

JES

JOURNAL OF
ENVIRONMENTAL
SCIENCES

ISSN 1001-0742
CN 11-2629/X

March 1, 2013 Volume 25 Number 3
www.jesc.ac.cn

PM_{2.5}

PM₁₀

OC

EC

PM_{2.1}



Sponsored by
Research Center for Eco-Environmental Sciences
Chinese Academy of Sciences

CONTENTS

Aquatic environment

Applicable models for multi-component adsorption of dyes: A review Babak Noroozi, George A. Sorial	419
Effects of sludge dredging on the prevention and control of algae-caused black bloom in Taihu Lake, China Wei He, Jingge Shang, Xin Lu, Chengxin Fan	430
Distribution characteristics and source identification of polychlorinated dibenzo- <i>p</i> -dioxin and dibenzofurans, and dioxin-like polychlorinated biphenyls in the waters from River Kanzaki, running through Osaka urban area, Japan Masao Kishida	441
Pre-oxidation with KMnO ₄ changes extra-cellular organic matter's secretion characteristics to improve algal removal by coagulation with a low dosage of polyaluminium chloride Lei Wang (female), Junlian Qiao, Yinghui Hu, Lei Wang (male), Long Zhang, Qiaoli Zhou, Naiyun Gao	452
Identification of causative compounds and microorganisms for musty odor occurrence in the Huangpu River, China Daolin Sun, Jianwei Yu, Wei An, Min Yang, Guoguang Chen, Shujun Zhang	460
Influences of perfluorooctanoic acid on the aggregation of multi-walled carbon nanotubes Chengliang Li, Andreas Schäffer, Harry Vereecken, Marc Heggen, Rong Ji, Erwin Klumpp	466
Rapid degradation of hexachlorobenzene by micron Ag/Fe bimetal particles Xiaoqin Nie, Jianguo Liu, Xianwei Zeng, Dongbei Yue	473
Removal of Pb(II) from aqueous solution by hydrous manganese dioxide: Adsorption behavior and mechanism Meng Xu, Hongjie Wang, Di Lei, Dan Qu, Yujia Zhai, Yili Wang	479
Cr(VI) reduction capability of humic acid extracted from the organic component of municipal solid waste Barbara Scaglia, Fulvia Tambone, Fabrizio Adani	487
Off-flavor compounds from decaying cyanobacterial blooms of Lake Taihu Zhimei Ma, Yuan Niu, Ping Xie, Jun Chen, Min Tao, Xuwei Deng	495
Pollutant concentrations and pollution loads in stormwater runoff from different land uses in Chongqing Shumin Wang, Qiang He, Hainan Ai, Zhentao Wang, Qianqian Zhang	502

Atmospheric environment

Influence of fuel mass load, oxygen supply and burning rate on emission factor and size distribution of carbonaceous particulate matter from indoor corn straw burning (Cover story) Guofeng Shen, Miao Xue, Siye Wei, Yuanchen Chen, Bin Wang, Rong Wang, Huizhong Shen, Wei Li, Yanyan Zhang, Ye Huang, Han Chen, Wen Wei, Quyu Zhao, Bin Li, Haisu Wu, Shu Tao	511
Synergistic impacts of anthropogenic and biogenic emissions on summer surface O ₃ in East Asia Yu Qu, Junling An, Jian Li	520
Effect of central ventilation and air conditioner system on the concentration and health risk from airborne polycyclic aromatic hydrocarbons Jinze Lv, Lizhong Zhu	531
Emission inventory evaluation using observations of regional atmospheric background stations of China Xingqin An, Zhaobin Sun, Weili Lin, Min Jin, Nan Li	537
An improved GC-ECD method for measuring atmospheric N ₂ O Yuan Yuan Zhang, Yujing Mu, Shuangxi Fang, Junfeng Liu	547
Adsorption of carbon dioxide on amine-modified TiO ₂ nanotubes Fujiao Song, Yunxia Zhao, Qin Zhong	554

Terrestrial environment

Factors influencing the contents of metals and As in soils around the watershed of Guanting Reservoir, China Li Xu, Tiejun Wang, Wei Luo, Kun Ni, Shijie Liu, Lin Wang, Qiushuang Li, Yonglong Lu	561
Photolysis of polycyclic aromatic hydrocarbons on soil surfaces under UV irradiation Chengbin Xu, Dianbo Dong, Xuelian Meng, Xin Su, Xu Zheng, Yaoyao Li	569
Sorption and transport studies of cetyl trimethylammonium bromide (CTAB) and Triton X-100 in clayey soil Sivaram Harendra, Kumaraswamy Vipulanandan	576

Environmental biology

Effects of soil water and nitrogen availability on photosynthesis and water use efficiency of <i>Robinia pseudoacacia</i> seedlings Xiping Liu, Yangyang Fan, Junxia Long, Ruifeng Wei, Roger Kjellgren, Chunmei Gong, Jun Zhao	585
Phytoremediation potential of charophytes: Bioaccumulation and toxicity studies of cadmium, lead and zinc Najjapak Sooksawat, Metha Meetam, Maleeya Kruatrachue, Prayad Pokethitiyook, Koravid Nathalang	596
Sulfur speciation and bioaccumulation in camphor tree leaves as atmospheric sulfur indicator analyzed by synchrotron radiation XRF and XANES Jianrong Zeng, Guilin Zhang, Liangman Bao, Shilei Long, Mingguang Tan, Yan Li, Chenyan Ma, Yidong Zhao	605
Hydrocarbon biodegradation and dynamic laser speckle for detecting chemotactic responses at low bacterial concentration Melina Nisenbaum, Gonzalo Hernán Sendra, Gastón Alfredo Cerdá Gilbert, Marcelo Scagliola, Jorge Froilán González, Silvia Elena Murialdo	613

