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CROSS INFECTION IN A HOSPITAL WARD AND DEPOSITION OF PARTICLES EXHALED FROM A SOURCE MANIKIN

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SUMMARY

The cross infection in a hospital ward is studied. Deposition of particles exhaled from a source manikin is investigated in a full-scale hospital ward ventilated by downward directed ventilation. Deposition on vertical surfaces close to the source shows distribution of particles directed upwards in the room. Deposition at the four beds shows that particles smaller than 10 μm disperse evenly in the ward, indicating that particles smaller than this size are airborne. The influence of top and bottom extraction openings on dispersion of particles is investigated. Results show that vertical distribution in the room is not affected by the position of the return openings. Deposition of particles at the four beds gives some indication of a less wide spread of particles with the use of ceiling-mounted return openings, and thereby a better protection of patients compared with bottom return openings.

INTRODUCTION

Spread of contaminants in hospital wards is a matter of utmost concern, and a need for a protecting air distribution system is evident. The cross infection problem was clearly demonstrated in the worldwide SARS outbreak in 2003 (Li et al., 2004a and 2004b), where it was shown that the danger was especially pronounced in the hospital environment (Li et al., 2004a, Qian et al., 2006). A further discussion of the importance of an effective ventilation system, and the possibility to protect people from airborne infection was given in a literature review by Li et al. (2007), where it was concluded, that there is a strong and sufficient evidence of a connection between ventilation and control of airflow directions in buildings and the transmission and spread of infectious diseases such as measles, TB, chicken pox, anthrax, influenza, smallpox and SARS.
The scope of this paper is to analyse spread of exhaled contaminants in a room ventilated by a vertical air distribution system. The SARS ward at the University of Hong Kong is used for the experimental studies. The SARS ward is a four-bed hospital ward with nine ceiling-mounted downward-directed diffusers. Two different levels of extraction opening locations are tested. Test particles are used to simulate exhaled viruses and bacteria.

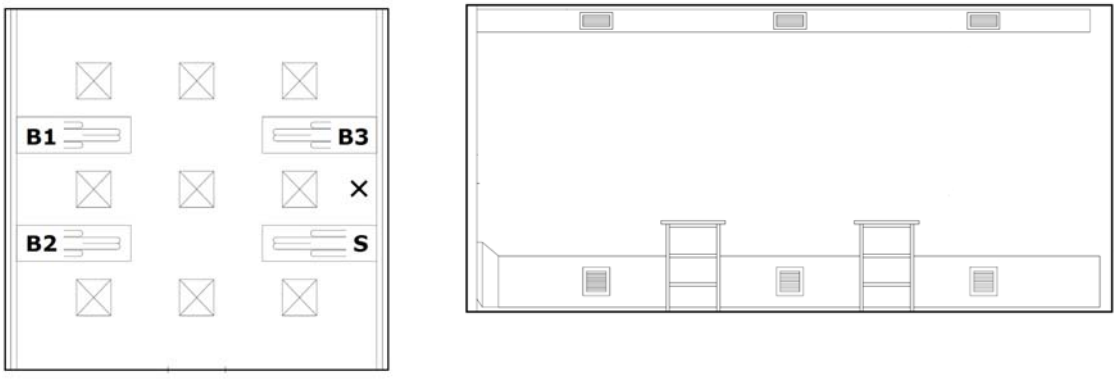
The experiments are carried out by the use of particles (test dust). Bacteria and viruses are transported on droplets or droplet nuclei. Droplet nuclei smaller than 5 μm exhibit a settling velocity below 1 m/h in still air, and can therefore follow the exhalation flows and the ambient airflows in, for 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 infection or evaporate, decrease in size and follow the airflow as droplet nuclei. Particles are therefore especially useful for the simulation of the movement of airborne infection both close to the source and at large distances outside infected people's microenvironment. The transport of fine particles is especially important because they may be much more readily inhaled than coarser particles as shown by Wells (1955).

