Displacement Ventilation System with Radiation Panel for Sickroom -Influence of Radiation Panel on Contaminant Concentration Profile -

N. Choi, K. Sagara, T. Yamanaka, and H. Kotani

Osaka University

T. Suzuki

Mitubishi Jisho Sekkei Inc.

T. Yamashita

SANKI Engineering Co.,Ltd

ABSTRACT

For the patient, the sickroom is a place for the medical treatment and is also the living space where they spend almost all time in a day. Therefore, high indoor air quality and thermal comfort are needed in the sickroom.

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. This study is intended to examine the validity of this system. This paper describes the experimental and calculated results on the influence of radiation panel on contaminant concentration profile.

1. 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. It is known that contaminant interface is formed at the height that airflow rate of supply is equal to the total airflow rate from heat sources. Therefore contaminant concentration profile can be predicted briefly. The relationship between the ventilation heat loss and contaminant concentration in the lower zone was investigated previously (Yamanaka and Kotani et al. 2001). It is, however, necessary to predict the effect of cold wall on the pollution 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 inspect validity of this system. This paper shows the experimental results of the displacement-ventilated room with one bed and one radiation panel, and the theoretical predictions of the vertical profile of contaminant concentration based on the calculation of previous study (Yamanaka and Kotani et al. 2001, Suzuki et al. 2008) are investigated.

In the previous study, were investigated the contaminant concentration inside displacement ventilated room with/without radiation panel. As a result, when radiation panel is used for heating, the stagnation of contaminant was observed. Supplied fresh air at floor level rises to the ceiling by plume from the panel. Therefore contaminant plume from a human body cannot rise to the ceiling level and stagnates at a certain height. It is supposed that stagnation might not happen when the panel condition is changed. This paper describes the experimental results on the influence of radiation panel on contaminant concentration profile. And the experimental results of vertical profile of contaminant concentration are compared with the calculated ones.

2. EXPERIMENT

2.1 Experimental Method

Experiments are performed in a full-scale displacement ventilated room with one bed, one radiation panel and one heated lying mannequin. The test room has 2.68m height, 3.0m width and 3.0m length, as shown in Figure 1. The walls are insulated with a 50mm thick polystyrene foam insulation material. The surroundings of the test room is kept at 23-25ºC. Room air temperature, wall surface temperature and contaminant concentration are measured.

Fresh air is supplied from 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 heating-cable. Heat generation rate of the mannequin is controlled at 40W as sensible heat load of slumbering human. Tracer gas is exhaled from the tube that is located on the mannequin. Carbon dioxide (CO_2) is used as tracer gas. CO_2 flow rate is controlled at 0.5L/min by mass flow controller.

Distance from panel to the bed, height of the panel, temperature of the panel and supply flow rate were set up as parameters. Table 1 shows the experimental conditions.

Figure 2 shows measurement points of temperature and CO_2 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). Concentrations (P1~P3, P6~P9) are measured at 12 points vertically (i.e. 72 points for all).

2.2 Experimental Results

In these experiments, the measurement results on the back face side of the panel and front face side of the panel are different because the panel back face side is insulated. Therefore the experimental results are expressed by mean value in equal height of the measurement points on the back face side of the panel and front face side of the panel.

Table 1. Experimental conditions

Parameter : Distance from Panel to Bed (D_p)					
Supply flow rate	200m³/h				
Temperature of Panel	40℃				
Height of Panel	0.4m				
Distance from Panel to Bed	40cm	30cm	20cm	5cm	0cm

Parameter : Surface Temperature of Panel (T_p)				
Supply flow rate	200m³/h			
Temperature of Panel	23℃	30℃	35℃	40℃
Height of Panel	0.4m			
Distance from Panel to Bed	0cm			

Parameter : Height of Panel (Y_{pb})						
Supply flow rate	200m³/h					
Temperature of Panel	40℃					
Height of Panel	0.2m		0.4m		0.8m	
Distance from Panel to Bed	0cm	30cm	0cm	40cm	0cm	40cm

