Novel bed integrated ventilation method for hospital patient rooms

Bivolarova, Mariya Petrova; Melikov, Arsen Krikor; Kokora, Monika ; Mizutani, Chiyomi ; Bolashikov, Zhecho Dimitrov

Published in:
Proceedings of ROOMVENT 2014, 13th SCANVAC International Conference on Air Distribution in Rooms

Publication date:
2014

In Proceedings of ROOMVENT 2014, October 19-22, Sao Paolo, Brazil, pages 49-56.

NOVEL BED INTEGRATED VENTILATION METHOD FOR HOSPITAL PATIENT ROOMS

Mariya P. Bivolarova[1], Arsen K. Melikov[1], Monika Kokora[1,2] , Chiyomi Mizutani[3] and Zhecho D. Bolashikov[1]

[1]International Centre for Indoor Environment and Energy, Department of Civil Engineering, Technical University of Denmark, Kgs. Lyngby, Denmark.
[2]Department of Environmental Engineering, Warsaw University of Technology, Warsaw Poland.
[3]Department of Textile and Clothing Science, Otsuma Women's University, Tokyo, Japan.

Abstract

This study presents a novel method for advanced ventilation of hospital wards leading to improved air quality at reduced ventilation rate. The idea is to evacuate the bio-effluents generated from patients' body by local exhaustion before being spread in the room. This concept was realized by using a mattress having a suction opening from which bio-effluents generated from human body are exhausted. Experiments were conducted in a full-scale two-bed hospital room mock-up, 4.7 x 5.3 x 2.6 m^3 (W x L x H). Only one of the patients' beds was equipped with the ventilated mattress. The room was air conditioned via mixing total volume ventilation system supplying air through a ceiling mounted diffuser. All experiments were performed at room air temperature of 23 °C. A thermal manikin was used to simulate a polluting patient on the bed equipped with the ventilated mattress. Two heated dummies were used to simulate an exposed patient and a doctor. Bio-effluents from the body were simulated by tracer gases released from manikin's armpits, groin region and feet. Contaminants' distribution in the occupied zone was analyzed. The performance of the ventilated mattress was assessed based on pollution concentration in the breathing zone of the exposed patient and the doctor. Various experiments were performed at three background ventilation rates, namely 27, 55 and 109 L/s (1.5, 3 and 6 air change rates, ACH). Two openings in the mattress, located at the feet and the pelvic region, were used to exhaust the air through the mattress at 1.5 L/s. The obtained results showed that the use of the advanced ventilation together with background ventilation rate of 1.5 ACH significantly improved the air quality in the room compared to the air quality in the case of 6 ACH background ventilation only.

Keywords: human bio-effluents, advanced ventilation, inhaled air quality, reduced exposure

1 Introduction

The quality of air in hospitals and other health care facilities is important not only for the health and recovery of the patients, but also for the health, comfort and work performance of the staff. Some studies have shown that hospital workers reported more indoor air problems and indoor air related symptoms (i.e. sick building syndrome symptoms) than the staff employed in the office buildings (Hellgren and Reijula 2006, Nordstrom et al. 1995).

In the indoor environment there are various pollutants that can reduce the air quality. Especially hospitals can contain a wide range of gaseous and biological contaminants (Saad

2003). People can be one of the major sources of both types of contaminants. Some of the pollutants found in the air can be generated from occupants' biological processes (breathing, perspiration, etc.). For instance, sweating allows the human body to regulate its temperature, but if not removed from the body, sweat left sit can produce a strong odour contributing greatly to the scent known as body odour (Yamazaki et al. 2010). Various non-volatile and volatile compounds emitted from people´s body (so-called "bio-effluents") are likely to create unpleasant odours and thus significantly to affect occupants olfactory perception of the air quality.

One way of minimizing the indoor air pollutants is to supply huge amounts of outdoor air to the space to dilute their concentration. The requirements for ventilation of health care facilities in the present standards are therefore normally high, e.g. it is recommended the ventilation rate for recovery wards and normal patient rooms to be up to 6 ACH (ASHRAE Standard 2008). However, this method not only results in high energy consumption, but also it may cause thermal discomfort because of draft. In addition depending on the type and design of the air distribution method (mixing and/or displacement air distribution, etc.) it may even bring the contaminants closer to the occupants.

