Appendix 1 - Airborne transmission risk assessment and far-reaching actions to reduce the spread of viral diseases in future buildings with improved ventilation systems

1 Introduction

This appendix summarises available information on ventilation rates and provides a method for cross-infection risks assessment which can be applied for typical rooms in non-residential buildings. Available information on COVID-19 allows to argue that transmission of this disease has been associated with close proximity (for which ventilation isn't the solution) and with spaces that are simply inadequately ventilated. The latter is supported by evidence from superspreading events where outdoor air ventilation has been as low as 1–2 L/s per person[xvii,xviii], that is by factor 5–10 lower than commonly recommended 10 L/s per person in existing standards. The question, how much ventilation would be needed to substantially reduce airborne transmission of SARS-CoV-2 and what are other factors such as air distribution and room size that matter is discussed in the following paragraphs. It is important to understand that this topic includes high uncertainties given the current state of knowledge and scientific developments may provide new information quickly. The scope of this appendix applies for long-range airborne transmission reduction only, so the ventilation solutions discussed do not affect 1-2 m close contact and surface contact transmission modes.

2 Ventilation rate, room size and activity effects on infection risk

As discussed in Section 2, at a greater distance than 1.5 m from an infected person, control of virus-containing aerosol concentrations depends on ventilation solutions. The overall dose when exposed to a virus, (for example, when sharing a room with somebody infected) is equal to the product of concentration and time. Thus, to reduce the dose and infection risk, ventilation has to be increased and the occupancy time to be reduced. In existing ventilation systems, it is typically not possible to increase the fan speed significantly, so the system can deliver the performance for which it is sized. Sometimes, it may be possible to increase total airflow rates by 10-20% overall and by balancing possibly more significantly in specific rooms. Other improvement measures are limited to those discussed in Section 4.1.

From a legal point of view, the outdoor air ventilation rate must fulfil at least national minimum requirements set in the local building code or other regulatory documents (which may also include specific regulation for COVID-19). If a national ventilation regulation does not exist, then typically local building laws will always contain a provision for "good building practice", referring to the use of national, European or international standards and guidelines. 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 m^2 (10–15 L/s per person) outdoor airflow rates in offices and to about 4 L/s per floor m^2 (8-10 L/s per person) in meeting rooms and classrooms.

Ventilation improvement in existing or new buildings brings the question: Are the ventilation rates of Category II enough, or more outdoor air ventilation is needed to reduce the risk of cross-infection? Infection risk is currently not addressed in these standards as a design criterion. On the other hand, cross-infection risk is well known and applied in the design of hospital buildings where it leads to ventilation with a 6-12 ACH rate (see Appendix 3). Hospital ventilation systems have worked well in COVID-19 conditions as cross-infections have been under control, illustrating that high capacity ventilation is capable to keep aerosol concentration at low level. In non-hospital buildings, there are evidently lower emission rates and smaller numbers of infected persons per floor area. So, a lower ventilation rate than in hospitals, for instance Category I ventilation rate, could be considered as a starting point for the risk reduction. It is also worth noting that 4 L/s per floor m^2 in meeting rooms and classrooms corresponds to 5 ACH and is not much below the air change rate of patient rooms with precautions against airborne risks.

Infection risk can be calculated for different activities and rooms using a standard airborne disease transmission Wells-Riley model, calibrated to COVID-19 with correct source strength, i.e., quanta emission rates. In this model, the viral load emitted is expressed in terms of quanta emission rate (E, quanta/h). A quantum is defined as the dose of airborne droplet nuclei required to cause infection in 63% of susceptible persons. With the Wells-Riley model, the probability of infection (*p*) is related to the number of quanta inhaled (*n*) according to equation (1)[xi]:

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

The quanta inhaled (*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):

$$n = C_{avg} Q_b \mathrm{D} \tag{2}$$

The airborne quanta concentration increases with time from an initial value of zero following a "one minus exponential" form, which is the standard dynamic response of a fully mixed indoor volume to a constant input source. A fully mixed material balance model for the room (equation (3)) can be applied to calculate the concentration:

$$\frac{dC}{dt} = \frac{E}{V} - \lambda C \tag{3}$$

where

E quanta emission rate (quanta/h);

V volume of the room (m^3);

λ first-order loss rate coefficient[liv] for quanta/h due to the summed effects of ventilation (λ_v, 1/h), deposition onto surfaces (λ_{dep}, 1/h), virus decay (*k*, 1/h) and filtration by portable air cleaner if applied ($k_{filtration}$, 1/h), $\lambda = \lambda_v + \lambda_{dep} + k + k_{filtration}$;

C time-dependent airborne concentration of infectious quanta (quanta/m^3).

The surface deposition loss rate of 0.3 1/h may be estimated based on data from Thatcher[lv] and Diapouli[lvi]. For virus decay Fears[lvii] shows no decay in virus-containing aerosol for 16 hours at 53% RH, whereas Van Doremalen[v] estimated the half-life of airborne SARS-CoV-2 as 1.1 h, which equates to a decay rate of 0.63 1/h. An average value of these two studies is 0.32 1/h.

For portable air cleaner, the filtration removal rate ($k_{filtration}$) depends on the rate of airflow through the HVAC filter (Q_{filter}), and the removal efficiency of the filter (η_{filter}):

$$k_{filtration} = \frac{Q_{filter}\eta_{filter}}{V} \tag{4}$$

For portable cleaners with a High-Efficiency Particle Air (HEPA) filter, the Clean Air Delivery Rate (CADR, m^3/h) is provided and the filtration removal rate can be calculated as $k_{\text{filtration}} = CADR/V$. It should be noted that the removal efficiency of filters and the CADR are particle-size dependent. These parameters are to be estimated based on the size distribution of virus-containing particles. Calculation examples provided in the following are conducted without air cleaners.

Assuming the quanta concentration is 0 at the beginning of the occupancy, equation (3) is solved and the average concentration determined as follows:

$$C(t) = \frac{E}{\lambda V}\left(1 - e^{-\lambda t}\right) \quad (5)$$

$$C_{avg} = \frac{1}{D}\int_0^D C(t)\,dt = \frac{E}{\lambda V}\left[1 - \frac{1}{\lambda D}\left(1 - e^{-\lambda D}\right)\right] \quad (6)$$

where

t time (h).

Calculation examples can be found from papers analysing the Skagit Valley Chorale event[lviii] and quanta generation rates for SARS-CoV-2[lix]. Quanta emission rates vary over a large range of 3 – 300 quanta/h depending strongly on activities so that higher values apply for loud speaking, shouting and singing and also for higher metabolism rates, as shown in Table 1. Volumetric breathing rates depend on the activity being undertaken as shown in Table 2.