Environmental health and toxicology

Biogeochemical reductive release of soil embedded arsenate around a crater area (Guandu) in northern Taiwan using X-ray absorption near-edge spectroscopy Kai-Ying Chiang, Tsan-Yao Chen, Chih-Hao Lee, Tsang-Lang Lin, Ming-Kuang Wang, Ling-Yun Jang, Jyh-Fu Lee	626
---	-----



Effect of central ventilation and air conditioner system on the concentration and health risk from airborne polycyclic aromatic hydrocarbons

Jinze Lv^{1,2}, Lizhong Zhu^{1,2,*}

1. Department of Environmental Science, Zhejiang University, Hangzhou 310058, China

2. Zhejiang Province Key Laboratory of Organic Pollution Process and Control, Hangzhou 310058, China

Received 28 June 2012; revised 12 July 2012; accepted 24 July 2012

Abstract

Central ventilation and air conditioner systems are widely utilized nowadays in public places for air exchange and temperature control, which significantly influences the transfer of pollutants between indoors and outdoors. To study the effect of central ventilation and air conditioner systems on the concentration and health risk from airborne pollutants, a spatial and temporal survey was carried out using polycyclic aromatic hydrocarbons (PAHs) as agent pollutants. During the period when the central ventilation system operated without air conditioning (AC-off period), concentrations of 2–4 ring PAHs in the model supermarket were dominated by outdoor levels, due to the good linearity between indoor air and outdoor air ($r_p > 0.769$, $p < 0.05$), and the slopes (1.2–4.54) indicated that ventilating like the model supermarket increased the potential health risks from low molecular weight PAHs. During the period when the central ventilation and air conditioner systems were working simultaneously (AC-on period), although the total levels of PAHs were increased, the concentrations and percentage of the particulate PAHs indoors declined significantly. The BaP equivalency (BaP_{eq}) concentration indicated that utilization of air conditioning reduced the health risks from PAHs in the model supermarket.

Key words: particulate; gaseous; PAHs; health risk; public place

DOI: 10.1016/S1001-0742(12)60079-5

Introduction

During the past two decades, indoor air pollution has drawn increasing attention all over the world. Many pollutants that people respire indoors come from outdoor sources, and long term exposure to them may cause cardiovascular disease, cancer, respiratory disease and so on (Calderon-Garciduenas et al., 2004; Knutsen et al., 2004; Schwartz, 1996; Schwarze et al., 2006). The exchange of pollutants between indoor and outdoor air is achieved by ventilation, therefore the ventilation pattern will have a significant effect on indoor air quality. In previous studies, the effects of open windows, ventilation frequency and air conditioner use on levels of indoor airborne pollutants were considered (Levy et al., 2002; Ohura et al., 2004). However, as far as we know there have been few studies concerning the influences of central ventilation systems on the concentrations and health risk from airborne pollutants.

Polycyclic aromatic hydrocarbons (PAHs), many of which are strongly potent carcinogens and/or mutagens (Alfheim et al., 1984), are generated from incomplete py-

rolysis of organic matter such as fossil fuel, cigarettes and coal. Residential heating, power generation, industry and automobile exhaust produce the dominant mass of PAHs outdoors (Baek et al., 1991; Maliszewska-Kordybach, 1999; Mastral and Callén, 2000), especially for cities; while tobacco smoke, cooking and heating are the major indoor sources (Baek et al., 1991; Gundel et al., 1995; Maliszewska-Kordybach, 1999). As smoking is gradually being forbidden in public places in recent years in China, the PAHs that people are exposed to in public places are mainly from outdoor sources. Besides, PAHs exist both in the gaseous and particulate phase. The proportion of either phase is determined by the molecular structure of each PAH. Generally, the ratio of gaseous to particulate PAH decreases as the molecular weight increases (Pankow, 1987). Therefore, PAHs are ideal for studying the effect of ventilation patterns on the concentrations of both gaseous and particulate pollutants.

This comparative study on the indoor to outdoor ratios of PAH concentrations for buildings was conducted to evaluate the effects of the central ventilation and air conditioner systems on PAH concentrations, as well as potential health risks.

* Corresponding author: Email: zlz@zju.edu.cn

1 Materials and methods

1.1 Sampling sites

Two large supermarkets (SMs) and two shopping centers (SCs), with identical central ventilation and air conditioner systems, were carefully selected in Hangzhou, China. The central air conditioner systems operated commonly during May to September to keep indoor temperature below outdoor temperature (AC-on period), while indoor temperature is higher than outdoor temperature when the air conditioner is not working (AC-off). Central ventilation is the only pattern for the air exchange between indoor and outdoor air in both AC-on and AC-off periods. The largest supermarket in Hangzhou, with business area of 24,000 m², was chosen as a model microenvironment with a central ventilation and air conditioner system for long-term air sampling. It was 50 meters away from a main street, around which automobile exhaust was the dominant source of airborne PAHs. The ventilation rate of the model supermarket (MS) was about 450 m³/min. Twelve non-smoking residences around the MS with natural ventilation were selected as the control. Other details of SMs, SCs and residences were presented in our previous study (Lu et al., 2008).

1.2 Air sampling

Gaseous and particulate PAHs were collected by 2.5 g XAD-2 adsorbent (Supelco, USA) and 25 mm glass fiber filter (GFF, Whatman, England) respectively. A mini-pump (DDY-1.5, Xingyu, China), which was placed at a height of 1.5–1.8 m above the ground, was used for air sampling at a flow rate of 1.0 L/min for 8 hr (8:30–16:30). The flow rates were measured before and after the sampling, with deviations less than 2%. Windows were closed during sampling in residences. Six samplers were set in the region of household appliances, cosmetics and daily necessities respectively, and two samplers were set on the roof of the SMs and SCs.

Fourteen samples in SMs and SCs were collected during March to April, 2006. A total of 58 samples for residences were collected in January, 2007. A total of 61 samples in the MS were taken during 2007 to 2010, of which 26 samples were taken during AC-off periods.

