Airborne transmission in a meeting room with mixing and displacement ventilation

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ABSTRACT

The main purpose of this study is to analyse the effects of heat gain, airflow rate, air distribution, and the location of an infector on the airborne transmission and infection probability in a meeting room. In a six-person meeting room the droplet nuclei of an infected person were simulated with tracer gas (SF_6) generated by a thermal breathing manikin. An overhead perforated duct (OPD) and low velocity unit (LVU) were used and their performance was compared. With OPD, the average contaminant removal efficiency in the breathing zone was quite uniformly between 0.9 and 1.1. With LVU, the average contaminant removal efficiency varied greatly between 0.2 and 10.1. The airborne generation was assumed to be 5 quantum/h by an infected person. The infection probability for every exposed person was found to be quite uniform with OPD, 1.4% with a heat gain and air flow rate of 38 W/m^2 and 61 l/s and 0.9% with a heat gain and air flow rate of 60 W/m^2 and 116 l/s after three hours' exposure. However, variation of the infection probability with LVU was significant and the highest risk reached 4%. The infection probability was lower if the exposed person was farther from the infector, or in the case of OPD if the infector was near the exhaust. With LVU, the infection probability depended on the airflow rate and the relative distance between the supply unit and the exposed person.

KEYWORDS

Airborne transmission, air distribution, heat gain, meeting room, tracer gas

1 INTRODUCTION

It is important to understand the mechanism of aerosol particles transmission in the occupied space and methods to reduce the risk of cross infection. By increasing the airflow rate, it is possible to reduce the infection risk in many cases. However, an increase of the airflow could increase the concentration level of aerosol particles locally (Memarzadeh and Xu, 2012). From the energy-efficiency point of view, it is not always the most optimal manner to reduce the infection risk. Recently it has been clearly proven that airflow distribution methods have a significant effect on the personal exposure to indoor air pollutants (Li et al., 2007). Thus, it is possible to reduce the infection risk with suitable air distribution and without increasing the total airflow rate.

Two main categories of air distribution are displacement ventilation and mixing ventilation. In mixing ventilation, the outdoor air is supplied at a high velocity outside the occupied zone, such as near or at the ceiling. This promotes good mixing with uniform temperature and pollution distribution in the occupied zone. In displacement ventilation, the principle is to replace but not to mix the room air with supply air, where the clean and cold air is utilizing convection flows of heat gains. To prevent the transmission of exhaled air, the ventilation approach should rely on source and air distribution control rather than on dilution, i.e., supplying large volumes of clean conditioned air. This includes organizing the airflow pattern from clean zone toward less clean zones inside the occupied space followed by efficient polluted air removal.

In a previous study (Su et al, 2021), the infection risk was numerically investigated for mixing and displacement ventilation systems in an office space. With displacement ventilation, the infection probability was 0.74% after four hours with 10.5 quantum/h by an infected person, which is lower than in well-mixed conditions (2.9 %). This indicated the buoyancy-driven air distribution methods may have good performance at preventing cross-infection. However, the infection risk is sensitive to the location of the infector with displacement ventilation (Batlle et al., 2021), depending on whether the infector is near or far from the air supply diffuser. Moreover, other factors such as the heat gain from equipment and solar heat gains were not considered in the study.

This paper presents analyse of airborne transmission and infection risk using overhead perforated duct (OPD) and low velocity unit (LVU) under different heat gain conditions and airflow rates. The infection risk is affected by the location of the infector in the room.

2 METHODS

The experiments were conducted in a full□scale test room, where a stable indoor climate can be maintained. The dimensions of the test room were 5.50 m (length), 3.80 m (width), and 3.60 m (height) from the floor to the ceiling. The heat gains used in the test room are summarized in **Error! Reference source not found.**

2.1 Thermal chamber and air distribution

A meeting table for six persons was placed in the middle of the room. The length and width of the meeting table was 5.2 m x 0.8 m. One breathing thermal manikin, one heated dummy, and 4 persons simulated by heated cylinders were placed around the table. The mixing air distribution was implemented with an overhead perforated duct (OPD) in the ceiling zone. The perforated duct was extended for the entire length of the room and the supplied airflow was downwards toward the direction of the floor. The diameter of the perforated duct was 200 mm and the total length was 5.5 m. The displacement air distribution was achieved with a low velocity unit (LVU). A rectangular perforated low velocity unit was installed in the middle of the wall opposite the door on the floor. The width and height of the low velocity unit was 1140 mm x 550 mm.

Table 1: Heat gains, airflow rates and design parameters under two heat gain levels.

