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Protection against cross infection in hospital beds with integrated personalized ventilation

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SUMMARY
Normally we protect ourselves from cross infection by supplying fresh air to a room by a diffuser, and the air is then distributed in the room according to different principles such as: mixing ventilation, displacement ventilation, vertical ventilation, etc.

However, there is a possibility to supply air directly to the breathing zone when people are lying in beds, e.g. in a hospital ward. This principle, called "Personalized Ventilation" has shown to be very efficient in the protection of people from cross infection.

The system supplies fresh air into the breathing zone through a pillow or a blanket. The system can also be used to reduce the emission of viruses or bacteria from the exhalation of a source patient. The air supplied from the personalized ventilation (PV) diffuser rises to the ceiling and with the right air distribution system it can be removed from the room.

The experiments in this paper are carried out with tracer gas and two thermal manikins in the experimental SARS ward at Hong Kong University. One of the manikins is the source manikin, and the other one the target. The measurements show that a very high degree of protection can be obtained with this system. Optimum flow rate and temperature of the supply air are addressed in the research work.

KEYWORDS
Personalized ventilation, Cross infection, Hospital bed, Vertical downward ventilation, Full-scale experiments, Thermal manikin

INTRODUCTION
More and more people spend a considerable amount of time in indoor environment. It is important to minimize the amount of pollutants that people are exposed indoors, to give an experience of a good air quality and to minimize the danger of cross infection in e.g. hospital wards. The last-mentioned problem was clearly demonstrated in the worldwide SARS outbreak in 2003 (Li et al., 2004a, 2004b), and it was shown that the problem is especially pronounced in the hospital environment (Li et al., 2004a; Qian et al., 2007). A further discussion of the importance of the ventilation system and the possibility to protect people from airborne infection was given from 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 air flow directions in buildings and the transmission and spread of infectious diseases such as measles, TB, chicken pox, anthrax, influenza, smallpox and SARS.

Different air distribution systems such as mixing ventilation, vertical ventilation and displacement ventilation offer different possibilities in the protection of people against pollutants. The pollutants are almost fully mixed in the occupied zone in a room ventilated by mixing ventilation and vertical ventilation, and they are removed by a diluting process (Nielsen et al., 2003; Nielsen et al., 2005; Nielsen et al., 2006). If the pollutant source is also the heat source, then displacement ventilation offers possibilities to work with two zones, a low zone with clean air and an upper zone with pollutants. It is possible to design a system with low pollutant exposure by occupants (Skistad et al., 2002), but in certain situations both a very low and a high exposure may exist in rooms with displacement flow as shown by Bjoern and Nielsen (2002) and Qian et al. (2004).

In this study, the personalized ventilation system (Low Velocity Personalized Ventilation (LVPV)) offers a design which utilizes the situations where the head or the body is in natural contact with surfaces as chairs, neck support pillows, beds, pillows, mattresses, clothing, etc. Those surfaces are designed also to be a supply opening of fresh air, for example by the use of fabric as a diffuser.

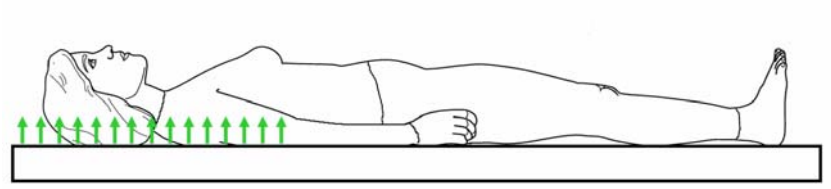

Figure 1. Sketch of bed with totally integrated air distribution system.

Figure 1 shows as an example a bed with a totally integrated supply system for a hospital ward. The LVPV system can also be used to prevent for example the so-called Sudden Infant Death Syndrome, which can be minimized by direct supply of air, independent of the orientation of the baby.

The PV system protects the patient in bed, but it is also possible to use the system to reduce the emission from an infected patient (source patient) as shown earlier in a room with displacement ventilation (Nielsen et al., 2007). This is important for the health care people in the hospital, who cannot be protected by the PV system. Those aspects are especially covered in this paper by the examination of a hospital ward with a traditional vertical ventilation system.

