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Indoor air quality at nine shopping malls in Hong Kong

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Abstract

Hong Kong is one of the most attractive shopping paradises in the world. Many local people and international tourists favor to spend their time in shopping malls in Hong Kong. Good indoor air quality is, therefore, very essential to shoppers. In order to characterize the indoor air quality in shopping malls, nine shopping malls in Hong Kong were selected for this study. The indoor air pollutants included carbon dioxide (CO_2), carbon monoxide (CO), total hydrocarbons (THC), formaldehyde (HCHO), respirable particulate matter (PM_{10}) and total bacteria count (TBC). More than 40% of the shopping malls had 1-h average CO_2 levels above the 1000 ppm of the ASHRAE standard on both weekdays and weekends. Also, they had average weekday PM_{10} concentrations that exceeded the Hong Kong Indoor Air Quality Objective (HKIAQO). The highest indoor PM_{10} level at a mall was 380 $\mu g/m^3$. Of the malls surveyed, 30% had indoor airborne bacteria levels above 1000 cfu/m^3 set by the HKIAQO. The elevated indoor CO_2 and bacteria levels could result from high occupancy combined with insufficient ventilation. The increased PM_{10} levels could be probably attributed to illegal smoking inside these establishments. In comparison, the shopping malls that contained internal public transport drop-off areas, where vehicles were parked with idling engines and had major entry doors close to heavy traffic roads had higher CO and PM_{10} indoor levels. In addition, the extensive use of cooking stoves without adequate ventilation inside food courts could increase indoor CO_2, CO and PM_{10} levels. © 2001 Elsevier Science B.V. All rights reserved.

Keywords: Shopping mall; Indoor air quality; Hong Kong; Carbon dioxide; Carbon monoxide; Particulate and Total bacteria count

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1. Introduction

Hong Kong is one of the most popular shopping paradises in the world (Heung and Qu, 1998; Choi et al., 1999). Many tourists are attracted to spend their time in shopping malls during their visit to Hong Kong (Heung and Qu, 1998). Besides tourists, local people like to go to shopping malls for entertainment. Therefore, healthy indoor air quality inside a shopping mall is very important to local people and international tourists. Undoubtedly, poor indoor air quality (IAQ) will lower the perceived comfort of air quality in a shopping mall. Increased indoor CO_2 levels in excess of 1000 ppm are closely related to occupant complaints of sick-building symptoms including drowsiness, eye, nose and respiratory irritation (Molhave, 1987; Molhave et al., 1999; Liao et al., 1991). As the Hong Kong government has recognized the potential health risk and problems related to indoor air pollution which occurs in office premises and public buildings, it is striving to investigate and manage the IAQ of various indoor environments (Environmental Protection Department, 1999). A shopping mall is regarded as a type of public building in Hong Kong. Unfortunately, there are few studies that focused on the air quality in shopping malls in particular, in Hong Kong.

Hong Kong is one of the most densely populated cities in the world (Lee, 1997). According to the data given by the Hong Kong Census and Statistics Department, approximately 1000 km^2 of the land in Hong Kong accommodated more than 6.98 million people at the end of 1999 (Census and Statistics Department, 1999). Also the territory has approximately 500 000 registered vehicles travelling on roads (The Annual Traffic Census, 1998). Hence, there is high population and vehicle density over the territory. Many Hong Kong shopping arcades are located on lower floors or inside basements of high rise commercial buildings that are situated in heavy traffic environments. High traffic densities and abnormal meteorological factors adversely influence the ambient air quality of Hong Kong. Lam et al. (1999) identified that nitrogen dioxide and suspended particulates are the most common and serious air pollutants in many traffic areas in Hong Kong. As fresh air supplied to the shopping malls comes from outdoors, the IAQ of the malls will be closely associated with the outdoor air that is often contaminated by automobile exhausts.

In addition to the air infiltration from outdoor air pollutants, there are several potential indoor sources that can generate air pollutants inside the shopping malls. In order to meet different needs of customers, shopping malls usually offer dining and entertainment facilities, such as department stores, supermarkets, food courts, cinemas and ice-skating rinks, in addition to boutiques. As there are numerous potential indoor sources of air pollutants, the investigation of indoor air pollutants at shopping malls becomes more complex. For instance, elevated levels of CO in ice skating rinks had been observed (Spendler et al., 1978; Brauer et al., 1993; Lee et al., 1994). Exhausted gases released from ice-resurfacing equipment with combustion engines could result in significant quantities of indoor air pollutants if inadequate ventilation occurs in an ice-skating rink (Yoon et al., 1996). Some indoor activities such as cooking and smoking inside the catering and shopping zones of a shopping mall can increase indoor CO and PM_{10} levels. The use of gas stoves for food cooking is one indoor source of CO (Gold, 1992). Indoor particulate level is closely dependent on the type of cooking fuel used. Traynor et al. (1986) found that indoor concentrations of respirable suspended particulate were significantly elevated at homes during the use of wood-burning stoves. Cigarette smoking could give rise to indoor air pollutants such as CO and PM_{10} (Sterling, 1991). In order to protect the health of general public and maintain their shopping and dining pleasures, the IAQ should be taken into consideration during the design and operational processes of shopping malls. The objectives of this study were to characterize the IAQ at nine selected Hong Kong shopping malls in Hong Kong and compare the results of this study with health-related IAQ objectives currently required in Hong Kong. Various IAQ sources at shopping malls were also identified in this study.

