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Validating Trace Metals Levels in $PM_{2.5}$ Aerosols from Indoor and Outdoor Polluting Premises

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Abstract: Problem statement: Our studies revealed high trace metals concentrations in $PM_{2.5}$ aerosols from Residential Buildings (RB-I) and enclosed Car Parks (CP-I) indoor than in outdoor Residential Buildings (RB-O) and Car Parks Outdoor (CP-O), indicating possible dust accumulation in confined premises from six Kuwait Governorate areas. **Approach:** Trace metals in $PM_{2.5}$ was high in the sequence of Bed Room (BR) >kitchen (FR) >Living Room (LR) due to improper ventilation and space-resident ratio. **Results:** Buildings Without Cars Parks (WCP) showed low $PM_{2.5}$ trace metals concentrations when compared to buildings with Car Parks (CP). High $PM_{2.5}$ trace metals in Governorate-IV were reflected by commercialization. Analysis showed high Al and Fe concentrations in all the categorized samples. The I/O ratio was >1 in all the samples indicating the influence of indoor attributes superseding the outdoor pollution sources. **Conclusion/Recommendations:** This study characterizes the trace metals variations in different areas, buildings with and without car parks and building components besides the application of preventive measures to air pollution.

Key words: Trace metals, $PM_{2.5}$, car-parks, buildings, air pollution

INTRODUCTION

Air pollution is a major environmental health problem affecting both developed and developing countries. This global concern involves ambient air quality in cities as well as indoor air quality including workplace and urban areas. Nearly three-fifths of the total global exposure to particulate matter, one of the most ubiquitous air pollutants, occurs in the rural areas of developing countries. This translates many million deaths a year. Despite increasing knowledge about harmful health effects of air pollution, preventive action is often slow to follow (World Health Organization, 2006). Many people know that outdoor air pollution can damage their health, but many do not know that indoor air pollution also can cause significant health effects. Man exposed to air pollutants indicates that indoor pollutants levels may be two to five times and occasionally more than 100 times, higher than outdoor pollutants levels (USEPA, 2009a). These levels of indoor air pollutants may be of particular concern because most people spend about 90% of their time indoors (USEPA, 2009b; Rada *et al*., 2009).

The sources of indoor air pollutants include biological contaminants (bacteria, molds, mildew, house dust, mites and pollen), carbon monoxide, lead, nitrogen dioxide, radon and second-hand smoke. Indoor air quality problems are not limited to homes. In fact, many public buildings have significant air pollution sources (Klinmalee *et al*., 2009). Some of these buildings may be inadequately ventilated. Finally, people generally have less control over the indoor environment than they do outside their homes. As a result, there has been an increase in the incidence of reported health problems (USEPA, 2009b; Zhao and Wu, 2009).

Recently, fine particles with an aerodynamic diameter less than or equal to $PM_{2.5}$ µm is being considered important in view of the greater health hazards than with the particles with higher diameter sizes. Smaller particles are found capable of penetrating more deeply into the respiratory tract near the gas exchange region and translocation beyond other organs (Balasubramanian and Lee, 2007). Further, the small particles is found to have high surface area per unit mass and contain more toxins based on the type of chemical components that adsorbed on the particles (Balasubramanian and Lee, 2007; Tucker, 2000). These particles contain organic and inorganic constituents that cause upper respiratory irritation, headaches, fatigue, allergic reactions and Environmental Illness (EI), Building Related Illness (BRI) or Sick Building Syndrome (SBS).

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The primary source of $PM_{2.5}$ in public indoor premises attributes to the type of business activity, population, the time spent by visitors/customers, the hygienic conditions maintained by the organization and the contribution of internal/external polluting agents of/from a given product (Lee *et al*., 2002). Besides these factors, secondary sources from gaseous pollutants through gas-to-particle conversion, re-suspension of particles by human movement and from soil matter also contribute as a source of $PM_{2.5}$ containing trace metals. The effect of $PM_{2.5}$ sources also increases depending on the levels of infiltration of particles from the outdoor combustion sources such as smoke from automobiles and incineration of waste materials. Indoor air quality may vary due to the infiltration from outdoor particles even in the absence of any indoor sources (Corsi *et al*., 2008; Liwei *et al*., 2008). Hence, it is essential to understand the relationship between the indoor and outdoor concentrations and the origin of indoor particles transport (USEPA, 2009a; Huang *et al*., 2007; Rashed, 2008).

