Implications of COVID-19 pandemic for application of natural ventilation


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The present COVID-19 crisis has increased the attention for health and hygiene indoors. Ventilation plays a significant role in the spread of COVID-19. According to the WHO (2020) transmission can occur more easily in situations where the "Three C's" apply:

- Crowded places with many people nearby;
- Close-contact settings, especially where people have close-range conversations;
- Confined and enclosed spaces with poor ventilation.

In this article we provide an update on the link between ventilation, the transmission of coronavirus SARS-CoV-2 and the potential advantages and/or risks of natural ventilation, based on scientific literature. The term 'natural ventilation' refers to airing through operable windows as well as background ventilation with natural air supply, e.g. through natural air intake grilles (window vents).

We answer the following questions:

- How does ventilation system design influence the transmission of coronavirus SARS-CoV-2?
- What are potential advantages and risks of natural ventilation compared to mechanical ventilation in relation to the transmission of SARS-CoV-2?

Airborne transmission

Although there's still an academic discussion ongoing on the importance of airborne transmission of SARS-CoV-2 (Tang et al, 2021), many studies related to the spread of COVID-19 indoors concluded that the role of transmission via aerosols is significant especially when people spent considerable amounts of time together in poorly ventilated spaces (e.g. Singh, 2020; Buonanno et al, 2020a: Li et al., 2020; Miller et al., 2020).

Persons with COVID-19 that breathe, talk or sing spread aerosols that contain viruses (Buonanno et al, 2020b). Increasing the ventilation rate is believed to reduce cross infection of airborne transmitted diseases by removing (exhaust ventilation) or diluting pathogen-laden microdroplets (airborne droplet nuclei) from a room. A higher ventilation rate can dilute the contaminated air inside spaces more rapidly and decreases the risk of cross infection (**Figure 1**). A higher ventilation rate will also transport contaminants (viruses) away from the space more rapidly. This is also relevant for other types of infectious respiratory diseases than COVID-19.

Persons with COVID-19 can be regarded as 'indoor sources' that spread pollutants. More specifically: viruses or virus infected (micro)droplets. The question is: how much of those pollutants enter the breathing zone and possibly the airways of other persons? One speaks of the ventilation diluting effect in this context. The more 'forceful' a space is ventilated, the lower the aerosol/virus concentration will be in the breathing zone of non-infected people and the smaller their chance of becoming infected. Current findings indicate that one needs to be exposed to a certain concentration of infected microdroplets for a certain time before becoming infected. In this context the susceptibility of those exposed also matters, which differs from person to person and is e.g. related to age and medical condition.

Impact of the ventilation system

As shown in the previous paragraph, ventilation is of the highest importance to avoid airborne transmission of COVID-19. Besides the amount of fresh air supply, there are some other factors related to the ventilation of buildings that influence the infection risk. We have listed the most important ventilation-related factors regarding airborne transmission of SARS-CoV-2 in the 'COVID-19 hexagon for ventilation systems' (**Figure 2**). In the paragraphs below we explain these factors.

For more general recommendations to prevent the spread of the COVID-19 through adequate building service system design and operation*.

First of all, sufficient **ventilation** (fresh air supply) must be guaranteed. In this context devices are needed that guarantee background ventilation (e.g. trickle ventilation, mechanical supply or operable windows). In terms of COVID-19 risks, however, we need to change the way we are used to look at ventilation. Traditionally all occupants within a space are considered as a pollution source (that spreads e.g. CO_2). We normally ventilate in order to exhaust all the pollutants produced by the occupants and replace indoor stale air by fresh outdoor air. In the case of aerosol transmission of respiratory diseases, we need to look at ventilation in a completely different way as we only have one or maybe a few sources of pollution (infected persons) in an indoor space. Ventilation is needed in order to **dilute** the virus concentration and decrease the exposure of the uninfected occupants to virus particles spread by others.

