The full length version of this article is available at www.rehva.eu > Publications & Resources > HVAC Journal

Protected zone ventilation reduces personal exposure to indoor pollution




GUANGYU CAO
VTT Technical Research Centre of Finland, Finland
guangyu.cao78@gmail.com

KAI SIREN
Aalto University, Finland
kai.siren@aalto.fi

PETER V. NIELSEN
Aalborg University, Denmark
pvn@civil.aau.dk

ATILA NOVOSELAC
University of Texas at Austin, USA
atila@mail.utexas.edu

The objective of this study is to exam the performance of protected zone ventilation (PZV), which is known as protected occupied zone ventilation (POV) as well, regarding protection of occupants from exposure to various indoor pollutants. Both gaseous and particulate pollutants were used to test the capacity of PZV to reduce the personal exposure to various indoor pollutant sources. Two breathing thermal manikins and a cough generator were used in this study to produce exhaled airflow and cough jets, which simulated different indoor pollutant source. PZV is able to separate an indoor space into a source zone and a target zone with different pollutant concentration. The direct exposure of target manikin to breathing airflow and a cough is significantly reduced by using PZV with higher supply air velocity. The results may be used to make a guideline to design an efficient PZV system for different industry and engineering applications.

Keywords: ventilation, protected zone ventilation, air jets, cross contamination, protective ventilation, air curtain

Introduction

Airflow distribution plays an important role in the indoor environment, where people spend over 90% of their time. Nowadays global epidemic respiratory diseases break out more often than ever, for example tuberculosis (TB) (1990), SARS (2003) and H1N1 (2009), which took place in many countries (WHO website and the CDC website). In some special application, the indoor air change rate can be as high as 12–42 ACH. However, recent studies show that mixing ventilation alone is not able to reduce substantially the exposure to indoor pollutant (Melikov et al. 2011, Mazumdar and Chen, 2009). Regarding the exposure to exhaled airflow, the exposure risk can be as high as 20 times by using MV than other ventilation method (Olmedo, 2012; Nielsen, 2014). However, it is very challenge for these methods to deal with both gaseous and particulate pollutants. Amongst some commonly used ventilation systems, the protected occupied zone ventilation (POV) was developed to reduce the personal exposure to indoor pollutant (Cao et al. 2011). POV has similar form as an 'air curtain', which may be used to prevent the transfer of heat from indoor to outdoor via door way (Sirén, 2003). Pollutants source will be located in the source zone, and even a sick person can be a pollutant source while breathing and coughing. By using CO_2 as indoor pollutant source, the protection efficiency of POV varies from 8% to 50% depending on the exhaust location, supply air velocity and the usage of partitions (Cao et al. 2013). A push-pull ventilation system was proved to be an efficient way to control contaminant and protect occupants. The term of protected zone ventilation (PZV) is similar to POV using downward plane jets to separate an indoor space into a source zone and a target zone, but can be used in some specific conditions.

However, little studies have discovered how different airflow distribution will affect indoor air quality with regards to the transport of gaseous and aerosols particles from the source zone and the target zone. The objective of study is to find out the performance of PZV/POV regarding protection of occupants from exposure to indoor pollutants.

Performance of POV to reduce the concentration of indoor gaseous pollutant in the target zone

Experimental setup and measurement conditions

All measurements were conducted in a full-scale test room for two office workers at Aalto University, Finland. The room has dimensions of (width × length × height) 2.0 m × 4.0 m × 2.65 m. The room was ventilated by a laminar airflow diffuser, as can be seen in **Figure 1**. Measurement were done with room temperature and supply air of 20°C other conditions are shown in **Table 1**.

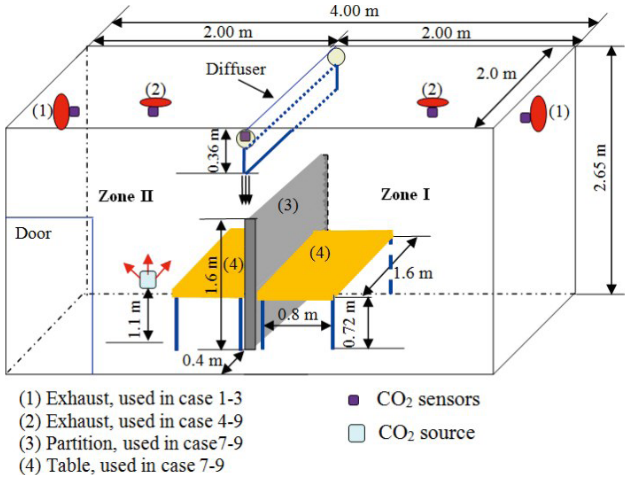


Figure 1. Sketch of measurement set-up of POV with the location of exhaust and diffuser (Cao et al. 2013).