Often airborne transmission through aerosols at a long distance, more than 2 - 3 metres or even several 100 metres, is distinguished from droplet-borne transmission through large droplets by close contact at a short distance, less than 2-3 metres.

Distribution of particles 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 by 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 (Riley et al., 1978, Qian et al., 2007).

TEST ROOM, MANIKINS AND PARTICLE GENERATOR

All experiments are made in the SARS test room at the University of Hong Kong, see Figure 1. The room has the dimensions 6.0 m × 6.7 m × 3.0 m. It is ventilated by nine diffusers of the size 600 mm × 600 mm. The room has two set of exhaust openings located below the ceiling along both end walls, and at the floor, as shown in Figure 1B. The six openings at the ceiling have a dimension of 150 mm × 300 mm, and they are located with the centre line 140 mm below the ceiling. The six openings at the floor have a dimension of 250 mm ×250 mm with a centre line which is 265 mm above the floor. The locations of the return openings were studied by using either the upper openings or the lower openings at a time.



A B

Figure 1. Test room at University of Hong Kong. The horizontal section, Figure 1A, shows the distribution of the nine diffusers and the four beds. One bed indicates the location of the source manikin, and the other beds show the location of the target manikins. The exhaust openings consist of either six openings close to the ceiling or six openings close to the floor, Figure 1B.

On average, the air distribution system has the following working conditions:

- 45 l/s per inlet, thus an air volume supply of 1450 m^3/h
- ~12 air change rates per hour
- Room temperature equal to ~ 24 ^oC

More detailed values are given in the chapter on experiments.

The airflow from the diffusers is directed downwards, and a typical flow pattern is shown in Figure 2.

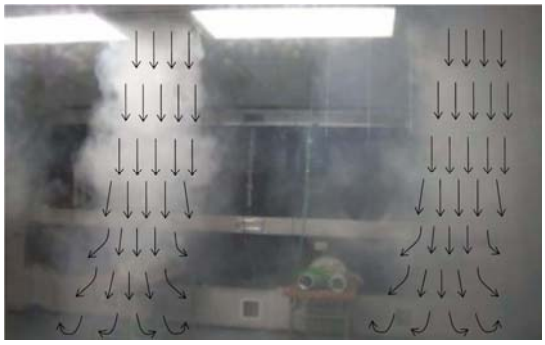


Figure 2. Flow visualisation of the downward-directed flow from two of the diffusers in the test room.

Four thermal manikins (S, B1, B2, B3) are placed in the beds shown in Figure 1A. They are lying on the back, see Figure 3. The source manikin (S) can either exhale in horizontal direction towards manikin B3, or in a vertically upward direction. All the manikins have a heat release of 80 W corresponding to a low activity level. The source manikin has a constant exhalation of either 1.74 L/min, 6.0 L/min or 13.7 L/min, corresponding to a velocity of 0.37 m/s, 1.27 m/s or 2.9 m/s, respectively. (For a person the pulmonary ventilation is 6 L/min at rest, and 30 L/min at moderate work with a respiratory rate of 12 min^{-1}).

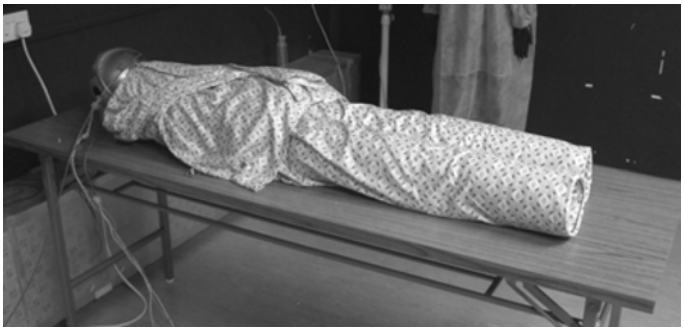


Figure 3. Thermal manikin lying on a bed in the full-scale hospital ward.

The test dust used is an equal mixture of Arizona Test Dust A2 Fine and Arizona Test Dust A4 Coarse. Table 1 gives the volume fraction of size distribution.

