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Variations in Indoor PM_{10} Concentrations in Sixteen Homes in Guiyang City, People's Republic of China

Y. L. Cheng,[1] M. Yan,[1] J. L. Li,[1] Z. R. Liu,[1] Y. H. Bai,[1] W. Tian,[2] D. G. Wu,[2] Q. Cheng[2]

[1] College of Environmental Sciences, Peking University, Beijing 100871, People's Republic of China
[2] Guiyang Environmental Protection Bureau, Guiyang, Guizhou Province 550003, People's Republic of China

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Numerous studies have confirmed that indoor environmental pollution is one of the major environmental factors that affect human health because most people spend over 80% of their time indoors (Jenkins et al.1992). Furthermore, susceptible subpopulations-such as infants, young children, the elderly, and people with illnesses and disability-tend to stay in the indoor environment even longer. Thus, in many cases, the effects of indoor air quality on human health far exceed those of the ambient environmental quality. Particulate matter (PM) is an important air pollutant. Particles with aerodynamic diameters greater than 30 μm tend to be removed from the air rather rapidly due to the gravitational deposition and, thus, do not have serious effects on human health. Particles with aerodynamic diameters smaller than 10 μm (PM_{10}) tend to stay in air much longer due to the aerodynamic conditions, and can enter the respiratory tract. Elevated level of PM_{10} has been associated with declined lung function and the incidences and severity of respiratory diseases (Pope 1991).

Located in the Southwestern China, Guiyang City is the capital of Guizhou Province and has a population of 3.5 million in 2004. In recent years, the city has experienced rapid economic growth. The housing conditions in the city have improved substantially. The objectives of this study were to characterize the PM_{10} concentrations in homes and to evaluate the factors affecting the indoor PM_{10} levels.

MATERIALS AND METHODS

Homes were selected on the basis of geographical locations, and included homes near the roadways and those away from roadways and in well-landscaped areas. The latter is referred to as the "green zone" in the following discussions. These two types of homes differ in the amounts of city traffic and vegetative coverage. Near-roadway homes are adjacent to one or more roads with heavy traffic, especially during rush hours. Brief descriptions of the monitoring sites are provided in Table 1. Among the 16 homes, six are located near roadways and the rest in the green zones. All the homes are urban flats on different floors of multi-storey residential buildings except H9, which is a single-storey house.

Correspondence to: Y. H. Bai

Table 1. Summary of the sampling sites[a].

Home No.	Location	Home age	Floor	No. occupants	Smoking	Pets	Kitchen ventilation
H1	NT	1	3rd	3	Yes	No	S
H2	NT	1	NA	3	No	Dog	N and V
H3	NT	2	29th	4	No	No	S
H4	NT	4	10th	4	Yes	No	S and N
H5	NT	4	10th	2	NA	No	S and N
H6	NT	2	16th	3	No	No	S and N
H7	GZ	5	3rd	5	Yes	No	NA
H8	GZ	5	8th	3	Yes	No	S
H9	GZ	4	1st	3	Yes	No	S
H10	GZ	4	2nd	4	No	No	S and N
H11	GZ	4	2nd	5	Yes	No	NA
H12	GZ	3	7th	5	No	No	V
H13	GZ	3	7th	4	Yes	No	S and N
H14	GZ	3	2nd	4	No	No	V
H15	GZ	1	30th	3	Yes	No	S and N
H16	GZ	1	26th	3	Yes	No	S

[a] NT= Near traffic, GZ= Green zone, S=Smoke fan, N=Natural ventilation, V=Ventilation fan, NA=Data not available.

During the period of air sampling, all of the homes were occupied. Nine of them had at least one smoker. The living rooms of all the homes selected were ventilated by opening window or using an air-conditioner. For the kitchens, ventilation was provided by operation of exhaust fans or smoke fan or through open windows. All homes used coal gas for cooking and electricity for heating. This study was conducted from September 2004 to January 2005, and covered two seasons: fall and winter. In each sampling season, each home was monitored twice a day (9:00-11:30, and 14:30-17:00) for two to three consecutive days using the identical sampling equipment.

