Short Communication

Indoor Air Quality Investigations at Five Classrooms

S. C. Lee* and Maureen Chang

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 (CO₂), sulphur dioxide (SO₂), nitric oxide (NO), nitrogen dioxide (NO₂), particulate matter with diameter less than 10 µm (PM₁₀), 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 PM₁₀ concentrations exceeded the Hong Kong standards, and the maximum indoor PM₁₀ level was even at 472 µg/m³. Air cleaners could be used in classrooms to reduce the high PM₁₀ concentration. Indoor CO₂ concentrations often exceeded 1,000 µl/l indicating inadequate ventilation. Lowering the occupancy and increasing breaks between classes could alleviate the high CO₂ concentrations. Though the maximum indoor CO₂ level reached 5,900 µl/l during class at one of the sites, CO₂ concentrations were still at levels that pose no health threats.

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

Received 23 September 1998. Accepted for publication 9 March 1999.

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-
mised interferences with normal school activities. Class­
rooms 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 PM10 level of 99 µg/m3 at TC in
1988. The classroom at TC had double-glazed windows
with two window type air-conditioners and five ex­
hust fans. SF is situated in an urban residential area;
cooling tower conditions the air inside the classroom.
Classrooms at MFS, MFC, and SJ were naturally venti­
lated. MFS is located in a rural area with an industrial
area nearby, MFC is located on a hillside near a resi­
dential/industrial area, and SJ is located in a residen­
tial area. Details of each sampling site are listed in
Table 1.

### Sampling and Analysis

Pollutants and parameters of interest were carbon
dioxide (CO2), temperature, relative humidity (RH),
formaldehyde (HCHO), particulate matter with diam­
eter less than 10 μm (PM10), bacteria, sulphur dioxide
(SO2), nitric oxide (NO), and nitrogen dioxide (NO2).
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 CO2, temperature,
and humidity measurements. The Q-TRAK uses a non­
dispersive infrared sensor for measuring CO2 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
PM10 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. SO2 were
analysed by a Thermo Electron (model 43B) Pulsed
Fluorescence SO2 Analyzer (Thermo Environmental In­
struments, Inc., Franklin, MA, USA) while NOx (NO,
NO2) were analysed by a Thermo (SKC Model 42)
Chemiluminescence NOx Analyzer (Thermo Environ­
mental Instruments, Inc.). Carbon dioxide, tempera­
ture, humidity, and PM10 were continuously moni­
tored. SO2, NOx, and bacteria levels were measured be­
fore 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 1 Detail parameters at each classroom

<table>
<thead>
<tr>
<th></th>
<th>TC</th>
<th>SF</th>
<th>MFS</th>
<th>MFC</th>
<th>SJ</th>
</tr>
</thead>
<tbody>
<tr>
<td>Floor area (m²)</td>
<td>60.8</td>
<td>46.9</td>
<td>48.3</td>
<td>83.7</td>
<td>52.5</td>
</tr>
<tr>
<td>Room volume (m³)</td>
<td>216</td>
<td>160</td>
<td>140</td>
<td>285</td>
<td>205</td>
</tr>
<tr>
<td>Indoor sampling floor</td>
<td>~42</td>
<td>~40</td>
<td>~40</td>
<td>~38</td>
<td>~39</td>
</tr>
<tr>
<td>Number of students occupying classroom</td>
<td>~7</td>
<td>~7</td>
<td>~7</td>
<td>~5</td>
<td>~2</td>
</tr>
<tr>
<td>Number of hours occupied per day (hr)</td>
<td>-40</td>
<td>2</td>
<td>-7</td>
<td>-38</td>
<td>-39</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Pollutants</th>
<th>Hong Kong Air Quality Objective</th>
<th>Hong Kong Interim Indoor Air Quality Guidelines</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sulphur dioxide</td>
<td>800 µg/m³ (1-h average)</td>
<td>350 µg/m³ (24-h average)</td>
</tr>
<tr>
<td></td>
<td>80 µg/m³ (annual average)</td>
<td></td>
</tr>
<tr>
<td>Nitrogen dioxide</td>
<td>300 µg/m³ (1-h average)</td>
<td>150 µg/m³ (24-h average)</td>
</tr>
<tr>
<td></td>
<td>80 µg/m³ (annual average)</td>
<td></td>
</tr>
<tr>
<td>Particulate matters with diameter less than 10 μm</td>
<td>180 µg/m³ (24-h average)</td>
<td>35 µg/m³ (annual average)</td>
</tr>
<tr>
<td>Formaldehyde</td>
<td>100 µg/m³ (1-h average)</td>
<td></td>
</tr>
<tr>
<td>Microbial/Biological Contaminants</td>
<td>1,000 CFU/m³ (1-h average)</td>
<td></td>
</tr>
</tbody>
</table>
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 CO₂ of 1,000 µl/l was used for comparison. The indoor and outdoor averages of CO₂, temperature, humidity, and PM₁₀ levels were calculated using the data when the classrooms were occupied.

