Protected zone ventilation for reducing personal exposure to indoor pollutants

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Presented by Jorma Heikkinen

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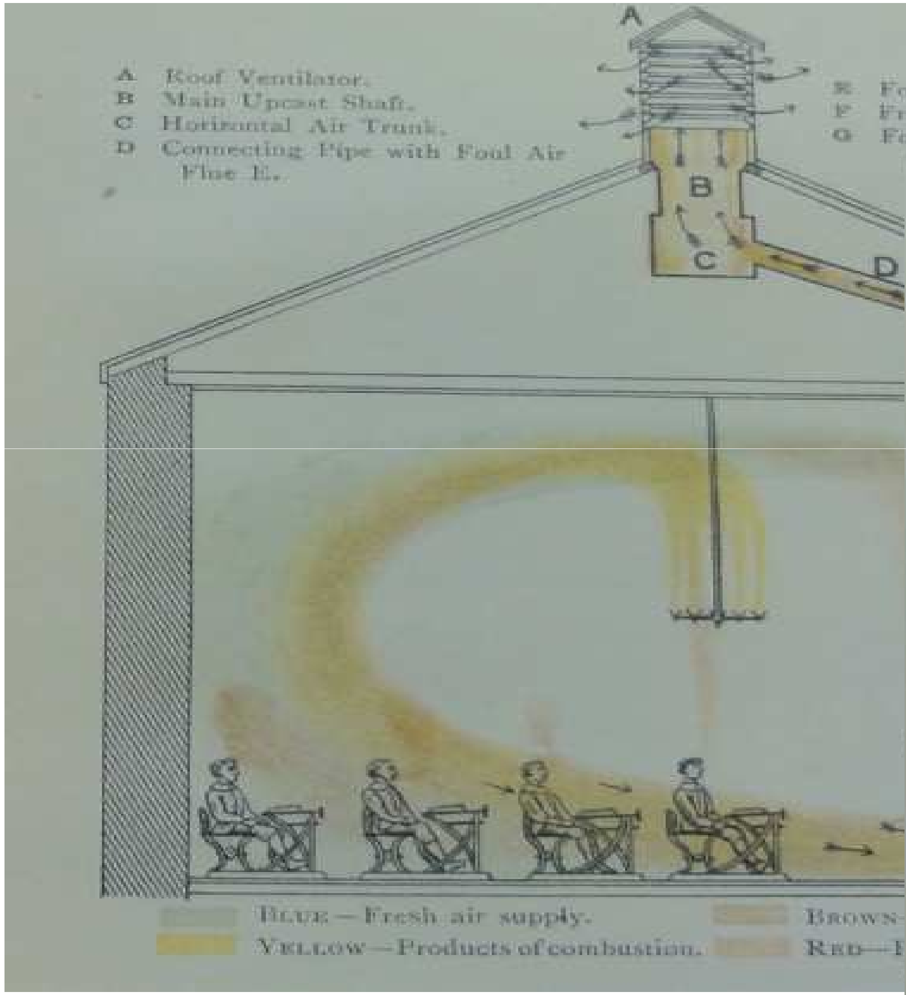
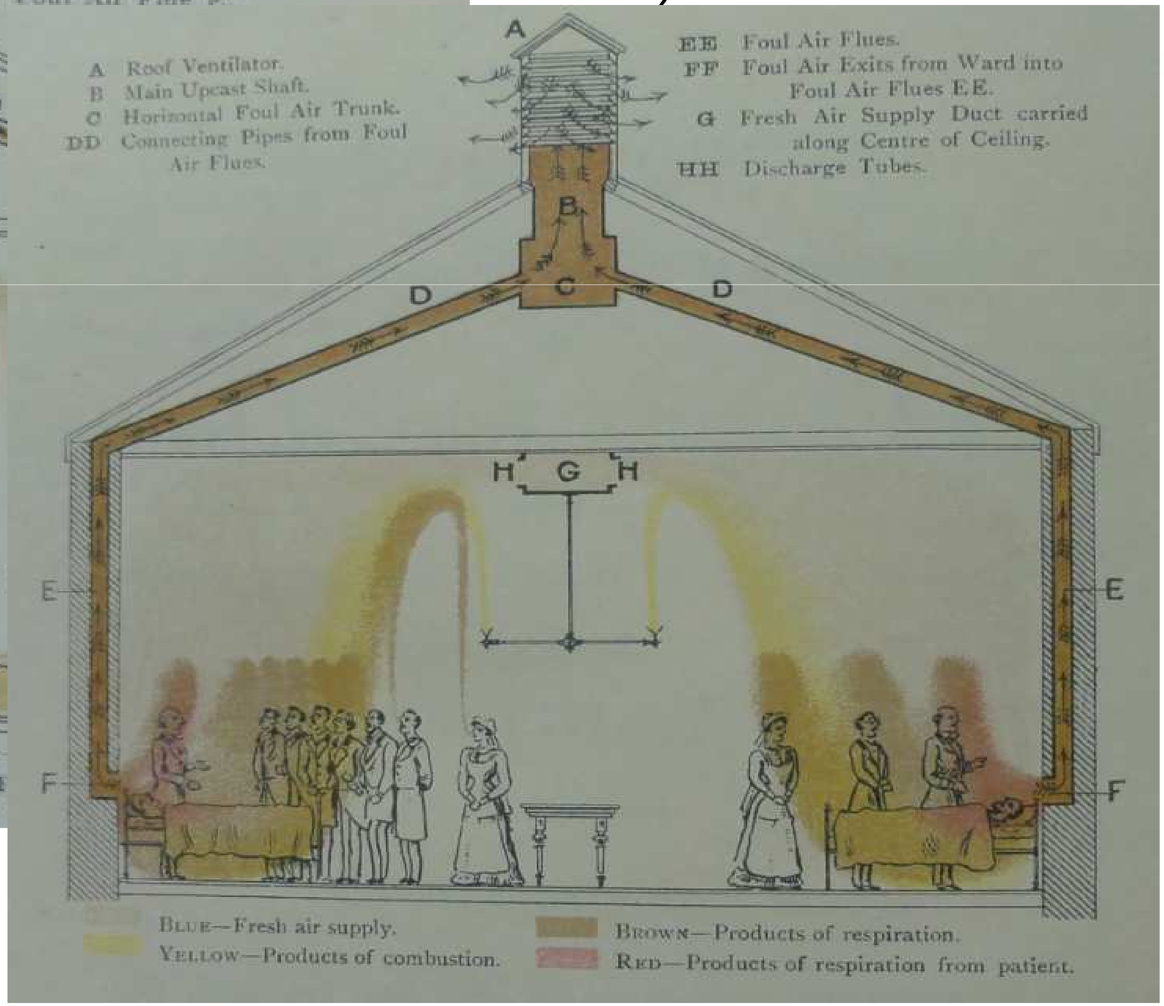
Introduction

Mixing of supply airflow and indoor pollutants



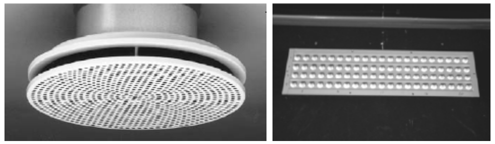
- Mixing ventilation in a classroom in 1899 (1899 Robert Boyle & Son)

- Ventilation system in a hospital (1899 Robert Boyle & Son)



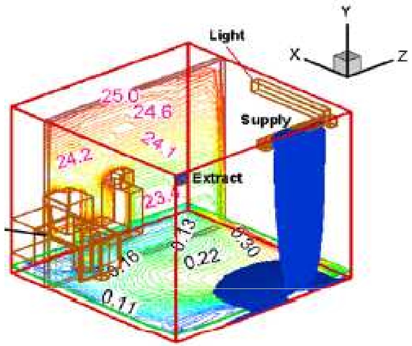
100 Years later

- **Mixing ventilation**

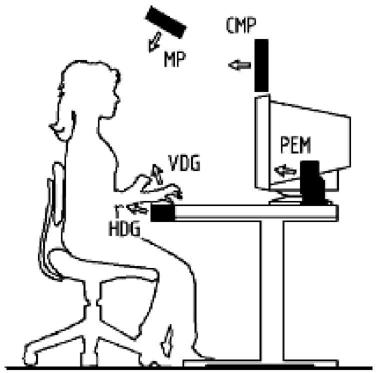


- **Displacement ventilation**

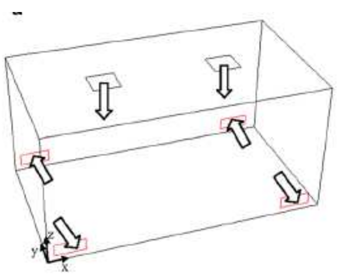
- **Hybrid ventilation**



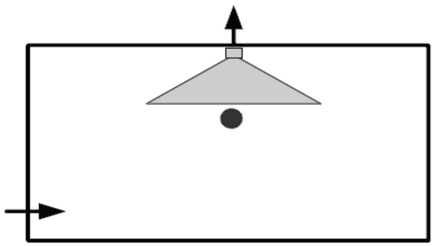
- **Personalized ventilation**



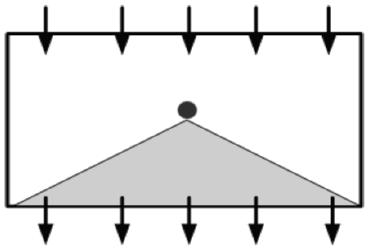
- **Stratum ventilation (SV)**



- **Local exhaust ventilation**



- **Piston ventilation**



Challenges

- Breathing zone (BZ), Personal zone (PZ), Occupied zone and Whole space

- **Can conventional ventilation methods prevent the exposure of occupants to various indoor pollutants or epidemic disease?**