The experiments focused on minimizing cross infection, but the described personalized ventilation system has of course all the features known from conventional PV systems, as e.g. the possibility to have individual control of the thermal environment, which in itself could be a positive feature in a bed environment. A low air temperature, different from the overall temperature in the room, can be supplied to the breathing zone, which will improve the perceived air quality.

METHODS

Figure 2 shows the SARS test chamber at the University of Hong Kong where all the experiments are made. 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, and six of them are located above the beds in the room. The air flow from the diffusers is directed downward. The room has the exhaust openings located just below the ceiling along both walls as shown in Figure 2.

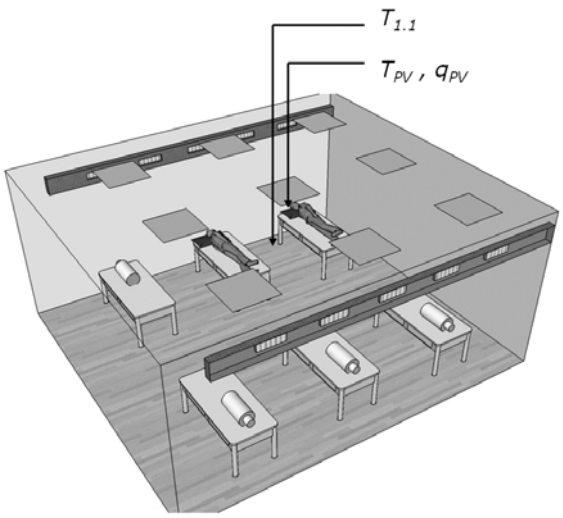

Figure 2. Test chamber at University of Hong Kong. The source manikin is located in the upper right corner, and the target manikin is opposite the source manikin. The variables in the figure express elements of a local Archimedes number.

The air distribution system has the following working conditions:

- 40 l/s per inlet, thus an air volume supply of 1300 m^3/h
- ~13 air change rates per hour
- Supply temperature T_o equal to 15.0 ^oC
- Room temperature $T_{1.1}$ equal to ~ 20 ^oC

Two geometrically detailed thermal manikins are placed in two beds shown in the upper right corner in Figure 2. They are lying on the side, facing each other, one is the source manikin, and the other is the target manikin, see Figure 3. Four other manikins of a more simple design are placed in the other beds. All the manikins have a heat release of 85 W corresponding to a low activity level. The source manikin has a large constant exhalation of 18 l/min, which gives a constant velocity of 2.67 m/s. This is a high level of exhalation, corresponding to the peak value of the exhalation of an individual at moderate work. (For a person the pulmonary ventilation is 6 l/min at rest and 30 l/min at moderate work with a frequency of respiration of 12 min^{-1}).

Figure 3. Source manikin is shown to the right and target manikin to the left in the figure. The two manikins are facing each other.

The effectiveness of personalized ventilation ε_{PV} at the target manikin is defined by (Melikov et al., 2002):

$$\varepsilon_{PV} = \frac{c_{\text{exp},o} - c_{\text{exp},PV}}{c_{\text{exp},o} - c_{PV}} \quad (1)$$

$c_{\text{exp},o}$ Contaminant concentration in the inhaled air without PV

$c_{\text{exp},PV}$ Contaminant concentration in the inhaled air with PV

c_{PV} Contaminant concentration in the supply from PV

The local efficiency $\varepsilon_{exp,PV}$ is an indicator which can be used to study the contaminant distribution when the LVPV system is used to minimize the emission of harmful exhalation from a source patient (assuming that it is an airway infection which is considered). The efficiency expresses the ratio between the target manikin's concentration in the breathing zone without and with a PV system at the source manikin.

$$\varepsilon_{\text{exp},PV} = \frac{c_{\text{exp},o}}{c_{\text{exp},PV}} \quad (2)$$

$c_{\text{exp},o}$ Concentration in the inhaled air at the target manikin without a PV system at the source manikin

$c_{\text{exp},PV}$ Contaminant concentration in the inhaled air at the target manikin with a PV system at the source manikin

The experiments are made with different flow rates to the pillows q_{PV}, and different supply temperatures T_{PV}, while the flow rate to the room from the general air distribution system q_o and the supply temperature T_o should be considered to be constant during all experiments. In practice there is some variation in the supply temperature to the room T_o. Experiments with different flow rates q_{PV} are therefore influenced by some variation in T_o. The problems are overcome by using the similarity principles and by expressing the measurements in a dimensionless form with the efficiency and the effectiveness as functions of an Archimedes number. There is no variation of the length scale in the experiments, and a local Archimedes number for the flow around the two manikins can be expressed in the following simplified way, see (Nielsen, 2001).

$$(T_{PV} - T_{1.1})/q_{PV}^2 \quad (\text{K s}^2/\text{m}^6) \quad (3)$$

$T_{1.1}$ is the air temperature measured in the height of 1.1 m between the source and the target bed, see figure 2.

