Natural Ventilation System for a School Building Combined with Solar Chimney and Underground Pit

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SUMMARY

The specific features of natural ventilation system combined with solar chimney and underground pit installed in a new school building and the measured results for four years are described. In summer and intermediate seasons outside air is introduced into the building of four stories through underground pit from the intake provided in the north end, brought into the different occupied rooms from which the room air is discharged to outside through the solar chimneys of 8 meters high above the roof by chimney action or pulling out action by wind. The measured results for four years after opening the school showed that the energy performance has improved year after year owing to the natural ventilation system. Some consideration on the improvements in the system performance is given for future design of natural ventilation with solar chimney.

1. INTRODUCTION

As can be seen in the minarets of vernacular buildings in hot countries, solar chimney is like the one to give rise to buoyant force by solar energy for natural ventilation. This effect could be enhanced by coupling with the underground pit where outside air is cooled down, thus bringing cool air into the occupied spaces.

The natural ventilation system combined with solar chimney and underground pit was introduced in the buildings of Kitakyushu University in the west island of Japan as shown in Figure 1. The performance of natural ventilation with supply and exhaust air volume and cooling effects, the relationship among the weather factors, indoor/outdoor temperature difference and the exhaust volume out of solar chimney for four years is summarized.

![Figure 1. Outside view of main building from southwest](image1)

![Figure 2. Solar chimney on the roof](image2)
2. OUTLINE OF BUILDING AND SYSTEM

The main building consists of two long buildings: north wing with office block attached and south wing as shown in Figure 3. The north wing is subdivided into four blocks of identical size. Field measurement was performed with the Block-1 of the north wing building at 10 minutes interval for a long term.

Figure 3. Measured block of north wing

Figure 4 shows the air flow routes during the period of natural ventilation from underground pit to solar chimney on the right side and the air flow routes of auxiliary air conditioning system on the left. Natural ventilation takes place by opening the grilles of outside air intake. During the heating season natural ventilation does not work in order to prevent heat loss, while outside air is introduced through the underground pit warmer than outside. The scheduled operation started since the second year.

Figure 4. Air flow routes of natural ventilation system (right) and air conditioning system (left)
3. PERFORMANCE OF NATURAL VENTILATION

3.1 Cooling and Heating Periods

Table 1 shows the number of days of natural ventilation during cooling and heating periods. It was found that the cooling period for natural ventilation turned to be greater year after year to occupy 57% of annual total days in the third and fourth years, while in heating period decreased to 43% in the last two years.

Table 1. Number of days of cooling and heating periods

<table>
<thead>
<tr>
<th>YEAR</th>
<th>1st</th>
<th>2nd</th>
<th>3rd</th>
<th>4th</th>
</tr>
</thead>
<tbody>
<tr>
<td>PERIOD</td>
<td>365</td>
<td>366</td>
<td>366</td>
<td>366</td>
</tr>
<tr>
<td>COOLING</td>
<td>185</td>
<td>170</td>
<td>209</td>
<td>211</td>
</tr>
<tr>
<td>HEATING</td>
<td>180</td>
<td>195</td>
<td>157</td>
<td>154</td>
</tr>
</tbody>
</table>

3.2 Operation period of Natural Ventilation

Figure 5 shows the monthly number of hours of natural ventilation estimated from the opening hours of the grilles of supply air for the corridor space. The operating hours of natural ventilation in the third year turned out 3,058 hours, while in the fourth year 1,702 hours. This decrease may be attributed to the cool summer in the third year and hot summer in the fourth year. The number of students increased in the fourth year by 25% and this must have affected this difference.

Figure 6 shows the percentage of monthly hours of natural ventilation and that of air conditioning operation with air handling units (AHU) in the third year. Except for the month of April and November when switching of heating and cooling operation was made, the percentage of natural ventilation operation during the cooling period was 45-60% in May through September and 80% in October.