Occasionally, besides the measurements observed during the Gulf War in Kuwait, the ambient air quality of $PM_{2.5}$ was found to exceed 15.0µg m^{-3}, the permissible limits to that of the national ambient air quality standards (World Health Organization, 2006; USEPA, 2009a). This attributes to the recent industrialization, congested traffic, increase in population and high indoor sedentary occupation. Recent construction activities visualizing with modernization and space management have led to the inbuilt car parks in many residential and public places in most of the Kuwait Governorates. The arrangement of multiple stacks and rows automobile parking in successive floors with inadequate ventilation and spacing contribute to the smoke retention from such automobiles emission.

The database from this study will help to identify hotspots of health threatening air pollution levels and high population risks. It will also help keep track of the major sources of pollution and their effect on public health. Economic costs to society and individuals of health impairment due to air pollution as well as cost-effective intervention strategies could be deduced from the outcome of this investigation Thus, based on the above, studies were conducted to determine and correlate the trace metals concentrations (a) in Particulate Matter ($PM_{2.5}$) collected from the components of residential buildings, (b) in car parks (enclosed or in their absence near the residential buildings) and also (c) ratio of I/O apportionment of $PM_{2.5}$ to deduce the potential hazards of air pollution to humans.

MATERIALS AND METHODS

Sampling sites and strategies: Four areas each from six Kuwaiti Governorates (Fig. 1) were chosen for the study. The six Kuwait Governorate areas encompassed: (a) G-I (Jahra): Situated at the North of Kuwait with residential, industrial and desert areas and thermal, power, desalination and water treatment plants, (b) G-II (Capital/Kuwait City): The central Kuwait zone with industrial and residential areas significant for its business centers, domestic wastewater outfalls, (c) G-III (Hawalli): Known for its business activities and residential areas (d) G-IV (Farwaniya): With densely populated residential areas (e) G-V (Mubarek Al-Kabeer): With moderately populated residential and recreational activities and (f) G-VI (Ahmedi): the southern region of Kuwait with oil fields, allied industries and scanty residential sites (Fig. 1).

Based on the importance of these Governorate areas, indoor samples were collected from (a) public enclosed Car Parks (CP) and (b) Residential Buildings (RB-I) and their indoor components namely, Living Room (LR), Bed Room (BR) and kitchen (FR) to determine the levels and effects of trace metals pollution in Particulate Matter ($PM_{2.5}$). Simultaneously, $PM_{2.5}$ samples outside each Car Park (CP-O) and Residential Building (RB-O) representing outdoor sample as well as Without Car Parks (WCP) were collected. Thus, indoor and outdoor samples were analyzed not only to evaluate the levels of indoor and outdoor pollution but also to determine the apportionment and relative hazards deduced from Indoor-Outdoor ratio (I/O) for a given area.