Next to background ventilation, frequent **airing** is very important to reduce the risk of airborne transmission of COVID-19. Airing, simply by opening windows or external doors, allows for rapid air refreshment. Within 10-15 minutes the contamination load in the room can be reduced substantially. This is relevant, for example, after a room has been used, to make sure that the air is fresh before new users come in. Ventilation rates that can be achieved by airing are generally much higher than the ventilation rate of mechanical ventilation systems.

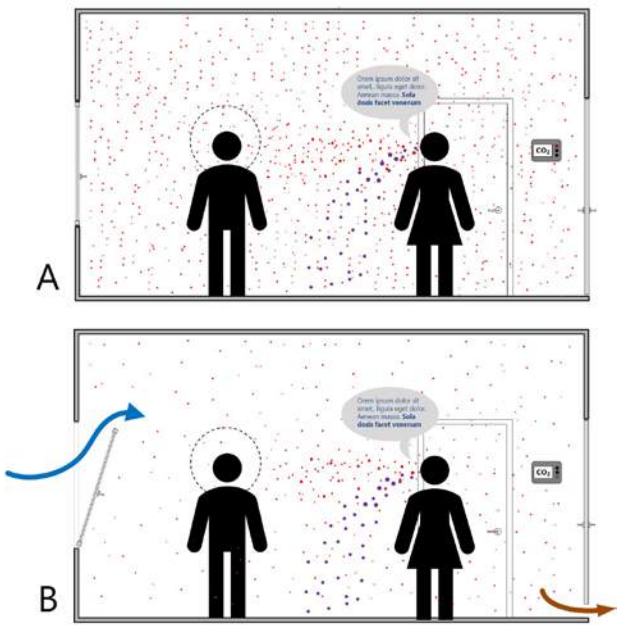

Figure 1. Aerosol / virus exposure in the breathing zone of a non-infected person (left) due to an infected (talking) person (right). The purple dots symbolize the spread of infected droplets. Red dots symbolize the spread of infected microdroplets (aerosols). The exposure is relatively HIGH in an insufficiently ventilated room (A). The exposure is much LOWER when a room is well-ventilated (B). (bba binnenmilieu, Stijn van der Horst).

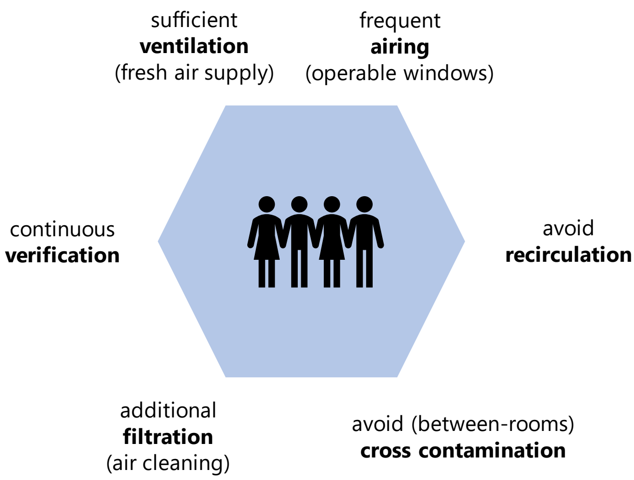

Figure 2. COVID-19 hexagon for ventilation systems (both natural and mechanical).

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

Building ventilation should be designed in such a way that between-rooms **cross contamination** cannot take place. Due to pressure differences, air will flow through a building in a certain direction. These pressure differences can be caused by either mechanical ventilation, wind pressure or stack effects. If the air flows from one room into another, the infection risk for the occupants will increase for example if the upstream room is contaminated. In, for example, apartment buildings, nursing homes and office buildings, avoiding the air flow between rooms is important in order to limit the spread of infections. This especially applies in situations with open windows and high-rise buildings (that might have strong vertical air flows).