Table 1
General comparisons of the nine shopping malls in Hong Kong

Site no.	Year of opening	Number of floors	Average area (ft^2) of each floor	Average no. of shops on each floor	Site location	Type of land use	Traffic flow	Shop features[a]	Car-park, entertainment and public transport facilities
SM1	1998	7	103 200	43	Kowloon Tong	R/C	Moderate	FW, SL, PCB, AV, USHF, JW, BG, SM, DS	Underground car-park, internal public bus station, ice-skating rink, cinema, food court, restaurant and bar
SM2	1986	3	11 400	50	Mong Kok	R/C	Very high	FW, AV, BG, DS	Food court
SM3	1989	6	130 000	40	Sha Tin	R	High	FW, SL, PCB, AV, USHF, JW, BG, SM, DS	Cinema, food court
SM4	1990	5	13 200	20	Kwun Tong	I/R	High	FW, AV	Attached car-park
SM5	1989	4	146 000	42	Tai Koo Shing	R/C	Moderate	FW, SL, PCB, AV, USHF, JW, BG, SM, DS	Internal enclosed car-park, ice-skating rink, cinema, food court, restaurants
SM6	1999	2	16 300	26	Tseng Kwun O	R	Moderate	USHF (mainly), SM	Attached car-park, food court
SM7	1983	4	28 700	25	Tsim Sha Tsui	C	High	FW, SL, PCB, AV, JW, BG	Food court, cinema
SM8	1984	2	14 800	32	Wan Chai	R/C	Very high	AV (mainly), FW	Nil
SM9	1995	13	34 400	20	Causeway Bay	C	Very high	FW, SL, PCB, AV, USHF, JW, BG, SM, DS	Internal enclosed car-park, cinema, food court

[a]*Abbreviations:* R, residential; C, commercial; I, industrial, FW, fashion and wear; SL, shoes and leather goods; PCB, personal care and beauty goods; AV, audio and visual compact disc and electrical appliances; USHF, upholstery shop and home furnishings; JW, jewelry and watches goods; BG, books and gifts; SM, supermarket; DS, department store.

2. Materials and methods

2.1. Field study

As shown in Fig. 1, the nine shopping malls selected are located in different geographical areas of Hong Kong. These monitoring sites were located in major commercial and residential districts where population and vehicle densities are relatively high in Hong Kong. Four shopping malls (SM1, SM2, SM4 and SM7) are located in Kowloon. Three shopping malls (SM5, SM8 and SM9) are situated in Hong Kong Island and two malls (SM3 and SM6) are located in the New Territories. Six of them (SM1, SM3, SM5, SM6, SM7 and SM9) are the biggest retail malls and the remaining shopping centers were the most popular meeting places for young people as these three malls contained a variety of trendy products and the latest video and audio electrical facilities and compact discs. All major entrances of selected shopping malls are located at street level and are left opened onto nearby traffic roads, providing direct access to both shoppers and outdoor air. SM1 is a detached building and the other malls are built on lower levels or inside basements of high rise commercial buildings. All shopping malls are multi-storied and ventilated with central air conditioning systems. General comparisons of the nine shopping malls are listed in Table 1.

2.2. Sampling and analysis

The IAQ survey at the shopping malls was conducted from June 1999 to October 1999. Four of the nine shopping malls were visited once only and other malls were monitored twice. Each air-monitoring visit was carried out on weekday and weekend evenings, respectively. Indoor and outdoor air samples were simultaneously taken at each site. The air pollutants investigated included: carbon dioxide (CO_2), carbon monoxide (CO), total hydrocarbon (THC), formaldehyde (HCHO), respirable particulate matter (PM_{10}) and airborne bacteria.

Two representative floors of each shopping mall with a relatively high flow of shoppers were selected for this study. These floors also included major entrances and exits, accesses to public transport stations, and the majority of shops, dining and entertainment facilities. Indoor samples

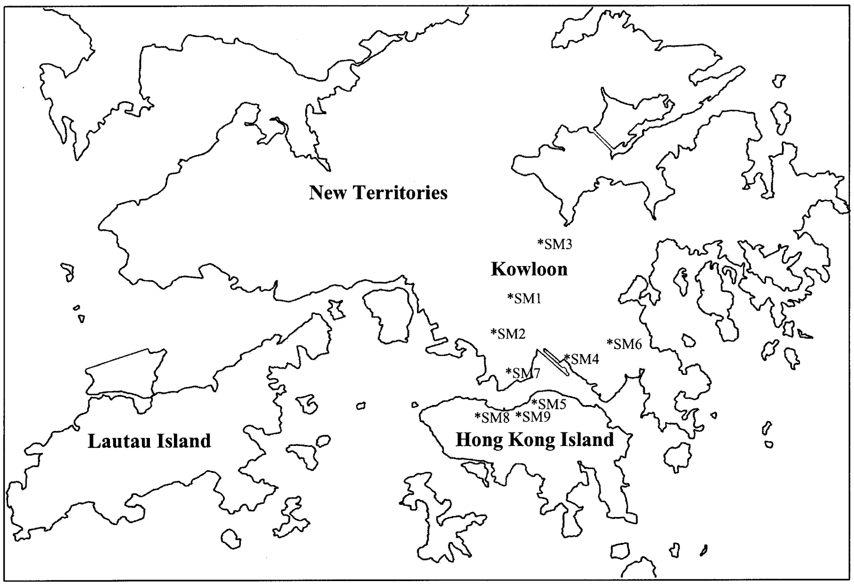

Fig. 1. Locations of sampling sites in Hong Kong.

were collected at discrete but representative sampling locations, as close to the central positions of selected floors as possible, within shopping areas while outdoor samples were taken at street levels in close proximity to the fresh air intake. The sampling probes or air intakes of the air monitoring equipment were placed at a height of approximately 1.5 m above the ground and also kept away from any source of targeted air pollutant. Both outdoor and indoor samples were taken between 19.00 h and 20.00 h during the evening. During sampling, various indoor parameters including numbers of floors, numbers and features of shops, smokers, floor area and ventilation type were recorded.