Parameter : Supply flow rate (Q_s)					
Supply flow rate	100m³/h	200m³/h		300m³/h	
Temperature of Panel	40℃				
Height of Panel	0.4m				
Distance from Panel to Bed	0cm	0cm	40cm	0cm	40cm

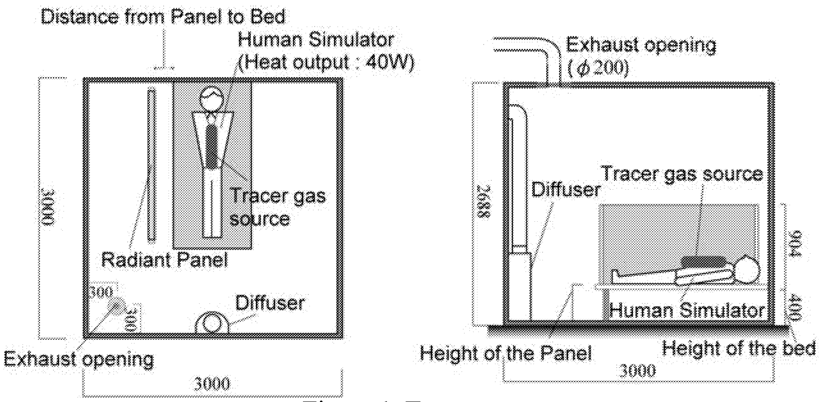


Figure 1. Test room

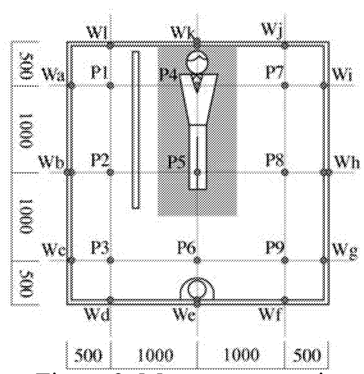


Figure 2. Measurement points

2.2.1 Vertical temperature distribution

Figure 3 shows the measured results of vertical profile of temperature. The horizontal axis of graph means the temperature difference from supply air temperature.

As graphs indicate, thermal stratification is formed in all cases. The average temperature of the front face side of the panel is a little higher than that of the back face side because of the heat generation by the panel.

The effect of distance from panel to bed (D_p) is shown in Figure 3(1). The vertical temperature distribution seems to rise as D_p becomes large. However, in fact, this is not an influence of D_p. It is considered that the reason is the difference of heat loss through walls, ceiling and floor. Because the temperature difference between the air in the room surrounding the experimental room and the room air was not the same in all experiments.

Figure 3(2) shows the effect of temperature of the panel (T_p). As T_p rises, heat generation rate inside the room also rises. Therefore, higher T_p causes larger vertical temperature gradient, and the thermal stratification is formed obviously.

