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## ADVANCED AIR DISTRIBUTION METHOD COMBINED WITH DEODORANT MATERIAL FOR EXPOSURE REDUCTION TO BIOEFFLUENTS CONTAMINANTS IN HOSPITALS

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**Keywords:** Local air distribution, Air cleaning, Indoor air quality (IAQ), Hospital environment

### SUMMARY

The separate and combined effect of a ventilated mattress and acid-treated activated carbon fibre (ACF) fabric on reducing the exposure to body generated gaseous pollutants in hospital environment was studied. Full-scale experiments were performed in a climate chamber furnished as a single-bed hospital patient room at reduced background ventilation rate of 1.6 air changes per hour. The bed of the patient was equipped with the ventilated mattress (VM) having an exhaust opening from which bioeffluents generated from human body were sucked and discharged from the room. To enhance the pollutant removal, acid-treated activated carbon fibre material was used in some of the experiments in the form of patient's cover. The simulated pollution source was ammonia gas released from the patient's groins. The results show that when using the ventilated mattress the ammonia gas concentration in the room was significantly reduced compared to the concentration measured when the VM was not in operation. The concentration of ammonia gas in the room was 100% removed when the VM operating at 1.5 L/s and the ACF material used as a cover were used together.

### INTRODUCTION

Many factors can affect the indoor air quality (IAQ) in hospitals. Some of the main causes for IAQ problems include lack of outdoor air, poor air distribution, and contamination from specific indoor sources. In hospitals and other healthcare facilities, it is a high priority to provide a comfortable environment with good air quality, in order to improve the care of patients and assist in their rapid recovery. People, especially patients who spend most of the time confined to the hospital bed

can be a major source of various volatile compounds (so-called “bioeffluents”). The spread of unpleasant smells into the air from patients’ body odour and waste can cause increased irritation and reduce the air quality perceived by occupants, visitors and staff. One of the compounds that it contributes greatly to the offensive odour of human waste (feces and urine) is ammonia (Nishida et al., 1981). Ammonia ( $\text{NH}_3$ ) has an unpleasant odour and causes irritation of the skin and mucous membranes. It is also a component of the human sweat (Hart, 1980).

The method of ventilating the entire room using the existing total volume air distribution (TVAD) principles is often not efficient enough to provide high quality environment and satisfy every occupant (e.g. patients, personnel and visitors). It also requires substantial energy use.

This study involves the implementation of a new pollution control system in the bed microenvironment for removing the human body pollutants. This new ventilation control strategy has been presented by Bivolarova et al. (2014). The method was called “ventilated mattress”. Part of the surface of the ventilated mattress was design as an exhaust opening for taking out polluted air. The idea behind the ventilated mattress (VM) is to capture and locally to exhaust the contaminants released from the body before being spread in the room. Figure 1 shows a sketch of a bed having the VM. There is a mesh inside the ventilated mattress which provides support and allows the exhaust air to move through the whole mattress. In Figure 1 it is shown possible locations of the exhaust opening on the mattress. Bivolarova et al. (2014a) reported that the lowest measured concentration of body emitted bioeffluents were achieved when this local exhaust opening was located under the groins of the lying patient.

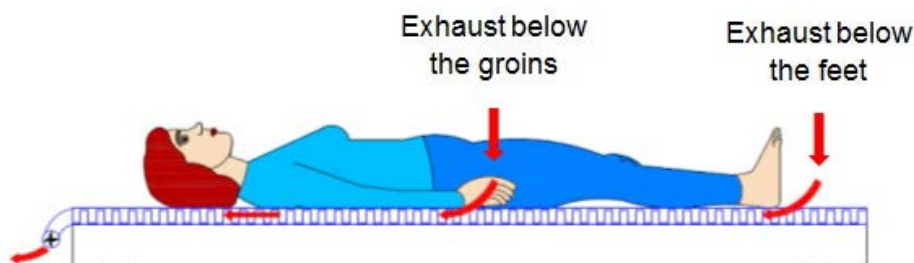


Figure 1. Bed with ventilated mattress.

In order to enhance the pollution removal within the bed of a patient, it can also be implemented some cleaning method. Typical removal methods for airborne molecular contaminants act on the principles of adsorption and chemical reaction. A commonly used adsorbent is activated carbon. Materials made of activated carbon fibres can serve as deodorants for unpleasant odours (Bivolarova et al., 2014b; Mizutani et al., 2014).

The goal of the current study was to investigate to what extent the exposure to airborne contaminants generated from the body will be reduced by the ventilated mattress combined with acid-treated activated carbon fibre material. Some of the results are presented in this paper.

