Exploring the potentials of micro-environment ventilation in mitigating airborne transmission risk

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Abstract. In the background of COVID-19, new requirements are occurring in the novel ventilation systems to mitigate airborne transmission risk in indoor environments. In this study, two micro-environment ventilation systems: personalized ventilation combined with radiant panel system (PVRP) and low velocity unit combined with radiant panel system (LVRP) were studied to explore the potential of reducing the airborne infection risk. In a simulated double layout office, the droplets generated by a thermal breathing manikin were used to simulate the breathing process of an infected person. Opposite the manikin, a heated dummy was as an exposed person. During the 102-minute measurement, the results show that the infection risk at the inhaled air with micro-environment systems is lowest. The heat gain levels do have much effect on infection risk with the PVRP system, but higher heat gain will increase the risk slightly with the LVRP system.

1 Introduction

Due to people spending more than 90% of their time indoors, the enclosed indoor environments, e.g., offices are among the most high‐risk spaces for airborne transmission when the indoor spaces are densely occupied and lack ventilation.

In large enclosures, as we know, occupied zones are made up of typically only a small volume of total space volume where the principle to control only the occupied zone is a well-known practice. For that reason, more concerns have been focused on the micro-environment of occupants to optimize trade-off energy conservation and indoor environment, where the main challenge is to supply clean air to the breathing zone and maintain thermal conditions.

Our previous studies [1–3] have focused on indoor climate, where two advanced micro-environment systems: personalized ventilation combined with radiant panel and low velocity unit combined with the radiant panel were studied. We analyzed the performance of two systems by physical measurements and short-term human subject tests. Based on the results, the indoor climate of micro-environment systems with less energy use was superior to the traditional mixed system. By offering the possibility to control their own micro-environment during subject tests, the number of satisfied respondents was significantly increased. However, the airborne transmission risk with two micro-environment ventilation systems has not been investigated. The ventilation strategy for controlling the airborne cross‐infection between humans to humans in the office should be paid more attention.

The objective of this study was to investigate the airborne transmission between two sitting persons in the closed office space. Three important influential parameters were varied systematically: heat gain level in the room (38 W/m2 and 73 W/m2), desk partition between two workstations, and air distribution system. The findings of this study are expected to contribute to improved control measures for airborne transmission of infection indoors. This paper is aimed to offer a better understanding and insights into effective ventilation design to maximize its ability in airborne risk control in the office.

2 Methods

2.1 Experimental set-up

In the test room, there were two workstations located in the middle of the room 0.6 m from the window panel in a longwise direction, as shown in Figure 1. The thermal breathing manikin and a heated dummy were located at each workstation. Both workstations were also equipped with a laptop. Window panels were heated depending on the cooling load demand of up to 30 – 40 °C simulating solar gain.

There were two air distribution systems in this study as shown in Figure 2 [1,2] :1) personalized ventilation combined with radiant panel system (PVRP); 2) low velocity unit combined with radiant panel system (LVRP)

In the PVRP system (Figure 2 a), there is a personalized ventilation air terminal device (ATD) was installed on each desk at a distance of 40 cm from the manikin or dummy to supply fresh air directly to the breathing zone. In the LVRP system (Figure 2 b), there was a low

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velocity unit (LV) installed over the radiant panels and fresh air was supplied through these panels which created the micro-environment in the occupied zone. The average distance between the low velocity units and the subject was 70 cm.

Diffuse ceiling ventilation was used to provide background ventilation outside the occupied zone with the LVRP and PVRP systems. Above the workstations, perforated radiant cooling panels were installed at a height of 2.1 m to provide local cooling.
The pulmonary ventilation rate of manikin was 6.0 l/min and the breathing frequency was 10 times/min. Each breathing cycle consisted of 2.5 seconds inhalation, 1.0 second break, and 2.5 secondes exhalations. The exhaled air mixed with tracer gas from manikin was heated to 35°C with being humidified.