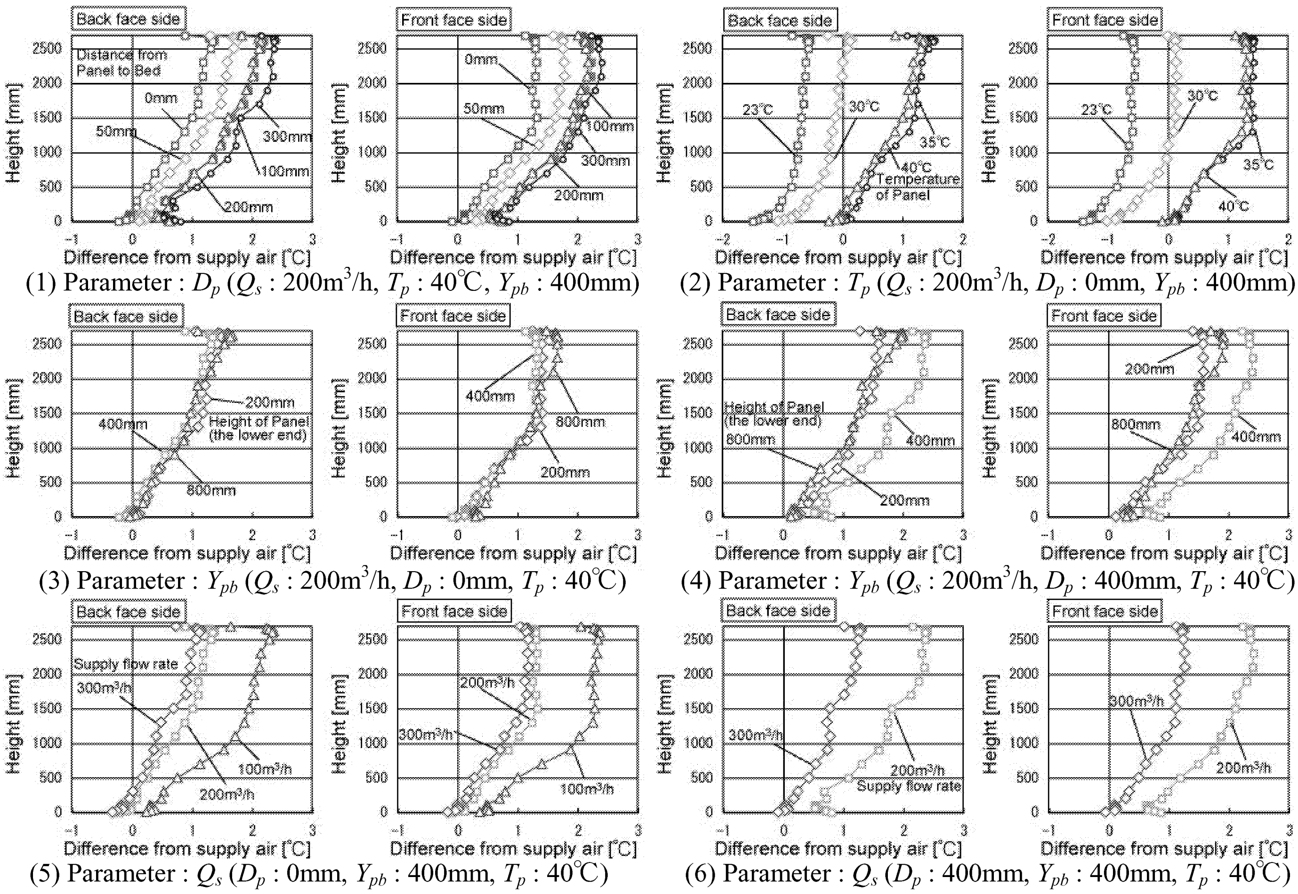
Figure 3(3), (4) shows the effect of the height of the panel (Y_{pb}). When Y_{pb} is 800mm and D_p is 0mm, the temperature rises at a high position, because the panel, that is a big heat source, is in the upper part.

The effect of the supply flow rate (Q_s) is shown in Figure 3(5), (6). As Q_s increases, temperature becomes low and a vertical temperature gradient becomes smaller, so the thermal stratification becomes weak.

2.2.2 Vertical profile of CO_2 *concentration*

Figure 4 shows the measured results of vertical profile of CO_2 concentration. Measured concentration minus supply air concentration is normalized by the concentration difference between supply and exhaust air.