In the recent years, advanced air distribution methods have been developed and studied (Melikov 2011). One of the novel methods based on advanced air distribution is a device, named Hospital Bed Integrated Ventilation and Cleansing Units (HBIVCU) (Melikov 2011), Melikov et al. 2010). These units, being mounted on the bed of the patients close to their heads, have proven to act as an efficient means to reduce the risk of airborne cross-infection.

The advanced techniques for air distribution and control of pollution dispersion can lead to exposure reduction and energy savings. In the present study a new pollution control system in the bed microenvironment especially for patients unable to move frequently from their beds was developed and tested. A local exhaust within the mattress of the bed (ventilated mattress), where the exhaust surface was facing the body of the lying person was implemented. The idea behind the ventilated mattress is to capture and exhaust locally the contaminants released from the body. The main purpose of this study was to find out how efficient this method will be in terms of occupants exposure to bio-effluents at reduced background ventilation rate compared to higher ventilation rates. A second objective of the study was to determine which will be the best position for the local exhaust opening on the mattress in order to decrease the bio-effluents to a minimum level.

2 Method

Full-scale experiments were performed in a climate chamber with dimensions: 4.7 m (width), 5.3 m (length), and 2.6 m (height). Mixing air distribution (MV) was used to supply 100% outdoor air to the chamber through a square diffuser mounted in the middle of the ceiling. No recirculation was used during the experiments. The air was exhausted through two perforated square diffusers located symmetrically on the ceiling (Figure 1).

The climate chamber was furnished to simulate a two-bed hospital room for patient care. The distance between the beds was adjusted to be 1.06 m. On each bed with dimensions 0.9 m x 2.0 m x 0.8 m (W x L x H) there was a mattress with thickness of 0.06 m. The mattresses were covered with a thin cotton sheet. A thermal manikin and a heated dummy with a simplified body form ("head", "torso" and "legs") were used to simulate lying patients in the two beds. The thermal manikin has the physics of an average Scandinavian female with a height of 1.68 m and size 38. The manikin consists of 23 body parts. Each body part was individually controlled to maintain surface temperature equal to the skin temperature of an average person in a state of thermal comfort. The heated dummy lying on the second bed was adjusted to generate heat with power of 80 W. Both simulated patients were lying on their

backs during the experiments. A second heated dummy (230 W) was used to simulate a doctor standing next to the manikin's bed at a 0.83 m distance from the manikin's mouth. During the experiments the two "patients" were covered with lightweight duvets. The manikin was dressed in a short-sleeve hospital pyjama and its total clothing isolation was 0.60 Clo. The layout of the test chamber is shown in Figures 1 and 2.

The manikin was referred to as a polluting patient since it was used as a source of bio-effluents. The bio-effluents were simulated by using a constant emission of three different tracer gases. CO_2, Freon 134a and N_2O were used to simulate emissions of bio-effluents from manikin's feet, pelvic area and armpits, respectively.

A ventilated mattress (VM) was placed on top of the regular mattress of the polluting patient's bed (Figure 2 and Figure 3). The ventilated mattress (VM) was used in some of the experiments to exhaust locally the contaminants emitted from the patient's body. Part of the surface of the VM is designed as an exhaust opening, from which contaminants generated from the human body (e.g. bio-effluents) are discharged by the VM. There is a mesh inside the ventilated mattress which provides support and allows the exhaust air to move through the whole mattress. For the purpose of the experiments the VM was connected to a separate exhaust system having an axial fan outside the chamber with a flexible duct (ø 80 mm). The exhaust flow rate of the VM was regulated by changing the frequency of the fan and by adjusting the damper installed in the duct connected to the VM. In order to adjust the desired airflow rate exhausted from the VM two air flow sensors (MFS-C-080) were installed in the duct. During the experiments with VM the exhaust airflow rate of the VM was adjusted to be 1.5 L/s. The ventilated mattress had two local exhaust openings, each with the same dimensions: 0.8 x 0.16 m^2 (L x W). The position of the two exhaust openings was either in the area where the patient's feet were or where the pelvic region of the thermal manikin was located (see Figure 3). The exhaust openings of the VM were covered with textile mesh with free area ratio of approximately 90%.

