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Seasonal variation of fine particulate matter in residential micro–environments of Lahore, Pakistan

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ABSTRACT

Shifting seasons greatly influence the use and management practices in residential built environments which subsequently affect the level of exposure to various pollutants indoors. The levels of fine particulate matter ($PM_{2.5}$) were monitored in fifteen households of Lahore, Pakistan during different seasons. DustTrak aerosol monitors (model 8520, TSI Inc.) were run simultaneously in the kitchens and living rooms of the selected sites for seventy two hours each. To aid analysis, houses were categorized in three groups according to floor area. For non–smoking houses there was little variation between 24 h average $PM_{2.5}$ concentrations in kitchens (270 to 295 µg/m³) although there was an increase in concentrations in living rooms as floor area increased. Across all houses the average $PM_{2.5}$ concentration was observed to vary during the seasons. In the kitchens the average PM levels were 326 µg/m³ during the spring falling to 133 µg/m³ in summer, 180 µg/m³ in monsoon, 395 µg/m³ in autumn and 448 µg/m³ during the winter. Similarly, in the living rooms, the mean PM levels observed were 190 µg/m³ in spring, 101 µg/m³ in summer, 158 µg/m³ in monsoon, 458 µg/m³ in autumn and 590 µg/m³ in winter. Factors contributing towards these levels were cooking (involving frequent frying), floor sweeping, and also movement of the occupants. Smoking at two sites and use of gas heaters during the winter were also identified as contributing sources. Apart from these sources, ventilation was identified to be the most singular attributing factor to the above mentioned variations in PM levels. Ventilation during the warm season ranged from 3.51 air changes per hour (ACH) to 7.68 ACH. On the contrary, ventilation decreased during the autumn and winter season (2.5 to 5.64 ACH) and this resulted in an accumulation of PM indoors. The levels of fine particulate matter were observed to be 3 to 23 times higher than the WHO established standard of 25 µg/m³.

Keywords: *Pakistan, particulate matter, seasonal variation, indoor micro-environments, air change per hour*

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1. Introduction

The indoor micro–environment is a complex habitat comprising of sources and sinks for a variety of pollutants many of which can result in significant health issues such as acute respiratory infections, cardiovascular problems and increased mortality (Pope, 2000; Samet et al., 2000). According to the World Health Organization, 4.3 million deaths could be attributed indoor air pollution in 2012 with almost all in low and middle income countries (WHO, 2014b). Many factors are responsible for the exposure to indoor pollutants, particularly particulate matter. These include building design and location, ventilation systems, furnishing, cooking, smoking, movement of the occupants and many more. Many studies have documented variable $PM_{2.5}$ levels resulting from a number of household activities (Chao and Cheng, 1998; Chao and Cheng, 2002; Ferro et al., 2004; Meng et al., 2005; Nasir and Colbeck, 2013).

Indoor air quality of built structures such as homes, offices, etc. is generally directly or indirectly a reflection of the ambient air quality. The environmental factors responsible for the ambient air quality may affect the indoor air quality and people are more exposed to a range of pollutants indoors than outdoors as their more time is spent indoors (Klepeis et al., 2001). Ambient air pollution in both urban and rural areas was estimated to cause 3.7 million premature deaths worldwide per year in 2012 (WHO, 2014b). Urban air pollution in Pakistan resulted in more than 22 600 deaths in 2005 of which over 9 000 were due to $PM_{2.5}$ (Sanchez–Triana et al., 2014). This pollution costs 1% of GDP and is a burden on the economy of the country (World Bank, 2006). Many studies have been conducted to monitor the concentrations of particulate matter in the indoor and outdoor environment and also to study their various sources in the developing countries (Balakrishnan et al., 2002; Balakrishnan et al., 2004; Dasgupta et al., 2006; Saksena et al., 2007; Fullerton et al., 2009).