Recirculation of exhaust air is ideally avoided. If centralized air handling units are equipped with a recirculation sector, exhaust air can be mixed with the fresh outdoor air for the purpose of energy efficient heating. If infected microdroplets are present in the exhaust air, there is a chance that they will re-enter the building. Therefore, central recirculation should be avoided (especially during a pandemic) to keep the infection risk as low as possible. Moreover, certain types of heat recovery devices, such as a rotary heat exchanger / enthalpy wheel, may carry over virus attached to microdroplets from the exhaust air side to the supply air side via leaks. More information about this topic can be found at the website**.

Filtration by room air cleaners can be useful to reduce the spread of COVID-19 (Elias & Bar-Yam, 2020). These local filtration systems remove microdroplets from air and can provide a similar dilution effect compared to ventilation. The use of this equipment is independent from the type of ventilation system in the building. To be effective, filters need to have at least the efficiency of HEPA filters (Elias & Bar-Yam, 2020; Ontario Medical Advisory Secretariat, 2005).

Other air cleaning techniques, such electrostatic precipitators or UVGI, often work quite well too (ASHRAE, 2020). However, many types of room air cleaners generate undesirable by-products, such as ozone, aldehydes and ultrafine particles, during operation (Zhang et al, 2011). Filtration systems ideally should be selected taking into account and avoiding such side-effects.

** https://www.rehva.eu/fileadmin/user_upload/REHVA_COVID-19_specific_guidance_document_-_Limiting_internal_air_leakages_across_the_rotary_heat_exchanger_.pdf

Mechanical ventilation systems are normally equipped with filters, though not as efficient as HEPA filters. Supply air filters are placed near the outdoor air inlet, while virus-contaminated air is generally inside the building. These filters therefore won't help to reduce the risk of virus transmission. Return air filters, on the other hand, could reduce the number of microdroplets that re-enter the building in case of HVAC systems that work with central recirculation or heat recovery equipment that allows for some leakage. Though, these filters normally are of much lower quality than the main (outdoor air inlet) filters and thus are even more inefficient in filtering out microdroplets from the air.

Continuous **verification** or monitoring of the indoor air quality (e.g. with CO_2 sensors in each room) helps users to operate the ventilation devices optimally and gives facility managers insight in the performance of ventilation systems.

Advantages and risks of natural ventilation

According to the formal definition, natural ventilation, unlike mechanical or fan-forced ventilation, uses the natural forces of wind and buoyancy to provide fresh air into buildings. Natural ventilation can be used for both background ventilation and airing (rapid air refreshment). In this article, we consider ventilation by natural air supply and mechanical exhaust as 'natural ventilation' as well.

There may be the perception that natural ventilation is hard to control compared to mechanical ventilation systems. Hence, mechanical ventilation systems are often preferred by system designers to reduce infection risks. However, natural ventilation systems certainly have strengths.

Very **high ventilation rates** can be achieved by airing. The ventilation rate that can be achieved depends on the window design (number, size and position of the windows, size of the opening) or the length and capacity of natural air intake grilles. In order to maintain sufficient ventilation, generally not all windows or natural air intake grilles have to be opened (depending of course upon the wind conditions). Airing by opening extra windows is a simple way to boost ventilation rates. Moreover, opening windows can provide **ventilative cooling** and thus extra ventilation is stimulated in summer.

Figure 3. Very high ventilation rates can be achieved by opening windows (airing) (Photo: Jesper Jørgen).

Another advantage of natural ventilation is that it is **easy to understand** for the end-user. It is clear if a window is open or not and if fresh air is able to enter the room straight from outside. It gives people control over their indoor environment and the quality of the air they breathe, which is even more important in times of COVID-19. Studies have shown that when people have control (or perceive to have control) over their indoor environment, they are more productive, feel more comfortable and have less building related symptoms (Boerstra, 2016).

It is possible to combine natural ventilation with **filtration** by room air cleaners with HEPA filters to capture (virus containing) microdroplets in room air.

