Protective Supply Air Distribution in Hospital Isolation Rooms

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Abstract

This study examines healthcare worker (HCW) exposure to patient exhaled airborne pathogens in hospital isolation rooms. Typically, negative pressure is applied to isolation rooms to prevent airborne infections escaping the room. However, negative pressure does not control the airflows inside the isolation room. This study investigates the effect of two different supply air distribution modes on HCW exposure to patient exhaled air: overhead mixing ventilation and local downward air supply. The experiments were carried out in an isolation room model built to a ventilation laboratory. Breathing thermal manikins were used to simulate the HCW and the patient. Smoke visualizations and tracer gas measurements were used to qualitatively and quantitatively assess the HCW exposure. The results show that supply air distribution notably affects the exposure and should be designed carefully in order to decrease the possible exposure. Especially the local downward ventilation showed potential to reduce the HCW exposure throughout the room compared to typical overhead mixing ventilation.

Introduction

Typically, patients with airborne infections are placed into negative pressure isolation rooms in hospitals. The negative pressure directs the airflow towards the isolation room thus preventing containment failures from happening. Inside the isolation the room the air flow patterns govern the dispersion of airborne pathogens. Typically mixing ventilation is recommended for isolation room ventilation (ASHRAE 2013). However, this does not always guarantee efficient mixing and quick dilution of airborne contaminants especially close to source. On the other hand, local supply air distribution mode can provide fresh air to breathing zone directly and hence yield more effective solution in reducing high contaminant concentrations already close to source. Thus proper supply air distribution can provide additional protection to healthcare workers (HCW) (complementary to personal protective equipment) and decrease the exposure risk to patient released airborne pathogens. In this study, the effect of two different supply air distribution modes on HCW exposure to airborne infections were tested: local downward and overhead mixing ventilation. The local downward air distribution mode provides fresh air to the occupied zone locally downward from the ceiling and mixing ventilation distributes the fresh air along the ceiling evenly over the room.

Methods

Isolation room model

The experiments were carried out in a simplified full-scale isolation room model. Figure 1 shows a schematic of the model layout and a picture inside the isolation room model. The model room was 4 m wide, 4.7 m long and 2.6 m high. Two different supply air distribution modes were examined in this study: overhead mixing ventilation and local downward ventilation. Three different supply air diffuser locations were tested: far away from the patient (A, See Figure 1), in the middle of the ceiling (B) and over the patient bed (C). There were two extracts in the model: the main extract was located in the ceiling level and a smaller one on the floor level simulating toilet extract. Constant supply air flow rate (169 L/s) and exhaust air flow rate (186 L/s) was used in the experiments (corresponding to 12 air changes per hour). The supply air temperature was 19 °C and the room air temperature 22.5 °C. The room had 800 W heat load (HCW 90 W, patient 90 W, lighting 110 W and solar load and equipment 510 W). In the experiments the HCW and the patient were simulated with breathing thermal manikins. The HCW manikin was simulated with a realistic manikin and the patient with a simplified heated dummy. HCW exposure was assessed in four different location inside the isolation room model: far away from the patient (1, see Figure 1), at the end of the patient bed (2), next to patient (3) and leaning over the patient (4). The patient manikin was lying on the bed with backrest tilted 20° upwards from the horizontal plane throughout the experiments. The nose and mouth of the manikins were attached to pumps enabling the simulation of breathing. The tidal volume of the breathing was set to 10 L/min and the frequency to 14 1/min. The exhalation temperature was set to 34 °C. These values corresponded to typical adult breathing parameters (Gupta et al. 2010, Höppe 1981).

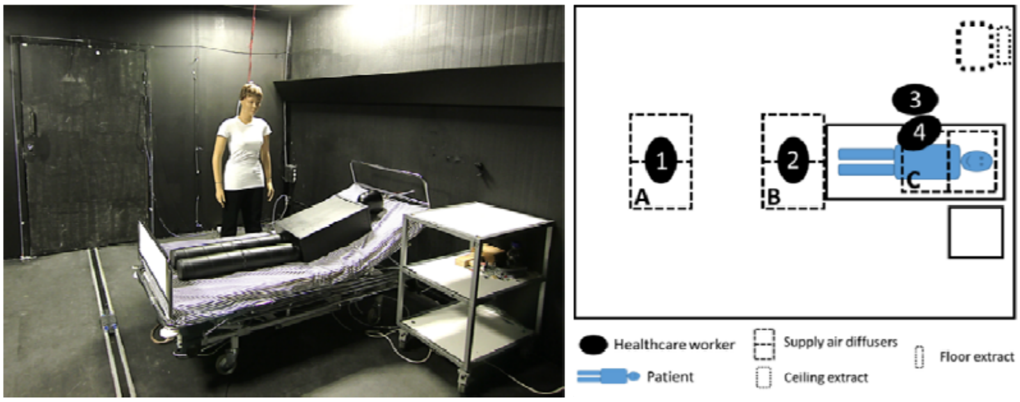

Figure 1. Picture of the isolation room model (on left) and a schematic of the layout (on right) showing the different HCW manikin (1-4) and supply diffuser (A-C) locations.