The effect of D_p on concentration distribution is shown in Figure 4(1). In the back side of the panel, interface of the concentration is formed clearly in all cases. However, in the front side of the panel, stagnation of CO_2 is seen in all cases excepting D_p is 0mm. When there is a space



(1) Parameter : D_p (Q_s : 200m^3/h, T_p : 40℃, Y_{pb} : 400mm)
(2) Parameter : T_p (Q_s : 200m^3/h, D_p : 0mm, Y_{pb} : 400mm)
(3) Parameter : Y_{pb} (Q_s : 200m^3/h, D_p : 0mm, T_p : 40℃)
(4) Parameter : Y_{pb} (Q_s : 200m^3/h, D_p : 400mm, T_p : 40℃)
(5) Parameter : Q_s (D_p : 0mm, Y_{pb} : 400mm, T_p : 40℃)
(6) Parameter : Q_s (D_p : 400mm, Y_{pb} : 400mm, T_p : 40℃)

Figure 3. Vertical temperature distribution

between panel and bed, fresh air in the lower level of the room is entrained to strong thermal plume of the panel through the space. The entrained air is heated and rises directly to the ceiling. Therefore the weaker plume of pollutant from human body can not rise to the ceiling and it causes stagnation on the way. As D_p increases, the level of stagnation strengthens. It indicates that whether the bed contacts with the panel or not influences the concentration profile so greatly.

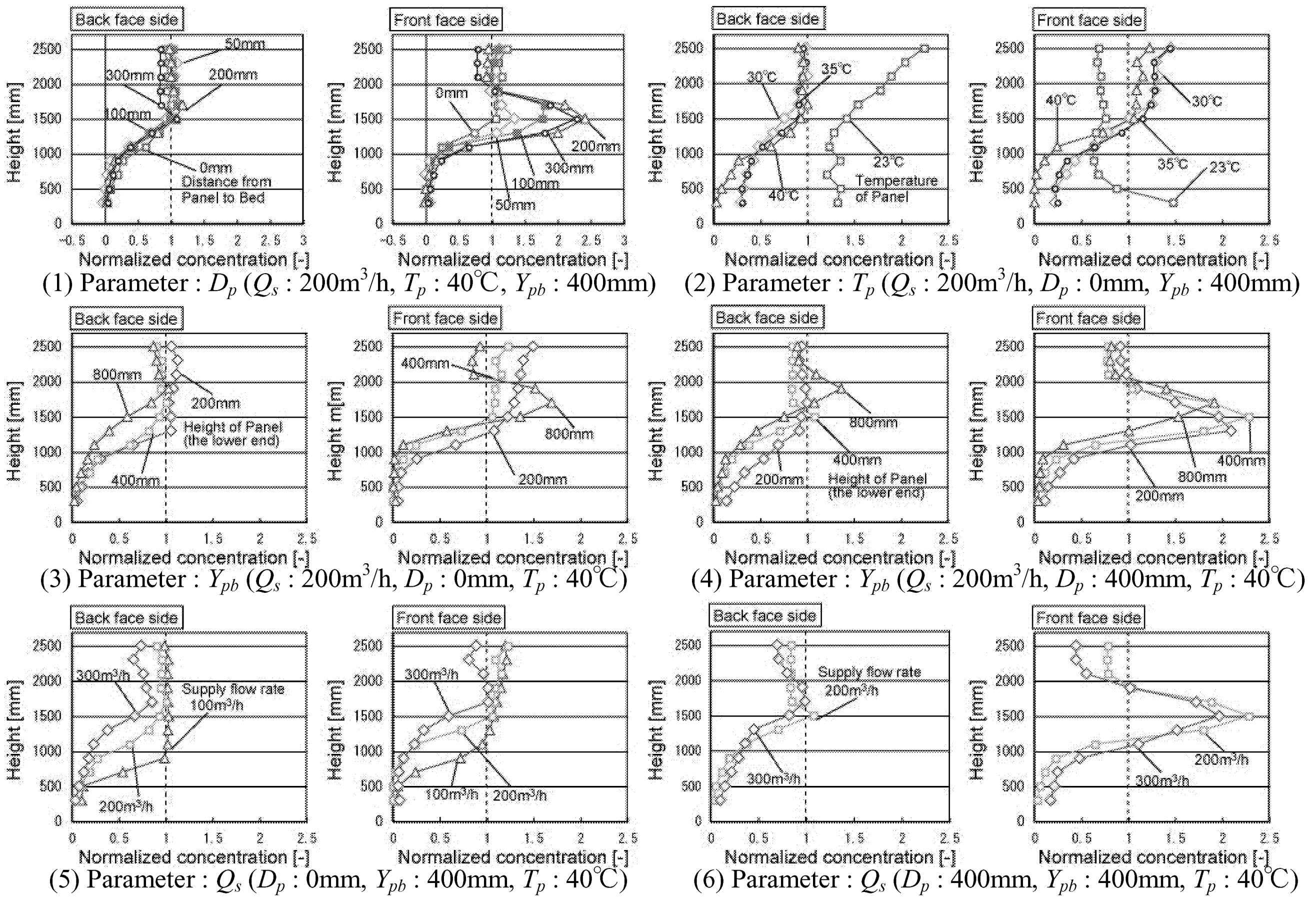
Figure 4(2) shows the effect of T_p on vertical concentration profile. When T_p is 23 deg.C, the downdraft is generated from the panel because the temperature of the panel is lower than the temperature of the room air. Therefore pollutant descends with downdraft to the floor. At the other T_p, the concentration interface of the front side of the panel is clearer than the back side.

