Mitigation of airborne transmission of respiratory viruses by ventilation – past, present and future

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SUMMARY

The importance of ventilation of spaces for occupants' health has been known for many years. Ancient Egyptians used natural ventilation to remove dust and thus to reduce respiratory diseases of stone carvers working indoors (Janssen 1999). In the past ventilation has been used to reduce airborne transmission of respiratory generated infectious agents in buildings. In the book "Natural and Artificial Methods of Ventilation" (Robert Byle & Son, London 1899), chapter X it is stated "The report on the influenza epidemic presented to Parliament by the Local Government Board indicates the extreme importance of proper ventilation – especially in schools – which is pronounced to be the only real safeguard against that disease.". Several ventilation solutions in classroom and hospital patient rooms are suggested in the book with focus on the clean air distribution. Thus, already two centuries ago the importance of clean air distribution for fulfilling the main goal of ventilation, namely to provide occupants with clean air for breathing has been considered.

During the last two decades, the importance of ventilation for reduction of airborne transmission of SARS-CoV-1 and SARS-CoV-2 has been widely discussed in numerous research papers. Guidelines and standards on how to prevent the spread of respiratory generated infectious aerosols in spaces have been developed (REHVA COVID-19 Guidance 2021, ASHRAE Standard 241 2023). Unfortunately, the important role of air distribution, as recognised many years ago, has been ignored. Instead, either complete mixing of the supplied clean/disinfected ventilation air with the air in the entire occupied zone or the air in the "breathing zone" of the occupied space (ASHRAE Standard 241 recommends lateral flow velocity lower than 0.25 m/s in the breathing zone of the occupied space). However, in practice it is difficult to comply with these recommendations. The airflow distribution in occupied spaces, the transport and the exposure of occupants to infectious aerosols is result of complex interaction of ventilation flow, buoyancy flows (generated by occupants, warm/cold surfaces, etc.), occupants' activities and location, etc. In the literature related to ventilation for reduction of airborne transmission a minimum amount of clean/disinfected ventilation air (L/s person) supply is recommended (the validity of the recommended values can be discussed). However, the ventilation rate is important for energy performance assessment of ventilation system, but it is of secondary importance for the clean air distribution to the breathing zone of each room occupant. The word "ventilation" comes from the Latin word "ventus" meaning wind. Similar to the wind, room airflow is defined with the magnitude and the direction of the flow velocity. The supplied clean/disinfected ventilation air mixes with the infected room air reduces the concentration of infectious aerosols but it also spreads the infected exhaled air in the room. Therefore, increase of the ventilation rate as recommended in the standards may change the airflow direction and spread of infected air and this process will be difficult to control in practice. Increase of the supplied ventilation rate may generate high velocity causing draught for the occupants, will result in design of large air-handling units and duct systems in new buildings and rebuilding of existing HVAC systems which will be costly and not always possible. The increase of the ventilation rate will increase the energy consumption. Use of stand-alone room air cleaners is better option during pandemics.

The importance of air distribution for the exposure of room occupants to the infected air exhaled by one of the occupants is shown in Figure 1. The results reveal huge differences in the normalised concentration of infected air by the exposed occupants. This indicates large differences in the infection probability for the compared air distribution cases. The importance of air distribution for the reduction of airborne cross-infection is shown in Figure 2. Use of personalised ventilation dramatically reduces the reproductive number, i.e. the cross-infection.

The air distribution has huge potential for reduction of airborne infection. Yet, the main discussion at present is on how much should be the ventilation rate in order to reduce airborne cross-infection. As discussed above this approach will not provide beneficial results in practice. Successful reduction of airborne cross infection by ventilation requires different approach. Carefully designed advanced air distribution has to be applied selectively in practice depending on the ventilated space, occupants' activity and density, requirements for flexibility of space use. Ventilation solutions that make it possible to remove/disinfect the exhaled air at the location of the occupant before it is mixed with the room air has to be developed. Clean air delivery to the breathing zone without enhancing the spread of infected exhaled air to other occupants should be aimed. Personalised ventilation installed at workstations as well as personal wearable ventilation solutions performing independently of occupants' activities

has to be developed and used. This approach will bring shared values by reduction of both airborne cross infection, cost of ventilation systems, energy consumption, etc. Occupants should be trained to actively use the new solutions.

