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Exposure Control Indoors with Wearable Personal Exhaust Unit

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Abstract

A wearable personalized ventilation (PV) unit to reduce the risk from airborne disease contamination is reported. The PV unit consists of a nozzle, installed on a headset, which is used to locally exhaust the exhaled air before it mixes with the surroundings. Experiments at 22 °C were performed in a full-scale test room furnished as a double bed hospital room. A breathing thermal manikin with a realistic free convection flow around the body and breathing cycle was used to mimic a sick doctor. A second thermal manikin and a heated dummy were used to resemble two lying patients. The air exhaled by the doctor was mixed with tracer gas (R134 A) to mimic airborne pathogens. The PV nozzle was positioned frontally 0.02 m from the mouth of the doctor exhausting 0.25 L/s air. The performance of the PV in combination with mixing background air distribution at 3 ACH was compared with the case of only mixing background air distribution at 3, 6 and 12 ACH. The use of the device showed a great potential in reducing the concentration of exhaled air in the room to the level measured under mixing ventilation alone at 12 ACH. The high potential to capture exhaled air, makes the wearable PV applicable as an efficient engineering control method that can reduce the spread of pathogen laden air from sick occupants in densely occupied spaces, i.e. cinemas, public transportation, office buildings etc.

Keywords - wearable Personalized Ventilation; contaminant control; hospital ventilation; airborne cross-infection; full-scale measurements

1. Introduction

In hospitals ventilation is expected to remove efficiently the droplets nuclei from bio-aerosols which may contain pathogens and are generated from sick person (patient, staff or visitor) or from different medical activities. Thus the hospital ventilation systems should be designed differently from those in commercial and residential buildings, as in the former case the main sources of contamination (pathogens) may come from respiratory activities. Ventilation rates exceeding 12 ACH for airborne infection control in isolation rooms are recommended by guidelines and standards [1, 2, 3].

Ventilating at 12 ACH can reduce the pollutant concentration to 0.1% from the initial fraction in 35 min and to 0.01% in 47 min. However such elevated ventilation rates result in: 1) significantly increased energy consumption to transport and condition the air supplied; 2) increased investment and maintenance costs of the building due to oversizing of the HVAC components and larger spaces to accommodate them; 3) elevated risk of draught discomfort for occupants. Furthermore, when ventilating based on the volume of the occupied space neither the pathogen infectivity nor the number of infective sources (patients, medical staff members, etc.) present in the room is accounted for.

An efficient way to evacuate the generated pathogens indoor is to capture them close to source origin. In hospitals this would mean at the breathing zone of the sick occupant. Incorporating localized ventilation at the hospital bed can ensure efficient extraction of respired flows by sick individuals and significant reduction of airborne pathogen spread indoors even at greatly reduced ventilation rates [4, 5, 6]. However this method will work as long as the sick occupant stays in bed. Another issue is that the doctor himself or visitors can be sick and can release airborne pathogens with expired air. In this case the localized bed incorporated ventilation will not be effective in reducing the airborne spread in the surroundings. Therefore a local exhaust orifice aesthetically incorporated into the mouthpiece of a headset could be used. It will capture the expired air directly at the breathing zone of the occupant. The captured air can be then cleansed and filtered via a miniaturized mobile unit containing a pump, filter and UVGI that can be attached to the clothing of the user similar to an iPod. The concept of using headset 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 [4, 7, 8, 9]. 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 such wearable PV unit used by doctor as local exhaust in a double bed hospital room to reduce the exposure levels to exhaled air for the patients.

