Experimental study on Indoor Environmental Quality for Four-bed Ward with Ceiling Induction Diffusers under Heating Condition

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This study investigates how some related factors of the air-conditioning system with ceiling induction diffusers effect on the indoor environment in the ward during the heating period. A series of experiments (10 cases) which are involved in two influential factors including the positions of exhausts and the conditions of curtains are carried out in a full scaled model room. The investigation aims to verify the trend and the degree of the influence of the relevant factors on the distributions of indoor temperature, contaminant concentration and the local mean age of air. The results show that the positions of the exhaust ducts play an important role on the normalized concentration distributions and have strong influence on the local mean age of air. Moreover, the barrier function of curtains to the contaminants is verified. There is a minor influence of curtains on the local mean age of air, though it can change the directions of the air flow.

Key Words: Sickroom, Ceiling induction diffuser, Ventilation effectiveness, Local mean age of air

Introduction

Effective ventilation in hospital wards is essential to improve air quality, eliminate smells and control respiratory disease transmission through air motion. A review on designing ventilation systems for hospital wards and other kinds of rooms where several beds were laid out\cite{1}. The review showed it may be possible to decline the contaminants in atmosphere due to ward ventilation improving. Some previous studies have been conducted for ventilation in different hospital facilities. The radiant air-conditioning system has allured much attention of the researchers and manufacturers due to the cosiness and efficiency\cite{2}. However, the radiant air-conditioning system such as water type ceiling radiant air-conditioning system and the radiant floor heating system could not be applied in some office buildings or hospitals because of some certain drawbacks\cite{3-5}. A dominant obstacle is that condensation happens frequently, the humid surroundings in particular, which needs to extra cost. Though this problem has been solved by improving the structure of system, to some extent, the new system becomes more complex and hard to servicing and maintenance\cite{6}.

As the experiments were conducted in a two-bed hospital ward with a downward ventilation system, the possibility of applying downward ventilation in a general hospital ward was investigated\cite{7}. A laminar flow was expected to be applied to reduce cross-infection risk brought by flow mixing. However, the pattern of downward laminar flow airflow hardly implements because of the incompatibility between turbulent flow mixing and thermal buoyancy.

Aim at the issue of ventilation system for hospital wards, some influential factors have been taken into consideration in the existing research. A one-person patient ward was researched by the experiments and the performance of both mixing and displacement ventilation was investigated\cite{8}. The results indicated

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that the location of the exhaust in relation to the restroom can not decided the air quality in the ward with displacement ventilation. In order to verify the feasibility of the air type induction radiant air-conditioning system which combined the inducement ventilation and radiant air-conditioning, the experiments of performance test were carried out\textsuperscript{[9]}. This system showed the insensitivity of air draught. Air flow patterns and mean air speeds were studied, and the different seasons were considered. The results indicated that the highest air speed under the high cooling load occurred in summer\textsuperscript{[10]}. It is considered that the pattern of ventilation system has an important impact on the indoor environment.

In previous studies, a four-bed hospital ward was simulated in a full scaled model room and the characteristics of the air-conditioning system with ceiling induction diffusers (CID) were verified under the condition of cooling\textsuperscript{[11-12]}. In this study, some experiments were conducted in winter, aimed at examining the influence of two relevant parameters on the indoor environmental quality in a sickroom.

1. Mechanism of CID system

The CID system and the schematic diagram of induction chamber are illustrated in Fig.1. In CID system, the air preprocessed by air-conditioning is sprung out at a speed of 3~5m/s through a banding nozzle with negative pressure, so indoor air is induced and mixed with the primary air. Specifically, the indoor air provides 40% and the primary air makes up 60% of the mixed air. Therefore, airflow rate can be reduced and consequently. Naturally, the temperature of the mixed air depends on the temperature-weighted for the air productions. The rectified mixed air blows out of some rigid diffusion fins installed on an aluminum inlet plate, and the initial speed is in a range from 0.2 m/s to 0.8 m/s. This mechanism, to some extent, is conducive to cozy indoor environment where the draft or inappropriate airflow rates might result in malaise.

