Evaluating Natural Ventilation Efficiency of the Central Horizontal Pivot Window in a Full-Scale Taiwan Typical Model Room.

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ABSTRACT

A Method for measuring the air exchange rate (ACH value) and distribution of pollutants in a bedroom has recently been developed. The purpose was to evaluate the natural ventilation efficiency to access ventilation characteristics and the indoor environment with the central horizontal pivot window. The developed method is able to conduct the required number of air change per hour when a certain indoor air quality needs to be maintained. This research was conducted by full-scale model experiments. The chamber experiment were carried out in a 3m x 2.4m x 3m(H) full-scale typical bedroom model with a single-bed of 0.9m x 1.9m x 0.45m(H). The opening angles we considered were between 0 degree to 180 degree. Tracer gas technology was applied in the measurements. Sulphur Hexafluoride(SF₆) as tracer gas was release with heat from an emulated human head in the full-scale model space, and the heat source was performed by a head model with the average heat flux at 58.2W/m². The location of the inlet opening characterized by the central horizontal pivot window was chosen for ventilation efficiency research. The concentration decay method and the constant concentration method of tracer gas technology were both used and compared to validate the results. The results showed that with the opening angle changed, the air exchange rate is also changed. The relationship between the opening angle and the ACH value can be conducted with an ellipse curve. The air exchange rate (ACH value) also can be conducted with two humps curve. We can evaluate the natural ventilation efficiency with combining these two factors, the ACH value and AEE value. Therefore, the results can be simplified by a diagnose chart. Hence, the natural ventilation efficiency in typical dwelling bedroom can be predicted by checking the diagnose chart.

1. INTRODUCTION

Taiwan, also known as Formosa, is an island located in the subtropical area. The average temperature is 22 °C in the north and 24.5 °C in the south. The report of the Central Weather Bureau of Taiwan states that the yearly average wind velocity in the densely populated coastal region of western Taiwan is around 2m/sec to 3m/sec. The climate in Taiwan is pleasant and suitable for the natural ventilation strategy [1]. Therefore, this study focuses on the opening angles and the air exchange rate in such natural-ventilated residential bedrooms, which have an opening toward the outside. To improve human comfort and health via changing the opening strategies, we take the kind of opening, central horizontal pivot window, as a factor to be considered. By changing the plate angle of the window, different air distribution in the bedroom can influence the air exchange rate and the air exchange efficiency.

According to the reports of Central Weather Bureau at Northern Taiwan, the outdoor environment analyzed by the ASHRAE Standard 55a - assessment of comfort level is shown as Figure 1. The

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result shows that the weathers in Spring, Fall and Winter in Northern Taiwan are very suitable for natural ventilation. Thus this research is focus on natural ventilation efficiency in typical dwelling room in the winter-time.[2]

2. METHOD

Typical bedroom model

As shown in Figure 2, the chamber experiment was carried out in a 3m x 2.4m x 3m(H) full-scale typical bedroom model with a single-bed of 0.9m x 1.9m x 0.45m(H). The location of the inlet opening characterized by the central horizontal pivot window, was chosen for ventilation efficiency research. A human heat source was performed by a head model with the heat flux at 58.2W/m²[3].

Figure 1 Thermal comfort zone on the ASHRAE psychometric chart for Fu-Long area (Northern Taiwan)

Figure 2 Perspective view of typical bedroom model with central horizontal pivot window.
The Central Horizontal Pivot Window

Figure 3 shows the sectional view of the central horizontal pivot window. For the Full-scaled dwelling experiment, we built an opening of 0.9m x 1.2m(H) with this window. According to the investigation of five urban office buildings, the inlet was performed with a laminar flow with five scale modes at 0m/sec, 0.3m/sec, 0.5 m/sec, 1.0m/sec and 2.0m/sec [4].