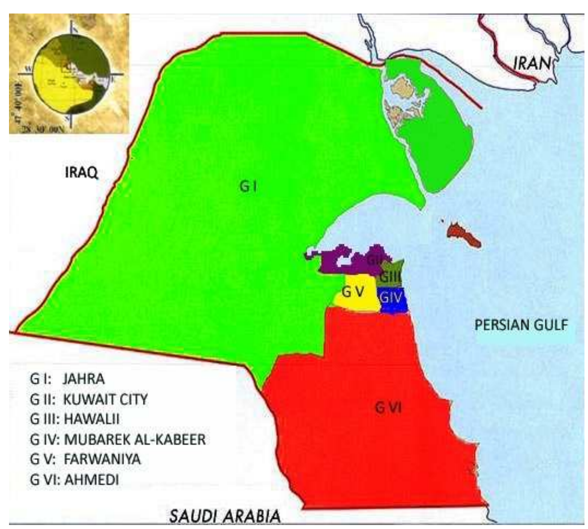

Fig. 1: Sampling sites of Kuwait

Sampling of Particulate Matter ($PM_{2.5}$): $PM_{2.5}$ samples were collected from enclosed and outdoor car parks and adjoining residential buildings during the years, November 2007-September 2009 using a standard protocol of two days period/week/every month. These premises were selected suspecting the dust dispersal from the populated public enclosed car parks near or inbuilt adjacent residential buildings that concerns indoor air quality. A test space was randomly selected within each building with a target population of <10 people at any given time to run the air sampler. Haz-dust (EPAM 5000) air monitoring system was used to collect the air through a $PM_{2.5}$ impactor. This instrument uses both nephalometry and the gravimetry principle in measuring $PM_{2.5}$ in indoor or outdoor premises. Nephalometry involves the near-forward light scattering of infrared radiation to immediately and continuously measure the concentration in mg m^{-3} of airborne dust particles. Simultaneously, the air particulate is impacted through a 47 Ø mm membrane filter of Federal Reference Method (EPA-FRM) style. The particles collected on the filter is weighed and analyzed for gravimetry analysis. Among the particulate sizes, the present study chose $PM_{2.5}$ due to its detrimental effect to human respiratory system than encountered with larger PM. Moreover, no published evidences on trace metals in $PM_{2.5}$ in relation between enclosed car parks and residential buildings were recorded in Kuwait and hence the present study.

Analysis of Particulate Matter ($PM_{2.5}$): Samples (41,472 numbers, Table 1) were individually weighed and predigested in 3 mL of concentrated Nitric acid (Ultra Pure-Merck Inc., US) in a sterile polystyrene centrifuge tubes (50 mL capacity) overnight. They were diluted to 50 mL with deionized distilled water and digested in an automatic microwave digester (Spectro-Prep CEM Inc., US). The digested solution was analyzed for trace metals concentration using ICP-MS.

Table 1: Particulate samples ($PM_{2.5}$) by gravimetry method

Description	Sampling details/Nos.
Sampling period days/ week	1
Sampling period/month	4
Total sampling days/month	4
Total sampling days/2 years	96
No. of governorates in Kuwait	6
Areas from each governorate	4
Premises sampled/area	18 (indoor 1× 3 rooms/bldg. × 5bldg +1 CP-I +1 CP-O +1 RB outdoor)
Total No. of indoor samples	96 × 6 × 4 ×15 = 34560
Total No. of outdoor samples	96 × 6 × 4 × 3 = 6912
Total No. of indoor + outdoor samples	41,472

RESULTS

Observations showed high trace metals in $PM_{2.5}$ sampled from enclosed Car Parks (CP-I) and indoor Residential Building (RB-I) components Such as Living (LR), kitchen (FR) and Bed Room (BR) than outside these premises (CP-O and RB-O), outdoor (Fig. 2). Comparatively, high trace metals were observed in $PM_{2.5}$ in Residential Buildings (RB) than Car Parks (CP) irrespective of indoor and outdoor $PM_{2.5}$ samples (Fig. 2). Governorate wise, indoor and outdoor samples revealed high trace metals concentrations in G-IV followed by G-III> G-II> G-I > G-V >G-VI (Fig. 2). Metals wise analyses showed high concentration of Fe followed by Al>Zn>Ni>Cu> Cd>Pb> V irrespective of indoor and outdoor samples (Fig. 3). However, both enclosed car parks and residential buildings showed high Fe and Al concentrations than their counterpart samples taken outdoor (Fig. 3). Except with a marginal difference between LR and BR in G-III samples, the components in residential buildings showed high trace metals in $PM_{2.5}$ in the sequence of BR>FR>LR in all the other Governorates (Fig. 4). Governorate wise trace metals concentrations in LR, BR and FR were found high in G-IV and followed similar sequence to that of the observations in Fig. 2.

