Control of exposure to exhaled air from sick occupant with wearable personal exhaust unit

Bolashikov, Zhecho Dimitrov; Melikov, Arsen Krikor; Barova, Maria I.

Published in:
Proceedings of Indoor Air 2014

Publication date:
2014

Topic B3: Control of indoor environment

CONTROL OF EXPOSURE TO EXHALED AIR FROM SICK OCCUPANT WITH WEARABLE PERSONAL EXHAUST UNIT

Zhecho D BOLASHIKOV[1,*], Maria I BAROVA[1] and Arsen K MELIKOV[1]

[1]International Center for Indoor Environment and Energy, Department of Civil Engineering, Technical University of Denmark, Kgs. Lyngby, Denmark

[*]Corresponding email: zdb@byg.dtu.dk

Keywords: Wearable personalized exhaust unit, Contaminant control, Hospital ventilation, Airborne cross-infection, Full-scale measurements

SUMMARY

Exposure reduction to exhaled air from a sick doctor wearing personal exhaust unit incorporated in headset-microphone was studied. Experiments were performed in a full-scale test room furnished as a double-bed hospital room with overhead ventilation at 3, 6 and 12 ACH. Room air temperature was 22 °C. Breathing thermal manikin with realistic body and breathing cycle was used to mimic doctor. Second thermal manikin and heated dummy were used to resemble lying patients. Exhaled air by the doctor was mixed with tracer gas to mimic pathogens. The unit was positioned frontally by the mouth of the doctor at three different distances. It was operated at 0.25 or 0.50 L/s under mixing background ventilation at 3 ACH. The use of wearable personal exhaust resulted in cleaner air in the room compared to mixing alone at 12 ACH. The high potential to capture exhaled air makes the device efficient against airborne pathogens.

INTRODUCTION

Hospital ventilation systems should be designed differently from communal ventilation, as in the former case the main sources of contamination (pathogens) are released indoors. Hence conventional methods for filtering or cleaning the air will not be efficient (Bolashikov et al. 2009). Elevated ventilation rates exceeding 6 ACH and up to 20 ACH are recommended in hospitals, AIA (2001), CDC (2003) and ASHRAE/ASHE 170 (2008). Elevated ventilation rates brings the following drawbacks: 1) significantly increased energy consumption in air handling and transport; 2) increased investment and maintenance costs in hospitals due to oversized HVAC systems and large unoccupied spaces to facilitate them; 3) elevated risk from thermal discomfort for occupants. The entire volume of space is ventilated without considering the pathogen infectivity and the number of infective sources present. Hence spaces are under-ventilated with respect to generated airborne pollution in the room.

An efficient way to evacuate the respiratory (breathing, coughing) generated pathogens indoor is to capture them close to source origin, i.e. near the breathing zone of the sick occupant. Incorporating localized exhaust at the hospital bed at the head sides can ensure efficient extraction of exhaled air by sick individuals. This will reduce the airborne pathogen spread indoors at greatly reduced ventilation rates, Bolashikov (2010), Melikov et al. (2010) and Melikov et al. (2011). However this method will work as long as the sick occupant stays lying in bed. Medical staff or visitors can be sick and can release airborne pathogens with

exhaled/coughed air. In this case the bed incorporated ventilation will not work in reducing the airborne spread in the surroundings. A local exhaust orifice aesthetically incorporated into the mouthpiece of a headset could be used. It will capture the expired air directly within the breathing zone of the occupant. The captured air can be then cleansed and filtered via a portable unit attached to the clothing of the user. The concept of using headset microphone incorporated personalized ventilation (PV) is not new. Such wearable PV was used to supply clean air directly into the breathing zone of the occupant with great efficiency at flow rates lower than 0.5 L/s, Bolashikov et al. (2003), Kaczmarczyk et al. (2006), Zhu et al. (2008) and Bolashikov (2010). However, using the PV device to extract locally the respired air has not yet been investigated.

In this paper results are presented showing the potential of wearable exhaust PV unit used by infected doctor to reduce the level of exposure for patients in a double bed hospital room.