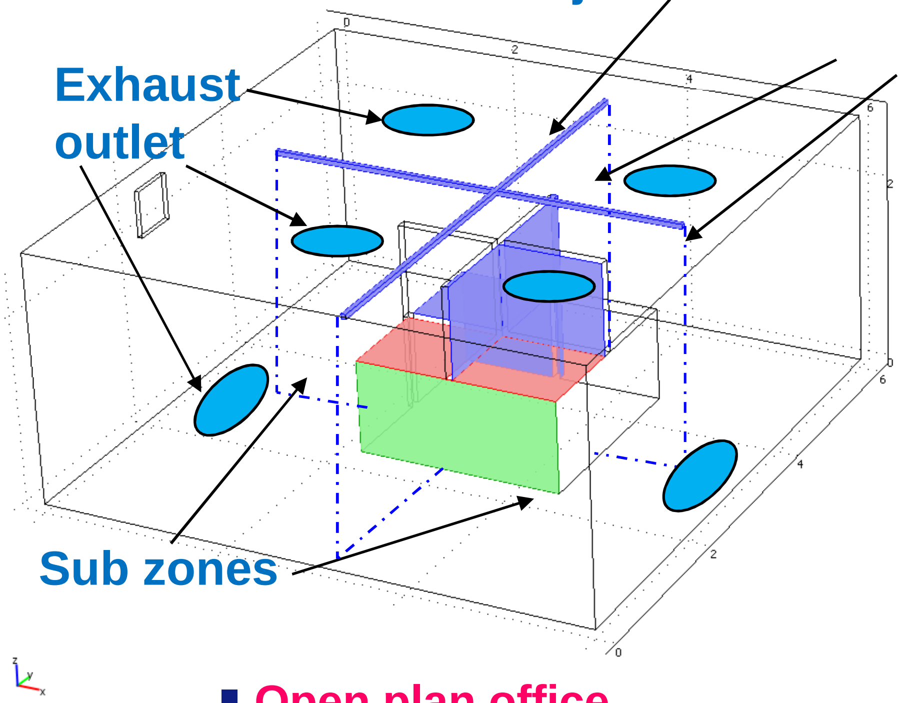
Like:
Measles (1985)
Tuberculosis (TB) (1990)
SARS (2003)
H1N1 (2009)
Avian influenza H7N9 (2013)
Seasonal pollen/cold/flu

Principle of the protected (occupied) zone ventilation (POV/PZV)

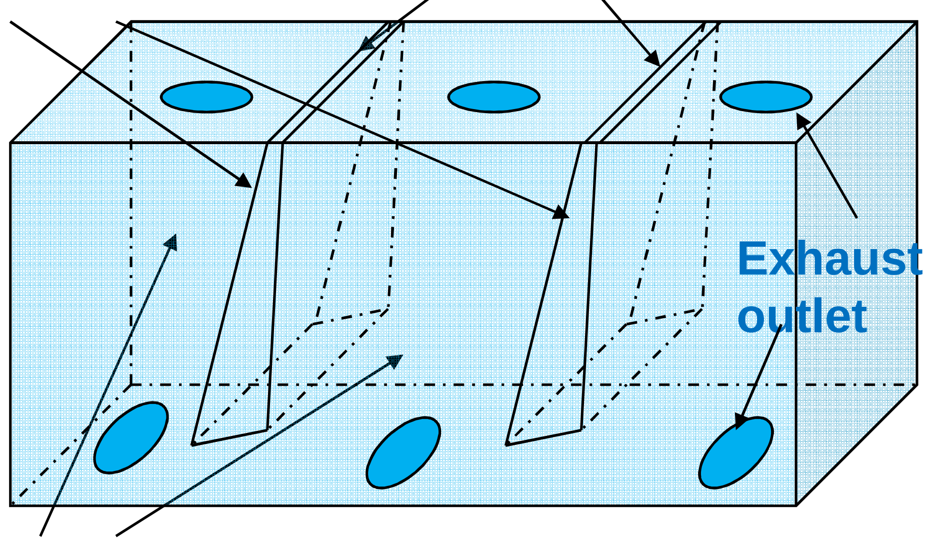
Protected occupied zone ventilation (POV/PZV) is a new ventilation method, which separates the indoor space into sub zones by plane jets to protect occupants from infection of epidemic respiratory disease by contaminated air, aerosols and particles in open plan office and public space.

(Cao et al. Indoor Air 2011Conference)

- For example: the open-plan office will be divided into four personal work areas or subzones by plane jet curtains or air curtains 4, which provide fresh air to the subzones. The plane jet curtains 4 prevent the possibly polluted air from moving from one subzone to other subzones.