The air bag sampling method was used to sample CO and THC. CO was analyzed with a Thermo Electron (model 48) Gas Filter Correlation CO Ambient Analyzer. A methane (MHC) and non-methane hydrocarbon (NMHC) analyzer (model Thermo-Electron 55C) analyzed THC. The measurement results from air bag sampling at the sampling locations at selected levels in a shopping mall were averaged to obtain the final concentrations. Prior to sampling, the air bags used for sampling were flushed with zero air several times in order to minimize the background contamination. At each floor, the air was subsequently drawn into 25-l Tedlar bags by a small portable air pump (Gilian Ltd., model HFS-513A) at a flow rate of 1 l/min for 1 h. After sampling, the air bags were put into a large black plastic bag to avoid exposure to direct bright light, and immediately transported to the laboratory for analysis.

Formaldehyde samples are collected using a SKC formaldehyde monitoring kit at 8-h intervals. A pair of bubblers is used for sampling HCHO. A bubbler used as a blank sample remains unopened with a solid cap during transportation and sampling. The other bubbler as a sampled bubbler is sealed with small holed cap whose opening has already been covered with a Knudsen diffusive disk with a specific disk factor. These two bubblers were used to sample HCHO at each shopping mall. After sampling, the screw septum caps of the sampled bubblers were removed and replaced by solid caps, and the samples were kept refrigerated and unexposed to sunlight and sent to the laboratory for analysis. HCHO absorbed during the exposure periods were determined by colorimetric analysis and then converted to give average concentrations.

The CO_2 and PM_{10} concentrations were collected by TSI portable Q-Trak (model 8550) and Dust-Trak (model 8520) monitors at 5-min intervals, respectively. The Q-Trak was calibrated with standard CO_2 gas at various concentrations. Pre- and post-zero-checking of the Dust-Trak monitor was carried out. The monitor measured PM_{10} at 1-min intervals at a flow-rate of 1.7 l/min, and the Dust Trak had been calibrated against a high-volume sampler (Andersen Instrument Inc.). Each filter used for high-volume sampling was conditioned at 50% relative humidity for 24 h before and after sampling. A sampled filter was weighed at least three times using an electronic microbalance (model A200 S-D1B, Sartorius Ltd.). Fig. 2 illustrates the PM_{10} concentrations measured by a high-volume sampler are well-correlated with the corresponding levels measured by a Dust-Trak. The correlation line has an R^2 coefficient greater than 0.90.

A Burkard single stage impactor with an agar plate was used to sample the airborne viable microorganisms. Plate count agar was used as nutrient media. Before sampling, the bio-aerosol sampler was sterilized with isopropyl alcohol. The bacteria samples were taken at 20 ml/min for 9 min. After sampling, the sample agar plates were removed from the sampler and covered with lids. Also, the plates were kept refrigerated and shipped back to laboratory for incubation. The samples were incubated at 35°C for 2 days for

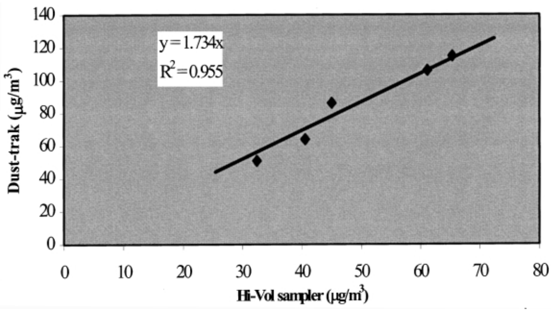

Fig. 2. Correlation of Dust-Trak and High Volume Sampler.

Table 2
Detection range and limits of the sampling methods

Air parameter	Detectable mechanism	Detectable range	Low detection limit
Carbon dioxide (CO_2)	Non-dispersive infra-red (NDIR)	0–5000 ppm	1 ppm
Carbon monoxide (CO)	Non-dispersive infra-red (NDIR)	0–1000 ppm	1 ppm
Total hydrocarbon (THC)	Flame ionization detection	0–200 ppm (non-methane hydrocarbon)	1 ppm
Formaldehyde (HCHO)	Colorimetric method	0.1–1.5 ppm	0.1 ppm
Respirable suspended particulate (PM_{10})	Light scattering	0.001–100 mg/m^3	1 $\mu g/m^3$
Airborne bacteria	Impacting on agar with incubation, followed by colony counting	0–2200 cfu/m^3	8 cfu/m^3

total bacteria counts. The colonies of bacteria were counted under a light microscope. In order to ensure the suitability of the sampling methods, the ranges and limits of the detection of sampling methods used in this study was summarized in Table 2. Additionally, duplicated indoor and outdoor air samples were collected at five out of nine of the shopping malls (SM1, SM2, SM3, SM4 and SM8) to ensure the consistency and repeatability of sampling data. In this study, the total sample size for each of the air pollutants measured in this study consisted of 56 indoor samples and 28 outdoor samples. Table 3 shows the sampling precision in terms of average relative standard deviation (R.S.D.) for each studied parameter.

