Air Exchange Rates in the Elementary Schools in Southern Japan

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ABSTRACT

The purpose of this study is to determine how levels of ventilation rates and indoor air quality vary in elementary schools in southern Japan. This study is based on field monitoring carried out as intermittent monitoring from summer to winter. The concentrations of Volatile Organic Compounds (VOCs) and the air exchange rates were measured in four classrooms in Kagoshima City. The measurements also included carbon dioxide (CO_2) in a selected classroom with occupancy of the pupils. The average air exchange rate of the classrooms measured during summer period was high at 18 h^{-1}, where windows and doors were all open. In winter, the air change rates were relatively low at 1 h^{-1} since windows were closed. The VOCs concentrations in the classrooms varied from summer to winter due to the changes of the air change rate and the thermal condition. Natural ventilation induced by opening windows had a significant effect on the indoor VOCs concentration in schools.

KEYWORDS

Elementary schools, VOCs, Air change rates, CO_2

INTRODUCTION

Indoor Air Quality (IAQ) has caught attention in recent years. Many studies on IAQ have found that levels of indoor Volatile Organic Compounds (VOCs) are often greater than the guideline values. IAQ at schools is of special concern since children spend much time there. Good air quality in classrooms favors children's learning ability, teachers and staffs' productivity (EPA, 1996). From the viewpoint of children's health and indoor air quality in classrooms, several researches were conducted in Europe and North America (Braganza *et al*., 2000; Elfman *et al*., 2000; Mathisen *et al*., 2000; Nielsen, 1994). A checklist on IAQ diagnosis for teachers or school health administrators has been developed (EPA, 2000).

In Japan, *The standard of school environmental hygiene* enforced in 1964 by the Ministry of Education has become administrative guideline of IAQ in schools. While the number of field studies on IAQ in residences and offices has been recently increasing in Japan, there are few studies on schools. Therefore field measurements on IAQ in schools are needed to characterize pollution levels. Pollution levels are affected by several factors, such as, outdoor pollution, furnishings and human activities. Sources of outdoor pollution are from automobile, incineration, and so on. Human activities include cleaning, waxing, polishing, etc.

In spite of the hot and humid summer climate, air-conditioners are not installed in most classrooms of public schools (except colleges) even in southern Japan. Heating systems are usually not installed either in the South. Cross ventilation, in particular, is preferred in summer not only for air exchange in classrooms but also to facilitate heat loss from the body for thermal comfort. Therefore, many typical classrooms are of open-plan with large windows through which air moves across rooms. Windows are closed in winter to shut out cold outdoor air. Levels of contaminants could be elevated in winter because of less cross ventilation. The three elementary school buildings investigated are located in the city of Kagoshima in southern Japan. Field measurements including the concentrations of VOCs and CO_2, and the air change rates are conducted in four classrooms in summer, autumn, and winter intermittently.

METHODS

Investigated Schools

Field measurements were conducted in three elementary schools located in the city of Kagoshima. The city of Kagoshima is located in southern Kyushu Island, Japan (31° 41'N, 130° 33'E). Four classrooms from the three schools were selected for VOCs and air change rate monitoring with occupancy in summer, autumn, and winter intermittently. Table 1 shows the selected classrooms and the measurement day. The ages of the classrooms, i.e., time in years after construction or renovation, of classroom no.1, 2, 3 and 4 are 41, 0.25, 33 and 2.25 years, respectively. The number of pupils in the classrooms is also listed in Table 1. CO_2 was only measured in classroom no.1. Typical plan of a classroom is presented in Figure 1. A typical classroom has 8m×8m tiled floor area with painted walls (a height of 3 m).

TABLE 1
Measuring days and number of pupils

No.	School	summer		autumn		winter	
1	FZ	23/06/00*	44**	09/11/00	39	09/11/00	41
2	TE	03/07/00	36	20/11/00	37	30/01/01	35
3	TE	03/07/00	40	20/11/00	37	30/01/01	39
4	YS	11/07/00	33	15/11/00	38	14/02/01	35

* : day/month/year
**: number of pupils occupying classroom

Measuring Methods

Pollutants and parameters of interest were VOCs, air temperature, and relative humidity, and air change rate. In classroom no.1, CO_2 was monitored, too. 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.