1.3 Analysis of PAHs samples

The determination of PAHs was described in our previous paper (Liu et al., 2001). In general, after air sampling, XAD-2 adsorbent samples were poured into a stoppered 25 mL glass tube with a 20 mL mixture of dichloromethane and acetonitrile ($V/V = 3/2$), while glass fiber filters were cut into pieces and placed in a stoppered 25 mL glass tube with 10 mL dichloromethane (Supelco, USA). Subsequently, the samples were sonicated for 30 min. During the sonication, the water in the ultrasonic bath was replaced frequently to prevent overheating. Then 10 mL extracts

of XAD-2 and 5 mL extracts of glass fiber filters were transferred into other glass stoppered tubes. Extracts with 30 μ L dimethyl sulfoxide (Supelco, USA) were evaporated under a gentle flow of nitrogen gas at room temperature and then 970 μ L acetonitrile was added (Supelco, USA).

The following 14 PAHs (Supelco, USA) were determined in the air samples: naphthalene (NA), acenaphthene (AC), phenanthrene (PHEN), anthracene (AN), fluoranthene (FLUR), pyrene (PY), benzo[a]anthracene (BaA), chrysene (CHRY), benzo[b]fluoranthrene (BbF), benzo[k]fluoranthrene (BkF), benzo[a]pyrene (BaP), dibenzo[a,h]anthracene (DA), benzo[ghi]perylene (BP), and indeno(1,2,3-cd)pyrene (IN). PAHs were determined using UPLC (ACQUITY, Waters, USA) equipped with a C18 column (ACQUITY UPLC 1.7 μ m, 2.1 \times 150 mm, Waters, USA) and a FLR detector. Data were analyzed by SPSS statistics 17.0.

1.4 Quality control

XAD-2 adsorbent was cleaned via soxhlet extraction in dichloromethane and methanol until no signal of PAHs was detected in UPLC. GFFs were heated at 400°C for 6 hr prior to use. PAHs corresponding to 100–800 ng/m³ in vapor phase and 2–10 ng/m³ in particulate phase were spiked onto XAD-2 and GFFs respectively to undertake a PAHs recovery study ($n = 5$). The recovery of NA was 77% for vapor phase and 78% for particulate phase. The recoveries of the other 13 PAHs all exceeded 85%, and the relative standard deviations of the recoveries of the 14 PAHs were less than 3.8%.

2 Results and discussion

2.1 Higher potential risks from the PAHs in SMs & SCs than in residences

A comparative study of SMs & SCs and residences, using central ventilation and natural ventilation respectively, based on our previous work, was carried out in the AC-off period (Lu et al., 2008; Zhu et al., 2009). **Table 1** shows that the average indoor to outdoor ratio (I/O) of 2–4 ring PAHs for SMs & SCs is 3.98 (0.94–12.51), significantly higher than 1.03 (0.63–1.68) for residences ($p < 0.05$), while the I/O of 5–6 ring PAHs are similar between SMs & SCs and residences ($p < 0.05$), except for BP ($0.01 < P < 0.05$). This indicated that people were faced with a higher health risk from 2–4 ring PAHs in SMs & SCs than in residences.

Two facts could cause the diversity of I/O for 2–4 ring PAHs. Firstly, there may be some stronger sources existing in SMs & SCs, for the I/O is always greater than 1 when significant sources were found indoors (Halsall et al., 2008; Liu et al., 2001; Ohura et al., 2004). Secondly, the different ventilation patterns used in the two kinds of microenvironment may greatly influence the outdoor-indoor air exchange.

Table 1 Indoor to outdoor ratios (I/O) of PAHs in SMs & SCs and residences

PAHs	Ring	Mean I/O		<i>p</i> value
		SMs & SCs	Residences	
NA	2	2.76	1.68	0.01–0.05
AC	3	12.51	1.57	< 0.01
PHEN	3	2.53	1.29	0.01–0.05
AN	3	9.30	0.95	< 0.01
FLUR	4	1.19	0.64	< 0.01
PY	4	1.31	0.78	< 0.01
BaA	4	1.65	0.69	< 0.01
CHRY	4	0.94	0.63	0.01–0.05
BbF	5	0.87	0.70	> 0.05
BkF	5	0.85	0.72	> 0.05
BaP	5	0.89	0.81	> 0.05
DA	5	1.09	0.80	> 0.05
BP	6	1.25	0.82	0.01–0.05
IN	6	0.96	0.79	> 0.05

Some data in **Table 1** have been published in our previous works (Lu and Zhu, 2008, 2009).

SMs: supermarkets; SCs: shopping centers.

2.2 Source identification of indoor PAHs

To evaluate the influence of large amounts of commodities with similar function placed together in a certain region, samplers were set at three different regions in SMs and SCs such as the household appliance region, cosmetic region and daily necessities region. As shown in **Fig. 1**, when the outdoor concentrations of naphthalene (NA) are below 420.58 ng/m³, the indoor concentrations in different regions exhibit a certain order, cosmetic region > daily necessities region > household appliance region, which indicated that certain sources of NA existed in the cosmetic and daily necessities regions. When the outdoor concentration of NA was over 420.58 ng/m³, there was no notable difference found among these regions, largely owing to the effect of outdoor NA. No significant sources of other PAHs were found in the SMs and SCs. Therefore, the relatively higher I/O of 2–4 ring PAHs in SMs and SCs compared to that in residences discussed in Section 2.1 was largely caused by different ventilation patterns.