3. Results and discussion

Figs. 3 and 4 show the indoor and outdoor average concentrations of CO_2, CO, THC, HCHO and PM_{10} at nine shopping malls on both weekdays and weekends. Outdoor and IAQ Objectives (Pang, 1994) currently recommended in Hong Kong are shown in Table 4. CO_2 concentration is widely used as an indicator of ventilation effectiveness in an enclosed space (ASHRAE, 1989). The average CO_2 levels at the shopping malls ranged from 500 to 2300 ppm. Figs. 3 and 4 illustrate four of the nine malls (SM2, SM3, SM4 and SM8) had average CO_2 levels that exceeded the HKIAQO of 1000 ppm on both weekdays and

Table 3
Sampling precision for selected indoor air pollutants

Air parameter	Average RSD[a] (%) of indoor air samples		Average RSD[a] (%) of outdoor air samples	
Sampling date	Weekday	Weekend	Weekday	Weekend
Carbon dioxide (CO_2)	10.5	11.2	10	11.4
Carbon monoxide (CO)	9.6	10.2	11.3	11.7
Total hydrocarbon (THC)	12.4	13.5	13.4	14.3
Formaldehyde (HCHO)	13.1	12.8	15.2	14.8
Respirable suspended particulate (PM_{10})	10.8	11.3	12.6	13.7
Airborne bacteria	9.6	10.4	13.7	12.2

[a] Relative standard deviation (indoor samples on weekdays = 20, indoor samples on weekends = 20, outdoor duplicate samples on weekdays = 10, outdoor duplicate samples on weekends = 10).

weekends. The weekend levels were generally higher than the corresponding weekday levels. This was probably due to higher occupancy density on weekend evenings than weekday evenings. Inadequate ventilation exchange rates, poor air distribution and the presence of indoor combustion sources in an indoor environment could cause ventilation problems (Jones, 1999). Among these nine shopping malls, SM2 and SM8 had considerable CO_2 levels on both weekday and weekend evenings. These two shopping malls were comparatively small in size with a ceiling height of approximately 2.8 m on each floor.

Furthermore, the malls contained many shops on each floor and the shopping areas with high shop density were crowded. Hence, the crowded shopping environment easily resulted in poor fresh air movement and distribution. The elevated CO_2 levels inside the SM2 and SM8 were probably due to inadequate ventilation. The high CO_2 levels obtained at SM2 might be partially contributed to by the sources of combustion in food courts. The small size of SM2 enhances the impact of the emissions from the food court so that the CO_2 level depends on cooking activities inside the food court during the weekdays. Also, indoor concentrations of CO_2 in other shopping areas, ventilated by air re-circulated from the food courts, could be greatly elevated.

The average CO levels at the surveyed shopping malls ranged from 890 to 5200 $\mu g/m^3$. The highest CO concentration was observed at SM2. All of the measured concentrations of CO at the shopping malls were below the HKIAQO and the HKAQO standards of 30 000 $\mu g/m^3$ (1-h average) and 10 000 $\mu g/m^3$ (8-h average), respectively. Generally, the traffic loading in the nearby roads of the malls during weekend evenings was heavier than that during weekday evenings. Therefore, average outdoor CO concentrations recorded at the malls for weekend evenings were higher than those for weekday evenings At SM1 and SM2, the malls had higher CO levels indoors than outdoors on both weekday and weekend evenings. The elevated concentration measured in SM1 was probably due to the close proximity of major entry doors to the public transport drop-off area constructed inside the SM1. This caused direct transfer of vehicular emissions from the partially enclosed parking area into its customer's

Table 4
Outdoor and IAQ objectives currently used in Hong Kong

Air parameters	HKAQO Hong Kong air quality objective for outdoor air	HKIAQO recommended indoor air quality objectives (IAQ) for Hong Kong
Carbon dioxide (CO_2)	N.A.	1000 ppm (8-h average)
Carbon monoxide (CO)	< 30 000 $\mu g/m^3$ (1-h average) < 10 000 $\mu g/m^3$ (8-h average)	< 30 000 $\mu g/m^3$ (1-h average) < 10 000 $\mu g/m^3$ (8-h average)
Nitrogen monoxide (NO)	N.A.	N.A.
Nitrogen dioxide (NO_2)	300 $\mu g/m^3$ (1-h average)	< 200 $\mu g/m^3$ (1-h average) < 50 $\mu g/m^3$ (8-h average)
Respirable particulate (PM_{10})	180 $\mu g/m^3$ (24-h average)	180 $\mu g/m^3$ (8-h average)
Formaldehyde (HCHO)	N.A.	< 100 $\mu g/m^3$ (1-h average) < 50 $\mu g/m^3$ (8-h average)
Airborne bacteria	N.A.	1000 CFU/m^3 (8-h average)