Activity	Quanta emission rate, quanta/h
Resting, oral breathing	3.1
Heavy activity, oral breathing	21
Light activity, speaking	42
Light activity, singing (or loudly speaking)	270

Table 1. 85th percentile quanta emission rates for different activitieslx.

Activity	Breathing rate, m^3/h
Standing (office, classroom)	0.54
Talking (meeting room, restaurant)	1.1
Light exercise (shopping)	1.38
Heavy exercise (sports)	3.3

Table 2. Volumetric breathing rateslxilxii.

Although SARS-CoV-2 quanta/h emission values include some uncertainties, it is already possible to calculate infection risk estimates and conduct comparisons on the effect of ventilation and room parameters. Results from such calculations are shown in Figure 6 for commonly used ventilation rates and rooms. It is assumed that in all calculated rooms, there is one infected person. The following time-averaged quanta emission rates calculated from activities shown in Table 1 were used: 5 quanta/h for office work and classroom occupancy, 15 quanta/h for a restaurant, 10 quanta/h for shopping, 21 quanta/h for sports and 19 quanta/h for meeting rooms. While typical COVID-19 infection rates in the general population have been in the magnitude of 1:1000 or 1:10 000, the assumption that only one infected person is in a room that is used by, e.g., 10 (office), 25 (school) or 100 persons (restaurant) is highly valid.

A risk assessment as shown in Figure 6. helps to build a more comprehensive understanding of how virus laden aerosols may be removed by ventilation. The results show that with Category II ventilation rates according to ISO 17772-1:2017 and EN 16798-1:2019, the probability of infection is reasonably low (below 5 %) for open-plan offices, classrooms, well-ventilated restaurants, and for short, no more than 1.5-hour shopping trips or meetings in a large meeting room. Small office rooms occupied by 2-3 persons and small meeting rooms show a greater probability of infection, because even in well ventilated small rooms the airflow per infected person is much smaller than that in large rooms. Therefore, in an epidemic situation small rooms could be safely occupied by one person only. In normally ventilated rooms occupied by one person there is no infection risk at all because of no emission source. There is also a very visible difference between 1 L/s m^2 and 2 L/s m^2 ventilation rate in an open plan office (note that 1 L/s m^2 is below the standard). Speaking and singing activities are associated with high quanta generation, but also physical exercises increase quanta generation and breathing rate that directly affects the dose. Thus, many of indoor sports facilities (excluding swimming pools and large halls) are spaces with higher probability of infection if they are not specially designed for high outdoor ventilation rates.

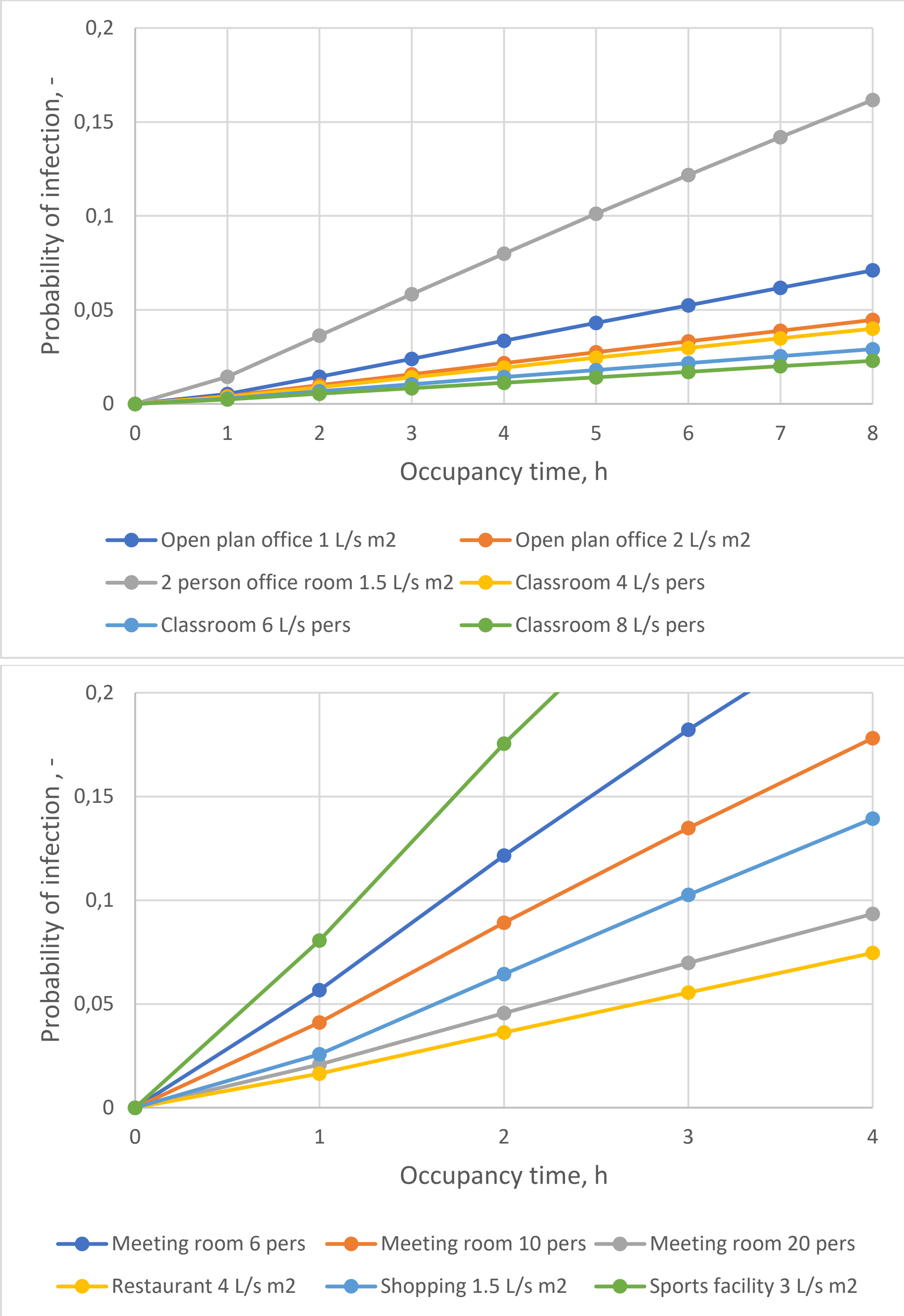

Figure 6. Infection risk assessment for some common non-residential rooms and ventilation rates calculated with the REHVA COVID-19 ventilation calculator. 1.5 L/s per m2 ventilation rate is used in 2 person office room of 16 m2, and 4 L/s per m2 in meeting rooms. Detailed input data is reported in Table 3.

