The characteristics of airborne transmission with convective and radiant cooling systems

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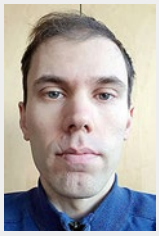

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The enclosed indoor environments are high-risk spaces for airborne transmission if spaces are densely occupied and poorly ventilated. Based on the recognized airborne infection risk, there is a raised demand to develop innovative micro-environment ventilation systems to mitigate the airborne transmission risk indoors. Air distribution is playing a significant role and to reach same concentration level in the breathing zone mixing ventilation requires much higher airflow rate than micro-environment solution.

Keywords: Airborne transmission, Infection risk, Micro-environment system, Air distribution, Heat gain level

Airborne transmission and air distribution

The COVID-19 pandemic was an extremely urgent threat to human life, and similar outbreaks may occur in the future. Based on WHO recommendations, ventilation systems are critical for reducing the infection risk for COVID-19. Understanding the characteristics and mechanism of aerosol transmission is important when applying effective practices for epidemic control.

Airborne transmission comes from the inhalation of aerosol droplets which are exhaled by an infected person. The exhaled aerosol droplets from an infected person transmitting to an exposed person is a combined interaction of various airflows, including the breathing flow, human body boundary layer flow, and the ventilation flow. The airflow pattern can have a significant effect on the distribution of infectious aerosol spatial and temporal concentrations in an occupied zone beyond the simple effect of an increased ventilation rate in the assumed fully mixed conditions. Therefore, more novel air distribution should be introduced to reduce the individual's exposure to air pollutants and infection risks. The target should be only to control the air quality close to the breathing zone. There could also be a need to introduce more advanced systems where users can influence their local micro-environment.

Convective and radiant cooling systems

This paper will introduce three air distribution methods, included two micro-environment systems and a perforated duct system, which is described in **Figure 1**. In personalized ventilation combined with radiant panel (PVRP) system (**Figure 1 a**), a PV (personalized ventilation) air terminal device (ATD) was installed on the desk at a distance of 40 cm from the simulated person to supply fresh air directly to the breathing zone [1]. In low velocity unit combined with radiant panel (LVRP) system (**Figure 1 b**), low velocity unit was installed just over the radiant panels and the air was supplied through those panels [2].

Diffuse ceiling ventilation was used to provide background ventilation outside the occupied zone. The perforated duct was located in the middle of the upper room space. The length of perforated duct was 5.5 m, and the diameter of the perforated duct was 200 mm. The supply air temperature was 17 °C with two micro-environment systems and 14 °C with the perforated duct system. With the perforated duct system, the supplied airflow was 116 ℓ/s and 61 ℓ/s with the 73 W/m² and 38 W/m², leading to air change rates of 5.5 h^{-1} and 2.9 h^{-1}, respectively. With the PVRP and LVRP systems, the total supply airflow rate was 42 ℓ/s with 38 W/m² and 73 W/m² and the air change rate was 2.2 h^{-1}. The rest of the cooling load was covered by the radiant panel.

The thermal breathing manikin consisted of 27 separately heated body segments and was used for the infected sitting person simulation (referred to below as the infector). The manikin was connected to an artificial lung to simulate real human breathing. The designed pulmonary ventilation rate was 6.0 ℓ/min. Each breathing cycle consisted of 2.5 seconds of inhalation, 1.0 second break, 2.5 seconds of exhalation and 1.0 second break. In this experiment, tracer gas SF_6 was utilized to simulate the virus-containing droplet nuclei in the exhaled air from the infector manikin at flow rate of 2 mℓ/s.