Series of experiments were conducted at three background ventilation rates, namely 27, 55 and 109 L/s (1.5, 3 and 6 air changes per hour, ACH). The air temperature inside the test chamber was controlled and kept at 23ºC during all experiments. The temperature around the chamber was kept 23ºC as well. The relative humidity in the chamber was not controlled; it was measured to be in the range of 25 – 40%. The air mixed with the tracer gases was sampled and its gas concentration was analyzed under steady-state conditions using an Innova 1303 multi-channel sampler and a photoacoustic multi-gas monitor Innova 1312. The concentration of the three gases was measured simultaneously at the mouth of the "doctor", mouths of the two "patients", at the supply and total exhaust air, and several other locations in the occupied zone of the room (see Figure 1). The experiments at 1.5 ACH were performed with the VM operating /VM not operating. Experiments at 3 and 6 ACH were conducted without using the ventilated mattress.

The performance of the ventilated mattress was assessed in regard to the excess concentration of the tracer gases above the background level, i.e. the concentration level of each of the three tracer gases in the supplied air was subtracted from the concentration in the measuring locations. 20 sampled values for each measuring point was acquired after reaching a steady state tracer gas concentration. The obtained data were normalized according to the following equation:

$$\text{Normalized concentration} = C_i/C_{i,Ref} \quad (1)$$

where C_i is the concentration acquired at the measuring location, $C_{i,Ref}$ is the concentration acquired at the measuring location at 1.5 ACH without using VM.

When the normalized concentration is less than "1" it means that the concentration obtained at the measured location (C_i) was less than the concentration at the reference point ($C_{i,Ref}$) and vice versa when the normalized concentration is higher than "1".

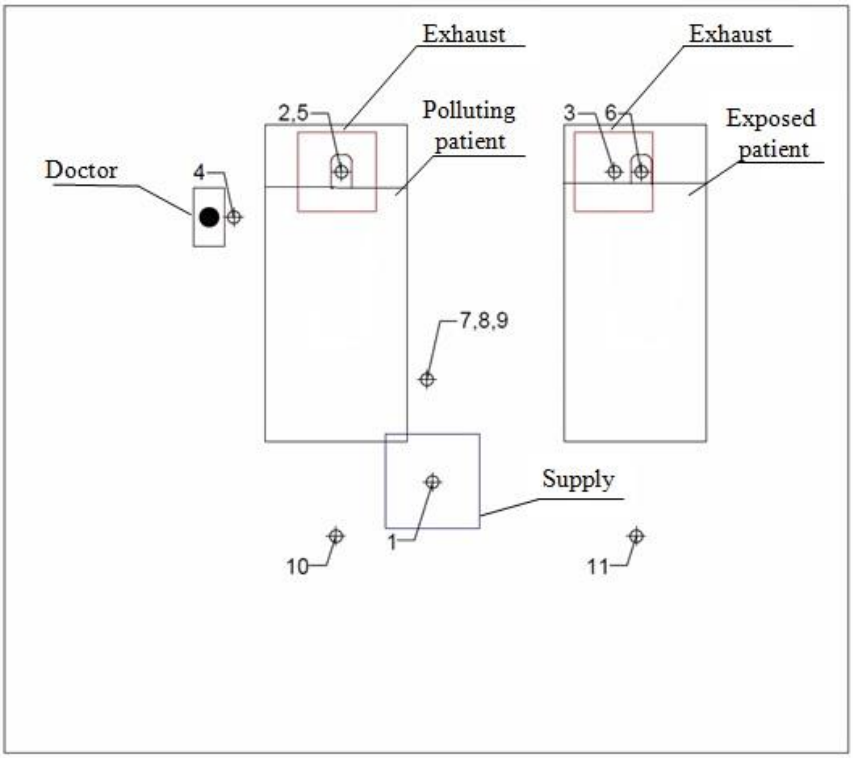


Figure 1. Top view sketch of the chamber layout. Measuring locations are shown: 1-supply, 2- exhaust over source patient, 3- exhaust over exposed patient, 4- mouth of doctor, 5- mouth of source patient, 6- mouth of exposed patient, 7- centre of the room 1.7m above the floor, 8- centre of the room 1.1m above the floor, 9- centre of the room 0.6m above the floor, 10- at feet of the source patient 1.7m above the floor, 11- at feet of the exposed patient 1.7m above the floor;