Indoor and outdoor air samples were taken simultaneously at each sampling site. Indoor air samples were collected in living room, bedroom, and kitchen. Whenever possible, the sampling locations were away from hallways, ventilation openings, and air drafts. The sampling points were 0.8 to 1.2m above the floor and at least 0.5 m away from walls. All of the outdoor air samples were taken at the street level, near the front door of the home. During the PM_{10} measurement, indoor and outdoor temperature and relative humidity were also recorded. Information about building characteristics and human activities was obtained by interviewing the occupants.

DustScan Scout Model 3020 Aerosol Monitors (Thermo Electron Co. NY, USA) with 15-mm air inlet tubing were used to measure the mass concentrations of PM_{10}. This instrument is based on the method of light scattering. The sampling flow rate was set to 1.7 L/min, measurement range 0 to 2 mg/m^3, and the readout

1-minute average. A continuous purge of filtered air keeps the light emitting and sensing optics clean. The unit maintains a consistent zero baseline by automatically re-zeroing itself with filtered air every 15 minutes. The instruments were controlled by software ScoutTerm Version 1.0. The aerosol monitors were calibrated against a known concentration of Arizona Road Dust. The corresponding mass resolution was 0.001 mg/L. On each sampling day, the monitors were checked with a span insert. Additional span checks were performed weekly by the investigator in the field. Automatic temperature compensation allowed the instrument to operate under changing environmental conditions.

RESULTS AND DISCUSSION

Data were statistically analyzed to determine the significance of variations in indoor and outdoor PM_{10} mass concentrations according to geographical locations, sampling seasons, and other factors (Table 2). The indoor daily average PM_{10} concentrations ranged from 93.2 to 193 $\mu g/m^3$ in fall and 53.3 to 164 $\mu g/m^3$ in winter; the corresponding outdoor PM_{10} concentrations ranged from 82.8 to 142 $\mu g/m^3$ in fall and 53.5 to 119 $\mu g/m^3$ in winter. Overall, the indoor concentrations were higher than the outdoor and the differences were statistically significant for both fall ($F=32.05$, $p<0.0001$) and winter ($F=25.15$, $p<0.0001$). Most indoor and outdoor daily average PM_{10} concentrations were below the China National Indoor Air Quality Standard of 150 $\mu g/m^3$ (daily average). The indoor-to-outdoor (I/O) ratios are shown in Figure 1. Four homes had I/O ratios less than one in the fall season, and one home in the winter season. The rest had I/O rations from 1.0 to 2.3. Information from questionnaires indicated that the four homes with low I/O ratios kept the windows and doors open most of the time in the fall and had less cooking activities than other homes.

The daily average outdoor PM_{10} concentrations for the monitoring sites near roadways were significantly higher than those in the green zone ($F=11.85$, $p= 0.0006$). The maximum outdoor PM_{10} concentration was 229 $\mu g/m^3$ in the sites near roadways, as compared with 146 $\mu g/m^3$ for homes in the green zones. The results suggest that penetration of automobile emissions and road dusts are a contributing factor to elevated indoor PM_{10} concentrations in homes near roadways. The daily average indoor PM_{10} concentrations were significantly higher than the outdoor concentrations for all the homes in the green zones ($F=37.68$, $p<0.0001$). Table 3 compares the results from this study with those from the selected cities in China and other countries. The levels of PM_{10} mass concentrations in this study are lower than those in the cities in the mainland of China (i.e., Beijing, Guangzhou), but higher than those in the cities in other countries (i.e., London, Amsterdam, and Birmingham) and Hong Kong, China.

The PM_{10} levels in different rooms in the same home may be different due to their functions. The survey showed that there were no combustion appliances in either the living room or bedroom. Thus, pollutants generated from fuel combustion should have higher concentrations in the kitchen. In the following discussion, the

