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Characteristics of Residential Indoor Carbonaceous Aerosols: A Case Study in Guangzhou, Pearl River Delta Region

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ABSTRACT

Nine residences located in Guangzhou were selected to characterise indoor fine particles ($PM_{2.5}$), organic carbon (OC) and elemental carbon (EC) during summer time. These nine residences were classified into 5 types, urban without smoker, urban with smoker, newly remodelled urban, roadside and suburban. The average indoor $PM_{2.5}$ concentration was 47.4 μg/m^3, consisting of 12.5 μg/m^3 of OC and 4.4 μg/m^3 of EC. OC and EC accounted for 24.6 % and 9.9 %, respectively, of the indoor $PM_{2.5}$ mass. Higher $PM_{2.5}$, OC and EC concentrations were observed in the urban residences with smokers and the roadside residence, suggesting the importance of indoor sources and outdoor penetration. The highest $PM_{2.5}$ and OC concentrations were observed in one of the urban residences with a smoker due to the contribution of indoor sources and the poor condition of ventilation in the kitchen. The highest EC was observed in the roadside residence, indicating the penetration of outdoor traffic emissions. Urban residences without smokers and recently remodelled residences had similar $PM_{2.5}$, OC and EC concentrations. The suburban residence had the lowest $PM_{2.5}$ and OC concentrations, while the EC concentration was lower than roadside residence but similar to other urban residences. Eight carbonaceous fractions by thermal/optical reflectance (TOR) method, namely OC1, OC2, OC3, OC4, OP, EC1, EC2 and EC3, were also studied. OC2, OC3 and EC1 were the most abundant fractions. EC1 was found to be the carbonaceous fraction which was mainly from outdoor vehicular emissions. OC2 and OC3 were likely to be contributed by smoking and cooking emissions in indoor microenvironments.

Keywords: Indoor air; $PM_{2.5}$; Organic carbon; Elemental carbon

INTRODUCTION

People spend up to 90% of their time indoors (Wallace, 1996). Most people spend 65–70% of their time inside their residences (Spengler and Sexton, 1983). Thus, indoor air quality, particularly in residences and its influence on human health are important.

In residential microenvironments, pollution of particulate matter (PM) can cause serious negative effects on human health; various epidemiological studies have shown strong associations between PM and adverse health outcomes, including cardio-respiratory hospital admissions and mortality (Pope *et al*., 1995; Anderson *et al*., 2001). In particular, fine particles (e.g. $PM_{2.5}$), due to their small size, can penetrate deeply into the human respiratory system and have a strong association with most types of respiratory illness and even mortality (Pope *et al*., 2002). To date, numerous studies were conducted to monitor residential indoor PM levels, to analyse its chemical composition, and to study its environmental and health impacts (Kamens *et al*., 1991; Chao *et al*., 1998; See and Balasubramanian, 2008; Ruiz *et al*., 2010). Carbonaceous fractions, i.e. organic carbon (OC) and elemental carbon (EC), have been regarded as the important constituents of $PM_{2.5}$. OC can include polycyclic aromatic hydrocarbons (PAH) and other components that have potential mutagenic and carcinogenic effects (Mauderly and Chow, 2008). EC has been linked to an increase in mortality from lung cancer and other respiratory ailments (Frazer, 2002). These fractions can be contributed by either indoor sources (e.g. cooking stoves) or penetration of outdoor pollutants (Cao *et al*., 2005; Polidori *et al*., 2007; Zhi *et al*., 2008).

The Pearl River Delta Region (PRDR), located in South China, is one of the most rapidly developing areas in China. Increasing anthropogenic activities have resulted in serious atmospheric PM pollution in the region (Cao *et al*., 2003).

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A numbers of research projects have focused on the concentration and chemical composition of ambient PM (Cao *et al*., 2004; Lai *et al*., 2007; Andreae *et al*., 2008; Shi *et al*., 2009). However, the exposure level and chemical composition of indoor PM can be different from the ambient environment (Williams *et al*., 2000). Hence, more concerns arise over indoor PM levels, its chemical composition and indoor/outdoor source contributions (Ward *et al*., 2007; Olson *et al*., 2008; See and Balasubramanian, 2008; Zhi *et al*., 2008).