2. Methodology

2.1 Layout of experimental chamber and settings

All of experiments are conducted in the showroom of KIMURA KOHKI Corporation in Osaka, Japan, which is a full-scaled model room with four beds. The dimensions of the room are 7.35m(d)×5.35m(w)×2.42m(h), as shown in Fig. 2 and Fig. 3. Polystyrene foam sheets (a kind of insulation material) are pasted on the north wall. There are four rectangular supply diffuser units (1200mm×500mm) set on the ceiling. Each bed is placed on the floor underneath supply diffuser. Around of each bed was outfit with a curtain and those beds were surrounded under this situation. As shown in Fig.3, there are the gaps because of part of lace curtain beneath the ceiling with the distance of 300mm. However, the gaps between the walls and curtains are blocked by adhesive plasters, in order to eliminate the influence on ventilation efficiency. Moreover, the same experiments were conducted as curtains were removed under the condition NC. The exhaust fan (BFS-80SC) produced by Mitsubishi Electric is set in the experimental room, and spiral ducts (φ150mm) are used as the exhaust ducts. Fig. 2 illustrates the layout of the exhaust ducts, and the corresponding heights are shown in Table 1. The whole test period lasts 14 days, from January 12\textsuperscript{th}, 2017 to January 25\textsuperscript{th}, 2017.

<table>
<thead>
<tr>
<th>No.</th>
<th>Item</th>
<th>Number of exhaust ducts</th>
<th>Position of exhaust ducts</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>4EC, 4EB</td>
<td>4</td>
<td>At the height of 50mm below the ceiling</td>
</tr>
<tr>
<td>B</td>
<td>4EB</td>
<td>4</td>
<td>At the height of 1200mm from the floor on the wall</td>
</tr>
<tr>
<td>C</td>
<td>4EC</td>
<td>1</td>
<td>In the centre of the room at the height of 50mm below the ceiling</td>
</tr>
</tbody>
</table>

Fig. 1 CID system

Fig. 2 Plan of experimental room [mm]

Fig. 3 A-A’ Section of experimental room [mm]
A spiral duct (Φ150mm, H1500mm) winded silicon heating-cable is applied to simulate human. Heat generation rate of each simulator is 40W, which means that one real patient provides the same sensible heat load. One black lamp is placed next to a bed at the height of FL+1000mm, for simulating the heat generated by household appliances. The power of each lamp is 55W, and four lamps supply 220W-power in total. The gas mixture (density is near to the air) composed by carbon dioxide (CO2) and helium (He) is used as tracer gas emitted from the chests of manikins. The flow rates of CO2 and He are regulated at 1.5L·min⁻¹ and 0.9L·min⁻¹ by mass flow controller, respectively and the tracer gas step-up method is conducted in this series of testing. In this study, two series of experiments are carried out and each series of experiments contains four cases. The main parameters are listed in Table 2. Moreover, the difference between the both series of experiments is the positions for tracer gas generation. Specifically, in order to investigate the temperature distribution and normalized concentration distribution in vertical profiles, the first batch of experiments simulates the contaminant from four patients (4B) and the second batch of experiments applies four diffusers to release the testing gas for analyzing the distribution of local mean age of air (4D). The different positions of tracer gas source of 4B and 4D are shown in Fig. 4.

### Table 2 Experimental conditions

<table>
<thead>
<tr>
<th>Case</th>
<th>Type 1</th>
<th>Type 2</th>
<th>Curtains around bed</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>4EC-NC</td>
<td>1EC</td>
<td>Open</td>
</tr>
<tr>
<td>2</td>
<td>4EC-C</td>
<td>1EC</td>
<td>Closed</td>
</tr>
<tr>
<td>3</td>
<td>4EB-C</td>
<td>4EB</td>
<td>Closed</td>
</tr>
<tr>
<td>4</td>
<td>4EC-C</td>
<td>4EC</td>
<td>Closed</td>
</tr>
<tr>
<td>5</td>
<td>4EC-NC</td>
<td>4EC</td>
<td>Open</td>
</tr>
</tbody>
</table>

