Effects of ceiling induction diffusers on indoor environmental quality of sickroom under the cooling air supply condition

Ying Li, Toshio Yamanaka, Hisashi Kotani, Kazunobu Sagara, Yoshihisa Momoi, and Mari Kuranaga

A series of experiments were carried out in a full-scaled model room to verify the characteristics of the air-conditioning system with ceiling induction diffusers. By the step-up tracer gas method and decay method, 10 cases with three varying parameters (the positions of exhausts, the heights of the exhaust ports and the states of the curtains around the beds) were designed to examine the influence on the indoor environment. It can be found that the exhaust ports had obvious influence on the normalised concentration distributions. The curtains made the indoor temperature higher than that of in without curtains and prevent the contaminant escaping out when in patients breathed. In terms of the local mean age of air, the ventilation efficiency presented an optimum result on a specific position of the exhaust port. However, there was minor influence on the air age caused by the height of the exhaust ports.

ABSTRACT
A series of experiments were carried out in a full-scaled model room to verify the characteristics of the air-conditioning system with ceiling induction diffusers. By the step-up tracer gas method and decay method, 10 cases with three varying parameters (the positions of exhausts, the heights of the exhaust ports and the states of the curtains around the beds) were designed to examine the influence on the indoor environment. It can be found that the exhaust ports had obvious influence on the normalised concentration distributions. The curtains made the indoor temperature higher than that of in without curtains and prevent the contaminant escaping out when in patients breathed. In terms of the local mean age of air, the ventilation efficiency presented an optimum result on a specific position of the exhaust port. However, there was minor influence on the air age caused by the height of the exhaust ports.

1. Introduction
Indoor environmental quality is essential to people who stay in the room. Inappropriate indoor environmental quality would lead to some uncomfortable feelings and make people upset. Based on the comfort in building, making a suitable air conditioning system that can modulate a desired degree of thermal comfort and wonderful indoor environmental quality in work environment has been considered by relevant scholars (Bragança, Sodjavi, Meslem, & Serres, 2016; Del Ferraro, Iavicoli, Russo, & Molinaro, 2015; Pourshaghaghy & Omidvari, 2012). A recent review study was performed to summarise and appraise the previous researches about the effect of ventilation on the indoor air quality (Jomehzadeh et al., 2017). In the light of hospital indoor environment, many studies were carried out. Sattayakorn, Ichinose, and Sasaki (2017) drew a conclusion that healthcare occupants in tropical region (in Thai hospitals) prefer slightly colder temperature than neutral. The acceptable temperature ranges for patient, visitor, and medical staff are at 21.8–27.9, 22.0–27.1, and 24.1–25.6 °C, respectively. The neutral temperature and preferred temperature for in patients were studied in Taiwan. The conclusion that patients expected a warmer indoor environment was validated (Hwang, Lin, Cheng, & Chien, 2007). A questionnaire about the subjective responses on thermal environment given by patients and staff had been finished in a hospital during winter (Hashiguchi, Hirakawa, Tochihara, Kaji, & Karaki, 2008). The survey indicated that introducing humidifiers in hospitals during winters
was an effective way to improve the low humidity environment and alleviate the discomfort for staff. In some European hospitals, to some extent, poor indoor air quality emerged as principal sources of indoor environmental dissatisfaction (De Giuli, Zecchin, Salmaso, Corain, & De Carli, 2013). Meanwhile, in terms of cooling and heating delivery systems for susceptible patients who have to stay in wards for long days, such as HIV patients, burned patients, etc., some relevant research was desired (Khodakarami & Nasrollahi, 2012). There is no doubt that indoor environmental quality in a sickroom plays an important role in public wards. However, lots of studies were concentrated on the field of thermal comfort instead of indoor environmental quality.

Air conditioning system is a kind of multifunctional facility in a hospital. In recent years, especially, the ceiling radiant air conditioning has attracted widespread attention (Boji, Cvetkovi, Marjanovi, Blagojević, & Djordjević, 2013), because this kind of air conditioning presented the excellent properties both on the high quality of indoor environment and energy conservation. Meanwhile, some deeper studies have been carried out due to many advantages that could be applied in the modern pragmatic projects (Niu, Zhang, & Zuo, 2002).