Infection risk with three air distribution methods

Figure 2 shows the tracer gas concentrations with two micro-environment and one fully mixed air distribution methods from t=0 to 102 min at different measured locations. With the perforated duct system, the concentration of the inhaled air of the exposed person was slightly higher than two micro-environment systems with airflow rate of 61 ℓ/s. This is because the local airflow of micro-environment systems protects the contaminant transmission from the infector compared with the fully mixed condition. With two micro-environment systems (PVRP and LVRP), the inhaled concentration of the exposed person was much lower than at the other locations in the test room. Moreover, compared to the LVRP system (15 ℓ/s per person), the SF_6 concentration with the PVRP system was slightly lower at the exposed person even with less local airflow rate (7 ℓ/s per person).

The airborne infection risk was calculated according to the dilution-based Wells-Riley model [3]. The quantum generation rate of a COVID-19 infector was assigned to be 5 quanta/h for office work. **Figure 3** shows that the infection risk that was the lowest for the inhaled air of the exposed person with all systems.

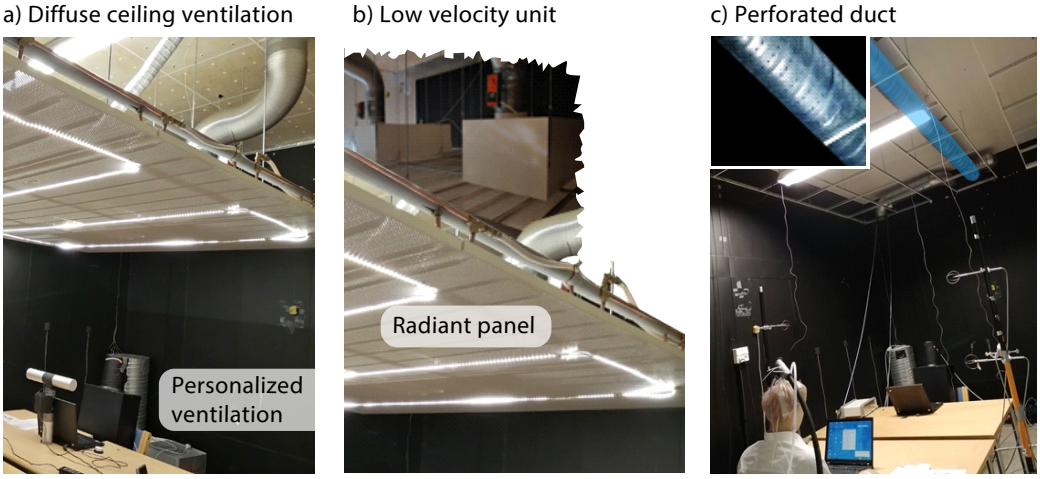

Figure 1. The setup of ventilation systems, a) personalized ventilation combined with radiant panel (PVRP), b) a low velocity unit combined with radiant panel (LVRP), c) perforated duct.