**2.2 Measurement for air flow rate**

Supply air flow and exhaust air flow were measured by tracer gas method. Carbon dioxide is applied as tracer gas to measure air flow rate. Initially, step A, CO2 is released into equipment room from the position of suction inlet of AHU (Air Handling Unit), marked as ★ in Fig. 5 (a). CO2 GAS ANALYZER (MI70, VAISALA), is used to measure and monitor the concentration of supply air and air near the suction inlet, named as $C_{i_a}$ and $C_i$, respectively. Subsequently, step B, CO2 is emitted in the exhaust duct, marked as ▲ in Fig. 5 (b). The concentration of exhaust duct and indoor air were measured and monitored by the same method, named as $C_{a}$ and $C_e$, respectively. Specifically, it takes three minutes to collect data at each measurement point. Since a part of tracer gas flowed into the equipment room through a gap between the door of the equipment room and the wall, it takes three minutes to collect data at each measurement point. Since a part of tracer gas flowed into the equipment room through a gap between the door of the equipment room and the wall, it takes three minutes to collect data at each measurement point.

The airflow rate of exhaust air can be calculated as equation (2):

$$Q_{a} = M/\left(C_{a} - C_{e}\right) \times \left(273 + \theta\right)/273$$

Where, $C_{i_a}$, $C_{i}$, $C_{a}$, $C_{e}$ [ppm] is the concentration of outdoor air, supply air and exhaust air, respectively. $C_{i}$, $C_i$, $C_{a}$ [ppm] is the air concentration near the suction inlet and indoor air concentration. $Q_{a}$, $Q_{i}$, $Q_{a}$ [m³/h] is the airflow rate of outdoor air, supply air and exhaust air, respectively. $M$ [m³/h] stands for emission rate of tracer gas and $\theta$ [°C] is the temperature of indoor air. As a result, supply air flow and exhaust air flow have constant rate at 450m³/h and 380m³/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.

### 2.3 Measurement points

Wall surface temperature, indoor air temperature and CO2 concentration are measured, when the indoor environment reached steady state. The measurement points are shown in Fig. 6. The values of wall surface temperature, captured by T-thermocouple (φ=0.32mm, Data logger Cadac 3, Etodenki Corporation), were collected from three heights in a vertical line. The measurement positions distribute in the room layout,
from W1 to W9. It means that 27 points are involved in testing wall surface temperature. Moreover, the other 12 measurement points (W10-W13) are set on the east wall. In terms of indoor ambient environment, the values of indoor air temperature are obtained from measurement positions P1-P12 and there are 11 measurement points along each measurement position vertically, i.e. 128 points in total. It is worth mentioning that there are 10 measurement points at each position from P1 to P4 (there is no measurement point at the height of 2420mm) because of the existing of a beam. Measurement positions P1-P10 can monitor the concentration of CO₂ where 4 measurement points at each position vertically serve purpose of collection by CO₂ recorder (RTR-576, TR-76Ui, T&D Corporation). There are 40 measurement points totally.

3. Results

3.1 Time variation of temperature

The air conditioning used in the experiment is controlled so that it turns OFF when the difference between the set temperature and the temperature measured by the temperature sensor in the room becomes ±1 °C or more. During heating, the air conditioning operates at set temperature of 23 °C (Temperature change of the measurement point near the temperature sensor was shown in Fig. 7 (a)). However, when the indoor air temperature tends to rise, air conditioning turns ON/OFF repeatedly during the heating period. The reason is that the high-capacity (6.47kW) with 800m³/h of the outdoor unit results in fluctuant temperature of supply air, when the outdoor air flow rate is small as 380m³/h. According to the large temperature change with the elapse time, we can see that the supply air temperature fluctuates greatly (Fig. 7 (b)), and the indoor air temperature shows a large fluctuation (Fig. 7 (c)). Therefore, we focused on one cycle of temperature fluctuation and showed the vertical temperature distribution of average value, maximum value and minimum value in one cycle.