In this type of air conditioning system, the air would be sprung out at a speed of 3–5 m/s through a banding nozzle, which was preprocessed by air-conditioning before entering the air supply chamber. Figure 1 is the schematic diagram of the induction chamber with negative pressure, in which indoor air is induced and mixed with the primary air. Thereinto, the indoor air makes up 40% and the primary air accounts for 60% of the total mixed air. Naturally, the temperature of the mixed air is determined by the temperature-weighted for the air proportions. Specifically, for instance, the mixed air temperature is 18 °C, which contains indoor air at 26 °C and supply air at 13 °C. Afterwards, the rectified mixed air is blown out at an initial speed of 0.2–0.8 m/s from some rigid diffusion fins which are installed on an aluminium inlet plate. This mechanism, to some extent, is conducive to relieving the malaise caused by the draft or inappropriate air flow rates. Compared with some other kinds of methods, the Ceiling Induction Diffusers of Low Speed (CID) is a better choice because of its low energy consumption and high comfort. Thus far, CID has been widely used in a raft of projects.

In this study, a full-scaled model room with four beds was assigned to simulate a real hospital ward and verify the characteristics of the air-conditioning system with CID. It aimed at examining the three relevant parameters which have effect on the following factors, including the distributions of indoor temperature, local mean age of air and contaminant concentration. Meanwhile, the way that these parameters influenced the indoor environmental quality (In this study, indoor environment involves indoor thermal environment and indoor air quality) in a sickroom would be discussed and the validity of this system would be proved.

2. Methodology

2.1. Experimental chamber

All of experiments in this study were finished in a showroom of KIMURA KOHKI Corporation, which was a full-scaled model room with four beds. The dimensions of the experimental room are 7.35 m (d) ×
5.35 m (w) × 2.42 m (h), as shown in Figures 2 and 3. Insulation material (polystyrene foam) was pasted on the both north wall and east wall, which thickness was 15 mm. The flow rate of supply air and exhaust air are 450 m³/h and 380 m³/h, respectively. This discrepancy of supply and exhaust flow rate might be caused by the returning air to the equipment room through the crack and the exfiltration flow through the other gaps. There were four rectangular supply inlets (1200 mm × 500 mm) to be set on the ceiling, which were built-in induction panels respectively. Underneath every supply inlet, a bed was placed. Spiral ducts (φ150 mm) were used as the exhaust ports to be set in the experimental room. Figure 2 illustrated the plane positions of the exhaust ports, and the according heights were shown in Table 1. The whole test lasted 19 days, ranging from November 7th, 2016 to November 25th, 2016.

The outdoor air temperature could reach 32 °C, due to the fact that the outdoor air was heated by the oil heater in the equipment room. A spiral duct (φ150 mm, H1500 mm) coated PVC heating-cable was applied to simulate human. Heat generation rate of each simulator was 40 W, which meant one real patient provided the corresponding sensible heat load. Black lamps were placed aside of each bed at the height of 1000 mm, for imitating the heat generated by household appliances such as TV, refrigerator etc. The power of each lamp was 55 W, and 220 W-power was supplied by four lamps in total. There were four pieces of heating carpets to be pasted on the both sides of polyethylene foam,
which function was to simulate the heat gain from windows. However, only three heating carpets (the heat generation rate of every heating carpet was 333.3 W) worked normally during the experiment and the total heat flux was 1000 W. One heating carpet placed in the inner of a wall was out of order during the experiment. Figure 2 showed the three heating carpets which kept working during the experiment period. In addition, the rated power of spotlight in the laboratory was 85 W. The method of step-up tracer gas and decay method were applied in this series of testing, which carbon dioxide (CO₂) and helium (He) were mixed into a gas mixture (molecular weight is 29). According to the four variable parameters, 16 cases were designed and 10 cases (relevant with three variable parameters) would be analysed in this paper. Three changing parameters contained dosing positions of exhaust, dosing the height of exhaust ports and with or without curtain around beds. Table 2 listed the experimental conditions of 10 cases mentioned in this study.