Results and discussion

Figure 2 shows the average values of measured CO_2 concentration in 6 cases. Results show that the supply air velocity of the plane jet affects the performance of POV. When supply air velocity is 1.75 and 1.5 m/s, the plane jet can separate the protected zone from the polluted zone at 800 ppm. With a lower supply air velocity, at 1.00 m/s, the plane jet does not prevent the transmission of pollutants from the polluted zone to the protected zone. There is almost no difference between the two zones in Case 3, 6 and 9. Which means the pollutant was mixed up in the entire room, which is similar to the performance of mixing ventilation.

Performance of PZV to reduce personal exposure to breathing airflow

Experimental setup

The climate chamber used in this study is an experimental room with surfaces that can change thermal conditions according to the ambient conditions in Aalborg University, Denmark. The test room was inside the chamber has a size of height, width, length equal to 5.20 m (length) x 2.00 m (width) x 2.50 m (height) (as shown in **Figure 3**). **Figure 3** shows the sketch of the

Table 1. Measurement conditions. (Cao et al. 2013)

	Q_{supply} (l/s)	Average velocity at slot (m/s)	Re at slot	Air change rate of the room	$Q_{e\text{-}left} = Q_{e\text{-}right}$ (l/s)	CO_2 release (L/min)
Case 1	35 ±1.0	1.75 ±0.05	1167	5.9	17.5 ±0.5	4.3 ±0.1
Case 2	30 ±1.0	1.50 ±0.05	1000	5.1	15.0 ±0.5	4.3 ±0.1
Case 3	20 ±1.0	1.00 ±0.05	667	3.4	10.0 ±0.5	4.0 ±0.1
Case 4	35 ±1.0	1.75 ±0.05	1167	5.9	17.5 ±0.5	4.3 ±0.1
Case 5	30 ±1.0	1.50 ±0.05	1000	5.1	15.0 ±0.5	4.3 ±0.1
Case 6	20 ±1.0	1.00 ±0.05	667	3.4	10.0 ±0.5	4.2 ±0.1
Case 7	35 ±1.0	1.75 ±0.05	1167	5.9	17.5 ±0.5	4.3 ±0.1
Case 8	30 ±1.0	1.50 ±0.05	1000	5.1	15.0 ±0.5	4.2 ±0.1
Case 9	20 ±1.0	1.00 ±0.05	667	3.4	10.0 ±0.5	4.0 ±0.1

