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Indoor and outdoor air quality investigation at schools in Hong Kong

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Abstract

Five classrooms in Hong Kong (HK), air-conditioned or ceiling fans ventilated, were chosen for investigation of indoor and outdoor air quality. Parameters such as temperature, relative humidity (RH), carbon dioxide (CO_2), sulphur dioxide (SO_2), nitric oxide (NO), nitrogen dioxide (NO_2), respirable particulate matter (PM_{10}), formaldehyde (HCHO), and total bacteria counts were monitored indoors and outdoors simultaneously. The average respirable particulate matter concentrations were higher than the HK Objective, and the maximum indoor PM_{10} level exceeded 1000 μg/m^3. Indoor CO_2 concentrations often exceeded 1000 μl/l in air-conditioning and ceiling fan classrooms, indicating inadequate ventilation. Maximum indoor CO_2 level reached 5900 μl/l during class at the classroom with cooling tower ventilation. Increasing the rate of ventilation or implementation of breaks between classes is recommended to alleviate the high CO_2 level. Other pollution parameters measured in this study complied with the standards. The two most important classroom air quality problems in Hong Kong were PM_{10} and CO_2 levels.

1. Introduction

Indoor air quality in workplace and residential environments caught attention of scientists and the public in recent years. Many studies have found indoor pollutant levels greater than outdoor levels (Montgomery and Kalman, 1989), and since people spend more than 90% of their time indoors; good indoor air quality is very important to us. Air pollutants produced by outdoor sources not only affect the environment, but also affect our health. Air quality at classrooms is of special concern since children are susceptible to poor air quality, and indoor air problems can be subtle and do not always produce easily recognisable impacts on health and well-being (USEPA, 1996). Failure to prevent indoor air pollution can increase the chance of long-term and short-term health problems for students and staff; reduce in productivity of teachers; and degrade the student learning environment and comfort. Investigation of air quality in classrooms helps us to characterise pollutant levels and implement corrective measures to improve air quality if necessary.

The cause of indoor air pollution is a combinatory effect of physical, chemical and biological factors, and the adequacy of ventilation in the environment. Indoor air pollutant sources are from the outdoors, HVAC and building equipment, furnishings, and human activities. Major outdoor air pollution comes from traffic, industrial, construction, and combustion sources (Wark and Warner, 1981). Good ventilation systems not only control temperature and humidity to provide thermal comfort, they also distribute adequate amounts of air to occupants and remove pollutants. An air-conditioned room does not imply exclusion of outdoor air pollutants.

Norback et al. (1990) studied the relationship between volatile organic compounds (VOCs), respirable dust, and personal factors to prevalence and incidence of sick building syndrome (SBS) in six primary schools.

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Average CO_2 concentrations were above 800 µl/l in all schools, such high levels indicated inadequate ventilation. VOC concentrations were relatively high at high temperatures, and the concentration of respirable dust was found to be higher at classrooms with low ventilation rates and high humidity. A relationship between concentration of respirable dust and eye irritation was also found. A linear correlation between indoor relative humidity and absenteeism was found in twelve schools in Canada (Green, 1975). A 20% reduction in absenteeism was observed when the indoor relative humidity was increased from 22 to 35%. The reduction in absenteeism is due to the reduction in survival rate of airborne micro-organisms at the elevated relative humidity. Air quality measurement for total volatile organic compounds (TVOC) and CO_2 at 185 schools in Sweden were carried out by Gusten and Strindehag, (1995). The study revealed that outdoor contamination sources 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 indoor air quality is the extent of human activities (number of students, length of lessons, breaks) in the premises. The difference between the indoor air TVOC level and the supply air TVOC level when correlated with CO_2 levels showed that human activity was the major contribution of TVOC to the classrooms. Three case studies of contaminated indoor air in school buildings were studied by Godish (1996). One of the cases involved mould infestation of classroom furnishings and materials. Upper respiratory problems and asthma-like symptoms were reported by students and staff. In another case, elevated indoor levels of formaldehyde were found due to emissions from pressed wood desks and shelving units. The third case involved mould infestation of a high school building. The cause of the infestation was due to moisture. Poor outdoor air quality and noise prompted schools in 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 in naturally ventilated classrooms in Hong Kong.

