The effect of natural ventilation on the indoor air quality in classroom of the elementary school without heating equipments during winter season

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ABSTRACT

Field survey on indoor air quality was conducted during winter season, in an elementary school at Kagoshima city. As the windows had been closed because of avoiding the cold outdoor air In the winter, CO_2 concen- trations under pupils staying in the classroom were over 1500 ppm at the end of the lesson. When the windows of the corridor facing outside had been open, the CO_2 concentrations in corridor were close to the outdoor CO_2 concentrations. It was found that the ventilation during the break could play an important role in CO_2 concentrations during the next lesson. The CO_2 emission rate from one third grader child was calculated as 0.011m^3/h. In terms of the rise of indoor CO_2 concentration since the lesson had started, it was found that the influence of the accumulation of the CO_2 before the lesson on the CO_2 concentration during the lesson was very large. The natural cross ventilation during the break of the lesson could be important. It turned out that the indoor CO_2 concentration did not exceed 1500 ppm in 75% of time of a 45-minute lesson where 39 children occupied and the air change rate was 0.6 h^{-1}, if indoor CO_2 concentration would decrease to outdoor level by opening windows during the break.

1. INTRODUCTION

According to the new Japanese building code enforced in 2003, all building should have mechanical ventilation system as a principle. For classrooms, the airchange rate of 0.3 h^{-1} was required by the new building code. On the other hand, many classrooms built before the new building code, do not have mechanical ventilation equipment. In these classrooms, room air was ventilated naturally by opening windows. Gohara and Iwashita reported that the average airchange rate of natural ventilation in the classrooms by opening windows during summer period was 18 h^{-1} and that with windows closed during winter period was 1 h^{-1} (2002). In the Japanese school environmental sanitary standard (2004), the airchange rate of 2.2 h^{-1} was required for keeping CO_2 concentration below 1500 ppm in elementary schools. This airchange value was determined with the assumption that the initial indoor CO_2 concentration would be equivalent to the outdoor CO_2 concentration. Since the indoor situation such as ventilation rate and number of the occupants, during the break of the lesson could have influence on the initial CO_2 concentration of each lesson, the initial concentration would not always be equivalent to the outdoor concentration. Therefore the initial CO_2 concentration and indoor situation during the break are measured in the classroom. The CO_2 emission rate per one pupil is also calculated with measured airchange rate and CO_2 concentration.

2. METHODS

Field measurement had been conducted in one elementary school located in the city of Kagoshima for 3 days between February 8th and 10th. The city of Kagoshima is located in southern Kyushu Island, Japan (31°41'N, 130°33'E). One classroom for 3rd grader pupil was selected for CO_2, VOCs and air change rate monitoring with occupancy during winter period. The age of the classroom, i.e., time in years after construction is 45 years. The plan of the classroom is presented in Figure 1. The classroom has 8m×8m tiled floor area with painted walls (a height of 3 m).

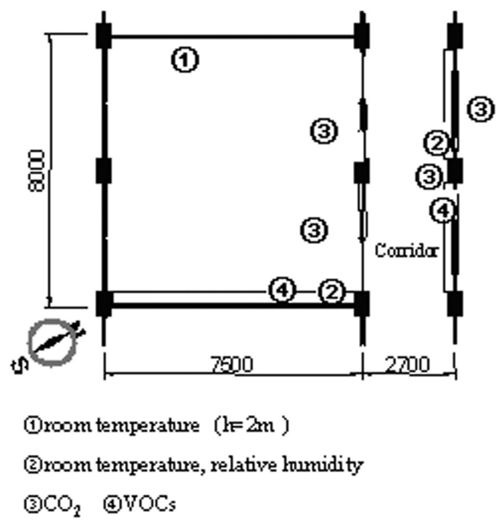

Figure 1: Typical plan of a classroom

Pollutants and parameters of interest were CO_2, VOCs, air temperature, relative humidity, and air change rate. Sampling equipment was placed at 1.1 m above the floor level. A sampling tube of Tenax TA was attached to an air pump for collection of VOCs in the air. The chemical analysis for VOCs was carried out by thermal desorption (Perkin Elmer, ATD400) combined with GC/MS system (Perkin Elmer, Turbomass). The air change rates were determined with the decay rate of tracer gas. Measurements for concentrations of CO_2 and SF_6 (as a tracer gas) were made with a multi-gas monitor based on infrared acoustic spectroscopy (Innova, type 1302). The air temperature and the relative humidity were measured continuously.

We asked teachers and pupils to spend their school life as usual on the measuring day. Staff recorded the frequency of opening/closing windows and doors, and operation of ventilation fans.