METHODOLOGIES

Experiments were designed and performed in a climate chamber with dimensions 4.75 m x 4.65 m x 2.60 m (W x L x H) furnished to simulate double-bed hospital room. The distance between the beds was set to 1.3 m, Figure 1. Five ceiling-mounted light fixtures (6 W each) provided the background lighting. The chamber was located in a larger hall, where the temperature was kept constant and equal to the air temperature in the test room. A dressed breathing thermal manikin (1.02 Clo) with realistic body geometry and surface temperature distribution was used to resemble a “infected doctor” standing next to one of the two beds: 0.55 m away, Melikov and Kaczmarczyk (2007). The doctor was facing the patient. The manikin consisted of 17 sections. The manikin was equipped with artificial lung to simulate breathing sick doctor. One full breathing cycle consisted of inhalation – 2.5 s, exhalation – 2.5 s and break – 1 s. The characteristics of the breathing cycle were: inhalation nose, exhalation mouth with tidal flow rate of 0.24 L/s (6 L/min), Hyldgaard (1994). A second thermal manikin of 23 body segments was used to simulate sick patient lying in one of the beds closest to the doctor. The manikin was dressed with hospital gowns of 0.38 Clo. Each manikin released on average 60 W sensible heat. A heated dummy with simplified body geometry was used to mimic the second patient lying in the other bed. It released also around 60 W of heat. The two beds were placed in parallel and both patients were facing the ceiling, Figure 1. During all experiments overhead mixing ventilation was used. The supply air was 100% outdoor air. The supply diffuser was a solid face plate square diffuser and a 3-way-discharge. Two square ceiling mounted diffusers with perforated face plate were used to exhaust the air from the room. They were installed above the heads of the two patients. The exhausted air was equally balanced between the two diffusers.

For the purpose of the experiment the headset incorporated wearable exhaust *PV* (*WEPV*) was simplified to test the effectiveness of capturing the contaminated exhaled air: a circular exhaust nozzle (d = 0.03 m) attached to a flexible pipe and positioned on a stand in front of the doctor’s mouth, Figure 2. The *WEPV* was connected to a separate ventilation system consisting of flexible pipe, reduction, 2 dampers, 2 iris orifices and a fan. The exhaust flow rate through the nozzle was 0.25 L/s or 0.5 L/s. The dumpers, the orifices and the fan were located outside the climate chamber, within the tall hall. The exhaled air captured by the *WEPV* was exhausted into the exhaust of the tall hall not to contaminate the surroundings.
The experiments without the headset device were performed at 3, 6 and 12 ACH. During the experiments with the headset the background ventilation in the chamber was kept at 3 ACH. The headset was positioned either 0.02 or 0.04 or 0.06 m from the mouth of the doctor, Figure

2c. Room air temperature was kept at 22˚C, while the relative humidity was not controlled but was measured to vary between 30% and 40% during all conditions. Air temperature and flow rate of supplied and exhausted air, air temperature inside the test room and the amount of air exhausted by the *WEPV* were constantly recorded and controlled to keep the set values.