RESULTS

Results from a room with constant concentration

The LVPV system has earlier been tested as a protection of a single patient. The experiments were made in a room with constant concentration all around the person with a level of $c_{exp,o}$, and an air supply pillow of the dimensions 500 mm × 850 mm. Figure 4 shows the results for

a manikin lying on the side measured by Nielsen et al. (2007). It is obvious that a very high effectiveness can be obtained in this case with isothermal flow from the PV system.

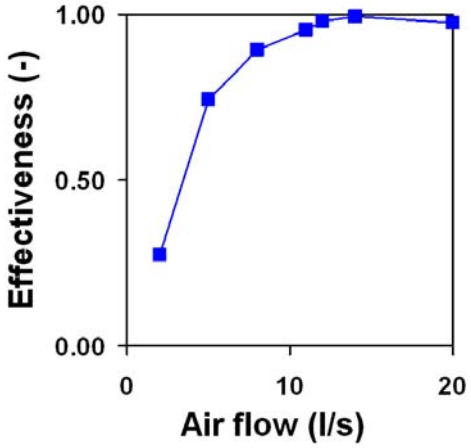

Figure 4. Effectiveness ε_{PV} for an air supply pillow with the pillow placed between the head and the shoulder. The patient is lying on the side.

Results from the SARS room with one PV device at the source patient

Figure 5 shows the efficiency at the position of the target manikin. It is obvious that the level of the concentration has been reduced at the target manikins' breathing zone. The local concentration, $c_{exp,PV}/c_{exp,o}$, has been reduced by a factor of 0.6. This is a reduction which probably can be larger elsewhere in the room. The figure also shows that the PV system should have a high flow rate q_{PV} and/or a small temperature $T_o - T_{PV}$ to obtain the highest efficiency, although the efficiency is not much influenced by small Archimedes numbers. The PV system is without any function as a source reduction device for $(T_{PV} - T_{1.1})/q_{PV}^2$ larger than 85,000. If it is considered that the general air distribution system is supplying air vertically downward at the patient, causing a high turbulence above the bed, it is surprising that the PV system works efficiently as a source reduction device.

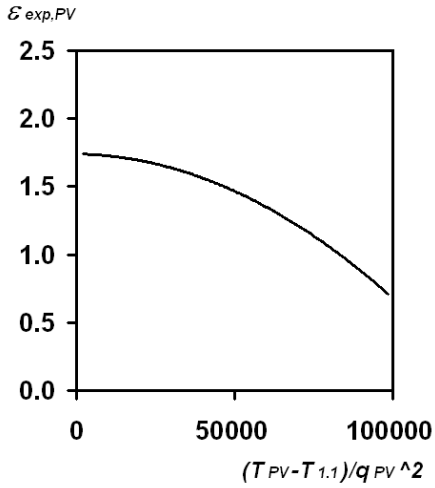

Figure 5. Ventilation efficiency in the breathing zone of the target manikin versus the local Archimedes number of the PV system at the source manikin. One pillow at the source manikin.

Results from the SARS room with two PV devices, one at the source manikin and one at the target manikin

Figure 6 shows the effectiveness of the PV system at the target manikin. Both the target manikin and the source manikin have a PV system. It is proven that an increased temperature of the flow from the pillow T_{PV} decreases the effectiveness, and that a high flow rate and isothermal flow (room temperature ~ 20 °C) give the best results. The general effectiveness is lower than found in the experiments shown in Figure 4. The vertical ventilation in the room, with a diffuser close to the PV device, decreases without doubt the effect of the PV system.