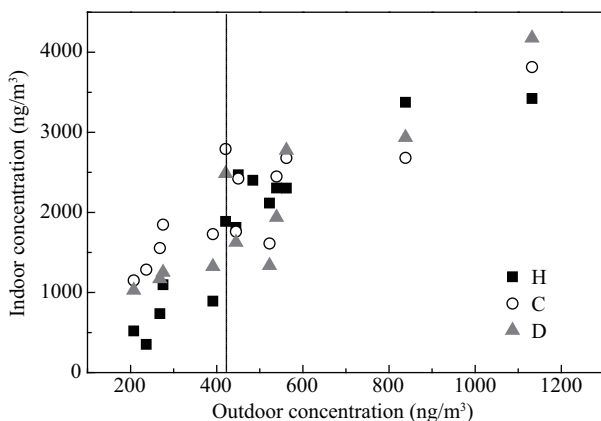


Fig. 1 Correlation between the indoor and outdoor concentrations of naphthalene NA. H: household appliance region; C: cosmetic region; D: daily necessities region.

Table 2 Linear correlations of PAHs between indoors and outdoors

PAHs	AC-off			AC-on		
	<i>n</i>	<i>r_p</i>	Slope	<i>n</i>	<i>r_p</i>	Slope
NA	9	0.989**	3.18	7	0.953**	5.86
AC	7	0.950**	4.54	7	0.157	–
PHEN	9	0.970**	2.30	6	0.527	–
AN	9	0.940**	2.14	6	0.731	–
FLUR	8	0.874**	1.54	7	0.561	–
PY	8	0.954**	2.02	7	0.762*	0.46
BaA	7	0.725	–	7	0.725	–
CHRY	9	0.769*	1.20	7	0.827*	0.37
BbF	8	0.623	–	7	0.446	–
BkF	9	0.100	–	6	0.778	–
BaP	8	–0.507	–	7	0.215	–
DA	8	0.401	–	6	0.412	–
BP	8	0.625	–	6	0.184	–
IN	–	–	–	5	0.080	–

** $P < 0.01$; * $P < 0.05$.

2.3 Effect of central ventilation on PAH transfer

We analyzed the data obtained in the model supermarket (MS) by linear regression. **Table 2** shows that the PAHs could be divided into two parts during the AC-off period. First, the r_p^2 of 2–4 ring PAHs were greater than 0.526 (except for BaA, $p > 0.05$), among which NA had the best linearity ($r_p^2 = 0.978$, $p < 0.01$). This proved that the concentrations of indoor 2–4 ring PAHs in the MS were largely controlled by outdoor levels when central ventilation worked alone, and the higher I/O for SMs and SCs (shown in **Table 1**) was largely due to the ventilation pattern rather than the indoor sources; Second, the r_p^2 of 5–6 ring PAHs were below 0.388, showing poor linearity between indoor and outdoor concentrations ($p > 0.05$). To better understand this diversity, the phase distribution of outdoor PAHs and r_p^2 are both given in **Fig. 2**. As can be seen in this figure, the r_p^2 decreased significantly with the proportion of vapor phase, revealing a significant effect of the ventilation pattern on the particulate PAHs transfer. This was owing to the fact that the filters in the central ventilation system blocked a portion of the particles during the air transfer process from outdoor to indoor. As no notable reduction of the concentrations was observed for 5–6 ring PAHs in indoor air, there should be other factors influencing the levels of the indoor particulate PAHs, such as dust resuspension (Saraga et al., 2010).

The slopes of 2–4 ring PAHs in the MS were 1.20–4.54, which were much higher than those in the residences. It was more likely that the MS acted as a sorbent, which concentrated the 2–4 ring PAHs from outdoors. Therefore people in public places ventilating like the MS may face higher risks from 2–4 ring PAHs than in residences with natural ventilation.

Source identification of PAHs in MS was evaluated by factor analysis (calculating by SPSS Statistics 17.0). **Figure 3** shows that Factor 1 explained 65.53% and 77.05% of the variance of outdoor PAHs in the periods of AC-off

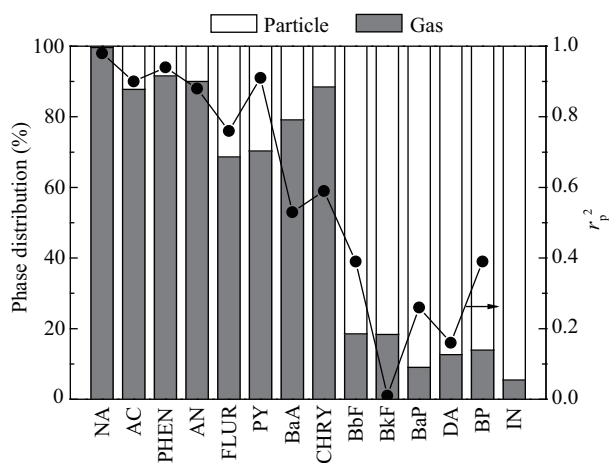


Fig. 2 Phase distribution and r_p^2 of PAHs in MS.

and AC-on, respectively. PAHs with high molecular weight (molecular weight) were mainly generated from high temperature splitting of organic matter (automobile exhaust). Factor 1 had high factor load on the high molecular weight PAHs and FLUR (Larsen and Baker, 2003; Li and Kamens, 1993; Simcik et al., 1999), which indicated that automobile exhaust was the major source of PAHs in the ambient air of the MS. The percentage variance of Factor 1 in the AC-off period was lower than that in the AC-on period, largely owing to the affects of coal burning in the AC-off period and climate change. The factors with high load on low molecular weight PAHs in indoor air were different from those outdoors, which was largely due to the fact that the filters in the central ventilation system blocked a portion of particles from outdoors, which thereby changed the relationship between the concentrations of the low and high molecular weight PAHs.

2.4 Effect of air conditioner on indoor PAHs levels

Table 2 shows that no linear correlation between PAHs indoors and outdoors was observed during the AC-on period, except for NA ($r_p = 0.953$, $p < 0.01$), PY ($r_p = 0.762$, $p < 0.05$) and CHRY ($r_p = 0.827$, $p < 0.05$), which was significantly different from the AC-off period. This is largely due to the fact that the air exchange between the indoor and outdoor air is lower when the air conditioner is operating than that when the central ventilation works alone. Moreover, the lower temperature indoors compared to outdoors would reduce the air exchange between indoor air and outdoor air.