### 2.2. Features of the subjects and experimental procedures

The mixed gas combined CO₂ with He as tracer gas was emitted from the chests of manikin. The flow rate of CO₂ and He was restricted at 1.5 and 0.9 L·min⁻¹ by mass flow meter, respectively. Wall surface temperature, indoor air temperature and CO₂ concentration were measured, when the indoor environment kept steady state. The measurement points of temperature and CO₂ concentration were given in Figure 4. The values of wall surface temperature, captured by T-thermocouple (φ = 0.32 mm, Data logger Cadac 3, Etodenki Corporation), were collected from 3 heights in a vertical line in the measurement positions W1–W9. It meant that 27 points were involved in testing wall surface temperature in total. In terms of indoor air temperature, the values of indoor air temperature were gotten from measurement positions P1–P12 and there were 11 points along each measurement position vertically, i.e. 128 points in total. It was worth mentioning that there were 10 measurement points at positions P1–P4 (there was no measurement point at the height of 2420 mm) because of the existing of a girder. Measurement positions of CO₂ concentration were assigned at P1–P10 and it was measured at 4 points in every position vertically (40 measurement points in total) by CO₂ recorder (TR-576, TR-76Ui, T&D Corporation). During the testing period, the instantaneous values were recorded per 30 s.

<table>
<thead>
<tr>
<th>No.</th>
<th>Item</th>
<th>Number of exhaust ports</th>
<th>Position of exhaust ports</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>4EC</td>
<td>4</td>
<td>50 mm below the ceiling</td>
</tr>
<tr>
<td>B</td>
<td>4EB</td>
<td>4</td>
<td>1200 mm above the floor on the wall</td>
</tr>
<tr>
<td>C</td>
<td>1EC</td>
<td>1</td>
<td>50 mm below the ceiling in the middle of four beds</td>
</tr>
<tr>
<td>D</td>
<td>2EC</td>
<td>2</td>
<td>50 mm below the ceiling at perimeter and interior side</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Table 1. Position of exhaust ports.</th>
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<table>
<thead>
<tr>
<th>Item</th>
<th>Condition</th>
<th>Exhaust position</th>
<th>Positions of tracer gas generation</th>
<th>Curtains around bed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Case 1</td>
<td>4EC-C-4B</td>
<td>4EC</td>
<td>4B</td>
<td>Shut</td>
</tr>
<tr>
<td>Case 2</td>
<td>4EB-C-4B</td>
<td>4EB</td>
<td>4B</td>
<td>Shut</td>
</tr>
<tr>
<td>Case 3</td>
<td>2EC-C-4B</td>
<td>2EC</td>
<td>4B</td>
<td>Shut</td>
</tr>
<tr>
<td>Case 4</td>
<td>1EC-C-4B</td>
<td>1EC</td>
<td>4B</td>
<td>Shut</td>
</tr>
<tr>
<td>Case 5</td>
<td>1EC-NC-4B</td>
<td>1EC</td>
<td>4B</td>
<td>Open</td>
</tr>
<tr>
<td>Case 6</td>
<td>4EC-C-4D</td>
<td>4EC</td>
<td>4D</td>
<td>Shut</td>
</tr>
<tr>
<td>Case 7</td>
<td>4EB-C-4D</td>
<td>4EB</td>
<td>4D</td>
<td>Shut</td>
</tr>
<tr>
<td>Case 8</td>
<td>2EC-C-4D</td>
<td>2EC</td>
<td>4D</td>
<td>Shut</td>
</tr>
<tr>
<td>Case 9</td>
<td>1EC-C-4D</td>
<td>1EC</td>
<td>4D</td>
<td>Shut</td>
</tr>
<tr>
<td>Case 10</td>
<td>1EC-NC-4D</td>
<td>1EC</td>
<td>4D</td>
<td>Open</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Table 2. Experimental conditions.</th>
</tr>
</thead>
</table>