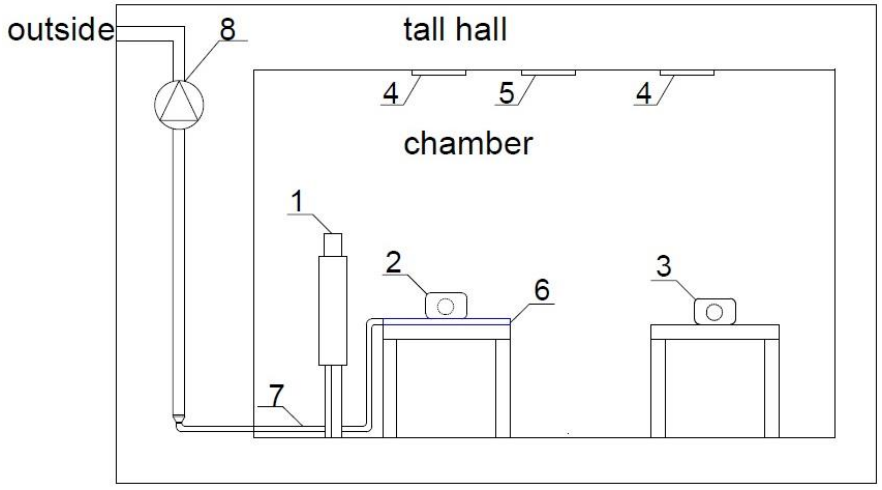


Figure 2. Side view sketch of the experimental set-up in the chamber: 1 –doctor, 2 –polluting patient, 3 – exposed patient, 4 – exhaust diffusers, 5 – supply diffuser, 6 – the ventilated mattress, 7 – exhaust duct from the ventilated mattress, 8 – axial fan.

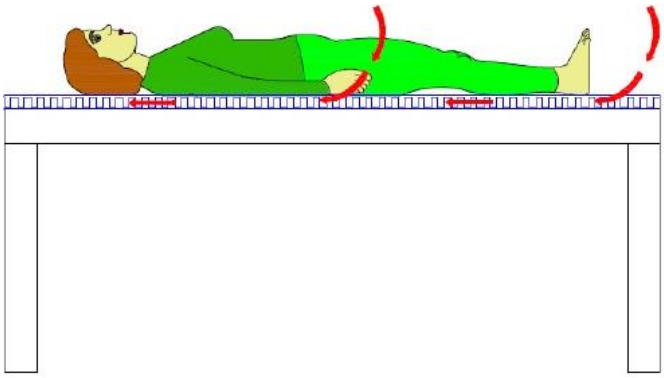


Figure 3. Patient bed with integrated ventilation method. The arrows show the location of the exhaust openings where the air is sucked through the ventilated mattress.

3 Results and Discussion

In Figure 4 the averaged excess N_2O concentration measured at 1.5 ACH with the VM operating is compared with the excess N_2O concentration measured at 1.5, 3 and 6 ACH without the VM. The ventilated mattress (VM) in this case was sucking air from the groin region of the manikin at a flow rate of 1.5 L/s. Figure 4 shows the N_2O concentration measured at the mouths of the two "patients" and mouth of the "doctor", and also at the centre of the room at 1.7 m height above the floor (point 7 in Figure 1). The results show that the concentration of N_2O is successfully reduced when using the VM under 1.5 ACH compared to the concentration measured under the three tested air change rates without using the VM. It should be noted that at 6 ACH background ventilation the tracer gas concentration in the air sampled at the "mouths" of the occupants (more than 26 ppm) was much higher than the concentration at 1.5 ACH combined with the VM (less than 3 ppm). The obtained results imply that even supplying high amounts of clean air to the room it was not possible to dilute the polluted air at the breathing zone of the occupants. The highest measured concentration during all cases was observed at the mouth of the polluting patient. At that measuring point there was only a slight difference between the concentrations measured at 3 ACH and 6 ACH. In a study by Bolashikov et al. (2012) it was shown that in fact the increased background ventilation rate under MV can help the spread of airborne pollutants (coughed air) indoors if the exposed person is close to the source. The present study shows that under all three ACHs without using the VM the concentration of the emitted pollutants from the armpits at the mouth of the polluting patient is higher than at the other measuring locations. This result is probably due to the polluting patient being in close proximity to the source. Compared to the measured concentration at the exposed patient mouth and at the centre of the room at 1.7 m height, higher N_2O concentration were observed at the mouth of the doctor under 1.5, 3 and 6 ACH without using the VM. The simulated doctor was standing next to the polluting patient bed in a closer distance to the pollution source compared to the second exposed patient or to the measuring point "centre 1.7 m". There was thus higher concentration at the breathing zone of the doctor.

