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COVID-19: Reduction of airborne transmission needs paradigm shift in ventilation

Paradigm shift in ventilation from space focused design to occupant focused design is needed. Ventilation, and indoor environmental systems in general, has to focus on source control, advanced air distribution and providing healthy and comfortable microenvironment to each occupant when, where and as much as needed. This will be win-win way to go ahead.

The debate on whether the transmission of COVID-19 can be airborne continues. New research supports that this rout of transmission is possible [1]. This rout of transmission is now considered by WHO, CDC, ECDC and by health authorities in numerous countries.

High viral loads of pathogens (COVID-19) are present in the pharynx early of the course of infection. During breathing, talking, singing, etc. forces are generated due to rapid shearing flows, vocal cord movement, opening and closing of terminal airways. As a result particles (droplets) of different size (0.05–500 μm) loaded with viruses are generated and expelled, especially by asymptomatic and pre-symptomatic infected people. Air movement surrounding an infected person transports the particles. The distance particles travel away from the infected person depends on several factors, including size of the particles, initial momentum they are expelled (i.e. type of respiratory activity), position of the head and the body of the person generating the particles, strength (velocity), structure (turbulent or laminar), direction, temperature and humidity of the surrounding airflow, individual differences between people with regard to respiratory activities, etc. At some distance, the larger particles land on surfaces (floor, furniture, body of another nearby person, etc.). The small particles stay airborne for relatively long time (up to several hours). The airborne particles may be inhaled by other people and eventually transmit infection. Successful infection depends on exposure (inhaled dose of particles with viruses) and time. With regard to the distance between infected and exposed person short-range exposure to large and small particles and long-range exposure mainly to small airborne particles can be defined. Results of different studies, summarized in Fig. 1, reveal that under typical indoor settings the short-range exposure occurs up to 1.5 m distance between infected and exposed persons [2]. Above 1.5–2 m distance, long-range exposure is predominant. The risk for the short-range exposure is much higher that for the long-range exposure.

Ventilation is recognized as an efficient method for reducing the airborne transmission of pathogens [2,9]. Research shows that increase of the outdoor air supply to occupied spaces can reduce substantially the risk of long-range exposure but is less effective to reduce the short-range exposure. The short-range exposure depends on the complex interaction of flows at the vicinity of the infected and exposed persons, including transient flow of respiration, free convection flow existing around human body and flow of ventilation [2,8]. The interaction depends on several factors such as positioning between infected and exposed persons, pulmonary ventilation rate, breathing mode, breathing cycle. Therefore it is difficult to control and to reduce the short-range exposure with the used at present methods for ventilation of entire volume of spaces. The exposure time, defined by short term and long term exposure, is also important for reduction the risk of airborne cross-infection.

The recently updated guidelines for reduction the risk of airborne infection with COVID-19 recommend a substantial increase of the ventilation rate, i.e. an increase in the amount of clean outdoor air supplied to spaces [10,11]. However, existing ventilation systems in buildings are designed for removal of heat and pollution loads under normal conditions, i.e. when there is no pandemic. The air-handling units, ducting and air supply and exhaust terminals are dimensioned to be economic and energy-efficient and thus allow for little increase in the ventilation rate. If the future ventilation systems are designed to supply large amount of outdoor air during pandemic they will not operate economically under normal conditions (no pandemic) with a greatly reduced supply airflow rate. Furthermore, they will not be feasible because of the high initial costs associated with large air handling units as well as large and voluminous ducting systems. The outdoor air supply rate can be increased by installing additional (portable) units, such as window fans and small free-standing air handling units. In addition, high-efficiency filters, stand-alone air cleaners and ultraviolet germicidal irradiation (UVGI) units installed in rooms or in ducts can be used to provide the equivalent of outdoor air supply to rooms.

Paradigm shift in ventilation design

Ventilation is intended primarily to provide occupants with clean air for breathing. Often the ventilation air is conditioned in order to maintain room temperature and humidity in comfortable ranges. The main principles to be followed during ventilation design are: remove/reduce air pollution (heat & contaminant), supply clean air where, when and as much needed, control of air distribution and active involvement of each occupant to obtain the preferred environment [12]. For reduction of airborne transmission source control means removal of polluted air exhaled by occupants before it is mixed with the surrounding room air and air distribution control means supply of clean air to the breathing zone.