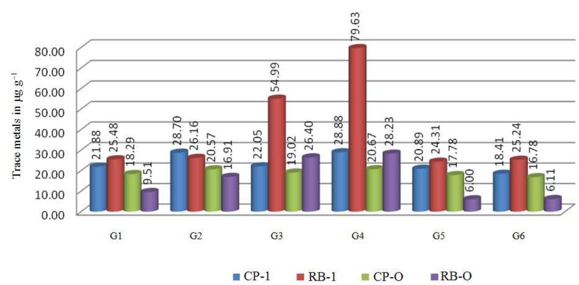

Fig. 2: Premises wise trace metals in $PM_{2.5}$ from indoor and outdoor Kuwait Governorates G1-G6: Kuwait Governorates, CP: Car Parks, RB: Residential Buildings, I: Indoor, O: Outdoor

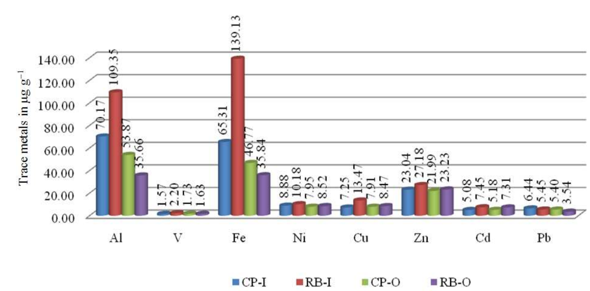

Fig. 3: Metals wise $PM_{2.5}$ from indoor and outdoor Kuwait Governorates NCP: Car Parks, RB: Residential Buildings, I: Indoor, O: Outdoor

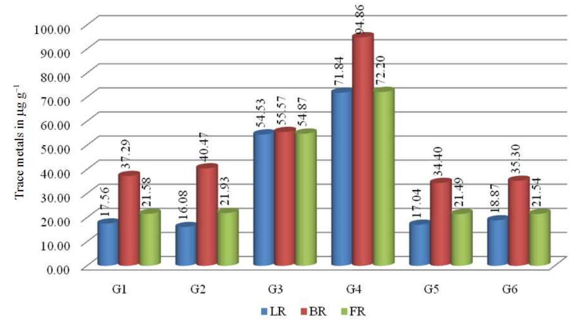

Fig. 4: Component wise $PM_{2.5}$ trace metals in residential buildings, off Kuwait Governorates G1-G6: Kuwait Governorates; LR: Living Room, BR: Bed Room, FR: Kitchen

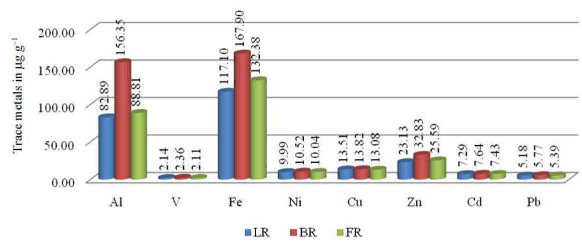

Fig. 5: Metals wise $PM_{2.5}$ trace metals in residential buildings, off Kuwait Governorates LR: Living Room, BR: Bed Room, FR: Kitchen

Table 2: ANOVA on premises (car-parks and residential buildings), Governorates and metals wise outdoor and indoor PM-2.5 aerosols levels in Kuwait

Variation	DF	MS	F	p-value	F crit	Significance
(a) Premises wise analysis						
Between group	3	664.83	6.10	0.006	3.28	*
Within group	23					
(b) Governorate wise analysis						
Between group	5	325.46	2.98	0.04	2.90	*
Within group	23					
(c) Metals wise analysis						
Between group	7	3290.72	10.09	0.001	2.48	*
Within group	31					

*: Significant; **: Not significant

Metals wise analyses showed high Fe and Al concentrations in BR followed by FR and LR (Fig. 5).

