REHVA COVID-19 guidance for HVAC systems operation and reduction the spread of viral diseases in workplaces

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REHVA COVID-19 Task Force
REHVA guidance for building services

- An addition to the general guidance for employers and building owners that is presented in the WHO document ‘Getting workplaces ready for COVID-19’.
- First version March 17, 2020 that has been updated April 3 and August 3
- Targeted to HVAC professionals and facility managers but may be useful for occupational and public health specialists deciding how to use buildings
- The scope is limited to commercial and public buildings

- Practical guidance on temporary, easy-to-organize measures that can be implemented in existing buildings
- Some discussion how to conduct a risk assessment and what would be more far-reaching actions to further reduce the spread of viral diseases in future in buildings with improved ventilation systems
Transmission routes

1. Close contact droplet and aerosol transmission (<1.5 m distance)
2. Long range airborne (aerosol based) transmission (> 1.5 m, droplet nuclei of 5-10 μm stay airborne for long time)
3. Surface (fomite) contact
4. Faecal-oral route
5. Resuspension

The means to deal with these routes are physical distance to avoid the close contact, **ventilation to avoid (long range) airborne transmission** and hand hygiene to avoid surface contact.
Traveling distance estimates for droplets

- Traveling distance estimates (after the initial jet has relaxed) for different sizes of droplets to be carried by room air velocities of 0.05 and 0.2 m/s before settling 1.5 m under the influence of gravity. ($\mu$m values in the figure refer to equilibrium diameters of desiccated respiratory droplets)

- An airborne virus is contained inside expelled respiratory fluid droplets that are suspended in air, ranging from less than 1 $\mu$m to more than 100 $\mu$m in diameter, which is the largest particle size that can be inhaled
- Exposure = dose (proportional to infection probability) is a product of the breathing rate, concentration and time
- In addition to outdoor air ventilation, virus laden particles can be removed with filtration or deactivated with UVG
Recognition of the airborne, aerosol-based transmission route

- Airborne transmission evidence for SARS in 2002/2003 for SARS-CoV-1 in Amoy Gardens, hospitals, hotels and residential homes
- Nishiura et al. 2020 analyzed superspreading events of SARS-CoV-2 and showed that closed environments with minimal ventilation strongly contributed to a characteristically high number of secondary infections - especially crowded spaces with poor ventilation need precautions
- Well known superspreading events reporting aerosol transmission are from a Guangzhou restaurant and Skagit Valley Chorale event where outdoor air ventilation rate was as low as 1-2 L/s per person
- To date, airborne transmission is recognized worldwide, including: European Centre for Disease Prevention and Control ECDC, WHO, the German Robert-Koch-Institut, US CDC, UK Government, Italian Government, the China National Health Commission...
Ventilation & HVAC in the infection control hierarchy

- **Elimination**
  - to physically remove the pathogen

- **Engineering Controls**
  - to separate the people and pathogen

- **Administrative Controls**
  - to instruct people what to do

- **Personal Protective Equipment**
  - to use masks, gowns, gloves, etc.

- Traditional infection control pyramid adapted from the US CDC (CDC 2015)
- Ventilation solutions are the main engineering controls to reduce the environmental risks of airborne transmission
15 recommendations for existing buildings

1. Ventilation rates
2. Ventilation operation times
3. Continuous operation of ventilation
4. Window opening
5. Toilet ventilation
6. Windows in toilets
7. Flushing toilets
8. Recirculation
9. Heat recovery equipment
10. Fan coils and induction units
11. Heating, cooling and possible humidification setpoints
12. Duct cleaning
13. Outdoor air and extract air filters
14. Maintenance works
15. IAQ monitoring
Longer and continuous ventilation operation

- Extended operation times are recommended: Change the clock times of system timers to start ventilation at nominal speed at least 2 hours before the building usage time and switch to lower speed 2 hours after the building usage time.
- Do not switch off ventilation at nights and weekends, but operate at lowered speed.
- Extended ventilation will remove virus particles from air and also released virus particles from surfaces out the building.
- The general advice is to supply as much outside air as reasonably possible. The key aspect is the amount of fresh air supplied per person.
- Enlarge the spacing among employees (min physical distance 2-3 m between persons) in order to foster the ventilation cleaning effect.
- Exhaust ventilation systems of toilets should always be kept on 24/7, and make sure that under-pressure is created, especially to avoid the faecal-oral transmission.
What to do if there is no mechanical ventilation?