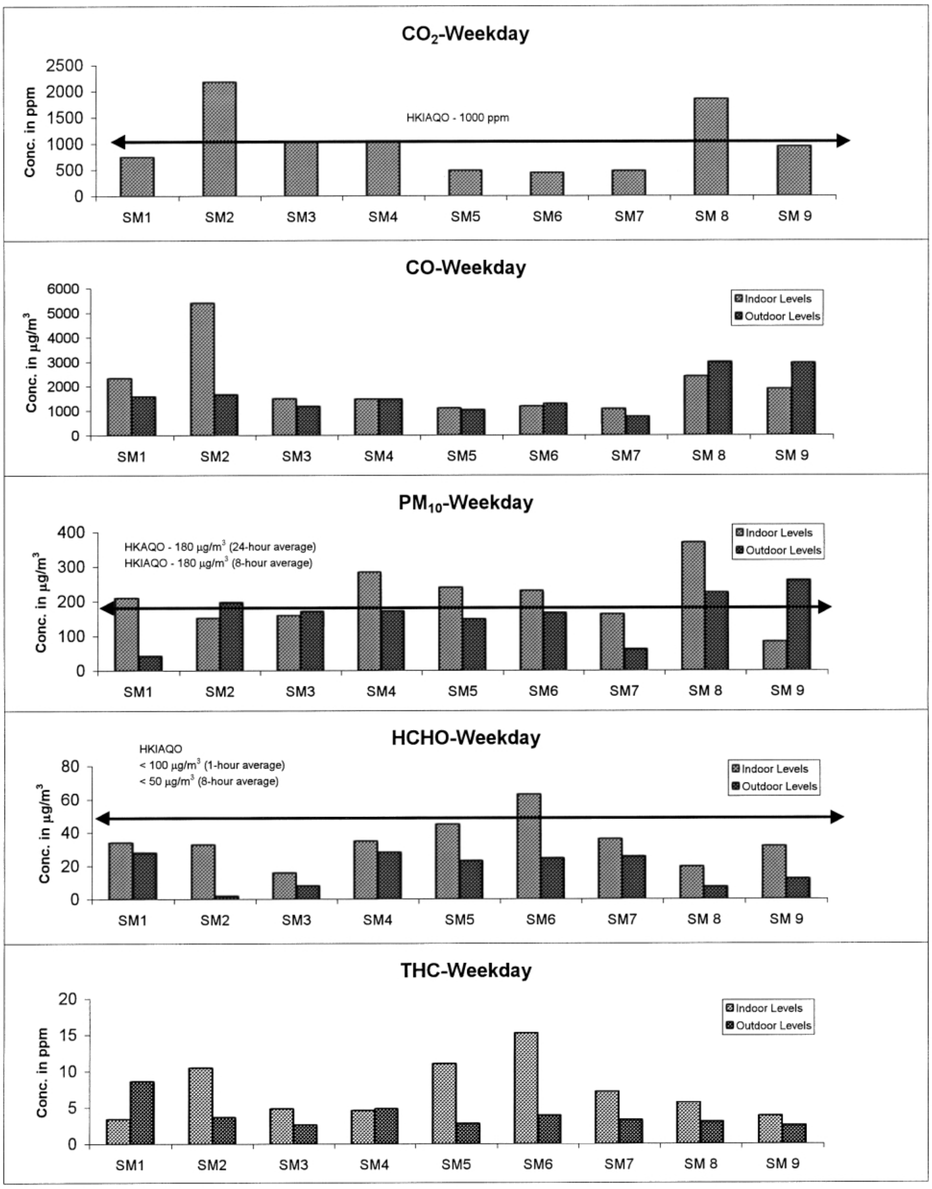

Fig. 3. Indoor/outdoor concentrations of air pollutant at shopping malls on weekdays.

shopping areas. Unfortunately, SM2 also had street-level entrances that were located at approximately 1.5 m from roadsides of heavily trafficked roads and there were many motor vehicles idling with running engines near to the entrances, the air pollutants from vehicular emissions were more likely to get direct access into the public building. Except in SM8, all of the shopping malls had their own food courts. SM1 and SM5 also have ice-skating rinks. In addition to the influence of outdoor vehicle exhausts, an increase in indoor CO levels was likely to result from the presence of indoor combustion sources. The operation of the fuel-powered ice-resurfacing equipment can result in elevated indoor concentration of CO (Brauer et al., 1993; Lee et al., 1994; Yoon et al.,