Natural ventilation also has some weaknesses. While high ventilation rates are possible with operable windows, it's hard to achieve a steady situation. With natural ventilation it can be more difficult to maintain a high enough ventilation rate continuously as the actual ventilation rate depends on **user behaviour**: if windows and natural air intake grilles stay closed the air supply will be limited. If they are overused (open all the time) this might lead to draft and temperature problems, especially in winter. However, automated systems that use e.g. CO_2 concentration to control window openings can reduce this weakness. The use of 'traffic light style' CO_2 monitors (**Figure 4**) can also help to remind end-users to open grilles and windows in a timely manner.

Figure 4. CO_2 monitor (Aranet4) with traffic light indication.

Moreover, **outdoor conditions**, such as the weather (wind speed, wind direction and temperature) and the outdoor environment around the building (traffic noise, outdoor pollution sources) influence the correct use of natural ventilation devices. Finally, safety can be an issue, e.g. related to burglary or the risk for falling out of windows.

Also mechanical supply systems have weaknesses. The strengths and weaknesses of both natural and mechanical ventilation solutions are summarized in **Table 1**.

This comparison might be read by some as if one solution (either natural or mechanical ventilation) is better than the other. We believe that a COMBINATION of natural ventilation and mechanical ventilation actually is the preferred outcome. When designing a new office building, school, nursing home, single family home, apartment complex or hotel, it would be in many cases best (in terms of infection risk management) to combine the two. For example, a combination of (well-designed, e.g. wind pressure reactive) natural air intake grilles (figure 5) with mechanical exhaust directly inside the living spaces. Ventilation system designs that use a

Figure 5. Self-regulating natural air intake grilles (DUCO).

Table 1. *Summary of strengths and weaknesses of natural ventilation and mechanical ventilation.*

	Natural ventilation (natural supply and exhaust)	Mechanical ventilation (mechanical supply and exhaust)
Strengths	✓ Very high air change rates can be achieved by airing. ✓ Due to by ventilative cooling extra ventilation is stimulated in summer. ✓ Room air cleaners with HEPA filter can be used. ✓ Easy to understand; direct user feedback and personal control.	✓ Ventilation rate is independent from wind conditions and outdoor temperature. ✓ Ventilation can be maintained during absence without safety consequences. ✓ Direction of air flow is clear. ✓ Room air cleaners with HEPA filter can be used.
Weaknesses	✕ Ventilation rate depends on user behaviour. ✕ Ventilation rate depends on outdoor conditions (e.g. weather, traffic noise). ✕ Use of ventilation facilities depends on the building design (usability, safety). ✕ Direction of air flow depends on indoor and outdoor conditions.	✕ Increasing the air change rate by airing is not possible. ✕ If centralized air handling units are equipped with a recirculation sector, virus particles can re-enter the building. ✕ No user feedback from mechanical ventilation.

combination of air supply via natural air intake grilles and mechanical exhaust directly in the space are far more robust when it comes to guaranteeing sufficient fresh air supply. Another combination is for example mechanical supply and exhaust in the living spaces and additional operable windows for airing purposes.

When using natural ventilation solutions, attention should be paid at the design stage to thermal comfort (e.g. draft risks), usability of ventilation facilities (e.g. ease of operation, safety issues), cross contamination risks and restrictions due to the outdoor environment. Monitoring of ventilation (CO_2) is recommended to stimulate the proper use of ventilation facilities.

Conclusion

COVID-19 should not restrain from the application of natural ventilation systems in buildings. In fact, mechanical and natural ventilation systems complement each other. In other words: especially the combination is gold. Mechanical ventilation systems create a constant hygienic air change rate while natural ventilation provides additional air change required to dilute air sufficiently, e.g. when spaces are used (temporarily) more intense or longer than normal. Moreover, ventilation by operable windows and natural air intake grilles is easy to understand for end-users and delivers immediate feedback. Therefore, in order to achieve a comfortable and healthy indoor environment and full user satisfaction, mechanically ventilated buildings should also be equipped with operable windows for personal control. When buildings are designed with natural air inlet grilles one can really boost the robustness of the design by additionally deciding for mechanical exhaust directly in the rooms. ■

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