Infection risk probability calculation workflow is illustrated in Table 3. The total airflow rate is calculated as a product of L/s per floor area ventilation rate value and the floor area, therefore the larger the room the larger the total airflow rate per infected person (1 infected person is assumed in all rooms). It should be noted that the number of occupants has no effect because the calculation is per infected person. The room height (volume) matters on the concentration development so that the source E is switched on at time t = 0 and the concentration starts to build up. In the calculation, 8-hour occupancy was considered and the average concentration is quite close to the steady state as the value in the parentheses is higher than 0.9 in all cases (1.0 will correspond to the steady state).

Case Specific Input Parameters													
	Floor area	Height	Ventilation rate per floor area	Qunta emission rate	Breathing rate	Occupancy time	Air change rate	Total first order loss rate	Room volume	x steady state concen-tration	Average concen-tration	Quanta inhaled (dose)	Probability of infection
	A (m^2)	h (m)	L/(s m^2)	quanta/h	m^3/h	Δt (h)	k_{ven} (h^{-1})	k_{tot} (h^{-1})	V (m^3)	[]	quanta/m^3	quanta	-
Open plan office 1 L/s m^2	50	3	1	5	0.54	8	1.2	1.82	150	0.93	0.02	0.07	0.071
Open plan office 2 L/s m^2	50	3	2	5	0.54	8	2.4	3.02	150	0.96	0.01	0.05	0.045
2 person office 1.5 L/s m^2	16	3	1.5	5	0.54	8	1.8	2.42	48	0.95	0.04	0.18	0.162
Meeting room 6 pers	18	3	4	19	1.1	8	4.8	5.42	54	0.98	0.06	0.56	0.428
Meeting room 10 pers	25	3	4	19	1.1	8	4.8	5.42	75	0.98	0.05	0.40	0.331
Meeting room 20 pers	50	3	4	19	1.1	8	4.8	5.42	150	0.98	0.02	0.20	0.182
Classroom 4 L/s pers	56	3	2	5	0.54	8	2.4	3.02	168	0.96	0.01	0.04	0.040
Classroom 6 L/s pers	56	3	3	5	0.54	8	3.6	4.22	168	0.97	0.01	0.03	0.029
Classroom 8 L/s pers	56	3	4	5	0.54	8	4.8	5.42	168	0.98	0.01	0.02	0.023
Restaurant 4 L/s m^2	50	3	4	15	1.1	8	4.8	5.42	150	0.98	0.02	0.16	0.147
Shopping 1.5 L/s m^2	50	3	1.5	11	1.38	8	1.8	2.42	150	0.95	0.03	0.32	0.272
Sports facility 3 L/s m^2	50	3	3	21	3.3	8	3.6	4.22	150	0.97	0.03	0.85	0.573

Table 3. Infection risk probability calculation workflow for the cases reported in Figure 6.

It is important to understand the limitations of the probability calculation:

- Results are sensitive to quanta emission rates which can vary over a large range, as shown in Table 1. The uncertainty of these values is high. Also, there are likely to be super spreaders that are less frequent but may have higher emission rates (as in the choir case[lviii]). This makes absolute probabilities of infection uncertain, and it is better to look at the order-of-magnitude (i.e. is the risk of the order of 0.1% or 1% or 10% or approaching 100%). The relative effect of control measures may be better understood from this calculation, given the current state of knowledge;
- Calculated probability of infection is a statistical value that applies for a large group of persons, but differences in individual risk may be significant depending upon the individual's personal health situation and susceptibility;
- Assuming full mixing creates another uncertainty because, in large and high-ceiling rooms, the virus concentration is not necessarily equal all over the room volume. In the calculation, a 50 m^2 floor area is used for an open-plan office. Generally, up to 4 m high rooms with a maximum volume of 300 m^3 could be reasonably well mixed; however, it is more accurate to simulate concentrations with CFD analyses. Sometimes, thermal plume effects from occupants may provide some additional mixing in high spaces such as theatres or churches.

These limitations and uncertainties mean that rather than predicting an absolute infection risk, the calculation is capable of comparing the relative effectiveness of solutions and ventilation strategies to support the most appropriate choice. The calculation model can show which strategy offers the lowest load for non-infected persons. The model can be applied to show low and high-risk rooms in existing buildings that is highly useful in the risk assessment of how buildings should be used during the outbreak. Calculation results are easy to convert to the form of relative risk. In Figure 7 this is done for an open plan office where 2 L/s per person ventilation rate (0.2 L/s per m^2) with occupant density of 10 m^2 per person is considered as 100% relative risk level. This ventilation rate that is a half of an absolute minimum of 4 L/s per person can be used to describe superspreading events. Results in Figure 7 show that a common ventilation rate of 2 L/s per m^2 will reduce the relative risk to 34% and doubling that value to 4 L/s per m^2 will provide relatively smaller further reduction to 19%.

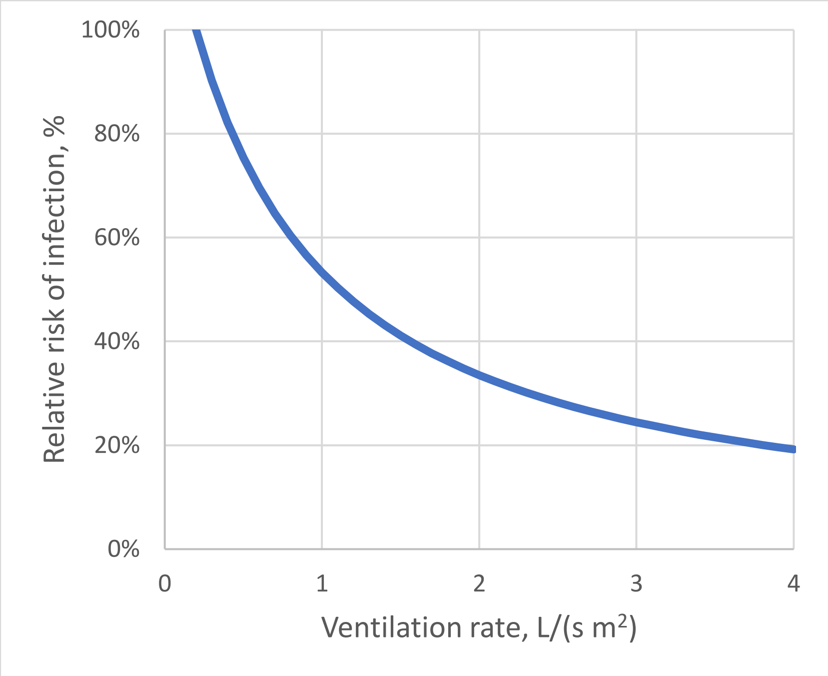

Figure 7. Relative risk in open plan office of 50 m2 where 2 L/s per person (0.2 L/s per m2) ventilation rate is considered as a reference level for a superspreading event with 100% relative risk.

