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Short Communication

Indoor Air Quality Investigations at Five Classrooms

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Abstract Five classrooms, air-conditioned or naturally ventilated, at five different schools were chosen for comparison of indoor and outdoor air quality. Temperature, relative humidity (RH), carbon dioxide (CO_2), sulphur dioxide (SO_2), nitric oxide (NO), nitrogen dioxide (NO_2), particulate matter with diameter less than 10 μm (PM_{10}), formaldehyde (HCHO), and total bacteria counts were monitored at indoor and outdoor locations simultaneously. Respirable particulate matter was found to be the worst among parameters measured in this study. The indoor and outdoor average PM_{10} concentrations exceeded the Hong Kong standards, and the maximum indoor PM_{10} level was even at 472 $\mu g/m^3$. Air cleaners could be used in classrooms to reduce the high PM_{10} concentration. Indoor CO_2 concentrations often exceeded 1,000 μl/l indicating inadequate ventilation. Lowering the occupancy and increasing breaks between classes could alleviate the high CO_2 concentrations. Though the maximum indoor CO_2 level reached 5,900 μl/l during class at one of the sites, CO_2 concentrations were still at levels that pose no health threats.

Key words Classroom air quality; Ventilation; Carbon dioxide; Respirable particulate matter; Hong Kong

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Introduction

Indoor air quality has caught attention of scientists and the public in recent years. Many studies had found indoor pollutant levels greater than the outdoors, and since we spend more time indoors, good indoor air quality is very important to us. Air quality at schools is of special concern since children are susceptible to poor air quality. Good air quality in classrooms favour children's learning ability, teacher and staff's productivity (USEPA, 1996). Investigation of air quality at classrooms helps us to characterize pollutant levels and implement corrective measures if necessary. Outdoor pollution, ventilation equipment, furnishings, and human activities affect indoor air quality. Sources of outdoor air pollution are from traffic, industrial, construction, and combustion activities (Wark and Warner, 1981). Good ventilation systems not only provide thermal comfort they should also distribute adequate fresh air to occupants and remove pollutants. The study by Gusten and Strindehag (1995) revealed that outdoor air pollutants play a major role in affecting the indoor air quality, and cleaning products and floor polish can temporarily add to the pollution content in classrooms. Other important factors influencing air quality indoors are the extent of human activities (number of students, length of lessons, breaks) on the premises. Poor outdoor air quality and noise prompt schools in Hong Kong (HK) converting naturally ventilated classrooms into air-conditioned classrooms. A study by Koo et al. (1997) found that the frequency of symptoms in students learning in air-conditioned classrooms were higher than those in naturally ventilated classrooms in Hong Kong.

The objectives of this paper are to characterise air pollution level at selected classrooms in Hong Kong, to compare the measured concentrations with established standards, and to suggest ways to reduce pollutant levels in classrooms.

Method

Site Description

Indoor and outdoor air samples were collected at five schools (TC, SF, MFS, MFC, and SJ) in HK. The schools were located in residential, industrial and rural areas. One classroom from each school was selected to mini-

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Table 1 Detail parameters at each classroom

	TC	SF	MFS	MFC	SJ
Floor area (m^2)	60.8	46.9	48.3	83.7	52.5
Room volume (m^3)	216	160	140	285	205
Indoor sampling floor	4	3	2	4	1
Number of students occupying classroom	~42	~40	~40	~38	~39
Number of hours occupied per day (hr)	~7	~7	~7	~5	~2

mise interferences with normal school activities. Classrooms in HK are usually decorated with tiles and painted walls; those with high noise levels have air-conditioners and double-glazed windows for noise elimination and ventilation. Other classrooms remote from traffic noise use ceiling fans for ventilation. TC is situated in an urban area with major traffic roads surrounding the school building. A study by the Hong Kong Environmental Protection Department recorded an annual average PM_{10} level of 99 μg/m^3 at TC in 1988. The classroom at TC had double-glazed windows with two window type air-conditioners and five exhaust fans. SF is situated in an urban residential area; a cooling tower conditions the air inside the classroom. Classrooms at MFS, MFC, and SJ were naturally ventilated. MFS is located in a rural area with an industrial area nearby, MFC is located on a hillside near a residential/industrial area, and SJ is located in a residential area. Details of each sampling site are listed in Table 1.