- In buildings without mechanical ventilation systems, it is recommended to actively use openable windows.
- Windows should be opened for 15 min or so when entering the room (especially when the room was occupied by others beforehand).
- Also, in buildings with mechanical ventilation, window opening can be used to boost ventilation further.
- Install CO₂ sensors at the occupied zone that warn against underventilation especially in spaces that are often used for one hour or more by groups of people, such as classrooms, meeting rooms, restaurants.
- Set the yellow/orange light to 800 ppm and the red light (or alarm) up to 1000 ppm in order to trigger prompt action to achieve sufficient ventilation even in situations with reduced occupancy.
Humidification and air-conditioning have no practical effect

- SARS-CoV-2 stability (viability) has been tested at typical indoor temperature of 21-23 °C and RH of 65% with very high virus stability at this RH. Together with previous evidence on MERS-CoV it is well documented that humidification up to 65% may have very limited or no effect on stability of SARS-CoV-2 virus.

- Therefore, the evidence does not support that moderate humidity (RH 40-60%) will be beneficial in reducing viability of SARS-CoV-2, thus the humidification is NOT a method to reduce the viability of SARS-CoV-2.

- SARS-CoV-2 has been found highly stable for 14 days at 4 °C; 37 °C for one day and 56 °C for 30 minutes were needed to inactivate the virus (Chin et al, 2020).

- AC has no effect in this context (recirculation excluded)

van Doremalen et al. 2020 Aerosol and surface stability of HCoV-19 (SARS-CoV-62) compared to SARS-CoV-1 (RH 65%)
Safe use of heat recovery sections

• Under certain conditions virus particles in extract air can re-enter the building. Heat recovery devices may carry over virus attached to particles from the exhaust air side to the supply air side via leaks.

• In the case of regenerative heat exchangers (rotors) the minimal leakage (seals + carry over) and correct pressure difference between exhaust and supply side are important.

• The leakage, carrying over also particles, may increase from the 2% to 20% if fans create higher pressure on the exhaust air side.

• Evidence suggest that rotors with adequate purge sector practically do not transfer particles, but the transfer is limited to gaseous pollutants (e.g. smells, tobacco smoke).

• Because the leakage does not depend on the rotation speed, it is not needed to switch rotors off. If needed, the pressure differences can be corrected by dampers or by other arrangements.
Inspection of rotary heat exchangers to limit internal leakages

Inspecting the heat recovery equipment, including measuring the pressure difference and estimating leakage based on temperature measurement.
No use of central recirculation

- Virus particles in return ducts can also re-enter a building when centralized air handling units are equipped with recirculation sectors (may be in use at least in older all-air heating and cooling systems)
- Recirculation dampers should be closed (via the Building Management System or manually)
- In air systems and air-and-water systems where central recirculation cannot be avoided because of limited cooling or heating capacity, the outdoor air fraction has to be increased as much as possible and additional measures are recommended for return air filtering:
  1. HEPA filters would be needed to completely remove particles and viruses from the return air (usually not easy to install in existing systems)
  2. Alternatively, duct installation of disinfection devices, such as ultraviolet germicidal irradiation (UVGI) also called germicidal ultraviolet (GUV), may be used
  3. A minimum improvement is the replacement of existing low-efficiency return air filters with ePM1 80% (former F8) filters
Filtration with ePM1 80% (former F8) filters

- An airborne virus is not naked but is contained inside expelled respiratory fluid droplets
- Most of exhaled droplets 1-10 μm
- F8 (ePM1) filters provide capture efficiency of 65-90% for PM1
- Therefore, good fine outdoor air filters provide reasonable filtration efficiency for a low concentration and occasional occurrence of viral sources

Farhad Memarzadeh, Particle generation by sneezing, coughing and during talking," [https://www.researchgate.net/publication/234076687_Improved_Strategy_to_Control_Aerosol_Transmitted_Infections_in_a_Hospital_Suite]
Room level circulation: fan coil, split and induction units