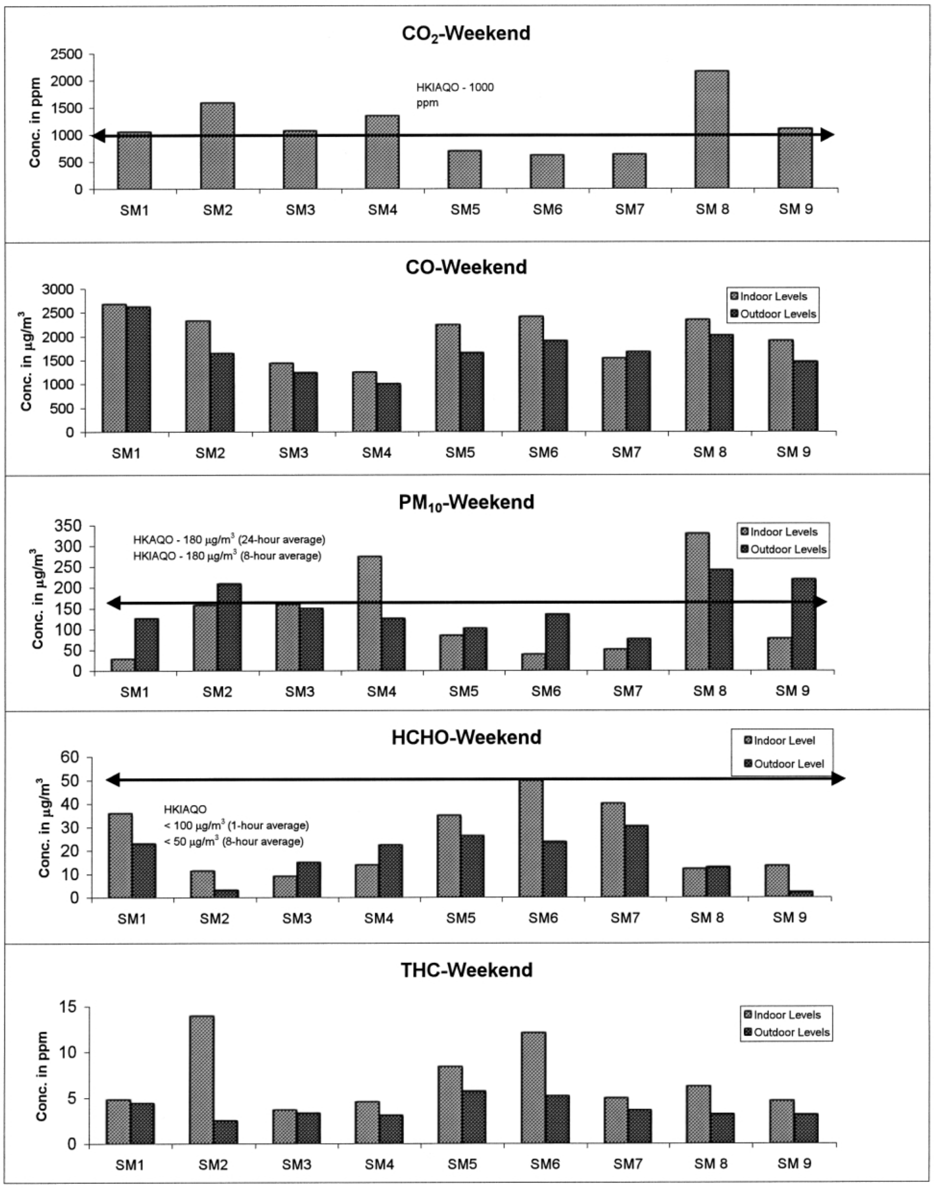

Fig. 4. Indoor/outdoor concentrations of air pollutant at shopping malls on weekends.

1996; Arto et al., 1997). Arto et al. (1997) revealed that exhaust gas emitted from the ice-resurfacers with combustion engines could cause the highest 1-h average concentrations of CO (2000–3300 $\mu g/m^3$) in indoor ice arenas. The increased indoor CO levels recorded at SM1 and SM5 were possibly attributed to the emissions from ice-skating equipment operated in their ice arenas. Furthermore, the elevated concentration of indoor CO surveyed at SM2 on weekday was likely to be caused by the extensive use of gas stoves without sufficient ventilation over its small, tightly built and poorly ventilated catering area.

As far as weekday and weekend average PM_{10} levels in selected shopping malls were concerned, the average PM_{10} level at the investigated shopping malls ranged from 35 to 380 μg/m^3. The indoor air pollution caused by PM_{10} for weekday evenings was higher than that for weekend evenings. This was proved by the results, showing that over 50% of the shopping malls (five out of nine) had average weekday concentrations above the HKIAOQ of 180 μg/m^3. It was also found that indoor levels of PM_{10} were usually higher than the respective outdoor levels in weekday evenings. The findings also showed that the average indoor levels of PM_{10} during the weekday evenings were nearly always higher than the corresponding PM_{10} levels measured during the weekend evenings. The elevated PM_{10} concentrations at the malls were probably due to the air infiltration of outdoors respirable airborne particulates emitted from vehicular emissions. This can be supported by the findings that the average outdoor PM_{10} concentrations measured in weekday evenings were usually higher than the respective weekend concentrations. On weekdays, SM4 and SM8 had higher indoor PM_{10} levels than the respective ambient levels on both weekday and weekend evenings. The maximum PM_{10} levels reached 285 and 377 μg/m^3 at SM4 and SM8, respectively. During the air sampling work, illegal smoking was always found inside these malls, although non-smoking policy had been implemented in the public buildings. Lee et al. (1999) found that 24-h average PM_{10} levels at some local shopping malls with tobacco smoking exceeded 260 μg/m^3. Hence, the increased indoor PM_{10} levels at SM4 and SM8 were probably due to tobacco smoke emission.

The outdoor levels of total hydrocarbon (THC) on both weekday and weekend evenings had slight variation between the weekday and weekend evenings, which approximately ranged from 2 to 5 ppm. Similarly, the indoor THC levels measured on both weekdays and weekends showed little fluctuations except at SM2, SM5 and SM6. The highest indoor THC levels obtained in SM2 was 14 ppm. At SM2, the weekend air monitoring was carried out when floor-cleaning works were in progress. It was found that internal cleaning works with the use of detergents were likely to make contributions to the indoor THC levels. In addition, the elevated levels of THC recorded at SM5 and SM6 were likely to be caused by the extensive uses of industrial solvents such as thinner, when internal decorative works inside the shopping malls were being carried out.