Changing seasons have previously been documented to affect the air quality as a result of increased or decreased dispersal of pollutants (Li and Lin, 2003; Ramachandran et al., 2003; Hanninen et al., 2011). Variation in the wind velocity, relative humidity and temperature are also responsible for varying the concentration of particulates over the seasons. During the winters, low wind speed and high humidity do not allow rapid dispersal of pollutants and trap the pollutants near the surface of earth. This leads to an increased concentration of particulate matter. In summers, relative humidity levels are comparatively low while the wind speed is increased so the pollutants tend to disperse readily. Also with the shift in seasons, the living style and behavior of people tends to change such as keeping the windows open for longer periods, use of fans and air conditioners during the summers while keeping the rooms air tight during the cold season with an increased use of fuel for space heating. These changing conditions may result in similar indoor and outdoor–related climate changes related to exposure to pollutants and their health effects (Wilby, 2007; Ebi and McGregor, 2008).

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In Pakistan indoor air pollution is not considered as a hazard at policy level. There is a lack of detailed baseline studies to quantify the representative levels of particulate matter in different indoor spaces. Jabeen et al. (2001) analyzed dust samples for heavy metals collected from nine houses in Gujranwala. Outdoor sources contributed towards indoor air quality with I/O ratios for lead varying from 0.35 to 0.97. Siddiqui et al. (2005a) undertook a study to investigate the prevalence of eye and respiratory disorders in women using biomass fuel for cooking and observed a strong association between the two factors. In another study, Siddiqui et al. (2005b) observed that exposure of mothers to smoke from wood burning resulted in low birth weight of children. Colbeck et al. (2008, 2010) observed PM_{10} levels as high as 8 555 µg/m^3 due to biomass burning with cleaning and smoking resulting in concentrations up to 2 000 µg/m^3. Akhtar et al. (2007) observed a strong link between prevalence of chronic bronchitis in women and exposure to emissions from biomass burning during cooking. Low birth weight was reported in infants whose mothers were exposed to emissions from wood smoke by Siddiqui et al. (2008). Siddiqui et al. (2009) concluded that PM emissions by biomass burning were too high and were unsafe for human health. Similarly a strong association between biomass burning and acute lower respiratory infections in children was studied by Janjua et al. (2012). They observed higher incidence of acute lower respiratory infections in children aged 5 years and below living in households where biomass was the primary cooking fuel. Recently, Nasir et al. (2013) monitored the levels of particulate matter in rural kitchens during the summers and winters and observed a fall in PM levels during the summers when the indoor kitchen was in not use.

Most of these studies focus on PM levels and associated health outcomes related with biomass burning in rural areas while the indoor air quality of urban centers has been ignored to a great extent. The impact of seasonality on $PM_{2.5}$ has not been extensively explored. Hence the present study was designed to monitor the levels of $PM_{2.5}$ in different indoor micro–environments of Lahore, Pakistan during the different seasons.

2. Methodology

2.1. Selection of sampling sites

Lahore (31°15'–31°45' N and 74°01'–74°39' E) is one of the most densely populated cities of the world. Its population was estimated to be 9 086 000 in 2013 (BOS, 2013). It is divided into nine administrative towns and a cantonment area. According to the Koppen climate classification, Lahore is a city characterized with a sub–tropical hot climate with five distinct seasons including foggy winters, pleasant springs, scorching summers, rainy monsoons and dry autumns.

In order to facilitate the selection of houses, three categories were defined according to the floor area of the houses and five houses selected from each category for monitoring purposes (n=15).

- Category A: $\leq$126.5 m^2
- Category B: >126.5 m^2 to 253 m^2
- Category C: >253 m^2

During each season, one representative house from each category was monitored for $PM_{2.5}$ making a total of three houses during each season. The sampling sites were labeled according to their categories and also according to the season in which sampling took place. Thus A–1 relates a house in category A and with sampling during the spring. Similarly sites labeled 2, 3, 4 and 5 were monitored during the summer, monsoon, autumn and winter season respectively (Figure 1). The number of occupants varied from three to thirteen in the selected sites. The floor area and location of the selected households along with other relevant details is summarized in Table 1.