2. Method

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 a hospital isolation room with two beds. The distance between the beds was set to 1.3 m. 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 size, shape and surface temperature distribution was used to resemble a "doctor" standing next to one of the two beds: 0.55 m away. The doctor was facing the patient. The manikin consisted of 17 sections. The manikin was equipped with an artificial lung [10] to simulate a breathing sick doctor. One full breathing cycle consisted of three steps and lasted 6 s: inhalation – 2.5 s, exhalation – 2.5 s and break – 1 s. The characteristics of the breathing cycle were: inhalation nose, exhalation mouth; tidal flow rate – 0.24 L/s (6 L/min) [11]. A second thermal manikin of 23 body segments was used to simulate a sick patient lying in the bed closest to the doctor. The manikin was dressed with patient pajamas of 0.38 Clo. Each manikin released 60 W sensible heat load on average. A heated dummy with simplified body geometry was used to mimic the second patient lying in the other bed. The two beds were placed in parallel and both patients were facing the ceiling. The layout of the set-up is shown in Fig. 1.

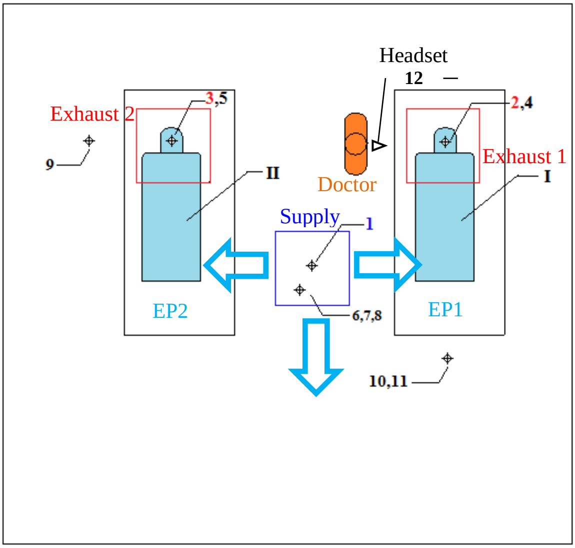


Fig. 1 Experimental set-up and locations of the sampling points for the tracer gas concentration measurements; top view: I- exposed patient 1(EP1), II- exposed patient 2(EP2), 1 – supply, 2 – exhaust over EP1, 3 – exhaust over EP2, 4 – mouth of EP1, 5 – mouth of EP2, 6 – centre of the room 1.7 m above 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

During all experiments overhead mixing ventilation was used. The supply air was 100% outdoor air with no recirculation. The supply diffuser was a square diffuser with an unperforated face plate with a 3-way-discharge. Two square ceiling mounted diffusers with perforated face plate were used for exhausting the air from the room. They were located above the heads of the patients. The exhausted air was equally balanced between the two diffusers.

For the purpose of the experiment the headset incorporated wearable PV exhaust was simplified to test the effectiveness of the concept in evacuating 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, Fig. 2. A separate ventilation system was used to operate the PV unit. It consisted of the nozzle of circular cross-section, flexible pipe, reduction, 2 dampers, 2 iris orifices and a fan in order to achieve the desired flow rate of 0.25 L/s. The system was constructed outside the climate chamber, within the tall hall. The exhaled air captured by the wearable PV unit was exhausted directly into the total volume ventilation exhaust of the tall hall.

a) b) c)

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

The experiments without the headset device were performed at 3, 6 and 12 ACH and were used as a reference. During the experiments with the headset the background ventilation in the chamber was set at 3 ACH. The headset was positioned 0.02 m from the mouth of the doctor, Fig. 2c. Room temperature was kept at 22˚C, while the relative humidity was not controlled but was measured to be between 30% and 40% during all experiments. Temperature and flow rate of supply and exhaust air, temperature inside the test room as well as the amount of air exhausted by the headset unit were recorded and controlled constantly to keep the set values.

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 concentration of tracer gas was kept the same for all tested cases. The tracer gas was used to simulate airborne droplets and droplet nuclei of less than 2 μm aerodynamic diameter [12] 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, the experimental chamber was kept slightly over-pressurized at 1.6±0.2 Pa during all measurements.