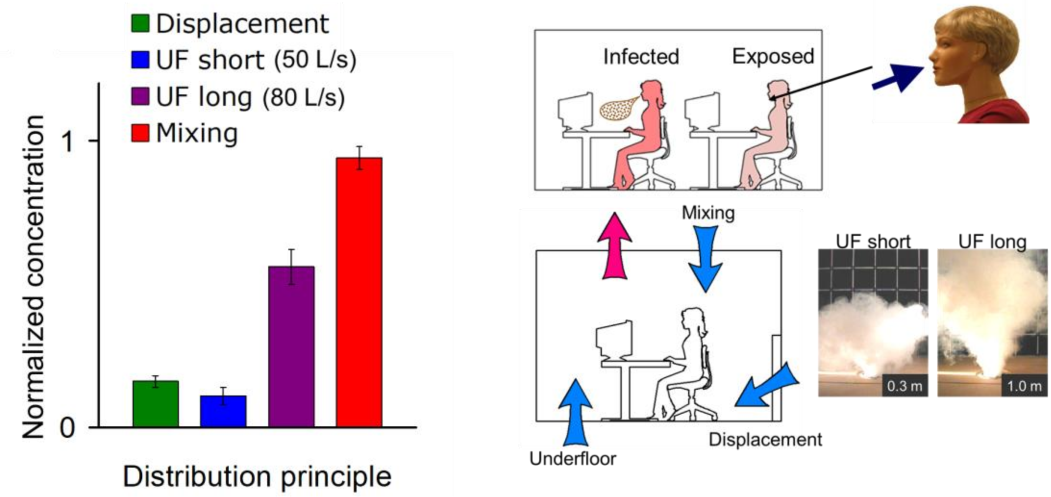

Figure 1: Experiments with full size breathing thermal manikin resembling two occupants in a room ventilated with different ventilation principles. Supply flow rate is 80 (50) L/s. Tracer gas concentration mixed with the air exhaled by the "infected occupant" is measured in the air inhaled by the exposed occupant. Normalised concentration is calculated as (Cin – Cs)/(Cex– Cs), where Cin, Cs, Cex are respectively tracer gas concentration in the inhaled air, the supplied ventilation air and the exhaust room air. Details in (Cermak and Melikov 2006).

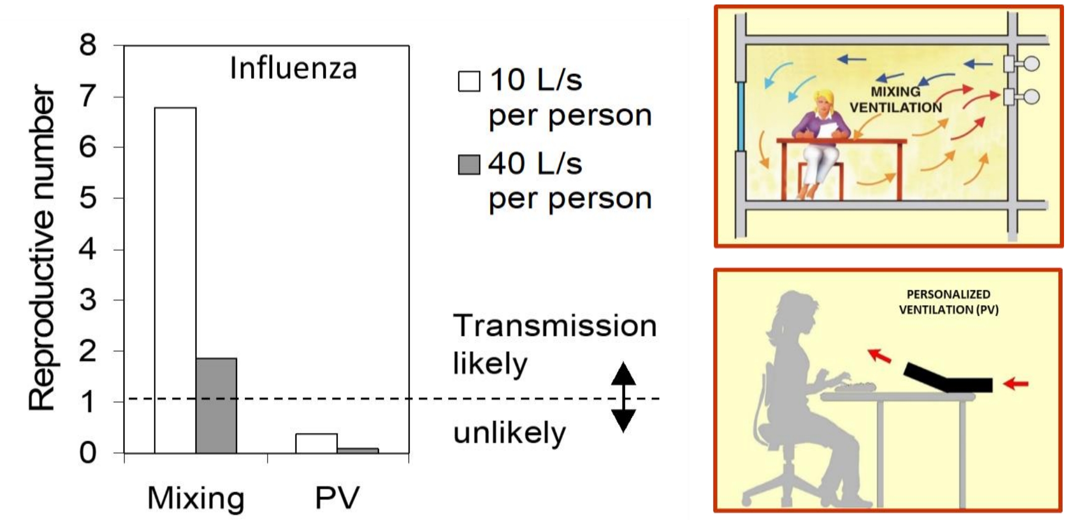

Figure 2: Comparison of the reproductive number defined as the number of secondary infections (influenza virus) that arise when a single infectious case is introduced into an office with 10 occupants where everyone is susceptible. The occupants spend 8 hours in the office ventilated by mixing ventilation or when each occupant has personalised ventilation. Comparison at 10 and 40 L/s person. Details in (Cermak and Melikov 2007).

KEYWORDS: Airborne transmission, air distribution, advanced ventilation

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