RB without enclosed Car Parks (WCP) or not cited near the vicinity of the RB showed low trace metals concentrations than with enclosed Car Parks (CP-I) and outside the Car Parks (CP-O) found near the vicinity of the RB (Fig. 6). ANOVA tests revealed significant difference in the case of premises, metals and Governorate wise analysis between enclosed Car Parks (CP-I), outside the Car Parks (CP-O), Without Car Parks (WCP) and Residential Buildings Outdoor and Indoor (RB-I and RB-O) respectively (Table 2-4).

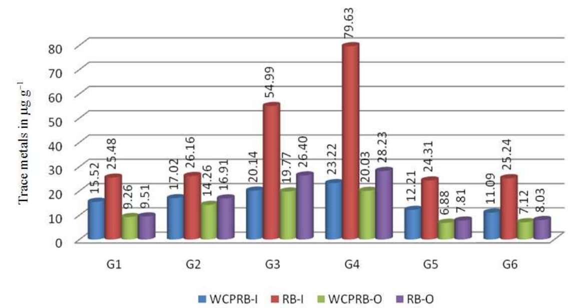

Fig. 6: Samples with and without car parks near residential buildings W: without, CP: Car parks, RB: residential buildings, I: Indoor, O: Outdoor

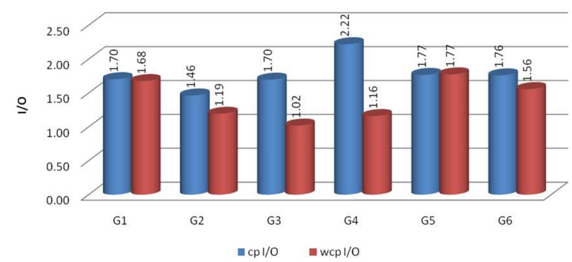

Fig. 7: Indoor and outdoor pollution ratio (I/O) with and without car parks

Table 3: ANOVA on the components of residential buildings (LR, BR, FR), governorates and metals wise outdoor and indoor PM- 2.5 aerosols levels in Kuwait

Variation	DF	MS	F	p-value	F crit	Significance
(a) Residential building wise analysis						
Between group	2	494.78	22.64	0.001	4.10	*
Within group	17					
(b) Governorate wise analysis						
Between group	5	1595.40	73.0	0.001	3.32	*
Within group	17					
(c) Metals wise analysis						
Between group	7	8601.80	35.19	0.007	2.76	*
Within group	23					

LR: Living Room; BR: Bed Room; FR: Kitchen; *: Significant; **: Not significant

Table 4: ANOVA with and without car parks in outdoor and indoor PM-2.5 aerosols on the premises and governorates wise levels in Kuwait

Variation	DF	MS	F	p-value	F crit	Significance
Residential building wise analysis						
Between group	3	930.82	11.81	0.0003	3.28	*
Within group	23					
Governorate wise analysis						
Between group	5	464.99	5.90	0.003	2.90	*
Within group	23					

LR: Living Room; BR: Bed Room; FR: Kitchen; *: Significant; **: Not significant

Governorate wise analysis revealed high I/O ratio in G-IV (2.22) and G-VI (1.76) followed by the other Governorates (Fig. 7). G-II had the least mean I/O ratio (1.28). However, I/O ratio in all the samples between Governorates and metals wise was more than 1 (Fig. 7).

Table 5: ANOVA on I/O ratio with and without car parks in Kuwait

Variation	DF	MS	F	p-value	F crit	Significance
Between group	1	0.714	11.07	0.020	6.60	*
Within group	11					

LR: Living Room; BR: Bed Room; FR: Kitchen; *: Significant; **: Not significant

Significant results on the Governorate wise I/O ratio were also obtained by ANOVA tests (Table 5).