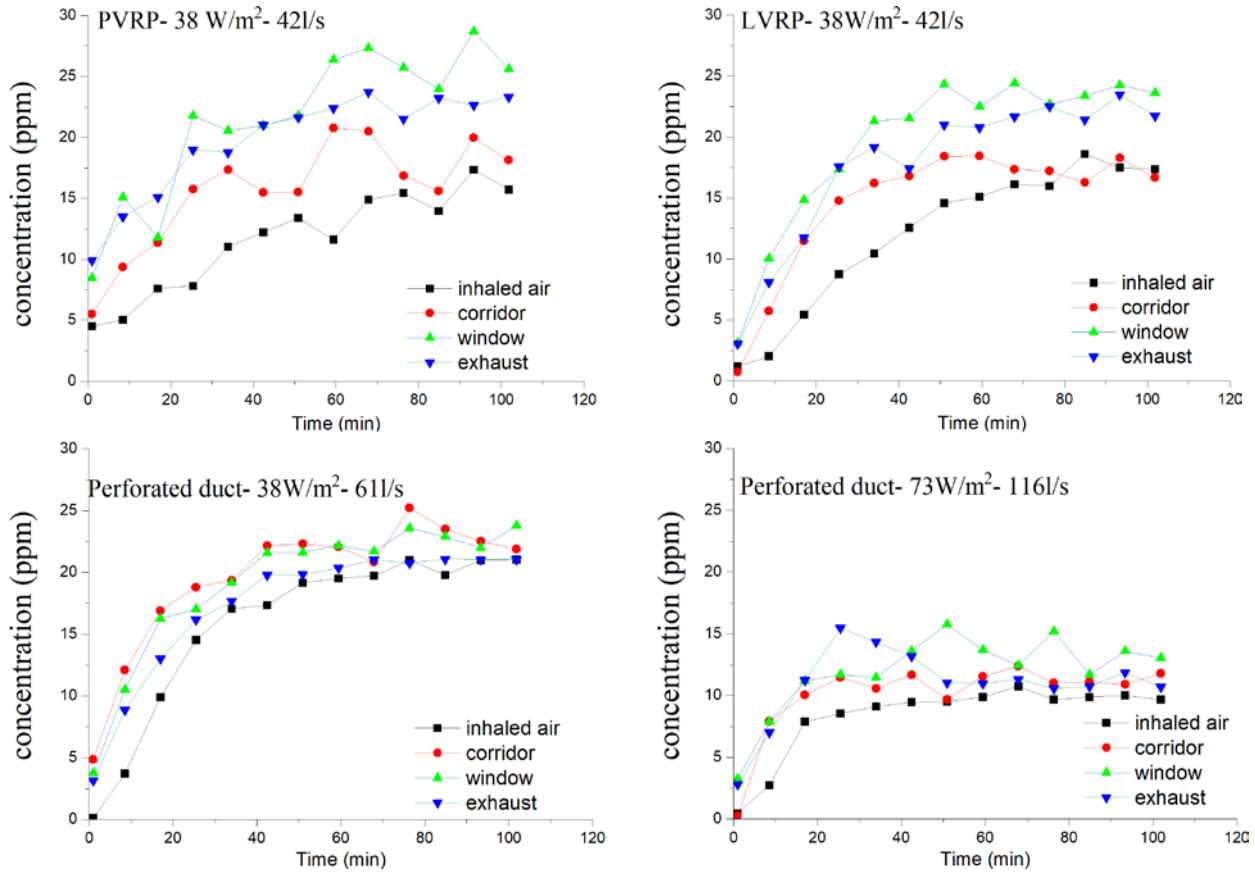

Figure 2. Measured tracer gas concentrations at different locations over time with two micro-environment (PVRP and LVRP) and one fully mixed (perforated duct) air distribution systems.