2.2. Data collection

Monitoring of particulate matter. Two of the most widely used methods employed for PM monitoring are the light scattering method and gravimetric method. Although the gravimetric method is more suitable as a reference method, light scattering is more suitable for preliminary measurements of aerosols (Niu et al., 2002). Among the many commercially available photometers, the DustTrak aerosol monitor (model 8520, TSI Inc.) has been known to give precise and accurate readings of $PM_{2.5}$ (Yanosky et al., 2002; Cheng, 2008) and was employed here to monitor $PM_{2.5}$ concentrations.

The DustTrak aerosol monitor (model 8520, TSI Inc.) is a direct reading real–time photometer and has a laser diode with 90° light scattering. Its sensitivity ranges between 0.001 to 100 mg/m^3 with a particle size range of 0.1 to approximate 10 µm. The aerosol monitors were factory calibrated before monitoring and the air flow rate was set at 1.7 L/min. The data logging interval was set at 1 minute and the sampling duration was 72 hours in each house. Two DustTrak monitors were run in parallel in the both micro–environments. The monitoring program covered the period from March, 2012 to January, 2013 and each sampling site was monitored only once during the study period.

Figure 1. *Location of houses (circle represents category A, rhombus indicates category B, star represents category C).*

$PM_{2.5}$ generation from different activities. Different activities result in varying concentrations of particulate matter. The source strengths of particulate matter arising from different activities being carried out in each sampling site were determined from a questionnaire which identified the time period during which a specific activity was being performed. The major activities identified included cooking, floor sweeping, material movement such as making bed, presence of people, space heating during winters and cigarette smoking.

Table 1. Profiles of the study sites

Sampling Site	Season	Month	Size of House (m^2)	Volume of Kitchen (m^3)	Volume of Living Room (m^3)	No of Occupants	Location	Type of Road	Distance From Main Road	Connection Between Kitchen and Living Room	No of Smokers
A1		March, 2012	505.8	31.15	47.57	8	Urban	Carpeted	0.5 km	Not Connected	0
B1	Spring	March, 2012	126.45	30.58	57.77	7	Urban	Carpeted	1 km	Not connected	1
C1		March, 2012	252.9	21.80	67.96	6	Urban	Carpeted	0.1 km	Connected	0
A2		May, 2012	126.45	73.40	57.09	8	Urban	Cemented	0.5 km	Not connected	0
B2	Summer	June, 2012	505.8	11.33	47.57	6	Urban	Cemented	1 km	Not connected	0
C2		June, 2012	202.32	50.97	72.49	7	Industrial, near railway lines	Cemented	0.1 km	Not connected	0
A3		August, 2012	126.45	13.88	50.97	6	Industrial, near railway lines	Carpeted	0.1 km	Not connected	0
B3	Monsoon	September, 2012	252.9	9.91	40.78	8	Urban	Carpeted	0.1 km	Not connected	0
C3		September, 2012	455.22	14.16	47.57	5	Urban	Carpeted	0.1 km	Not connected	0
A4		October, 2012	126.45	20.39	40.78	13	Urban, Industrial, Main Road under construction	Cemented	0.1 km	Not connected	0
B4	Autumn	October, 2012	303.48	18.12	40.78	5	Urban, Industrial	Carpeted	0.1 km	Connected	0
C4		November, 2012	177.03	40.78	54.37	4	Urban	Carpeted	0.5 km	Not connected	0
A5		December, 2012	379.35	9.91	22.65	3	Urban	Carpeted	0 km	Partially connected	0
B5	Winter	January, 2013	177.03	11.33	28.32	13	Urban	Carpeted	0.5 km	Not connected	1
C5		January, 2013	101.16	18.12	33.98	4	Urban, Industrial	Unpaved	0.1 km	Not connected	0