Here we present a case study of residential indoor $PM_{2.5}$ and its carbonaceous fractions (i.e. OC and EC) during the summertime in Guangzhou city, which is one of the megacities in PRDR with a population of more than 10 million. The objectives of this study were to characterise indoor $PM_{2.5}$, OC and EC in different types of residences and to investigate the contribution of indoor/outdoor sources to indoor microenvironments in a polluted region.

EXPERIMENTAL METHODS

Sampling Sites

The nine sampling sites were classified into five categories:

Type A: Urban residence without smoker (Sites A1, A2 and A3);

Type B: Urban residence with smoker (Sites B1 and B2,);

Type C: Recently remodelled urban residences (<3 months) (Sites C1 and C2);

Type D: Roadside residence located 100 m away from one of the highest traffic roads in central Guangzhou city (Site D);

Type E: Suburban residence (Site E).

A questionnaire was given at each residence to survey the information of all residences and the living habits of households. As shown in Table 1, the main cooking fuels were liquefied petroleum gas (LPG) and piped coal gas (PCG). All homes except for Site E were naturally ventilated during the day and mechanically ventilated by air-conditioner during the night for 8 to 10 hours. Also, there was no significant local outdoor pollution source other than motor vehicles.

Sample Collection

Mini-volume samplers (Airmetrics, Eugene, USA) were used to collect indoor $PM_{2.5}$ samples during the period of June to July, 2003. With a Φ47 mm quartz microfibre filter (QM/A) (Whatman, Maidstone, UK), the sampler was operated at a flow rate of 5 L/min for 24 hours. These devices were inspected and calibrated at the Hong Kong Polytechnic University, Hong Kong, before sampling. Quartz filters were used as the sampling medium and they were pre-heated at 900°C for 3 hours to remove carbonaceous contaminants. After sampling, samples were stored in a refrigerator at about 4°C before chemical analysis to prevent evaporation of volatile components. Before and after the field sampling, an electronic microbalance with a sensitivity of ± 1 μg (MC5; Sartorius, Goettingen, Germany) was used to weigh the filters at a constant temperature of 25 ± 1°C and relative humidity of 40 ± 5%.

A $PM_{2.5}$ sampler was placed in the middle of each residence. The indoor sampling heights were about 1.5 m above ground in order to simulate the breathing zone and to avoid potential interferences from excessive particle re-suspension. Three samples were collected indoors at each site and one outdoor sample was collected at the balcony at each site. Moreover, one system blank was also collected at each site as a reference. A total of 45 filters (27 indoor, 9 outdoor and 9 system blank) were collected for this carbonaceous analysis.

Carbonaceous Aerosol Analysis

$PM_{2.5}$ samplers were analyzed for OC and EC using a DRI Model 2001 Thermal/Optical Carbon Analyzer (Atmoslytic, Calabasas, USA) following the Interagency Monitoring of Protected Visual Environments (IMPROVE) thermal/optical reflectance (TOR) protocol (Chow *et al*., 1993; Chow *et al*., 2004a). A 0.526 cm^2 punch aliquot of sampled quartz filter was submitted for combustion at different temperatures. This produced four OC fractions (OC1, OC2, OC3 and OC4 at 120°C, 250°C, 450°C, and 550°C, respectively, in a helium atmosphere), a pyrolyzed carbon fraction (OP, determined when reflected laser light attained its original intensity after oxygen was added to the helium atmosphere), and three EC fractions (EC1, EC2, and EC3 at 550°C, 700°C, and 800°C , respectively, in a 2% oxygen/98% helium atmosphere). The IMPROVE protocol defines OC as OC1 + OC2 + OC3 + OC4 + OP, and EC as EC1 + EC2 + EC3 – OP. The analyzer was calibrated with known quantities of CH_4 every day.

Table 1. Description of nine indoor sampling sites in Guangzhou, China.

