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Inter-comparison of air pollutant concentrations in different indoor environments in Hong Kong

Shun-Cheng Lee*, Hai Guo, Wai-Ming Li, Lo-Yin Chan

Research Centre for Urban Environmental Technology and Management, Department of Civil and Structural Engineering, The Hong Kong Polytechnic University, Hung Hum, Kowloon, Hong Kong

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Abstract

Indoor air quality in selected indoor environments in Hong Kong such as homes, offices, schools, shopping malls and restaurants were investigated. Average CO_2 levels and total bacteria counts in air-conditioned classrooms, shopping malls and restaurants were comparatively higher than those measured in occupied offices and homes. Elevated CO_2 levels exceeding 1000 ppm and total bacteria counts resulted from high occupancy combined with inadequate ventilation. Average PM_{10} levels were usually higher indoors than outdoors in homes, shopping malls and restaurants. The highest indoor PM_{10} levels were observed at investigated restaurants due to the presence of cigarette smoking and extensive use of gas stoves for cooking. The restaurants and shopping malls investigated had higher formaldehyde levels than other indoor environments when building material, smoking and internal renovation work were present. Volatile organic compounds (VOCs) in both indoor and outdoor environments mainly resulted from vehicle exhaust emissions. It was observed that interior decoration work and the use of industrial solvents in an indoor environment could significantly increase the indoor levels of VOCs. © 2002 Published by Elsevier Science Ltd.

Keywords: Indoor air quality; Carbon dioxide; PM_{10}; Formaldehyde; Total bacteria counts; VOCs

1. Introduction

During the past several decades, indoor air pollution has become a public health concern. Hundreds of outbreaks of illness among occupants of new or recently remodeled offices, schools, and other public access buildings have been reported (Godish, 1989). In Hong Kong, the Environmental Protection Department commissioned an indoor air quality investigation collecting data from offices and public places in 1997. The result indicated that many local offices and public buildings had serious problems of indoor air quality (HKEPD, 1999). The characterization of building-related health complaints as being due to a sick building implies that the chemicals in indoor air are one of the sources which cause indoor air quality and occupant illness problems (Fellin and Otson, 1994).

Numerous studies and reviews were published regarding various aspects of indoor air quality (Godish, 1989; Samet and Spengler, 1991; Berglund et al., 1992; Knoppel and Wolkoff, 1992). For example, the US EPA carried out a Total Exposure Assessment Methodology (TEAM) study (Pellizzari et al., 1985a, b, c; Wallace et al., 1984; Wallace, 1986). The main finding in the TEAM study was that residential indoor air concentrations significantly exceeded outdoor air concentrations for all of the prevalent volatile organic compounds (VOCs). Traynor et al. (1986) found that indoor concentrations of respirable suspended particles (RSP) were significantly elevated at homes during the use of wood-burning stoves. Stock (1987) investigated the indoor air quality inside 43 conventional houses and reported that the concentrations of formaldehyde

*Corresponding author. Tel.: +852-2766-6011; fax: +852-2334-6389.

E-mail address: ceslee@polyu.edu.hk (S.-C. Lee).

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ranged from 0.03 to 0.18 ppm, with a geometric mean of 0.07 ppm. Elevated indoor levels of RSP, CO, formaldehyde and VOCs were observed at restaurants (Benfenati et al., 1998; Shields et al., 1995; Baek et al., 1997; Zhang and Kirk, 1999; To et al., 2000).

There are many sources of indoor air pollution including various outdoor sources, cooking, smoking, building materials and furnishings, heaters and office equipment. The sources vary depending on the type of building studied. Hong Kong is a metropolitan city with high population and vehicle density over the territory (Lee, 1997; Census and Statistics Department, 1999). Many residences, shopping malls, restaurants and schools are situated in heavy traffic environments (Li et al., 2001; Lee et al., 2001, 2002). The indoor air quality of these places is closely associated with the outdoor air that is often contaminated by automobile exhausts. Previous studies have indicated that concentrations of air pollutants were substantially higher indoors than outdoors (Spengler et al., 1979, 1981; Moschandreas et al., 1987; Palmes et al., 1977; Madany and Danish, 1992; Brown et al., 1992). Therefore, healthy indoor air quality is very crucial to people and communities.