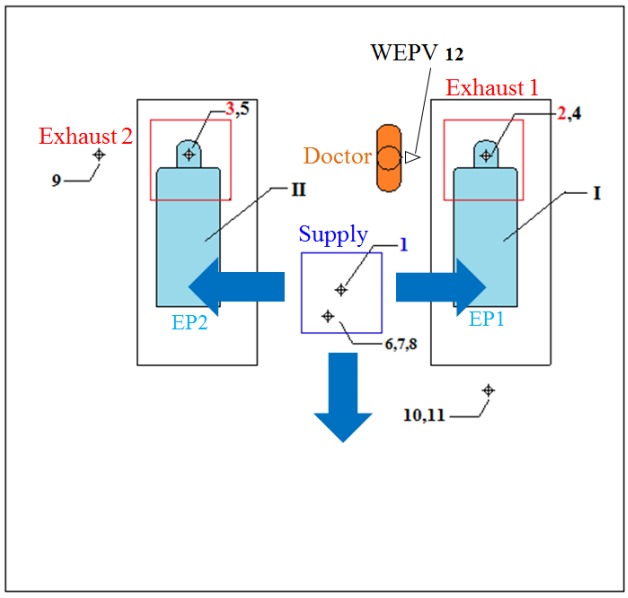
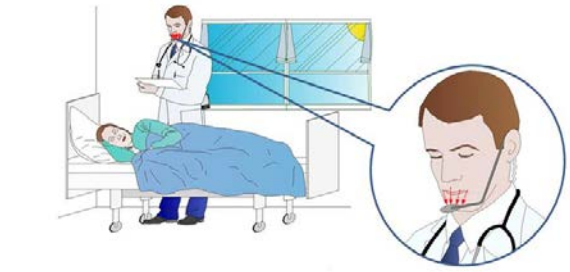
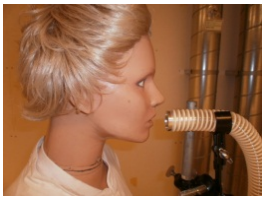


Figure 1. Experimental set-up and locations of the sampling points for the tracer gas concentration measurements; top view: I- exposed patient 1(*EP1*), II- exposed patient 2(*EP2*), 1 – supply, 2 – exhaust over *EP1*, 3 – exhaust over *EP2*, 4 – mouth of EP1, 5 – mouth of *EP2*, 6 – centre of the room 1.7 m above the floor, 7 – centre of the room 1.1 m above the floor, 8 – centre of the room 0.1 m above the room, 9 –left from *EP2* 1.7 m above the floor, 10 – at feet of *EP1* 1.7 m above the floor, 11 – at feet of *EP1* 1.1 m above the floor, 12 – *WEPV* exhaust.



a)

b)



c)

Figure 2. Headset incorporated wearable PV exhaust: a) conceptual design, b) tested nozzle geometry, c) simplified design

During all experiments *R 134a* tracer gas was used. It was dosed in the air exhaled by the breathing thermal manikin used to simulate the sick doctor. The dozed tracer gas was kept the same for all tested cases, i.e. 4.2 mg/s. The tracer gas was used to simulate airborne droplets

and droplet nuclei of less than 3 μm aerodynamic diameter, Camargo-Valero et al. (2011) and Li et al. (2014), that may carry one or many pathogens. The exhaled air from the manikin (doctor) was also heated to ensure a density close to that of air exhaled by a human being. In order to avoid transport of tracer gas (*R 134a*) from the surrounding hall, in case of gas leakage from gas bottle, the experimental chamber was kept over-pressurized at 1.6±0.2 Pa. The tracer gas concentration was measured with two sets of multi gas sampler and analyzer based on the photo acoustic principle at 12 points, Figure 1: 1) in ventilation supply, 2) in exhaust over exposed patient 1 (*EP1*), 3) in exhaust over the exposed patient 2 (*EP2*), 4) at the mouth of *EP1*, 5) at the mouth of *EP2*, 6) at the centre of the room 1.7 m above the floor, 7) at the centre of the room 1.1 m above the floor, 8) at the centre of the room 0.1 m above the floor, 9) left from *EP2* (0.55 m distance from the mouth) 1.7 m above the floor, 10) close to the feet of *EP1* at 1.7 m above the floor, 11) close to the feet of *EP1* at 1.1 m above the floor. The twelfth measurement point was for measuring the concentration in the air exhausted by the headset. Therefore this point was used for the conditions that included the headset device. Neither the manikin simulating *EP1* nor the heated dummy (*EP2*) were breathing. The sampling tube of *R 134a* was placed at the mouth 0.005 m away. As reported in the literature the tracer gas concentration measured in this way is equal to the tracer gas concentration in the air inhaled by the breathing thermal manikin, Melikov and Kaczmarczyk (2007).