DISCUSSION

High trace metals concentrations of $PM_{2.5}$ were observed in samples collected from Residential Buildings (RB) irrespective of the six Governorates (Fig. 2). This could be attributed to (a) the dust accumulated in various rooms either from the outdoor or internally developed from the various products (carpets, stationery, unused utensils or due to seldom cleaning process) used or liberated such as smoke and fumes, (b) frequent use of doors or exit system by the resident inmates that may gain outdoor pollutant entry despite some being controlled by the air conditioning system and (c) poor maintenance of A/c system that lead to invisible Particulate Matter ($PM_{2.5}$) flow. This supports the earlier studies (USEPA, 2009b; Klinmalee *et al*., 2009). Besides residential buildings, high trace metals concentrations was also observed in enclosed car parks (CPI) which can be attributed to dust accumulation in the parking area, particles movement through the smoke emission from cars and inadequate spacing area.

In the present study, it is interesting to note that the outdoor samples from CP-O and RB-O showed comparatively less trace metals concentration in $PM_{2.5}$. This may be attributed to the free movement and wide dispersal of particulates in a given area (Rashed, 2008). The above reasons clearly indicates that high deposition and accumulation of trace metals concentrations in $PM_{2.5}$ takes place in indoor samples as a result of low wind action and poor ventilation than the observations in outdoor samples (Zhao and Wu, 2009). Governorate wise analysis revealed G-IV with high trace metals concentrations from both indoor and outdoor samples than the other Governorates samples (Fig. 2). This attributes to the high human activities, increased population as a result of the availability of public utilities, industrialization and establishment of commercial and recreational centers in this Governorate. The influence of high pollution in specific regions for a given country due to industrialization or urbanization was not uncommon over the recent years (Tucker, 2000; Lee *et al*., 2002; Huang *et al*., 2007; Rashed, 2008). Trace metals in $PM_{2.5}$ in samples from the other Governorates differed in their sequence of trace metals concentrations to justify that $PM_{2.5}$ varied differently to pollutant's dispersal of a given premises under investigation. Metals wise analysis revealed high concentrations of Fe and Al irrespective of the sampled Governorate areas (Fig. 3). High concentrations of Fe and Al could be a result of their excessive usage or the release of these metals from day-to-day byproduct usage in the indoor condition (Corsi *et al*., 2008). Enclosed car parks showed more Fe and Al than with samples taken outside the car parks (Fig. 3). Significant differences were observed between CP and RB, Governorates and metals wise analyses for both indoor and outdoor samples (Table 2-4). Results showed a substantial quantity of dust accumulation in houses (BR) that was laid with carpets than with polyvinyl or vinyl or tiled floored houses (Fig. 4). This supports the earlier study (Corsi *et al*., 2008). Besides, dust accumulated in clothes and utilities, overcrowded with people in limited space attributes for such high trace metals in the BR. Trace metals in BR was followed by FR that could be attributed to smokes, fumes from cooking process and supported the earlier observations (Liwei *et al*., 2008). Among the metals, Fe and Al showed high concentrations in the sequence of BR>FR>LR (Fig. 5).

Comparative observations showed low trace metals concentrations in Residential Buildings and Car Parks of both Indoor and Outdoor samples (RB-I, RB-O, CP-I, CP-O) respectively than with RB without enclosed Car Parks (WCP) or car parked far away (>3 m) from residential buildings (Fig. 6).

I/O ratio >1 from the six Kuwaiti Governorates samples indicated that the indoor and outdoor pollution in all these samples were mainly from the dust accumulation. I/O ratio also revealed that the influence of pollution from the outdoor was comparatively low despite their additions through the doors or entry systems of a given premises (Fig. 7). High I/O ratio in G-IV (>1) indicated the influence of high human activities and its population than the other Governorates (Fig. 7). I/O ratio was low in RB that had neither enclosed Car Parks (WCP) nor cars parked >3m from the RB suggesting the low distribution of $PM_{2.5}$ and its respective metals concentrations as a result of adequate air circulation in nature (Klinmalee *et al*., 2009; Zhao and Wu, 2009; Balasubramanian and Lee, 2007; Lee *et al*., 2002). Despite the above, the I/O ratio was found >1 in WCP suggesting a significant difference in the $PM_{2.5}$ and its metals due to I/O influx in the RB (Table 5) and as a result of high $PM_{2.5}$ in Kuwait's ambient air than the permissible limits (15 $\mu g\ m^{-3}$) (World Health Organization 2006; USEPA, 2009a).