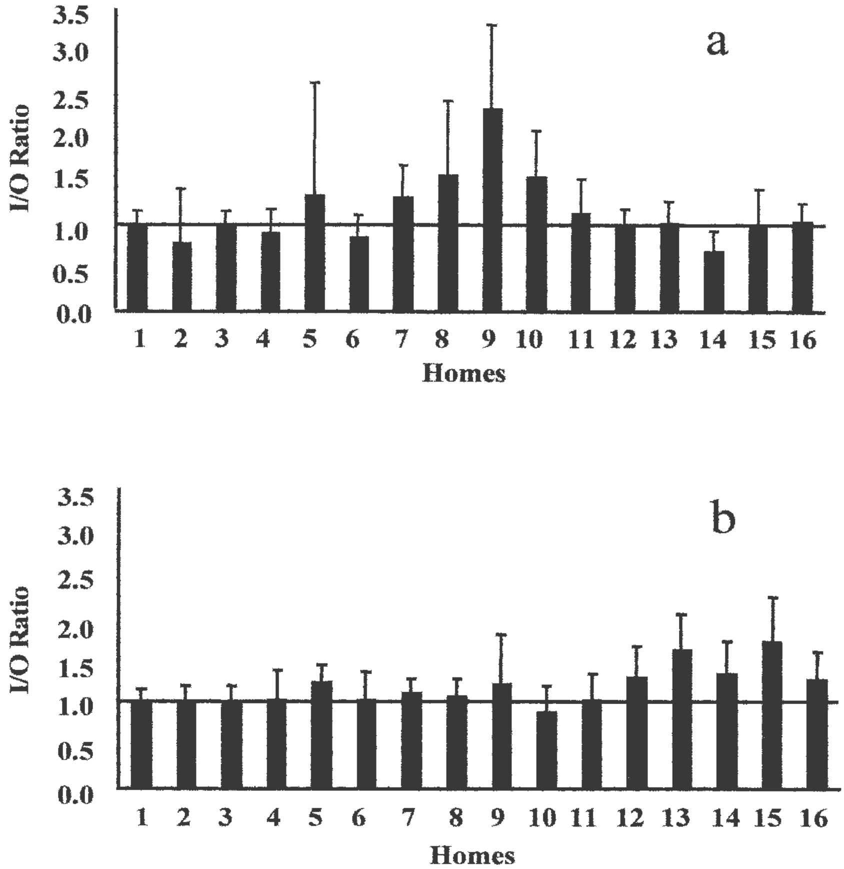

Figure 1. The I/O ratio for all homes in fall (a) and winter (b).

Table 2. Statistics of PM_{10} concentration measurements ($\mu g/m^3$).

Sampling Location	N	Mean	Max	Min	S.D.
Indoor	587	122	353	15.0	50.1
Outdoor	96	106	229	34.0	38.2
Near traffic - indoor	228	97.3	200	15.0	38.7
Near traffic - outdoor	52	105	229	34.0	44.0
Green zone - indoor	359	130	353	45.0	52.2
Green zone - outdoor	44	95.2	146	54.0	29.7
Smoking	324	130	353	38.0	35.6
No smoking	227	106	225	15.0	24.4

Table 3. Comparison of the PM_{10} mass concentrations in Guiyang with other cities (μ g/m^3).

Sampling site	Date	Mean indoor	Mean outdoor	References
Birmingham, UK	One year, 1998	15.0-88.0	13.4-27.0	Jones et al. 2000
Amsterdam, Holland	Jan.–Apr. 1995	22.0-37.0	36-43	Fischer et al. 2000
London, UK	Apr.–Oct. 1998	11.8-26.0	18.5-38.6	Ní Riain et al. 2003
Hong Kong	Fall/winter, 2001	63.3	69.5	Christopher et al. 2002
Beijing, China	Nov. 2003	77.2-167	112-235	Zhang et al. 2005
Guangzhou, China	Summer, 2003	128	144	Wang et al. 2006
Guiyang, China	Fall/winter, 2004	123	106	This study

data for the living room and bedroom are combined because of their similarity. As shown in Figure 2, the mean concentrations of PM_{10} recorded in the living rooms and bedrooms were generally lower than those measured in the kitchens. The average PM_{10} concentrations for the living rooms ranged from 52.0 to 149 μg/m^3 with an average of 107 μg/m^3 in fall, and from 60.1 to 169 μg/m^3 with an average of 122 μg/m^3 in winter. The average PM_{10} concentrations for the kitchens ranged from 54.6 to 182 μg/m^3 with an average of 126 μg/m^3 in fall, and from 60.8 to 217 μg/m^3 with an average of 132 μg/m^3 in winter. The average levels of PM_{10} in the kitchens exceeded those in the living rooms by 3% to 31%. The results also indicate that PM_{10} have high-level correlations between rooms (R^2 = 0.82, n = 187).