Type	Site ID	Floor	Home area (m^2)	Number of inhabitant	Build year	Remodelling year	Ventilation condition	Cooking fuel	Smoker
A	A1	4	68	5	1997	None	Air-condition, 10-hr at night	LPG	No
	A2	8	53	3	1998	None	Air-condition, 10-hr at night	LPG	No
	A3	22	144	3	2000	2001	Air-condition, about 8-hr at night	PCG	No
B	B1	6	97	3	1999	2000	Air-condition, about 8-hr at night	LPG	Yes
	B2	5	73	4	1990	2002	Air condition at night	PCG	Yes
C	C1	9	60	3	1997	2003	Air-condition, about 8hr at night	LPG	Yes
	C2	11	106	2	2002	2003	Air-condition, 10-hr in bedroom	PCG	No
D	D	6	43	3	1979	1996	Air condition, about 8-hr at night	LPG	No
E	E	2	85	3	2000	2000	Natural ventilation	LPG	No

The detection limits for OC and EC were 0.9 μg/m^3 and 0.2 μg/m^3, respectively. The reproducibility determined from replicate analyses was below 5% for total carbon (TC), and 10% for OC and EC.

RESULTS AND DISCUSSION

Indoor $PM_{2.5}$ Mass Concentrations

The mass concentrations of indoor $PM_{2.5}$ are listed in Table 2. Indoor $PM_{2.5}$ concentrations ranged from 31.8 to 95.2 μg/m^3 with an average of 47.4 μg/m^3. Outdoor $PM_{2.5}$ ranged from 33.1 to 50.8 μg/m^3 with an average of 40.1 μg/m^3.

Three sampling sites of Type A had similar $PM_{2.5}$ concentrations. Site A3, located on the 22nd floor, had the lowest outdoor $PM_{2.5}$ concentration, but had similar indoor $PM_{2.5}$ levels as sites A1 and A2. This indicates that indoor sources might contribute more to indoor PM than outdoor sources. Two Type B sites had higher $PM_{2.5}$ concentrations, especially Site B2 where $PM_{2.5}$ concentrations were much higher than all the other sites (86.7–95.2 μg/m^3). The difference in $PM_{2.5}$ concentration between Type A and B showed that smoking was an important contributor to the indoor $PM_{2.5}$ level. Smoking was reported as one of the major indoor sources by Liu (2001). Chao and Wong (2002) also found that the average $PM_{2.5}$ concentration in smoking homes in Hong Kong was 18% higher than non-smoking homes. Even though the limited data in this study is insufficient to draw broad conclusions, the results suggest that the contribution of smoking should be large. The highest $PM_{2.5}$ concentration was observed at Site B2, which may be attributed to not only smoking but also additional indoor sources such as cooking etc. As reported, gas cooking is one of the most important sources of fine particles for indoor microenvironments (Abt *et al*., 2000). Although cooking was one of the daily activities in all investigated residences, several reasons may cause the considerably high $PM_{2.5}$ level at Site B2. The condition of a gas stove can affect the burning efficiency and particle emission (Minutolo *et al*., 2008). Also, type of food, amount of food, and different cooking methods can affect the emissions of PM (See and Balasubramanian, 2008). Nevertheless, a poorly running ventilator (older device and lower design power than other residences) was found in the kitchen, suggesting that the poor ventilation of the kitchen could be the reason for such high $PM_{2.5}$ concentration. Previous study has shown that the ventilation for indoor microenvironments can influence the particle loss and air exchange rate (Meng *et al*., 2009). The poor ventilation in the kitchen may strongly increase the particle concentration during the cooking time. The particles could be diffused afterward to other parts of the residence, such as living room where the sampler was placed (Balasubramanian and Lee, 2007).

The recently remodelled apartments (Type C) had similar PM levels to Type A. This indicates that remodelling is a negligible contributor to $PM_{2.5}$ in residential microenvironments. Without smoking emissions, $PM_{2.5}$ concentrations at Site D (Type D), which is located beside a high traffic road, were higher than those in non-smoking residences of Type A and close to the values obtained from Site B1 of smoking type. This result suggests that the penetration of vehicular emissions should not be neglected (Ho *et al*., 2004). Low and stable $PM_{2.5}$ concentrations were observed at Site E which is located in the suburban area of Guangzhou. However, the $PM_{2.5}$ concentration was slightly lower than Type A but lower still than outdoor $PM_{2.5}$, indicating indoor sources are more important for indoor fine particles than outdoor penetration at this site.

