Experimental Study of Airflow in Naturally Ventilated Double Skin Facade

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Abstract: Along with the worldwide use of Double Skin Facade (DSF), the detailed research of the airflow in ventilation cavity, especially for naturally ventilated DSF, becomes extremely significant. However, until now, there is a lack of field measurements and validate simple ventilation models.

In this paper, field measurements are conducted to analyze the temperature distribution and air flow rates in naturally ventilated DSF. Different field measuring techniques are analyzed. Tracer gases are recommended to determine the air flow rate. On the base of measured data, a simple ventilation model is developed to predict the air flow rate in DSF cavity.

Keywords: Double Skin Facade, Air flow rate, Field measurement, Tracer gases, Natural ventilation, Ventilation model

1 INTRODUCTION
Cavity ventilation system is used to remove the cavity heat in Double Skin Facade (DSF), and has a great contribution on the improvement on the DSF thermal performance. Former researchers have conducted some experiments on DSF natural ventilation system. Dirk measured the pressure differences through inlet grids to determine the air flow rates, and the experimental results are compared with a room ventilation model. R.Letan simulated the building ventilation through DSF using CFD, and conducted laboratory experiments to verify the simulation results. Park also conducted a field measurement of DSF and carried out real time control of DSF.

However, there are two deficiencies in the former studies. First, there is a lack of discussion on measuring methods, such as surface temperature and air flow rate. Second, the room ventilation model should be developed to suit the DSF. Consequently, this paper analyzed the different measuring techniques used for DSF, and takes the first step to develop a DSF ventilation model.

2 EXPERIMENTS
2.1 Measuring Techniques

2.1.1 Temperature
All contact sensors on glazing surface, such as thermocouple, show non-negligible temperature increase because of solar absorption by the sensor and electric wires. In this paper, a comparison experiment is conducted to determine the measuring accuracy. Two 2mm T type thermocouples are fixed in the centre of one glazing; one is explored under the solar intensity of 350 W/m², the other is not. The results show that the explored sensor showed 0.5°C higher than the shaded one. So it is concluded that for 0.2mm T type thermocouple, the measuring error of glazing surface temperature is less than 0.5°C, which is acceptable for a field measurement.

2.1.2 Air flow rate
In literatures, three techniques are described to measure airflow rates of naturally ventilated DSF: (1) the pressure difference across inlet/outlet (Dirk Saelens); (2) wind speed in cavity by
placing anemometers (Park1); (3) tracer gas techniques. The first two methods can only be used in some DSF with particular structure. While, tracer gas is a more common way, which is mostly used for the building ventilation, but seldom used in DSF. In this paper, tracer gas in a constant emission way is used to determine the air flow rate in naturally ventilated cavity. One thermal bulb-type anemometer is also placed in the cavity to give a referenced air velocity.

2.2 Location and Equipments

The Experimental Double Skin facade unit is located in the Low Energy Demo Building of Tsinghua University, China. The experimental unit is on the third floor, in the middle of the east facade. This unit is consisted by a single pane exterior glazing, an aluminium blind and a double panes interior glazing. Two top-swing window openings in the facade are electrically controlled (fig 1 and fig 2).

2.3 Results

The experiments are conducted during 8:00am~10:00am in each day from 6th Sep to 15th Oct. 2005. Data are used when the outdoor wind velocity is lower than 2.5m/s in the height of 10m with a direction of north, and the solar intensity on east facade is 200-600W/m². The outdoor temperature rises from 16°C to 30°C.

In the cavity, the blind shading divides the cavity into two spaces. The temperature distributions in both exterior and interior space are showed in fig 3.

Figure 1. Location of sensors
- presents the thermocouples. There are about 30 temperature points. ◎ presents the tracer gas inlet, which was a plastic tube with a diameter about 5cm. This tube is as long as the cavity width. There are more than 2000 small holes on the tube, which ensure a steady and linear release of tracer gases. There are 6 sampling points (Δ) in the middle height of the cavity.

Figure 2. Dimension of openings
- presents the tracer gas inlet, which was a plastic tube with a diameter about 5cm. This tube is as long as the cavity width. There are more than 2000 small holes on the tube, which ensure a steady and linear release of tracer gases. There are 6 sampling points (Δ) in the middle height of the cavity.

Figure 3. air temperature vertical distribution with a maximum solar intensity of 330W/m²

(a) Time: 8:00~10:00 am Exterior space
(b) Time: 8:00~9:30 am Interior space
The above diagrams show that in exterior space, the temperature is stratified vertically. Where the height is lower than 1.4m (half of total height), the temperature rises with height linearly. While, in the height of over 1.4m, the temperature keeps constant and small fluctuates around the outlet. However, in interior space, the temperature shows little vertical difference, less than 2ºC.