Experimental Procedure

At the start of the experiments both thermal manikins and the dummy were switched on. For the experiments with headset the device was positioned in front of the mouth of the doctor at any of the three tested distances and the system exhausting the exhaled air was adjusted to the tested air flow rate. All measurements commenced after steady-state conditions were achieved, i.e. steady tracer concentrations at the centre of room and in both TV exhausts (located at the ceiling) measurement locations. After reaching a steady state, 15 samples for each measurement point were acquired.

Analyses of Results

The obtained tracer gas concentration data were normalized (ε) according to the following equation:

$$\varepsilon = (C_m - C_s)/(C_m(3ACH) - C_s(3ACH))$$

,where ε is normalized concentration (evacuation effectiveness), C_m is concentration acquired in the measuring location, *Cs* is concentration acquired in total volume ventilation supply, $C_m(3ACH)$ – concentration in the measuring point at 3ACH (without headset) and $C_s(3ACH)$ is concentration in the total volume ventilation supply at 3ACH (without headset). This in fact presents the evacuation performance of the WEPV unit or dilution efficiency (in the cases of mixing ventilation alone at 6 and 12 ACH) relative to the pollutant dilution in the room when ventilated at 3 ACH and no source control applied. A value of 1 means that the evacuation effectiveness was like the dilution provided by mixing ventilation operated at 3 ACH. The lower the value than 1 the better the performance of the ventilation system with respect to pollutant evacuation is.

RESULTS AND DISCUSSION

The measured concentration of *R 134a* tracer gas and its normalized value are presented in Figure 3 and Figure 4. The following abbreviations are used in the legend of Figure 3 and

Figure 4: *ACH*: air changes per hour, *W/O*: without, *HS*: headset (*WEPV*). The abbreviations used to code the studied cases should be read as follows: 1st is the background ventilation level in the room, 2nd comes the presence or absence of headset within the breathing zone of the occupant, 3rd is the exhaust air flow of the *WEPV* unit tested and last, i.e. 4th, is the distance the unit was positioned from the mouth of the occupant (thermal manikin). For example the abbreviation *3 ACH_HS 0.25 L/s_0.02 m* should be understood as: background room ventilation is at 3 ACH, the doctor is wearing the headset (*WEPV*), which exhausts 0.25 L /s and is located at 0.02 m away from the doctor's mouth.

As can be seen from Figure 3 exhausting 0.25 L/s locally by the *WEPV* helped reduce the spread of exhaled air from the doctor into the room. Increasing the distance between the doctor's moth and the nozzle resulted in increase of the normalized concentration, i.e. decrease in evacuation effectiveness. The best performance at this exhaust flow rate of 0.25 L/s was when the *WEPV* was placed 0.02 m from the mouth of the doctor. At this case the evacuation performance of the *WEPV* unit was even better compared to the dilution provided by the total volume ventilation operated alone at 12 ACH. When the doctor was with the *WEPV* the normalized concentration in all measured locations, but at the feet of EP1, at 1.7 m above the floor, was lower compared to the case when the room was ventilated at 12 ACH and the device was not used. When the *WEPV* was set 0.04 m from the mouth of the doctor its evacuation performance was still better compared to total volume ventilation alone at 6 ACH. Similarly to the case when the *WEPV* was 0.02 m away from the doctor's mouth the highest normalized concentration of exhaled air was measured at the feet of *EP1* at 1.7 m above the floor. This trend was also noticed when the *WEPV* was 0.04 m from the mouth of the doctor. Apparently the airflow pattern in the room pushes the pollutants towards the feet of the patients: 3-way supply diffuser. This needs to be further studied.