- In rooms with fan coils only or split units (all-water or direct expansion systems), the first priority is to achieve adequate outdoor air ventilation. In such systems, mechanical ventilation is usually independent of the fan coils or split units and two options are possible to achieve ventilation:
  1. Active operation of window opening together with the installation of CO2 monitors as indicators of outdoor air ventilation;
  2. Installation of a standalone mechanical ventilation system (either local or centralized, according to its technical feasibility)
- Fan coil units have coarse filters that practically do not filter smaller particles but may still collect potentially contaminated particles which may then be released when fans start to operate
- Fan coils only in common spaces are recommended to be continuously operated so that fans of these units will not be switched off but are continuously in operation at low speed
Outdoor air filtration and room air cleaners

- Outdoor air filters (filter class F7 or F8 or ISO ePM1) are not designed to capture viruses - the size of the smallest viral droplets in respiratory aerosols of about 0.2 mm (PM0.2) is smaller than the capture area of F8 filters (capture efficiency 65-90% for PM1).
- However, outdoor air is not a source of viruses, thus no need to replace filters.
- No need to clean ventilation ductworks as well.
- In the case of air cleaners, to be effective, HEPA filter efficiency is needed.
- Air cleaners with electrostatic filtration principles (not the same as room ionizers!) often work quite well too.
- Because of limited airflow through air cleaners, the floor area they can effectively serve is normally quite small (min capacity 2 ACH) and is to be located close to breathing zone.
- Maintenance personnel needs to apply common protective measures when replacing filters including respirators, because filters may have active microbiological material on them.
Summary of practical measures for HVAC operation

1. Provide adequate ventilation of spaces with outdoor air
2. Extended ventilation operation times: 2 hours before and after the building usage time
3. Not switching ventilation off at nights and weekends, but keeping at a lower speed
4. Open windows regularly (even in mechanically ventilated buildings)
5. Keep toilet ventilation in operation 24/7
6. Avoid open windows in toilets to maintain the right direction of ventilation
7. Instruct building occupants to flush toilets with closed lid
8. Switch air handling units with recirculation to 100% outdoor air
9. Inspect heat recovery equipment to be sure that leakages are under control
10. Adjust fan coil settings to operate so that fans are continuously on
11. Do not change heating, cooling and possible humidification setpoints
12. Carry out scheduled duct cleaning as normal (additional cleaning is not required)
13. Normal maintenance schedule for the replacement of central outdoor air and extract air filters
14. Use of protective measures including respiratory protection for maintenance personnel
15. Introduce an IAQ sensor network that allows occupants and facility managers to monitor that ventilation is operating adequately
Fundamental issues

Addressed by scientist in the petition to WHO (Morawska et al. 2020):

1. Ventilation rates should be increased;
2. Air should not be recirculated;
3. Individuals should avoid staying directly in the flow of air from another person;
4. The number of people sharing the same indoor environment should be minimized;

No 3 addresses air distribution - not easy to change in existing buildings
Many research needs for future - ventilation rates, air cleaners, air distribution, hygiene of components, maintenance of systems ...
Airborne transmission risk assessment

- COVID-19 disease has been associated with close proximity (for which ventilation isn't the solution) and with spaces that are simply inadequately ventilated.
- In superspreading events the outdoor air ventilation has been as low as 1-2 L/s per person (Guangzhou restaurant, Skagit Valley).
- Would 10 L/s per person recommended in existing standards be enough? No evidence available.
- Some evidence of no cross infections from hospitals (about 40 L/s per patient, 6-12 ACH).

- Typical sizing according to ISO 17772-1:2017 and EN 16798-1:2019 results in default Indoor Climate Category II to 1.5 - 2 L/s per floor m² (10-15 L/s per person) outdoor airflow rates in offices and to about 4 L/s per floor m² (8-10 L/s per person) in meeting rooms and classrooms.
- 4 L/s per floor m² in meeting rooms and classrooms corresponds to 5 ACH.
The probability of infection ($p$) is related to the number of quanta inhaled ($n$):

$$p = 1 - e^{-n}$$

$n$ (quanta) depends on the time-average quanta concentration ($C_{avg}$, quanta/m$^3$), the volumetric breathing rate of an occupant ($Q_b$, m$^3$/h) and the duration of the occupancy ($D$, h)

$$n = C_{avg} Q_b D$$

A fully mixed material balance model for the room:

$$\frac{dC}{dt} = \frac{E}{V} - \lambda C$$

where
- $E$ quanta emission rate (quanta/h);
- $V$ volume of the room (m$^3$);
- $\lambda$ first-order loss rate coefficient for quanta/h due to the summed effects of ventilation ($\lambda_v$, 1/h), deposition onto surfaces ($\lambda_{dep}$, 1/h) and virus decay ($k$, 1/h);
- $C$ time-dependent airborne concentration of infectious quanta (quanta/m$^3$).