Most of the time of natural ventilation took place during the night 18:00 – 8:00, which covered 80% of the total.
3.3 Air flow volume during the period of natural ventilation

In fact quite a large size of exhaust fan is installed on the roof for the toilets of four floors, which affects the performance of natural ventilation. The air flow volume of natural ventilation from the inlet to the underground pit and that from solar chimney to outside are different depending on whether the toilet exhaust fan is operating or not.

Figure 6. Percentage of hours of natural ventilation and AHU (air handling unit) in cooling and heating periods in the 3rd year

It can be recognized that the supply air volume from the underground pit and the exhaust air volume out of solar chimney tend to increase year after year owing to the improvements of occupants behavior.

The supply air volume from the underground pit of 6,100m$^3$/h and the exhaust air volume out of solar chimney of 4,100m$^3$/h are found quite stable for four years.

3.4 Cooling effects under natural ventilation

There are two types of natural ventilation: the first one is the effects of cooling outside air by the underground pit. The second one is the effects of cooling the building skeleton by the outside air after flowing from the underground pit until being exhausted out of the solar chimney.

Figure 7. Monthly cooling effects by natural ventilation
Figure 7 and Table 2 show the values of the cooling effect under natural ventilation. It can be found that the sensible cooling effect in the underground pit in spring and summer is negative.

<table>
<thead>
<tr>
<th>Year after school opening</th>
<th>Outside air cooled by underground pit</th>
<th>Skeleton cooled by circulated air</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>1st</td>
<td>-4.74</td>
<td>10.14</td>
<td>5.40</td>
</tr>
<tr>
<td>2nd</td>
<td>1.03</td>
<td>26.39</td>
<td>27.63</td>
</tr>
<tr>
<td>3rd</td>
<td>-9.91</td>
<td>68.80</td>
<td>58.89</td>
</tr>
<tr>
<td>4th</td>
<td>-7.50</td>
<td>24.80</td>
<td>17.30</td>
</tr>
</tbody>
</table>

This may be attributed to the fact that the underground temperature delays by one month against the outside air temperature in their peak values as shown in Figure 8 and that the cool air introduced from outside during the night is warmed slightly within the underground pit by natural ventilation. However, the slightly warmed outside air is still cool and eventually enters into the building to cool the building structure. When it enters into occupied spaces in winter, the warmed air in the underground pit would bring a natural heating effect.

4. AMOUNT OF HEAT EXCHANGE WITHIN THE UNDERGROUND PIT

4.1 Operation hours of AHU

Figure 9 shows the annual variation of air handling unit (AHU) operation hours. It was found that the AHU operation hours in the fourth year during cooling and heating periods increased by 69% and 18% respectively. This was due to the increase in the number of students and hotter summer.
4.2 Amount of heat exchange within the underground pit

The amount of heat exchange within the underground pit in the fourth year was 34.9GJ during cooling period and 20.4GJ during heating period against 39.2GJ and 38.5GJ respectively in the third year.

Table 3 shows the monthly amount of heat exchange within underground pit within the month the amount of heat exchange turned out maximum. The highest value in cooling period of the fourth year may be due to the decrease in air flow speed within the underground pit below 0.5m/s with higher inlet temperature.

<table>
<thead>
<tr>
<th>Period</th>
<th>1st year</th>
<th>2nd year</th>
<th>3rd year</th>
<th>4th year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cooling</td>
<td>July-01</td>
<td>July-02</td>
<td>August-03</td>
<td>July-04</td>
</tr>
<tr>
<td></td>
<td>2.99kJ/m3</td>
<td>3.00kJ/m3</td>
<td>4.75kJ/m3</td>
<td>5.58kJ/m3</td>
</tr>
<tr>
<td>Heating</td>
<td>December-01</td>
<td>January-03</td>
<td>January-04</td>
<td>February-05</td>
</tr>
<tr>
<td></td>
<td>3.87kJ/m3</td>
<td>2.98kJ/m3</td>
<td>4.06kJ/m3</td>
<td>2.97kJ/m3</td>
</tr>
</tbody>
</table>

The greatest monthly amount of the heat exchange of the cooling period occurred in August with 5.58kJ/m³ and that of the heating period in January with 2.97kJ/m³ in terms of total heat exchanged against the air volume through the underground pit in monthly cumulative values.