Sampling and Analysis

Pollutants and parameters of interest were carbon dioxide (CO_2), temperature, relative humidity (RH), formaldehyde (HCHO), particulate matter with diameter less than 10 μm (PM_{10}), bacteria, sulphur dioxide (SO_2), nitric oxide (NO), and nitrogen dioxide (NO_2). Sampling equipment was placed at 1.5 m above ground level at both indoor and outdoor locations. A Q-TRAK IAQ Monitor (TSI, Model 8551; TSI, Shoreview, MN, USA) was used for CO_2, temperature, and humidity measurements. The Q-TRAK uses a non-dispersive infrared sensor for measuring CO_2 levels; a thermistor for measuring temperature and a thin-film capacitive sensor for measuring relative humidity. An SKC formaldehyde monitoring kit was used for 24-h formaldehyde measurements. Indoor and outdoor PM_{10} levels were measured using a TSI DUSTTRAK. A Portable Air Sampler for Agar Plates (Burkard) was used for sampling bacteria at 20 ml/min. Agar plates were incubated at 32°C for 48 h. Tedlar air sampling bags and a portable sampling pump (SKC Airchek sampler, Model 224–43XR) with flow rate at 1 ml/min were used for air samples. The air bags were then transferred to the laboratory for analysis. SO_2 were analysed by a Thermo Electron (model 43B) Pulsed Fluorescence SO_2 Analyzer (Thermo Environmental Instruments, Inc., Franklin, MA, USA) while NO_x (NO, NO_2) were analysed by a Thermo (SKC Model 42) Chemiluminescence NO_x Analyzer (Thermo Environmental Instruments, Inc.). Carbon dioxide, temperature, humidity, and PM_{10} were continuously monitored. SO_2, NO_x, and bacteria levels were measured before and after school hours. Duplicate samples for formaldehyde and bacteria were obtained. Field blanks for formaldehyde and bacteria were brought to the sampling sites to ensure no contamination during sample handling and transportation. Equipment for analysing air bag samples are daily calibrated, Q-TRAK and DUSTTRAK were calibrated according to

Table 2 The Hong Kong Interim Indoor Air Quality Guidelines and Hong Kong Air Quality Objective

Pollutants	Hong Kong Air Quality Objective	Hong Kong Interim Indoor Air Quality Guidelines
Sulphur dioxide	800 μg/m^3 (1-h average) 350 μg/m^3 (24-h average) 80 μg/m^3 (annual average)	
Nitrogen dioxide	300 μg/m^3 (1-h average) 150 μg/m^3 (24-h average) 80 μg/m^3 (annual average)	
Particulate matters with diameter less than 10 μm	180 μg/m^3 (24-h average) 55 μg/m^3 (annual average)	
Formaldehyde		100 μg/m^3 (1-h average)
Microbial/Biological Contaminants		1,000 CFU/m^3 (1-h average)

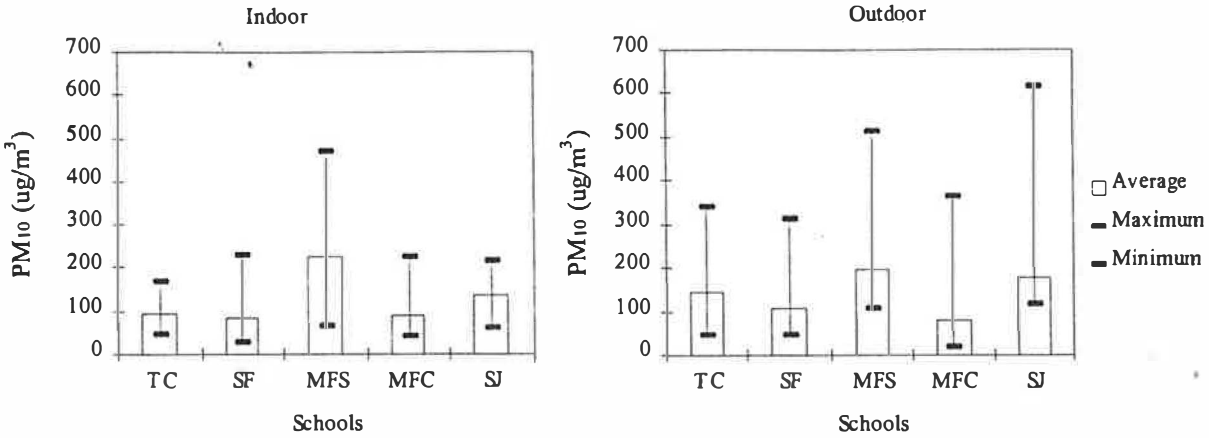

Fig. 1 Comparison of indoor and outdoor PM_{10} levels at the five schools (HKIAQ, HKAQO 180 μg/m^3)

manufacture specifications. The Hong Kong Air Quality Objectives (HKAQO) and Interim Indoor Air Quality Guidelines (HKIAQ) (EPD, 1994) for pollutants relevant to this study are listed in Table 2. The American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) Standard 62–1989 (ASHRAE, 1989) for CO_2 of 1,000 μl/l was used for comparison. The indoor and outdoor averages of CO_2, temperature, humidity, and PM_{10} levels were calculated using the data when the classrooms were occupied.