The tracer gas concentration was measured with two sets of multi gas sampler and analyzer based on the photo acoustic principle at 12 points: 1) in ventilation supply, 2) in exhaust over exposed patient 1, 3) in exhaust over the exposed patient 2, 4) at the mouth of the doctor, 5) at the mouth of the exposed patient, 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 exposed patient 2 (0.55 m distance from the mouth) 1.7 m above the floor, 10) close to the feet of the sick patient 1.7 m above the floor, 11) close to the feet of the sick patient 1.1 m above the floor, Fig. 1. 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 the exposed patient closest to the doctor (patient 1) nor the heated dummy (patient 2) was 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 [10].

2.1. Experimental Procedure

The air temperature in the laboratory hall and in the chamber was kept 22 ^{o}C throughout the whole experiment. 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 concentrations at centre of room and in both TV exhausts (located at the ceiling).

After reaching a steady state, 15 sampled values for each measurement point were acquired.

Temperature was measured throughout the experiments and after that a mean value was calculated for all the measurement locations.

2.2. Analyses of Results

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

$$\varepsilon = (C_m - C_s)/(C_{m(3ACH)} - C_{s(3ACH)}) \quad (1)$$

C_m – concentration acquired in the measuring location

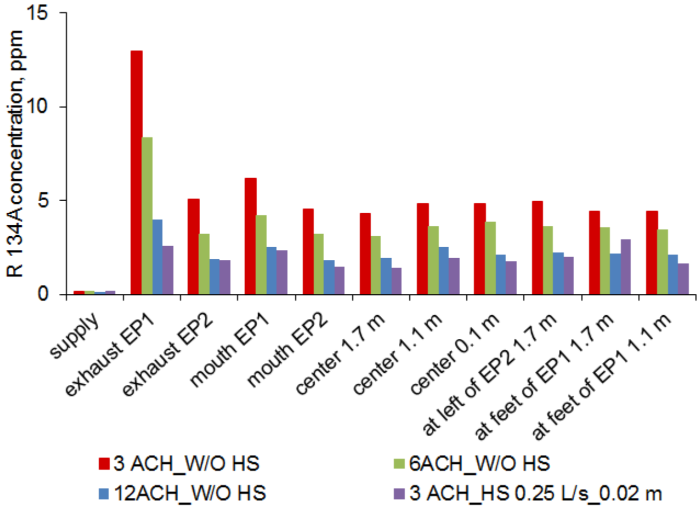
C_s – concentration acquired in total volume ventilation supply

$C_{m(3ACH)}$ – concentration in the measuring point at 3ACH (without headset)

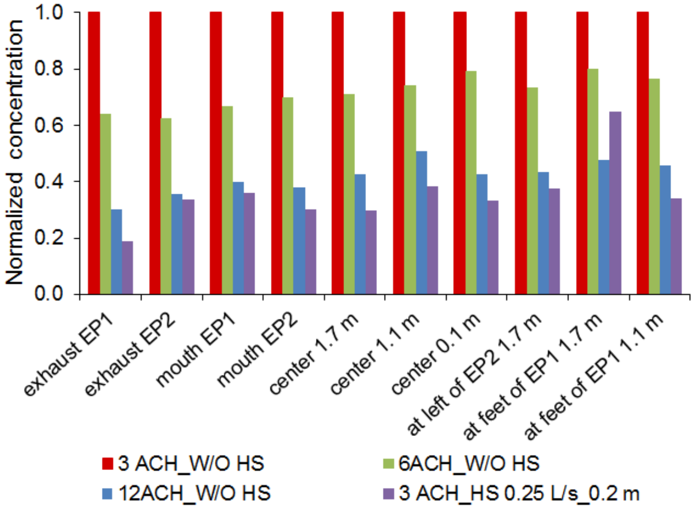
$C_{s(3ACH)}$ – concentration in the total volume ventilation supply at 3ACH (without headset)

3. Results

The measured concentration of R 134A tracer gas and its normalized value are presented in Fig. 3. The following abbreviations are used in the legend of Fig. 3: ACH: air changes per hour, W/O: without, HS: headset. 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 suction air flow of the headset unit tested and last, i.e. 4th, is distance of the unit from the mouth of the occupant wearing the headset. 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 occupant (doctor) is wearing the headset, which exhausts 0.25 L/s 0.02 m away from the mouth of the person (doctor).