In recent years, the economic activity of the metropolitan Hong Kong has greatly changed from production to servicing industries. The proportion of the workforce working in an office environment has a steady increase during recent decades. According to the statistical data provided by the Census and Statistics Department in 1999 (Census and Statistics Department, 1999), office workers in Hong Kong accounted for more than 30% of the workforce. About 40% of the Hong Kong citizens are children who spend most of their time studying at school. Furthermore, Hong Kong is one of the most popular food and shopping paradises in Asian countries (Li et al, 2001; Lee et al., 2001). On a daily basis, many local and foreign people enjoy spending some time in a shopping mall or trying out different kinds of restaurants. Therefore, it is very important to occupants of buildings that the air quality in these indoor environments should remain healthy and comfortable. Although the Hong Kong Government benefited from the growth in the service sector, it now faces a new challenge caused by the occurrence of indoor air pollution in local offices and public buildings. In Hong Kong, there are few studies intended to characterize and compare indoor levels of air pollutants identified in different indoor environments. Little data are available on the general understanding of indoor air quality. Therefore, the aims of this study are to determine and inter-compare concentrations of air pollutants in different indoor environments, and to compare the results with health related Hong Kong indoor air quality objective (HKIAQO) that are currently used in Hong Kong for IAQ management (HKEPD, 1999). The indoor air quality objectives for office buildings and public places in Hong Kong are presented in Table 1.

Table 1
Indoor air quality objectives for office buildings and public places in Hong Kong (draft) (HKEPD, 1999)

Air parameter	Unit	8-h average based	
		Level I	Level II
Carbon dioxide (CO_2)	ppm	<800	<1000
Carbon monoxide (CO)	μg/m^3	<2000	<10000
Respirable suspended particles (PM_{10})	μg/m^3	<50	<180
Nitrogen dioxide (NO_2)	μg/m^3	<40	<150
Ozone (O_3)	μg/m^3	<50	<120
Formaldehyde (HCHO)	μg/m^3	<30	<100
Total volatile organic compounds (TVOC)	μg/m^3	<600	<3000
Radon	Bq/m^3	<150	<200
Airborne bacteria	CFU/m^3	<500	<1000
Room temperature	°C	20–25.5	<25.5
Relative humidity	%	40–70	<70
Air movement	m/s	<0.2	<0.3

2. Methodology

2.1. Field study

Indoor air quality investigation was conducted to characterize the air quality of selected indoor environments in Hong Kong. Thirty-nine sites were selected from different local areas. Four restaurants, 10 schools, 10 commercial offices, nine shopping malls and six residential flats were investigated for their existing indoor and outdoor air quality.

2.1.1. Home

Six homes in Hong Kong were selected for this study. General description of these homes was given in Table 2.

Except for Home 2, which is adjacent to a heavily trafficked road, other homes are flats on different floors of multi-story residential buildings.

2.1.2. Office

A total of 10 offices in Hong Kong were selected. General descriptions of the offices were given in Table 3.

These offices have sealed with windows and are ventilated using mechanical ventilation and air-conditioning (MVAC) systems. All offices are located in the busy commercial districts with heavy traffic. The offices

Table 2
General comparison of homes investigated in this study

Site No.	Location	Home type	No. of occupants	Smoking	Cooker fuel type	Frequency of house cleaning
Home 1	Kwun Tong	Public	3	Yes	Town gas	Infrequent
Home 2	Jordon	Private	7	Yes	LPG gas	Infrequent
Home 3	Shatin	Public	3	No	LPG gas	Weekly
Home 4	Lam Tin	Private	5	No	Town gas	Daily
Home 5	Wong Tai Sin	Public	5	Yes	LPG gas	Infrequent
Home 6	Siu Sai Wan	Private	4	No	Town gas	Daily

LPG: liquefied petroleum gas; Town gas: natural gas.

Table 3
General comparison of offices investigated in this study

Site No.	Site location	No. of occupancy	Floor	Floor area (m^2)	Volume (m^3)
Office 1	Central	30	25th	135	405
Office 2	Central	7	22nd	110	385
Office 3	Central	11	18th	121	375.1
Office 4	Central	6	13th	83	257.3
Office 5	Central	1	35th	18	3.2
Office 6	Hung Hom	1	7th	10.5	2.8
Office 7	Hung Hom	1	7th	10.5	2.8
Office 8	Hung Hom	1	7th	10.5	2.8
Office 9	Hung Hom	5	7th	10.5	2.8
Office 10	Wanchai	15	4th	87	3.2

are occupied during air monitoring. Anti-smoking policy was implemented in these monitoring sites.

2.1.3. School

Indoor and outdoor air samples were collected from 10 schools in Hong Kong. Seven of the schools (schools 1–5, 7 and 8) are primary schools for student whose age ranges from 5 to 13 years old. Three other schools are kindergartens for children with a range of ages from 2.5 to 5 years old. Two classrooms with different types of ventilation were selected in each of the schools and the kindergartens. One classroom is ventilated with sealed windows and window-type air conditioners with exhaust fans. The other is only ventilated with opening ceiling fans, door and windows. Seven of the surveyed schools (schools 2–4 and schools 7–10) are located in residential areas. The rest are situated in mixed urban and industrial areas near traffic roads where there are many vehicles idling with running engines. Three busy roads on which there are many buses and trucks travelling are situated near school 5. General descriptions of the 10 schools are given in Table 4.