The used at present ventilation of spaces (mainly based on mixing air distribution) do not comply with these principles. It is energy inefficient because entire space is ventilated (also unoccupied volume) by supply of huge amount of conditioned air. The clean air, supplied far from the breathing zone of the occupants, is mixed with the room air and therefore is polluted and warm by the time it is inhaled. It is difficult, almost

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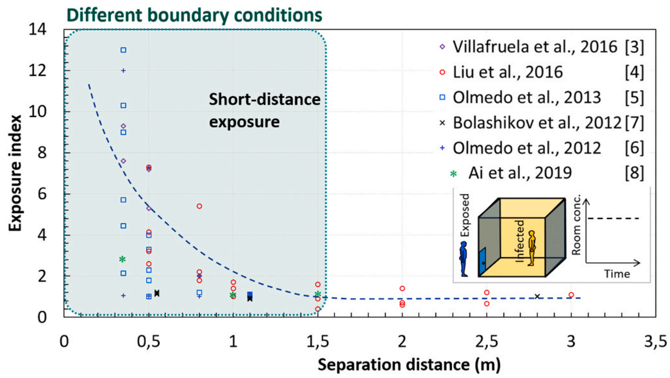

Fig. 1. Exposure as a function of distance between infected and susceptible persons [2–7].

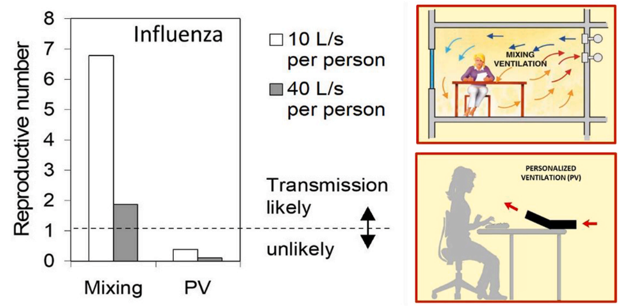

Fig. 2. Reduction the risk of airborne infection with mixing ventilation (mixing) and personalized ventilation (PV). Office room with 10 occupants working together for 8 hours. Reproductive number shows number of secondary infections that arise when a single infectious case is introduced into a population where everyone is susceptible.

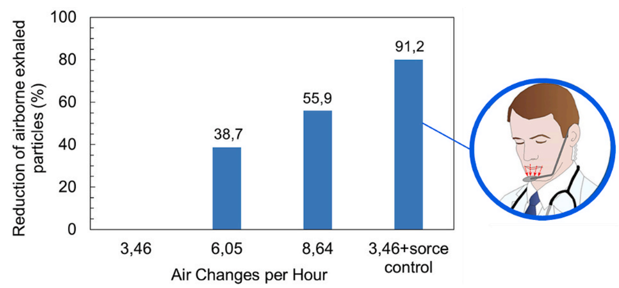

Fig. 3. Reduction of exhaled aerosols in a meeting room (20 m^2, 50 m^3) med 10 persons. Calculations according to Ref. [17]: Low pollution building, Category III - 3,46 ACH; Category II - 6,05 ACH; Category I - 8,46 ACH; Category III 3,46 ACH + source control (the 10 persons use headset with installed exhaust with 80% efficiency).

impossible, to control the airflow distribution in the occupied zone.

Paradigm shift is needed in design of future ventilation [13]. The focus will be each occupant but not the space. Systems that comply with the defined above main principles of ventilation design have to be developed. Ventilation systems based on source control and advanced air distribution will make it possible to improve the quality of the indoor environment, to satisfy more occupants and to minimize energy use. Smaller systems requiring less space for ducting and air handling units will be used. The risk of short-range/long range exposure and short term/long term exposure will be reduced, more occupants will be accommodated in spaces because the requirement for social distancing will be relaxed, etc. The paradigm shift requires upgrading the present total volume ventilation with advanced ventilation solutions for each particular application. In other words there is need to move from building attached ventilation systems to building detached systems [14].

Fig. 2 compares the risk of airborne cross-infection with properly designed personalized ventilation providing clean air to the breathing zone and the risk with mixing ventilation [15]. High level of risk reduction at much less clean air supply flow rate (much less energy consumed) is achieved with the personalized ventilation.

The focus on each occupant will lead to development of wearable ventilation as the headset installed personal ventilation shown in Fig. 3 [16]. Room air is sucked by a fan in a small box attached to the belt of the user. The air is disinfected (UVGI and filtered) in the box. A small tube connects the box with a nozzle incorporated around the microphone of the headset. During inhalation, disinfected air is supplied directly to the mouth/nose. During exhalation the process is reverse: the exhaled air is collected, disinfected in the box and released to the room. Up to 80% exhaled air is collected and disinfected (source control) and up to 90% clean air is supplied to inhalation (advanced air distribution). The results of calculations based on assumption of complete air mixing in a meeting room with 10 persons show huge reduction of airborne exhaled particles in the room at background ventilation of 3,46 air changes per hour (ACH) when all 10 occupants wear headset personal ventilation compared to when the background ventilation in the room is increased from 3,46 to 8,64 air changes per hour.

In summary

During the last 20 years, we have had SARS, MERS and Covid-19. It should be clear that such emerging viruses are not an imaginary threat. A large-scale pandemic will be difficult to control until we take into account aerosol transmission, while awaiting a vaccine. The role of ventilation is essential for reduction of airborne transmission. The paradigm shift in the ventilation practice is needed urgently in order to respond to the need.

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