The Hong Kong Air Quality Objectives (HKAQO) and Interim Indoor Air Quality Guidelines (HKIAQ) (Pang, 1994) for pollutants relevant to this study are listed in Table 1. The American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) Standard 62-1989 (ASHRAE, 1989) is used for comparison of CO_2 levels measured.

The objectives of this paper are to characterise the concentrations of different indoor air pollutants at schools in Hong Kong, to compare the measured concentrations with relevant standards, and to suggest ways to reduce the exposure of school children to undesirable pollutants.

2. Method

2.1. Site description

Indoor and outdoor samples were obtained from five classrooms at different schools in Hong Kong. The five schools were TC, SF, MFS, MFC, and SJ. Selection was based on the location of the school (residential, industrial and rural areas). A five-day indoor and outdoor air quality investigation at each school were carried out from November 97 to January 98. TC is located at an urban area with major traffic roads surrounding the school building. The classroom had double-glazed windows for excluding noise and was equipped with two window-type air-conditioners and five exhaust fans for ventilation purposes. SF is located in an urban residential area and the classroom was air conditioned by a water cooling tower. Classrooms at MFS, MFC, and SJ were ceiling fans ventialted. MFS is located in a rural area with light industrial area nearby, MFC is located

Table 1
The Hong Kong Interim Indoor Air Quality Guidelines and Hong Kong Air Quality Objectives

Pollutants	Hong Kong Air Quality Objectives	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		1000 CFU/m^3 (1-h average)

Table 2
Detailed sampling parameters at each school

	TC	SF	MFS	MFC	SJ
Area	Urban	Urban	Rural	Industrial	Residential
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
Mode of ventilation	Window type air conditioning	Water cooling tower	Ceiling fan	Ceiling fan	Ceiling fan

on a hillside near a light industrial area, and SJ is located in a residential area. Details of each sampling site and site specific parameters are listed in Table 2.

2.2. Sampling and analysis

Pollutants and parameters of interest were carbon dioxide (CO_2), temperature, relative humidity (RH), formaldehyde (HCHO), respirable particulate matter (PM_{10}), total bacteria and primary air pollutants such as sulphur dioxide (SO_2), nitric oxide (NO), nitrogen dioxide (NO_2). Sampling equipment were placed at 1.5 m above floor level at indoor and outdoor locations. A Q-Trak IAQ monitor (TSI, model 8551) was used for CO_2, temperature, and RH measurements. A SKC formaldehyde monitoring kit was used for formaldehyde measurements. Indoor and outdoor PM_{10} levels were measured using a Dust Trak (TSI). 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 with one field blank per batch of sample. Tedlar air sampling bags and a portable sampling pump (Airchek sampler, model 224-43XR) at 1 ml/min were used for grab 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 Analyser while NO_x (NO+NO_2) were analysed by a Thermo Electron (model 42) chemiluminescence NO_x Analyser. Carbon dioxide, temperature, RH, and PM_{10} were continuously monitored. Formaldehyde samples were collected for 24-h periods, and SO_2, NO_x, and bacteria levels were measured before and after school hours. Duplicate samples for formaldehyde and bacteria were made. Field blanks for formaldehyde and bacteria were brought to the sampling sites to ensure no contamination during sample handling and transportation. Equipment for measuring air bag samples is daily calibrated, and the Q-Trak and Dust Trak were calibrated according to manufacture specifications. The indoor and outdoor averages of CO_2, temperature, RH, and PM_{10} levels were calculated using the data when the classrooms were occupied.

3. Results and discussion

Fig. 1 shows the indoor and outdoor PM_{10} levels measured at the five classrooms. Both the indoor and outdoor average PM_{10} levels at MFS exceeded the 24-h PM_{10} HKAQO and all the average PM_{10} levels at the five schools were above the annual standard. PM_{10} levels measured at the five classrooms ranged from 21–617 μg/m^3. High level of PM_{10} in HK is mainly caused by vehicle exhaust emissions; other sources might come from industrial processes or construction activities. The high outdoor PM_{10} level at MFS was caused by the heavy trucks travelling within the vicinity and affected the indoor level as well. TC and SF have air-conditioning classrooms. PM_{10} produced by traffic outside TC was restrained from the indoors. The indoor and outdoor PM_{10} concentrations measured at SF were similar, but since the outdoor measurement was obtained on the roof of the building, the PM_{10} level might be underestimated. High outdoor PM_{10} concentration at SJ might originate from construction activities within the school campus that affected the indoor PM_{10} level. Since