Measurement of ventilation rates. All the sampling sites in this study were naturally ventilated. Fans and occasionally air conditioners were switched on during the warmer months. The air change per hour (ACH) was measured to determine the amount of ventilation available at each site. A concentration decay method was employed using CO_2 as the tracer gas. A Gas Probe IAQ (BW technologies) was employed for measuring the CO_2 concentrations. The ventilation was measured in both the kitchen and living room of each sampling site. The procedure was undertaken in the absence of people in the room so that CO_2 levels were not affected. The background level of CO_2 was noted prior to releasing the gas into the room. After injecting the gas into the room, its levels were monitored as they decreased over time with monitoring continuing until background levels were achieved. Ventilation was determined by plotting the time in hours against the natural log of CO_2 concentration where ACH was the slope of the best–fit line (Fischer–Mackey, 2010).

Data analysis. The obtained concentrations of $PM_{2.5}$ for 72 hours were converted into 24–h average concentrations. The data were analyzed further to obtain hourly maximum and hourly minimum statistics to gain an insight into the fluctuations in levels and for comparison with the background levels. Seasonal variation was studied by comparing the mean concentrations of particulate matter in each sampling site during the different seasons. One–way ANOVA was applied to observe any significant impact of seasons on particulate matter concentrations (α=0.05) Correlations between air exchange rate and PM concentrations were determined to study the role of ventilation rates in defining the $PM_{2.5}$ levels in the indoor air. SPSS (v.16.0) was employed for statistical analysis.

3. Results

The concentrations of fine particulate matter were observed to vary in different seasons in all three categories. The mean $PM_{2.5}$ levels followed a similar trend as the concentrations reached the lowest averages during the summer season, slightly increasing during the monsoon, and reaching its peak during the winters (Figures 2a–2c). Since the measurements were carried out in different houses, a one–way ANOVA was applied to examine if there were statistically significant differences in the mean values of $PM_{2.5}$ obtained during different seasons at a significance level of 0.05. The results revealed that a substantial seasonal variation was observed in PM concentrations in both the kitchens [F (4, 10)=7.642, p=0.004] and living rooms of the sampling sites [F (4, 10)=16.153, p=0.00].

Apart from the impact of seasonality, the levels of particulate matter were observed to be strongly defined by the various activities being carried out in each household. The major activities identified were cooking and floor sweeping in the kitchens and the presence of people performing different household activities and movement of material items such as furniture or making the bed etc., in the living rooms. Space heating during the winters and smoking in two sampling sites (B1 and B5) were also contributing factors towards indoor levels of fine particulate matter. In kitchens, the mean levels observed during cooking were found to be 481 µg/m³ (±353 µg/m³) during breakfast preparation, 321 µg/m³ (±242 µg/m³) during lunch, and 449 µg/m³ (±173 µg/m³) when preparing dinner. Floor sweeping in both micro–environments lead to almost similar concentrations of particulate matter i.e. 318 µg/m³ in kitchens and 301 µg/m³ in living rooms. The presence of people engaged in various household activities lead to an average PM concentration of 369 µg/m³. Gas heaters were employed for space heating which caused an increase in $PM_{2.5}$ levels up to an average of 745 µg/m³. Smoking was undertaken at two sites and variable concentrations were observed (Table 2). The accumulating levels of particulate matter fluctuated significantly during different seasons as is evident in Figures 3a and 3b.

The average $PM_{2.5}$ values along with hourly maximum and hourly minimum concentrations are summarized in Tables 3a, 3b and 3c. These statistics were obtained to gain an insight into the background levels in each household as well as the maximum concentrations achieved during the routine activities in a day. The highest hourly maximum concentration was 4 744 µg/m³ and was in the presence of smoking. The air exchange rate in living rooms ranged between 2.77 ACH (4.36 L/s/person) to 3.33 ACH (10.48 L/s/person) during the winters and increased to 5.42 ACH (7.67 L/s/person) to 6.69 ACH (17.68 L/s/person) during the summer season. In the kitchens, only a semi–open kitchen exhibited higher rates of air exchange (11.68 ACH or 8.04 L/s/person) while majority of them had a ventilation rates between 2.5 (5.66 L/s/person) to 7.86 ACH (2.64 L/s/person)

A significant correlation between ventilation rates and PM concentrations was observed in the living room (0.015<0.05) while the case was opposite in kitchens (0.985>0.05).