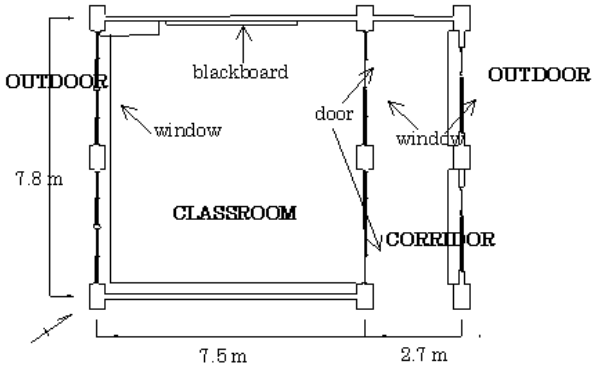

Figure1: Typical plan of a classroom:

Figure 2: Classroom no.1 in summer:

RESULTS AND DISCUSSION

Temperature and Relative Humidity

The air temperature and the relative humidity as a function of time in classroom no.1 and outdoors during the daytime on the summer measuring day (June 23, 2000) are shown in Figure 3. Between 08:00 and 17:00, the windows were open. The classroom temperature exceeded 30 °C at 11:00, and was constant around 30.5 °C after that. The indoor relative humidity was over 70 % in the morning and over 65% in the afternoon. The sedentary pupils took lessons with wiping off their sweat on the measuring day in classroom no.1. High temperatures and high humidity characterize the summer climate of the classrooms in southern Japan.

While the outdoor temperature was very high in summer, it was rather low in winter even though southern Japan has hot and humid climate. Since the room temperature was often lower than 15 °C in winter, the windows had been mostly closed to block cold outdoor air.

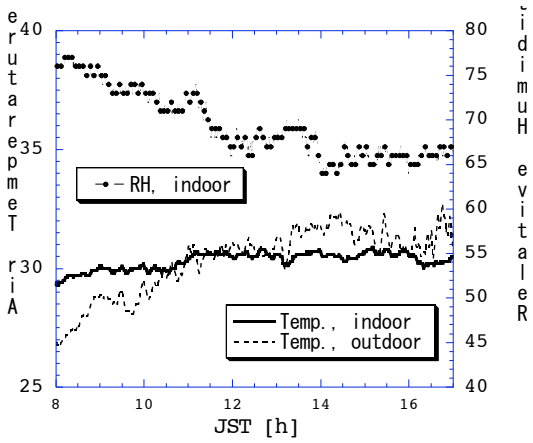

Figure 3: Diurnal variation of the air temperature and the relative humidity in classroom no.1 in summer:

Diurnal and Seasonal Variation of VOCs Concentrations

Figure 4 shows the diurnal variation of VOCs concentrations in four classrooms in summer. This figure depicts the VOCs concentrations obtained under the condition where windows were closed, and those where windows were open. Since the ages of classroom no.1, and no.3 in Figure 4 were older than 30 years, the levels of VOCs emission from paints and adhesives were conceived to be low. However the concentration of 1.4-dichlorobenzene in classroom no.1 were rather high. The concentration of 1.4-dichlorobenzene was found to be high at 460ug/m^3 in the toilet of school FZ with mothballs. Probably 1.4-dichlorobenzene detected in classroom no.1 came from this toilet beside the classroom.