3.2 Vertical temperature distribution

In order to research how the parameters influence the vertical temperature distributions, we compare the temperature of the first batch of experiments simulated the contaminants from patients. The vertical temperature distributions of maximum value, minimum value and average value in one cycle were shown in Fig.8~Fig.10.

According to Fig.8~Fig.10, the temperature developing tendencies change with the heights of the measurement points. Five cases collected the similar vertical temperature distribution, in which insignificant differences appeared. The values of vertical temperature show that the temperature increases gradually with the height. Especially, from the maximum values and average values, the significant temperature differences appear at the height of 2200mm, which result from the fact that the warm air has been out of the air supply diffusers stays in the upper part of the room during the heating period. It complies with the comfort evaluation standard of ISO since the temperature difference does not exceed 3°C from FL+100mm to FL+1100mm.
the concentration of supply air increased (Fig. 12 (a)). Since the concentration of CO₂ was collected by CO₂ recorders in the experiment, in order to eliminate errors during the process of measurement, CO₂ recorders were calibrated after finishing data collecting, where the data obtained would be used to process experimental data. Seal CO₂ recorders in a polyethylene bag followed by injecting calibration gas into the bag. Three groups of experiments were conducted with different concentration of span gas, 500ppm, 1000ppm and 1500ppm respectively. Values of CO₂ concentration were recorded, when there was no obvious fluctuation during the experiment. Created calibration lines for CO₂ recorders based on the correct gas concentration. These calibration lines are important data to revise the measured concentration. It is an effective way to ensure measurement accuracy. As the concentration variation of outdoor air as well as exhaust air are illustrated in Fig. 12 (b) and the indoor air concentration change is shown in Fig. 12 (c), it can be seen that there were some slight fluctuates during the measurement period. It was found that these phenomena were related to rather the changes of outdoor air concentration than the stability of CO₂ recorders.

According to the contamination balance in equipment room, formula (3) can be gotten.}

\[
C_{OA}Q_{OA} + (1 - \eta_r) M = C_{SA}Q_{SA}
\]

Where, \(C_{OA}\) [ppm] is the concentration of outdoor air and \(C_{SA}\) [ppm] is the concentration of supply air, \(Q_{OA}\), \(Q_{SA}\) [m³/h] is the airflow rate of outdoor air and supply air, respectively, \(M\) [m³/h] stands for emission rate of tracer gas and \(\eta_r\) was the ratio of tracer gas disributed in the experimental room. Based on the formula (3), the value of \(\eta_r\) can be calculated as formula (4) and shown in Table 3.

\[
\eta_r = 1 - (C_{OA}Q_{OA} - C_{SA}Q_{SA}) / M
\]

According to the Eq. (5), the normalized concentration could be calculated.
\[ C_n = (C_r - C_{ea}) / (C_{ea} - C_{in}) \]  \hspace{1cm} \cdots (5)

Here, \( C_n \) [ppm] is normalized concentration, and \( C_{ea} \) [ppm] is the concentration of exhaust air and \( C_r \) [ppm] is the concentration of point P.

### Table 3 The ratio of tracer gas distributed in the experimental room

<table>
<thead>
<tr>
<th>Item</th>
<th>Condition</th>
<th>( \eta_r )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Case 1</td>
<td>1EC-NC-4B</td>
<td>0.10 ± 0.41</td>
</tr>
<tr>
<td>Case 2</td>
<td>1EC-C-4B</td>
<td>0.11 ± 0.41</td>
</tr>
<tr>
<td>Case 3</td>
<td>4EB-C-4B</td>
<td>0.32 ± 0.63</td>
</tr>
<tr>
<td>Case 4</td>
<td>4EC-C-4B</td>
<td>0.20 ± 0.49</td>
</tr>
<tr>
<td>Case 5</td>
<td>4EC-NC-4B</td>
<td>0.24 ± 0.54</td>
</tr>
<tr>
<td>Case 6</td>
<td>1EC-NC-4D</td>
<td>0.18 ± 0.48</td>
</tr>
<tr>
<td>Case 7</td>
<td>1EC-C-4D</td>
<td>0.11 ± 0.41</td>
</tr>
<tr>
<td>Case 8</td>
<td>4EC-C-4D</td>
<td>0.24 ± 0.57</td>
</tr>
<tr>
<td>Case 9</td>
<td>4EC-C-4B</td>
<td>0.12 ± 0.42</td>
</tr>
<tr>
<td>Case 10</td>
<td>4EC-NC-4D</td>
<td>0.26 ± 0.56</td>
</tr>
</tbody>
</table>

