Displacement Ventilation System with Radiation Panel for Sickroom
- Contaminant Concentration Profile of Displacement Ventilated Room with Heat Loss through Window -

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ABSTRACT

The sickroom is a place for the medical treatment and is also the living space where they spend almost all time in a day for patients. Therefore, high indoor air quality and thermal comfort are needed in the sickroom. In this study, we propose to use the displacement ventilation as a means of obtaining high indoor air quality, in combination with radiation panel for individual control of thermal environment for a sickroom. In the previous study, temperature distribution and contaminant concentration profile inside insulated displacement-ventilated room with radiation panel are figured out. However, an actual sickroom has a window and it is predicted that convection flows along the window have much influence on the temperature distribution and contaminant concentration profile. This paper shows experiment results to examine the effect of airflow along the window in the displacement-ventilated room with the radiation panel.

INTRODUCTION

The mechanism of displacement ventilation is referred in many textbooks or papers (REHVA, 2002, Skistad, H, Mundt, E, Nielsen, P, Hagstrom, K, Railio, J). The model for predicting vertical profile of temperature is suggested by Nielsen and Mundt. The relationship between the ventilation heat loss and contaminant concentration in the lower zone of the room was investigated previously (Yamanaka and Kotani et al. 2001). It is, however, necessary to predict the effect of cold wall on the contaminant concentration of the air in the lower zone for occupants. The approach to predict the profile of temperature and contaminant concentration was examined by means of macro-model (Higashimoto and Yamanaka et al. 2003). As observed above, a lot of studies for displacement ventilation are researched, but displacement ventilation for sickroom has not been studied enough.

Most sickrooms in Japan have four beds for each room and there is a problem of odor diffusion from the human body or the body waste. It is also difficult to control thermal environment individually. Therefore it was proposed to use displacement ventilation for whole room and the radiation panel for each patient on the bed. This study is intended to examine validity of this system. In the previous study, it is investigated the contaminant concentration inside the displacement ventilated room with radiation panel. When those experiments are conducted, all walls of the test room were insulated. However, an actual sickroom has windows. When temperature of window is lower than indoor air temperature, downdraft is generated on the window. On the other hand, when temperature of the window is higher than indoor air temperature, updraft is generated. It is supposed that downdraft and
updraft affect temperature stratification and contaminant concentration in the displacement ventilated room.

This paper shows the experimental results in the displacement ventilated room that is installed window with one bed and one radiation panel.

**METHODS**

Experiments are performed in a full-scale displacement ventilated room with one bed, one radiation panel and one heated lying mannequin. The displacement ventilated room is built in the test room where indoor temperature can be controlled. The displacement ventilated room has 2.68m in height, 3.0m in width and 3.0m in depth, as shown in Figure 1. The walls are insulated with a 50mm thick polystyrene foam. And window is installed on the one of the walls. The window is made of 5mm thick acrylic sheet and installed at the height of 700 – 2300mm. The temperature of the test room is controlled and it assumed outside temperature. Room air temperature, wall surface temperature and contaminant concentration are measured.

Fresh air is supplied from the half-cylinder displacement-type diffuser. It is located on the floor along the rear wall. The exhaust outlet is a 200 φ hole located in the corner on the ceiling. The heated lying mannequin is made of wood with the heating-cable. Heat generation rate of the mannequin is controlled at 40W as sensible heat of the metabolic rate of slumbering human. Tracer gas is exhaled from the tube that is located on the breast of the mannequin. Carbon dioxide (CO₂) is used as tracer gas. CO₂ flow rate is controlled at 0.5L/min by the mass flow controller. Figure 2 shows measurement points of temperature and CO₂ concentration. Measurement point of air temperatures are 9 points (P1~P9) in horizontal plane and 22 points in vertical direction, that is 198 points in total. Wall surface temperatures (Wa~Wl) are measured at 6 points vertically (i.e. 72 points for all). Outside air temperature is measured at 6 points horizontally (i.e. 36 points for all) and 9 points vertically. Table 1 shows experimental conditions.