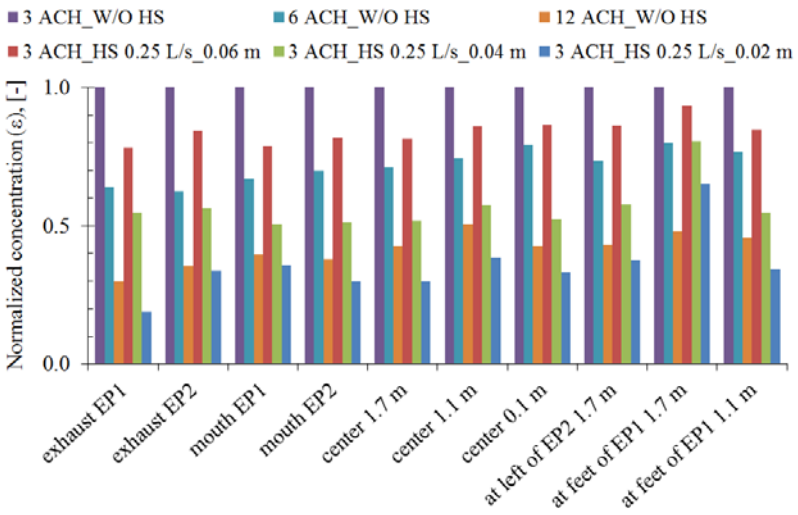


Figure 3. Normalized concentration, when the doctor was without or with the WEPV exhausting at 0.25 L/s and positioned 0.02, 0.04 or 0.06 m distance from doctor's mouth.

Comparison of the evacuation effectiveness of the unit when exhausting at 0.50 L/s is shown in Figure 4. The distance at which the *WEPV* was placed from the mouth affected its performance. The further the *WEPV* was moved from the mouth the lower the evacuation performance was. At the closest distance of 0.02 m the *WEPV* was evacuating the exhaled air better compared to the dilution provided by the total volume ventilation when operated at 12 ACH. However at the mouth of EP1, the patient whose bed was closest to doctor, the normalized concentration was higher for the case *3 ACH_HS 0.50 L/s_0.02 m* compared to *12*

ACH_W/O HS. It is well known that the velocity distribution across exhaust opening is not uniform and is influenced by wake formations near the rim of the nozzle resulting in pulling background room air as well, Awbi (2003). The exhaust flow pulled more room air at the *WEPV* nozzle rim, which resulted in less exhaled air captured. Also the normalized concentration at the feet of EP1 at 1.7 m above the floor was slightly higher compared to mixing alone at 12 ACH, Figure 4. Again the airflow pattern in the room might have pushed the pollutants towards the feet of the patients. This needs to be further studied.

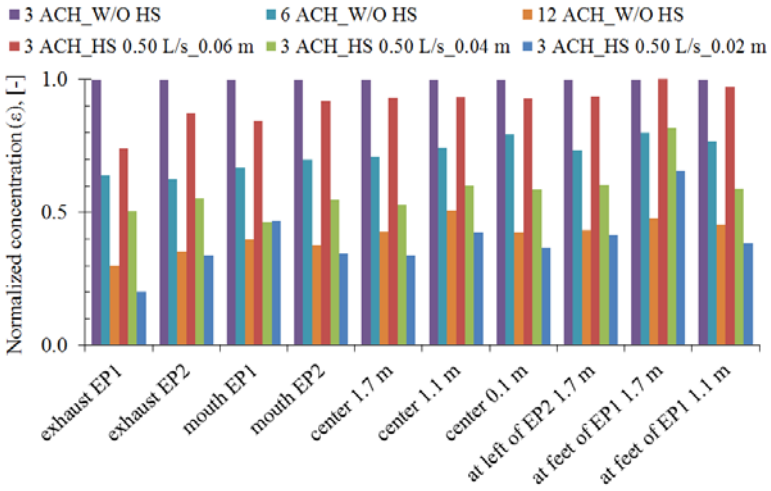


Figure 4. Normalized concentration, when the doctor was without or with the WEPV exhausting at 0.50 L/s and positioned 0.02, 0.04 or 0.06 m distance from doctor's mouth.