As can be seen in Table 3, although the total concentration of PAHs in the AC-on period was slightly higher than that in AC-off period, the percentage of particulate PAHs in the AC-on period was much lower. Figure 4 shows that the concentrations of particulate 4–6 ring PAHs outdoors were similar between the AC-off and AC-on periods, while those indoors in the AC-on period were significantly lower than in the AC-off period. This was largely due to the fact that the air conditioner system, which circulates the indoor air

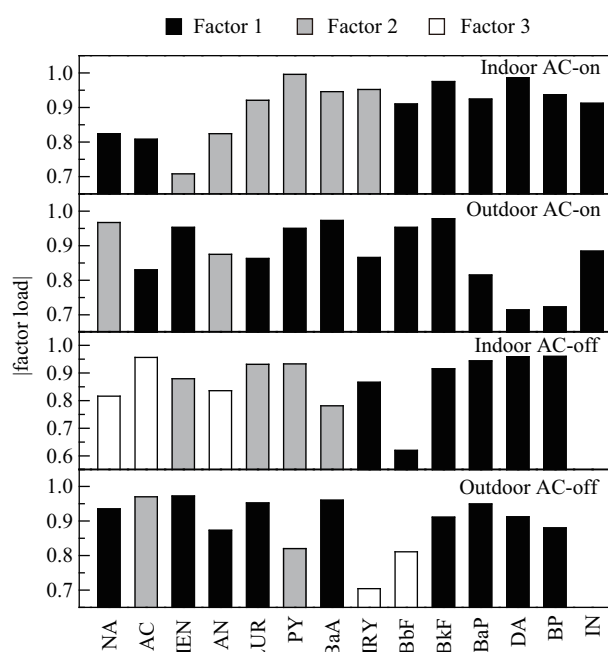


Fig. 3 Factor analysis of PAHs in MS.

through the ventilation ducts, thereby blocks a portion of particulate PAHs. The levels of gaseous PAHs in the AC-off period were higher than in the AC-on period. However, their difference indoors was smaller than that outdoors, mainly owing to the lower temperature indoors and the reduction of particulate PAHs by the air conditioner.

2.5 Assessment of health risk

Several approaches have been developed to evaluate the potencies of a complex mixture of PAHs with respect to inhalation cancer risks to humans. The BaP equivalency (BaP_{eq}) concentration is widely applied to assess toxicity potencies by using a list of toxic equivalency factors (TEFs) based on BaP (Petry et al., 1996). Figure 5 shows that the indoor BaP_{eq} concentration was 2.14 ± 1.09 fold and 1.30 ± 0.65 fold higher than the outdoor BaP_{eq} concentration in the AC-off and AC-on periods, respectively. Although the concentration of the outdoor BaP_{eq} in the AC-on period was higher than that in the AC-off period, the indoor BaP_{eq} concentration in the AC-on period was 28.9% lower. This was due to the air conditioner reducing the levels of particulate PAHs, which have higher health risks.

Nowadays, central ventilation systems have been widely adopted in millions of public places in China. Based on the data we obtained, ventilation patterns should be selected carefully and designed properly to decrease the magnification effect of pollutants from outdoor sources by buildings. Although application of air conditioning along with central ventilation systems decreases the air exchange rate, it may decrease the health risks from outdoor pollutants, especially for particulate phases.