Experimental methods

Smoke visualizations and tracer gas experiments were carried out to assess the performance of the two supply air distribution modes and HCW exposure to patient exhaled airborne tracers. Smoke visualizations were carried out in order to visualize the supply air distribution and the dispersion of the patient exhaled air. In the experiments the smoke was generated with a smoke machine and dosed to exhalation of the patient or to supply duct. Additional lights were used inside the isolation room model to illuminate a sheet where the smoke flow was examined. The smoke movements were recorded with a digital camera (Canon 7D, Canon Inc., Japan). Still images of the recorded videos are shown in this paper.

Tracer gas measurements were carried out in order to quantitatively assess the local average HCW exposure to the patient exhaled airborne contaminants. A tracer gas (SF6, Sulphur hexafluoride) was used as a tracer to mark the patient exhaled air and to simulate airborne infections. A tracer gas analyzer (Brüel&Kjær type 1302, Brüel&Kjær A/S, Denmark) was used to measure the tracer concentrations from different points inside the isolation room model. The sampling interval of the analyzer was c. 40 s. The tracer gas was dosed with a mass flow meter to the patient exhalation. Prior to dosing, the tracer gas was mixed with air and the mixture supplied to the isolation room with the patient manikin exhalation through nose. The tracer concentration in the isolation room model was allowed to reach steady state before actual measurements from the extracts and from the inhalation of the HCW began. Tracer concentration in the HCW inhalation was monitored for an hour to increase statistical significance (sample size) (Kierat et al. 2018). The exposure of the HCW manikin was assessed with so called susceptible exposure index (Qian and Li, 2010). The index is defined as:

$$\varepsilon = \frac{C_i - C_s}{C_R - C_s},$$

where C_i is the tracer concentration in the inhalation of the HCW manikin, C_s the tracer concentration in the supply air and C_e the tracer concentration in the exhaust. In steady state conditions average concentrations can be used in the equation. If the tracer concentration in the supply air is close to zero, the equation above reduces to:

$$\varepsilon = \frac{C_i}{C_e}.$$

Basically, the index scales the locally inhaled tracer concentration with exhaust concentration and the higher the value the higher the local relative exposure.

Results

Still images of the recorded smoke visualizations are shown in Figure 2. Only the visualizations with the supply air diffusers above the patient are shown. The dispersion of the patient exhaled air with the local downward ventilation is shown on left and with the overhead mixing ventilation on right. The visualizations illustrate that the downward air supply directed the exhaled air away from the HCW's breathing zone more efficiently than the overhead mixing ventilation. Hence the HCW exposure close to patient (source) is expected to be smaller with the local downward ventilation in the illustrated case.

Figure 2. Smoke visualizations of the dispersion of the patient exhaled air. The case with local downward supply is shown on left and with overhead mixing on right. The diffusers were placed in the ceiling above the patient in both cases.

Tracer gas measurement results are shown in Figure 3. As with the smoke visualizations, only the results when the supply diffusers were above the patient are shown. Tracer gas measurements showed notable difference in the exposure index values when the HCW was leaning over the patient where the local downward air supply mode produced substantially smaller exposure than the overhead mixing ventilation. Further away from the patient the differences in susceptible exposure index values between the two supply air distribution modes were found to be smaller. Similar trend with differences were found with other supply air diffuser locations as well.

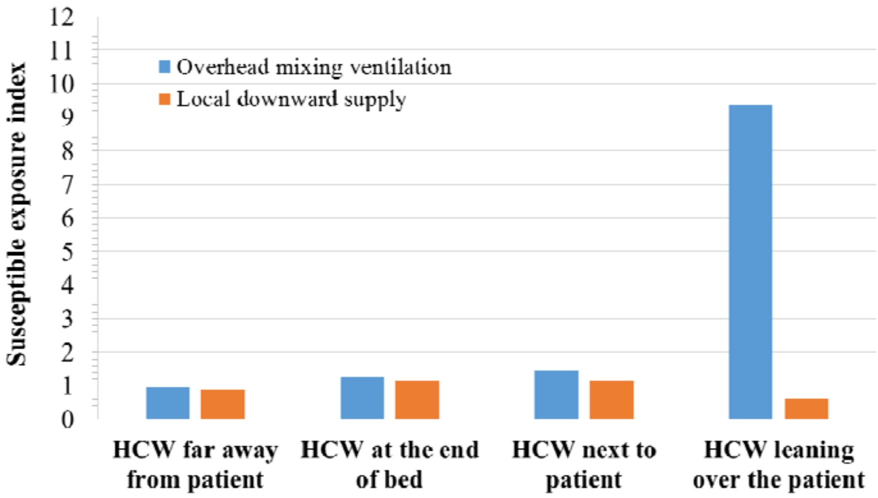

Figure 3. Tracer gas measurement results when the supply air diffusers were located in the ceiling above the patient.

Conclusions

Both the smoke visualizations and the tracer gas measurements showed that supply air distribution affects highly the patient exhalation dispersion and the HCW exposure to it especially close to the source. Local downward air supply was found to have the potential to reduce the exposure of the HCW to patient exhaled airborne contaminants. However, the performance of this and other local air distribution methods in isolation rooms should be studied in more detail in the future. For instance, thermal comfort of the patient and HCW should be examined carefully in order to maintain comfortable thermal environment together with low exposure values.

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