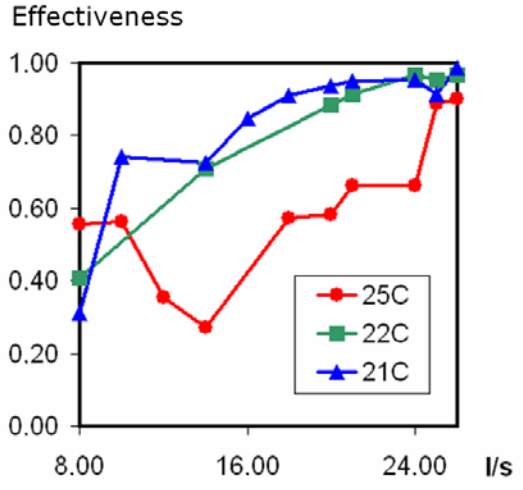

Figure 6. Effectiveness of the PV system at the target manikin. Both the source manikin and the target manikin have PV systems.

The results obtained by two PV systems (two pillows) can also be studied according to the similarity principles. Figure 7 shows this depiction, and it is indicated that the flow rate should be high, and that the flow from the PV device should be isothermal, corresponding to a small value of $(T_{PV} - T_{1.1})/q_{PV}^2$.

Smoke experiments show that the isothermal flow from the PV device surrounds the breathing zone of the manikins before it rises to the ceiling where it is exhausted, Figure 8.

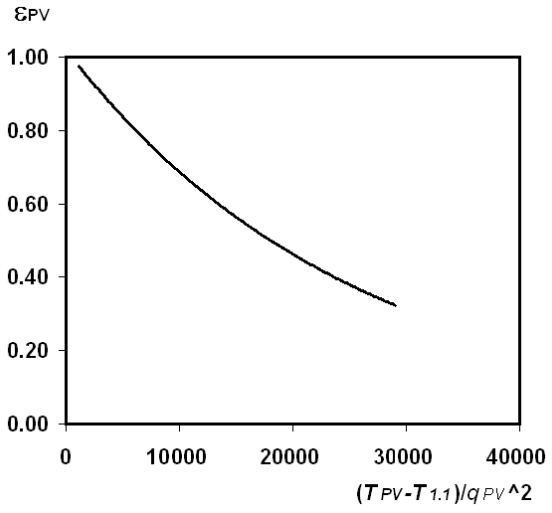

Figure 7. Ventilation effectiveness for the target manikin versus the local Archimedes number.

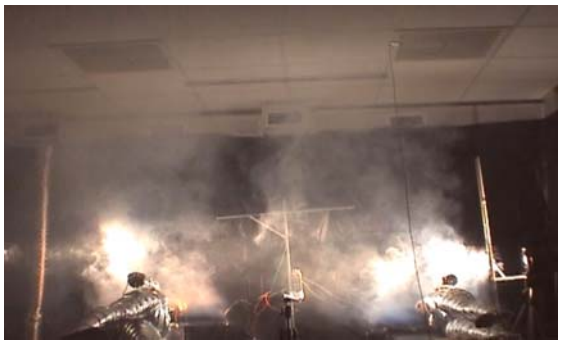

Figure 8. Smoke experiment with PV systems at both source and target manikins. The breathing zones are surrounded by smoke (clean air) and not disturbed by the supply flow from the general ventilation system in the room. $T_{1.1}$ = 23 ^{o}C, q_{PV} = 26 l/s.

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CONCLUSIONS
The low velocity personalized ventilation system (LVPV) integrated as a pillow in a bed works efficiently as a protection against airborne cross infection in a hospital ward. The ward uses a standard downward ventilation system with an air change rate of 13 h^{-1}.

When the ward uses vertical downward ventilation from ceiling-mounted diffusers, and a high location of the exhaust openings, then the LVPV system is able to reduce the emission from a source patient and thus reduce the risk of airborne cross infection for the health care people in the ward. Earlier research has shown that the LVPV system also reduces the risk of cross infection in a hospital ward with displacement ventilation.

The experiments show that the isothermal flow from the PV device (pillow) gives the highest effectiveness. High flow rates (q_{PV} > 12 to 20 l/s) from the device are also important for a high effectiveness.

The effectiveness of the LVPV system (pillow) is influenced by the downward ventilation system with ceiling-mounted diffusers close to the patient and to the PV system. High flow rates (q_{PV} > 12 to 20 l/s) from the device give the best results.

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