※ It is noteworthy that the minimal values of \( \eta_r \) are calculated by the outdoor air flow rate of 380m³/h with the assumption that the airflow rate of returning air to the equipment room through the crack is 70 m³/h, i.e. there is no exfiltration flow through the other gaps. While, the counterpart maximums are calculated by the outdoor air flow rate of 450m³/h with the assumption that there is no returning air to the equipment room through the crack, namely, the total airflow rate of exfiltration flow through the other gaps is 70 m³/h. It may sound a kind of contradiction, because no returning airflow cannot convey any tracer gas to the equipment room. It can be suggested that some amount of mutual airflow across the door of equipment room convey the emitted tracer gas.

### 3.4 Normalized concentration distribution

#### 3.4.1 Influence on normalized concentration distribution caused by the positions of exhaust ducts

In order to research how the positions of the exhaust ducts influence normalized concentration distributions, the other two factors are fixed (curtains are wrapped and the tracer gas is breathed out from four manikins). By changing the positions of the exhaust ducts, some experiments are carried out.

Supply air concentration and the exhaust concentration were defined as 0 and 1, respectively. Fig. 13 provides some noteworthy data with respect to the vertical concentration distributions. It was clear from the subgraphs that CO2 spread to the entire room uniformly. It can be seen that the ventilation efficiencies were high due to four exhaust ducts, and the values of normalized concentration in the case 4EB-C-4B was smaller than those of in the other two cases. This demonstrates that the condition 4EB presents the excellent ventilation efficiency, in which the exhaust duct is close to the resource of contaminant.

#### 3.4.2 Influence on normalized concentration distribution caused by curtains

**3.4.2.1 Position of the exhaust ducts: 4EB**

On the premise of the position of the exhaust ducts fixed on 4EC and tracer gas breathed out of the manikins, the experiments were carried out under the different situations of curtains. The normalized concentrations in vertical profiles are shown in Fig. 14.

![Fig. 14 Normalized concentration distributions](image)

(Contaminant source position: 4B, location of the exhaust ducts: 4EC, two different situations of the curtains)

It is clear that the normalized concentration shows a few differences among these cases. Generally speaking, the normalized concentration is higher at the case under the situation of curtain being open. However, some obvious differences are observed at some measurement points inside the curtain, because of the barrier function of curtains to the contaminants. As a whole, the influence of the curtains on the contaminant removal efficiency is reckoned to be minor.

**3.4.2.2 Position of the exhaust ducts: 1EC**

When the position of exhaust duct is fixed in the centre of the room at the height of 50mm below the ceiling(1EC) coupled with the tracer gas breathed out of the manikins, the normalized concentrations in two cases are analyzed under the different situations of the curtains.

Fig. 15 illustrated the distribution of normalized concentration between the two cases (1EC-C-4B and 1EC-NC-4B). The value of normalized concentration is higher as the curtain is wrapped around the bed. Contaminant generated from the patients is
prone to flow to the exhaust duct when the curtains are removed, because the position of the exhaust duct is outside the curtain. The contaminant removal efficiency is better than that in situation of beds being wrapped when exhaust duct is fixed at 1EC.