The effect of the position of the local exhaust opening of the mattress on the pollution removal was also studied. The normalized pollution concentration, when the exhaust of the VM was located either at the feet or at the groin (pelvic) area of the polluting patient, is shown in Figure 5. The results were obtained at 1.5 ACH background ventilation and VM exhaust operated at 1.5 L/s for two of the generated pollution sources, namely patient's feet (CO_2) and armpits (N_2O). The normalized concentration for both cases was much lower than

"1". It can be seen from the figures that the normalized concentration measured in all points were almost equal to zero for both cases except for the case when the VM was locally exhausting from the feet and the pollution source was patient's armpits (Figure 5b). It might be due to the fact that the local exhaust at the feet was further away from the armpits compared to when it was located below the pelvis. In Figure 5a it can be seen that when the VM exhaust opening was located at the groins, it was able to reduce the pollution level emitted from the feet to the same level even slightly better compared to when it was exhausting from the feet. In fact, it seems that when the exhaust opening was placed at the pelvic area the VM has the best removal performance for the two generated pollution sources. These results show that the location of the exhaust opening along the mattress matters.

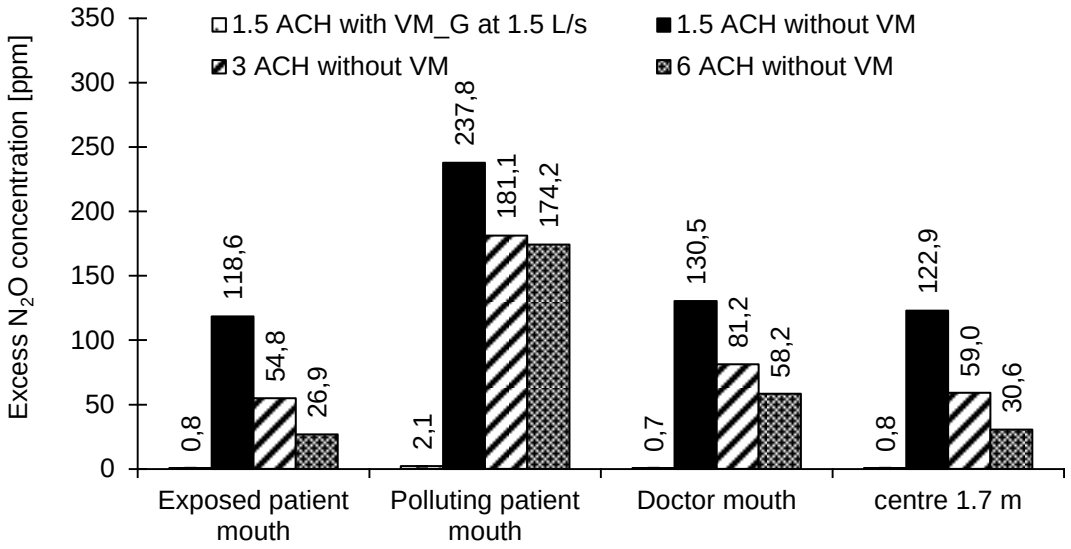
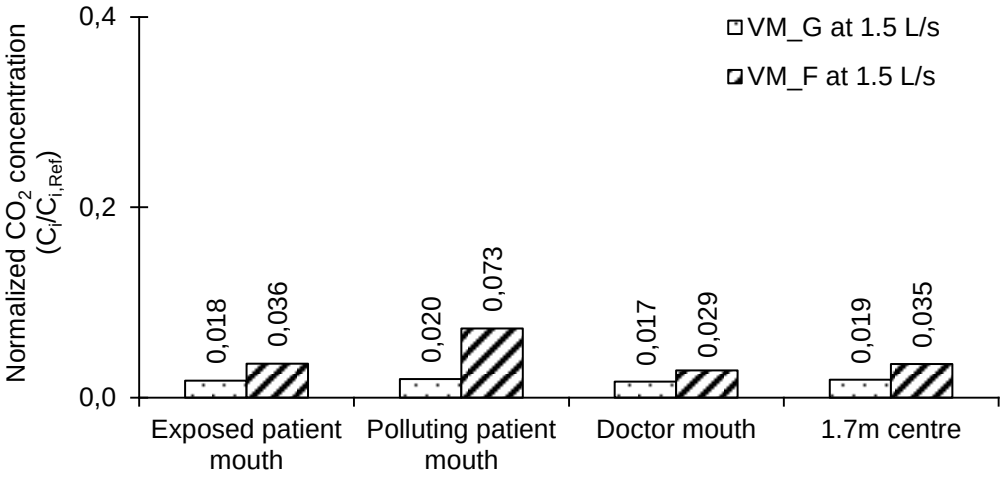
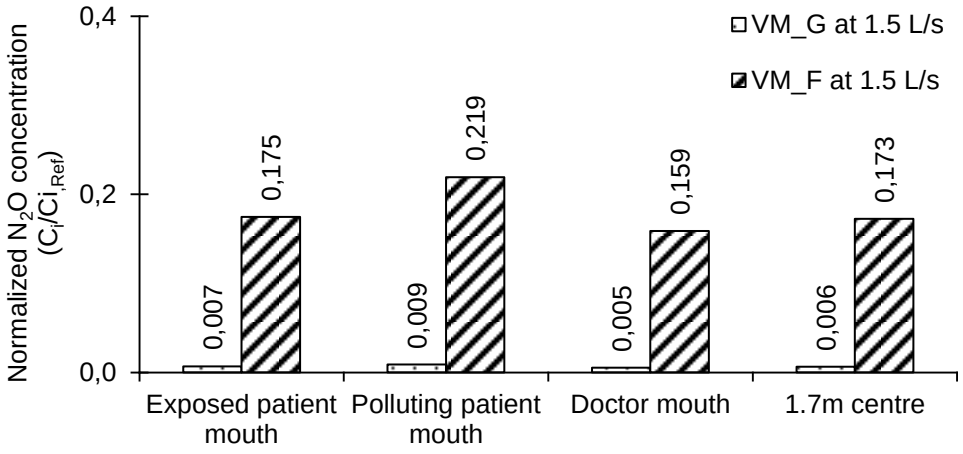


Figure 4. Averaged excess N_2O concentration measured at 1.5 ACH combined with the VM working at 1.5 L/s and at 1.5, 3 and 6 ACH without the VM. VM_G stands for VM exhausting air from the groin region of the polluting patient.