(Concentration in larger rooms is not fully mixed - air distribution issues)
Quanta emission rates from literature

- Common cold/rhinovirus (Yuexia Sun et al. 2011) 1-10 quanta/h
- Influenza (Mesquita, Noakes and Milton 2020) 0.1-0.2 q/h in average, but 630 q/h max daily rate
- SARS-CoV-2 (Buonanno G, Morawska L, Stabile L, 2020):

<table>
<thead>
<tr>
<th>Activity</th>
<th>Quanta emission rate, quanta/h</th>
</tr>
</thead>
<tbody>
<tr>
<td>Resting – Oral breathing</td>
<td>2.0</td>
</tr>
<tr>
<td>Resting – Speaking</td>
<td>9.4</td>
</tr>
<tr>
<td>Resting – Loudly speaking</td>
<td>60.5</td>
</tr>
<tr>
<td>Standing – Oral breathing</td>
<td>2.3</td>
</tr>
<tr>
<td>Standing – Speaking</td>
<td>11.4</td>
</tr>
<tr>
<td>Standing – Loudly speaking</td>
<td>65.1</td>
</tr>
<tr>
<td>Light exercise – Oral breathing</td>
<td>5.6</td>
</tr>
<tr>
<td>Light exercise – Speaking</td>
<td>26.3</td>
</tr>
<tr>
<td>Light exercise – Loudly speaking</td>
<td>170</td>
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<tr>
<td>Heavy exercise – Oral breathing</td>
<td>13.5</td>
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<tr>
<td>Heavy exercise – Speaking</td>
<td>63.1</td>
</tr>
<tr>
<td>Heavy exercise – Loudly speaking</td>
<td>408</td>
</tr>
</tbody>
</table>
Calculation examples

- Assumption of 1 infected person in all rooms
- 5 quanta/h for office work and classroom occupancy
- 1.5 L/s per m$^2$ ventilation rate in 2 person office room of 16 m$^2$
- 50 m$^2$ open plan office
- 56 m$^2$ classroom
Calculation examples

- 7 q/h for a restaurant, 10 q/h for shopping, 16 q/h for sports and 23 q/h for meeting rooms
- 4 L/s m² in meeting rooms of 15, 25 and 50 m²
- 50 m² for other rooms
- The total airflow rate in L/s per infected person matters
- Common cold (5 q/h) design criterion of $p=0.05$ at 8 h occupancy possible in most of rooms (not in small 2-3 person rooms)

![Probability of infection vs Occupancy time graph](image)

- Meeting room 6 pers
- Meeting room 10 pers
- Meeting room 20 pers
- Restaurant 4 L/s m²
- Shopping 1.5 L/s m²
- Sports facility 3 L/s m²
Propagation and spread by air currents directed to a person

- New meaning for air movement/distribution
- ECDC addresses in their HVAC paper "Air flow generated by air-conditioning units may facilitate the spread of droplets excreted by infected people longer distances within indoor spaces."
- In reality, combined effect of directed air flow of the split unit and the poor ventilation (1 L/s per person) known in the Guangzhou restaurant
- Unfavorable airflow patterns may increase the concentration in the breathing zone for instance in some displacement and underfloor systems (Pantelic & Tham 2013, Bolashikov et al. 2012)
Conclusions

• While there are many possibilities to improve ventilation solutions in future, it is important to recognize that current technology and knowledge already allows the use of many rooms in buildings during a COVID-19 type of outbreak as long as ventilation rates correspond to or ideally exceed existing standards

• Regarding the airflow rates, more ventilation is always better, but to dilute the aerosol concentration the total airflow rate in L/s per infected person matters

• This makes large spaces ventilated according to current standards reasonably safe, but smaller rooms occupied by fewer people and with relatively low airflow rates pose a higher risk even if well ventilated

• Limiting the number of occupants in small rooms, reducing occupancy time and applying physical distancing will in most cases keep the probability of cross-infection to a reasonable level