- Which function was to simulate the heat gain from windows. However, only three heating carpets (the heat generation rate of every heating carpet was 333.3 W) worked normally during the experiment and the total heat flux was 1000 W. One heating carpet placed in the inner of a wall was out of order during the experiment. Figure 2 showed the three heating carpets which kept working during the experiment period. In addition, the rated power of spotlight in the laboratory was 85 W. The method of step-up tracer gas and decay method were applied in this series of testing, which carbon dioxide (CO₂) and helium (He) were mixed into a gas mixture (molecular weight is 29). According to the four variable parameters, 16 cases were designed and 10 cases (relevant with three variable parameters) would be analysed in this paper. Three changing parameters contained dosing positions of exhaust, dosing the height of exhaust ports and with or without curtain around beds. Table 2 listed the experimental conditions of 10 cases mentioned in this study.

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3. Results

3.1. Influence on the vertical temperature distributions and normalised concentration distributions

It can be seen, from Figure 5, a part of tracer gas breathed out of the manikins and then flowed into the equipment room through a crack between the door of the equipment room and the floor. As the result, the concentration of supply air increased. According to the Equation 1, the standardised concentration could be calculated. It is worthy to mention that the equipment room and the ceiling chamber were excluded from the experimental system. Figure 6 illustrated how the steady-state concentration ($C_p$) was calculated by an exponential function, which was a needed parameter in Equation 1. Meanwhile, the ratio of tracer gas remaining in the experimental room was defined as $\eta$, which value can be worked out from the Equation 3. The values of $\eta$ were shown in Table 3. Figures 7–12 showed the temperature distributions and normalised concentration distributions in vertical profiles. Due to the symmetry, the normalised concentration distributions at P1–P8 were shown in this paper.
Figure 5. Flow path of the pollutant (tracer gas breathed out of the manikins).

Figure 6. Method of calculating the steady-state value.

Figure 7. Vertical temperature distributions (contaminant source position: 4B, with curtain, position of the exhaust ports: 4EC, 2EC and 1EC).
\[ C_n = \frac{C_p - C_{SA}}{\frac{nM}{Q}} = \frac{C_p - C_{SA}}{\frac{M}{Q} + C_O - C_{SA}} \]  \hspace{1cm} (1)

\[ Q = Q_{SA} \]  \hspace{1cm} (2)

\[ \eta = 1 - \left( \frac{C_{SA} - C_O}{M} \right) Q \]  \hspace{1cm} (3)

where \( C_p \) was the steady-state concentration at each measurement point, and \( \eta \) was the ratio of tracer gas remaining in the experimental room for cases mentioned in this study, which was shown in Table 3.
3.2. Caused by the positions of exhaust ports

In this study, some experiments were carried out under the condition that the curtains were wrap-
ing around the beds (e.g. case 2, case 4 and case 5). By changing the positions of the exhaust ports,
these cases were studied.

In detail, in Figure 7, similar vertical temperature distributions were achieved in all cases. In the
each of cases, the temperature gaps at the same position in the ward area were no more than 3 °C,
which means that a comfortable thermal environment was formed. The temperature gaps among
the three cases, however, were caused by the different outdoor air temperatures probably.

Moreover, Figure 8 provided some noteworthy data with respect to the vertical concentration dis-
tributions. At the beginning of the testing, respectively, outdoor air concentration and the exhaust
concentration were defined as 0 and 1. It was clear from the subgraphs that CO₂ spread to the entire
It can be seen that the value of normalised concentration in the case 1 was smaller than that of in the other two cases. This showed that contaminants can escape out of the room adequately, as long as the exhaust ports were designed appropriately. For example, the position near the bed was the optimum choice which was the sources of the odour gas.

### 3.3. Caused by the height of the exhaust ports

In order to research how the height of the exhaust ports had an effect on the vertical temperature distributions and normalised concentration distributions, the other two factors kept fixed (curtains wrapped the beds and tracer gas breathed out of the manikins). Meanwhile, the height of the exhaust ports were designed at two different positions: underneath the ceiling 50 and 1200 mm above the floor.