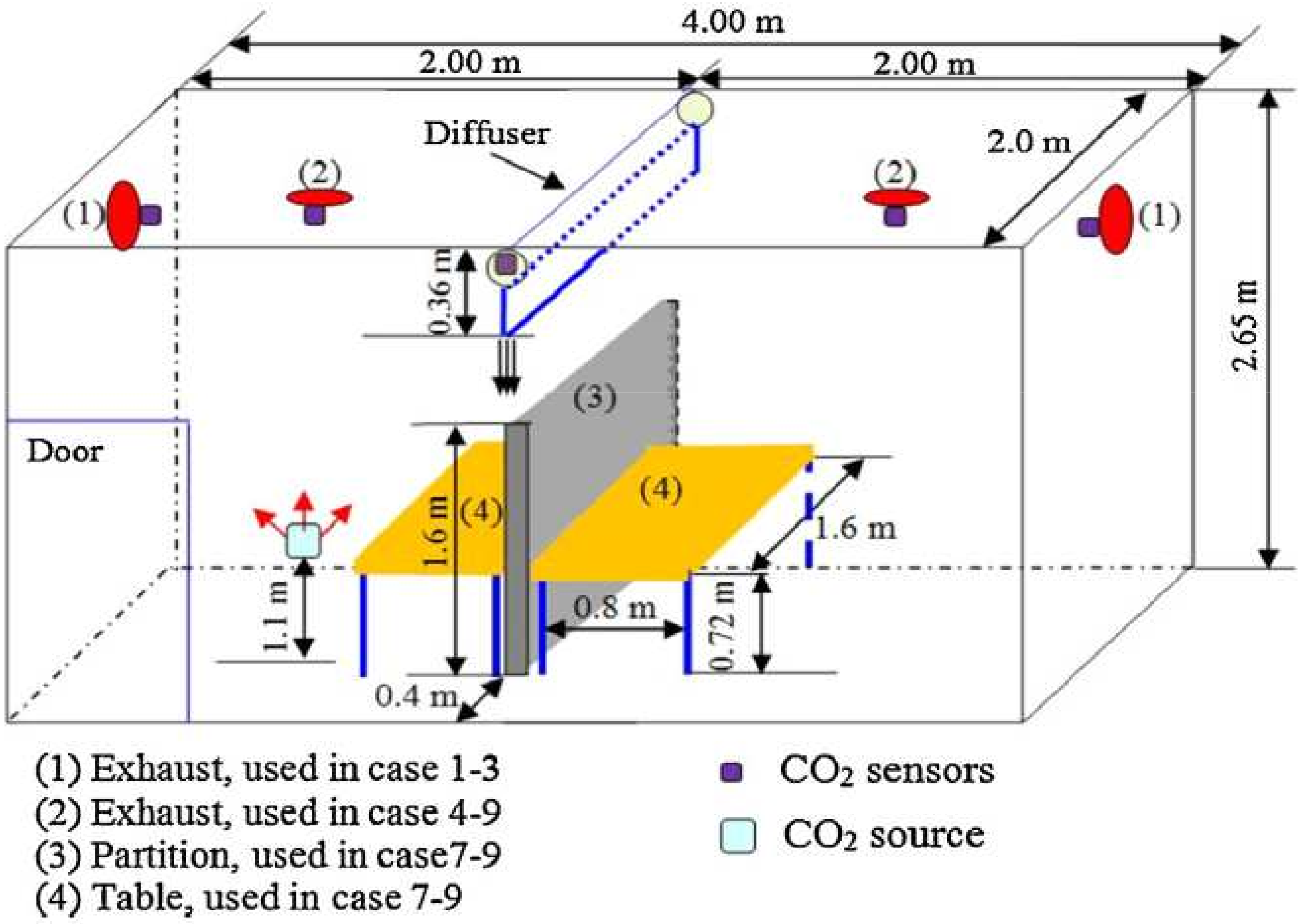


- **Open plan office**



- **Public space**

Case study 1 – POV/PZV against gaseous pollutants



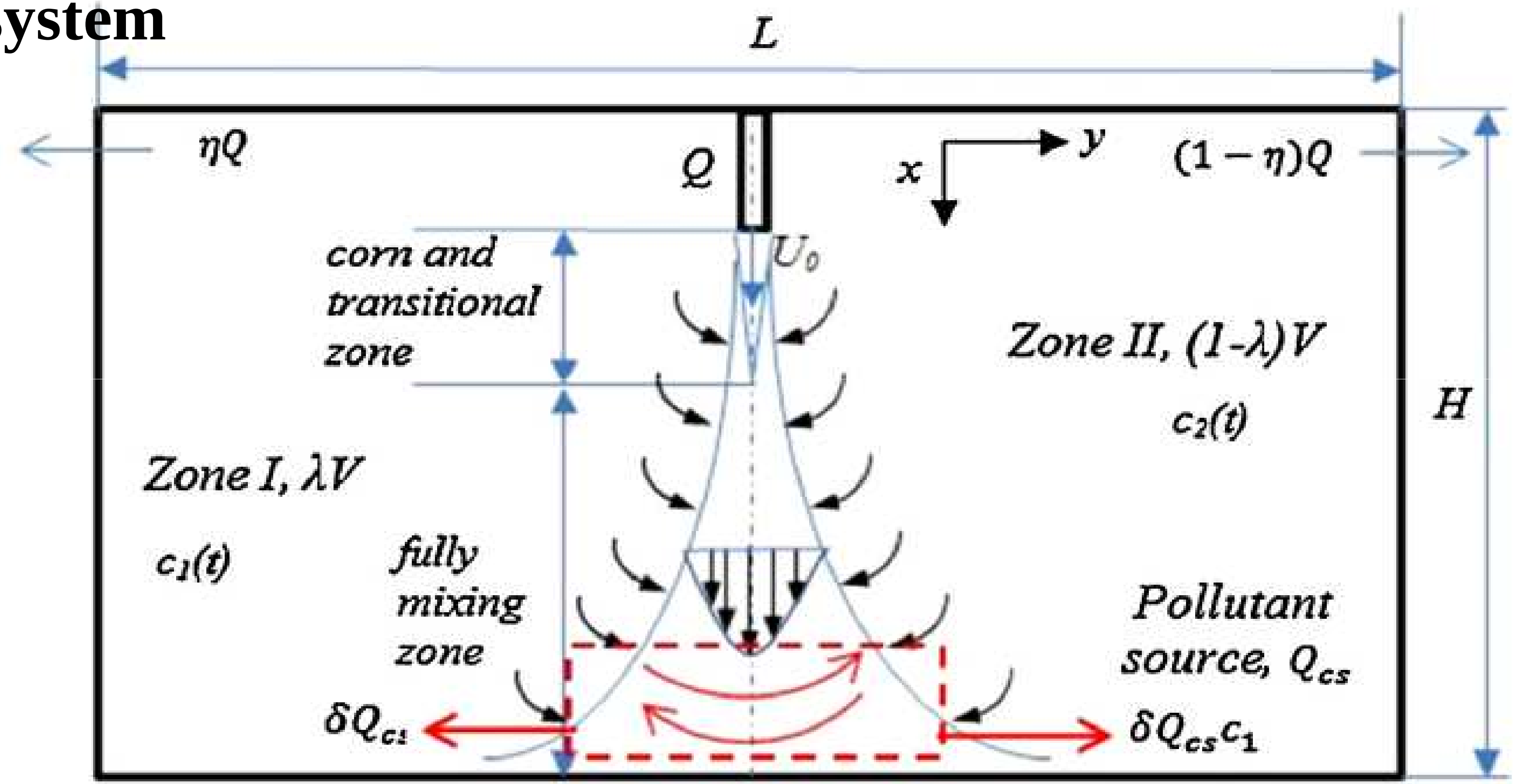
Sketch of measurement set-up of POV/PZV with the location of exhaust and diffuser

Smoke visualization

Photos of air jet development using smoke (supply air velocity 1.75 m/s), (a) front view, (b) side view.

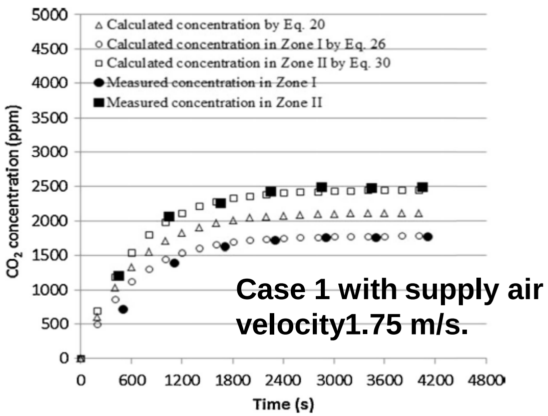
- Smoke visualization: downward plane jet separated the source zone from the target zone

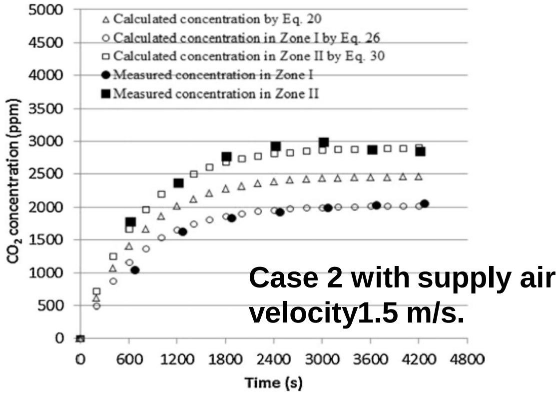
Modelling of pollutant transmission with a POV/PZV system

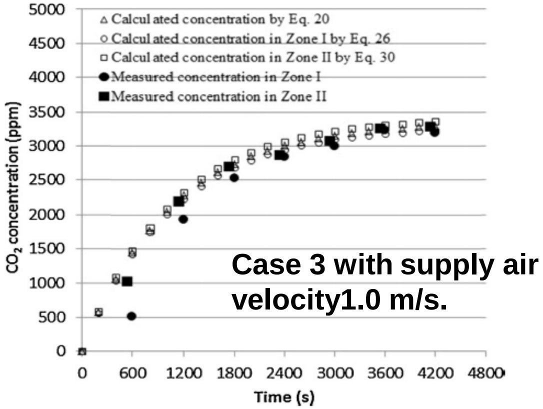


modelling of contaminant transferring in a room with a plane jet in the middle of the room

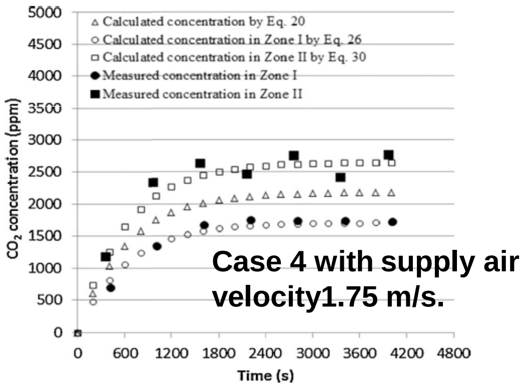
Concentration variation in Zone I and Zone II (Case 1-3)

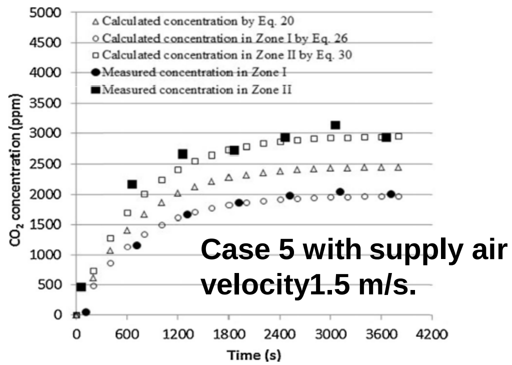


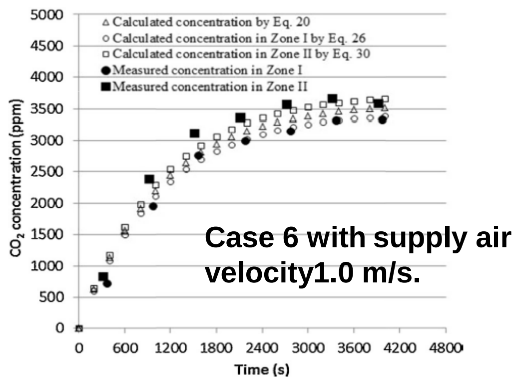




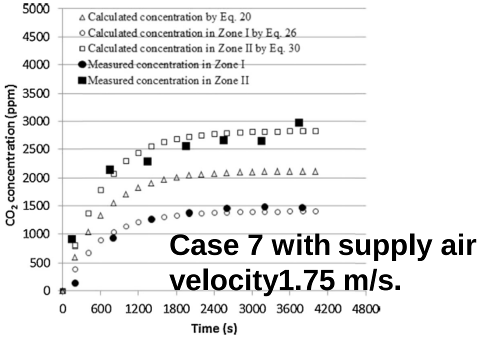
Concentration variation in Zone I and Zone II (Case 4-6)