The Tracer Gas Techniques – Concentration Decay Method

This is the most basic method of measuring air-exchange rates and is used to obtain discrete air-exchange rates over short periods of time. A small quantity of tracer-gas is thoroughly mixed into the room air. The source of gas is then removed and the decay in the concentration of tracer-gas in the room is measured over a period of time. To ensure that the tracer-gas concentration is the same at all points in a room at any particular time a big mixing fan is run throughout the measurement period. Provided that no tracer-gas is supplied to the room during the measurement period and the airflow through the room is constant, the concentration of tracer-gas is found to decay exponentially with time. By plotting the natural logarithm of gas concentrations against time a straight line is obtained and the gradient of the line is the air-exchange rate in the room:

\[
N = \frac{\ln C(0) - \ln C(\tau)}{\tau_1}
\]

where,
- \( C(0) \) = concentration at time = 0 (m³/m³)
- \( C(\tau_1) \) = concentration at time = \( \tau_1 \) (m³/m³)
- \( \tau_1 \) = total measurement period (h)

If an approximately straight line is not obtained, then the room air cannot be considered well mixed and the results are thus not valid. The only equipment needed for this measurement method is a gas monitor, a bottle of tracer-gas, and a mixing fan. This makes the method cheap and easy to perform.

The Tracer Gas Techniques – Constant Concentration Method

This method is used for continuous air-exchange rate measurements in one or more zones. It is particularly useful for conducting analyses in occupied buildings. When using the constant-concentration measurement method concentrations of tracer-gas are measured by a gas monitor in a zone. This information is then sent to a computer which controls the amount of tracer-gas "dosed" into the zone in order to keep its concentration constant. In this cases, however, the air in the room does not have to be perfectly mixed. Provided that the concentration of tracer-gas in the zone is constant over time, the continuity equation reduces to:

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Air Exchange Rate, \( N(\tau) = \frac{F(\tau)}{V \cdot C} \) .................................................. (2)

where, \( F \) = introduction rate of tracer-gas into room, \( (\text{m}^3/\text{h}) \), \( V \) = volume of air in room, \( (\text{m}^3) \)
\( C \) = concentration of tracer-gas in room-air, \( (\text{m}^3/\text{m}^3) \), \( \tau \) = time, \( (\text{h}) \)

The air-exchange rate is directly proportional to the tracer-gas emission rate required to keep the concentration constant. This method offers two great advantages: not only can it be used to obtain an accurate long-term average air-change rate in situations where the air-exchange rate varies -- for example, in occupied buildings; but it can also be used to document these variations in detail. As with the constant-emission method, tracer-gas costs may be an important consideration. The constant-concentration method is also particularly well suited to the continuous determination of the infiltration, from outside air into each individual room in a building.

The Initial Boundary Condition Setup

Because the full-scaled experiment chamber is at the base floor of the building, the situation of the environment is rarely changed in one day. However, to ensure the conditions of experiments are the same as each one case, a validation of the experiment chamber is made by four factors: Temperature, Humidity, Air velocity and the air-tightness of the chamber in boundary condition. As following figures shows, the temperature of the chamber is closely at the same temperature in one day. As the figure 5 shows, the air-tightness of the chamber is pretty good (5ppm leaked in 3hours), so the error made by chamber is controlled at the experiment time.

3. RESULTS AND DISCUSSION

Results of Full-Scaled Chamber Experiment

According to the initial experiment setup, the ventilation efficiency was performed by this typical chamber. The concentration decay method and the constant concentration method were used for experiments. Sheet 1 shows the result of one of the cases performed by tracer-gas technique by the muti-gas monitor (B&K type 1302, type 1303). Sheet 2 shows the results of different open-angle of the central horizontal pivot window at 0 m/s situation.
Sheet 1: one of the experiment results of different cases

<table>
<thead>
<tr>
<th>D-Case45</th>
<th>Concentration Decay</th>
<th>Constant Concentration</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1.png" alt="Graph" /></td>
<td><img src="image2.png" alt="Graph" /></td>
<td><img src="image3.png" alt="Graph" /></td>
</tr>
</tbody>
</table>