		Heat gain and cooling load balance	
Total heat flux	W/m²	**60**	**38**
Floor area	m²	21	21
Total heat gain	W	1253	805
Manikin	W	80	80
Dummy	W	85	85
4 Cylinder dummies	W	4*80=320	4*80=320
2 Laptops	W	2*40=80	2*40=80
2 Lights	W	2*45=90	2*45=90
Heated Window panels	W	133	105
Solar load at floor	W	420	0
Equipment of manikin	W	45	45
Supply air flow rate	L/s	116	61
Air change rate	1/h	5.5	2.9
Supply air temperature	°C	16	14
Design room air temperature	°C	25	25
Cooling load	W	-1253	-805

2.2 Experimental conditions

The operative temperature was controlled at 25 ±1 °C at a height of 1.1 m. The supply air temperature was kept at 14 °C with 38 W/m² and 16 °C with 60 W/m². The exhaust air temperature was around 25 °C. The supplied airflow rates were 116 l/s and 61 l/s with the 60 W/m² and 38 W/m^2 to be balanced with the total heat gain used. A thermal breathing manikin was used to simulate an infected sitting person in the room space, and one heated dummy and four heated cylinders represented the exposed persons. The breathing cycle of the manikin consisted of 2.5 s inhalation, 1 s break, 2.5 s exhalation and 1 s break.

To investigate the behaviour of gaseous indoor-emitted pollutants, a tracer gas can be used to simulate droplet nuclei from the exhaled air and to study the effect of the air distribution on the local concentration levels. In the previous study, it was demonstrated that the tracer gas technique is applicable to analysing airborne transmissions in air distribution studies (Ai et al., 2020). The tracer gas concentration in the inhaled air of exposed persons and exhaled air infector was measured by Multi-gas Sampler and Monitor. This equipment took air samples via plastic tubes in the breathing zone and analysed the components in the air. In this study, tracer SF_6 was released by exhaling through the nose of the thermal manikin with a pulmonary ventilation rate of 6 l/min. This was dosed directly into the artificial lung of the infector. The dosing rate was 2 ml/s, resulting in a contaminant concentration of the exhaled flow around 20,000 ppm. The breathing air of the manikin was heated to a setpoint of 35 °C and humidified to a level of 85%. During the experiment, continuous tracer gas measurements using a multi-gas sampler and monitor were taken at 7 locations, including the breathing zone of the 5 exposed persons, and at the exhaust and supply duct. The distance between two face-to-face persons' noses was 1.2 m and between two side-by-side persons it was 1.05 m. To investigate the effect of the infector's location on the exposure level, the manikin was placed at 4 different locations in each case as shown in **Error! Reference source not found.** and the exhaust point was near P4. A Wells–Riley model was used that assumed that the whole room volume was fully-mixed and in steady-state conditions.

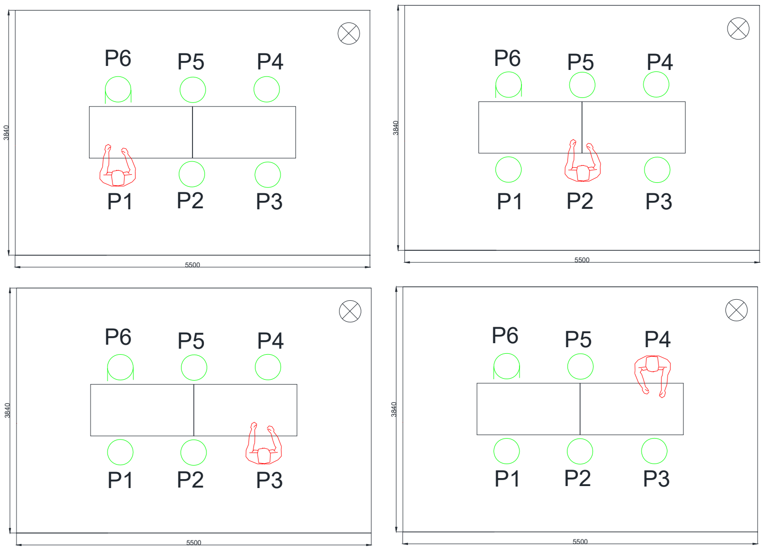


Figure 1: The locations of the infector (red breathing thermal manikin) in the test room.