Results and Discussion

Figure 1 shows the indoor and outdoor PM_{10} levels measured at the five schools. PM_{10} levels measured at the five schools ranged from 21 to 617 μg/m^3. The indoor and outdoor average PM_{10} levels at MFS exceeded the 24-h PM_{10} HKAQO. High PM_{10} levels in Hong Kong are mainly caused by vehicle exhaust emissions. MFS, though located in a rural area, has highways nearby (~75 m from the school boundary). Heavy trucks travelling on the highway produced a lot of particulate matter which affected the indoor level as well. PM_{10} produced by traffic outside TC was somehow restrained from entering the indoor. The indoor and outdoor PM_{10} concentrations measured at SF were similar, but since outdoor measurements were obtained on the roof, the outdoor PM_{10} level could be underestimated. High outdoor PM_{10} concentrations at SJ were originated from construction activities inside the school campus. Since high level of particulate matter is inevitably present in HK, air cleaners could be used in classrooms to reduce indoor PM_{10} levels.

Indoor average CO_2 levels at TC and SF had CO_2 levels above the ASHRAE standard (Figure 2). The highest CO_2 concentration recorded at SF even reached 5,900 μl/l (the instrument's maximum detection limit). High levels of CO_2 observed in SF were due to inadequate air exchange by closing windows, doors, and the ventilation system. Overcrowded classroom could also be the reason for high CO_2 level. In general, air-conditioned classrooms had higher indoor CO_2 levels (average above 1,000 μl/l) when occupied compared with ceiling fans ventilated classrooms (average below

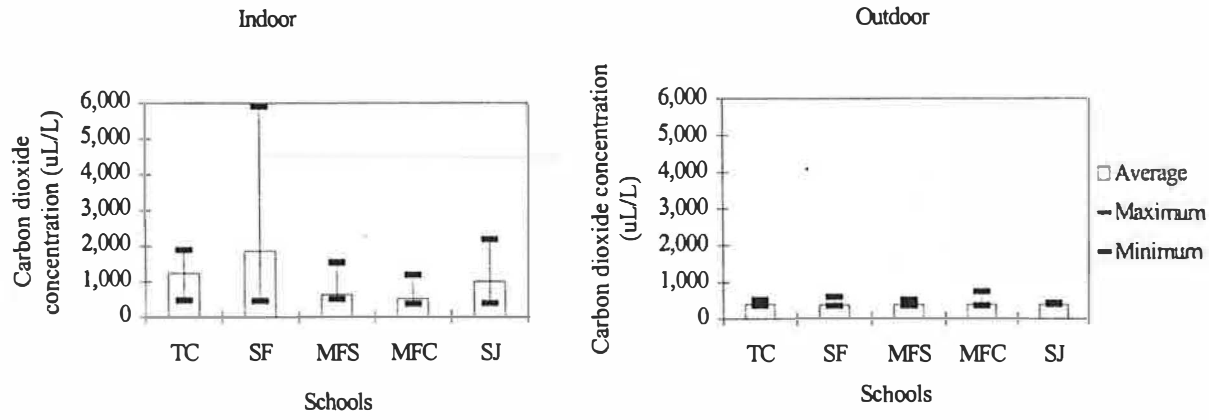

Fig. 2 Comparison of indoor and outdoor CO_2 levels (ASHRAE standard 1,000 μL/L)

1,000 μl/l). This result was comparable with those by Norback et al. (1990) where average CO_2 levels were above 800 μl/l.

Figure 3 shows the variation of indoor CO_2 concentrations on a typical sampling day at TC and MFS. A strong correlation of CO_2 level with occupancy had observed. Carbon dioxide build-up began when students started occupying classroom at TC, and reached a maximum of 1,600 μl/l at 8:20 a.m. The CO_2 concentration remained high until the morning break. Rapid increase and saturation of CO_2 concentration was observed in all TC measurements. The MFS classroom showed CO_2 concentration profiles unlike TC. CO_2 did not reach a "saturation level", but fluctuated between 500 and 1,000 μl/l. CO_2 concentrations remained low when the classroom was unoccupied during lunch break, and after school. The morning CO_2 peak at about 8:00 a.m. corresponded to students entering the classroom. Similar variations in CO_2 level related to usage of classrooms were observed at other ceiling fans equipped classrooms. Average indoor temperature ranged from 17.2 to 23.2°C while the outdoor temperature ranged from 14.0 to 27.3°C. Indoor temperature suggested by ASHRAE should be 19 to 23°C in the winter. Indoor RH varied between 55.5% and 75.1% and outdoor RH varied between 53.5% and 83.6%. The indoor and outdoor RH values were similar and within normal ranges.