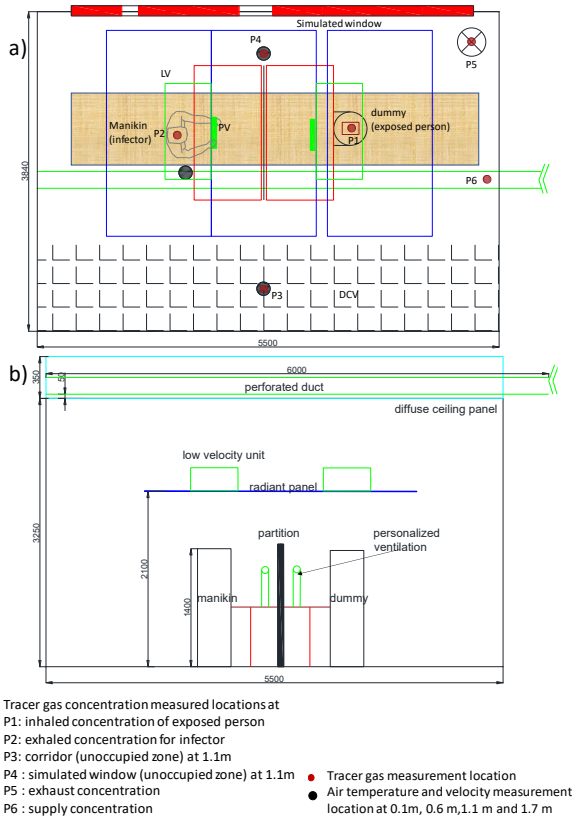


Fig. 1. The layout of the test chamber a) from top view and b) from side view

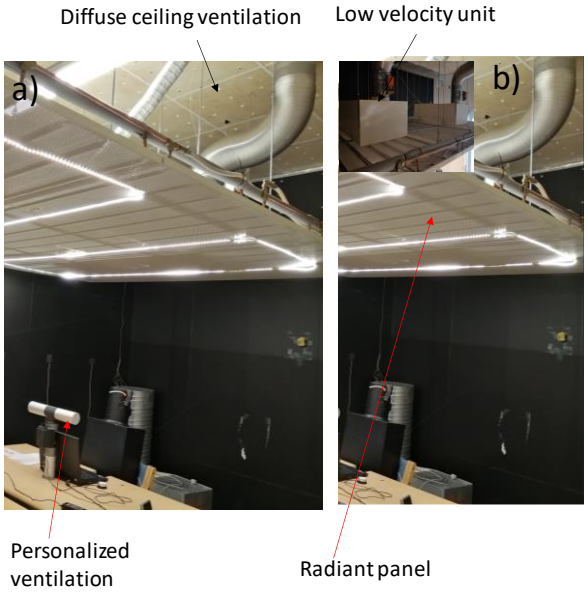


Fig. 2. The real - life setup of ventilation system, a) Personalized ventilation combined with radiant panel (PVRP), b) Low velocity unit combined with radiant panel (LVRP)

2.2 Measured parameters and instrumentation

Tracer gas SF6 was utilized to simulate the virus - containing droplet nuclei in the exhaled flow from the infector manikin. It was dosed directly into the artificial lung of the infector. The dosing rate was 2 ml/s and the breathing rate of the manikin infector is 6 l/min, resulting in a contaminant concentration of the exhaled flow around 20000 ppm.
With the PVRP and LVRP systems, the total supply airflow rate was 42 l/s with 38 and 73 W/m and the air change rate was 2.2 h-1. The supplied airflow rate was according to Standard EN15251 [4] Category B for low-polluting buildings. The recommended ventilation rate for this category is 2 l/s, m2. The rest of the cooling load was covered by the radiant panel.

2.3 Evaluation indices

According to the concept of dilution, the dilution ratio is defined as the ratio between the source concentration to the contaminant concentration at the target position (Equation (1)). The dilution ratio can vary among different positions relative to the contaminant source transiently. The dilution-based airborne infection risk proposed is obtained as Equation (5) by combining Equations (2) – (4).

$$D = \frac{C_{infector}}{C_{exposed}} \quad (1)$$

$$C_{quantum} = \frac{q}{D * p_{infector}} \quad (2)$$

$$N_{quantum} = \int_0^T p_{exposed}\, C_{quantum}(t)\, dt \quad (3)$$

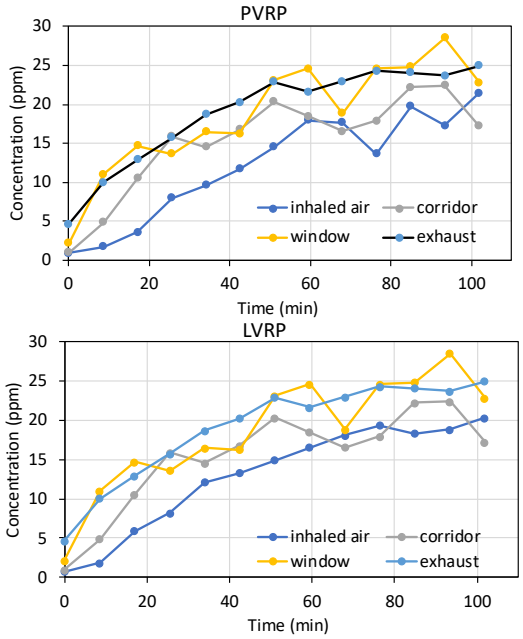
$$P_D = 1 - e^{-N_{quantum}} \quad (4)$$

$$P_D = 1 - e^{-\int_0^T \frac{q * p_{exposed}}{D(t) * p_{infector}} dt} \quad (5)$$

where $C_{infector}$ and $C_{exposed}$ are the airborne contaminant concentrations at the infectious point and exposed position respectively (ppm); $C_{quantum}$ is the airborne quantum concentration at the exposed position (quanta/m3); D is the dilution ratio at the exposed position; $p_{infector}$ is the breathing rate of the infector (m3/s); q is the quantum generation rate (quanta/s); $N_{quantum}$ is the inhaled quanta by the exposed person during the given exposure period; P_D is the airborne infection risk with the exposed person during the given exposure period estimated by the dilution-based estimation method proposed; $p_{exposed}$ is the breathing rate of the exposed person (m3/s).