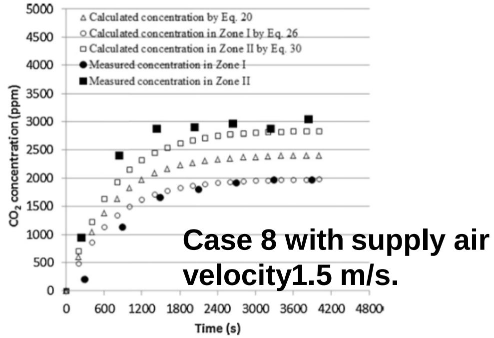


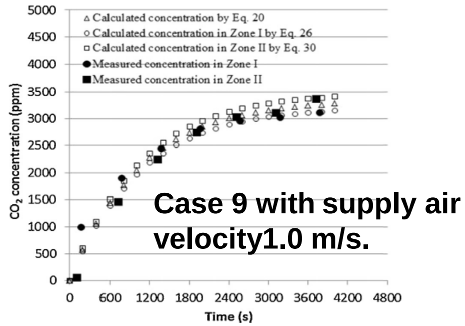




Concentration variation in Zone I and Zone II (Case 7-9)







Two - zone model

In Zone I, the change in concentration of pollutant follows the volume balance of pollutant:

$$\lambda V \frac{dc_1}{dt} = \eta Q c_s - \eta Q c_1 + \delta Q_{cs}$$

In Zone II, the change in concentration of pollutant follows the mass balance of pollutant:

$$(1-\lambda) V \frac{dc_2}{dt} = (1-\delta) Q_{cs} + (1-\eta) Q c_s - (1-\eta) Q c_2 + \delta Q_{cs} c_1$$

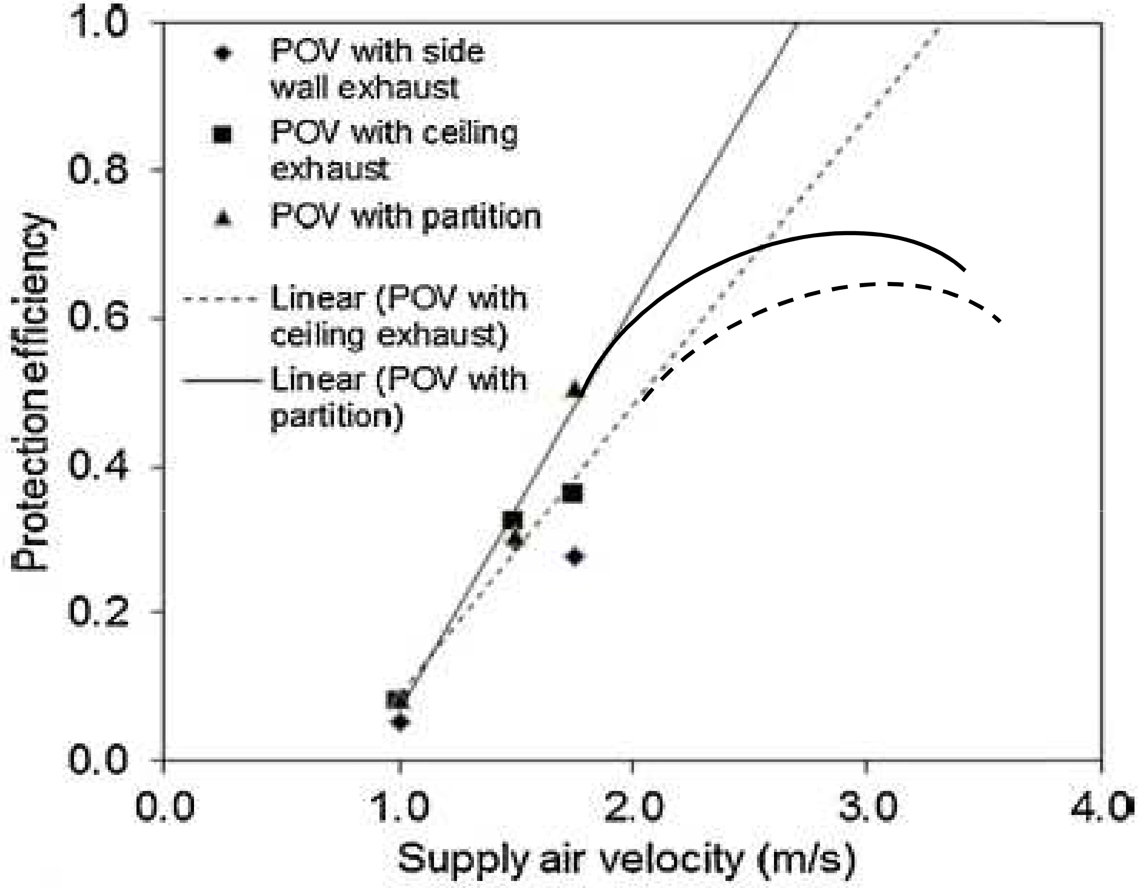
where λ is the space ratio of the Zone I to the whole room, here λ=0.5, when the volume of Zone I is equal to Zone II; η is the exhaust air ratio of Zone I to the overall exhaust air in the room, here η=0.5, when the exhaust in the two zones are equal; δ is the contaminant transfer co-efficiency, which includes both the diffusion and the mixing processes of the jet discharging. If the plane jet impinges the floor evenly, the airflow rate enters Zone I and Zone II should be equal.

The protection efficiency

- The protection efficiency (PE) of POV/PZV (Cao et al. 2013)

$$\eta = \left(1 - \frac{c_1}{c_2}\right) 100\%$$

where c_1 is the pollutant concentration in the exhaust in the protected zone, and c_2 is the pollutant concentration in the exhaust in the polluted zone.