The dust is supplied to the source through a unit with a fan that mixes the dust with air at a steady rate, and at a steady size distribution according to the distribution given in Table 1.

Table 1. Volume fraction percentages of size distribution in the test dust.

Size [µm]	A2 Fine [%]	A4 Coarse [%]
1	2.5 to 3.5	0.6 to 1.0
2	10.5 to 12.5	2.2 to 3.7
3	18.5 to 22.0	4.2 to 6.0
4	25.5 to 29.5	6.2 to 8.2
5	31.0 to 36.0	8.0 to 10.5
7	41.0 to 46.0	12.0 to 14.5
10	50.0 to 54.0	17.0 to 22.0
20	70.0 to 74.0	32.0 to 36.0
40	88.0 to 91.0	57.0 to 61.0
80	99.5 to 100	87.5 to 89.5
120	100	97.0 to 98.0
180	-----	99.5 to 100
200	-----	100

The dust is collected on horizontal microscope slides of the size of 25 mm × 75 mm. In the experiments with the exhalation in horizontal or vertically upward direction slides are located on a vertical line between the beds S and B3 at a distance of 0.9 m from the heads of both S and B3. In the experiments with location of the return openings, the slides are located on a vertical line at the end of bed S at a distance of 1.8 m from the exhalation area (mouth). In both cases they are mounted at a height of 0.0, 0.5, 1.0, 1.5, 2.0, 2.5 m above the floor.

Dust collecting slides are also mounted in the breathing zone of all four manikins S, B1, B2 and B3.

Thirty minutes after the source has been closed, the microscope slides are covered with clean glass, and the number and size of the particles are counted in a microscope, see Zhou (2006).

MEASUREMENTS AND DISCUSSION

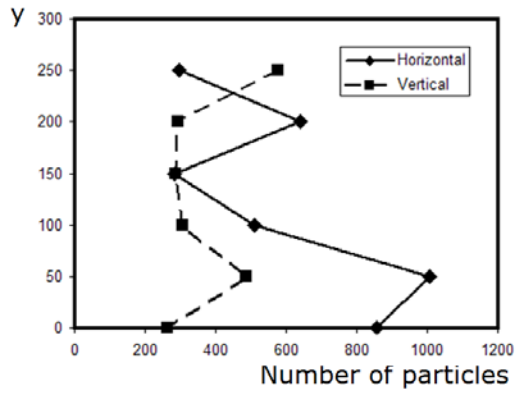
Two sets of experiments are made. The first set of experiments is about exhalation at the source, and both the exhalation rate and the direction of the exhalation are studied in four experiments (experiments 1 to 4). The second set of experiments is a study of the influence of the return opening location (experiments 5 to 6).

Table 2. Conditions for experiments 1 to 4.

Experiments	Exhalation direction	Exhalation velocity [m/s]	Air change rate [h^{-1}]	Mean air temp. [°C]	Duration [min]
1	Horizontal	0.37	11.6	23.7	61
2	Vertical	0.37	12.0	24.0	60
3	Horizontal	2.90	12.4	25.6	15
4	Vertical	2.90	12.4	25.8	15

Figure 4 shows the vertical distribution of particles in the room in the experiments 1 to 4 in the position between the beds S and B3. It is seen that a horizontal exhalation from the source manikin S gives an increased deposition at the height of 0.5 m compared to the deposition in the case of a vertical exhalation. This is especially pronounced for the high exhalation velocity.

The deposition of particles larger than 10 µm is only 1 % (in number) of the total deposition at the height of 0.5 m in the case of low exhalation flow, while it is 18 % at high exhalation flow. The level of particles larger than 10 µm is very low above the height of 0.5 m. This is in agreement with the general experience that droplet-borne transmission through large droplets only takes place at a short distance, less than 2-3 metres.