WEPV was performing slightly better when exhausting 0.25 L/s compared to 0.50 L/s at all measured locations, Figure 5. This again can be explained by the fact that under the increased exhaust flow the WEPV pulled more room air on the nozzle sides resulting in less exhaled air captured. This can also be seen in the tracer gas concentration measured in the air captured by the *WEPV*, Figure 6. As can be noticed the concentration of *R 134a* when *WEPV* positioned at 0.04 and 0.02 m and was exhausting 0.25 L/s was higher than when it was exhausting 0.05 L/s suggesting less dilution with room air. The *WEPV* unit shows great potential at reducing the spread of pathogen laden air indoors. The present paper shows that applying local control, i.e. exhausting expired air within the breathing zone, can result in significantly reduced spread of infected exhaled air in hospital wards. This will result in lowered exposure of occupants to airborne pathogens and decreased supply of background air to dilute the room air. For the measurement with the headset the mixing ventilation was operated at 3 ACH. The use of the headset device showed that the background concentration in the measured locations was lowered to that at 12 ACH background ventilation and without the headset. It is important to be note that the nozzle for this condition was placed 0.02 m away from the doctor's mouth, typical position of a headset microphone piece.

Previous research on the headset PV showed that the device is also very efficient in supplying clean air into the inhalation Bolashikov et al. (2003), Zhu et al. (2008) and Bolashikov (2010). In practice, the headset can be made with a micro-pump (reversible to supply or exhaust the air) enclosed in a small casing with a mini-filter and mini-UVGI (ultra violet germicidal irradiation). The box can be worn attached to a belt around the waist of the user. The pump can be reversed and can start exhausting the exhaled air. Obviously further improvements in the design and airflow direction control of the headset are needed in order to be comfortable and not disturbing for wearing. Its small dimensions and simplicity will allow its application

not only in hospital environment but in many densely occupied spaces: at reception desks, auditoriums, public transport services, airplanes, etc.

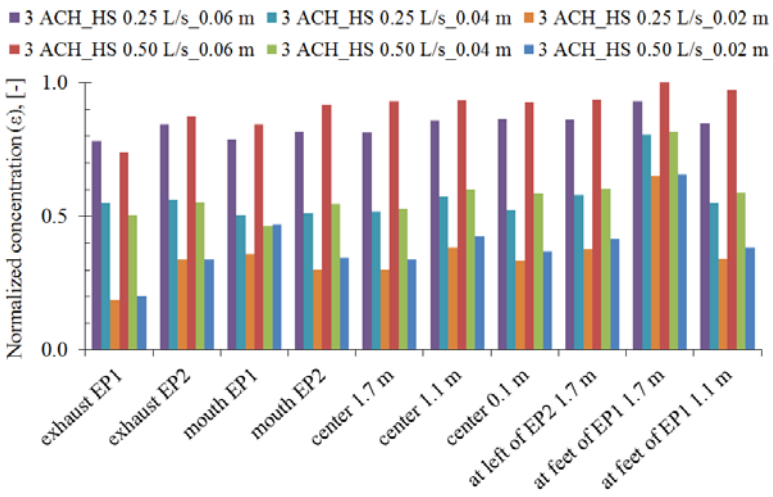


Figure 5. Normalized concentration when *WEPV* was exhausting 0.25 L/s and 0.50 L/s and was positioned 0.02, 0.04 or 0.06 m distance from doctor's mouth.

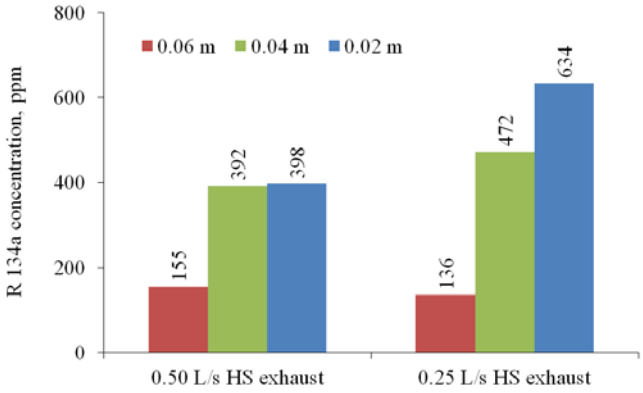


Figure 6. Tracer gas concentration measured at the exhaust of the headset *WEPV* under the two exhaust flows.

CONCLUSIONS

The present study focused on the reduction in exposure to exhaled air by a "sick" doctor wearing headset incorporated exhaust device (*WEPV*) in a simulated double bed hospital room ventilated by mixing air distribution.