In addition to THC measurements, formaldehyde concentrations were also measured at the shopping malls. HCHO levels at the surveyed public places ranged from 15 to 60 μg/m^3. None of the investigated malls, except SM6, exceeded the standard HKIAQO of 8-h average HCHO level of 50 μg/m^3. It was found that the indoor average HCHO levels obtained on weekday evenings were higher than those measured on weekend nights. Besides, the results of this study illustrated that the 8-h indoor average concentrations at selected shopping malls were nearly always higher than their corresponding outdoor concentrations. Maroni et al. (1995) revealed that the background concentration of formaldehyde in outdoor air was generally lower than 122 μg/m^3. The findings of this study for the measurement of outdoor formaldehyde concentrations were in good agreement with what Maroni et al. reported. The highest HCHO level which exceeded the HKIAQO standard of 50 μg/m^3 (8-h average) was obtained at SM6. The concentration of HCHO within a given indoor space depends on the presence of emission sources. SM5 and SM6 had higher HCHO levels indoors than outdoors due to the extensive use of industrial solvents and paints that could contribute to the indoor HCHO concentrations. The solvent emissions mainly came from on-going internal decorative works inside the shopping malls. Temporary cessation of the works on weekends caused a decrease in indoor HCHO concentrations. Moreover, the highest HCHO concentration was observed in SM6. SM6 was located in a newly developed residential area and many retail shops inside the SM6 sell pressed wood furniture and building materials. It was estimated that the highest levels of HCHO were probably due to the emissions from the pressed wooden products and building materials sold in the upholstery shops.

The average bacteria levels at the surveyed shopping malls ranged from 600–1800 cfu/m^3. Fig. 5 illustrated the comparison between indoor airborne bacteria levels on weekday and weekend evenings. The results showed that three of the nine malls (SM2, SM5 and SM8) had indoor airborne bacteria levels above 1000 cfu/m^3 set by HKIAQO. Also, it was found that many shopping malls had higher average bacteria levels on weekend evenings than weekday evenings. The reason for high weekend bacteria level was normally high occupancy density. The airborne concentrations of viable organisms are not only related to occupancy loading, but also the frequency of cleaning works inside the malls and the cleanliness of internal surfaces of air ducts and ventilation. The