a)



b)

Fig. 3 a) Measured concentration values, b) Normalized concentration, when the doctor was without or with a headset exhausting at 0.25 L/s and 0.02 m distance from mouth standing near the head of EP1 and the room was ventilated at 3, 6 and 12 ACH

The highest values of the concentrations were obtained at 3 ACH and decreased uniformly with increasing of the air change rate due to the increased dilution. Higher portion of the polluted air reached the exhaust over the exposed patient 1 (EP1) under all three conditions. This is due to the proximity of the doctor to the exhaust above patient 1 and the buoyancy effect that governed the spread of the air jet exhaled by the doctor. For the other measurement points the obtained concentrations maintained approximately equal level and were more than 50% lower than the concentration measured at the exhaust over EP1. Exception was the concentrations measured at the mouth of EP1, the values for which were slightly higher than for the other measurement locations for all three conditions. These results are explained by the fact that the doctor was close and facing EP1. The air distribution pattern in the room had a great impact. From performed visualizations with smoke generator, was seen that a recirculation zone was formed above the bed of EP1. It mixed the air exhaled by the doctor with the surrounding room air and brought it within the breathing zone of the lying patient. Nevertheless great portion of the exhaled air moved upwards especially at the lower flow rates of 3 and 6 ACH, parts of it spread in the room by the background airflow pattern. The exposure to exhaled air from a sick standing doctor was decreased more than 50% at 12 ACH compared to 3 ACH, Figure 3b. However, at 6 ACH the reduction was much lower – around 30% and for some measurement points it didn’t exceeded 20%. It is noticed that the increase in the air change rate had the highest impact on the two exhausts since the normalized concentrations at these point were the lowest. This is due to the higher dilution of exhaled air when it reached the exhausts.

When the headset was positioned at 0.02 m distance from the mouth of the doctor the measured and the normalized concentrations were lower or within the same range as at 12 ACH and without the headset. Clearly the use of local exhaust helped to reduce the spread of exhaled air in the room. The measured background concentration of exhaled air from a sick doctor was comparable or even lower than when ventilating with the recommended by the standards minimum of 12 ACH for isolation rooms.

4. Discussion

Creating healthy and comfortable environment in hospital premises is of great importance for fast recovery of patients, increase the performance of the medical personal and protection of both patients and medical staff from airborne cross infection.

The results of the present study show that elevated ventilation rates corresponding to up to 12 ACH are not sufficient to protect the occupants (exposed patients) from airborne exposure to exhaled air by a sick medical staff member. Similar results apply for the case when the exposure to exhaled air comes from a sick lying patient [4, 5, 6]. The studies investigated the exposure to only one source, i.e. one sick patient. In case of pandemics, the density of the patients in hospitals will be higher than usual and consequently the risk of airborne cross infection will rise significantly. Relying only on total volume ventilation to effectively dilute the contaminated air and reduce the risk of cross infection is not enough and may not be possible. For example, increasing the number of sick patients to two in the same room, assuming that they both release the same amount of pathogens in the room air will require supply of twice more ventilation air to the room in order to achieve the same dilution as when the patient is alone. In case of isolation double bed room this will result to 24 ACH! Hence a new approach of ventilation is needed. The ultimate goal should be to provide better indoor environment and to reduce the risk of airborne cross-infection at reduced ventilation rate by more efficient air distribution than the mixing air distribution used in hospital wards today.

The present paper shows that applying local control, i.e. exhausting expired air from within the breathing zone, can result in significantly reduced levels of exhaled air in hospital wards. This will result in lowered exposure of occupants to airborne pathogens and less supply air to dilute the room air. The concentrations of tracer gas measured at the mouth of the two patients and in the room were almost the same. The measured concentrations decreased with the increase of the ventilation rate. For the measurement with the headset the TV 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 the level of 12 ACH and without the headset. It is important to be mentioned that the nozzle for this condition was placed 0.02 m away from the doctor's mouth.