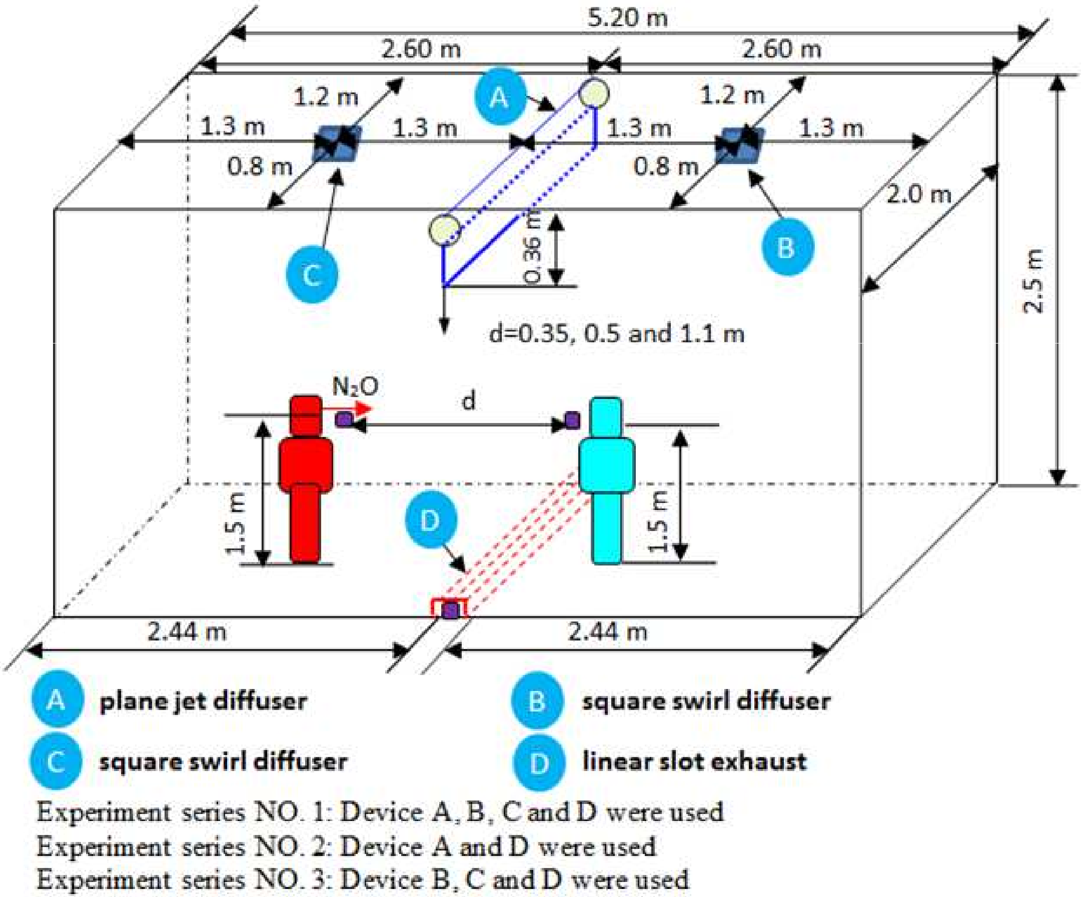


Protection Efficiency as a function of supply air velocity

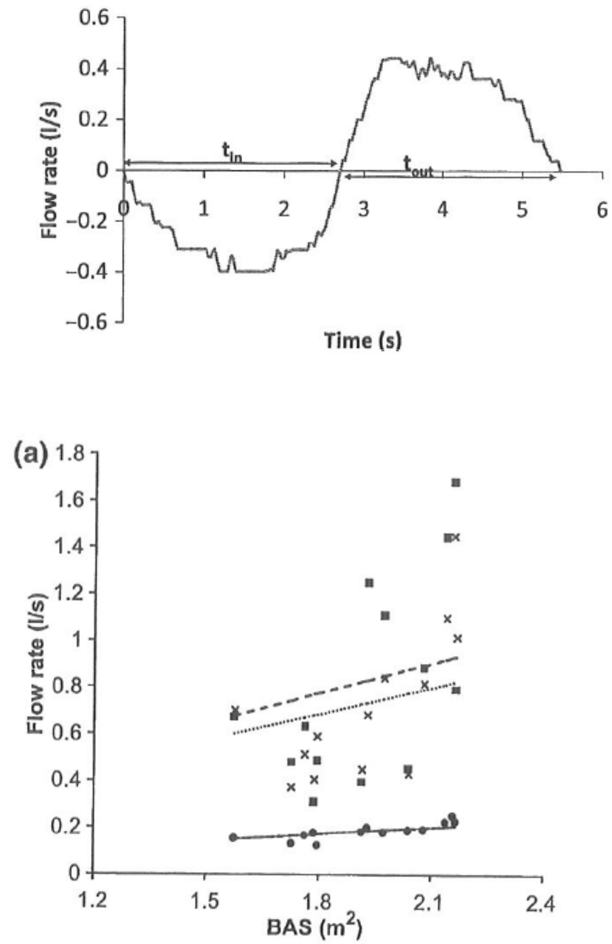
Conclusions (I)

- A POV/PZV system is able to separate the room into two zones with a different concentration level of contaminant.
- The POV/PZV may protect people from the cross-contaminant in a room with an unknown internal gaseous pollutant source.
- The models developed in this study are capable of predicting the transient pollutant concentration in the protected zone and the polluted zone.

Case study 2 – POV/PZV against breathing

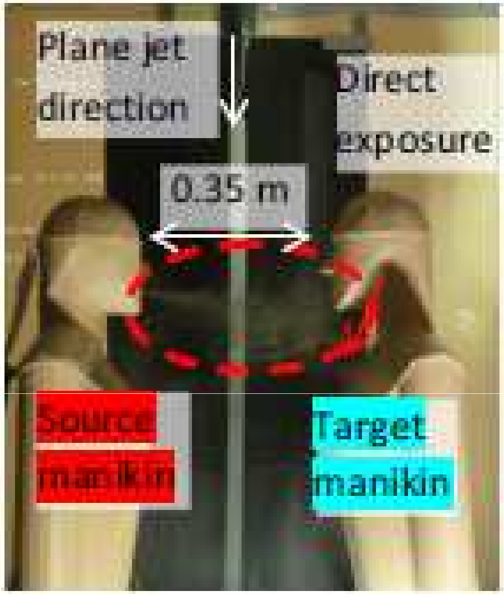


(Cao et al. 2014, Indoor Air)

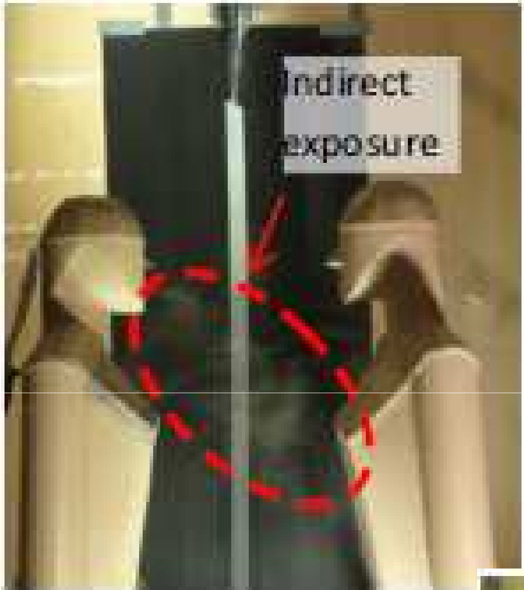


(Kupta et al. 2009, Indoor Air)