Indoor $PM_{2.5}$ concentrations in this study were higher than those reported in other urban areas such as Brisbane, Zurich, Beijing and Taipei (Monn *et al*., 1997; Li and Lin, 2003; Morawska *et al*., 2003; Liu *et al*., 2004), but comparable with those observed previously at different sites in Hong Kong (Chao and Wong, 2002; Cao *et al*., 2005).

Except for Site E, the indoor/outdoor (I/O) ratios of $PM_{2.5}$ were close to 1 or higher than 1, showing that the indoor fine PM level was comparable to or higher than outdoor PM level in the selected sites. The two highest ranges of I/O ratio were observed at Site B2 (1.9–2.1) and Site A3 (1.4–1.8).

OC and EC Concentrations in Indoor Environments

The concentrations and percentages of OC and EC in $PM_{2.5}$ are shown in Table 3. The average indoor $PM_{2.5}$ TC concentration was 16.9 μg/m^3. It ranged from 7.2 to 42.6

Table 2. $PM_{2.5}$ concentrations at different indoor microenvironments in Guangzhou, China during June–July 2003.

Type	Abbreviation	Indoor $PM_{2.5}$ Concentration (μg/m^3)			Outdoor $PM_{2.5}$ concentration (μg/m^3)	I/O Ratio*
		Sample 1	Sample 2	Samples 3		
A	A1	35.5	44.5	37.5	37.4	1.0–1.2
	A2	39.3	39.5	43.1	46.0	0.9
	A3	42.6	37.9	34.7	24.1	1.4–1.8
B	B1	52.7	48.9	31.8	34.2	0.9–1.5
	B2	86.7	95.2	91.0	45.3	1.9–2.1
C	C1	46.4	39.9	40.3	50.2	0.8–0.9
	C2	48.4	38.0	43.2	33.1	1.2–1.5
D	D	55.4	45.3	50.4	41.9	1.1–1.3
E	E	32.6	32.5	32.7	50.8	0.6

* Outdoor $PM_{2.5}$ sample was not collected on the same day as indoor sample

Table 3. Statistical summary of the average concentrations and percentages of OC and EC in different indoor environments of Guangzhou (n = 3 for each location).

Type	Locations	OC concentrations ($\mu g/m^3$)	$OC/PM_{2.5}$ (%)	EC concentrations ($\mu g/m^3$)	$EC/PM_{2.5}$ (%)	OC/EC ratio
A	A1	9.2 ± 1.4*	23.0 ± 0.1	3.7 ± 0.5	9.3 ± 0.3	2.5
	A2	9.5 ± 1.7	23.2 ± 3.2	2.9 ± 0.6	7.2 ± 1.0	3.2
	A3	9.1 ± 0.8	23.8 ± 2.2	3.1 ± 1.6	7.8 ± 3.4	3.0
B	B1	10.5 ± 2.6	23.5 ± 0.1	5.3 ± 1.4	11.9 ± 0.5	2.0
	B2	34.5 ± 6.1	37.8 ± 5.1	3.1 ± 1.6	3.4 ± 1.6	11.1
C	C1	9.0 ± 3.3	20.4 ± 4.1	3.5 ± 2.6	7.8 ± 4.7	2.6
	C2	10.2 ± 1.5	24.1 ± 1.6	5.2 ± 3.5	12.0 ± 6.9	2.0
D	D	11.4 ± 2.1	22.6 ± 2.8	7.6 ± 3.7	14.9 ± 6.1	1.5
E	E	6.9 ± 1.0	21.3 ± 3.1	4.5 ± 1.0	13.9 ± 3.2	1.5
Ref. Ave. outdoor concentration		8.4 ± 3.3	19.3 ± 6.0	3.7 ± 1.4	9.3 ± 3.0	2.5

* The concentration is presented as mean ± standard deviation

$\mu g/m^3$, which accounted for 19.0 to 44.8% of $PM_{2.5}$ mass. This shows that TC was an important fraction of indoor $PM_{2.5}$ at all sites.