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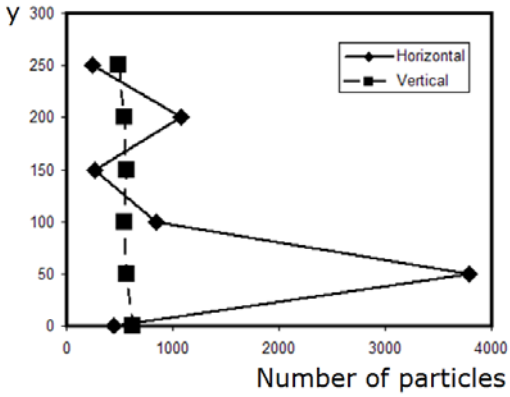
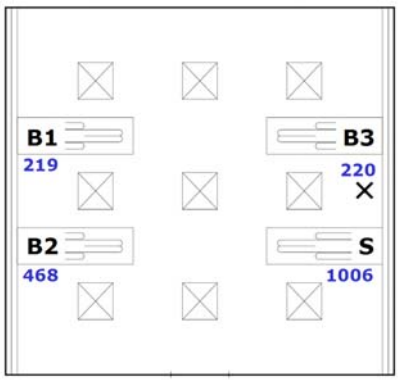


B

Figure 4. Vertical distribution of particles at a position between the beds S and B3. Figure A corresponds to an exhalation velocity of 0.37 m/s, and Figure B to 2.9 m/s.



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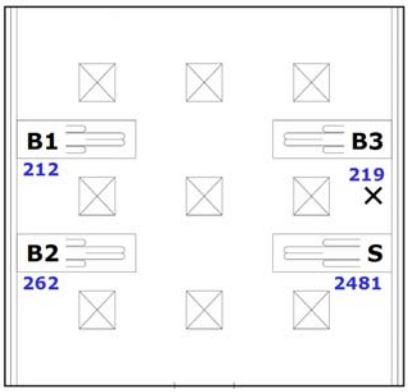

B

Figure 5. Particle distribution at the four beds in experiments 3 and 4 where the exhalation velocity is 2.9 m/s. Figure A corresponds to horizontal exhalation, and Figure B to vertically upward exhalation.

Figure 5 shows the distribution of particles in the room. The gravity effect on the particles means that most particles will stay at the source bed S when the exhalation from the manikin is vertically directed upwards. The distribution of particles to the other beds does not seem to be strongly dependent on the direction of the exhalation. Most of the particles at B1, B2 and B3 are smaller the 10 µm, corresponding to a particle size which is typical for airborne transmission.

The second set of experiments is a study of the influence of the position of the return opening, i. e. either at the floor, which is recommended by CDC (1994), or at the ceiling (experiments 5 to 6), see Table 3. The exhalation of the source manikin is in a vertically upward direction.

Table 3. Conditions for experiments 5 and 6.

Experiment	**Exhalation velocity [m/s]**	**Air change rate [h^{-1}]**	**Mean air temp. [°C]**	**Duration [min]**
5 – Return at floor	1.27	12.1	23.5	21
6 – Return at ceiling	1.27	12.0	24.0	30

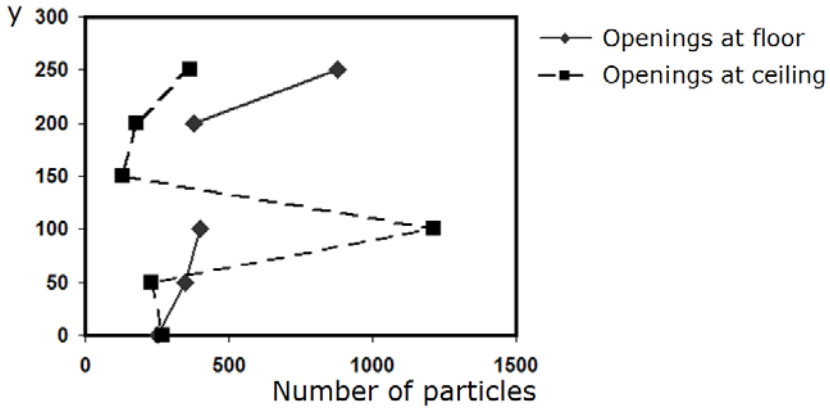

Figure 6. Vertical distribution of particles at a position at the end of bed S at a distance of 1.8 m from the exhalation area (mouth).