Smoke visualization: Direct exposure and indirect exposure



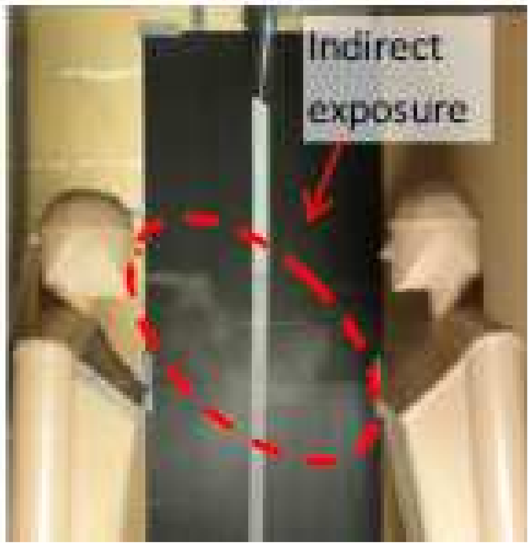
Downward jet velocity is 1.8 m/s



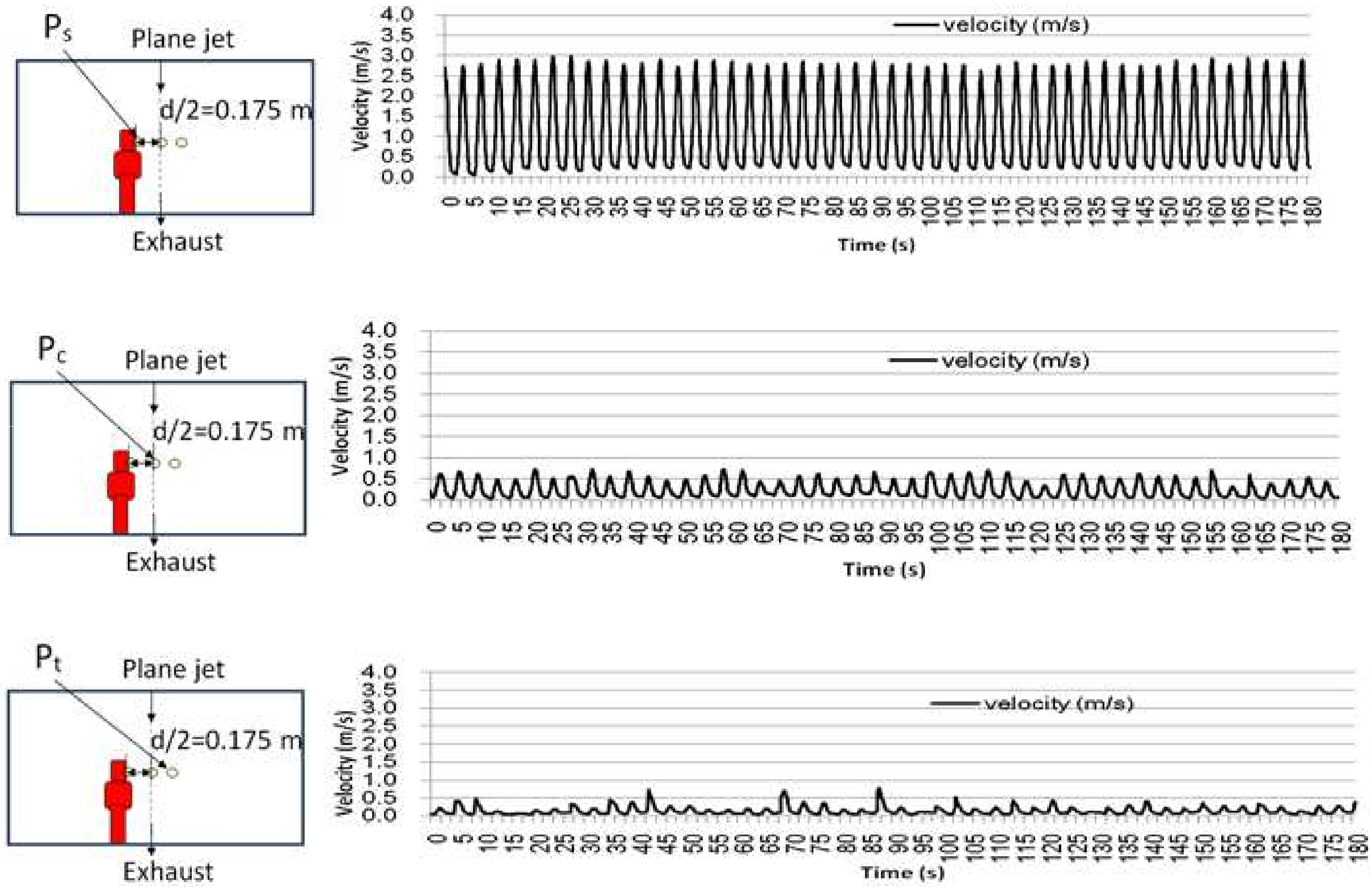
Downward jet velocity is 2.2 m/s

Downward jet velocity is 1.8 m/s

Downward jet velocity is 2.2 m/s

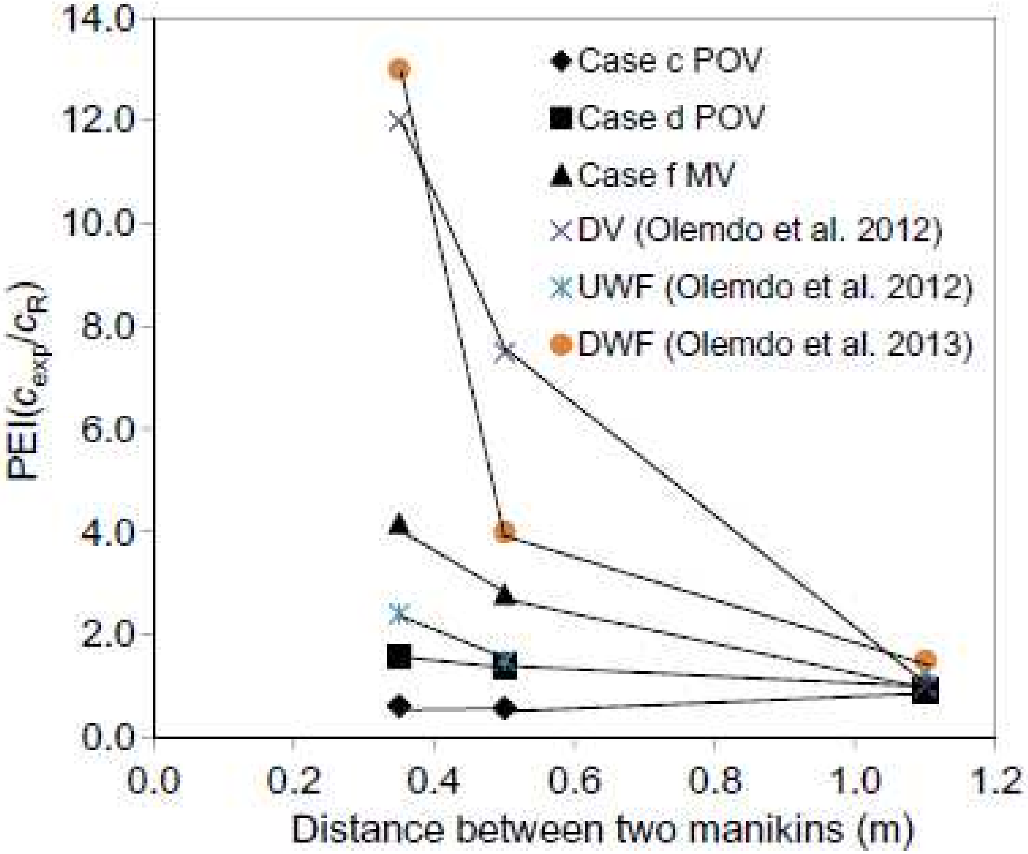


Instantaneous velocity of breathing



Instantaneous velocity at P_s, P_c and P_t (Cao et al. 2014, ASHRAE)

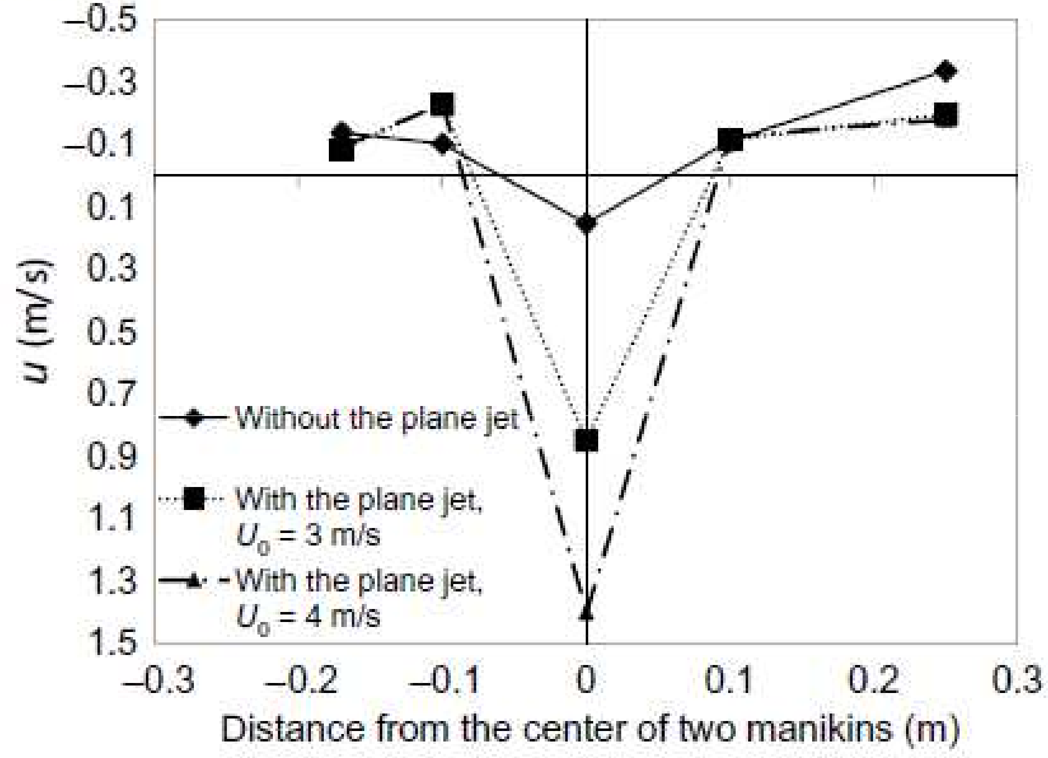
Personal Exposure in various ventilation modes



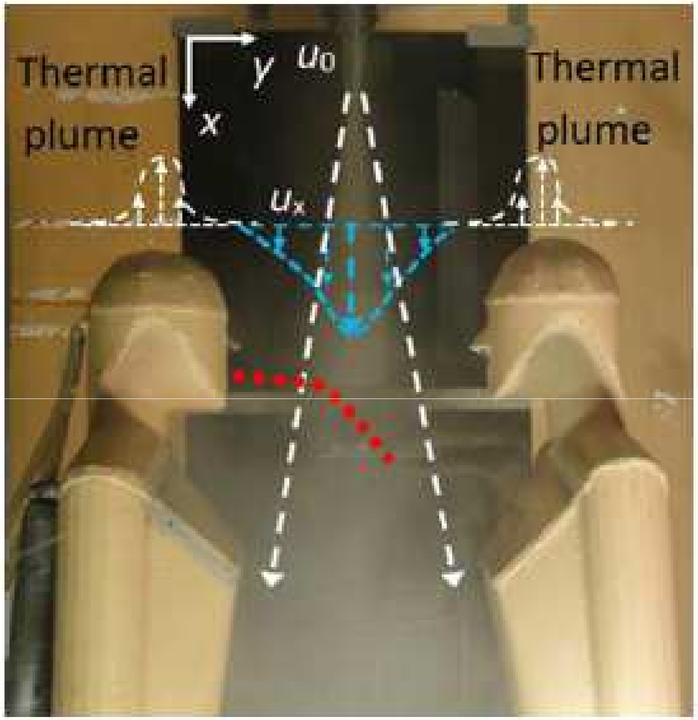
- Comparison of the c_{exp}/c_R values obtained using different ventilation methods

Airflow velocity close to the two BTMs

(a)



(b)