Finally, Figure 7 allows to estimate what is the difference between Category II and I ventilation rates. With 10 m^2 per person occupant density, the airflow rates become 1.4 and 2.0 L/s per m^2 in Category II and I respectively when low polluting materials are considered. Thus, Category II ventilation results in 43% relative risk and Category I in 34% that shows significant improvement as the curve has quite deep slope at that range.

3 CO_2 concentration as a ventilation indicator

An easy way to monitor the ventilation performance is to use CO_2 sensors as recommended in Section 4.13. CO_2 readings describe outdoor ventilation rate adequately under normal occupant density. When persons enter a room, it takes some time before the concentration builds up and reaches the steady state value. In well ventilated rooms, CO_2 concentration builds up quickly, in meeting rooms and classrooms within 30 minutes and in offices less than in one hour. More specifically, the speed of the concentration build-up depends on the room time constant which is reciprocal of air change rate (63% of concentration change happens within 1 time constant and 95% within 3 time constants). Thus, CO_2 readings provide reliable indication about the ventilation sufficiency after the time of couple of the time constants.

At the same ventilation rate, the CO_2 concentration is lower if occupancy is reduced for instance, because of physical distancing or administrative measures. CO_2 concentration dependency on occupant density is illustrated in Figure 8 for an office with two ventilation rates. 2 L/s per m^2 ventilation corresponds to good practice of indoor climate Category I which is capable to keep CO_2 concentration below 800 ppm if there is at least 7 m^2 floor area per occupant. In the case of smaller ventilation rate of 1 L/s per m^2, at least 10 m^2 per person is needed to keep CO_2 concentration below 1000 ppm.

On the CO_2, the bottom line is that high CO_2 indicates poor ventilation without question. Low CO_2 is good, but it's not by its own a confirmation of a low risk of aerosol transmission; occupant density, occupancy duration and room size are to be considered too.

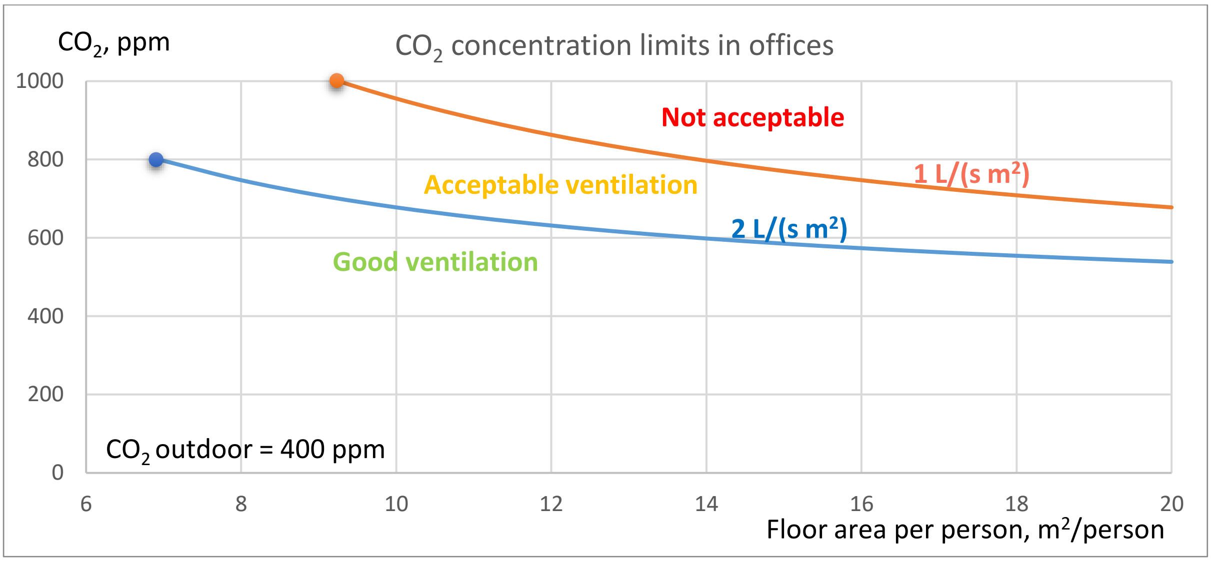

Figure 8. CO_2 concentration (absolute values that include outdoor concentration) dependency on ventilation rate and occupancy in offices.

4 Propagation and spread by air currents directed to a person

While air movement is commonly treated as a draught that is a local thermal discomfort issue, in rooms with an infected person, this can take on a new meaning. Because of studies of a Guangzhou restaurant and some previous airplane infections, this phenomenon of spread by air movement is well known. A strong directed airflow toward an infected person may carry little-diluted viral material in an aerosol towards a susceptible person in a very high concentration, which may propagate the virus within a specific part of the room, as shown by Figure 9. The ECDC addresses this possibility (see Section 3), concluding that "Air flow generated by air-conditioning units may facilitate the spread of droplets excreted by infected people longer distances within indoor spaces." However, in this specific case, it is not known what were the relative contributions of the directed air flow of split unit and the poor ventilation to the infections in the Guangzhou restaurant. Only the combined effect of these two factors is known along with the fact that the ventilation was negligible, being only about 1 L/s per person. This indicates that the very low level of ventilation was likely the main cause of the outbreak in the restaurant.

Although the air conditioning unit was not likely to be the main contributor in this specific case, the issue of directed air flow should be taken seriously in future air distribution design. Low velocity air distribution solutions which do not provide either strong air currents or draughts are already widely available and should now be applied more widely.

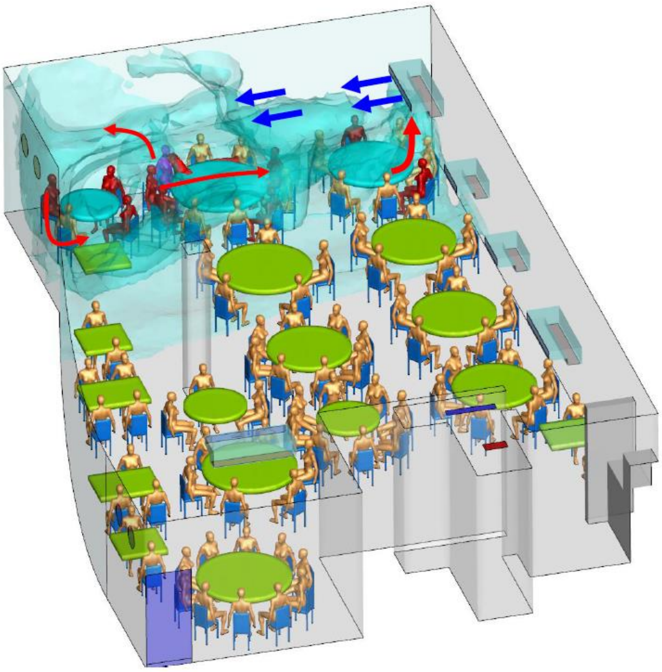

Figure 9. CFD simulated air distribution by split unit in Guangzhou restaurantxvii. The index person is shown with magenta-blue and nine infected persons with red. (Figure: courtesy Yuguo Li

Air distribution may have a crucial effect on the concentration of viral material in room air. It can both locally reduce or increase concentrations remarkably. A number of papers show that assuming well-mixed air in a space is in many cases an oversimplification that fails when it comes to particles and aerosol concentrations. Increasing the ventilation rate may in some situations even increase the concentration in the breathing zone because of unfavourable airflow patterns. Such evidence is reported for some displacement and underfloor systems[lxiii][lxiv].