2.1.4. Shopping mall

Nine comparatively large-scaled and popular shopping malls in Hong Kong with high occupancy density were selected for this survey. Air sampling works were conducted on both weekdays and weekends. Nine shopping malls were located in different geographical areas of Hong Kong. These monitoring sites were located in major commercial and residential districts where population and vehicle densities were relatively high in Hong Kong. Six of them were the biggest retail malls and the remaining shopping centers were very popular meeting places for young people as they contained a variety of trendy products, updating video, audio electrical facilities and compact discs. All major entrances of selected shopping malls were located on street levels and left opened onto nearby traffic roads, providing direct access both to shoppers and outdoor air. All shopping malls were multi-storied and ventilated with central air-conditioning systems. General comparisons of the nine shopping malls are listed in Table 5.

2.1.5. Restaurant

Four restaurants were selected in order to investigate their indoor air quality. These included a Korean barbecuing restaurant, a Chinese hot-pot restaurant, a Chinese dim sum restaurant and a Western canteen. All these restaurants were ventilated using central air-conditioning systems. In addition, these restaurants were located in urban areas with busy traffic. All of

Table 4
General comparison of schools investigated in this study

Site No.	Site location	No. of occupants	Ventilation condition	Floor	Floor area (m^2)	Volume (m^3)
School 1	Shau Kei Wan	41	With AC	4th	46.9	258
		40	Without AC	4th	46.9	258
School 2	Yuen Long	42	With AC	5th	52.5	263
		41	With AC	3rd	52.5	263
School 3	Tai Wai	35	With AC	4th	52.5	242
		35	Without AC	4th	52.5	242
School 4	Tuen Mun	35	With AC	4th	47	216
		35	With AC	3rd	47	216
School 5	Kowloon City	38	With AC	3rd	48	216
		38	Without AC	3rd	48	216
School 6	Prince Edward	30	With AC	6th	51	218
		30	Without AC	6th	51	218
School 7	Tseung Kwan O	30	With AC	3rd	48.3	217
School 8	Yuk Yuen	37	With AC	4th	46.9	217
School 9	North point	20	With AC	2nd	52.5	147
School 10	Kowloon Tong	20	With AC	2nd	48	147

Table 5
General comparisons of shopping malls investigated in this study

Site No.	Year of opening	Average area of each floor (m^2)	Average No. of shops on each floor	Type of land use	Traffic condition	Car-park, entertainment and public transport facilities
SM1	1998	9587	43	R/C	Moderate	Underground car-park, internal public bus station, ice-skating rink, cinema, food court, restaurant and bar
SM2	1986	1059	50	R/C	Very high	Food court
SM3	1989	12,077	40	R	High	Cinema, food court
SM4	1990	1226	20	I/R	High	Attached car-park
SM5	1989	13,563	42	R/C	Moderate	Internal enclosed car-park, ice-skating rink, cinema, food court, restaurant
SM6	1999	1514	26	R	Moderate	Attached car-park, food court
SM7	1983	2666	25	C	High	Food court, cinema
SM8	1984	1375	32	R/C	Very high	Nil
SM9	1995	3196	20	C	Very high	Internal enclosed car-park, cinema, food court

R: residential; C: commercial; I: industrial.

the restaurants were occupied during the periods of air sampling. General characteristics of these four restaurants are listed in Table 6.

2.2. Sampling and analysis

2.2.1. Air pollutants

The air pollutants investigated in this study included: carbon dioxide (CO_2), volatile organic compounds (VOCs), formaldehyde (HCHO), total bacteria (TBC), and respirable suspended particles (RSP, aerodynamic diameters $<10\,\mu m$).

A portable Q-Trak monitor (model 8551, TSI Inc., MN, USA) was used to monitor the indoor and outdoor CO_2 concentrations. A Dust-Trak air monitor (model 8520,TSI Inc., MN, USA) was used to measure PM_{10} concentrations in both indoor and outdoor air, respectively. The Dust monitor measured PM_{10} at 1 min intervals at a flow rate of 1.7 l/min.

Indoor and outdoor formaldehyde samples were collected using a SKC formaldehyde monitoring kit.

Table 6
General characteristics of restaurants investigated in this study

Parameter	Rest 1	Rest 2	Rest 3	Rest 4
Type of restaurant	Korean barbecue	Chinese hot-pot	Chinese dim sum	Western cafeteria
Average area of each floor (m^2)	210	590	250	320
No. of food service workers	10	30	11	14
Maximum No. of seats accommodated	70	120	100	85
Land uses	Commercial urban area	Commercial urban area	Commercial urban area	Commercial urban area
Traffic density	High	High	High	High
Use of cooking oil	Peanut oil	Peanut oil	Peanut oil	Peanut oil
Type of gas stove	Liquefied petroleum gas	Liquefied petroleum gas	Natural gas	Natural gas
Cooking method	Frying food in oil on a hot frying pan in its dining area	Boiling food in soup inside a hot-pot in its dining area	Steaming dim sum meal in a fixed food court in its dining area	Food prepared in kitchen and no combustion sources present in its dining area

Please refer to our previous papers for detailed information (Lee et al., 2001, 2002; Li et al., 2001).