4. Discussion

Since the climate of Lahore is hot and dry for the most part of the year, so windows are kept open for maximum time during the spring, summer and monsoon season. Even during the months of autumn, windows remain open for at least some part of the day. The situation is reverse during the winters when gas heaters are employed for heating and so the rooms are kept air–tight to keep the cold out. As a result the pollutants are trapped within the indoor environments posing an increased exposure. Our results reflected the impact of this change in behavior on fine particulate matter concentration in both indoor environments as higher levels of particulate matter were observed during the autumn and winters than during the warmer months.

Overall, the concentrations of particulate matter were lower during the spring, summer and monsoon season despite the increase in ventilation which allows infiltration from outdoors. Since wind velocity is generally higher during the warmer seasons, pollutants do not accumulate and do not have a significant impact on the indoor air quality despite increased infiltration from outdoors. The circumstances during the autumn and winter season are altered when the pollutants are trapped near the surface of earth. Moreover, since the doors and windows are kept closed for most part of the day and people also try to spend maximum time indoors, PM concentrations tends to increase. Many other studies also observed similar results in both the indoor and outdoor environments (He et al., 2001; Ye et al., 2003; Tiwari et al., 2011; Massey et al., 2012; Massey et al., 2013).

Naz (2011) investigated the impact of season upon particulate matter concentration in a residential house of Lahore, Pakistan. It was observed that during the winter season, the respective average concentrations for PM_1, $PM_{2.5}$ and PM_{10} in the kitchen were 4 to 10 times higher than the observed levels during the summers. Similarly the average values obtained in the living room were 2 to 3 times higher during the winters than in summers. Ventilation was found to play a significant role in defining the PM concentrations in both seasons.

Likewise, the concentrations generally tend to decrease significantly during the monsoon since the rain settles down the suspended particles (Agrawal and Khanam, 1997; Massey et al., 2012). On the contrary, the monsoon season was not observed to significantly affect the particulate levels observed in this study in the absence of heavy rains during the monitoring period while the recorded levels were lowest during the summer season and highest during the winters.

Apart from the meteorological factors, generation of particulate matter is also affected by the various types of activities carried out in a household. Some of major activities in the indoor environment like smoking, building, food preparation and building maintenance strategies, fuel type usage can affect indoor air quality. Smoking and use of low quality fuels fairly increase the fine particulate matter fraction. The use of low quality fuel also causes the high ratio emission of PM which should be critically considered (Majewski et al., 2011). Natural gas was the principal cooking fuel used in all the selected sampling sites with occasional use of Liquefied Petroleum gas (LPG) in a few residencies. Although LPG has been known to be a more effective source of volatile organic compounds than natural gas (Lee et al., 2002), both fuels are considerably much cleaner fuels than the biomass fuels in terms of particulate generation (Shimada and Matsuoka, 2011).