Vertical profiles of temperature were shown in Figure 9. The similar vertical temperature distributions were collected both in case 1 and case 2. There was hardly temperature difference between the two cases except for the positions P3, P4, P7, and P8, which were located near to window. It was valid to consider that these gaps were caused by the difference in indoor and outdoor temperature.

<table>
<thead>
<tr>
<th>Item</th>
<th>Condition</th>
<th>$\eta$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Case 1</td>
<td>4EC-C-4B</td>
<td>0.48</td>
</tr>
<tr>
<td>Case 2</td>
<td>4EB-C-4B</td>
<td>0.53</td>
</tr>
<tr>
<td>Case 3</td>
<td>2EC-C-4B</td>
<td>0.38</td>
</tr>
<tr>
<td>Case 4</td>
<td>1EC-C-4B</td>
<td>0.36</td>
</tr>
<tr>
<td>Case 5</td>
<td>1EC-NC-4B</td>
<td>0.32</td>
</tr>
<tr>
<td>Case 6</td>
<td>4EC-C-4D</td>
<td>0.49</td>
</tr>
<tr>
<td>Case 7</td>
<td>4EB-C-4D</td>
<td>0.49</td>
</tr>
<tr>
<td>Case 8</td>
<td>2EC-C-4D</td>
<td>0.42</td>
</tr>
<tr>
<td>Case 9</td>
<td>1EC-C-4D</td>
<td>0.42</td>
</tr>
<tr>
<td>Case 10</td>
<td>1EC-NC-4D</td>
<td>0.33</td>
</tr>
</tbody>
</table>

Figure 12. Normalised concentration distributions (contaminant source position: 4B, position of the exhaust ports: 1EC, with and without curtain).
Furthermore, according to the charts in Figure 10, there was no large difference for normalised concentration among all of the measurement points except for P2, P3, and P8. In general, the normalised concentration of exhaust port labelled 4EB was smallest. According to the relevant statistics, it can be concluded that the contaminant will be emitted out of the room more efficiently if the exhaust port is closer to the source of gas generation.

### 3.4. Caused by curtains

Compared with case 4 and case 5, Figure 11 demonstrated temperature profiles. The difference was whether the curtains wrapped around the bed or not. The graphs showed similar vertical temperature distributions in both cases. It was apparent that the temperature in case 5 was slightly higher than that in case 4. To some extent, curtains made the indoor temperature higher than that of in without curtains. This result reflected that the curtains had an effect on the heat transmission.

In addition, Figure 12 illustrated the normalised concentration distributions in cases 4 and 5. The values of normalised concentration were close to 1 in both cases, but an obvious rising appeared at P7 and P8 caused by the nearby contaminant source. It can be known that there was a slight difference in the aspect of normalised concentration when the measuring points were placed nearby the contaminant source and inside of the curtains. It meant when in patients panted, the curtains around the bed would prevent the contaminant escaping out.

### 3.5. Local mean age of air

It took a period of time to make the supply air reach an arbitrary point in the space, and this kind of period was defined as the age of air. There were multiple paths can achieve the air movement from an inlet to a point, however, the local mean age of air is well known and widely used as one of the important parameters in assessing the effectiveness of ventilation and air distribution phenomenon (Sandberg, 1983, 1981). Injecting some tracer gas to experimental room and measuring the consequent concentration is an effective way to estimate the local mean age of air. Typically, three kinds of injection methods are widely used: pulse method, tracer gas step-up method and decay method.

Pulse method makes a certain amount of tracer gas be introduced to the inlet duct, and the response for the concentration at a monitoring point will be observed continuously. The concentration will be maintained at a steady state value, when steady state is reached. Under the condition of no returning air, basically, pulse method is one of the effective ways to estimate local mean age of air with HVAC system. Therefore, in this paper, the local mean age of air was calculated by the pulse method.