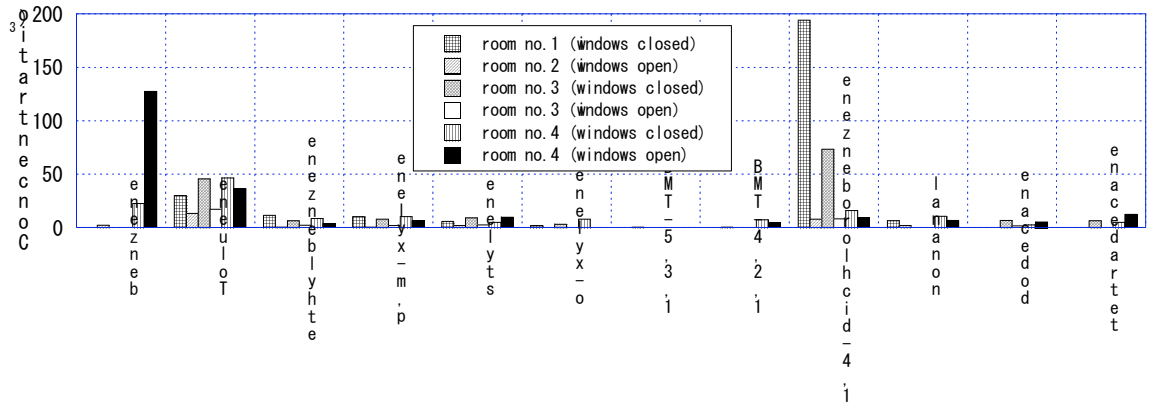

Figure 4: Variation of VOCs concentrations in old classrooms with windows open/closed in summer:

Figure 5 presents summer VOCs concentrations in classroom no.2 with windows closed and those with windows open. Since classroom no.2 and classroom no.3 are located at the same school (school TE), summer VOCs concentrations in classroom no.3 with windows closed are also shown in Figure 5 as a comparison. VOCs concentrations in classroom no.2 were higher than those in classroom no.3, showing that young classroom no.2 emitted much VOCs from paints and adhesives, such as toluene, xylene, TMB, and so on. Because of more cross ventilation rate, VOCs concentrations in classroom no.2 with windows open, were lower than those with windows closed, and below the guideline values established by the committee of the Ministry of Health, Labor and Welfare of Japan (MHLW, 2000).

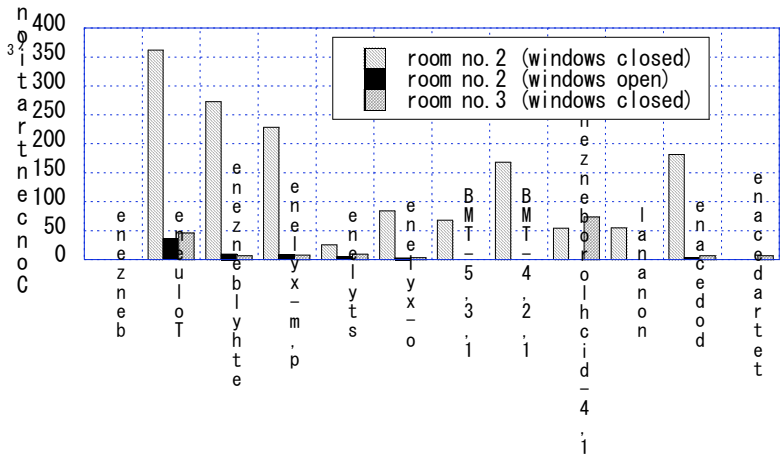

Figure 5: Variation of VOCs concentrations in a new classroom (no.2) and an old classroom (no.3) in summer :

In summer and autumn, windows of the classrooms were kept open during the occupancy period. In terms of toluene concentration, the concentration in summer was higher than that in autumn, because the room temperature in summer was higher. Although the room temperature in winter was lower than in autumn, indoor toluene concentration in winter was higher. This is because less cross ventilation is introduced to the classrooms in winter with windows closed.

Air Change Rate

The air change rates of natural ventilation in the selected four classrooms measured with tracer gas decay method are presented in Figure 6.
These tracer gas measurements were conducted after class, reproducing the real occupancy situation. The average air change rates were high at 18 h^{-1} both in summer and autumn, since all windows were widely open. In winter, the air change rates were relatively low at 1 h^{-1} since windows were closed. This air change rate of 1 h^{-1} is less than the recommended minimum value of 2.2 h^{-1} in "the standard of school environmental hygiene (2002)".