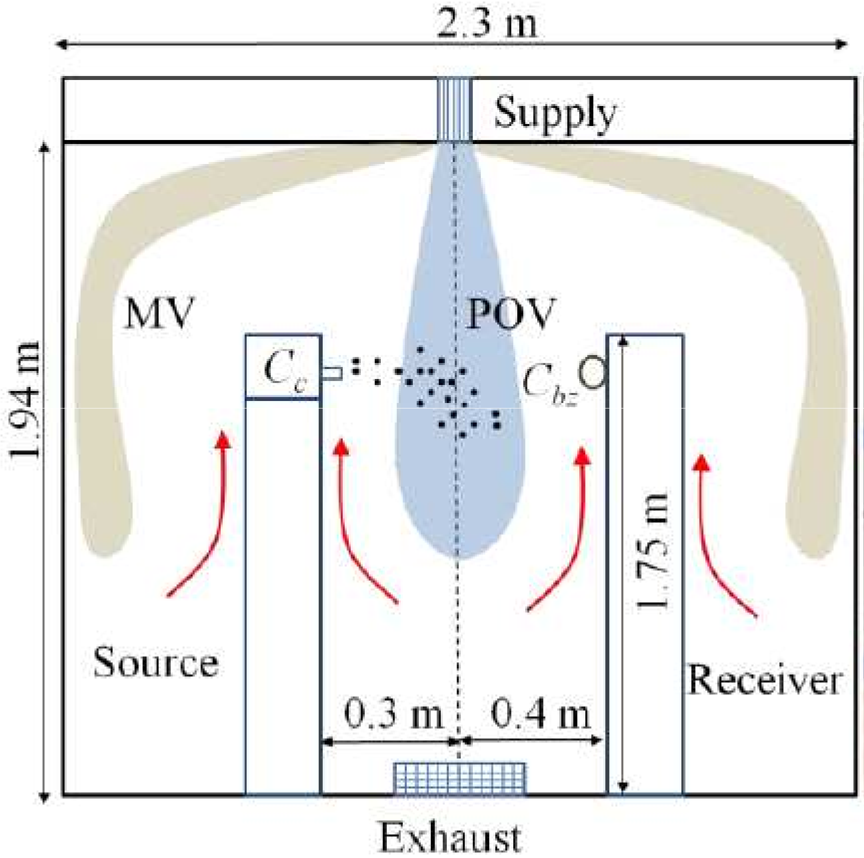


- (a) Velocities above the manikin for a distance of 0.35 m between two manikins and (b) The downward plane jet from the jet diffuser, and the upward thermal plume, visualized for Case d when the supply airflow velocity was 3.0 m/s

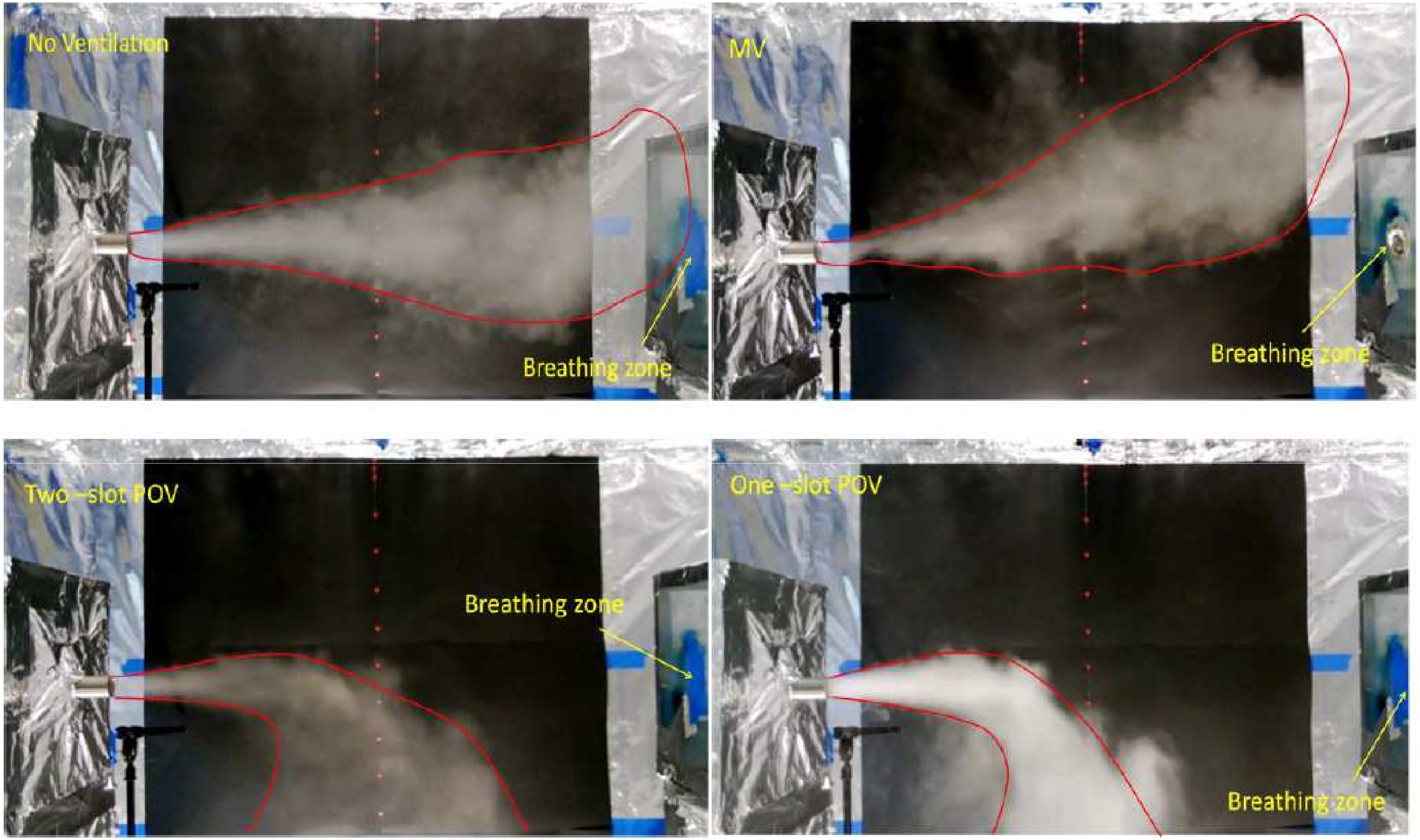
Conclusions (II)

- The personal exposure to the respiratory activities may be very high when the distance between two people becomes very close.
- The downward airflow in POV/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 is significantly reduced by using POV/PZV with higher supply air velocity.

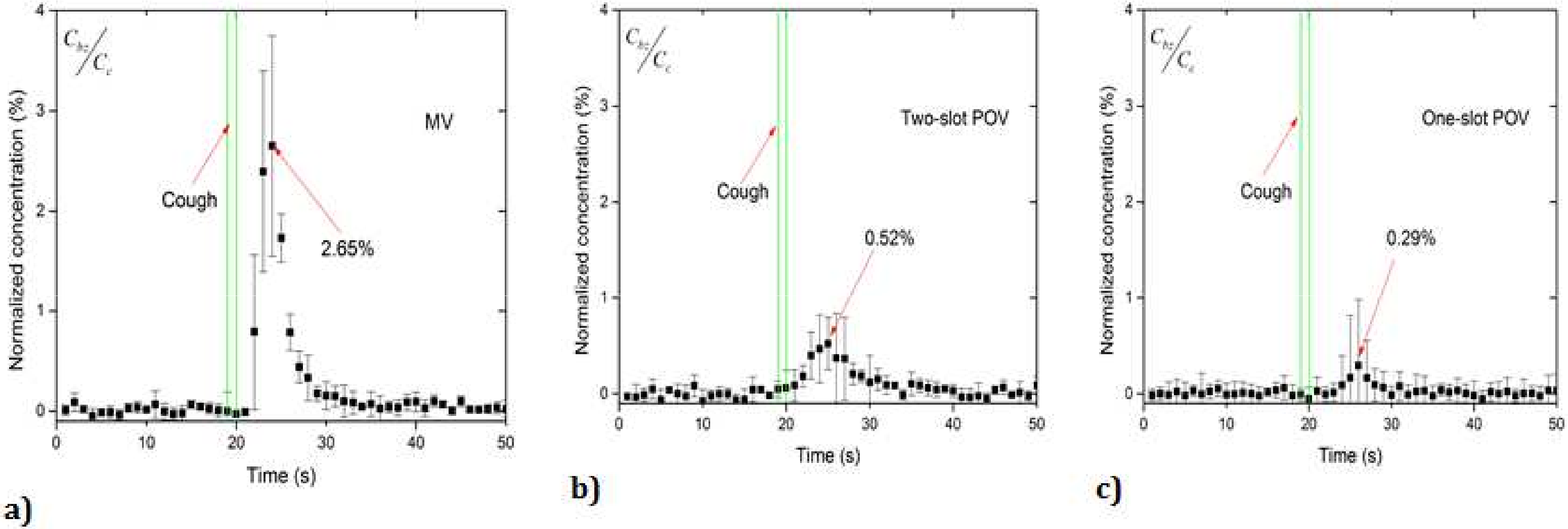
Case study 3 – POV/PZV against coughing



- Schematic of the chamber and experimental setup



Smoke visualization of a cough jet under different ventilation patterns (Liu et al. 2014 Indoor Air Conference)