The average indoor OC concentration ranged from 5.0 to 39.8 $\mu g/m^3$ with an average of 12.5 $\mu g/m^3$ and the average indoor EC concentration was 4.4 $\mu g/m^3$ ranging from 1.3 to 11.6 $\mu g/m^3$. The OC concentrations were higher than EC concentrations at all sites. Outdoor OC and EC averages were 8.0 $\mu g/m^3$ and 3.7 $\mu g/m^3$ and were in the range of 2.2–13.0 $\mu g/m^3$ and 2.3–6.2 $\mu g/m^3$, respectively. Higher indoor OC and EC levels than outdoors suggests that carbonaceous fractions were produced more by indoor sources rather than outdoor pollutant penetration.

OC and EC accounted for 19.6–25.4% and 6.4–9.5% of indoor $PM_{2.5}$ in non-smoking homes (Type A). Similar percentages of OC and EC were found at Site B1, 23.4–23.7% for OC and 11.6–12.5% for EC. The highest OC concentrations were observed at Site B2 (27.8–39.8 $\mu g/m^3$), accounting for 32.1–41.8% of $PM_{2.5}$. EC concentrations at Site B2 were comparable with the other sites. As mentioned above, smoking and, especially, poor ventilation during cooking may contribute to elevated OC levels. This is in accordance with a recent report that cooking may contribute more to indoor OC enhancement (Polidori *et al*., 2007). The composition of carbonaceous aerosols from cooking can also be influenced by the cooking methods, condition of the gas stove and food type. No evidence showed that recently remodelled residences (Type C) had elevated OC or EC. As expected, elevated OC and EC were found at traffic influenced Site D; the highest EC concentrations, ranging from 9.8 to 13.8 $\mu g/m^3$, were observed here. EC is a tracer of direct emission of combustion products from vehicle exhaust (Turpin and Huntzicker, 1991). The outdoor EC concentration at this site was the highest, which was 1.7–2.7 times that of EC from the residences of Type A, B and C. This is in agreement with a recent study in a freeway tunnel where more EC was detected than OC (Chiang and Huang, 2009). It also indicates that the outdoor penetration was important for the EC elevation. At Site E, EC concentrations were comparable to the other sites, and the OC concentration was the lowest observed.

A summary of carbonaceous components of indoor and outdoor $PM_{2.5}$ in different locations are shown in Table 4. Indoor average of OC was higher than those reported in Oslo and Los Angeles but comparable to observations in Hong Kong and Singapore. This may be due to the different types and strength of indoor sources such as cooking. The indoor EC average was lower than in a roadside flat in Singapore but higher than other studies in Hong Kong, Oslo and Los Angeles, showing that outdoor penetration was substantial. This is in accordance with previous studies that indoor air quality was influenced by outdoor concentrations (Ho *et al*., 2004; Ruiz *et al*., 2010). Outdoor OC and EC averages were similar to those in Hong Kong but higher than those observed in Oslo and Los Angeles. Outdoor OC measured in Singapore had lower OC concentration but higher EC concentration than in this study.

Table 4. Summary of carbonaceous components of $PM_{2.5}$ in different residential microenvironments.

Location	Period	Indoor		Outdoor		Reference
		OC	EC	OC	EC	
Hong Kong	March–April, 2004	17.2 ± 7.3	2.9 ± 1.0	8.9 ± 3.0	2.4 ± 0.9	(Cao *et al*., 2005)
Singapore	May, 2004	10.5	6.6	5.5	4.5	(Balasubramanian and Lee, 2007)
Oslo, Norway	June, 2002	4.6 (0.7–14.1)	0.4 (0.2–0.5)	2.1 (1.1–3.2)	0.5 (0.2–0.8)	(Lazaridis *et al*., 2008)
Los Angeles, USA	July–August, 2005	5.9 ± 2.1	1.4 ± 1.0	5.2 ± 1.8	1.4 ± 0.7	(Polidori *et al*., 2007)
Guangzhou	June–July, 2003	12.6 ± 8.2	4.3 ± 2.2	8.4 ± 3.3	3.7 ± 1.4	This study