**Table 1. Experimental conditions**

<table>
<thead>
<tr>
<th>Outside Temperature (°C)</th>
<th>Distance from Panel to Bed (mm)</th>
<th>No Use of Panel</th>
</tr>
</thead>
<tbody>
<tr>
<td>16</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>20</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>22</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>24</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>30</td>
<td>○</td>
<td>○</td>
</tr>
</tbody>
</table>

Supply Air Temperature: 25°C
Supply Flow Rate: 200m³/h
Heat Output of Person Simulator: 40W
Temperature of Panel: 40°C

**Figure 1. Plan view of testroom**

**Figure 2. Cross section view of testroom**

**Figure 3. Measurement points**
measured at 5 points in vertical direction of PO. Concentrations (P1~P3, P6~P9) are measured at 12 points vertically (i.e. 72 points for all).

Table 1 shows the combination of experimental conditions. Experimental parameters are outside temperature ($T_o$) and the distance from the panel to the bed ($D_p$). The supply air temperature is controlled at 25deg.C and the supply flow rate is 200m$^3$/s. The temperature of the radiation panel is 40deg.C.

**RESULTS**

Heat loss through perimeters and ventilation

Table 2 shows the temperature difference between the supply air and the exhaust air, ventilation heat loss and the conduction heat loss through the perimeters for each condition. The ventilation heat loss was calculated from the temperature difference between the supply air and the exhaust air. And the conduction heat loss was calculated from temperature difference between indoor and outdoor wall surface. If the temperature difference between the supply air and the exhaust air is small, it means the thermal stratification is weak. If the temperature difference is smaller than zero, it cannot be said that displacement ventilation is achieved. The conditions of low $T_o$, there is the difference between total heat generation and total heat loss. It can be said that draft from inside of the room to outside becomes superior as the temperature difference between indoor air and outdoor air becomes larger.

Influence of Outside temperature ($T_o$)

**Vertical temperature distribution**

Figure 4 shows the measured results of the vertical profile of temperature. The horizontal axis of graph means the temperature difference from the supply air temperature.

As graphs indicate, thermal stratification is formed in all cases. The vertical temperature distribution rises as $T_o$ becomes higher. In conditions of using radiation panel, when $T_o$ is 16, 20, 22deg.C, the indoor air temperature of the displacement ventilated room is lower than supply air temperature 25deg.C. In conditions without the radiation panel, excepting the case that $T_o$ is 30deg.C, the supply air temperature is higher than indoor air temperature in all cases. The case with no use of the panel, thermal stratification is weaker than other cases, because the heat generation is lower.

**Vertical profile of CO$_2$ concentration**

Figure 5 shows the measured results of the vertical profile of CO$_2$ concentration. Measured concentration minus supply air concentration is normalized by the concentration difference between supply and exhaust air.

When $D_p$ is 0mm, the effect of $T_o$ is shown in Figure 5(1). When $T_o$ is low ($T_o$ : 16, 20, 22 deg.C), the CO$_2$ concentration is high in any height of the room and the interface of the concentration is not seen. Because the supply air temperature is higher than the indoor air temperature, the supply fresh air As $T_o$ becomes higher, the contaminant concentration of the lower zone decreases. The interface of the concentration is formed clearly when $T_o$ is 30 deg.C.

*“* means no use of panel.

**Table 2. Ventilation heat loss and conduction heat loss**

<table>
<thead>
<tr>
<th>Distance from Panel to Bed ($D_p$ (mm))</th>
<th>0</th>
<th>20</th>
<th>22</th>
<th>24</th>
<th>29</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Heat Generation (W)</td>
<td>237</td>
<td>238</td>
<td>221</td>
<td>222</td>
<td>215</td>
</tr>
<tr>
<td>Temperature difference between supply air and exhaust air (°C)</td>
<td>-0.725</td>
<td>-0.834</td>
<td>0.063</td>
<td>0.236</td>
<td>-1.830</td>
</tr>
<tr>
<td>Ventilation Heat Loss (W)</td>
<td>-50</td>
<td>-57</td>
<td>4</td>
<td>16</td>
<td>-124</td>
</tr>
<tr>
<td>Conduction Heat Loss through Perimeters (W)</td>
<td>257</td>
<td>257</td>
<td>189</td>
<td>191</td>
<td>122</td>
</tr>
</tbody>
</table>