Figure 4(3), (4) shows the effect of Y_{pb} on vertical concentration profile. As Y_{pb} becomes higher, concentration interface is also formed at higher level. In the back side of the panel, concentration interface is formed clear in all cases. When Y_{pb} is 800mm, even if D_p is 0mm, stagnation of contaminant is seen. It is because there is a space between lower end of the panel and bed. When D_p is 400mm, the stagnation is formed in all cases in the front side of the panel. It can be said that the height of the panel has no influence on the stagnation phenomenon, if there is no space between lower end of the panel and bed.

The effect of Q_s on concentration distribution is shown in Figure 4(5), (6). The stagnation of contaminant can be seen in all cases in the front side of the panel.

3. Model Validation

In the previous study (Iwamura et al, 2007), the authors confirmed the interface layer model is valid enough to predict the vertical contaminant concentration in the sick room with lying person ventilated by displacement. When radiation panel is added, contaminant stagnation is formed because of the strong plume of the panel. However, the interface layer model doesn't consider the stagnation of human contaminant plume. Therefore, the authors developed an improved model to consider contaminant stagnation. It is called improved interface layer model.



(1) Parameter : D_p (Q_s : 200m^3/h, T_p : 40℃, Y_{pb} : 400mm)
(2) Parameter : T_p (Q_s : 200m^3/h, D_p : 0mm, Y_{pb} : 400mm)
(3) Parameter : Y_{pb} (Q_s : 200m^3/h, D_p : 0mm, T_p : 40℃)
(4) Parameter : Y_{pb} (Q_s : 200m^3/h, D_p : 400mm, T_p : 40℃)
(5) Parameter : Q_s (D_p : 0mm, Y_{pb} : 400mm, T_p : 40℃)
(6) Parameter : Q_s (D_p : 400mm, Y_{pb} : 400mm, T_p : 40℃)