### Table 4

<table>
<thead>
<tr>
<th>Condition</th>
<th>Room average age of air &lt;\text{t}_a\rangle [\text{min}]</th>
<th>Air exchange efficiency (\eta) [-]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1EC-NC-4D</td>
<td>17.0</td>
<td>0.66</td>
</tr>
<tr>
<td>1EC-C-4D</td>
<td>16.1</td>
<td>0.69</td>
</tr>
<tr>
<td>4EB-C-4D</td>
<td>14.1</td>
<td>0.79</td>
</tr>
<tr>
<td>4EC-C-4D</td>
<td>13.0</td>
<td>0.74</td>
</tr>
<tr>
<td>4EC-NC-4D</td>
<td>14.7</td>
<td>0.76</td>
</tr>
</tbody>
</table>

### 3.5 Local mean age of air

#### 3.5.1 Measurement method

The age of air is a period that it makes the supply air reach an arbitrary point in the space. Actually, numerous approaches can enforce the air movement, and the local mean age of air is well known which is used as one of the main parameters to estimate the performance of ventilations and air distribution. Measuring the changing concentrations subsequently after tracer gas injection is a practical way to assess the local mean age of air. In this study, pulse response theory is applied to calculate the local mean age of air[13].

\(R_p(t)\) represents the concentration of tracer gas at point \(P\) caused by injecting a unit amount of tracer gas. \(R_p(t)\) means the function for unit impulse. If a small amount of injection \(M\) [\text{m}^3] is emitted as shown in Fig. 16 a), Eq. (6) is for the calculated concentration \(C_p(t)\):

\[
C_p(t) = \int_0^\infty M(t-\tau)R_p(\tau)\,d\tau = \int_0^\infty Q_{\Delta t}\cdot C_{\Delta t}(t-\tau)R_p(\tau)\,d\tau \quad \cdots\cdots (6)
\]

Where, \(R_p(t)\) is the impulse; \(C_{\Delta t}(t)\) [\text{ppm}] is the concentration of tracer gas at the diffusers shown as Fig. 16 (b); \(Q_{\Delta t}\) [\text{m}^3/\text{h}] stands for the flow rate of supply air and \(\tau\) [s] stands for time lag.

An appropriate of \(R_p(t)\) is assumed as Eq. (7) and was shown in Fig. 16 d).

\[
R_p(t) = \begin{cases} 
  b\cdot e^{-c(t-\tau)} & \tau > \alpha \\
  0 & \tau < \alpha
\end{cases} \quad \cdots\cdots (7)
\]

According to the calculation of \(R_p(t)\), constant \(b\) and \(c\) are determined by the solver modules in EXCEL after the optimum (Fig. 16 (c)), constant \(\alpha\) is selected artificially. And according to the Eq. (8), the local mean age of air \(\tau_p\) at an arbitrary point \(P\) can be obtained.

\[
\tau_p = \int_0^\infty tR_p(t)\,dt / \int_0^\infty R_p(t)\,dt \quad \cdots\cdots (8)
\]

An ventilation significant coefficient efficiency \(\eta\)\(^{[10]}\), which has a double value of so-called air change efficiency, can be calculated by Eq. (9).

\[
\eta = \frac{\tau_p}{\langle t \rangle} \quad \cdots\cdots (9)
\]

Where, \(\langle t \rangle\) is the average age of air.

The nominal ventilation time \(\tau_n\) can be given by the Eq.(10), where \(V\) [\text{m}^3] stands for the volume of the room.

\[
\tau_n = V/Q_{\Delta t} \quad \cdots\cdots (10)
\]
Firstly, the effect of the positions of exhaust ducts on the local mean age of air is analyzed. Under the situation of the bed being wrapped by the curtains, Fig. 17 shows the results of the air age when the positions of the exhaust ducts are changed. It can be seen that the local mean ages of air under the condition of 4EB are smaller than those of at the other two conditions, where the positions of four exhaust ducts are laid at approximately 1200mm above the floor on the wall. It can be inferred that the air from the air supply diffusers goes down quickly and the air flows to the lower space within the curtains earlier.

Then, in Table 4, comparing the conditions of 4EC and 1EC, the room average age of air under the condition of 4EB is the lowest and the air exchange efficiency under the condition of 4EB show the maximum values. It can be considered that the ventilation efficiency of 4EB is excellent.