3 RESULTS

3.1 Airborne transmission

Error! Reference source not found. shows the tracer gas distribution at different measured locations when the manikin was at P1 and the dummy at P6. The tracer gas concentration was increased with time and reached a steady state after 60 min and 34 min at the exhaust with an airflow rate of 61 l/s and 116 l/s, respectively. After the tracer gas concentration at the exhaust reached a stable level, the average concentration in the room with OPD was 21.3 ppm and 11.3 ppm with a heat gain of 38 W/m^2 and 60 W/m^2, respectively. The average contaminant removal efficiency [35] was 0.9 and 1.1 with an airflow rate of 61 l/s and 116 l/s, respectively. Therefore, the air distribution was mixed well in the whole space.

With OPD, the concentration distribution was quite uniform at each location, and the average standard deviation was only 0.3 to 0.6 ppm. However, the tracer gas distribution varied spatially and temporally with LVU. After the concentration reached steady state conditions at the exhaust point, the minimum concentration was 2.0 ppm, but a maximum value of 52.3 ppm occurred in the breathing zone. The highest standard deviation was 11.2 ppm. Therefore, the horizontally supplied airflow from LVU created a varied air movement, especially close to the opposite wall. Additionally, fluctuations of the concentration at P6 increased with a higher airflow rate.

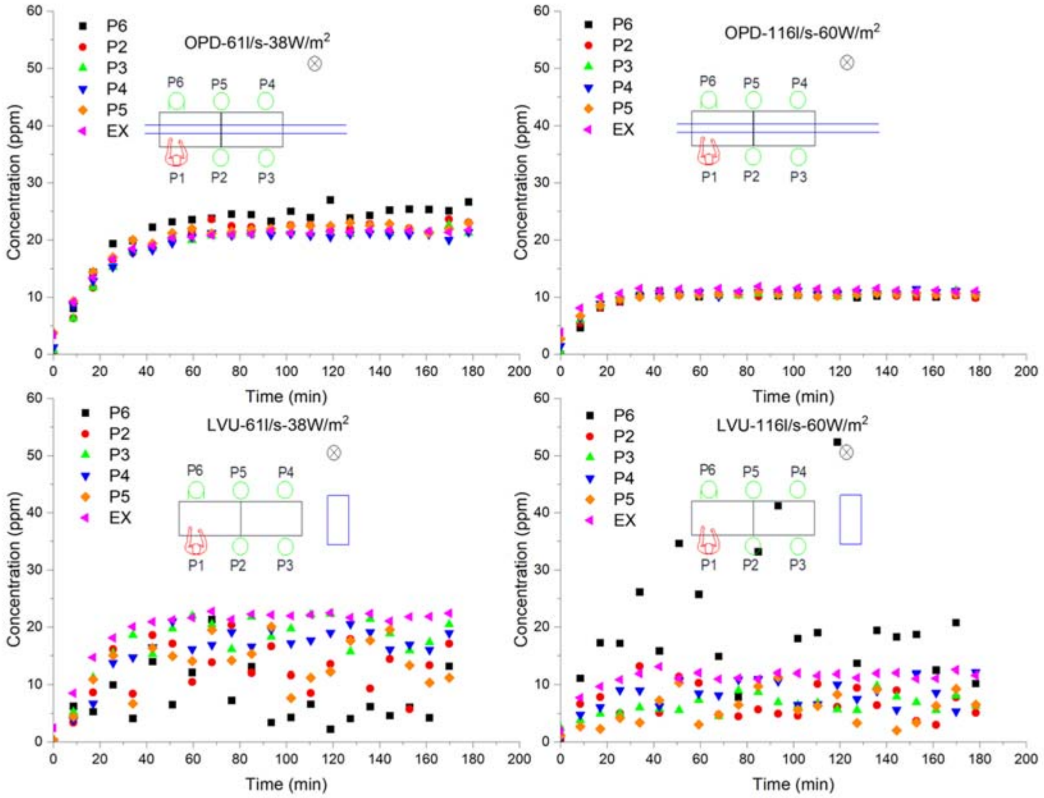
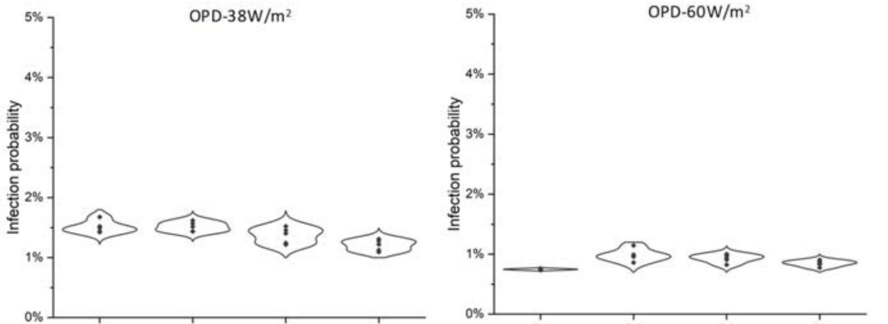


Figure 2: The concentration distribution of tracer gas at different locations when the manikin was at P1 with OPD and LVU with two heat gains of 38 W/m^2 and 60 W/m^2.