Based on the concentration of tracer gas from inlet $C_s(t)$ [ppm] and the measured value of concentration in a measuring point $C_p(t)$ [ppm], pulse response $R_p(t)$ for the measuring point would be estimated. Necessarily, the influence caused by primary air should be removed. All $C_p(t)$ and $C_s(t)$ should subtract their original values. However, such approach also eliminated CO$_2$ in $C_s(t)$. As the compensation, the amount of CO$_2$ injection should be added to $C_s(t)$. The final simulated $C_s(t)$ was shown as Figure 13(a).

Assuming that a small amount of tracer gas had been injected, the concentration of measured gas at point $P$ was $R_p(t)$, namely, the unit response function. Similarly, if a small amount of tracer gas $M$ [m$^3$] was injected, the measured concentration $C_p(t)$ should be calculated as the following equation:

$$C_p(t) = \int_0^\infty M(t-\tau)R_p(\tau)d\tau = \int_0^\infty Q \cdot C_s(t-\tau)R_p(\tau)d\tau$$

(4)

If no constraint was given, however, in some cases the issue above would be an ill-posed problem. What’s more, sometimes, $R_p(t)$ result was unreasonable. $R_p(t_i) < 0$ for some $i$ is never acceptable, e.g. because there is no minus concentration in the real world.
In order to solve this problem, a reasonable model of $R_p(t)$ was assumed as Equation 5.

$$R_p(t) = \begin{cases} \frac{b}{c} e^{a} & t > a \\ 0 & t \leq a \end{cases}$$

(5)

In this way, the optimum $R_p(t)$ was provided. Moreover, it is essential to minimise the following error function by adding constraints. A result for a minimisation of sample error was shown in Figure 13(c) and the corresponding result of $R_p(t)$ was shown in Figure 9(d).

Based on the calculation of $R_p(t)$, according to Equation (6), the best response factor $a$ was manually selected and then factors $b$ and $c$ were determined by the modules solver in EXCEL. The local mean age of air $\tau_p$ at an arbitrary point $P$ can be easily obtained.

$$\tau_p = \frac{\int_0^\infty tR_p(t)dt}{\int_0^\infty R_p(t)dt}$$

(6)

When the local average air age was uniform over the entire room, the room average age of air $\langle \tau \rangle$ would be available. In addition, the average air distribution performance of the room in the space was characterised by the average air exchange efficiency $\eta_{eff}$ and the calculating formula was presented as the following equation:

$$\eta_{eff} = \frac{\tau_n}{\langle \tau \rangle}$$

(7)

The nominal ventilation time $\tau_n$ can be gotten by Equation (8), where $V$ [m$^3$] stood for the volume of the room, and $Q$ [m$^3$/h] was the supply air flow rate.
Calculation results for both the average age of air and air exchange efficiency were shown in Table 4. Here three sets of results for analysis were listed. Meanwhile, the corresponding analyses and comparison were illustrated in Figures 14–17.

First, the influence caused by the positions of exhaust ports on the local mean age of air was analysed. Coupled with the conditions of curtains wrapping around the beds, the positions of the exhaust ports were changed (e.g. case 6, case 8, and case 9) and the results of the vertical distributions were illustrated in the Figure 14. Moreover, in Table 3, the local mean age of air under the condition 1EC is smallest and the rate of the mean air exchange under the condition 1EC showed the maximum value. It can be considered that the ventilation efficiency was excellent with this kind of the exhaust port condition. In terms of the horizontal distributions (Figure 17(a,c,d)), the values of local mean age of air showed the maximums under all three conditions when the measuring points were far away from the inlet. It meant that the distance from the inlet to the measuring points had an effect on the air age significantly.