Generally, viral aerosol concentration control is a new consideration for room air distribution where viral material from a point source (an infected person with unknown location) should be effectively diluted and locally removed at the same time. Therefore, a fully mixing air distribution system, capable of completely mixing contamination from a point source in a large room in one hand, and vertical stratification and exhausts capable of removing the higher concentration before it is completely mixed, would be beneficial. Additionally, personal ventilation solutions can be useful as they help to reduce concentrations locally in workplaces. There is no obvious way to combine such mutually contradictory features. Thus, dilution rates, effectiveness of contaminant removal and efficiency of air changes for all possible types of air distribution including personal ventilation solutions should be the subject for air distribution research. This should consider the situation of one randomly located point source instead of a common situation with more or less equally distributed emission sources distributed in rooms with no infected persons.

5 Cross-contamination aspects of ventilation and AC systems

High ventilation hygiene levels and strict avoidance of any cross-contamination are well known aspects of hospital and industrial ventilation design. In other non-residential buildings the issue is more speculative because of contaminants with lower risks and the more economical and energy-efficient solutions used. The need for more widespread infection control, however, will raise new questions for the use of recirculation and potential leakages in heat recovery equipment, as well as about safe distances between exhaust and intake air openings. Recirculation is technically easy to avoid in any climate, and there are available alternatives, such as more energy-efficient heat, cold, and humidity recovery solutions. However, further research into pollutant transfer may be needed. For instance, pollutant transfer studies of rotors (enthalpy wheels) are more than 20 years old, and more studies about particle and gas-phase transfer and the effects of hygroscopic coatings may also be needed. The same applies to air cleaning technologies for which research and standardization are in the development phase.

6 Summary and the research agenda

While there are many possibilities to improve ventilation solutions in future, it is important to recognise 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 and a cross-infection risk assessment is conducted (as shown in Section 2). 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 they are 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. For future buildings and ventilation improvement, Category I ventilation rates can be recommended as these provide significant risk reduction compared to common Category II airflow rates.

Proposed research agenda:

- Future research should tackle cross-contamination, air distribution, and outdoor air ventilation capacity aspects as the first priority;
- Quick and affordable retrofit solutions of improved ventilation efficiency resulting in reduction of risk of infection should be a specific focus for existing buildings (that can be developed as a part of energy efficient low carbon retrofit to meet 2030/2050 goals);
- Risk management may be improved by dedicated use of IAQ monitoring systems designed not just to detect high CO_2 concentration situations but designed to translate CO_2 concentration trends (depending upon room size, a normal number of persons present in the room, etc.) into an evaluation of Wells-Riley infection risks;
- Research funding agencies and industry should invest in developing practical technical solutions to protect against the aerosol transmission of infectious diseases in indoor environments, buildings, and on public transport systems;
- Building codes, standards, and guidelines should be revised and updated to improve preparedness for future epidemics;
- The proposed actions will provide concurrent benefits for reducing the risk of airborne transmission of viral diseases and general health in times between epidemics.

Appendix 2 – Inspection of rotary heat exchangers to limit internal leakages

The main indicator of internal leakage of contaminated air leaving the room to supply air through the exchanger is expressed by Exhaust Air Transfer Ratio (EATR) in %. EATR is a function of the pressure difference between the supply air side downstream of the exchanger (p_{22}) and the extract air side upstream of the exchanger (p_{11}), and its value depends on the type of sealing and conditions. But also, the rotor speed and purge sector have an impact on EATR. The main target is to keep over pressure on the supply air side, and in this way, maintain any possible leakage from supply to exhaust air (i.e. EATR = 0%). In well-equipped air handling units (AHUs), pressure taps to measure p_{11} and p_{22} are normally available.

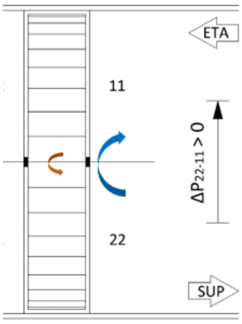

Figure 10. $\Delta P_{22\text{-}11}$ in AHU

For a correctly designed, set-up and maintained rotary heat exchanger, the leakage of potentially contaminated by pathogens extract air to supply air stream is typically very low and without practical meaning. Nevertheless, in the case of incorrect layout of AHU fans or lack of a correct pressure balance setting within the AHU, the leakage may be significantly higher.

Measures to keep the exhaust air leakage low

The air leakage across a rotary heat exchanger depends on a number of factors described below. The facility management staff normally have no impact on the location of fans, but other measures to eliminate or minimise leakage should be taken during commissioning, inspection and regular maintenance.

Correct position of fans

A prerequisite for minimising internal leakages is the correct positioning of fans. The available fans position configurations are shown on Figures 11-14. The most recommended configuration includes both fans located downstream within the exchanger (see Figure 11), In this configuration, with correctly balanced pressures ($p_{22\text{-}11} > 0$) and properly set-up purge sector, EATR is usually below 1%. In contrast, the most adverse configuration in terms of leakage includes both fans on the building side (see Figure 12) In the worst case, for this configuration EATR can amount to as much as 10–20%[6].

[6] Eurovent Recommendation 6-15. Estimation based on Eurovent Certified data.