Figure 4. Vertical contaminant distribution

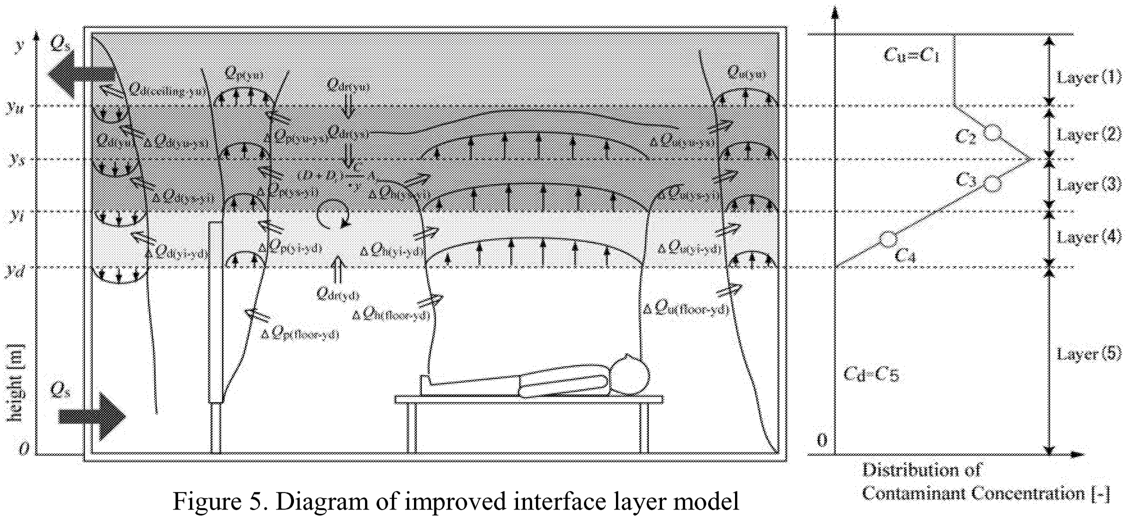


Figure 5. Diagram of improved interface layer model

3.1 Improved interface layer model

The outline of the improved interface layer model is described in Figure 5. In this model, the room is divided into five layers in a vertical direction. C1~C4 in formula indicate the mean contaminant concentration of each layer. y_i is the height of the contaminant interface. It is demonstrated that the height of contaminant stagnation is y_v and that the contaminant flows in Layer (1) and Layer (3) with the same rate.

The contaminant balance of the Layer (2) can be expressed by

$$C_1 Q_{d(yu)} + \frac{M}{2} = C_s Q_{d(yv)} + C_2(\Delta Q_{p(yv-yu)} + \Delta Q_{w+(yv-yu)} + \Delta Q_{w-(yv-yu)})$$

The contaminant balance of the Layer (3) can be expressed by

$$C_k Q_{d(yv)} + \frac{M}{2} = C_3(\Delta Q_{p(yi-yv)} + \Delta Q_{w+(yi-yv)} + \Delta Q_{w-(yv-yi)} + \Delta Q_{h(yi-yv)}) + (D+D_t)\frac{\partial C}{\partial y}A_f$$

The contaminant balance of the Layer (4) can be expressed by

$$C_5 Q_{u(yd)} + (D+D_t)\frac{\partial C}{\partial y}A_f = C_4(\Delta Q_{p(yd-yi)} + \Delta Q_{w+(yd-yi)} + \Delta Q_{w-(yi-yd)} + \Delta Q_{h(yd-yi)})$$

The contaminant balance of the Layer (5) can be expressed by

$$C_1\Delta Q_{w-(yc-yu)} + C_2\Delta Q_{w-(yu-yv)} + C_3\Delta Q_{w-(yv-yi)} + C_4\Delta Q_{w-(yi-yd)} = C_5(Q_{w+(yd)} + (\Delta Q_{p(yf-yd)} + \Delta Q_{w+(yf-yd)} + \Delta Q_{h(yf-yd)}))$$

The contaminant balance of the whole room can be expressed by

$$C_u = C_e = \frac{NM}{Q_s}$$

By the previous study (Skistad et al, 2002), at the height of the stagnation of contaminated air, y_v, the temperature of ambient air and the temperature of the plume are equal. y_v can be

$$y_v = 0.35 \times P_{ch}^{\frac{1}{3}} \times \left(\frac{\partial T}{\partial y}\right)^{-\frac{1}{2}} - 0.3$$

expressed by

The airflow rate of thermal plume from human and panel is calculated by the formula from previous study (Hamaguchi et al). The flow rate along a wall is calculated from the previous paper (Xu et al, 2001).