The studied novel advanced air distribution method, namely the ventilated mattress (VM), proved to be an effective way in removing the bio-effluents generated from the body of a lying person in bed. The implemented local exhaust opening into the mattress below the feet/pelvis was quite efficient in evacuating the generated bio-effluents before being spread throughout the room air. The performance of the local exhaust operated at 1.5 L/s was high even when its location was not directly under the source of bio-effluents, i.e. the armpits and feet in case of "groins exhaust" or armpits in case of "feet exhaust". VM coupled with mixing overhead ventilation at 1.5 ACH was able to remove more than 98 % of the generated from feet and armpits bio-effluents by the lying patient, when the VM was sucking from the groins. Therefore it is expected that this method will significantly improve the quality of the room air the occupants breathe. Especially for patients unable to move from the bed and cannot frequently take baths, the VM can help make their stay in the hospital more pleasant by evacuating their body odour. The VM has the potential to remove also other pollutants such as skin flakes from people and also faeces of dust mites find on the mattress of the bed (Ucci et al. 2011). It has been shown that desquamated skin flakes are carriers of the pathogenic bacteria Staphylococcus aureus (Davies and Noble 1962). The VM has the option to be equipped with filter and/or ultraviolet germicidal irradiation (UVGI) source mounted inside the VM so that the sucked air to go through the UVGI and kill the pathogens.



