Indoor Air Quality and Thermal Environment of Elementary Schools in Winter

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ABSTRACT

This study aims at investigating the actual conditions of indoor environment in schools in order to obtain fundamental information for proper ventilation design of buildings. Indoor environment of two new elementary schools in Tohoku district of Japan was investigated for a week in the winter 2005. Temperature and humidity, concentrations of Carbon Dioxide (CO₂), ventilation airflow rates, concentrations of chemical substances, and the opening condition of the windows and doors were measured in the three classrooms of each school. The CO₂ concentration was higher than 1500 ppm in many hours due to the lack of ventilation. Exhaust airflow rate at the outlet was only 10 percent of the design values. This is due to no maintenance of the ventilation systems and no cleaning of filters. It was observed that meshes for protecting insect of the outlet of exhaust ducts. The CO₂ concentration was higher than 1500 ppm in some classrooms because exhaust airflow rate at outlet was very low. In winter it is difficult to open the windows because outdoor temperature was very low. Maintenance of ventilation system is very important in order to increase exhaust airflow rate at outlet and improve indoor air quality.

KEYWORDS

Elementary school, School buildings, Opening condition of the windows and doors, Ventilation airflow rate, Concentration of Carbon Dioxide

INTRODUCTION

Recently along with the revision of Japanese Building Standards Act, the rule that had to be installed forced ventilation system was decided, and it was provided that air change rate in classrooms should be kept more than 0.3 ACH constantly. Otherwise according to the Standard for school environmental sanitation, air change rate needs to be kept more than 2.2 ACH constantly in elementary school in order to keep CO₂ concentration was lower than 1500 ppm. Therefore it was thought that 0.3 ACH was kept by forced ventilation system and 2.2 ACH was kept by opening the windows. But there are opinions that are difficult to kept 2.2 ACH by opening the windows. For discussing this problem, the data of ventilation airflow rate in actual classroom are
needed, but the numbers of investigation reports of ventilation airflow rate in classrooms in Japan are limited. This study aims at investigating the actual conditions of indoor environment in schools in order to obtain fundamental information for proper ventilation design of buildings. Indoor environment of two new elementary schools in Tohoku district of Japan was investigated for a week in the winter 2005. Temperature and humidity, concentrations of Carbon Dioxide (CO₂), ventilation airflow rates, concentrations of chemical substances, and the opening condition of the windows and doors were measured in the three classrooms of each school.

METHODS

The two elementary schools in Tohoku district (northern region of Japan) had been investigated. Table 1 shows the outline of the schools investigated. There is School A in the center of city, and the numbers of children are declining in School A. In School B of the suburbs the numbers of children are increasing. Both schools had been built within 3 years, and both classrooms and special classrooms had been installed forced ventilation systems. The investigation period in School A was from 28th January 2005 to 3rd February 2005, and that in School B from 18th February 2005 to 24th February 2005. In investigation period there are usually classes in each school. Table 2 shows the outline of the classrooms investigated. The investigated classrooms are 2 classrooms existed upper and lower floors and a special classroom. Temperature and humidity, concentrations of Carbon Dioxide (CO₂), ventilation airflow rates, concentrations of chemical substances, and the opening condition of the windows and doors were measured in the three classrooms of each school. Ventilation airflow rate was estimated by the CO₂ concentration change and passive tracer method. Two pattern of measuring conditions had been investigated. One is the quiet condition that there is no people from evening Friday to morning Monday. In quiet condition windows and doors in classroom were all closed and airconditioner was stopped. Other is the active condition that children attend the class from A.M. 7:00 to P.M. 4:00 in weekday. In active condition children could opened the windows and doors freely. And ventilation system was always run in both case.

<table>
<thead>
<tr>
<th>Date of completion</th>
<th>School A</th>
<th>School B</th>
</tr>
</thead>
<tbody>
<tr>
<td>March, 2004</td>
<td>March, 2003</td>
<td></td>
</tr>
<tr>
<td>Total floor area</td>
<td>11,121m²</td>
<td>9,018m²</td>
</tr>
<tr>
<td>Structure</td>
<td>Reinforced concrete building (4 floors)</td>
<td>Reinforced concrete building (4 floors)</td>
</tr>
<tr>
<td>Occupants</td>
<td>Children 370, Teacher 25</td>
<td>Children 982, Teacher 62</td>
</tr>
<tr>
<td>Ventilation system</td>
<td>classroom: Forced exhaust system, special classroom: Forced supply and exhaust system</td>
<td>Forced supply and exhaust system</td>
</tr>
</tbody>
</table>