A Burkard single stage impactor (Burkard Manufacturing Co. Ltd., Hertfordshire, England) with an agar plate was used to sample the airborne bacteria. Plate count agar was used as nutrient media. The bacteria samples were taken at 10 ml/min for 9 min. The bacteria samples were incubated at 35°C for 2 days for total bacteria counts in an oven. The colonies of bacteria were counted under a light microscope.

For VOC sampling, a batch of clean canisters for sample collection was evacuated before sampling. Time integrated VOC air samples were obtained using mass flow controllers (model FC4101CV-G, Autoflow Inc., CA) at flow rates of 0.093 l/min for 1 h and 0.012 l/min for 8-h air sampling. Canister samples for VOCs were collected both indoors and outdoors. After sampling, the canisters were immediately transported to air laboratory for analysis within 3 h. Detailed description of the analysis can be found in our previous papers (Lee et al., 2001, 2002; Li et al., 2001).

2.2.2. Quality assurance and quality control

Before sampling, the Q-Trak was calibrated with standard CO_2 gas at a known concentration. Pre- and post-checking of the Dust-Trak monitor was carried out. The Dust-Trak monitor cannot directly give mass concentration of PM_{10} as it is designed to measure aerosol. Therefore, a separate calibration test was done to convert the Dust-Trak data into corresponding concentration obtained by gravimetric method. Details for calibration can be found in our previous papers (Lee et al., 2001, 2002; Li et al., 2001).

Prior to sampling, the SUMMA® canisters were cleaned for five times by sequential evacuating and pressurizing with humidified zero air. Background checks were performed on 25% of the cleaned evacuated canisters to clarify that all target compounds were <0.2 ppbv. TO-14 standard calibration gas (Toxi-Mat-14 M Certified Standard, Matheson) at 0.2 ppbv was analyzed for seven times analysis. The method detection limits can be obtained by multiplying the standard deviation of the seven replicate analyses of the GC-MS system and the *t*-test value for 99% confidence.

In order to monitor contamination during storage, transport and sample collection, replicate sampling were carried out for formaldehyde and bacteria measurements. Field blanks of formaldehyde and bacteria samples together with field samples were carried into the sampling sites but the blanks remained unopened. The bio-aerosol sampler was sterilized with isopropyl alcohol prior to sampling. After sampling, the sample agar plates was removed from the sampler and covered with lids. Also, the sample plates were kept refrigerated at 4°C and shipped back to laboratory oven for incubation. If the number of bacteria colony on the collection agar plates increases, the probability of overlapping or contact of colonies will be greatly enhanced. Therefore, the recommended upper count limits for colonies ranging from 200 to 300 CFU per plate are made provided that the colony size are assumed to be similar (ACGIH, 1994).

For formaldehyde sampling, the actual samples as well as the blank samples were refrigerated at 4°C and unexposed to sunlight during transport to air laboratory for analysis immediately. Aliphatic aldehydes can react with MBTH solution to produce colored products.

In order to minimize the interference of other aliphatic aldehyde, a separate calibration test was done to compare the results given by SKC passive formaldehyde samplers with the respective concentrations determined by active air sampling using adsorbent cartridges coated with 2,4-dinitrophenylhydrazine (2,4-DNPH).

3. Results and discussion

3.1. Carbon dioxide concentrations

The average concentrations recorded at five different indoor environments are shown in Fig. 1. The average indoor CO_2 levels in air-conditioned classrooms, shopping malls and restaurants were equal to or higher than 1000 ppm stated in the HKIAQO level II standard. Indoor CO_2 levels were found to be more variable in restaurants and shopping malls than other indoor environments. Variable and considerable human occupancy could lead to the high and changeable CO_2 levels in these buildings.

Apart from the effect of occupancy, these public buildings contained a lot of indoor sources that can generate CO_2. For example, the shopping malls contained food courts in which cooking activities and illegal smoking were usually found. In the restaurants, there were gas stoves in their dining areas for food cooking. Undoubtedly, these indoor sources could considerably increase the indoor CO_2 concentrations. The highest average CO_2 levels were as much as 2400 and 2220 ppm at the surveyed restaurants and shopping malls, respectively. In comparison, average levels of CO_2 were two times higher indoors than outdoors. Since home, office and air-conditioning classroom were always small in size, the effect of high occupancy on CO_2 concentration become more significant in the small indoor environments. This was supported by the fact that the air-conditioned classrooms that have higher occupancy density than the offices and homes resulted in average indoor CO_2 levels exceeding the HKIAQO level II standard. Furthermore, the CO_2 levels greatly varied with the students' activities inside the classrooms. The elevated CO_2 levels recorded in the air-conditioned classrooms were attributed to over-crowding conditions and insufficient fresh air supply.