3.2 Infection probability

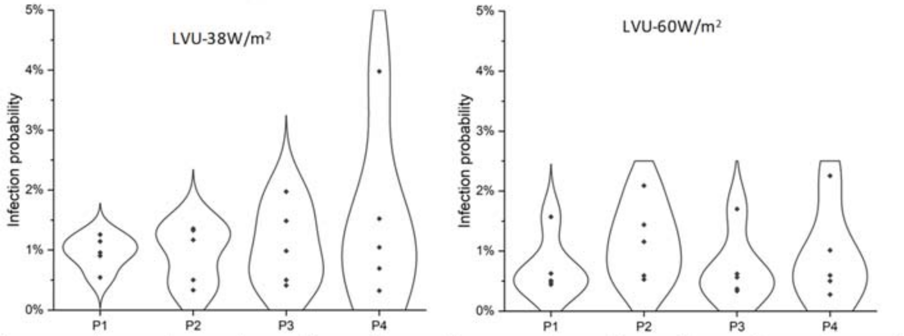
Error! Reference source not found. shows the infection probability variations for different exposed persons when the infector changed its location. When the airflow rate was increased from 61 l/s to 116 l/s with OPD, the average infection probability was reduced by 35% after three hours (from 1.4% to 0.9%). Therefore, the airflow rate level had a significant effect on the infection probability with OPD. The average infection probability in the room was decreased from 1.1% to 0.9% when the airflow rate was increased from 61 l/s to 116 l/s with LVU. Therefore, the increasing airflow rate with LVU reduced the exposure risk by 16%.

With a heat gain of 38 W/m^2, the average infection risk was 1.4% and 1.2% with OPD and LVU, respectively. The average performance of LVU is superior to OPD. With a heat gain of 60 W/m^2, the average infection risk was quite similar (0.9%) with OPD and LVU. However, with LVU, there were large differences and fluctuations. The highest standard deviation reached 1.4%. The average standard deviation with LVU was 0.7% and 0.6% with heat gains of 38 W/m^2 to 60 W/m^2, respectively. The corresponding value was only 0.1% with OPD.



	P1	P2	P3	P4	Mean
Mean	1.5%	1.5%	1.4%	1.2%	1.4%
Standard Deviation	0.1%	0.1%	0.1%	0.1%	0.1%

	P1	P2	P3	P4	Mean
Mean	0.7%	1.0%	0.9%	0.8%	0.9%
Standard Deviation	0.0%	0.1%	0.1%	0.0%	0.1%



	P1	P2	P3	P4	Mean
Mean	1.0%	0.9%	1.1%	1.5%	1.1%
Standard Deviation	0.3%	0.5%	0.7%	1.4%	0.7%

	P1	P2	P3	P4	Mean
Mean	0.7%	1.2%	0.7%	0.9%	0.9%
Standard Deviation	0.5%	0.6%	0.6%	0.8%	0.6%

Figure 3: The infection probability with OPD and LVU in the test room.

4 CONCLUSIONS

The infection probability in the meeting room was investigated by full-scale tests. Air distribution methods with an overhead perforated duct (OPD) and low velocity unit (LVU) were analyzed under two heat gain levels (38 W/m^2 and 60 W/m^2) and two airflow rates (61 l/s and 116 l/s). The following findings can be concluded:

- With OPD, the average contaminant removal efficiency was between 0.9 and 1.1. However, with LVU, the average contaminant removal efficiency varied spatial and temporal between 0.2 and 10.1.
- The infection probability was quite uniform (SD=0.1%) with the OPD, especially at a higher heat gain level. The variation of infection probability with LVU was significant. The highest standard deviation reached 1.4%.
- The highest risk was reached at 4% with LVU when the infector was located near the supply unit. The lowest risk was only 0.3%. Therefore, both best and worst situations were achieved with LVU, indicating that it can offer (in this specific case) superior performance to OPD if properly designed.
- When the infector sat near the exhaust, the infection probability was the smallest with 38 W/m^2. Therefore, the proper air distribution combined with local exhaust is most effective for source removal.

5 ACKNOWLEDGEMENTS

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