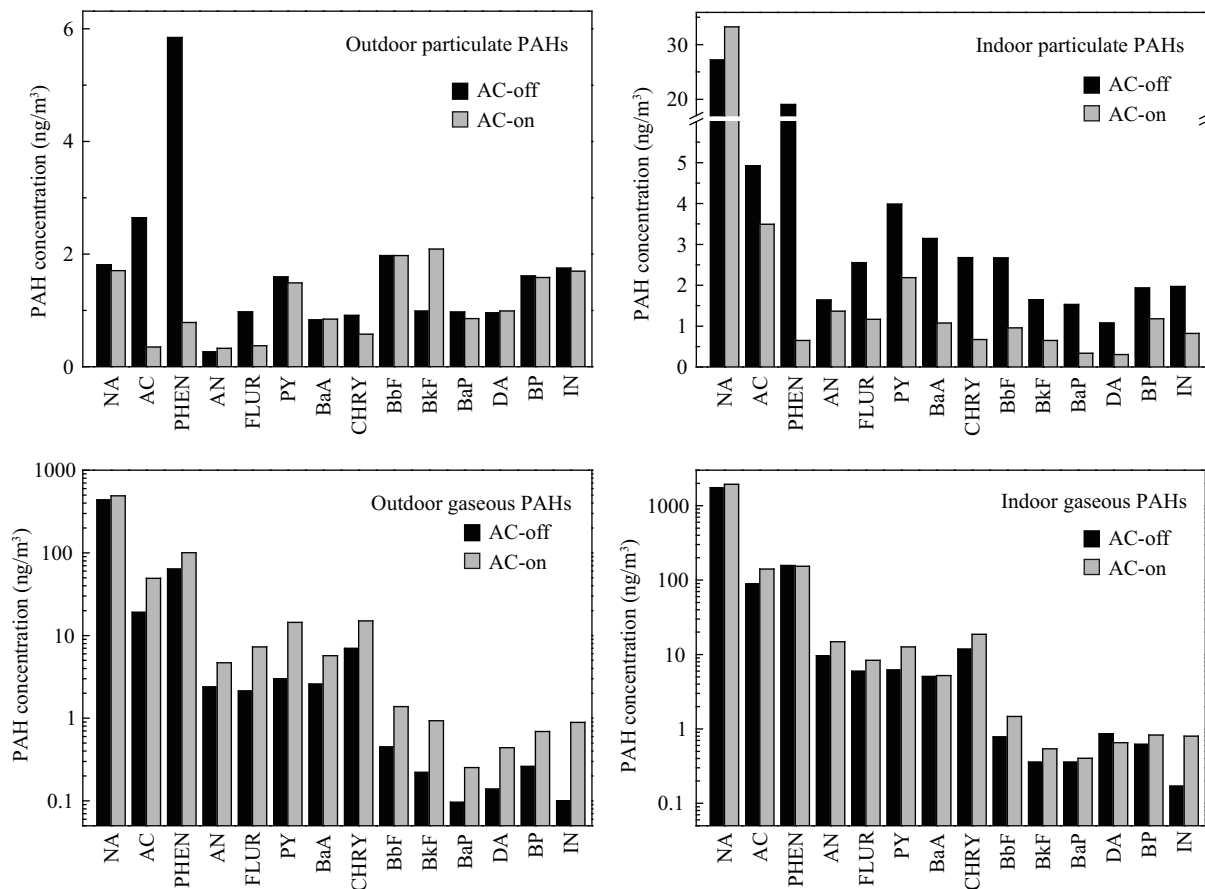


Fig. 4 Concentrations of gaseous and particulate PAHs in indoor and outdoor air.

Table 3 Average concentrations and phase distribution of PAHs in MS

PAHs	AC-off			AC-on		
	Concentration (ng/m ³)	Particulate (%)	Gaseous (%)	Concentration (ng/m ³)	Particulate (%)	Gaseous (%)
NA	1772.08	1.53	98.47	1968.78	1.69	98.31
AC	94.46	5.22	94.78	144.46	2.42	97.58
PHEN	176.13	10.81	89.19	154.33	0.42	99.58
AN	11.27	14.54	85.46	16.25	8.41	91.59
FLUR	8.51	30.00	70.00	9.50	12.26	87.74
PY	10.17	39.16	60.84	14.84	14.73	85.27
BaA	8.22	38.23	61.77	6.30	17.08	82.92
CHRY	14.46	18.51	81.49	19.34	3.48	96.52
BbF	3.45	77.38	22.62	2.43	39.42	60.58
BkF	2.00	82.18	17.82	1.19	54.39	45.61
BaP	1.89	81.08	18.92	0.74	45.32	54.68
DA	1.94	55.49	44.51	0.96	31.84	68.16
BP	2.55	75.66	24.34	2.01	58.81	41.19
IN	2.14	92.06	7.94	1.62	50.75	49.25
Total	2109.27	3.60	96.40	2342.72	2.05	97.95

3 Conclusions

The I/O ratios of the 2–4 ring PAHs for the shopping centers and supermarkets with central ventilation systems were significantly higher than those for residences with a natural ventilation pattern. In the model supermarket, a good linearity ($r_p > 0.874, p < 0.01$) was observed between low molecular weight PAHs in indoor and outdoor air

in the AC-off period, which indicated that the concentrations of low molecular weight PAHs indoors were largely dominated by the outdoor levels when central ventilation worked alone. The slopes of the 2–4 ring PAHs in the MS were much higher than 1, revealing a magnification effect of the 2–4 ring PAHs levels outdoors. When central ventilation and air conditioning operated simultaneously, the concentrations of PAHs increased, while the levels

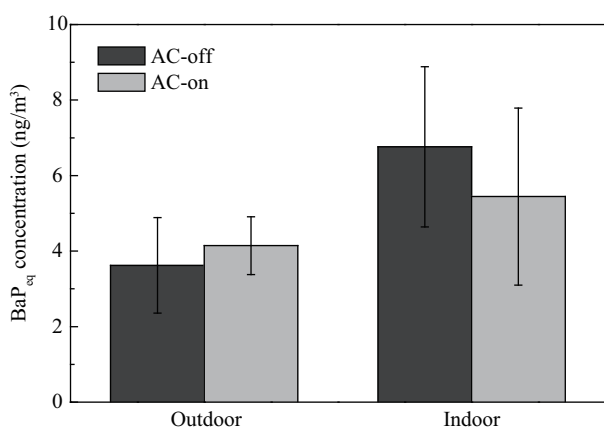


Fig. 5 BaP_{eq} concentrations of PAHs in the AC-on and AC-off period.

and percentages of indoor particulate PAHs decreased significantly. The I/O ratio of BaP_{eq} in the AC-off period was 1.65 times higher than that in the AC-on period, which shows that the operation of the air conditioner in the MS reduced the potential health risks of airborne PAHs.

Acknowledgments

This work was supported by the National High Technology Research and Development Program (863) of China (No. 2010AA064902).