Abundances of OC and EC in indoor and outdoor $PM_{2.5}$ are shown in Table 3. OC and EC accounted for 24.6 ± 5.6% and 9.9 ± 4.8% of indoor $PM_{2.5}$, and outdoor $PM_{2.5}$ had average percentages of 19.3 ± 6.0% OC and 9.3 ± 3.0% EC. The percentage of $PM_{2.5}$ attributable to OC indoor was close to that reported in a case study in Hong Kong (24.4–32.6%) but the percentage of EC was higher than reported values of 3.6–6.9% in Hong Kong (Cao *et al*., 2005).

In order to convert the measured mass of OC to total organic matter (OM) mass, OC concentration was multiplied by a factor that is an estimate of the average molecular weight per carbon weight for the organic aerosol (Kleefeld *et al*., 2002). Here a factor of 1.6 is used to estimated the OM in $PM_{2.5}$ (Turpin and Lim, 2001). Moreover, the total carbonaceous aerosol (TCA) mass was calculated from the sum of OM and EC. The estimated OM and TCA accounted for 39.4% and 49.3% of indoor $PM_{2.5}$, respectively.

OC to EC ratios were used to study the emission and transformation characteristics of carbonaceous aerosols. The OC/EC ratios in $PM_{2.5}$ varied between 1.2 and 21.2 with an average of 3.3 for indoor environments. The outdoor OC/EC ratios varied from 0.9 to 5.6, averaging 2.3. The highest OC/EC ratios were observed at Site B2, ranging from 8.7–21.2. This may be caused by the strong OC related sources such as smoking and cooking as discussed above. Excluding the OC/EC ratios from Site B2, OC/EC ratios at other sites ranged from 1.2 to 6.1 with an average of 2.5, which were close to outdoors. It suggests that the indoor and outdoor carbonaceous fractions were related to some extent. According to the survey (Table 1), 8 of 9 residences had their windows open during the day for natural ventilation and closed at night for air conditioning during the sampling period, which favoured the penetration of outdoor pollutants during the day time.

The correlation of indoor OC and EC was investigated and poor correlation with a correlation coefficient (R) of 0.20 was found (Fig. 1). The 3 outliers are all from Site B2 which had the highest OC concentration range compared to the other sites. When the data of OC and EC at Site B2 were excluded, the correlation of indoor OC and EC vastly improved (R = 0.70). This suggests that indoor concentrations of OC and EC were interrelated through common sources, except at Site B2.

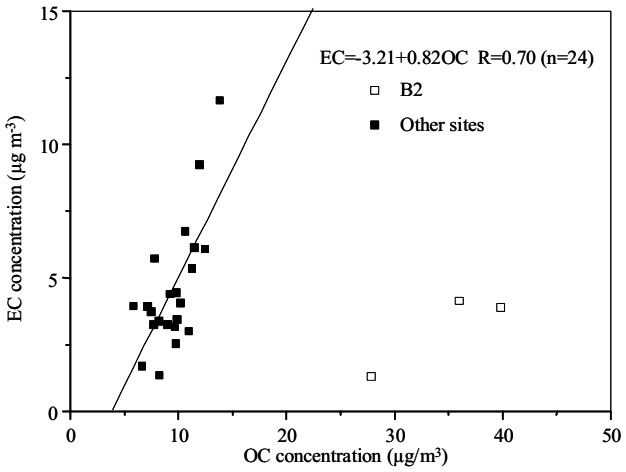

Fig. 1. Correlation between indoor EC and OC concentrations.