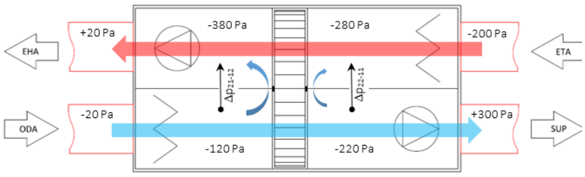

Figure 11. Best configuration. Both fans after the rotor

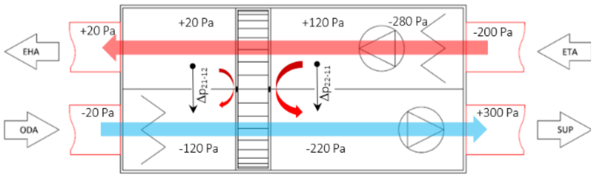

Figure 12. Both fans on building side

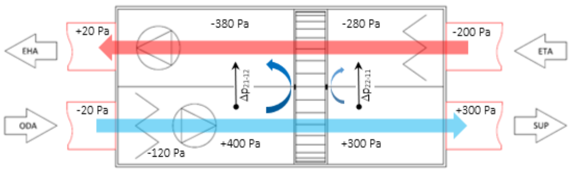

Figure 13 Both fans on the outdoor side

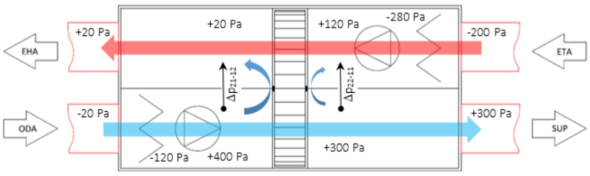

Figure 14 . Both fans upstream the exchanger.

Balancing pressure difference

The next step to minimise a leakage is to set the correct difference between pressures p_{22} and p_{11}. Pressure p_{11} should be at least 20 Pa less than the pressure p_{22}. Depending on the configuration of fans, this can be done by throttling as follows:

- If both fans are placed after the rotor (Figure 11): adjust the throttle in the extract air so p_{11} will become at least p_{22} – 20 Pa. If the throttling device (e.g. damper) is not available in an AHU, it should be installed in the ductwork.
- Both fans on the building side (Figure 12): There is no possibility to use throttling in this case.
- Both fans on the outdoor side (Figure 13): There is no need to use throttling in this case.
- Both fans upstream of the rotor (Figure 14): adjust the throttle in the supply air so p_{11} will become at least p_{22} – 20 Pa. If the throttling device (e.g. damper) is not available in an AHU, it should be installed in the ductwork.

Correct application of the purge sector, position and setting

The purge sector is a device that can practically eliminate the leakage resulting from the rotation of the wheel (carry-over leakage). Its location and setting (angle) must be arranged according to the AHU manufacturer's guidance depending on the configuration of fans and pressure relations.

Effective sealing of the rotor

Perimeter and middle beam sealing prevent air leakage from the supply side to the exhaust side. Seals are subject to wear and their performance deteriorates with time. The condition of the seals should be checked during periodic inspection and, if necessary, the seal should be restored to its original state in accordance with the manufacturer's instructions.

Method to estimate leakage (EATR) for on-site tests

The precise testing of internal air leakage must be carried out in the laboratory. However, a draft of the new upcoming standard prEN308 provides a simple method for estimation of EATR in service using temperature measurements that can be performed on-site. The test procedure includes measurements of temperatures t_{11}, t_{21} and t_{22} in steady-state conditions with the rotor stopped (heat transfer deactivated). Next, EATR is calculated as:

$$EATR = \frac{t_{22} - t_{21}}{t_{11} - t_{21}}$$

Where,

t_{11} is temperature exhaust air inlet;

t_{21} is temperature supply air inlet;

t_{22} is temperature supply air outlet.

Leakage related to the rotation of the wheel (carry-over) cannot be determined by this method.

Appendix 3 - Ventilation in patient rooms

Ventilation systems for special patient rooms like airborne infectious isolation rooms (AIIR) have been well developed for infection risk control[7]. These rooms apply two principles: by preventing the spread of airborne microbes adjoining rooms and the surrounding area and by reducing the amount of airborne microbes in patient room with efficient ventilation. To prevent the spread by airborne transmission from a source patient to susceptible patients and other persons in a patient room, it is important to keep the patient room with negative pressure comparing with adjacent rooms in hospitals. Patient rooms with negative pressure are also known as 'Class N isolation room', 'airborne infection isolation' and 'infectious isolation units'. A few recommendations are presented here specifically for the operation of patient rooms during COVID-19 temporary hospital settings according to several national regulations/standards[8][9][10][11][12]. Generally, hospital ventilation systems designed according to these regulations/standards have provided adequate airborne infection risk control for COVID-19 disease so that no cross-infections have been reported from modern hospitals.

For normal areas/patient rooms:

- Normal patient rooms that are not intended for patients with infectious diseases, need at least 4 air changes per hour (ACH).
- If used for airborne precaution, it should be updated to meet the requirement for isolation rooms, where adequate ventilation is considered to be at least 6 ACH (equivalent to 40 L/s/patient for a 4x2x3 m^3 room).

For temporary areas/wards for patients with infectious diseases:

- Healthcare facilities without enough single isolation rooms in emergency departments should designate a separate, well-ventilated areas/wards where patients with suspected COVID-19 can wait.
- If feasible, ventilation system should be updated to meet the requirement for isolation rooms.

For isolation rooms with airborne infections:

- AIIR air shall be exhausted directly to the outdoors, using HEPA filter whenever it is possible to avoid possible cross contamination if the exhaust air outlet are nearby windows or outdoor air intakes.
- Ensure supply air ducts are independent of the common building supply air system.
- The supply airflow rate should be 6-12 ACH (e.g. equivalent to 40-80 L/s/patient for a 4x2x3 m^3 room) for existing isolation rooms, ideally at least 12 ACH for new constructions. See Figure 15 for illustration of the effect of high airflow rates.
- Recommended negative pressure differential is ≥5 Pa to ensure that air flows from the corridor

[7] Guidelines for the classification and design of isolation rooms in health care facilities, Victorian Advisory Committee on Infection Control 2007. http://docs2.health.vic.gov.au/docs/doc/4AAF777BF1B3C40BCA257D2400820414/$FILE/070303_DHS_ISO%20RoomGuide_web.pdf

[8] ASHRAE Standard 170-2013

[9] VDI 6022 https://www.vdi.de/richtlinien/unsere-richtlinien-highlights/vdi-6022

[10] https://www.fhi.no/publ/eldre/isoleringsveilederen/

[11] https://www.cdc.gov/infectioncontrol/guidelines/environmental/appendix/air.html#tableb2

[12] https://www.who.int/publications/i/item/WHO-2019-nCoV-IPC-2020.4

into the patient room.

- Exhaust air shall be located directly above the patient bed on the ceiling or on the wall.
- Ensure the room is as airtight as possible
- Extract air from the patient room and toilet should not be recirculated and returned to the room.
- Fit a local audible alarm or local visual means in case of fan failure and negative differential pressure is not maintained.
- A separate exhaust system dedicated to each room that removes a quantity of air greater than that of the supply system.
- If possible, anteroom or air lock should be used to prevent the transmission of infectious agent from the door opening of the AIIR.