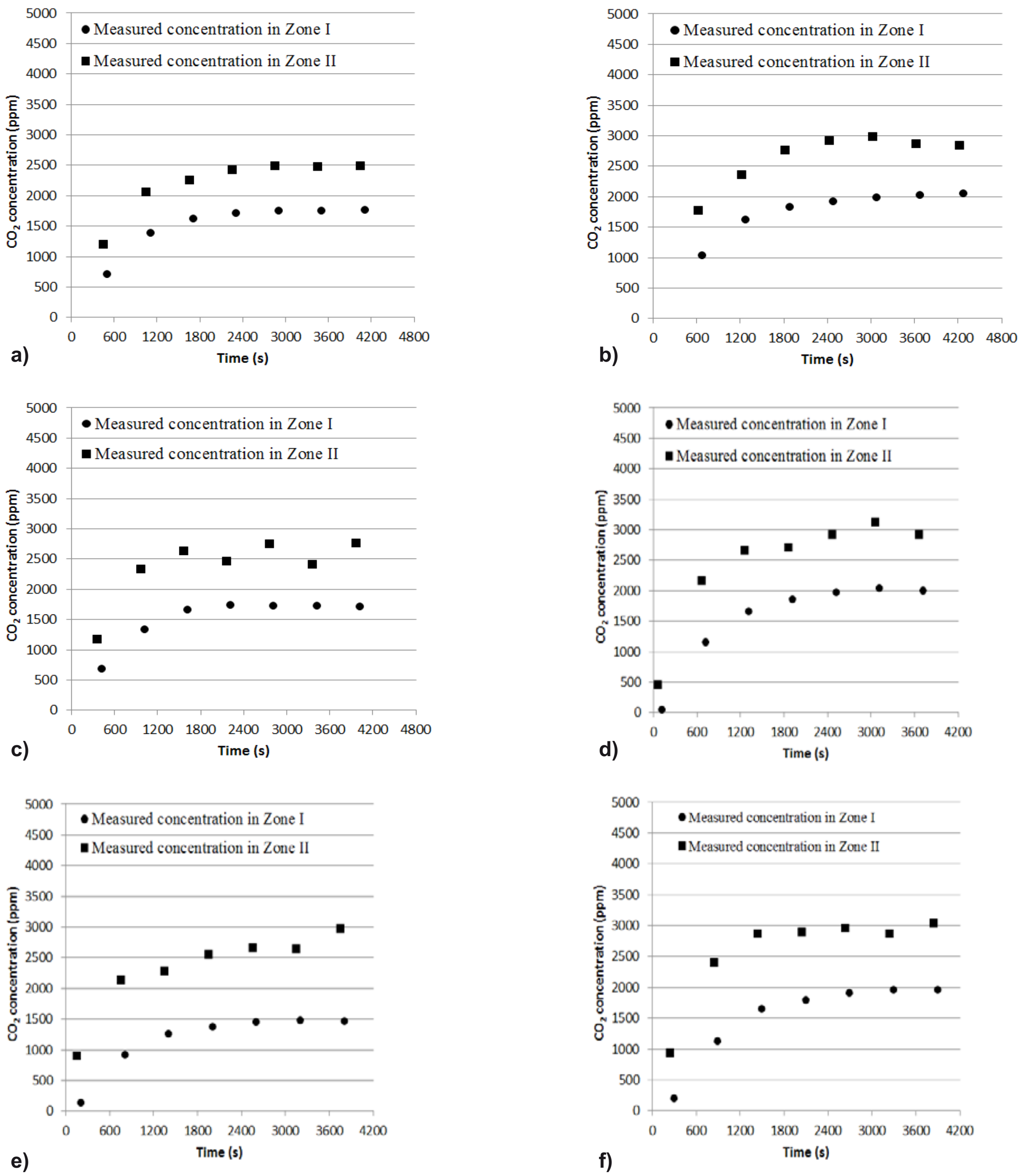


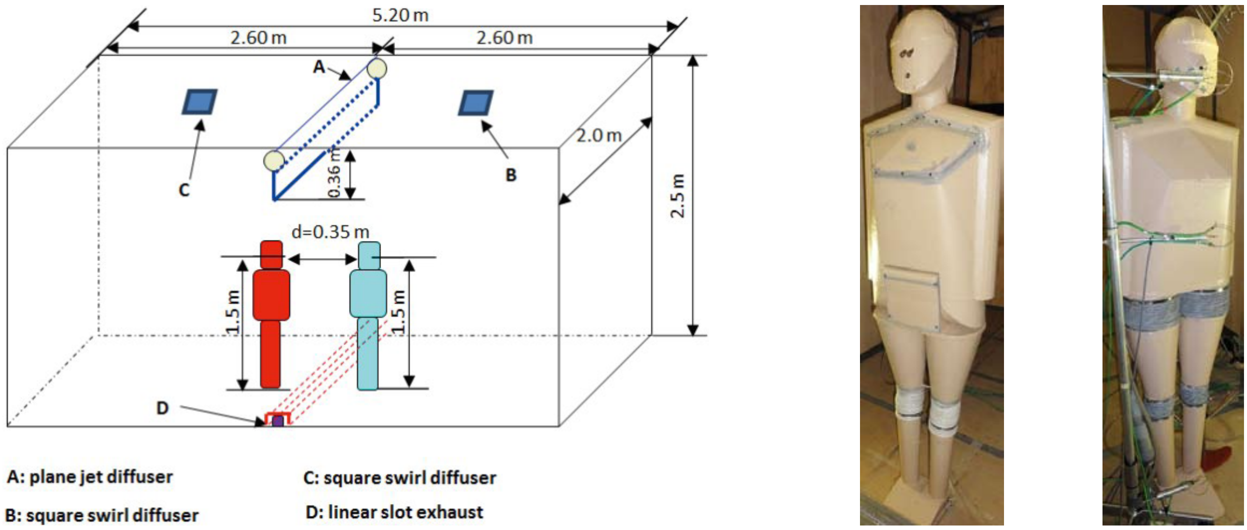
Figure 2. Calculated and measured CO_2 concentration: a) Case 1, b) Case 2, c) Case 4, d) Case 5, e) Case 7, f) Case 8 (Cao et al. 2013).

test room and the locations of the breathing thermal manikin (BTM) and air diffusers.

Mechanical lungs are connected to the manikin to simulate breathing functions. The breathing frequency of the two manikins in the experiments is kept at 16 times/minutes. The manikin simulates a standing person, which has a metabolic rate of 1.2 met. The volume of breathing air is kept at 8.8 L/minutes for each manikin.

