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Risk of cross-infection in a hospital ward with downward ventilation

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ABSTRACT

A two-bed hospital ward with one standing healthcare person and a ceiling-mounted lowimpulse semicircular inlet diffuser is simulated in a full-scale room. Tracer gas is used for simulating gaseous contaminants, and the concentration is measured at different air change rates and different postures of the patients. A textile partition between the beds, which is typical in a hospital ward, is used for protection of the patients in some of the experiments. Three different layouts of return openings are tested. One layout with one opening at the ceiling, another with four openings at the wall opposite to the inlet diffuser, and one with a high location of these four openings. The downward recirculating flow is on average parallel with the partition, and in most cases the partition does not decrease cross-infection. A high location of the four return openings decreases the risk of cross-infection.

1. Introduction

Spread of contaminants in hospital wards has been a matter of utmost concern since the severe SARS outbreak in 2003, and a need for an efficient air distribution system is especially pronounced in the hospital environment [1–3]. A discussion of the importance of the ventilation system and the possibility to protect people from airborne infection was given in a literature review [4], where it was concluded that there is a strong and sufficient evidence of a connection between ventilation and control of air flow directions in buildings and the transmission and spread of infectious diseases such as measles, TB, chickenpox, anthrax, influenza, smallpox and SARS.

Different air distribution systems such as mixing ventilation, downward ventilation and displacement ventilation offer different possibilities in the protection of people against airborne pathogens. The pollutants are almost fully mixed in the occupied zone in a room ventilated by mixing ventilation and downward ventilation, and they are removed by a diluting process [5–7]. If the pollutant source is also a heat source, then displacement ventilation offers possibilities to work with two zones, a low zone with clean air and an upper zone with contaminants. It is possible to design a system with low exposure of people, [8], but in certain situations both a very low and a high exposure may also exist in rooms with displacement flow as shown in [9,10] as the exhaled air and droplet nuclei may be trapped or “locked up” due to thermal stratification.

Flow with a displacement effect can also be obtained in a room ventilated by a ceiling-mounted low velocity diffuser. The air distribution in the room is mainly controlled by buoyancy forces from the heat sources, if the downward flow from the diffuser is located in areas without thermal load. The displacement flow, which exists in different areas of the room, may indicate the possibility of obtaining improved protection in those areas [11]. Those possibilities are addressed in this article, where the air distribution system is used together with different locations of return openings, and without and with partitions between beds.

In this paper downward ventilation is used as an expression for a system with a ceiling-mounted low velocity diffuser giving a downward supply flow.

2. Simulation of cross-infection

This article describes the cross-infection caused by the movement of airborne particles (bacteria and viruses) in the room air flow, and how the problem can be minimised and eventually be controlled by the ventilation system and the air distribution systems.

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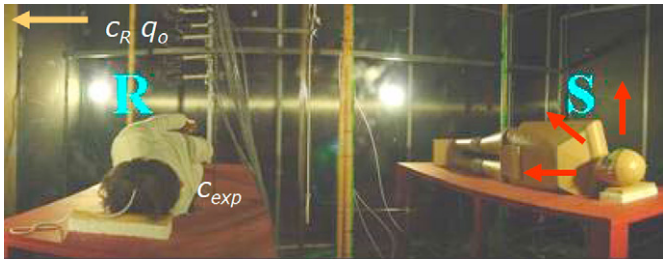

Fig. 1. Two patients (life-size manikins) in a hospital ward. The right patient is the source of airborne infection, and the left patient is the target.

The experiments are carried out by tracer gas. The tracer gas has the same density as the air in the room, and the results are therefore valid for the situation where bacteria and viruses are transported on droplets (droplet nuclei) smaller than 5–10 μm. Droplet nuclei smaller than 5 μm exhibit a settling velocity below 1 m/h in still air, and can therefore follow the persons' exhalation flows and the ambient air flows in for example a hospital ward. Large droplets are also part of the cross-infection process, but they settle either on surfaces close to the source of the infection, or evaporate, decrease in size and follow the air flow as droplet nuclei. Tracer gas is therefore especially useful for simulation of the movement of airborne infection at large distances outside infected people's microenvironment. Furthermore, the transport of fine particles is important because they may be much more readily inhaled than the coarser particles as shown by Wells [12].

Tracer gas concentration can not be directly used as a measure of the health risk, but it can give an indication of this risk. The health risk can be estimated from the Wells–Riley model which, among other things, gives a link between the concentration in a person's inhalation and the connected risk of infection as shown by Riley et al. [13] and Qian et al. [14]. All the measurements and discussions in this article are based on steady state conditions, however, the Wells–Riley model will introduce the time as a parameter, as e.g. the number of infected cases over a period of time.