Table 2. The outline of the classrooms

<table>
<thead>
<tr>
<th>School A</th>
<th>Number of children</th>
<th>Floor level</th>
<th>Floor area (m²)</th>
<th>Ceiling height (m)</th>
<th>Ventilation system</th>
<th>Incidental facilities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Classroom (1st grade)</td>
<td>28</td>
<td>2/4 floor</td>
<td>68</td>
<td>3.0</td>
<td>E</td>
<td>Heating system</td>
</tr>
<tr>
<td>Classroom (4th grade)</td>
<td>28</td>
<td>3/4 floor</td>
<td>68</td>
<td>3.0</td>
<td>E</td>
<td>Heating system</td>
</tr>
<tr>
<td>Music room</td>
<td>-</td>
<td>4/4 floor</td>
<td>103.5</td>
<td>3.0</td>
<td>S&amp;E</td>
<td>Air conditioner</td>
</tr>
<tr>
<td>School B</td>
<td>Classroom (4th grade)</td>
<td>35</td>
<td>2/4 floor</td>
<td>68</td>
<td>3.05</td>
<td>E</td>
</tr>
<tr>
<td>Classroom (6th grade)</td>
<td>33</td>
<td>3/4 floor</td>
<td>68</td>
<td>3.05-4.0</td>
<td>E</td>
<td>Heating system &amp; Humidifier</td>
</tr>
<tr>
<td>Computer room</td>
<td>-</td>
<td>2/4 floor</td>
<td>95.6</td>
<td>3.05</td>
<td>S&amp;E</td>
<td>Air conditioner</td>
</tr>
</tbody>
</table>

Measurement methods

Temperature and humidity: Thermometers were installed the front, back (1.5m above the floor), center (0.1m, 1.1m and 2.7m above the floor) in the classroom, the corridor in front of the classroom (1.1m above the floor), and the outdoor (1.1m above the floor). Temperature and humidity was measured at 10-minute intervals.

CO₂ concentration: Figure 1 shows CO₂ concentration gas monitor (New Cosmos Electric Co.) Gas monitors were installed fornt classroom, the corridor and the outdoor and measured at 5-minute intervals.

Ventilation rate: Ventilation rate was estimated by the CO₂ concentration change and passive homogeneous emission method (hereafter denoted by passive method).

Passive method: Passive method was carried out using passive tracer gas samplers and dosers (Okuizumi, Kumagai and Yoshino, 2002). Passive method reveals the local mean age of air at the sampling point. The air change rate was calculated as the inverse of the local age of air. Two kinds of tracer gases (PMCH and HFE) were used. One is released from four corner of the classroom and the other from the four corner of the classroom and corridor in front of the classroom. The ventilation rate between the first floor and the second floor could be obtained (Heidt et al, 1991). Under this arrangement, the volume of outdoor air entering to the classroom and the airflow rate between classroom and corridor were calculated by the emission rate of the tracer gas and cumulated volume of the gas in the sampler.

Evaluation method by CO₂ concentration change: The mean ventilation airflow rate was calculated by the CO₂ concentration change and the integral value of the gas emission change between the beginning point of the class and the finishing point of the class (45 minutes). Gas emission was calculated by the number of teacher and children in the classroom.

Indoor air quality: Table 3 shows the outline of measurement of chemical substance concentrations. Carbonyl compounds and volatile organic compounds (VOCs) measured. Sampling points was the center of the classroom and corridor (2.7m above the floor) and the outdoor (1.1m above the floor).

The number of occupants and the opening condition of the windows and doors: The number of occupants and the opening condition of the windows and doors were checked in weekday by the same person.

Measurement of airflow at inlet / outlet: The airflow meter manufactured by Kona Sapporo Co. was used to measure the airflow rate at inlet/outlet of the classroom equipped with forced ventilation system. The airflow rate was measured at an interval of 10 second, and the mean value was recorded when the environmental conditions became steady. When measuring with the airflow meter, the air change rate is defined as the total amount of airflow rate at the outlets divided by the total room volume.

Figure 1. CO₂ concentration gas monitor (New Cosmos Electric Co.)
The concentration of outdoor. But in School B that was about 2500 ppm which was very high concentration. This may be due to the closing windows of corridor facing outdoor. In School A CO concentration was about 700 ppm which was little higher than CO concentration of outdoor. But in School B that was about 2500 ppm which was very high concentration. This may be due to the closing windows of corridor facing outdoor.

RESULTS AND DISCUSSION

Temperature and humidity: Figure 2 shows the results of the mean temperature and humidity in weekday (children attend the class). The temperature become stable to 19 degrees in classroom and special classroom and about 15 degrees in corridor. Temperature difference between upper and lower levels of the classroom in School A was about 3 degrees, on the other hand that in School B was about 8 degrees. Humidity in School A was higher than that in School B because humidifier was installed and run in each classroom in School B when children attended the class.

Measurement of airflow at outlet: Figure 3 shows the results of measurement of airflow rate at outlets. The running mode of ventilation system in the School A (first & fourth grade) set maximum mode and that in music and computer room set heat transfer maximum mode. Air change rate in School A and B classroom and computer room was lower than 2.2 ACH. Air change rate in all room was lower than that of design values. Especially exhaust airflow rate in classroom was 10 percent lower than that of design values. This is due to no maintenance of the ventilation systems and no cleaning of filters. It was observed that meshes for protecting insect of the outlet of exhaust ducts (Figure 4).