3.2 Calculated results

Figure 6 shows the comparisons of the calculated results of vertical profile of contaminant concentration with experimental ones. The experimental results are averaged values of the same height. In this Figure, the calculation(1) is the result by interface layer model and the calculation(2) is the result by improved interface layer model. When D_p is 0 mm, contaminant plume from human body rises to the ceiling, therefore, contaminant stagnation can not be seen. In this case, the interface layer model (calculation (1)) that doesn't consider stagnation coincides with experimental result. However, when D_p is parameter, excepting D_p of 0mm, contaminant stagnation can be seen in the front side of the panel in all cases. Therefore, results of the front side of the panel coincide with calculation result (2). And results of the back side of the panel coincide with calculation (1). It can be said that heights of contaminant stagnation by calculation coincide with experimental results.

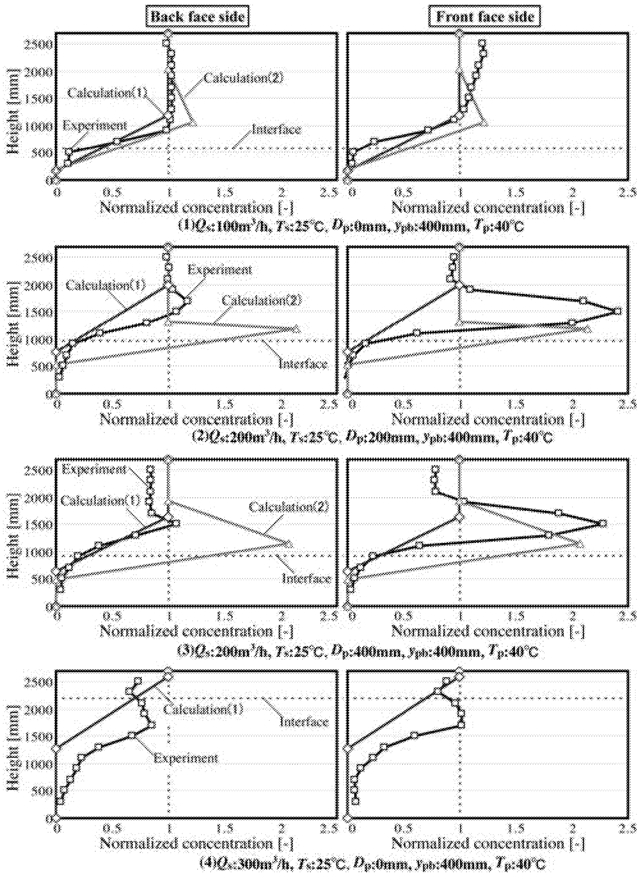


Figure 6. Vertical contaminant distribution

5. CONCLUSIONS

- When radiation panel is contacted with bed, the thermal plume of pollutant from human is entrained to plume of panel and rises to the ceiling.
- If there is a space between panel and bed, the fresh air near the floor is entrained to the convective thermal plume of the panel and rises to the ceiling. It causes stagnation of contaminant.
- If there is no stagnation, the calculated results of interface layer model coincide with experimental results.
- The case that stagnation is formed, the developed interface layer model is available.

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Symbol

A_f : Floor area	[m^2]
C : Contaminant concentration	[-]
$D+D_t$: Diffusion coefficient by molecular and turbulance	[m^2/h]
M : Contaminant emission rate per heat source	[m^3/h]
N : Number of the human	[-]
Q : Flow rate	[m^3/h]
$Q_{u(y)}$: Upward air flow rate at height of y	[m^3/h]
$Q_{d(y)}$: Downward air flow rate at height of y	[m^3/h]
T : Temperature	[℃]
y : Height above floor	[m]

Subscript

$w+$: Upward air flow of the wall
$w-$: Downward air flow of the wall
h : Human
p : Panel
i : Contaminant interface
u : Above the interface layer
d : Below the interface layer
e : Exhaust air
v : Height of stagnation of human plume