3. RESULTS

3.1 Temperature

The air temperature as a function of time in the classroom and outdoors during the daytime on February 8th, 9th, and 10th, are drawn in Figure 2, Figure 5, and Figure 8, respectively. Since heating equipment was not installed in this classroom, the increase of the room temperature was mainly caused by the occupancy of the pupils. Even there was no heating, the room temperature for the measurement period meets the Japanese school environmental sanitary standard (18 – 20 deg C, in winter). The opening area of the windows as a function time on February 8th, 9th, and 10th is shown in Figure 3, Figure 6, and Figure 9, respectively. As the windows of the corridor faced outdoors had been closed between 8:30 and 13:30 on February 10th, the air temperature of the corridor was the intermediate between the room temperature and outdoor temperature. The windows of the corridor faced outdoors had been open except above period and the air temperature of the corridor was closed to the outdoor temperature for this period.

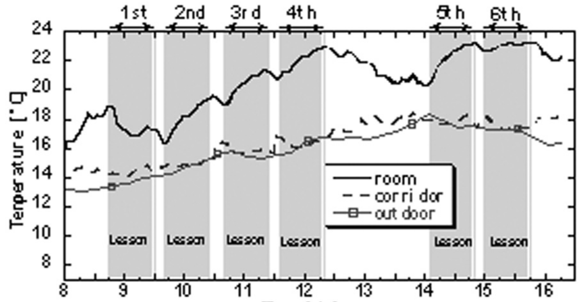

Figure 2: Temperature on February 8th

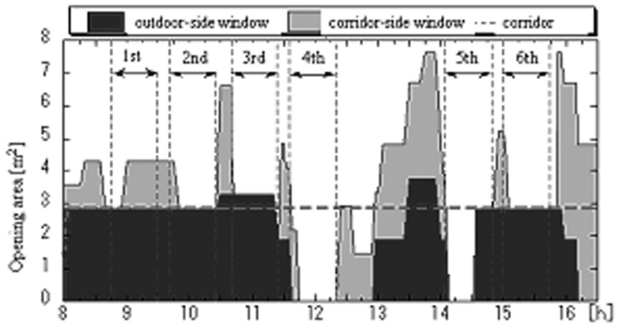

Figure 3: Opening area of windows February 8th

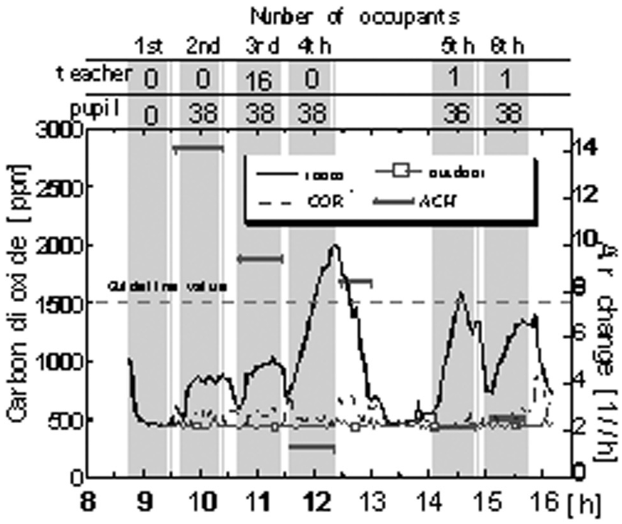

Figure 4: CO_2 and airchange rate on February 8th (COR.*: corridor, ACH: airchange rate)