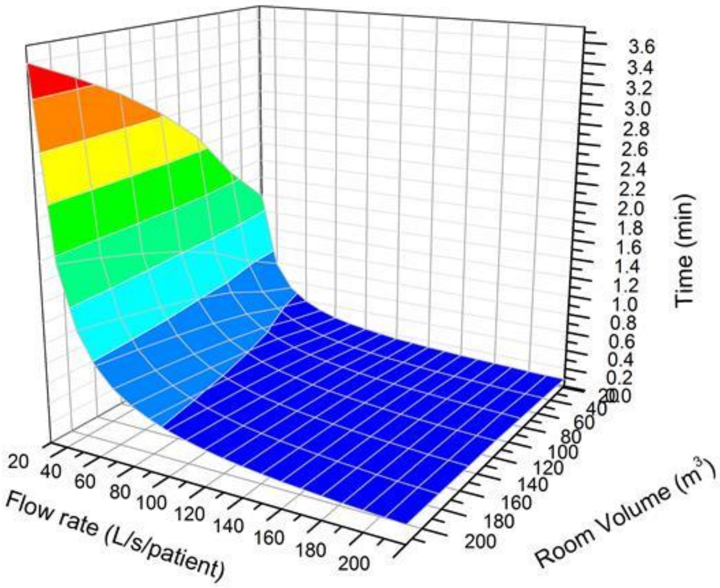

Figure 15. illustration of high airflow rates. Time to replace the air in the room as a function of airflow rate and room volume.

If natural ventilation is used, higher ventilation rates are recommended because of unstable operation of ventilation where sufficient ventilation cannot be guaranteed at all times. Natural ventilation is suitable for the use only in favourable climate conditions. Comprehensive natural ventilation guidance is provided by WHO[13].

[13] Natural Ventilation for Infection Control in Health-Care Settings. WHO 2009. https://www.who.int/water_sanitation_health/publications/natural_ventilation.pdf

Appendix 4 - COVID-19 ventilation and building services guidance for school personnel

In this document we summarise advice on the operation and use of building services in schools, in order to prevent the spread of the coronavirus disease (COVID-19) virus (SARS-CoV-2). This guidance is focussing on school principals, teachers and facility managers.

Before taking preventive measures, it requires some basic understanding of transmission of infectious agents. In relation to COVID-19 four transmission routes can be distinguished:

1. in close contact of 1-2 m via large droplets and aerosols (when sneezing or coughing or talking);
2. via the air through aerosols (desiccated small droplets), which may stay airborne for hours and can be transported long distances (released when breathing, talking, sneezing or coughing);
3. via surface contact (hand-hand, hand-surface etc.);
4. via the faecal-oral route.

More backgrounds on transmission routes of SARS-CoV-2 can be found in Section 2 of this document.

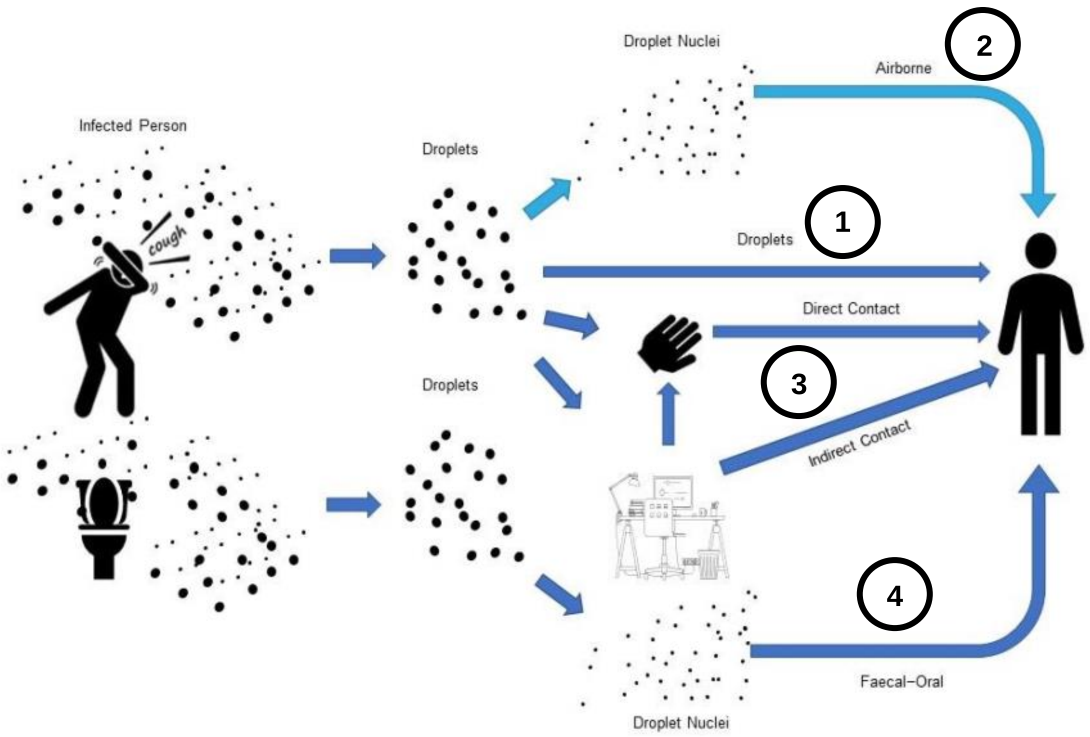

Figure 16. Exposure mechanisms of COVID-19 SARS-CoV-2 droplets. (Figure: courtesy Francesco Franchimon)

General guidance for employers and building owners that is presented in e.g. the WHO document 'Guidance for COVID-19 prevention and control in schools' and national guidelines focus on monitoring of symptoms, keeping distance and good hygiene practices (transmission routes via large droplets and via surface contact). In order to keep the risk of infection as low as reasonably achievable, we additionally recommend measures on ventilation (airborne transmission) and sanitary installations (faecal-oral transmission).

Ventilation

In many European schools sufficient ventilation is a challenge. Today, many schools in Europe are naturally ventilated (e.g. using windows). Natural ventilation significantly depends on the temperature difference between the indoor and the ambient air and the current wind situation. As a result, a sufficient natural ventilation cannot be guaranteed at all times. Mechanical ventilation systems can ensure a continuous air exchange throughout the year.

Below some practical instructions are given to optimize ventilation in the short-term:

- Secure ventilation of spaces with outdoor air. Check whether the ventilation systems in classrooms, either natural or mechanical, are functioning well:
    - ✓ Check whether windows and grilles can be opened;
    - ✓ Clean ventilations grilles so that the air supply is not obstructed;
    - ✓ Have mechanical ventilation systems checked for their functioning by your maintenance company;
- Install a CO_2 monitor with traffic light indication (Figure 17) at least in the classrooms in which ventilation depends on opening windows and/or outdoor grilles. This visualises the need for extra ventilation by opening windows. Make sure that the CO_2 monitor is placed at a visible position in the classroom, away from fresh air inlets (e.g. open windows), typically on the internal wall at occupied zone height of about 1.5 m. In times of Corona, we suggest to temporarily change the default settings of the traffic light indicator (yellow/orange light up to 800 ppm and red light up to 1000 ppm) in order to promote as much ventilation as possible.

