air purifiers with HEPA filters may be used provided that the filters are well maintained.
- CO2 sensors may be used to monitor air quality, and the effectiveness of ventilation.

Maintaining healthy air quality does not replace or eliminate the need of using facial masks and social distancing but complements those measures during this global pandemic.

Actions CMRE has taken regarding air quality are:

- Installation of air purifiers with HEPA filters in some areas
- Monitoring air quality in different locations with two portable CO2 meters
- Established a policy for staff to work with windows open as much as possible
- Hired an HVAC engineer to make recommendations for short term and longer term improvements to ventilation systems
- Reduced the number of staff in Centre buildings to 30% and re-allocated work spaces to maximize the distance between people.

Acknowledgements

The author would like to thank Dr Daniel Hutt who provided valuable suggestions and comments during the revision of this report.

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Document Data Sheet

Security Classification		Project No.
RELEASABLE TO THE PUBLIC		COVID-19 TF
Document Serial No.	**Date of Issue**	**Total Pages**
CMRE-SP-2020-001	March 2021	24 pp.

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Title

Airborne transmission risk: ventilation and filtration in occupied buildings during the SARS-CoV-2 pandemic

Abstract

During the SARS-CoV-2 pandemic, many mitigation strategies have been employed to reduce the risk of transmission between individuals, including hygienic practices such as washing hands and objects frequently, wearing face masks, maintaining social distance between people, reducing room occupancy and tracking the health status of individuals. This document examines mitigation strategies related to airborne transmission of the SARS-CoV-2 virus inside occupied buildings. Topics covered include the impact of air conditioning and ventilation systems on the potential spread of SARS-CoV-2, recommendations for best practices, and the effectiveness of filtration on mitigating the risk of contagion.

Keywords

COVID-19, NVHR, HEPA, SARS-CoV-2, transmission risk, ventilation, filtration

Issuing Organization

NATO Science and Technology Organization
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