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Figure 4(2) shows the effect of $T_o$ when $D_p$ is 300mm. Contaminant concentration profile denotes same tendency of the case that $D_p$ is 0mm when $T_o$ is low ($T_o$: 16, 20, 22 deg.C). In the previous study, when there is a space between panel and bed, stagnation of CO2 is seen in the front side of the panel. (N. Choi, T. Yamanaka, H. Kotani, et al. 2008) Because fresh air in the lower level of the room is entrained to strong thermal plume of the panel through the space and rises directly to the ceiling, the weaker plume of pollutant from human body can not rise to the ceiling. However, the stagnation of contaminant concentration is not seen in all cases except when $T_o$ is 30 deg. C. It can be said that pollutant air descends with downdraft that is generated from window.

The case of not using panel is shown in Figure 5(3). Even if $T_o$ is 24deg.C, contaminant concentration of lower zone is high. When $T_o$ is 30deg.C, the stagnation of contaminant concentration is seen in both sides of the panel. It can be said that the window plays role of the heating radiation panel, because $T_o$ is higher than indoor air temperature.

When supply air temperature is higher than indoor air temperature, supply fresh air does not spread on the floor, rising in front of the diffuser. Therefore fresh air is exhausted directly and the contaminant concentration of all room is high.

**Influence of Radiation Panel**

**Vertical temperature distribution**

Figure 6 shows the measured results of vertical profile of temperature. Because the total heat output in the room is almost same, there is not a large difference between conditions of $D_p = 0$mm, 300mm. However, the condition of ‘No use of panel’, the temperature distribution is lower than other conditions, because panel that generates large heat is not used. When $T_o = 30$deg.C, the temperature difference among the condition of ‘No use of panel’ and $D_p = 0$mm, 300mm is small than other conditions.
Vertical profile of CO₂ concentration

Figure 7 shows the measured results of vertical profile of CO₂ concentration. The contaminant interface in using radiation panel is clearer than when the radiation panel is not used. The distance from panel to bed has no influence on the contaminant concentration, excepting the condition of \( T_o = 30\,\text{deg.C} \). When \( T_o = 30\,\text{deg.C} \), the stagnation of contaminant...
can be seen in the conditions of $D_p = 300\text{mm}$ and no use of panel. The case of not using panel, the stagnation of contaminant is seen at the both sides of panel.

**CONCLUSIONS**

- When outdoor temperature is low and heat loss through the window is large, it can be said that the distance from panel to bed has no influence on contaminant concentration profile. Because of downdraft from the window, pollutant air descends to the floor and the contaminant stagnation is not formed.
- When outdoor temperature is high, if there is a space between the panel and the bed, the fresh air near the floor is entrained to the convective thermal plume of the panel and rises to the ceiling. It causes the stagnation of the contaminant. And outdoor air temperature is higher than indoor air temperature, the window plays role of the heat radiation panel.
- If indoor air temperature is lower than supply air temperature, supply air does not extend to the floor and it rises in front of the diffuser. In this case, it can not be said that the room is displacement ventilated.

**DISCUSSION**

In order to achieve displacement ventilation, cool and fresh air is supplied from an opening close to the floor while hot and contaminant air is sucked out through the exhaust opening near the ceiling. However, if there is a window in the displacement ventilated room, heat loss through the window becomes to be large and it affects temperature distribution of the room and we can not achieve displacement ventilation. It means that when window is installed in displacement ventilated room, the window with high thermal performance of insulation should be chosen. In future, we will improve the calculation model to predict the vertical contaminant concentration by using experimental results of this study.

**ACKNOWLEDGEMENT**

The authors wish to thank Mr. Sasaki and Mr. Yamane who helped us with experiments.

**REFERENCES**