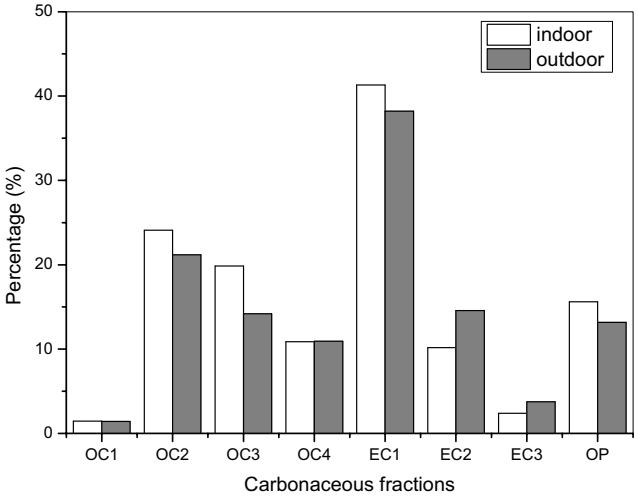

Fig. 2. Average abundances of eight carbonaceous fractions in TC in indoor and outdoor $PM_{2.5}$.

The Characterization of 8 Carbon Fractions of Indoor $PM_{2.5}$

The average indoor abundances of OC1, OC2, OC3, OC4, EC1, EC2, EC3 and OP in $PM_{2.5}$ TC at the nine sites were 1.5%, 24.1%, 19.8%, 10.9%, 41.3%, 10.2%, 2.4% and 15.6%, respectively (Fig. 2). The average outdoor abundances of OC1, OC2, OC3, OC4, EC1, EC2, EC3 and OP in $PM_{2.5}$ TC were 1.4%, 21.2%, 14.2%, 10.9%, 38.2%, 14.6%, 3.7% and 13.2%, respectively (Fig. 2). Although there were substantial site-to-site variations, OC2, OC3 and EC1 were generally the most abundant carbonaceous fractions. Indoor carbonaceous fraction profiles had more OC2, OC3 and EC1 abundances than outdoors, while more EC2 was observed in outdoor profiles. OC2 has been associated with indoor sources such as cooking and smoking (Cao *et al*., 2005); OC3 was found to be enriched in cooking emissions (Chow *et al*., 2004b). As expected, Site B2 with poor ventilation during cooking had the highest OC2 concentration of 10.6 ± 2.0 μg/m^3 and OC3 concentration of 10.1 ± 2.0 μg/m^3, accounting for abundances of 29.1% for OC2 and 27.8% for OC3 in TC. Beside Site B2, high abundances of OC2 were found at sites A3 (23.7%), C1 (25.7%), C2 (32.1%) and E (25.5%). Sites A3, C1 and C2 used PCG as the cooking fuel and this indicates that PCG might be an important contributor to OC2 during cooking. EC1 was the most abundant carbonaceous fraction in indoor and outdoor carbon fraction profiles at all sites. The highest abundance was observed at Site D (50.9%), which is located 100 m away from a high traffic road. Except for cooking produced EC1 (Chow *et al*., 2004b), EC1 is likely to be primarily from penetration of outdoor vehicular emissions, as EC1 and EC2 have been reported as the most abundant carbonaceous species in the exhaust of motor vehicles (Watson *et al*., 1994). EC1 was also found as the most abundant species in the ambient carbon fraction profile in Guangzhou during the summer of 2002 (Cao *et al*., 2004).

CONCLUSIONS

The indoor $PM_{2.5}$, OC and EC concentrations at five types of residences (9 sites) in Guangzhou during summer were determined. The average 24-h indoor $PM_{2.5}$ mass concentration was 47.4 μg/m^3. Carbonaceous fractions (OC and EC) accounted for 24.6 ± 5.6% and 9.9 ± 4.8% of indoor $PM_{2.5}$ mass, suggesting the importance of carbonaceous aerosol in indoor PM. Among 8 carbon fractions, OC2, OC3 and EC1 were the most abundant fractions in TC.

Indoor and outdoor sources contribute to indoor $PM_{2.5}$, OC and EC loadings, and indoor sources were found to play more important roles than outdoor sources. In particular, smoking and cooking can increase the PM and OC levels in indoor microenvironments. Outdoor pollutant penetration should not be neglected in certain residences near strong outdoor sources such as high traffic roads. For different types of residence, those with good ventilation during cooking and without a resident smoker presented lower levels of $PM_{2.5}$. Higher indoor OC concentrations were observed in those homes with strong indoor source influences, such as smoking and poor ventilation. No obvious increases of $PM_{2.5}$, OC or EC were shown in the recently remodelled homes.

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