Sheet 2: Results of the full-scaled experiment at different open angle at 0 m/s inlet wind

<table>
<thead>
<tr>
<th>Case</th>
<th>Room-average age (hr)</th>
<th>Local mean age of air (hr)</th>
<th>Air-Exchange Efficiency</th>
<th>ACH decay (h⁻¹)</th>
<th>ACH constant (h⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Outlet</td>
<td>Head</td>
<td>Center</td>
<td>Decay</td>
</tr>
<tr>
<td>Case15</td>
<td>0.614</td>
<td>0.926</td>
<td>0.917</td>
<td>0.936</td>
<td>24.56%</td>
</tr>
<tr>
<td>Case30</td>
<td>0.742</td>
<td>0.417</td>
<td>0.411</td>
<td>0.392</td>
<td>28.10%</td>
</tr>
<tr>
<td>Case45</td>
<td>0.669</td>
<td>0.453</td>
<td>0.354</td>
<td>0.413</td>
<td>33.87%</td>
</tr>
<tr>
<td>Case60</td>
<td>0.445</td>
<td>0.252</td>
<td>0.179</td>
<td>0.228</td>
<td>28.30%</td>
</tr>
<tr>
<td>Case75</td>
<td>0.526</td>
<td>0.326</td>
<td>0.218</td>
<td>0.312</td>
<td>30.98%</td>
</tr>
<tr>
<td>Case90</td>
<td>0.347</td>
<td>0.177</td>
<td>0.157</td>
<td>0.154</td>
<td>25.51%</td>
</tr>
<tr>
<td>Case105</td>
<td>0.517</td>
<td>0.372</td>
<td>0.353</td>
<td>0.302</td>
<td>35.96%</td>
</tr>
<tr>
<td>Case120</td>
<td>0.547</td>
<td>0.370</td>
<td>0.340</td>
<td>0.372</td>
<td>33.79%</td>
</tr>
<tr>
<td>Case135</td>
<td>0.614</td>
<td>0.525</td>
<td>0.382</td>
<td>0.390</td>
<td>42.71%</td>
</tr>
<tr>
<td>Case150</td>
<td>0.491</td>
<td>0.272</td>
<td>0.224</td>
<td>0.231</td>
<td>27.69%</td>
</tr>
<tr>
<td>Case165</td>
<td>0.821</td>
<td>0.442</td>
<td>0.480</td>
<td>0.516</td>
<td>26.90%</td>
</tr>
</tbody>
</table>

Figure 6: Results of ACH and opening angle
Figure 7: ACH, opening angle and inlet velocity relationship
By the results of 0 m/s inlet velocity, the results can be conducted to a predict formula, and it can be reduced to (referring to figure 6):

Max Opening ACH Value at different size of the pivot window \( = \) \( H \)......................... (3)

Predict formula, \( ACH_{\text{vrw}} = H \times \sqrt{1 - \cos^2 \theta} = H \times |\sin \theta| \)................................. (4)

**The Effect of Inlet Wind**

Figure 7 shows the air exchange rate at different opening angles and inlet velocities. Obviously, at an angle of 90 degrees the ACH value didn’t increase with the inlet velocity. Another interesting finding was that at angles from 90 degrees to 180 degrees, the ACH value increased more than at angles from 0 degrees to 90 degrees. This difference was caused by the airflow of inlet and outlet path. When the situation was that the inlet velocity was between 0.3m/sec and 0.5m/sec and the opening angle was between 0 degrees and 90 degrees, the ACH value was lower than zero (m/sec) inlet situation. For this reason, the heat source that was caused by the driving force of human heat counterpoised the inlet wind pressure.

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**REFERENCES**


**KEY WORDS**
Tracer-gas technique, Natural ventilation, ACH, Central horizontal pivot window