Indoor and outdoor SO_2 levels ranged from 5 to 16 μg/m^3, but average SO_2 levels were similar at the five schools. Average NO and NO_2 concentrations varied from 21–133 μg/m^3 and 38–81 μg/m^3, respectively. Indoor and outdoor NO concentrations varied from 1–304 μg/m^3 and 1–422 μg/m^3, respectively while indoor and outdoor NO_2, levels varied from 15–213 μg/m^3 and 23–295 μg/m^3, respectively. Average NO_2 concentrations at the five schools complied with the HKIAQ (80 μg/m^3), except for the MFS outdoor average (81 μg/m^3). The HKIAQ guideline for NO_2 was exceeded on a few occasions and the outdoor concentration even reached 195 μg/m^3 at TC. This high NO_2 concentration was caused by vehicular exhaust emissions from nearby traffics. Formaldehyde concentrations ranged from undetectable to 27 μg/m^3 and all measured levels were within the HKIAQ guideline. Since there was no apparent source of formaldehyde from classroom furnishings at the five schools, low levels of HCHO were measured. Average biological counts were within the HKIAQ level of 1,000 CFU/m^3, but some outdoor samples had total bacterial counts exceeding 800 CFU/m^3. Indoor bacteria samples had lower concentrations than the outdoors.

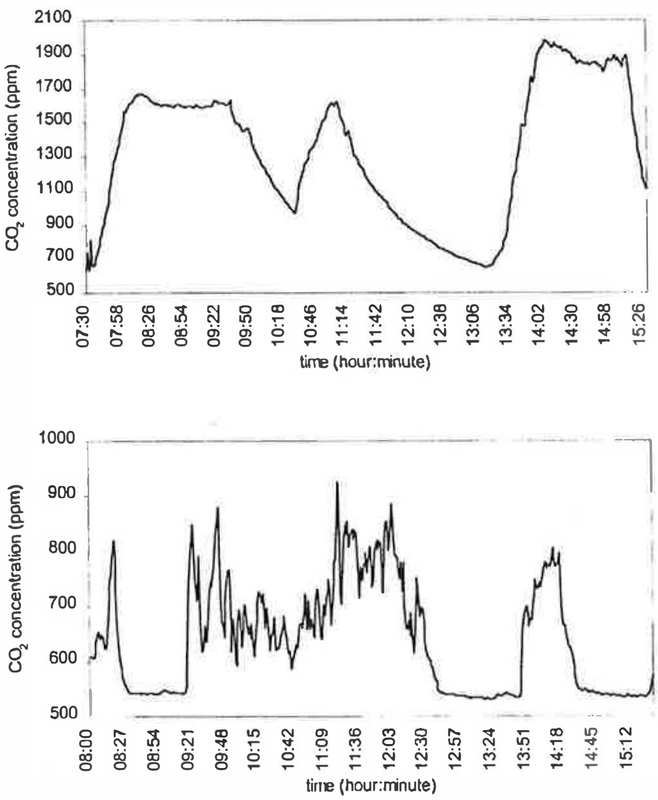

Fig. 3 Indoor carbon dioxide level at TC (air-conditioned) and MFS (natural ventilation)

Conclusion

The major problem concerning classroom air quality in Hong Kong identified from this study was high dust concentrations. The indoor and outdoor average PM_{10} concentrations exceeded the respective indoor and outdoor standards. The highest PM_{10} level was even at 617 μg/m^3, it was three times higher than the 24-h average standard. Though CO_2 levels measured in this study did not pose health threat, the indoor CO_2 concentrations exceeded the ASHRAE standard due to overcrowded classrooms and inadequate ventilation. Maximum indoor CO_2 level was as high as 5,900 μL/L during class and the variation of CO_2 level depends on the occupancy and student activities. Implementation of more breaks and recesses between classes, and decreasing the occupancy per classroom might help to reduce the level of CO_2. Increase the rate of ventilation could also remove the accumulated CO_2; for example, the use of ceiling fans, exhaust fans could increase the exchange of indoor air with the outdoor, but further investigation is necessary because increased ventilation could also increase the indoor concentration of outdoor generated pollutants. Average SO_2, NO_2, HCHO, and bacteria concentrations measured at each school did not exceed the respective standards. HCHO levels were substantially lower than the HKIAQ standard since there were no apparent sources indoors and classroom furnishings only have small contribution.

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