## METHODOLOGIES

Full-scale experiments were performed in a stainless steel climate chamber furnished as a single-bed hospital patient room. The dimensions of the chamber were as follows: length - 3.6 m, width - 2.5 m and height - 2.5 m. Two heated dummies were used to simulate a lying patient and a standing doctor next to the bed. The standing dummy was positioned 20 cm from the side of the bed near the head of the lying dummy. One dummy consists of 3 parts – “legs”, “torso” and “head”. Inside each dummy six light bulbs were operating during the experiments. One bulb was installed in the head, one in the torso and 2 in each leg. The total generated heat power was 62 W for the “patient” and 130 W for the “doctor”. During the experiments the legs and the torso of the lying dummy were covered with a double sheet. The experimental setup is shown in Figure 2.

In all experiments the bed of the patient was equipped with the ventilated mattress (VM) having a local exhaust opening under the area where the legs of the dummy connects the torso (i.e. the groin area). The dimensions of the local exhaust opening were: 0.8 m length x 0.16 m width. The VM was connected to a separate exhaust system. The exhaust flow rate of the VM was regulated by changing the frequency of an axial fan and by adjusting the damper installed in the duct that connected the VM to the fan. The exhaust airflow rate of the mattress was adjusted to be 1.5 L/s  $\pm$  0.2 during all experiments when the mattress was working.

In some of the experiments a cleaning textile material was used as well. The tested material was nonwoven activated carbon fibre (ACF) fabric that had been chemically treated with acid. The nonwoven textile was produced from activated pitch-based carbon fibre. In this study the ACF material was used as a patient’s cover. The size of the tested ACF cover was 1.54 m (width) x 1.95 m (length). Each time when an ACF cover had to be used for the experiments, a new sample of the material was used. In order to hold the ACF cover on top of the dummy, a regular double sheet was placed on top of the ACF cover. The properties of the studied ACF material are given in Table 1.

Table 1. Properties of acid-treated activated carbon fibre fabric

Specific surface area (m <sup>2</sup> /g)	Pore volume (mL/g)	Pore diameter (nm)	Thickness (μm)
1350	0.6	1.9	17

To simulate the emission of odorants from the body, ammonia gas was released from the lying dummy’s “groin” area. A specially designed gas-generator system was used to generate ammonia gas. The gas generator consisted of two gas washing bottles each having an inlet and an outlet nozzle. The inlets were connected to a diaphragm pump, which was supplying fresh air to the washing bottles. The flow rate of the pump was controlled to be constant (0.2 L/min) by a gas Rotameter. To generate ammonia gas, each washing bottle contained 300 mL distilled water mixed with 35.3 mL of 28% ammonium hydroxide (NH<sub>4</sub>OH) solution. The two outlets of the washing bottles were connected through tubes to a perforated plastic ball in order to ensure a

uniform spatial dispersion of the generated ammonia gas. The air mixed with the ammonia gas was sampled by an Innova 1303 Multi-channel Sampler and its ammonia gas concentration was analyzed using a Photoacoustic Multi-gas Monitor Innova 1312. The concentration of the ammonia gas was measured simultaneously at the mouth of the “doctor”, mouth of the “patient”, at the air supply duct, at the total exhaust opening, and at 1.7 m height. All measuring positions inside the chamber are shown in Figure 2.

During all experiments the climate chamber was air conditioned using underfloor air distribution supplying 10 L/s (1.6 ACH) including three fans constantly operating to generate complete mixing inside the chamber. The total air in the room was exhausted through a circular opening located on the ceiling (shown in Figure 2). The temperature inside the chamber was not controlled and was measured to be in the range of 29 – 30 °C. The experimental conditions comprised background ventilation alone at 1.6 ACH, background ventilation at 1.6 ACH plus the ventilated mattress operating at 1.5 L/s with and without using the ACF cover, background ventilation at 1.6 ACH and only using the ACF cover. The experimental conditions are listed in Table 2.