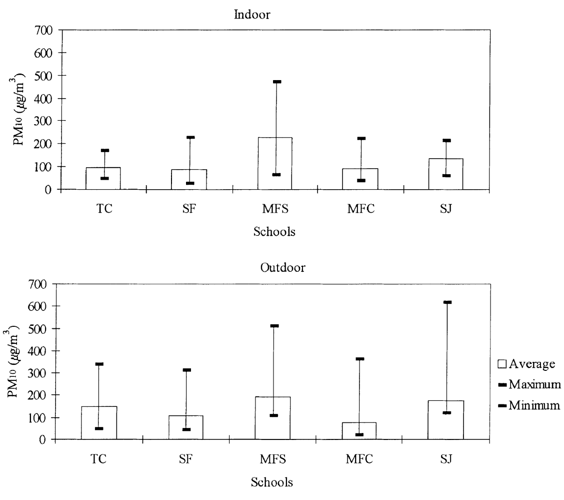

Fig. 1. Indoor and outdoor PM_{10} levels at the five classrooms (HKIAQ, HKAQO 180 μg/m^3).

particulate matter is inevitably present at high levels in HK, the use of air cleaners to reduce indoor PM_{10} levels could be feasible way of mitigation.

Average indoor CO_2 levels at the two air-conditioned classrooms (TC and SF) exceeded the ASHRAE CO_2 standard, but other average indoor and outdoor concentrations complied with the standard (Fig. 2). All maximum indoor CO_2 levels at the five classrooms were higher than 1000 μl/l and the highest CO_2 concentration was recorded at SF reached 5900 μl/l. Closing of windows, doors, and the air-conditioning system during school hours caused the high level of CO_2 in SF. Overcrowded classrooms could also be the reason for CO_2 levels close to 1000 μl/l. The maximum occupancy in classroom environment that was recommended by the ASHRAE Standard 62–1989 is 50 person/100 m^2. The occupancy at the five classrooms was 65, 85, 83, 45, and 74 for TC, SF, MFS, MFC and SJ respectively. The classrooms exceeded the Standard except for MFC. The effect of metabolic emission accumulation was further demonstrated in the air-conditioned classrooms. TC and SF had higher indoor CO_2 levels than classrooms without (MFS, MFC and SJ).

Fig. 3 shows the variation of indoor and outdoor CO_2 concentrations on a typical sampling day at TC (air-conditioned) and MFS (naturally ventilated). For TC, note that the outdoor CO_2 level was relatively constant, but a few peaks were observed due to traffic emissions or other sources; while the indoor level was influenced by human occupancy. Carbon dioxide build-up began when students start occupying the classroom, and reached a maximum of 1600 μl/l at 8:20 am. The CO_2 concentration remained high until the morning break. CO_2 levels declined during the morning break and increased when the classroom was again occupied.

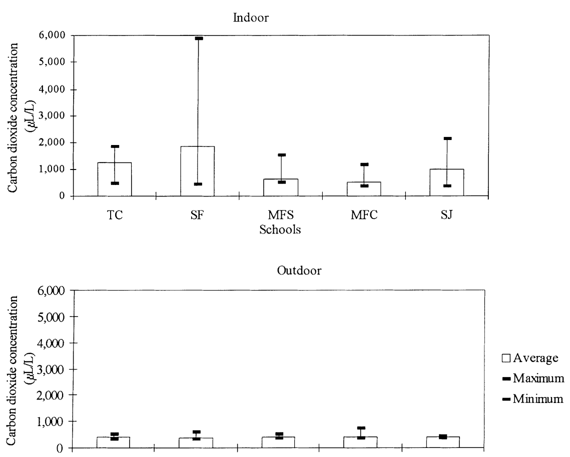

Fig. 2. Indoor and outdoor CO_2 levels at the five classrooms (ASHRAE standard 1000 μl/l).