- The use of the headset exhaust device at 3 ACH background ventilation rate reduced the exposure of the patients as well as the background tracer gas concentration; the reduction was higher at suction flow rate of 0.25 L/s than at 0.50 L/s;
- The increase of the distance of the device from the mouth from 0.02 m to 0.06 m reduced its ability to evacuate the exhaled air (evacuation effectiveness);
- When the *WEPV* was 0.02 m from the doctors mouth it reduced the spread of exhaled air better than the dilution provided by mixing ventilation at 12 ACH for both exhaust flows tested of 0.25 and 0.50 L/s;
- Similarly, when the *WEPV* was 0.04 m from the doctors mouth it reduced the spread of exhaled air better than the dilution provided by mixing ventilation at 6 ACH for both exhaust flows tested of 0.25 and 0.50 L/s;

ACKNOWLEDGEMENT

This research was supported by the Danish Agency for Science Technology and Innovation. Project No. 09-064627.

REFERENCES

AIA (2001) Guidelines for design and construction of hospital and health care facilities. American Institute of Architects, Academy of Architecture for Health, Facilities Guidelines Institute, United States, Washington, DC.

ASHRAE/ASHE Standard, 170 (2008) Ventilation of Health Care Facilities. American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., Atlanta, GA.

Awbi H (2003) *Ventilation of Buildings*. Second edition, Spon Press, Taylor & Francis Group, London and New York.

Bolashikov ZD, Nikolaev L, Melikov AK, Kaczmarczyk J and Fanger PO (2003) Personalized ventilation: air terminal devices with high efficiency. In: Proceedings of Healthy Building, vol. 2, 850–5, Singapore.

Bolashikov ZD and Melikov AK (2009) Methods for air cleaning and protection of building occupants from airborne pathogens. *Building and Environment*, **44**, 1378-1385.

Bolashikov ZD (2010) Advanced Methods for Air Distribution in Occupied Spaces for Reduced Risk from Air-Borne Diseases and Improved Air Quality. Ph.D. thesis, R-239, Byg, DTU, Denmark.

Camargo-Valero MA, GIlkeson CA, Noakes CJ (2011) Tracer-gas as a surrogate method for tracking airborne pathogen transport in indoor environment. In: Proceedings of Indoor Air, Paper ID: a586 4.

CDC (2003) Guidelines for environmental infection control in health-care facilities. Department of Health and Human Services Centers for Disease Control and Prevention, Atlanta, GA, U.S.

Hyldgaard CE (1994) Humans as a source of heat and air pollution. In: Proceedings of ROOMVENT, 4th International Conference on Air Distribution in Rooms, 414–433, Krakow, Poland.

Kaczmarczyk J, Melikov AK, Bolashikov Z, Nikolaev L and Fanger PO (2006) Human response to five designs of personalized ventilation. *International Journal of Heating Ventilation and Refrigeration Research*, **12 (2)**, 367-384.

Li F, Liu J, Pei J, Lin CH and Chen Q (2014) Experimental study of gaseous and particulate contaminants distribution in an aircraft cabin. Atmospheric Environment, **85**, 223-233.

Melikov AK and Kaczmarczyk J (2007) Indoor air quality assessment by a breathing thermal manikin. *Indoor Air*, **17 (1)**, 50-59.

Melikov A, Bolashikov Z, Brand M (2010) Experimental investigation of performance of a novel ventilation method for hospital patient rooms. In: Proceedings of 21st Congress of International Federation of Hospital Engineering, Tokyo Japan, 17-19 November.

Melikov A, Bolashikov Z, Georgiev E (2011) Novel ventilation strategy for reducing the risk of cross infection in hospital rooms. In: Proceedings of Indoor Air, Paper 1037.

Zhu SW, Bolashikov Z and Melikov AK (2008) Examination on performance of headset incorporated personalized ventilation unit using CFD method. In: Proceedings of Indoor Air, Paper ID: 1018, Copenhagen. Denmark, 17-22 August.