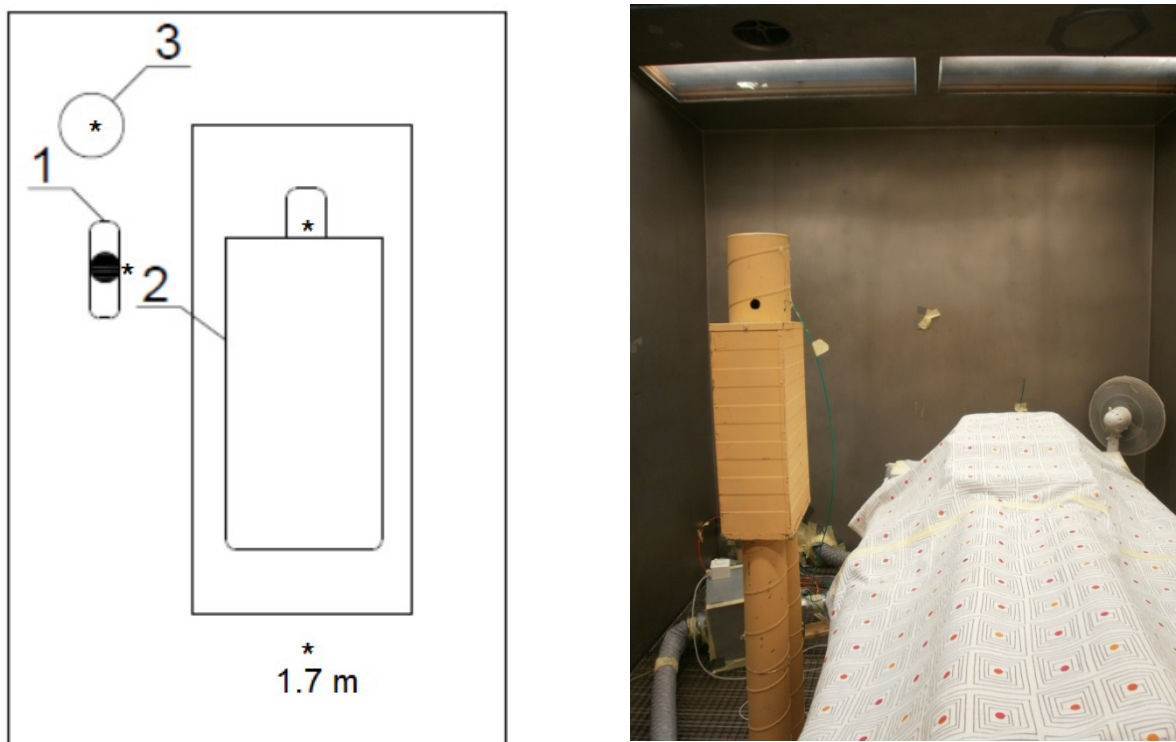


Figure 2. Experimental setup: (left) floor plan of the chamber showing the position of the sample tubes (\*), where 1 – “doctor”, 2 – “lying patient” on a bed, 3 – total exhaust opening; (right) interior of the chamber with the standing dummy next to the bed with the ventilated mattress and the lying dummy on it.

Table 2. Experimental conditions.

Condition	Ventilation type	Type of cover
1.6 ACH	Mixing	regular sheet
1.6 ACH + VM	Mixing + ventilated mattress	regular sheet
1.6 ACH + ACF cover	Mixing	ACF cover + regular sheet
1.6 ACH + VM + ACF cover	Mixing + ventilated mattress	ACF cover + regular sheet

One experiment lasted approximately 7 hours, i.e. counted from the time the ammonia gas dosing was started. 20 sampled values for each measuring point was acquired after reaching a steady state ammonia gas concentration in the chamber. In this paper the obtained concentrations of ammonia gas are expressed in terms of normalized concentrations:

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

where  $C_i$  is the average concentration acquired at the measuring location,  $C_{i,Ref}$  is the average concentration acquired at the measuring location during the reference condition '1.6 ACH'.

## RESULTS AND DISCUSSION

Figure 3 compares the results of the normalized ammonia gas concentration distribution in the room for the different tested conditions. The normalized concentration for the condition at 1.6 ACH at all points is equal to 1. The results below 1 show that the concentration of polluted air at the measuring points was reduced compared to the concentration obtained at 1.6 ACH. The values above 1 show the concentration at the measuring points exceeded the concentration obtained for 1.6 ACH at the same points. As we can see from Figure 3, the concentration of ammonia gas in all measuring points decreased with about 70% when the ventilated mattress was operating (at condition '1.6 ACH + VM'). When only the ACF cover was used at 1.6 ACH, we can see that the exposure reduction was more prominent compared with the results obtained at '1.6 ACH + VM'. The measured ammonia gas concentration at the mouth of the patient was slightly higher compared with the concentration at the other measuring locations for that condition - '1.6 ACH + ACF cover'. This is probably because there was not full mixing in the room and the patient's mouth was close to the source (since the patient was also the source of pollutants). The most significant result was that the exposure to ammonia gas was entirely reduced (i.e. the normalized concentration is zero) when combining the ventilated mattress and the ACF cover.