Hong Kong Environmental Protection Department commissioned an 18-month consultancy study on indoor air pollution in offices and public places in October 1995 (HKEPD, 1997). Forty offices, 20 restaurants, 8 shopping malls, 5 cinemas, 2 wet markets and selected concourses/platforms of the Mass Transit Railway, were investigated. It was found that 37.5% of offices had, over an 8-h period, a mean carbon dioxide level exceeding 1000 ppm. The CO_2 concentrations ranged from 506.3 to 2369 ppm in offices and public places. This is consistent with the results obtained in this study.

3.2. Concentrations of PM_{10}

Fig. 2 illustrates that average indoor PM_{10} concentrations at domestic residences, restaurants and shopping malls were higher than the HKIAQO level II standard of 180 $\mu g/m^3$, and were two or three times higher than those measured in offices and air-conditioned classrooms. The mean PM_{10} concentrations in outdoor air ranged from 30 to 182 $\mu g/m^3$. High average outdoor levels of PM_{10} were found at the residences and the shopping malls, respectively. The increased concentrations of PM_{10} were probably related to the locations of outdoor air sampling and nearby heavy traffic roads. For air measurement in selected homes, parallel outdoor air samples were taken near to the main entrance lobbies of the residential buildings. For shopping malls, simultaneous outdoor air sampling were carried out near to the main entrances. During air measurements,

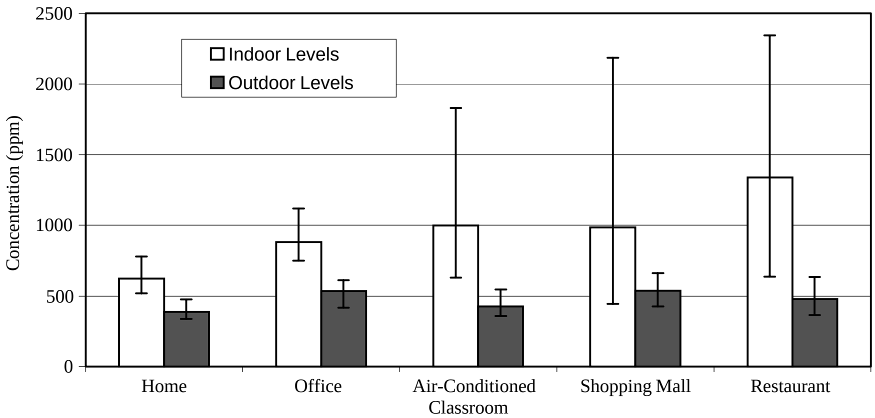

Fig. 1. Inter-comparison of CO_2 concentrations in different indoor environments.

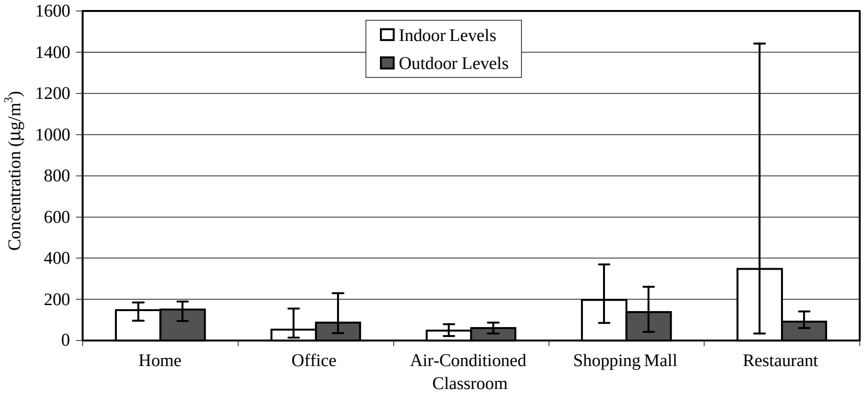

Fig. 2. Inter-comparison of PM_{10} concentrations in different indoor environments.

many people walked in and out of these buildings frequently. Therefore, re-suspension of particulate matters deposited on floor surfaces probably resulted in the elevation of PM_{10} concentrations at the entrance areas.

In Hong Kong, many offices and public buildings are ventilated with MVAC system. Today, many classrooms are installed with window-type air-conditioners and ventilated with the air conditioners and exhaust fans. RSP carried in ambient air are drawn into the office, public buildings and classrooms, and will be filtered through the filtration process of the MVAC systems. The filters of the air conditioners are used to reduce the amounts of particulate matters from entering into the classrooms. The results showed the filtration processes of the ventilation systems were effective for office and classroom environments. However, the average PM_{10} concentrations remained higher indoors than outdoors at the shopping malls and restaurants. The presence of indoor sources could contribute to the elevated levels of PM_{10} at these public buildings. In addition, although the residential households are mostly naturally ventilated with opening windows, the majority of homes selected are flats on higher floors of the residential blocks and are located away from potential outdoor sources. It was believed that the impact of RSP in ambient air on the residential households was possibly reduced. Therefore, it can be predicted that the increased PM_{10} levels measured at homes, shopping malls and restaurants were most likely related to the presence of indoor PM_{10} sources and PM_{10} generating activities such as cooking, sweeping and smoking.