All the experiments described in this article have been made in a test room without people in motion. The activity level of the staff will in practice have a great influence over the concentration distribution in the room, and it is found that mixing ventilation is considerably more robust in this respect compared with displacement ventilation, Brohus et al. [15]. Door opening can also disturb the concentration distribution in the ward, see Tang et al. [16].

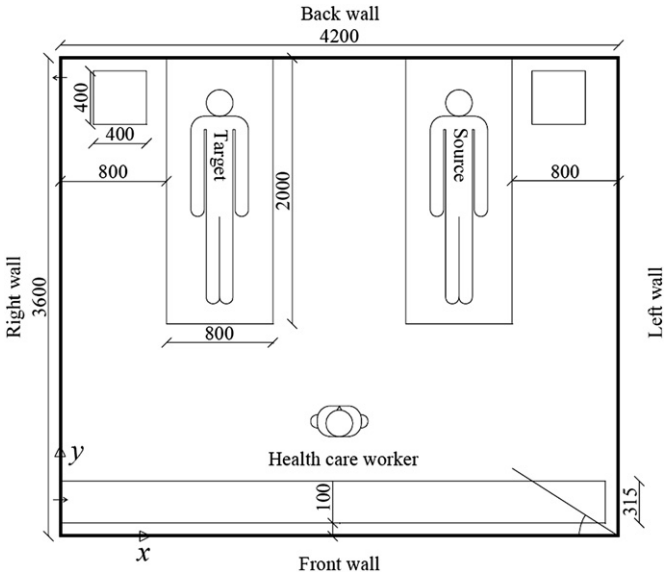

Fig. 2. Layout of a full-scale room simulating a hospital ward.

The cross-infection experiments are based on transport of tracer gas through the air, and the effect of the air distribution system and source level can be explained from Fig. 1. The figure shows, as an example, a situation in a hospital ward with a source patient (manikin S) and a target patient (manikin R). The source has the level of S and represents the respiratory activity of a potentially infectious patient, or related medical procedures such as the use of nebulizer. The source does not represent the effect of coughing. The target manikin (patient or healthcare person) inhales a concentration expressed by c_{exp}. The room is supplied with an air flow rate of q_o, and the concentration in the exhaust of the room c_R is thus

$$c_R = S/q_o \tag{1}$$

The personal exposure index ε_{exp} for the target manikin R is

$$\varepsilon_{exp} = \frac{c_R}{c_{exp}} \tag{2}$$

and the following expression is obtained for the exposure of the target manikin

$$c_{exp} = \frac{1}{q_o}\cdot\frac{1}{\varepsilon_{exp}}\cdot S \tag{3}$$

Equation (3) shows that the inhaled concentration of any airborne infection from the source manikin can be reduced by using a high flow rate q_o to dilute the infected particles to a low level of concentration. Furthermore, Equation (3) shows that systems that generate a large ventilation index ε_{exp} for the target patients or healthcare personnel should be preferred.

3. Test room and manikins

Fig. 2 shows the full-scale room. The dimensions of the room are in accordance with the requirements of the International Energy Agency Annex 20 work with length, width and height equal to 4.2 m, 3.6 m and 2.5 m. The figure shows the layout with a textile terminal located 100 mm from the side wall.

Fig. 3 shows the different layouts of return openings. In Fig. 3A the return opening is located on the back wall close to the ceiling to support the displacement flow, which occurs in the room. Fig. 3B shows the layout with four return openings which can change positions to address this effect. Two openings are located at each bed and the vertical distance between the openings is 0.96 m. Fig. 3C shows the partitions between the beds. The partition is made of textile. It is attached to the wall with the return openings, and there is an opening above the floor of 10 cm, and another one below the ceiling of 40 cm. The opening in the passage is of 1.1 m. The partition is tested in most of the experiments to see if it will change the exposure index of the target manikins.

The layout of the room shows a general hospital ward, and not a specific hospital ward built in accordance with protected environment regulations.

Fig. 3 also shows the furnishings and the heat load of the room. The heat load consists of two desk lamps (92 W) and two manikins (150 W) producing a total heat load of 242 W. A manikin representing a healthcare person (120 W) is added to some of the experiments, which gives a total heat load of 362 W. All surfaces are adiabatic, and a solar gain is not considered.