Then, the influence caused by the height of exhaust ports on the local mean age of air was analysed. The heights of the exhaust ports were designed at two different positions: underneath the ceiling 50 mm and 1200 mm above the floor. Both the cases were that the curtains were wrapping around the beds (case 6 and case 7). From Figure 15, it can be observed that the results of the vertical distributions were close considerably between the both conditions. In addition, the horizontal

![Figure 14. Vertical distributions of local mean age of air (contaminant source position: 4B, with curtain, position of the exhaust ports: 4EC, 2EC and 1EC).](image-url)
The distributions of the local mean age of air (Figure 17(a,b)) showed larger values in both conditions when the measuring points were outlying from the inlets. Moreover, the similar values of mean air exchange rate were shown in Table 3. It can be considered that there was minor influence on the air age caused by the height of the exhaust port.

Eventually, the influence caused by curtains was analysed. Compared with case 9 and case 10, Figure 16 demonstrated the vertical distributions of local mean age of air. The difference was whether the curtains wrapped around the bed or not when the exhaust port condition was 1EC. When the curtains wrapped around the bed, the local mean age of air at P6–P8 within the space of 1200 mm from the floor.
curtains became small. The air movement was obstructed due to the four inlets were placed inside the curtains. Regarding to the horizontal distributions, the contaminant spread out in the room efficiently when there was no curtain. Moreover, it was apparent that almost the same rates of the mean air exchange were shown in Table 3 under the two conditions (Figure 17(d,e)). This result expressed that the ventilation performance of the whole room presented the same level roughly, although the air flow was affected by the curtains to some extent.

4. Conclusions

In this paper, the effects on the distributions of indoor temperature, local mean age of air and contaminant concentration caused by some relevant parameters were examined. From what have been discussed above, the following conclusions were drawn:

(1) The position of the exhaust ports plays an influential role on the indoor environment. The vertical temperature difference was minor in the ward area caused by the position of the exhaust ports. However, the significant influence caused by the position of the exhaust ports was shown on the normalised concentration distributions. The appropriate position for the exhaust ports can make the contaminant escape out of the room effectively. The optimum choice was to place the exhaust ports near the beds because this position was close to the sources of the odour gas.

(2) The height of the exhaust ports was also a major factor towards the indoor environment. Compared with the normalised concentration distributions, vertical temperature distributions showed few differences. When the height of the exhaust ports is closer to the source of gas, the contaminant will be emitted out of the room efficiently.

(3) Whether the curtains wrapped around the beds or not would bring the different effects on the indoor environment. To some extent, the curtains had an effect on the heat transmission. Basically, curtains made the indoor temperature higher than that of in without curtains. Similarly, the curtains influenced the normalised concentration distributions. The curtains around the bed would prevent the contaminant escaping out, when in patients panted.

(4) The local mean age of air influenced by the same three factors were given by these studies. The ventilation efficiency was excellent with the kind of the exhaust port condition 1EC, because the rate of the mean air exchange showed the maximum value. In terms of the horizontal distributions, the distance from the inlet to the measuring points had an effect on the air age significantly. The values of local mean age of air showed the maximums, when the measuring points were far away from the inlet. The results of the vertical distributions were close considerably, even though the heights of the exhaust ports changed. Meanwhile, the similar level of the horizontal distributions of the local mean age of air was shown when the
measuring points were far away from the inlets. It can be considered that there was minor influence on the air age caused by the height of the exhaust port. Concerning the curtains, some obvious influences were presented in this study. The air movement was obstructed, when the inlets were placed inside the curtains. When the curtains wrapped around the bed, the local mean age of air within the space of curtains became small. With regard to the horizontal distributions, the contaminants spread out in the room efficiently when there was no curtain. Generally, the ventilation property of the whole room presented the same level, although the air flow was affected by the curtains to some extent.

The prominent advantage of the air-conditioning system with ceiling induction diffusers with low velocity is the high comfort of the air-conditioned environment, in which the uniform and stable temperature distributions both in the horizontal direction and vertical direction were included. In order to research this issue deeply, CFD will be used to analyse the further contents in the future.

Acknowledgments

The authors hope to express gratitude to KIMURA KOHKI Corporation who helped us a lot.

Disclosure statement

No potential conflict of interest was reported by the authors.

Funding

This work was supported by the KIMURA KOHKI Corporation.

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