Results and Discussion

Figure 1 shows the indoor and outdoor PM₁₀ levels measured at the five schools. PM₁₀ levels measured at the five schools ranged from 21 to 617 µg/m³. The indoor and outdoor average PM₁₀ levels at MFS exceeded the 24-h PM₁₀ HKAQO. High PM₁₀ 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. PM₁₀ produced by traffic outside TC was somehow restrained from entering the indoor. The indoor and outdoor PM₁₀ concentrations measured at SF were similar, but since outdoor measurements were obtained on the roof, the outdoor PM₁₀ level could be underestimated. High outdoor PM₁₀ 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 PM₁₀ levels.

Indoor average CO₂ levels at TC and SF had CO₂ levels above the ASHRAE standard. Figure 2. The highest CO₂ concentration recorded at SF even reached 5,900 µl/l (the instrument’s maximum detection limit). High levels of CO₂ 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 CO₂ level. In general, air-conditioned classrooms had higher indoor CO₂ levels (average above 1,000 µl/l) when occupied compared with ceiling fans ventilated classrooms (average below

Fig. 1 Comparison of indoor and outdoor PM₁₀ levels at the five schools (HKIAQ, HKAQO 180 µg/m³)
1,000 µl/l). This result was comparable with those by Norback et al. (1990) where average CO₂ levels were above 800 µl/l.

Figure 3 shows the variation of indoor CO₂ concentrations on a typical sampling day at TC and MFS. A strong correlation of CO₂ 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 CO₂ concentration remained high until the morning break. Rapid increase and saturation of CO₂ concentration was observed in all TC measurements. The MFS classroom showed CO₂ concentration profiles unlike TC. CO₂ did not reach a “saturation level”, but fluctuated between 500 and 1,000 µl/l. CO₂ concentrations remained low when the classroom was unoccupied during lunch break, and after school. The morning CO₂ peak at about 8:00 a.m. corresponded to students entering the classroom. Similar variations in CO₂ 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 average indoor and outdoor RH values were similar and within normal ranges.

Indoor and outdoor SO₂ levels ranged from 5 to 16 µg/m³, but average SO₂ levels were similar at the five schools. Average NO and NO₂ concentrations varied from 21–133 µg/m³ and 38–81 µg/m³, respectively. Indoor and outdoor NO concentrations varied from 1–304 µg/m³ and 1–422 µg/m³, respectively while indoor and outdoor NO₂ levels varied from 15–213 µg/m³ and 23–295 µg/m³, respectively. Average NO₂ concentrations at the five schools complied with the HKIAQ (80 µg/m³), except for the MFS outdoor average (81 µg/m³). The HKIAQ guideline for NO₂ was exceeded on a few occasions and the outdoor concentration even reached 195 µg/m³ at TC. This high NO₂ concentration was caused by vehicular exhaust emissions from nearby traffics. Formaldehyde concentrations ranged from undetectable to 27 µg/m³ 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/m³, but some outdoor samples had total bacterial counts exceeding 800 CFU/m³. Indoor bacteria samples had lower concentrations than the outdoors.

Conclusion

The major problem concerning classroom air quality in Hong Kong identified from this study was high dust concentrations. The indoor and outdoor average PM₁₀ concentrations exceeded the respective indoor and outdoor standards. The highest PM₁₀ level was even at 617 µg/m³, it was three times higher than the 24-h average standard. Though CO₂ levels measured in this study did not pose health threat, the indoor CO₂ concentrations exceeded the ASHRAE standard due to overcrowded classrooms and inadequate ventilation. Maximum indoor CO₂ level was as high as 5,900 µL/L during class and the variation of CO₂ 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 CO₂. Increase the rate of ventilation could also remove the accumulated CO₂; 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 SO₂, NO₂, 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.

Acknowledgements
This project is sponsored by Research Projects, the Hong Kong Polytechnic University. The authors would like to thank Mr. W. F. Tam and Mr. W. S. Lam for technical support in the laboratory. The support from all the Principals, staff, and students at the five schools are also appreciated.

References

Pang, S.W. (1994) “Interim Indoor Air Quality Guidelines for Hong Kong”, Environmental Protection Department, Hong Kong.