References

- Alfheim I, Becher G, Hongslo J K, Ramdahl T, 1984. Mutagenicity testing of high-performance liquid-chromatography fractions from wood stove emission samples using a modified *salmonella* assay requiring smaller sample volumes. *Environmental Mutagenesis*, 6(1): 91–102.
- Baek S O, Field R A, Goldstone M E, Kirk P W, Lester J N, Perry R, 1991. A review of atmospheric polycyclic aromatic hydrocarbons: Sources, fate and behavior. *Water, Air, and Soil Pollution*, 60(3-4): 279–300.
- Calderon-Garciduenas L, Reed W, Maronpot R R, Henriquez-Roldan C, Delgado-Chavez R, Calderon-Garciduenas A et al., 2004. Brain inflammation and Alzheimer's-like pathology in individuals exposed to severe air pollution. *Toxicologic Pathology*, 32(6): 650–658.
- Gundel L A, Mahanama K R R, Daisey J M, 1995. Semivolatile and particulate polycyclic aromatic hydrocarbons in environmental tobacco smoke: cleanup, speciation, and emission factors. *Environmental Science and Technology*, 29(6): 1607–1614.
- Halsall C J, Maher B A, Karloukovski V V, Shah P, Watkins S J, 2008. A novel approach to investigating indoor/outdoor pollution links: Combined magnetic and PAH measurements. *Atmospheric Environment*, 42(39): 8902–8909.
- Knutsen S, Shavlik D, Chen L H, Beeson W L, Ghamsary M, Petersen F, 2004. The association between ambient particulate air pollution levels and risk of cardiopulmonary and all-cause mortality during 22 years follow-up of a non-smoking cohort. *Epidemiology*, 15(4): S45.
- Larsen R K, Baker J E, 2003. Source apportionment of polycyclic aromatic hydrocarbons in the urban atmosphere: A comparison of three methods. *Environmental Science and Technology*, 37(9): 1873–1881.
- Levy J I, Dumyahn T, Spengler J D, 2002. Particulate matter and polycyclic aromatic hydrocarbon concentrations in indoor and outdoor microenvironments in Boston, Massachusetts. *Journal of Exposure Analysis and Environmental Epidemiology*, 12(2): 104–114.
- Li C K, Kamens R M, 1993. The use of polycyclic aromatic hydrocarbons as source signatures in receptor modeling. *Atmospheric Environment*, 27(4): 523–532.
- Liu Y J, Zhu L Z, Shen X Y, 2001. Polycyclic aromatic hydrocarbons (PAHs) in indoor and outdoor air of Hangzhou, China. *Environmental Science and Technology*, 35(5): 840–844.
- Lu H, Zhu L Z, Chen S G, 2008. Pollution level, phase distribution and health risk of polycyclic aromatic hydrocarbons in indoor air at public places of Hangzhou, China. *Environmental Pollution*, 152(3): 569–575.
- Maliszewska-Kordybach B, 1999. Sources, concentrations, fate and effects of polycyclic aromatic hydrocarbons (PAHs) in the environment. Part A: PAHs in air. *Polish Journal of Environmental Studies*, 8(3): 131–136.
- Mastral A M, Callén M S, 2000. A review on polycyclic aromatic hydrocarbon (PAH): Emissions from energy generation. *Environmental Science and Technology*, 34(15): 3051–3057.
- Ohura T, Amagai T, Fusaya M, Matsushita H, 2004. Polycyclic aromatic hydrocarbons in indoor and outdoor environments and factors affecting their concentrations. *Environmental Science and Technology*, 38(1): 77–83.
- Pankow J F, 1987. Review and comparative-analysis of the theories on partitioning between the gas and aerosol particulate phases in the atmosphere. *Atmospheric Environment*, 21(11): 2275–2283.
- Petry T, Schmid P, Schlatter C, 1996. The use of toxic equivalency factors in assessing occupational and environmental health risk associated with exposure to airborne mixtures of polycyclic aromatic hydrocarbons (PAHs). *Chemosphere*, 32(4): 639–648.
- Saraga D E, Maggos T E, Sfetsos A, Tolis E I, Andronopoulos S, Bartzis J G et al., 2010. PAHs sources contribution to the air quality of an office environment: experimental results and receptor model (PMF) application. *Air Quality, Atmosphere and Health*, 3(4): 225–234.
- Schwartz J, 1996. Air pollution and hospital admissions for respiratory disease. *Epidemiology*, 7(1): 20–28.
- Schwarze P E, Ovrevik J, Lag M, Refsnes M, Nafstad P, Hetland R B et al., 2006. Particulate matter properties and health effects: consistency of epidemiological and toxicological studies. *Human and Experimental Toxicology*, 25(10): 559–579.
- Simcik M F, Eisenreich S J, Liou P J, 1999. Source apportionment and source/sink relationships of PAHs in the coastal atmosphere of Chicago and Lake Michigan. *Atmospheric Environment*, 33(30): 5071–5079.
- Zhu L, Lu H, Chen S, Amagai T, 2009. Pollution level, phase distribution and source analysis of polycyclic aromatic hydrocarbons in residential air in Hangzhou, China. *Journal of Hazardous Materials*, 162(2-3): 1165–1170.

Editorial Board of Journal of Environmental Sciences

Editor-in-Chief

Hongxiao Tang Research Center for Eco-Environmental Sciences, Chinese Academy of Sciences, China

Associate Editors-in-Chief

Jiuhui Qu Research Center for Eco-Environmental Sciences, Chinese Academy of Sciences, China
Shu Tao Peking University, China
Nigel Bell Imperial College London, United Kingdom
Po-Keung Wong The Chinese University of Hong Kong, Hong Kong, China

Editorial Board

Aquatic environment

Baoyu Gao
Shandong University, China
Maohong Fan
University of Wyoming, USA
Chihpin Huang
National Chia Tung University
Taiwan, China
Ng Wun Jern
Nanyang Environment &
Water Research Institute, Singapore
Clark C. K. Liu
University of Hawaii at Manoa, USA
Hokyong Shon
University of Technology, Sydney, Australia
Zijian Wang
Research Center for Eco-Environmental Sciences,
Chinese Academy of Sciences, China
Zhiwu Wang
The Ohio State University, USA
Yuxiang Wang
Queen's University, Canada
Min Yang
Research Center for Eco-Environmental Sciences,
Chinese Academy of Sciences, China
Zhifeng Yang
Beijing Normal University, China
Han-Qing Yu
University of Science & Technology of China

Terrestrial environment

Christopher Anderson
Massey University, New Zealand
Zucong Cai
Nanjing Normal University, China
Xinbin Feng
Institute of Geochemistry,
Chinese Academy of Sciences, China
Hongqing Hu
Huazhong Agricultural University, China
Kin-Che Lam
The Chinese University of Hong Kong
Hong Kong, China
Erwin Klumpp
Research Centre Juelich, Agrosphere Institute
Germany
Peijun Li
Institute of Applied Ecology,
Chinese Academy of Sciences, China

Michael Schloter

German Research Center for Environmental Health
Germany

Xuejun Wang

Peking University, China

Lizhong Zhu

Zhejiang University, China

Atmospheric environment

Jianmin Chen

Fudan University, China

Abdelwahid Mellouki

Centre National de la Recherche Scientifique
France

Yujing Mu

Research Center for Eco-Environmental Sciences,
Chinese Academy of Sciences, China