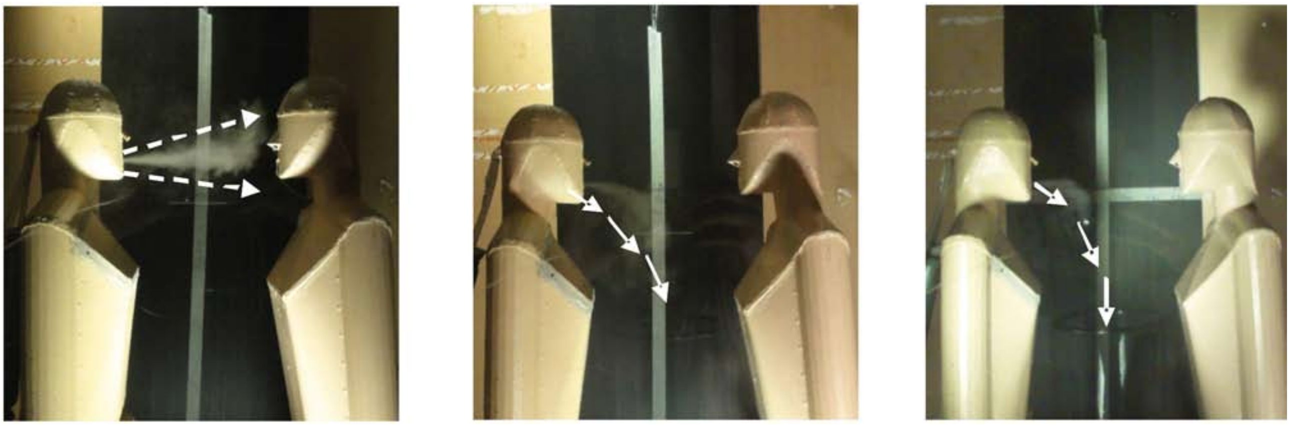
Visualization of the cross-infection risk between two persons

As the cross-infection risk will be very high when the distance between two manikins gets as close as 0.35 m, this section presents the visualization results of the cross-infection risk between two persons with PZV. At a distance of 0.35 m between two manikins, the exposure, c_{exp}/c_R, could be as high as 13 by using downward flow ventilation (c_{exp} is the inhaled concentration of the target person and c_R is the concentration in the return of the



a) b) c)

Figure 3. Sketch of measurement set-up of PZV and photos of BTMs, a) Sketch of measurement set-up, b) source BTM c) target BTM .



a) b) c)

Figure 4. Photos of smoke visualization between two BTM with and without downward plane jet, a) without downward plane jet, b) jet velocity 2.2 m/s, c) jet velocity 3.0 m/s.

room). **Figure 4** shows that when there is no downward plane jet between the two breathing thermal manikins, the exhaled air from the source manikin can easily approach the breathing zone of the target manikin. The exhaled airflow bends to the lower part of the target manikin, which lowers the risk of the cross infection between source manikin and target manikin. When the supply velocity is increased up to 3.0 m/s, the exhaled airflow cannot penetrate the download plane jet anymore.

Performance of POV to reduce personal exposure to a cough jet

Experimental setup

The experiments were performed in a chamber, which is located in the University of Texas at Austin, with dimensions of 2.3 m (length) × 1.94 m (height) × 2.1 m (width) (see **Figure 5**). POV was used to separate a space into a source zone and a protected zone. Total particle concentration was used to calculate the personal exposure value, which means all particle sizes will be summed together by using Aerodynamic Particle Sizer Spectrometer (APS) Model 3321 and AeroTrak particle counter Model 8220.

Results and discussion

The dimensionless exposure index is used to express the risk of personal exposure (PE) to a cough jet (Cao et al. 2013). **Figure 6** shows that the average peak normalized concentration in the breathing zone for MV is 5 times and 20 times higher than by two-slot POV and one-slot POV respectively. The one-slot POV has great potential to reduce the peak concentration than a traditional MV.