3.3. Airborne bacteria

Fig. 3 illustrates indoor and outdoor average levels of bacteria recorded at homes, offices, air-conditioned classrooms, shopping malls and restaurants. The indoor bacteria levels were below the HKIAQO level II standard of 1000 CFU/m^3. However, the mean bacteria level exceeded the HKIAQO level II standard at the surveyed air-conditioned classrooms. The concentration of airborne bacteria in the air-conditioned classrooms was as high as 2220 CFU/m^3. The results showed that total bacteria counts were higher indoors than outdoors.

Shopping mall, restaurant, office and classroom are highly occupied indoor environments. The highest average occupancy density was found in the classroom environment. It indicated that the indoor environments with high occupancy density (number of occupants per unit floor area) had average indoor levels of airborne bacteria higher than the buildings with less number of occupants per unit floor area. High bacteria counts were probably due to high occupancy loading, poor hygienic condition of occupant and inadequate ventilation rates. Apart from the effect of occupancy, high total bacteria counts measured in air-conditioning classrooms were probably due to operation of window-type air-conditioning systems with closed fresh air vents. Hence, insufficient amounts of fresh air were provided to dilute the bacteria concentrations recorded at the classrooms containing sick people.

HKEPD (1997) reported that the bacteria count was higher than the recommended level of 1000 CFU/m^3 in 20% of the offices. The levels of bacteria count were between 38.67 and 4891 CFU/m^3 in offices and public places. The indoor bacteria levels were below the HKIAQO level II standard of 1000 CFU/m^3 in offices, restaurants and shopping malls in this study, while the mean bacteria counts were 1003 and 2140 CFU/m^3 at restaurants and shopping malls, respectively, in the study of HKEPD.

3.4. Concentration of VOCs

Fig. 4 shows the 8-h average levels of formaldehyde recorded at five selected indoor environments ranging

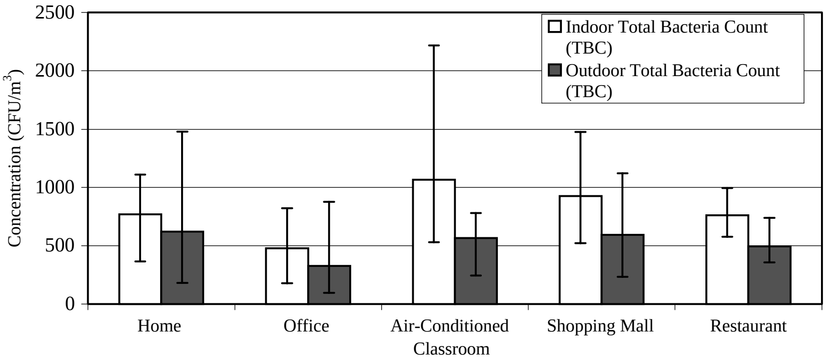

Fig. 3. Inter-comparison of TBC in different indoor environments.

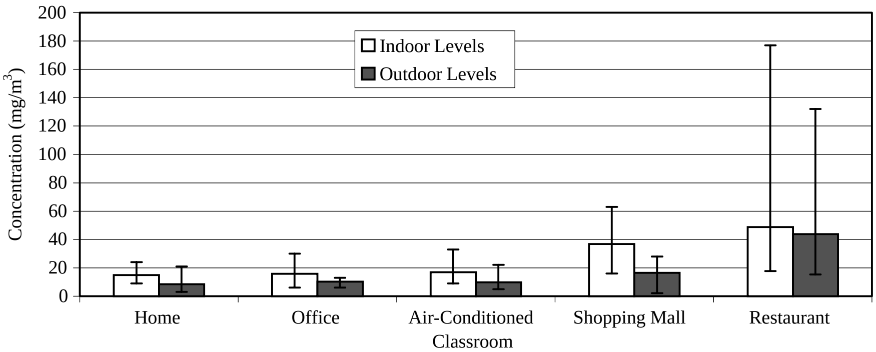

Fig. 4. Inter-comparison of HCHO concentrations in different indoor environments.

from 18 to 43 μg/m^3. The indoor levels did not exceed the HKIAQO standard of 100 μg/m^3. Furthermore, these HCHO levels were found to be higher indoors than outdoors. This reflected that formaldehyde was predominant indoors. For shopping malls and restaurants, the average indoor HCHO levels were more variable. The HKIAQO level II standard for indoor formaldehyde was exceeded on a few occasions at the investigated restaurants. In addition, the elevated formaldehyde levels in shopping malls were probably due to the emissions from pressed wood products sold by upholstery shops and painting solvents for interior construction works and illegal smoking. On the other hand, the extensive use of new pressed wood furniture and smoking in the restaurants were also likely to increase overall indoor formaldehyde levels.