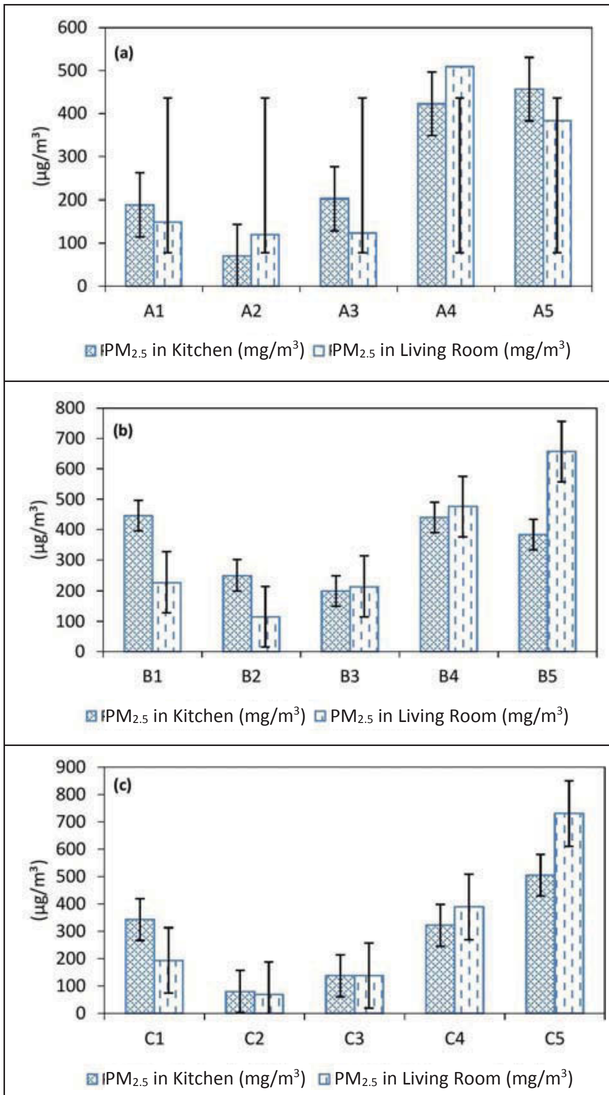

Figure 2. *Seasonal variation of fine particulate matter in category* ***(a)*** *A houses,* ***(b)*** *B houses,* ***(c)*** *C houses (error bars represent standard error).*

Among the various types of household activities carried out in a routine day in a house, cooking has been recognized to be the leading source of particle generation (Gilbert et al., 2005). Jones et al. (2000) also noted that cooking and indoor smoking contributed more towards higher $PM_{2.5}$ levels than cleaning activities. Many studies have documented varying PM levels arising from different cooking methods in the kitchens. Frying has been acknowledged to elevate $PM_{2.5}$ levels by 30 times the background values while grilling increased the levels by a factor of 90 (He et al., 2004). Similar observations have been reported by Huboyo et al. (2011).

Fried items are a compulsory part of the breakfast table in Pakistan as the traditional breakfast is considered incomplete without *"Parathas"* (a type of fried flat bread), usually to be eaten with fried eggs and omelettes. A similar breakfast was enjoyed by almost all the tenants in our sampling sites. Consequently, the generation of particulate matter during breakfast was normally noted to be much higher in the designated households than during cooking lunch or dinner.

Concentrations as high as 1 126 µg/m³ were recorded while preparing breakfast during the course of this study. Movement of people performing their daily routine activities also caused a noticeable increase in particulate matter level with an average value of 369 µg/m³. Floor sweeping was the third major contributor towards PM generation and re–suspension in the selected micro–environments.

Besides these daily household activities of the occupants, two other occasional activities had their share in defining the indoor levels of particulate matter. These include smoking within the house (only done in two sampling sites) and space heating (only during the winters). Space heating is required only during the short period of winters in Lahore and gas heaters are the primary source used to keep the rooms warm. Moreover decreased ventilation during the winters also has its share in increasing the intensities of particulate concentrations in the indoor settings. The average PM levels during space heating were recorded to be 745 µg/m³.

Table 2. *Concentrations of fine particulate matter obtained during various activities carried out in sampling sites (* Space heating only during the winters; ** Smoking carried out in only two households)*

Activities in Kitchens	Average (µg/m³)	Maximum (µg/m³)	Minimum (µg/m³)	St Dev. (µg/m³)
Activities in kitchens				
Cooking				
Breakfast	481.3	1 125.9	82.3	353.5
Lunch	320.6	907.4	57.46	242.2
Dinner	448.9	812.4	77.6	239.9
Floor sweeping	318.4	632.3	56.1	173.5
Activities in Living Rooms				
Floor sweeping	300.9	638.8	81.6	186.3
Presence of people	368.9	946.7	80.6	267.8
* Space heating	745.1	1 094.0	485.4	314.0
** Smoking	359.1	553.0	165.2	274.2

For the houses where smoking took place (B1 and B5), the average PM levels noted during the smoking activity were three times higher during the winter season than during the spring season; (553 µg/m³ vs. 165 g/m³). A three times increase in mean PM levels due to smoking indoors has been recorded by He et al. (2004) while in the present study, the background levels were also exceeded (1.8 times in B1 and 2.47 times in B5).