This suggests that the performance of heat exchange within the underground pit has not been degraded in comparison with that in the past three years.

4.3 Percentage of reduction in energy for air conditioning

Table 4 shows the annual variation of energy for air conditioning recorded in the central monitoring system for the building of north wing and office block. Energy for air conditioning was 2,201GJ in cooling period and 4,077GJ in heating period in the fourth year. The number of students has increased every year after school opening.

<table>
<thead>
<tr>
<th>The year after school opening</th>
<th>Period of data</th>
<th>Energy for air conditioning</th>
<th>Number of registered persons</th>
<th>Energy for air conditioning per registered person</th>
<th>Energy for air conditioning per floor area</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Cooling period</td>
<td>Heating period</td>
<td>Total (GJ)</td>
<td>Office block (Persons)</td>
</tr>
<tr>
<td>1st</td>
<td>May/2001 ~ Apr./2002</td>
<td>1.919</td>
<td>3.630</td>
<td>5.549</td>
<td>48</td>
</tr>
<tr>
<td>2nd</td>
<td>May/2002 ~ Apr./2003</td>
<td>1.734</td>
<td>3.456</td>
<td>5.190</td>
<td>41</td>
</tr>
<tr>
<td>3rd</td>
<td>Apr./2003 ~ Mar./2004</td>
<td>1.278</td>
<td>3.389</td>
<td>4.667</td>
<td>46</td>
</tr>
<tr>
<td>4th</td>
<td>Apr./2004 ~ Mar./2005</td>
<td>2.201</td>
<td>4.077</td>
<td>6.278</td>
<td>47</td>
</tr>
</tbody>
</table>

*Floor area of measurement : Office block = 2659.75m², North wing = 17543.75m², Total 20203.50m²

Energy used for air conditioning in the third and fourth years was 4.83GJ/person/year and 5.01GJ/person/year respectively or 0.231GJ and 0.311GJ/m² year, which were found smaller than the preceding two years.
5. DISCUSSION

Some consideration on the improvements in the system performance is given for future design of natural ventilation with solar chimney.

1. In the design of the solar chimney, it is primarily important to reduce friction loss for the sake of obtaining higher driving force of solar chimney. The solar chimney of this building had bent portions in the course of air flow due to some problems against planning scheme.

2. The simple method to find an optimum shape of solar chimney in terms of height and horizontal dimensions should be proposed.

3. The optimum relationship between the size of solar chimney and the length of underground pit should be identified. The section and length of the underground pit of this building could have been a little smaller.

4. Proper combination of natural ventilation system and auxiliary air conditioning system should be investigated. The system in this building seemed a little too complicated.

5. Behaviour of occupants should be taken into account in the system design. For example mosquito screen should have been provided for the windows to be opened.

6. CONCLUSION

1. The hours of natural ventilation have increased year after year. From the third year to the fourth natural ventilation was performed for 61% of the cooling period of 5,016 hours and the cooling effects during the hours of natural ventilation was 58.9GJ. This is regarded as instruction to the occupants to realize not to switch AHU on whenever natural ventilation could be possible.

2. The total amount of heat exchange within the underground pit while AHU operating in the third year after school opening was found 71.7GJ. The monthly cumulative value of the heat exchanged within the underground pit was 4.75kJ/m³ in cooling period and 4.06kJ/m³ in heating period.

3. Energy used for air conditioning in the north wing and office block in the third year after school opening was proved to be 4.83GJ/ person/year or 0.231GJ/ m²/year, which was lower than that of the previous year because of an increase in the number of students.

4. The effect of reducing the fresh air load by the use of underground pit under AHU operation in the third year after school opening could be recognized as 30.7% in cooling period and 11.3% in heating period. Percentage of reduction on the energy used for air conditioning of the north wing and office block turned out 12.3% in cooling period and 3.8% in heating period.
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REFERENCES