![Fig. 17 Local mean age of air](Contaminant source position: 4D, with curtain, position of the exhaust ducts: 4EC, 4EB and 1EC)

Subsequently, the influence of curtains is studied. The difference is the situations of the curtains under the same condition of 4EC. From the Fig. 18, it can be seen that the results of the vertical distributions are similar in the both conditions. Specifically, the air exchange efficiency is 0.74 (in Table 4) under the situation of the bed being wrapped by the curtains and it is 0.76 under the situation of curtains removed. The exhaust duct is included in the inner space of the curtain under the condition of 4EC, which results in that curtains show a minor influence on the mean age of air. To some extent, curtains prevent the contaminants escaping from the closed space around the bed.

Eventually, the local mean ages of air in two cases are analyzed under the different situation of the curtains, where the exhaust ducts are laid in the centre of the room at the height of 50mm below the ceiling (1EC). According to the Fig.19, the measured points at the lower position outside the curtains (P1-P5) have the lower local mean ages of air, which results from air movement in the lower position inside the space of curtains. Air exchange efficiency for two different situations of curtains are 0.66 and 0.69, respectively. The better performance can be found under the condition of 1EC and the curtains being removed.

![Fig. 19 Local mean age of air](Contaminant source position: 4D, location of the exhaust ducts: 1EC, two different situations of the curtains)

**Concluding remarks**

This study investigates how some relevant parameters effect on the distribution of indoor temperature, local mean age of air and contaminant concentration during the heating period. The main conclusions can be drawn as follow:

1) The indoor temperature fluctuates obviously with the change of supply air temperature due to the fact that air conditioning turns ON/OFF repeatedly during the heating period, which results from the large capacity of the outdoor unit (800m³/h) and the low outdoor air flow rate (380m³/h).

2) Insignificant differences of vertical temperature distribution exist in different cases which have the different conditions. The values of the wall temperature and air temperature almost show the constants at some measured points, which are placed at the high positions. The related fact is that the warm air has been out of the air supply diffusers stays in the upper part of the room during the heating period.

3) The position of the exhaust ducts play an influential role on the normalized concentration distributions. Basically,
the contaminant removal efficiency improves obviously when the exhaust ducts are closer to the source of contaminants.

4) In terms of the influence of the curtains on the indoor environment, to some extent, the barrier function of curtains to the contaminants is verified.

5) The positions of the exhaust ducts have strong influence on the mean age of air. The lower local mean age of air and the better efficiency of average air exchange can be obtained when the exhaust ducts close to the source of contaminants. There is a minor influence of curtains on the local mean age of air, though it can change the directions of the air flow.

6) Compared with cooling, the lower air exchange efficiency ($\eta < 1.0$) is obtained under heating condition because of the vertical temperature stratification (only 2.8 °C). However, it measures up the comfort evaluation criteria of ISO since the temperature difference does not exceed 3 °C from FL+100mm to FL+1100mm in residential area. In addition, according to the values of $\eta$, although the system does not reach complete mixing ventilation thoroughly, normalized concentration distributions show the minor difference, i.e., there are fewer contaminants to be stuck.

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References


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暖房時における天井吹出し型誘引ユニットを有する
4床病室内環境に関する研究

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相良 和伸¹, 桃井 良尚¹, 藏 永 真理¹

キーワード：病室・天井吹出し型誘引ユニット・換気効率・局所平均空気濃度

概 要：本研究では、天井吹出し型誘引ユニットを病室に
導入することを提案し、その有用性を検証することを目的
としている。本報では、暖房時に天井吹出し型誘引ユニッ
ト空調を有する4床病室を模擬した実験を行い、排気
口の位置、ベッド周りのカーテンの有無が室内温度、濃度
分布及び局所平均空気濃度分布に与える影響について検討を
行った。暖房時実測より、排気口の位置が規準化濃度分布
および空気濃度分布に大きい影響を及ぼすこと、更に、汚染
物質に対するベッド周りのカーテンのバリア機能が確認さ
れた。一方、ベッド周りのカーテンの有無が空気濃度に与え
る影響は比較的小さいと言えることがわかった。

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