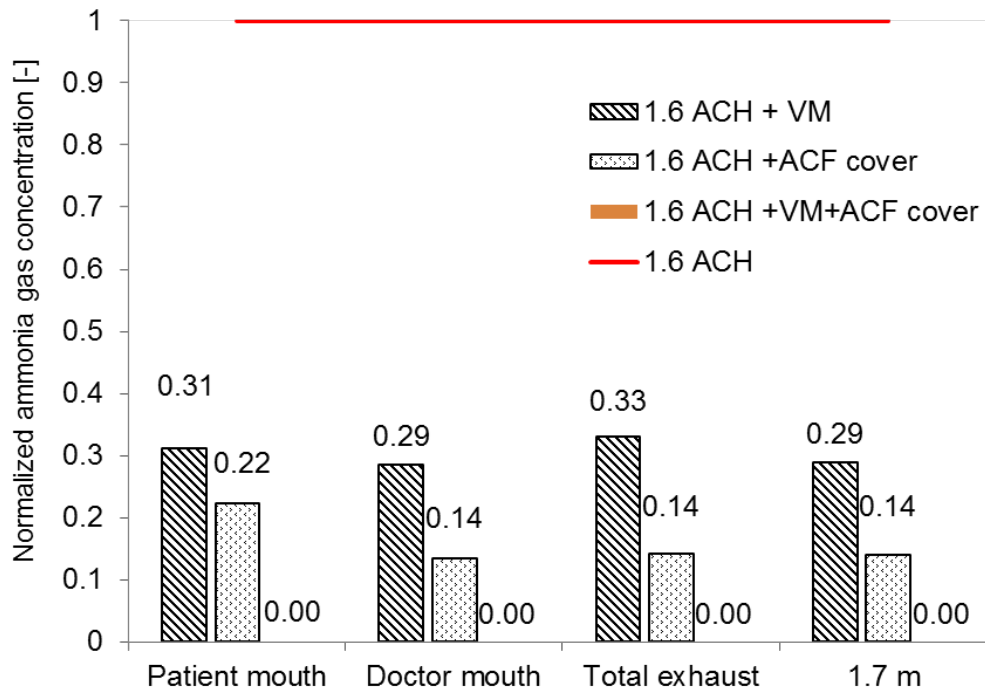


Figure 3. Distribution of ammonia gas in the room.

The ability of the ventilated mattress to evacuate different tracer gases, that were used to simulate airborne contaminants generated by the body, has previously been reported to be highly efficient (Bivolarova et al., 2014a). The objective of the present study was to find out how good control strategy will be the ventilated mattress in removing ammonia gas as a body pollutant since the ammonia is one of the compounds that can be released from the human body. Furthermore, the study aimed to test if it is possible to enhance the efficacy of the VM when combined with an air cleaning material. The cleaning material that was used in the current study was acid-treated activated carbon fibre fabric and it has been already shown that this material is efficient in removing ammonia gas (Bivolarova et al., 2014b; Mizutani et al., 2014).

In this study, the VM and the ACF material used separately as a pollution control strategy were found to substantially reduce the concentration of ammonia gas at low room background ventilation rate of 1.6 ACH. The present standards and guidelines for health care facilities recommend ventilation rate of up to 6 ACH for recovery wards and general patient rooms (ASHRAE 170 2008, CDC guidelines 2005). However, the elevated ventilation rates cause high energy consumption for the building. It has been reported that in a simulated hospital patient room with overhead mixing air distribution and 6 ACH, it is not enough to minimize the exposure of patients and other occupants to the bioeffluents released from a lying patient's body (Bivolarova et al. 2014a).

Huge potential for improving the indoor air quality, as the results in Figure 3 show, have the VM and ACF material combined together since the ammonia gas concentration in the room was reduced to zero. These findings support the idea that when applying control strategies such as local exhaust and air cleaning materials

close to the pollution source is much more effective approach to reduce the exposure of occupants to airborne contaminants indoors than only using background air distribution at elevated ventilation rates.

The activated carbon fibre material used in this study was tested only in the form of a cover/blanket for the patient. However, it may have potential applications in clothing or in furnishings for the deodorization of air in the vicinity of building occupants. For example, it may find application as pajamas of the hospitalized patients. It is also possible the ACF material to be used as a filter and be installed in the exhaust duct of the ventilated mattress. In this way, the polluted air sucked by the mattress will be cleaned locally and discharged back into the room. Further work is required to establish this. Further research also should be done to investigate the effect of saturation on the removal efficiency of the ACF material. The previous studies show that the material efficiency is not influenced by the air temperature or relative humidity (Bivolarova et al., 2014b). However, when the acid-treated ACF material is exposed to higher air velocities of 1.2 m/sec, the deodorant effect of the material decreases (Mizutani et al., 2014). This finding should be considered if the ACF material will be incorporated in the exhaust duct of the VM. Although in the case of the ventilated mattress, the high velocities should not be an issue since only small amount of air is exhausted through the mattress.

## **CONCLUSIONS**

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

- The separate and combined use of the VM and acid-treated activated carbon fibre (ACF) fabric as a cover (blanket) was an effective way of reducing exposure to human body contaminants indoors at reduced background ventilation rate.
- Acid-treated activated carbon fibre (ACF) fabric applied as a cover efficiently reduced the concentration of ammonia gas released from the body.

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