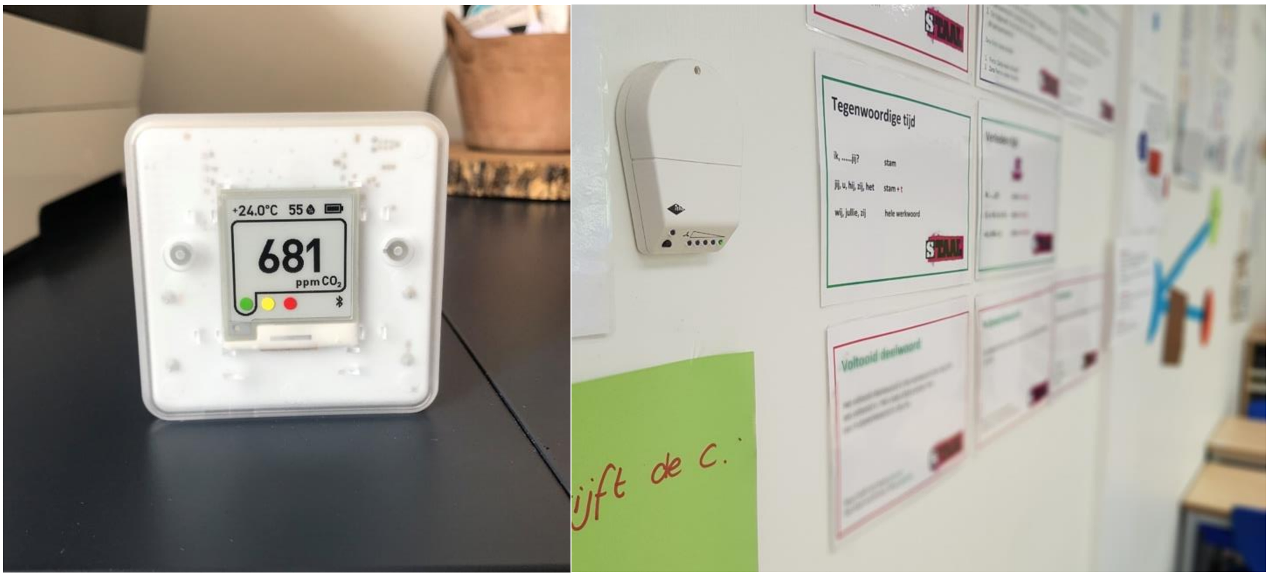

Figure 17. Examples of CO_2 monitors with traffic light indicator showing the indoor air quality.

- Check operating hours of mechanical ventilation systems. Switch ventilation to nominal speed at least 2 hours before the school starts and switch off or to lower speed 2 hours after occupancy. Keep toilet ventilation in the nominal speed in similar fashion as the main ventilation system.[14]
- Switch air handling units with central recirculation to 100% outdoor air.
- Adjust the setpoints of CO_2 controlled ventilation systems (if present). With these systems, the amount of air exchange is automatically reduced with lower occupancy to save energy. In order to reduce the risk of transmission of infectious diseases full ventilation is needed, even if only part of the students is present. Ask your maintenance company if CO_2 controlled ventilation is present in your building. Generally, they are also the ones to adjust the setpoints.
- Give teachers instructions on how to use the ventilation facilities:
    - ✓ Open windows and ventilations' grilles as much as possible during school hours. Opening windows just underneath the ceiling reduces the draught risk. In rooms with mechanical

[14] More detailed ventilation operation guidance is provided in Section 4.1.

air supply and exhaust this is usually not necessary, but extra ventilation is positive and does not disrupt the ventilation system.

- ✓ Ensure regular airing with windows during breaks (also in mechanically ventilated buildings).
- ✓ Make sure that ventilation facilities are not obstructed or blocked by curtains or furniture.
- ✓ Keep an eye on any installed CO_2 monitors (ask pupils to assist). Be aware that more aerosols are released during activities such as singing or sport.
- ✓ Use local cooling systems, like fan coils or split units, as you usually do[15]. Though, make sure that there is ***always*** supply of fresh outdoor air by mechanical ventilation systems or operable windows.

Figure 18. Open windows as much as possible during school hours and ensure airing during breaks.

In the long-term it obviously makes sense to structurally improve the ventilation, since poor indoor air quality leads to, among others, headache, fatigue and reduced learning performance.

Some contractors and maintenance companies are now offering to replace filters, but this is NOT necessary to reduce infection risks. Only replace filters when necessary or already planned. In addition, one talks about cooling and humidification of air. Adjusting the setpoints of the climate system to lower values is NOT necessary and useless in schools. The same goes for placing humidifiers, because there is NO evidence that this is effective. Focus on things that really matter, such as proper ventilation.

Sanitary

[15] More detailed guidance on fan coils and split units is provided in Section 4.6.

Points of attention for the sanitary facilities (taps, toilets, sewers):

- Flush all toilets, water taps and showers before the school reopens. If water taps haven't been used for several weeks, the water that is still in the pipes may be of poor quality.
- Check if water taps in all toilets are in operating condition (with soap dispensers and paper towels) or provide other facilities to disinfect hands after using the toilet.
- Replace frequently used water taps with taps with a sensor, so that they can be used without touching them.
- Make sure that floor drains do not run dry to avoid an open connection to the sewer. Fill the drains regularly with water. Add some oil to prevent the water seal from evaporating quickly.
- Give the instructions to flush toilets with closed lid and wash hands after toilet use.

More information

https://www.rehva.eu/activities/covid-19-guidance

https://www.who.int/emergencies/diseases/novel-coronavirus-2019/advice-for-public

https://www.who.int/emergencies/diseases/novel-coronavirus-2019/technical-guidance/guidance-for-schools-workplaces-institutions

https://www.unicef.org/media/66216/file/Key%20Messages%20and%20Actions%20for%20COVID-19%20Prevention%20and%20Control%20in%20Schools_March%202020.pdf?sfvrsn=baf81d52_4

Feedback

If you are specialist in the issues addressed in this document and you have remarks or suggestions for improvements, feel free to contact us via info@rehva.eu. Please mention 'COVID-19 interim document' as subject when you email us.

Colophon

This document was prepared by the COVID-19 Task Force of REHVA's Technology and Research Committee, based on the first version of the guidance developed in the period between March 6-15th 2020 by REHVA volunteers.

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