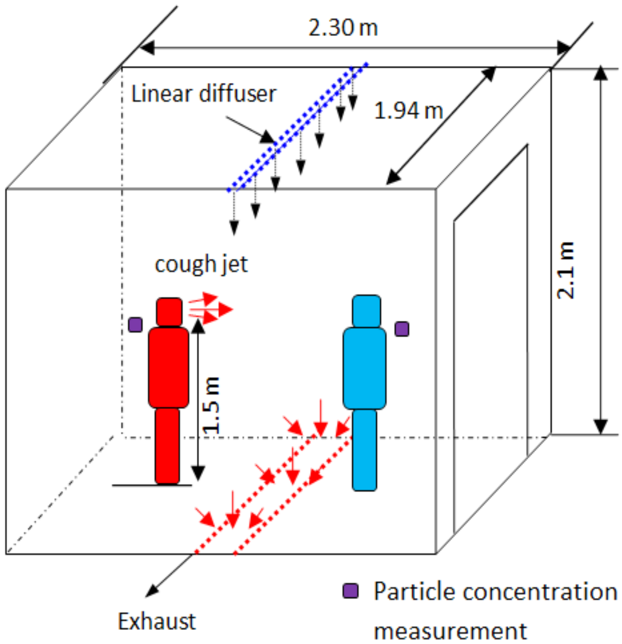


Figure 5. Sketch of measurement set-up of POV and photos of the setup.

Conclusions

The PZV/POV systems using a plane jet is able to separate the room into two zones with a different concentration level of contaminant. This indicates the PZV may protect people from the cross-contaminant in a room with an unknown indoor pollutant source. By using partitions and upper exhaust in PZV, the protected zone can be kept at a lower contaminant concentration in the same room. The personal exposure to the respiratory activities may be very high when the distance between two people becomes very close. The downward airflow in PZV system may bend the exhaled airflow downward and reduce the direct exposure of the target manikin to the source manikin. The direct exposure of target manikin to breathing airflow and a cough is significantly reduced by using PZV with higher supply air velocity. The results may be used to guide the design of an efficient PZV system for different industry and engineering applications. More detailed studies are needed to get a better understanding of the performance of the PZV under different conditions. ■

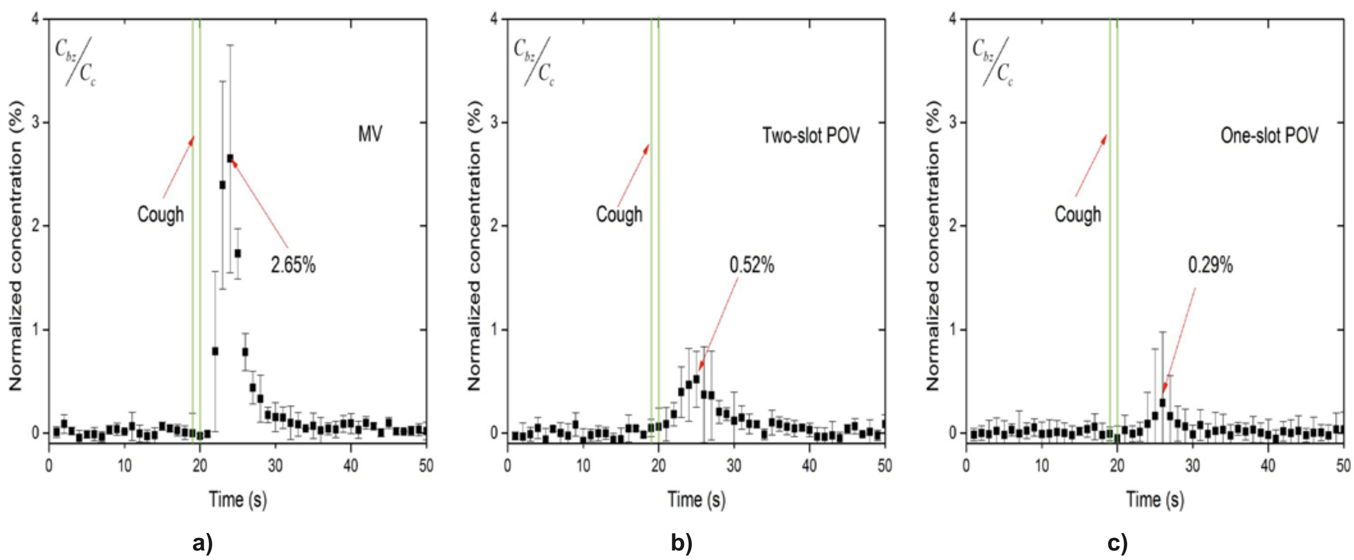


Figure 6. Normalized concentration of coughed particles (0.77 µm) in the breathing zone, a) with MV, b) with POV (two-slot), c) POV (one-slot) (Liu et al. 2014)

Acknowledgement

The authors wish to express their thanks for financial support from the Academy of Finland through the postdoctoral project POWER-PAD (NO. 259678).

References

Please see the complete list of references of the article in the html-version at **www.rehva.eu** -> REHVA Journal