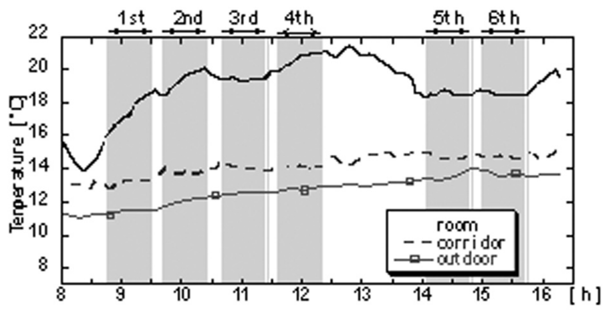

Figure 5: Temperature on February 9th

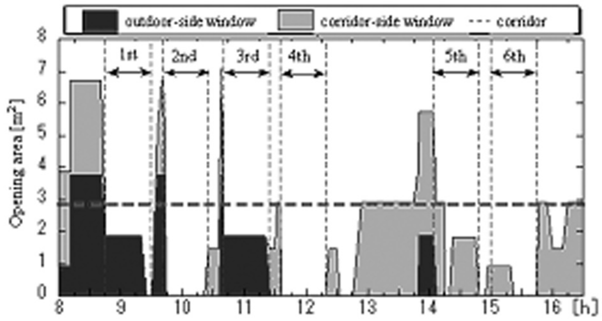

Figure 6: Opening area of windows February 9th

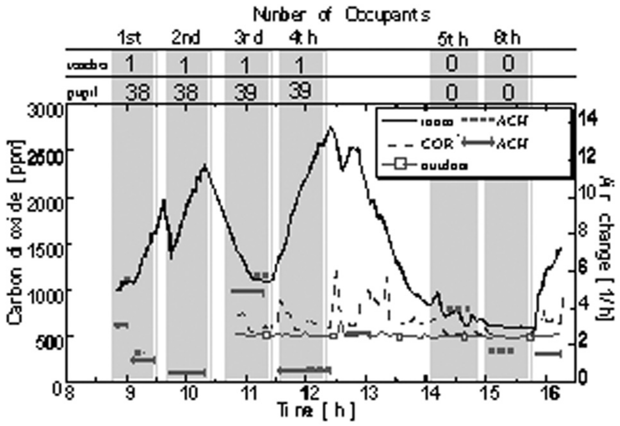

Figure 7: CO_2 and airchange rate on February 9th

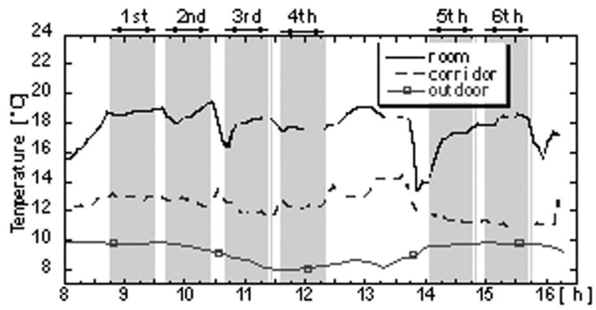

Figure 8: Temperature on February 10th

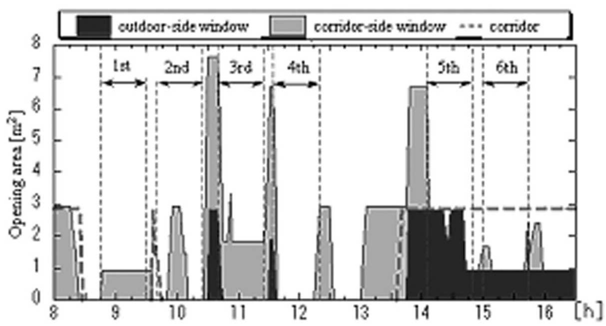

Figure 9: Opening area of windows February 10th

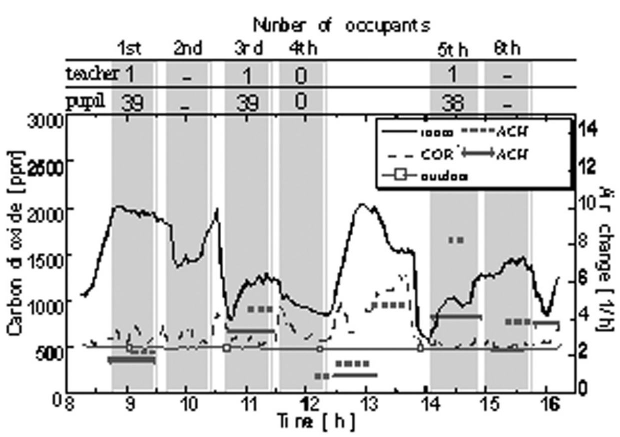

Figure 10: CO_2 and airchange rate on February 10th

3.2 CO_2 concentration

Figure 4, Figure 7, and Figure 10 show the variation of indoor CO_2 concentrations and airchange rate in the classroom on February 8th, 9th, and 10th, respectively. The airchange rate was determined with tracer gas decay method (presented in straight line) and CO_2 concentration method (in dotted line).

On February 8th, when the widows had been mostly open, the indoor CO_2 levels were below the guideline value. On February 9th and 10th, when the opening area of the windows had been relatively small, the indoor CO2 levels were often above the guideline value. During the lunch and "after lunch break" the CO_2 concentrations in the corridor were often above 1000 ppm, because some pupils occupied there.

3.3 CO_2 emission rate

The CO_2 emission rate per one pupil was determined with the following equation.

$$C(t) = \frac{m}{Q}\left(1 - e^{-N \times t}\right) \qquad (1)$$

where

C(t): Indoor CO_2 concentration above outdoor [-]

m: CO_2 emission rate from pupil [m^3/h]

Q: Ventilation rate in the classroom [m^3/h]

N: Airchange rate of the classroom [h^{-1}]

Non-linear regression analysis was applied for the above equation, and CO_2 emission rate per one pupil was determined to be 0.011 m^3/h.

4. DISCUSSION

The opening area of the windows in the classroom divided by the wall was defined as "opening ratio" with the unit of m^2/m^2. The relationship between the opening ratio and the measured airchange rate is presented in Figure 11. The correlation coefficient between them is rather high at 0.87.