Simple calculation of the air supply flow rate by mixing ventilation at 12 ACH and at 3 ACH but coupled with the headset operated at 0.25 L/s and for the volume of the occupied space equal to that of the climate chamber, i.e. 57.4 m^3, show that nearly 4 times more conditioned outdoor air needs to be supplied by the mixing ventilation alone at 12 ACH.

To justify the use of the headset PV unit as local exhaust that can evacuate successfully expelled air more experiments are needed to study the impact of body movement, nozzle geometry, flowrate, distance from breathing zone etc.

Previous research on the headset PV showed that the device is also very efficient in supplying clean air into the inhalation [4, 7, 9]. 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. 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.

5. Conclusion

The present study focused on the reduction in exposure to exhaled air by a "sick" doctor wearing headset incorporated exhaust device in a simulated double bed hospital room ventilated by mixing air distribution. The use of the headset as a local exhaust device at 3 ACH background ventilation rate reduced the exposure of the patients as well as the background tracer gas concentration below the levels registered at 12 ACH.

6. Acknowledgment

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7. References

[1] ASHRAE/ASHE Standard, 170-2008, "Ventilation of Health Care Facilities, American Society of Heating, Refrigerating and Air-conditioning Engineers", Inc. 1791 Tullie Circle NE, Atlanta, GA 30329.

[2] AIA (2001). "Guidelines for design and construction of hospital and health care facilities." Washington, D.C., American Institute of Architects, Academy of Architecture for Health., Facilities Guidelines Institute, United States.

[3] CDC (2003). “Guidelines for environmental infection control in health-care facilities.” Atlanta, GA 30333, U.S. Department of Health and Human Services Centers for Disease Control and Prevention (CDC).
[4] Z.D. Bolashikov, 2010, Advanced Methods for Air Distribution in Occupied Spaces for Reduced Risk from Air-Borne Diseases and Improved Air QualityPh.D. thesis, R-239,BYG, DTU, Denmark.
[5] A.Melikov, Z. Bolashikov, M. Brand, 2010, “Experimental investigation of performance of a novel ventilation method for hospital patient rooms.” 21st Congress of International Federation of Hospital Engineering (IFHE), Tokyo Japan, November 17th to 19th, 2010.
[6] A. Melikov, Z. Bolashikov, E. Georgiev, 2011, “Novel ventilation strategy for reducing the risk of cross infection in hospital rooms.” In: Proceedings of Indoor Air 2011.Paper 1037.
[7] Z.D. Bolashikov, L. Nikolaev, A.K. Melikov, J. Kaczmarczyk, P.O.Fanger, 2003, “Personalized ventilation: air terminal devices with high efficiency.” Proceedings of Healthy Building; 2:850–5 [Singapore].
[8] J. Kaczmarczyk, A.K. Melikov, Z. Bolashikov, L. Nikolaev and P.O. Fanger, 2006, “Human response to five designs of personalized ventilation, International Journal of heating.” Ventilation and Refrigeration Research 12 (2), pp.367-384.
[9] S.W. Zhu, Z. Bolashikov, A.K. Melikov, 2008, “ Examination on performance of headset incorporated personalized ventilation unit using CFD method.” Proceedings of Indoor Air 2008. 17-22 August 2008. Copenhagen. Denmark - Paper ID: 1018.
[10] A.K. Melikov. and J. Kaczmarczyk., 2007, “Indoor air quality assessment by a breathing thermal manikin.” Indoor Air 17 (1). pp.50-59.
[11] C.E. Hyldgaard, 1994, Humans as a source of heat and air pollution. In: Proceedings of ROOMVENT '94, 4th International Conference on Air Distribution in Rooms, Krakow, Poland, pp. 414–433.
[12] M.A. Camargo-Valero, C.A. GIlkeson, C.J. Noakes, 2011, Tracer-gas as a surrogate method for tracking airborne pathogen transport in indoor environment. Proc. Indoor Air 2011, a586 4.