In the study of HKEPD (1997), the observed HCHO concentration was as high as 975 μg/m^3 at restaurants. The mean HCHO concentrations were 162 and 139 μg/m^3 at restaurants and cinema, respectively, which exceeded the HKIAQO level II standard of 100 μg/m^3.

The most abundant and frequently found VOCs were benzene, toluene, ethylbenzene, *p*/*m*-xylene and *o*-xylene among the five different types of indoor environments. Average, minimum and maximum indoor and outdoor concentrations of these VOCs were listed in Table 7.

When comparing the indoor and outdoor levels of VOCs, shopping malls had higher indoor levels of benzene and toluene than homes, offices, air-conditioned classrooms and restaurants. Also, higher concentrations of benzene and toluene in ambient air were obtained at the shopping malls. The elevated indoor concentrations of benzene and toluene were probably due to the infiltration of outdoor air polluted by airborne benzene and toluene. On the other hand, two of the six investigated malls were being implemented internal decorative and repair works during air monitoring. The works possibly contributed to the indoor concentrations of these two organic compounds.

In addition, the average concentrations of ethylbenzene, *m*,*p*-xylene and *o*-xylene recorded at the offices were not only higher indoors than outdoors, but were more abundant than those measured in other types of indoor environments selected. One of the six offices surveyed was a small printing office that contained two bulky dry-process photocopiers. Two sets of printers with dry-process copying operation were frequently

Table 7
Inter-comparison of indoor and outdoor VOCs in different indoor environments

VOCs (μg/m^3)	Indoor					Outdoor					I/O ratios
	Max.	Min.	Med.	Mean	S.D.	Max.	Min.	Med.	Mean	S.D.	
Benzene											
Home	9.28	0.67	5.84	5.31	3.48	9.78	0.42	2.63	3.88	3.34	1.37
Office	9.26	1.63	2.34	4.02	3.28	8.09	1.76	2.63	3.89	2.66	1.03
Air-conditioned classroom	12.2	0.68	0.83	3.13	4.60	24.51	0.49	0.80	4.97	9.60	0.63
Shopping mall	22.26	1.11	9.38	9.39	7.70	24.54	3.25	4.92	8.18	8.22	1.15
Restaurant	18.30	0.10	6.81	7.17	7.18	9.46	3.25	8.04	7.54	2.29	0.95
Toluene											
Home	81.58	31.41	39.26	51.13	23.07	142.48	6.36	23.36	41.11	51.38	1.24
Office	84.90	22.37	44.01	44.29	22.60	70.01	9.42	40.58	39.56	22.06	1.12
Air-conditioned classroom	48.26	6.09	14.17	17.74	15.80	137.50	7.47	9.84	31.02	52.20	0.57
Shopping mall	221.76	18.88	68.31	96.60	83.60	184.22	20.41	53.60	69.16	61.67	1.40
Restaurant	31.48	0.15	4.26	8.46	11.75	6.63	0.45	1.53	2.33	2.36	3.63
Ethylbenzene											
Home	4.80	N.D.*	2.42	2.64	1.86	15.71	N.D.	5.35	6.22	5.77	0.42
Office	21.43	1.06	9.31	8.98	7.80	13.55	0.79	3.54	5.24	5.00	1.72
Air-conditioned classroom	17.42	1.06	1.54	4.20	6.50	62.92	0.26	0.37	10.90	25.49	0.39
Shopping mall	4.03	N.D.	0.95	1.64	1.78	1.36	N.D.	0.14	0.32	0.52	5.14
Restaurant	21.52	0.66	8.17	8.40	6.42	5.81	0.04	5.06	3.92	2.39	2.15
m,p-Xylene											
Home	10.60	2.68	4.68	5.45	2.74	42.48	6.36	23.36	12.20	3.46	0.45
Office	51.92	N.D.	8.95	13.68	19.30	12.50	0.53	3.23	5.44	5.32	2.51
Air-conditioned classroom	11.88	1.28	1.76	3.30	4.20	29.92	0.22	0.42	5.46	11.99	0.60
Shopping mall	43.03	0.70	1.14	13.56	15.72	7.70	0.40	2.77	3.65	2.73	3.71
Restaurant	24.55	0.13	7.81	8.82	8.59	11.00	2.33	6.75	6.61	4.02	1.34
o-Xylene											
Home	11.04	1.06	3.41	4.18	3.55	12.54	N.D.	3.23	3.98	4.44	1.05
Office	45.10	N.D.	13.21	49.88	16.22	9.15	1.14	2.44	4.42	3.68	11.28
Air-conditioned classroom	2.55	1.06	1.63	1.66	0.50	2.51	0.26	0.37	0.98	1.02	1.69
Shopping mall	28.38	1.10	3.19	8.81	10.81	10.60	0.84	2.11	3.75	3.79	2.35
Restaurant	4.14	1.90	2.94	3.01	1.02	9.08	1.50	2.22	3.44	2.93	0.87

* N.D.: not detected.