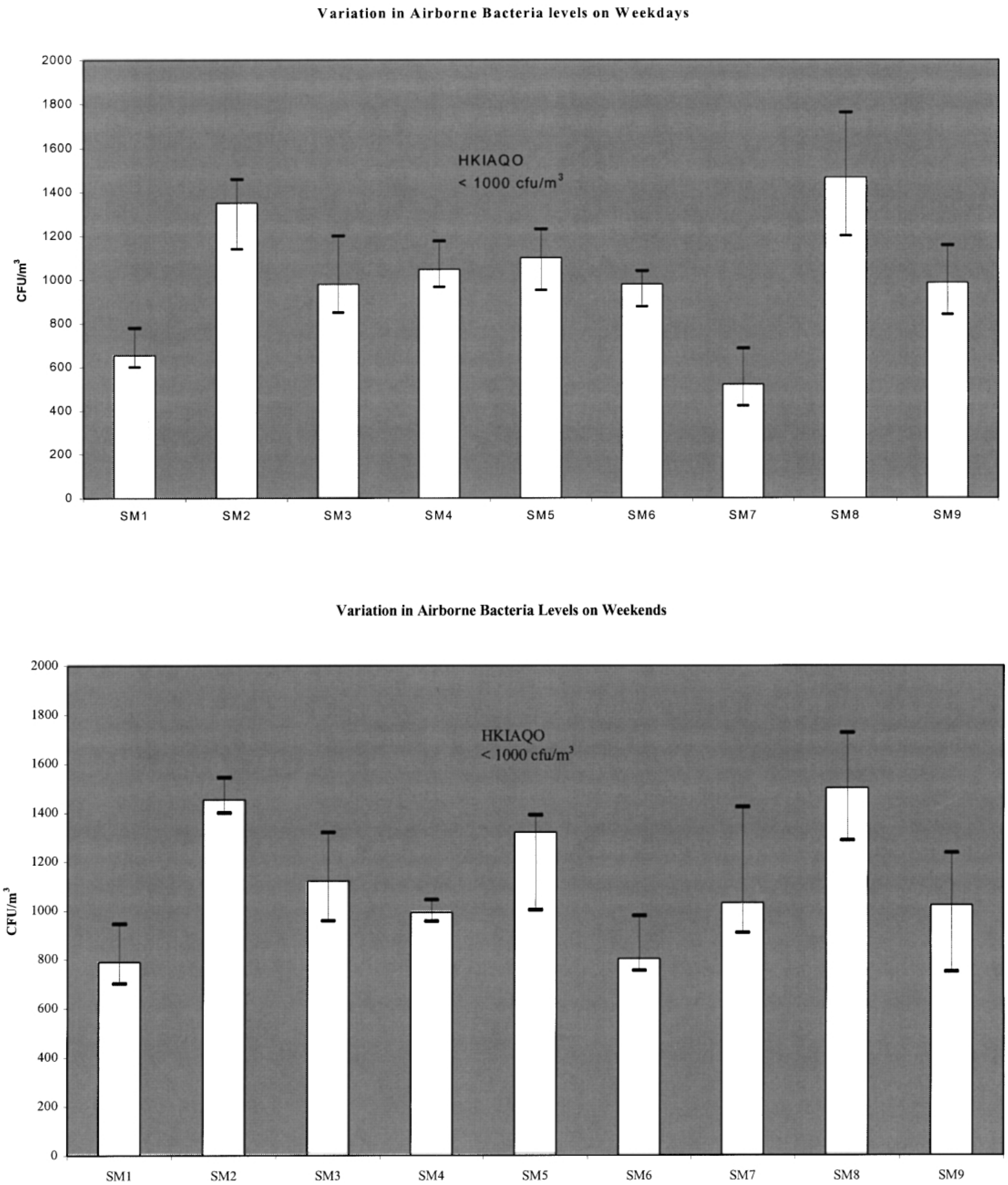

Fig. 5. Weekday and weekend airborne bacteria levels at selected shopping malls.

problem of insufficient ventilation easily occurred in SM2 and SM8. The elevated airborne bacteria levels observed in shopping malls were probably due to insufficient ventilation. The finding was supported by the results that considerably high total bacteria counts were observed at SM2 and SM8 when there was inadequate ventilation on both weekday and weekend evenings. A considerably high concentration of airborne bacteria only indicates that there is a great possibility of suffering from health-related illnesses due to the exposure to airborne viable microorganisms.

This study of IAQ in selected shopping malls in Hong Kong gives us some implications. Firstly, the ASHRAE association has stated that ventilation conditions are insufficient when CO_2 levels exceeds 1000 ppm. Of the shopping malls investigated, 40% had the problem of inadequate ventilation, as CO_2 levels observed in excess of 1000 ppm set by the ASHRAE standard were found at these malls. It is suggested that the property parties of the malls should monitor the ventilation effectiveness under the condition of occupancy, the amount of fresh air should be provided to achieve sufficient ventilation. Emmerich and Persily (2000) introduced a CO_2-based ventilation system that is able to use indoor CO_2 concentrations to control the demand of outdoor air intake based on the actual occupant levels in an enclosed space. Provision of separate ventilation to air pollutant generating areas in a shopping mall is indispensable. Also, the owners of the shopping malls should make sure that fresh air intakes are not blocked and not located in any environment where the air is likely to be polluted (Rock and Moylan, 2000). Secondly, the shopping malls with entrances facing directly onto nearby busy traffic roads, loading and unloading areas for buses, minibuses and taxies are easily susceptible to the outside air contaminated by vehicular exhausts. Higher levels of CO and PM_{10}, which are major air pollutants emitted from the automobile emissions, were observed at these malls. Relocalizing the entrances away from heavy traffic areas and installing air curtains as virtual barriers at the opening doorways can alleviate the effects of the air infiltration. Thirdly, the property managers of the malls should properly manage any potential air pollutant sources: (1) by promoting and implementing an anti-smoking policy in their shopping malls; (2) by providing adequate ventilation to any areas generating air pollutants such as food courts and ice-skating rinks; (3) by providing shop renters with appropriate IAQ management guidelines for the use of building materials and furnishings and implementation of renovation works in any parts of a shopping mall; (4) by managing good housekeeping such as maintenance programs for mechanical ventilation and air-conditioned (MVAC) systems to minimize the growth of microorganisms inside the air duct system; (5) by carrying out the regular assessment of IAQ in their malls.

4. Conclusion

The average indoor CO_2 and airborne bacteria levels recorded at more than half of the shopping malls surveyed exceeded the HKIAQO standard. This study found that many shopping malls had higher indoor CO_2 and bacteria levels on weekend evenings than on weekday evenings. The highest CO_2 and bacteria levels were as high as 2300 ppm and 1800 cfu/m^3, respectively. The elevated indoor concentrations were due to overcrowded shopping spaces, and high occupancy without sufficient ventilation. The indoor average PM_{10} levels at half of the investigated shopping malls on weekday evenings exceeded the HKIAQO of 180 $\mu g/m^3$. The average PM_{10} level was as high as 380 $\mu g/m^3$, which was more than twice higher than the HKIAQO. The elevated indoor PM_{10} levels were the result of illegal smoking inside the shopping malls. This study showed that the indoor air pollution by PM_{10} on weekdays was worse than on weekends. For CO and formaldehyde, many of the shopping malls did not exceed the HKIAQO standard. The average indoor levels of CO at the shopping malls ranged from 890 to 5200 $\mu g/m^3$. Indoor CO levels were elevated in shopping malls that contained internal public transport drop-off areas where vehicles were being idled. Additionally, the relatively small and poorly ventilated shopping malls, which have food courts and major entry doors in close proximity to heavily trafficked roads, were likely to be polluted by air pollutants. It was found THC and HCHO levels were increased when internal decorative and cleaning works inside the shopping malls were being carried out. Indoor HCHO level was occasionally higher than the HKIAQO standard of 50 $\mu g/m^3$ (8-h) where there are many retail shops selling pressed wooden furnishings and furniture and building materials inside a shopping mall. The small and tightly built shopping malls, combined with inadequate ventilation and high density of occupancy, were easily susceptible to indoor air pollution. It is recommended that the owner of a shopping mall with potential sources of indoor air pollutants should regularly inspect the IAQ of its shopping mall in order to provide and maintain a healthy and comfortable shopping environment.

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