a)



b)

Figure 5. Normalized concentration for cases when the VM was exhausting from either feet or groins at 1.5 ACH when a) pollution source was patient's feet (CO_2) and b) pollution source was patient's armpits (N_2O.) VM_F stands for VM exhausting from feet, VM_G stands for VM exhausting from groins.

Different methods for air cleaning (filter, deodorant materials, UVGI, etc.) can be easily incorporated into the VM exhaust part, where the polluted air will be cleaned locally and discharged it back into the room. This will increase the flexibility of the patient bed and it will be possible the bed to be moved around. The VM can also be directly plugged (plug and operate concept) to the total volume exhaust system taking the exhausted air directly out of the building.

The use of the VM in hospitals and other health care facilities will reduce the high energy costs due to the high ventilation rates required for the patients' rooms. The results from the current study showed that the concentration of the contaminated air was less in the case at 1.5 ACH (27 L/s) with VM operated at 1.5 L/s than when the chamber was ventilated at 6 ACH (109 L/s), which is four times higher than 1.5 ACH.

4 Conclusions

The following conclusions can be drawn based on the results of the present study:

- The VM (exhausting 1.5 L/s of air) in conjunction with MV at 1.5 ACH proved to be an efficiently method in reducing the measured concentrations of bio-effluents emitted from the body in the room compared to the measured concentrations under MV at 1.5, 3 or 6 ACH and without using the VM;
- The use of the VM not only can improve the air quality by reducing the unpleasant body odours, but also can lead to significant energy savings;
- The lowest measured concentrations of bio-effluents were achieved when the VM was sucking from local exhaust positioned under the pelvic (groin) area of the lying patient.

5 Acknowledgement

This research was funded by European research project FP7-People-2012-ITN-Drant Agreement number 315760.

6 References

ANSI/ASHRAE ASHE Standard 170-2008. *Ventilation of Health Care Facilities*.

Z. D. Bolashikov, A. K. Melikov, W. Kierat, Z. Popiołek and M. Brand. *Exposure of health care workers and occupants to coughed airborne pathogens in a double bed hospital patient room with overhead mixing ventilation*. HVAC&R Research, issue 18(04), pp.602-615. 2012.

R. R. Davies, W. C. Noble. *Dispersal of bacteria on desquamated skin*. Lancet 1962; 2: 1295± 7.

U-M Hellgren, K. Reijula. *Indoor-air-related complaints and symptoms among hospital workers.* Scand J Work Environ Health 2006; 32(Suppl 2):47–9.

A. K. Melikov, 2011. *Advanced Air Distribution*. ASHRAE Journal, vol. 53, no. 11, pp. 73-77.

A. K. Melikov, Z. D. Bolashikov, E. Georgiev. *Experimental investigation of performance of a novel ventilation method for hospital patient rooms*. 21st Congress of International Federation of Hospital Engineering (IFHE), Tokyo, Japan., 2010.

K. Nordstrom, D. Norback, R. Akselsson. *Influence of indoor air quality and personal factors on the sick building syndrome (SBS) in Swedish geriatric hospitals*. Occup Environ Med 1995; 52(3):170–6.

S. G. Saad. *Integrated environmental management for hospitals.* Indoor and Built Environment. London, v. 12, n. 1-2, p. 93-98, Feb. 2003.

M. Ucci, P. Biddulph, T. Oreszczyn, D. Crowther, T. Wilkinson, SEC. Pretlove, et al. *Application of a transient hygrothermal population model for house dust mites in beds: assessment of control strategies in UK buildings*. J Build Perform Simul 2011;4:285e300.

S. Yamazaki, K. Hoshino, M. Kusuhara. *Odor associated with aging*. Anti – Aging Medicine 7 (2010) 60-65.