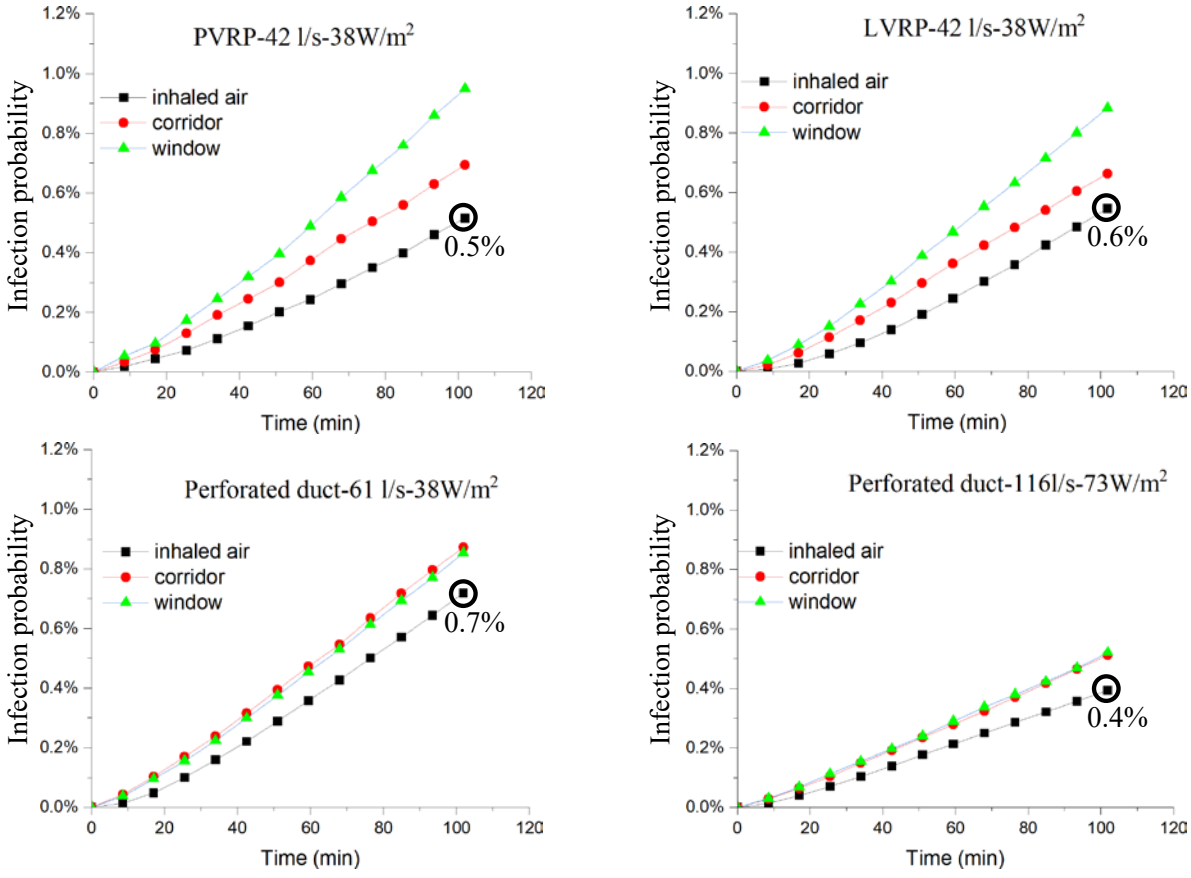

Figure 3. The airborne infection risks at different locations over time calculated using the dilution-based Wells-Riley model.

This indicates that indoor air is not fully mixing in the test room with any of the analyzed air distribution methods. It should be noted that with the micro-environment systems, the variation in the infection risk at the different locations was larger than the perforated duct system. The infection risk of the exposed person after 102 min was 38%, 26%, and 11% lower than that on the window side with PVRP, LVRP, and perforated duct system, respectively. This indicates that the micro-environment systems are able to better reduce the airborne transmission risk in the inhaled air than the perforated duct. The infection risks at the inhaled air measurement point were 0.6% and 0.5% with the LVRP and PVRP systems, respectively. This result shows that PVRP system was slightly superior to the LVRP system for the protective effect.

With the perforated duct system, the infection risk of the exposed person decreased from 0.7% to 0.4% when the airflow rate increased from 61 ℓ/s to 116 ℓ/s after 102 minutes. Compared with the micro-environment systems (0.5% -0.6% with 42 ℓ/s), the infection risk of the exposed person was lower with an airflow rate of 116 ℓ/s (0.4%). This depicts clearly that air distribution is player significant role in infection risk, and fully mixed ventilation requires in this case around 2 times higher airflow rate to have lower infection risk than micro-environment system.

Conclusion

The adaptation of micro-environment systems can help supply the local airflow from a personalized ventilation or low velocity unit to the occupant breathing zone directly. Based on the results, the concentration was lower with the micro-environment systems than fully mixed air distribution The infection risk of the exposed person was around 0.5% with the micro-environment systems (42 ℓ/s) and 0.7 % (61 ℓ/s) with the perforated duct system after 102 minutes. In this measurement, fully mixed ventilation requires around 2 times higher airflow to have lower infection risk than micro-environment system. ■

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Reference

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