The indoor levels of PM_{10} in the kitchen were probably attributable to cooking activity. Several studies found that airborne particles levels were considerably affected by certain cooking styles such as frying (Chao et al., 1998). All of the surveyed homes in Guiyang city followed Chinese cooking styles, in which stir-frying in a wok is common way of preparing dishes. Most of the PM_{10} daily average concentrations in living rooms were below the China National Indoor Air Quality Standard of 150 μg/m^3. On the other hand, more kitchen samples exceeded the standard: 18.8% in fall and 37.5% in winter. During winter season, homeowners tend to keep windows and doors closed to keep warm. Inadequate ventilation could increase the pollutant levels in the kitchen.

A major source of indoor PM_{10} mass could be attributed to environmental tobacco smoke (ETS). In this study, significant difference was found between homes with and without smokers (F=7.5, $p<0.0001$). The average indoor PM_{10} levels in homes with and without smokers were 131μg /m^3 and 107 μg /m^3, respectively.

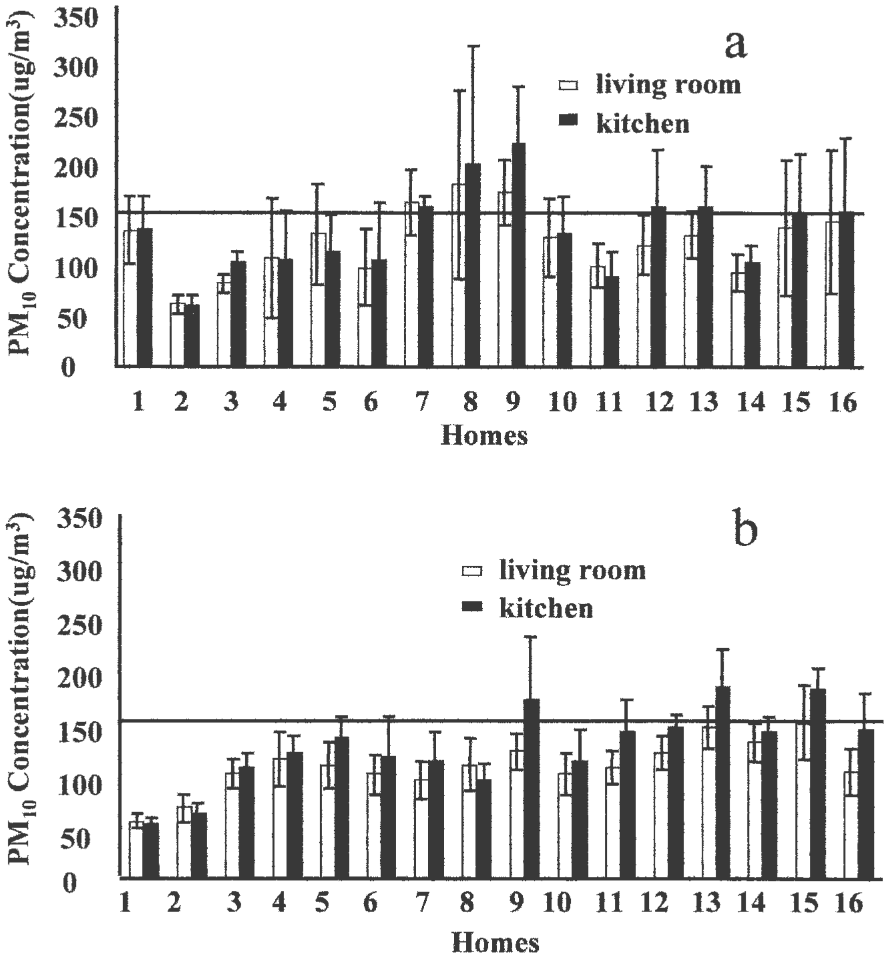

Figure 2. Concentration of PM_{10} in living rooms and kitchens of all monitoring homes in fall (a) and winter (b). The horizontal lines denote the China National Indoor Air Quality Standard for PM_{10}.

The additional PM_{10} concentration due to smoking ranged from 38.0 to 353 $\mu g/m^3$, depending upon the number of smokers. The I/O ratios in smoking homes were greater than one almost all the time during the day, indicating the dominance of smoking as a source of indoor particles.

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