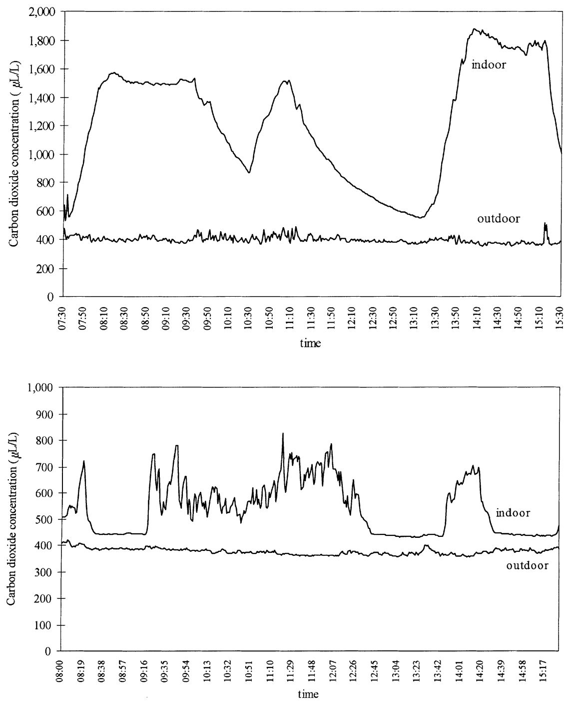

Fig. 3. Typical indoor variation of carbon dioxide and the respective outdoor carbon dioxide levels at TC and MFS.

Increase and decrease of CO_2 concentrations were observed during lunch break, but a higher saturation level of CO_2 was observed. Rapid saturation of CO_2 concentration was observed in other TC measurements. The ceiling fan ventilated classroom (MFS) showed CO_2 variation unlike those of TC. CO_2 did not reach a "saturation level", but fluctuated between 500 and 1000 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 am corresponded to students entering the classroom before school starts. Similar variations in CO_2 level related to usage of classrooms were observed at other classrooms with similar ventilation mode. Average indoor temperature ranged from 17.2–23.2°C while the outdoor temperature ranged from 14.0 to 27.3°C. Indoor temperature suggested by ASHRAE should be 19–23°C in the winter. The indoor temperature is slightly lower than the recommended level, but temperature is difficult to control at naturally ventilated classrooms. Indoor RH varied between 55.5% and 75.1% and outdoor RH varied between 53.5% and 83.6%.

Indoor and outdoor SO_2 levels ranged from 5–16 μg/m^3, but average SO_2 levels were similar at the five classrooms. The use of low sulphur content fuels lower the ambient SO_2 levels. Average NO and NO_2 concentrations varied from 18–115 μg/m^3 and 31–67 μg/m^3 respectively. Indoor and outdoor NO concentrations varied from 1–264 μg/m^3 and 1–366 μg/m^3 respectively while indoor and outdoor NO_2, levels varied from 12–176 μg/m^3 and 19–244 μg/m^3 respectively. Average NO_2 concentrations at the five classrooms were below the HKIAQ.

The HKIAQ guideline for NO_2 was exceeded on a few occasions and the outdoor concentration even reached 244 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 below the HKIAQ guideline. Since there was no apparent source of formaldehyde in furnishings at the five classrooms, low levels of HCHO were measured. Average biological counts were below the HKIAQ level of 1000 CFU/m^3, but some outdoor samples had total bacterial counts exceeding 800 CFU/m^3. Indoor bacteria samples had lower concentrations than outdoors.

4. Conclusion

The major problem in regard to classroom air quality in Hong Kong was particulate matter. The indoor and outdoor average PM_{10} concentrations exceeded the indoor and outdoor standards. The highest PM_{10} level even reached 617 μg/m^3, which was more than three times the 24-h average standard. Indoor CO_2 concentrations exceeded the ASHRAE standard due to overcrowded classrooms and inadequate ventilation. Implementation of more breaks and recesses between classes might alleviate the high level of CO_2. The occupancy of classrooms in Hong Kong often exceeded the maximum occupancy of the ASHRAE 62-1989 standard. Decreasing the number of students in each classroom can also lower the CO_2 level. Increase the rate of ventilation could remove the accumulated CO_2; for example, the use of ceiling fans, exhaust fans could increase the exchange of indoor air with the outdoor. HCHO levels were substantially lower than the HKIAQ standard since there were no apparent sources indoors and classroom furnishings have small contribution.

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