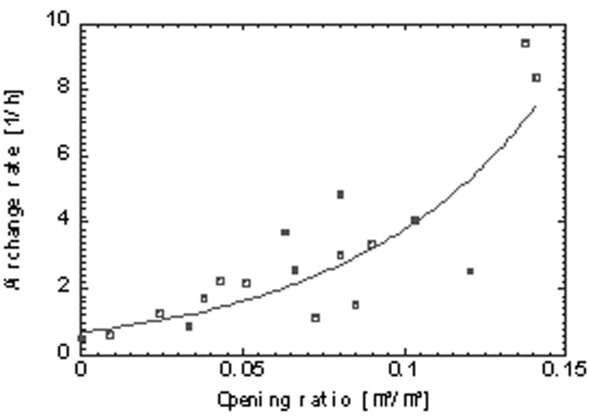

Figure 11: Airchange rate as a function of opening ratio

As mentioned above, the guideline value of the airchange rate was determined with the assumption that the initial indoor CO_2 concentration would be equivalent to the outdoor CO_2 concentration. However the initial indoor CO_2 concentration in the 4th lesson on February 9th was 1300 ppm as seen in Figure 7 and was not equivalent to outdoor concentration. Therefore we tried to compare this measured indoor CO_2 concentration in the 4th lesson on that day with CO_2 concentration assuming that initial concentration would be equal to outdoor concentration. Figure 12 shows the measured indoor CO_2 concentration in the 4th lesson on February 9th, the simulated indoor CO_2 concentration with the condition that initial indoor concentration was the outdoor concentration, and the accumulated CO_2 concentration. The simulated CO2 concentration was determined with the following equation and using "$C_I = C_o$". The accumulated CO_2 concentration was presented by the 1st term of the right side of the equation (2) with C_I of 1300 ppm.

$$C - C_0 = (C_1 - C_0) \times e^{-N \times t} + \frac{m}{Q}\left(1 - e^{-N \times t}\right) \qquad (2)$$

where:
C: Indoor CO_2 concentration [-]
C_o: Outdoor CO_2 concentration [-]
m: CO_2 emission rate [m^3/h]
C_I : Initial indoor CO_2 concentration [-]
Q: Ventilation rate [m^3/h]

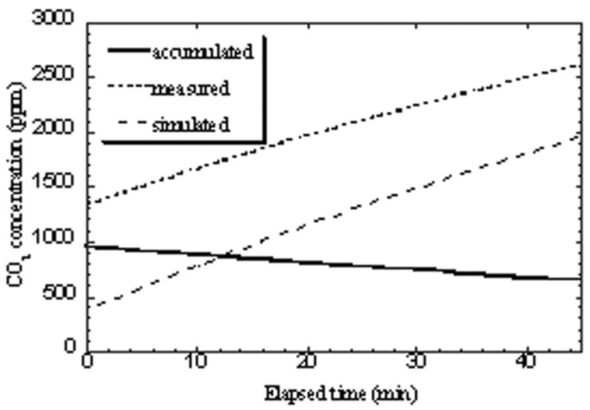

Figure 12: Measured CO_2, simulated CO_2 with "$C_1 = C_o$", and accumulated CO_2 concentrations

Since the simulated CO_2 concentration was below 1500 ppm until t=30 (min) as seen in Figure 11, the initial indoor CO_2 concentration would be important for keeping good air quality.

The initial CO_2 concentration in the lesson could be influenced by the ventilation condition during the break just before the lesson. Then we considered three cases of CO_2 concentrations during the break of 15 minutes: 1) the classroom was occupied by pupil with airchange of 20 h^{-1}, 2) the classroom was not occupied by pupil with airchange of 20 h^{-1} and 3) the classroom was occupied by pupil with airchange of 2 h^{-1}. The airchange rate of 20 h^{-1} was measured during the windows all open, and that of 2 h^{-1} was during closed. The three cases are drawn in Figure 12. The case 2) would be occurred when the pupil left the classroom to the school grounds with the windows open. The initial CO_2 concentration would be equivalent to the outdoor level if the condition of the case 2) was occurred.

5. CONCLUSION

The measurement on temperature, humidity, CO_2 and VOCs concentrations and airchange rate was conducted in a classroom without heating equipment during winter period. The following results were obtained:
1) Since the opening ratio of the windows was low during winter period, the indoor CO_2 concentration was often over 1500 ppm.
2) The CO_2 concentration in the corridor was close to the outdoor concentration.
3) The initial CO2 concentration had a large influence on the average indoor CO2 concentration during the lesson. The ventilation during the break between the lessons could be important for better indoor air quality during the lesson in classroom.

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