3 Results

Figure 3 shows the tracer gas distribution with three air distribution systems from t= 0 min to t = 102 min at different measured locations. The tracer gas was dosed to the test room at t = 0 min and the concentration starts to build up. At the first stage, the tracer gas concentration was increased with time until t = 42 min. At the second stage, the concentration reached a stable value at every location until the end. With two micro-environment systems (PVRP and LVRP), the concentration at inhaled air of exposed person was lower than the other locations in the test room. Moreover, compared with the LVRP system (15 l/s/person), the SF6 concentration with the PVRP system is slightly smaller at the exposed person even with less local airflow rate (7 l/s/person). Due to the background ventilation was supplied in the corridor area and far from the infector, the tracer gas concentration at the corridor side is smaller than the window side.



The airborne infection risks at the inhaled air, corridor, and window are calculated according to Equation (5), as shown in Figure 4. The quantum generation rate of a COVID-19 infector is assigned to be 5 quanta/h according to REHVA COVID-19 GUIDEANCE. The infection risk is the lowest at the inhaled air of the exposed person with both systems. This indicates that both air distribution systems can protect the exposed person from the infection. Compared with the LVRP system, the infection risk at inhaled air is slightly lower than the PVRP system and similar at the corridor and window sides. This result shows that the protective effect with the PVRP system is a little superior to the LVRP system. With the PVRP and LVRP systems, the infection risk at the corridor area is lower than the window area.

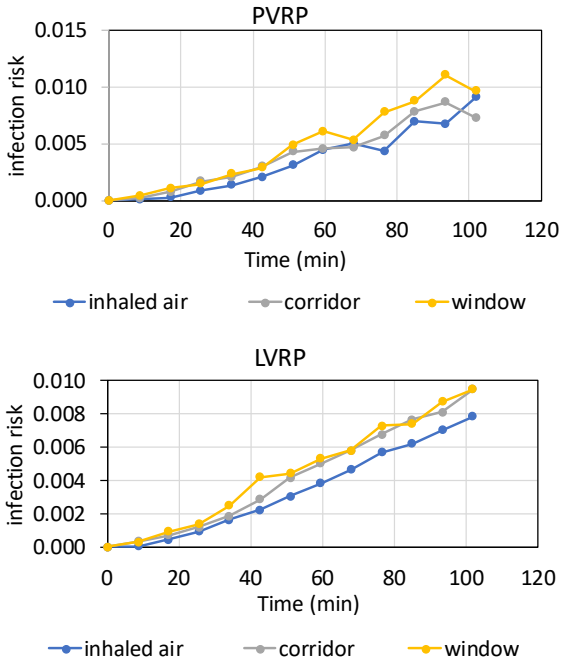


Fig. 4. The airborne infection risks at different positions over time.

Figure 5 shows the effect of the heat gain levels (38 and 73 W/m2) on the infection risk with different air distribution systems at the end of the test. It can be noted that the variation of infection risk caused by the change of heat gain is different with the two systems. The difference of infection risk can be ignored at inhaled air corridor and window under two heat gain with PVRP system. This means that the infection risk is not affected by the heat gains with the PVRP system. Nevertheless, the effect of heat gain on the LVRP and perforated duct systems is converse. With the LVRP system, the infection risk under 73 W/m2 is slightly higher than under 38 W/m2. The possible reason is that the strong convection flow from the heated window with 73 W/m2 will disturb the protective effect created by the low velocity unit to an extent and lead to a more uniform thermal environment. Therefore, the performance of the LVRP system is more sensitive to heat gain than the PVRP system.

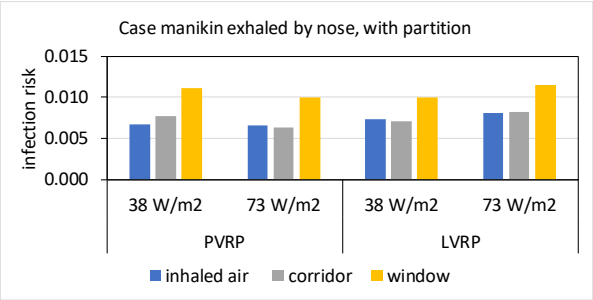


Fig. 5. The airborne infection risks with different heat gains at the end of test (t = 102 min).

4 Conclusions

In this study, the airborne transmission risk between the face to face sitting persons in the simulated office was investigated. To investigate the effect of indoor heat gain level on the airborne transmission with different ventilation systems, the design heat gains were 38 W/m2 and 73 W/m2. Meanwhile, the effect of the desk partition on the airborne transmission was investigated.

With the micro-environment systems (PVRP and LVRP), the local airflow from the personalized ventilation or low velocity unit can be supplied to the breathing zone of the occupant and create a different micro-environment around the human body.

Based on the results, the infection risk at the inhaled air with micro-environment systems is the lowest. This means the airborne transmission can be reduced with the micro-environment systems. The heat gain levels do have much effect on infection risk with the PVRP system, but higher heat gain will increase the risk with the LVRP system.

ACKNOWLEDGEMENT

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