Figure 6 shows the vertical distribution of particles at the two different locations of the return openings. It is not obvious, that a low location of the return opening decreases the number of particles, especially when it is taken into account that the duration of particle emission is 30 minutes for a ceiling return opening, and only 21 minutes for a floor return opening. In both cases there are very few large particles (> 10 µm) at the vertical measuring line, even at floor level. Large particles are deposited on the source bed S and on the floor close to the bed. It even looks as if the ceiling-mounted return opening is most efficient in removing smaller particles. This is probably because the thermal plume of the manikin moves particles to the ceiling region. It is not

possible to give an explanation of the high number of particles measured at a height of 1 m when the return openings are located at the ceiling.

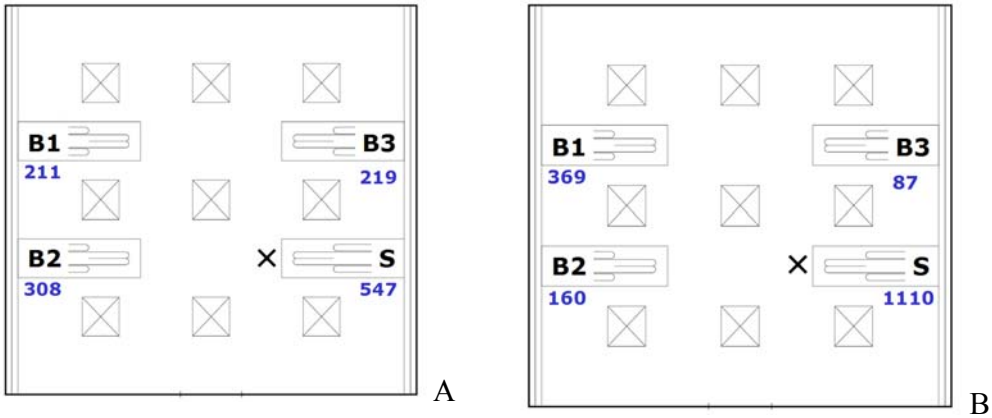

Figure 7. Number of particles distributed at the four beds in experiments 5 and 6. The exhalation velocity is 1.27 m/s. Figure A shows measurements for return openings at the floor, and Figure B shows measurements for ceiling-mounted openings.

Figure 7 shows the particle distribution in the room. The distribution shows a high level at source S when the ceiling-mounted return openings are used. In this connection it must be taken into consideration that the source, in this case, has a 50 % longer emission time, see Table 3. Deposition of particles at the three other beds gives some indication of a less wide spread of particles by the use of ceiling-mounted return openings, and thereby a better protection of patients compared with bottom return openings.

CONCLUSIONS

Calibrated dust is used to simulate the distribution of droplets and droplet nuclei in a full-scale room. The geometry corresponds to a four-bed hospital ward with downward ventilation. The full-scale room is equipped with one source manikin and three target manikins.

It is shown that particles larger than 10 μm have a deposition within a distance of 1 m from the source manikin when the exhalation is horizontal, and the constant exhalation flow is up to 14 L/s. This is in agreement with the general experience that droplet-borne transmission through large droplets only takes place at a short distance, less than 2-3 metres.

The deposition of large particles is even closer to the source when the exhalation of the source manikin is directed vertically upwards.

It is also shown that particles smaller than 5 – 10 μm are distributed in the room as an effect of the air distribution system. This is typical of airborne transmission.

Return openings at the floor do not seem to be very effective in removing large particles. Large particles will be deposited on the source bed and on the floor. It even looks as if the ceiling-

mounted return opening is most efficient in removing smaller particles. This is probably because the thermal plume of the manikin moves particles to the ceiling region.

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