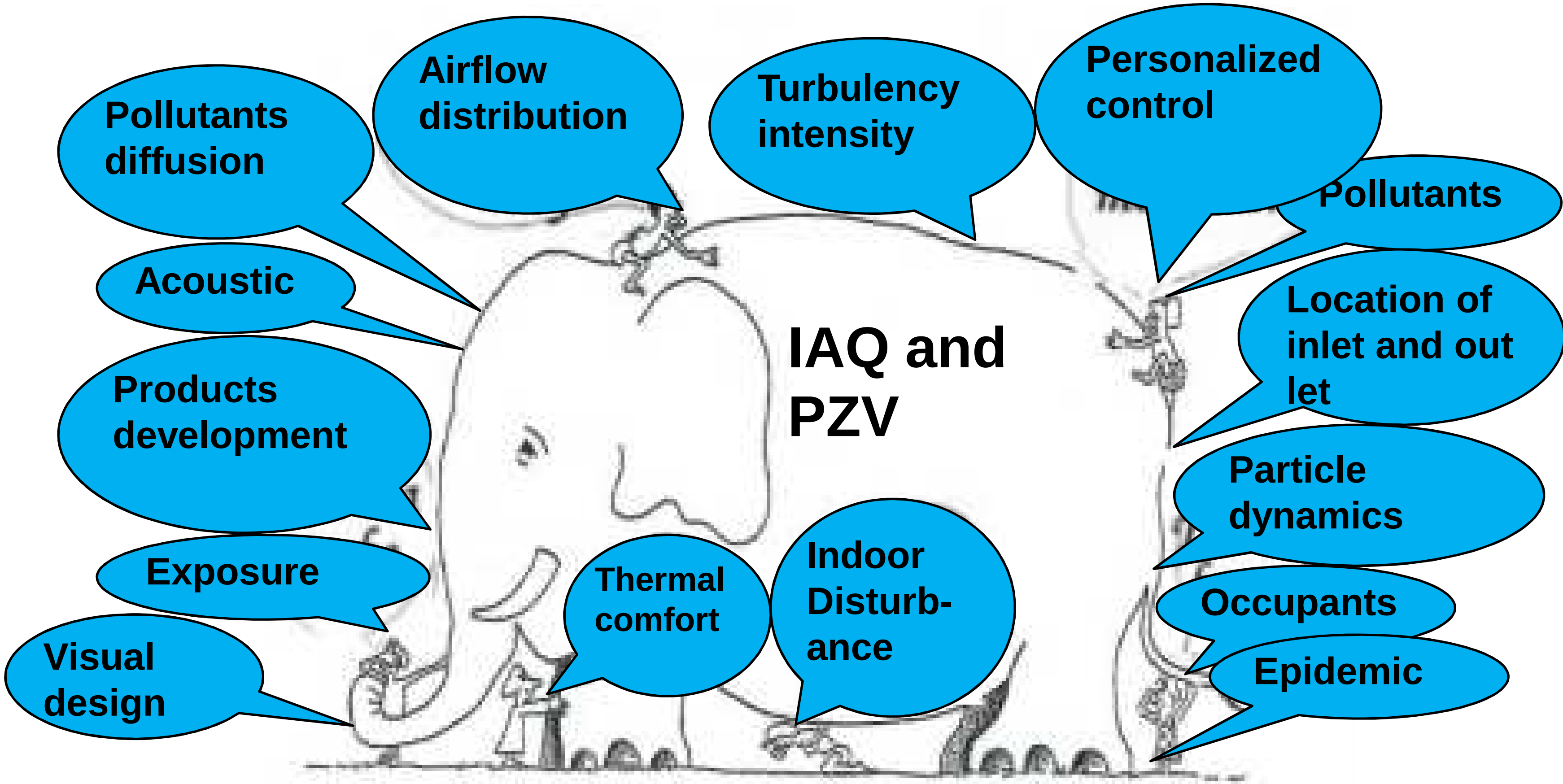


Normalized concentration of coughed particles (0.77 μm) in the breathing zone (Liu et al. 2014 Indoor Air Conference)

Conclusions (III)

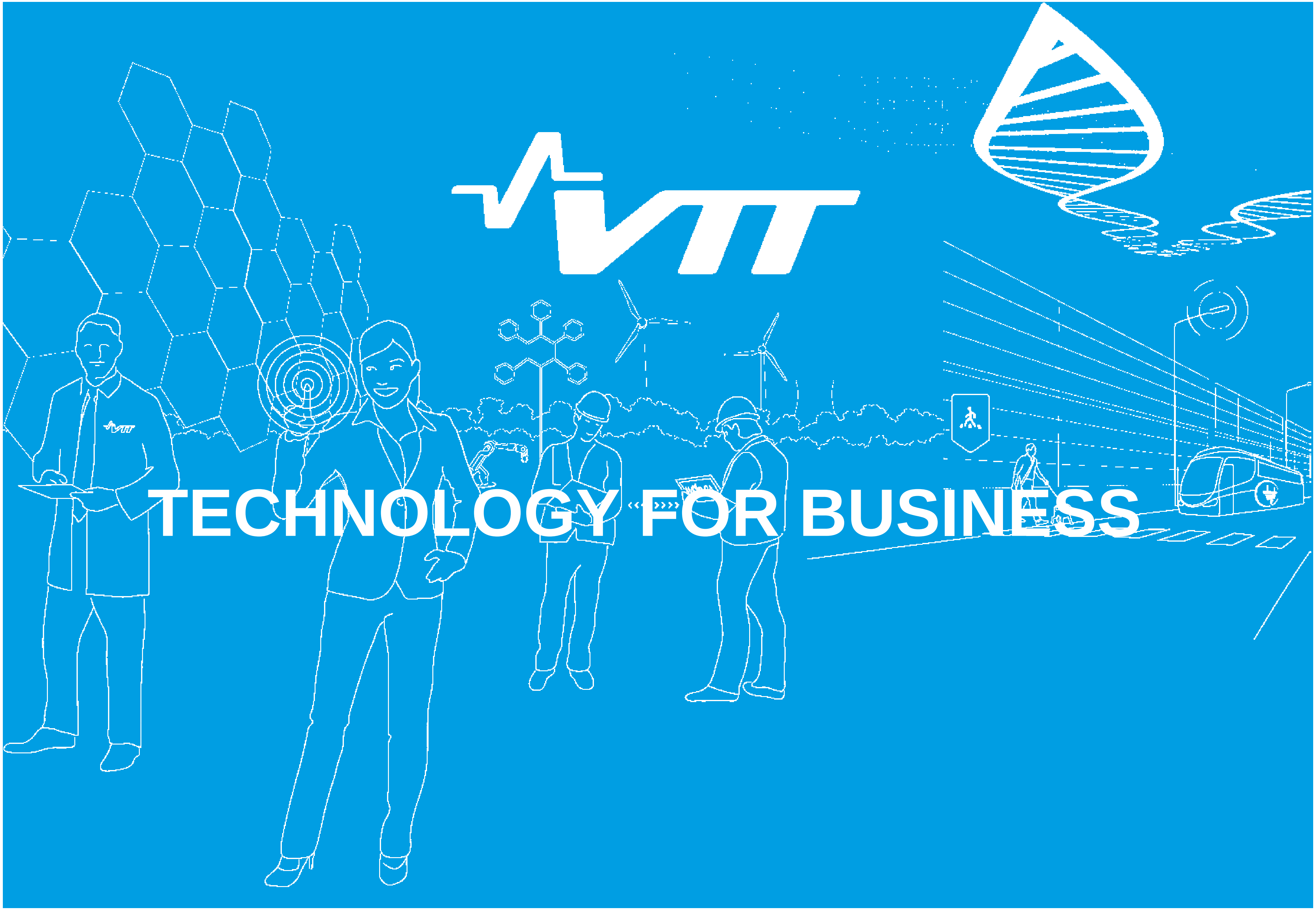
- The PZV is able to reduce the risk of direct exposure to particles coughed by another person by deflecting a high momentum cough jet.
- The peak exposure level in the breathing zone of the receiver occupant is decreased up to one order of magnitude compared to a MV system.
- While maintaining the airflow rate, the one-slot POV presents an enhanced protection efficiency than the two-slot POV.

The big elephant of PZV has a long way to go



Acknowledgments

- Thanks for the financial support from the Academy of Finland through the post-doctoral project POWER-PAD (NO. 259678).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