used, and the extensive use of personal printers was observed in other five administrative offices. Therefore, it was predicted that these three VOC species identified in the printing office were related to the operation of the printing machinery. It was possible that the higher concentrations of ethylbenzene, *m*,*p*-xylene and *o*-xylene recorded at the offices were attributable to the extensive use of office printers. Indoor concentrations of benzene, toluene, ethylbenzene and *m*,*p*-xylene were usually found to be more variable in offices, shopping malls and restaurants than in homes and air-conditioned classrooms, as indicated by the greater difference between maximum and minimum values for these organic pollutants. The mean ratios of indoor to outdoor concentrations (I/O ratio) of these five VOC species in offices, shopping malls and restaurants were greater than or close to one. These results reflected that indoor sources influenced the surveyed offices, shopping malls and restaurants. The findings in this study were similar to the results obtained by HKEPD (1997).

3.5. Percentage of compliance with HKIAQO for the air contaminants

The percentages of compliance with HKIAQO for the air contaminants in selected indoor environments are given in Table 8. For CO_2, $<47.5\%$ of air samples were well within HKIAQO level I and 54.2% within HKIAQO level II. Out of 156 air samples, 43.1% and 83.5% complied with HKIAQO level I and level II, respectively, for RSP (PM_{10}). 202 air samples were analyzed for formaldehyde (HCHO). 78.4% and 91.7%

Table 8
Percentages of compliance with 2-level Hong Kong IAQ objectives

Category of indoor environment	Air pollutant	No. air sample	HKIAQO level I standard (8-h average)		HKIAQO level II standard (8-h average)	
			Standard	Percentage (%)	Standard	Percentage (%)
Home (living room)	CO_2	18	<800 ppm	100	<1000 ppm	
	PM_{10}	18	<50 μg/m^3	0	<180 μg/m^3	>90
	HCHO	20	<30 μg/m^3	100	<100 μg/m^3	
	TBC	20	<500 cfu/m^3	>60	<1000 μg/m^3	>90
Home (Kitchen)	CO_2	18		<30		>90
	PM_{10}	18		0		>80
	HCHO	20		100		
	TBC	20		>30		50
Office	CO_2	20		20		<70
	PM_{10}	20		20		100
	HCHO	26		100		
	TBC	26		80		90
School (air-conditioned classroom)	CO_2	20		30		60
	PM_{10}	20		70		100
	HCHO	26		100		
	TBC	26		50		60
School (non-air-conditioned classroom)	CO_2	20		100		
	PM_{10}	20		50		100
	HCHO	26		100		
	TBC	26		50		80
Shopping mall (weekday)	CO_2	20		<45		>50
	PM_{10}	20		100		<45
	HCHO	28		22		100
	TBC	20		22		<45
Shopping mall (weekend)	CO_2	20		30		30
	PM_{10}	20		30		78
	HCHO	28		55		100
	TBC	20		11		22
Restaurant	CO_2	20		25		25
	PM_{10}	20		75		75
	HCHO	28		50		75
	TBC	20		50		75
Total	CO_2	156		<47.5		54.2
	PM_{10}	156		43.1		83.5
	HCHO	202		78.4		91.7
	TBC	178		>44.1		64.0

of samples were compliant with HKIAQO levels I and II, respectively. For the TBC, more than 44.1% and 64% of air samples were below the HKIAQO level I and level II, respectively.

4. Conclusion

The indoor air quality in home, office, classroom, shopping mall and restaurant were characterized. All of the investigated indoor environments had 8-h average concentrations of VOCs below the HKIAQO levels I and II. Average CO_2 levels measured in air-conditioning classrooms, shopping malls and restaurants were comparatively higher than those measured in offices and homes. The average CO_2 levels reached or exceeded the HKIAQO level II standard of 1000 ppm. It was probably due to the combined effects of high occupancy and insufficient ventilation. Eight hour average PM_{10} levels were usually higher indoors than outdoors at homes, shopping malls and restaurants. The highest PM_{10} levels were observed at restaurants and homes as tobacco smoking could generate the airborne particles. The indoor levels of PM_{10} in shopping malls were found to be higher on weekdays than on weekends. This result was due to the presence of illegal smokers and the use of gas stoves for cooking within the dining areas of the malls.

In addition, higher indoor bacteria levels were found in air-conditioned classrooms. Average indoor bacteria levels in occupied classrooms were about two to four times higher than those measured in commercial offices, respectively. High bacteria counts were probably due to high occupancy loading, poor hygienic condition of occupant and inadequate ventilation rates. Shopping malls and restaurants had higher formaldehyde levels than other indoor environments when there were presence of potential formaldehyde sources such as tobacco smoking, building materials and internal renovation works.

The effects of indoor sources of VOCs were more variable in homes, offices, shopping malls and restaurants than in air-conditioned classrooms. Interior decoration works and the use of industrial solvents in the investigated shopping malls could significantly increase the indoor levels of VOCs.

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