Min Shao

Peking University, China

James Jay Schauer

University of Wisconsin-Madison, USA

Yuesi Wang

Institute of Atmospheric Physics,
Chinese Academy of Sciences, China

Xin Yang

University of Cambridge, UK

Environmental biology

Yong Cai

Florida International University, USA

Henner Hollert

RWTH Aachen University, Germany

Christopher Rensing

University of Copenhagen, Denmark

Bojan Sedmak

National Institute of Biology, Ljubljana

Lirong Song

Institute of Hydrobiology,
the Chinese Academy of Sciences, China

Chunxia Wang

National Natural Science Foundation of China

Gehong Wei

Northwest A&F University, China

Daqiang Yin

Tongji University, China

Zhongtang Yu

The Ohio State University, USA

Environmental toxicology and health

Jingwen Chen

Dalian University of Technology, China

Jianning Hu

Peking University, China

Guibin Jiang

Research Center for Eco-Environmental Sciences,
Chinese Academy of Sciences, China

Jaeseong Lee

Hanyang University, South Korea

Sijin Liu

Research Center for Eco-Environmental Sciences,
Chinese Academy of Sciences, China

Tsuyoshi Nakanishi

Gifu Pharmaceutical University, Japan

Willie Peijnenburg

University of Leiden, The Netherlands

Chonggang Wang

Xiamen University, China

Bingsheng Zhou

Institute of Hydrobiology,
Chinese Academy of Sciences, China

Environmental catalysis and materials

Hong He

Research Center for Eco-Environmental Sciences,
Chinese Academy of Sciences, China

Junhua Li

Tsinghua University, China

Wenfeng Shangguan

Shanghai Jiao Tong University, China

Yasutake Teraoka

Kyushu University, Japan

Ralph T. Yang

University of Michigan, USA

Environmental analysis and method

Zongwei Cai

Hong Kong Baptist University,
Hong Kong, China

Jiping Chen

Dalian Institute of Chemical Physics,
Chinese Academy of Sciences, China

Minghui Zheng

Research Center for Eco-Environmental Sciences,
Chinese Academy of Sciences, China

Municipal solid waste and green chemistry

Pinjing He

Tongji University, China

Environmental ecology

Rusong Wang

Research Center for Eco-Environmental Sciences,
Chinese Academy of Sciences, China

Editorial office staff

Managing editor Qingcai Feng
Editors Zixuan Wang Suqin Liu Zhengang Mao
English editor Catherine Rice (USA)

JOURNAL OF ENVIRONMENTAL SCIENCES

(<http://www.jesc.ac.cn>)

Aims and scope

Journal of Environmental Sciences is an international academic journal supervised by Research Center for Eco-Environmental Sciences, Chinese Academy of Sciences. The journal publishes original, peer-reviewed innovative research and valuable findings in environmental sciences. The types of articles published are research article, critical review, rapid communications, and special issues.

The scope of the journal embraces the treatment processes for natural groundwater, municipal, agricultural and industrial water and wastewaters; physical and chemical methods for limitation of pollutants emission into the atmospheric environment; chemical and biological and phytoremediation of contaminated soil; fate and transport of pollutants in environments; toxicological effects of terrorist chemical release on the natural environment and human health; development of environmental catalysts and materials.

For subscription to electronic edition

Elsevier is responsible for subscription of the journal. Please subscribe to the journal via <http://www.elsevier.com/locate/jes>.

For subscription to print edition

China: Please contact the customer service, Science Press, 16 Donghuangchenggen North Street, Beijing 100717, China. Tel: +86-10-64017032; E-mail: journal@mail.sciencep.com, or the local post office throughout China (domestic postcode: 2-580).

Outside China: Please order the journal from the Elsevier Customer Service Department at the Regional Sales Office nearest you.

Submission declaration

Submission of an article implies that the work described has not been published previously (except in the form of an abstract or as part of a published lecture or academic thesis), that it is not under consideration for publication elsewhere. The submission should be approved by all authors and tacitly or explicitly by the responsible authorities where the work was carried out. If the manuscript accepted, it will not be published elsewhere in the same form, in English or in any other language, including electronically without the written consent of the copyright-holder.

Submission declaration

Submission of the work described has not been published previously (except in the form of an abstract or as part of a published lecture or academic thesis), that it is not under consideration for publication elsewhere. The publication should be approved by all authors and tacitly or explicitly by the responsible authorities where the work was carried out. If the manuscript accepted, it will not be published elsewhere in the same form, in English or in any other language, including electronically without the written consent of the copyright-holder.

Editorial

Authors should submit manuscript online at <http://www.jesc.ac.cn>. In case of queries, please contact editorial office, Tel: +86-10-62920553, E-mail: jesc@263.net, jesc@rcees.ac.cn. Instruction to authors is available at <http://www.jesc.ac.cn>.

Journal of Environmental Sciences (Established in 1989)

Vol. 25 No. 3 2013

Supervised by	Chinese Academy of Sciences	Published by	Science Press, Beijing, China
Sponsored by	Research Center for Eco-Environmental Sciences, Chinese Academy of Sciences		Elsevier Limited, The Netherlands
Edited by	Editorial Office of Journal of Environmental Sciences P. O. Box 2871, Beijing 100085, China Tel: 86-10-62920553; http://www.jesc.ac.cn E-mail: jesc@263.net , jesc@rcees.ac.cn	Distributed by	Domestic Science Press, 16 Donghuangchenggen North Street, Beijing 100717, China Local Post Offices through China Foreign Elsevier Limited http://www.elsevier.com/locate/jes
Editor-in-chief	Hongxiao Tang	Printed by	Beijing Beilin Printing House, 100083, China
CN 11-2629/X	Domestic postcode: 2-580		Domestic price per issue RMB ¥ 110.00

ISSN 1001-0742



9 771001 074130