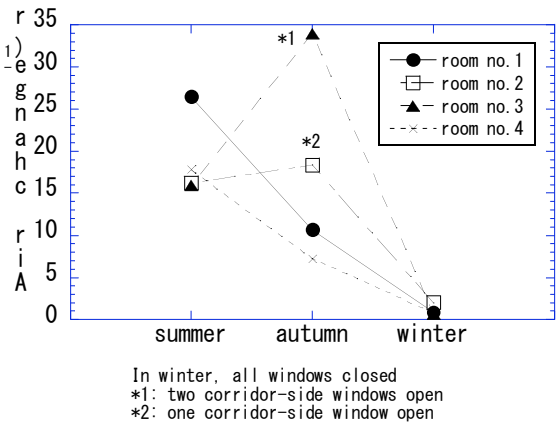

Figure 6: Air change rates in four classrooms:

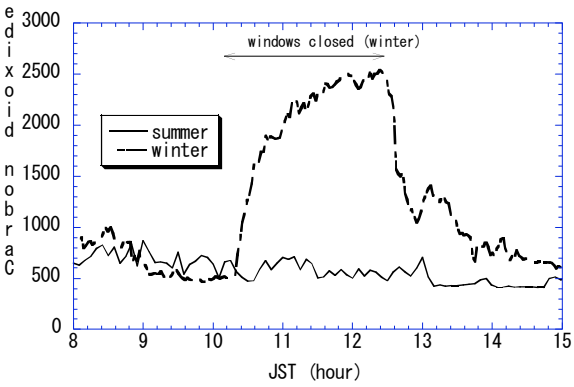

Figure 7: Diurnal variation of carbon dioxide (CO_2) concentrations in classroom no.1 in summer and winter:

CO_2 Concentration

Figure 7 shows the variation of indoor CO_2 concentrations in classroom no.1 both in

summer and winter. Indoor CO_2 levels in winter were above "the standard of school environmental hygiene". The highest CO_2 concentration found in winter even reached 2500 ppm. High levels of CO_2 observed in winter were due to inadequate air change due to closed windows, doors, and the ventilation system. On the other hand, indoor CO_2 levels in summer were below the standard value because of enough cross ventilation because of open windows.

CONCLUSIONS

The purpose of this study is to determine how levels of indoor air quality vary in classrooms of elementary schools in southern Japan. Field study on indoor air quality was carried out as intermittent monitoring from summer to winter. The following conclusions were obtained:

1) Indoor climate of classrooms in southern Japan was very hot and humid in summer. High temperature might have negative effects on physiological/mental condition and performance of pupils, even they opened the windows for inducing cross ventilation during their occupancy.

2) Highest concentrations of toluene, ethylbenzene, and xylenes were obtained in the latest painted classroom and exceeded the guideline values.

3)The air change rate of the classroom measured in summer was greater than 10 h^{-1}, and as almost the same as that in autumn. In winter, the air change rate was reduced to 1 h^{-1} due to less cross ventilation with windows closed.

5) High concentration of 1,4-dichlorobenzene was found in the toilet and in the adjoining classroom.

6) More ventilation is needed in winter, since indoor CO_2 concentration exceeded the guideline value.

7) Natural ventilation induced by opening windows had a significant effect on the indoor VOCs concentration in schools.

References

EPA (1996), Indoor Air Quality Basics for Schools
EPA (2000), Indoor Air Quality -Tools For Schools-
Ministry of Education, Culture, Sports, Science and Technology, Japan (2002), Standard of School Environmental Hygiene
Ministry of Health, Labor, and Welfare (MHLW), Japan (2000), Guideline for Indoor VOCs including Formaldehyde in Housing
Nielsen A. (1994), Measurements of indoor climate in school class rooms and improvement methods, Proc. of Healthy Buildings 1994, Vol.2, 583-588