Figure 4 shows the cavity air flow rates as a function of inlet and outlet temperature differences. Least-squares procedure indicates that there is a proportional relationship between air-flow rates and the square root of the temperature difference. One more point should be paid attention is that when the air temperature difference is smaller than 2ºC, the air flow rates are no longer reduced. It can be explained by the wind effect. In small temperature difference cases, the wind effect should be taken in to account.

3 SIMULATION MODEL

3.1 Ventilation Model

The airflow in the cavity is caused by two driving forces: buoyancy effect and wind pressure. The ASHARE Handbook Fundamentals indicates that when the wind velocity in the height of 10m is lower than 2.5m/s, and the wind direction is north, wind pressure difference between two openings is about 0.02 pa, which is much more less than stack effect, so can be ignored.

Karl T Andersen proposed air flow rate caused by buoyancy effect as follow.

\[ Q = A \sqrt{\frac{2(\Delta p_1 + \Delta p_2)}{\rho_o (\xi_1 + \xi_2)}} \]  

Where
- \( A \) = the area of the openings;
- \( \Delta p_1, \Delta p_2 \) = the pressure differences across the openings
- \( \xi_1, \xi_2 \) = the form resistance of openings;
- \( Q \) = Air flow rate

Experiment results (fig 3) shows that the air temperature vertically stratifies. There is a critical height (\( H_r \)). Where the height is lower than \( H_r \), the temperature rises with height linearly. In the height of over \( H_r \), the temperature keeps constant. Consequently, a parameter \( \eta = H_r/H \) is defined to describe the temperature distribution. When \( \eta = 0 \), the temperature is uniform, and when \( \eta = 1 \), the temperature linearly rises. \( \eta \) value has a strong correlation with the structure of DSF. Generally, for one-story DSF with a relative wide cavity, \( \eta \) is about 0.5, while for multi-story DSF with a narrow cavity, \( \eta \) trends to be 1.

According to the relationship between density and temperature of ideal air, one can get:

\[ Q = A \sqrt{\frac{(1-\eta)^2(T_r - T_o)gH}{2T_r(\xi_1 + \xi_2)}} \]  

Figure 4. Air flow rate as a function of temperature differences
3.2 Comparison between model and experiment results

Table 1 and figure 5 give the results of model and experiments, where the form resistances are $\xi_1 = 12.3; \xi_2 = 15.1$, determined by CFD simulation. Table 1 state that the buoyancy model with the $\eta$ of 0.5 gives the best predicted values, especially in the range of 3 to 5°C. However, in the low range (2-3°C) and the high range (above 5°C), the predicted values are about 10% higher than measured values. Considering the measuring errors, this deviation is acceptable.

Table 1 the average values of predicted and measured air flow rate

<table>
<thead>
<tr>
<th>Temperature Difference</th>
<th>Air flow rate (m³/s)</th>
<th>Measurement</th>
<th>$\eta=0$</th>
<th>Dev.</th>
<th>$\eta=0.5$</th>
<th>Dev.</th>
<th>$\eta=1$</th>
<th>Dev.</th>
</tr>
</thead>
<tbody>
<tr>
<td>2-3°C</td>
<td>0.31</td>
<td>0.39</td>
<td>26%</td>
<td>0.34</td>
<td>9%</td>
<td>0.29</td>
<td>-6%</td>
<td></td>
</tr>
<tr>
<td>3-4°C</td>
<td>0.42</td>
<td>0.48</td>
<td>16%</td>
<td>0.42</td>
<td>1%</td>
<td>0.35</td>
<td>-17%</td>
<td></td>
</tr>
<tr>
<td>4-5°C</td>
<td>0.45</td>
<td>0.53</td>
<td>18%</td>
<td>0.46</td>
<td>2%</td>
<td>0.38</td>
<td>-15%</td>
<td></td>
</tr>
<tr>
<td>&gt;5°C</td>
<td>0.49</td>
<td>0.62</td>
<td>26%</td>
<td>0.54</td>
<td>9%</td>
<td>0.44</td>
<td>-10%</td>
<td></td>
</tr>
</tbody>
</table>

Fig 5. Air flow rate as a function of temperature difference, outdoor wind speed < 2m/s

4 CONCLUSIONS

In this paper, the airflow in naturally ventilated DSF has been experimentally analyzed. The accuracy and applicability of different measuring techniques are analyzed. As a result, the 0.2mm T type thermocouples for surface temperature measuring and tracer gases for airflow rate are recommendable.

According to the experimental data, the air temperature is stratified vertically in the cavity. Air flow rate shows a proportional relationship with the square root of the inlet and outlet temperature difference.

A simple ventilation model is developed, which predicts best when the temperature differences are 3-5°C.

However, the effect of cavity blind shading is ignored in this simple model. A detailed model considering the influence of cavity shading and all kinds of opening forms is being developed.

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