CONCLUSION

The time-bound records maintained for the main indoor sources that affected the indoor air quality (High I/O ratio in indoor samples) included the dust from various sources (stationeries, household products, groceries and packing materials in indoor residential components and to a lesser extent, kitchen and tobacco smokes, cleaning and general human activities, such as movement within the indoor environment. Further, metals wise I/O ratios suggest that certain chemical constituents of indoor particles, were largely influenced through migration of outdoor particles (I/O >1or ~1). Hence, this study not only determined the intensity of trace metals levels, the potential indoor and outdoor air quality affecting the different premises and residents of Kuwait, but augment to identify, ascertain and develop appropriate mitigation system to various ailments in humans caused by reparable particulates.

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REFERENCES

Balasubramanian, R. and S.S. Lee, 2007. Characteristics of indoor aerosols in residential homes in urban locations: a case study in Singapore. J. Air Waste Mgm. Assoc., 57: 981-990.

Corsi, R.L., J.A. Siegel and C. Chiang, 2008. Particle resuspension during the use of vacuum cleaners on residential carpet. J. Occup. Environ. Hyg., 5: 232-238. DOI: 10.1080/15459620801901165

Huang, H., S.C. Lee, J.J. Cao, C.W. Zou and X.G. Chen *et al*., 2007. Characteristics of indoor/outdoor PM2.5 and elemental components in generic urban, roadside and industrial plant areas of Guangzhou City, China. J. Environ. Sci. China, 19: 35-43.

Klinmalee, A., K. Srimongkol and N.T.K. Oanh, 2009. Indoor air pollution levels in public buildings in Thailand and exposure assessment. Environ. Monit. Assess., 156: 581-594. DOI: 10.1007/s10661-008-0507-z

Lee, S.C., H. Guo, W.M. Li and L.Y. Chan, 2002. Inter-comparison of air pollutant concentrations in different indoor environments in Hong Kong. Atmos. Environ., 36: 1929-1940.

Liwei, T., Z. Guoqiang, Z. Quan, M.J. Moschandreas and H. Junhong *et al*., 2008. The impact of kitchen activities on indoor pollutant concentrations. Indoor Built Environ., 17: 377-383. DOI: 10.1177/1420326X08094626.

Rada, E.C., M. Ragazzi, D. Antolini, E. Malloci and M. Venturi, 2009. Indoor air measurement of PM-10 in different conditions. Prog. Environ. Sci. Technol., 2: 571-557

Rashed, M.N., 2008. Total and extractable heavy metals in indoor, outdoor and street dust from Aswan City, Egypt. Clean-Soil Air Water, 36: 850-857. DOI: 10.1002/clen.200800062.

Tucker, W.G., 2000. An overview of PM2.5 sources and control strategies: Fuel process. Technology, 65: 379-392.

USEPA, 2009a. National Ambient Air Quality Standards (NAAQS). Air and radiation. http://www.epa.gov/air/criteria.html

USEPA, 2009b. The inside story: A guide to Indoor air Quality. US-EPA office of air and radiation office of radiation and indoor air (6609J). http://www.epa.gov/iaq/pubs/insidest.html

World Health Organization, 2006. Air Quality Guidelines-Global Update-2005. WHO, ISBN: 92 890 2192 6, pp: 484.

Zhao, B. and J. Wu, 2009. Effect of particle spatial distribution on particle deposition in ventilation rooms. J. Hazard. Mater., 170: 449-456. DOI: 10.1016/j.jhazmat.2009.04.079