CO2 concentration and the opening condition of windows and doors: Figure 5 shows the CO2 concentration, air change rate, The number of occupants, the opening condition of the windows and doors and temperature in School A (first grade) in 3rd February. CO2 concentration tended to be higher than 1500 ppm in the continuously class after a short break. The windows and doors opened scarcely in class. Otherwise the windows and doors opened in a rest time and air change rate was higher than 2.2 ACH and CO2 concentration decreased highly. Temperature decreased little when the windows and doors opened frequently in a rest time. But temperature usually became stable to 20 degrees. Air change rate calculated using CO2 concentration change was lower than 2.2 ACH (except rest time).

CO2 concentration and the opening condition of windows and doors in each class: Figure 6 shows the mean percentage that CO2 concentration was higher than 1500 ppm in weekday and the opening area of the windows and doors. In School A the percentage was low relatively because the windows and doors facing corridor and outdoors opened regularly. On the other hand the percentage was very high. This may be caused by the lack of exhaust airflow rate at outlet by forced ventilation system, the lack of opening windows and doors facing outdoor and the large number of children. Figure 7 shows CO2 concentration and temperature of classroom, corridor and outdoor in weekday. Temperature of corridor in both school was about 15 degrees which was middle between classroom and outdoor. In School A CO2 concentration of corridor was about 700 ppm which was little higher than CO2 concentration of outdoor. But in School B that was about 2500 ppm which was very high concentration. This may be due to the closing windows of corridor facing outdoor.

Table 3. The outline of measurement of chemical substance concentrations

<table>
<thead>
<tr>
<th>Chemical substance</th>
<th>Measuring method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbonyl compounds</td>
<td>Sampler: DNPH cartridge (Tokyo Kenbikyoin Foundation) Sampling method: Passive sampling Analysis method: HPLC1100 (Hewlett Packard 1100)</td>
</tr>
<tr>
<td>VOC</td>
<td>Sampler: ATD sampler (Wako Pure Chemical Co.) Sampling method: Passive sampling Analysis method: GC-MS (HP6890-HP5973, Hewlett Packard, USA)</td>
</tr>
</tbody>
</table>
Figure 2. Temperature and Humidity in Weekday

Figure 3. Result of Measurement of Airflow at Outlet

(a) Percentage that CO₂ Con was higher than 1500 ppm in weekday

(b) CO₂ Con, ACH Change and Number of Occupants

(c) Opening Area of Windows and Doors in Each Class

(d) Temperature and Humidity Change in Classroom

Figure 5. Measurement Result in School A (1-2) in 3rd Feb.

Figure 4. Condition of meshes for protecting insect of the outlet of exhaust ducts (Right: Surface, Left: Back)

Figure 6. CO₂ Con and Opening Area in Weekday (Children be in Classroom)

(a) Opening Area in Weekday (Children be in Classroom)

(b) Opening Area of Windows and Doors

Figure 7. CO₂ Con and Temperature of Classroom, Corridor and Outdoor in Weekday (Children be in Classroom)

(a) ACH by Passive Method

(b) Opening Area of Windows and Doors in Each Class

Figure 8. ACH by Passive Method and Opening Area in Weekday

Figure 9. ACH by CO₂ Con in Weekday (Children be in room)
outdoor in all day.

**Passive method:** Figure 8 shows the mean air change rate by passive method and the opening area of windows and doors. Air change rate was higher than 9.3 ACH because tracer gas did not adsorb to passive sampler (Passive sampler could detect more than 200 µg/m³) in fourth grade of School A. Air change rate was high in music and computer room because exhaust airflow rate at outlet was high although the opening area of windows and doors was little. Air change rate was low in sixth grade of School B because exhaust airflow rate at outlet was low and windows and doors facing outdoor opened scarcely. Fresh air was supplied 80 percent from the windows and doors facing corridor.

**Air change rate by CO₂ concentration change:** Figure 9 shows air change rate by CO₂ concentration change in weekday. In School A air change rate by CO₂ concentration change corresponded to the opening area of windows and doors (Fig 6 (b)). Otherwise in School B there was no relationship between air change rate by CO₂ concentration change and the opening area. This may be due to the lack of exhaust airflow rate although the windows and doors facing corridor usually opened.

**Concentration of chemical substances:** Carbonyl compounds and VOCs measured. Concentration of all chemical substances did not exceed the guideline established the Ministry of Health, Labor, Welfare of Japan. There was hardly any concentrations of ethylbenzene, xylene and p-Dichlorobenzene.

**CONCLUSIONS**

Air change rate in all room by forced ventilation system is lower than that of design values. This is due to no maintenance of the ventilation systems and no cleaning of filters. Maintenance of ventilation system is very important in order to increase exhaust airflow rate at outlet and improve indoor air quality. Fresh air was supplied 80 percent from the windows and doors facing corridor. But air supply from the corridor should be avoided if air of corridor would be contaminated.

**References**