These observations also highlighted the role of ventilation as the air exchange rates in B1 and B5 were 5.25 and 2.98 ACH respectively. Nasir and Colbeck (2013) also made similar observations as the PM levels in smoking apartments dropped to half during the summers. The background concentrations were also higher during the winters than in summers as ventilation rates dropped during winters.

The minimum air changes per hour in any indoor environment should be 4 ACH i.e. the air within a room is replaced four times in an hour. However, the air change rate varies with building requirements, floor area and the number of occupants residing in the building. According to (ASHRAE, 2013), the minimum ventilation in a naturally ventilated building should be 3.5 L/s/person to ensure a healthy environment for occupants.

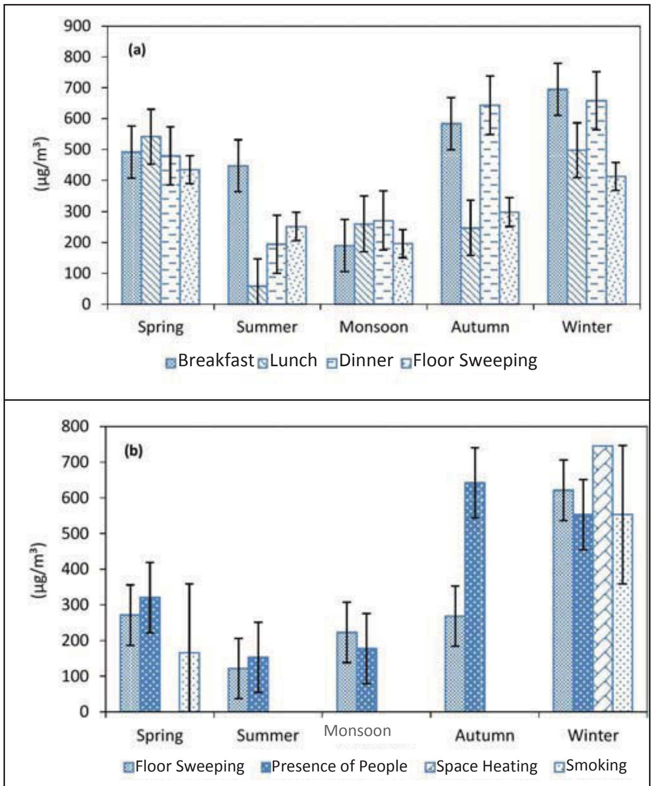

Figure 3. *Comparative concentrations of $PM_{2.5}$ during different activities performed in the **(a)** kitchens, **(b)** living rooms (error bars represent standard error).*

Being naturally ventilated, the selected sampling sites were not air–tight or insulated. Moreover the doors and windows were kept open for varying periods throughout the day thereby disrupting a constant air exchange rate throughout.

Insulation, HVAC, building material and air exchange rate are some of the factors which seem to contribute in determining the indoor air quality. The use of air conditioners in the indoor environment is reported to enhance the air quality and dilute the indoor airborne pollutants.

Our results provide an insight into this matter as air conditioners were in use during the summer season in houses sites A3 and C3. House B3 was also monitored during the summer season, but in the absence of air conditioner in the room, the $PM_{2.5}$ levels were considerably higher (213 µg/m³) than in sites A1 (123 µg/m³) and C3 (138 µg/m³).

The ventilation rates in the living room of A3 and C3 dropped from 6.08 ACH and 6.67 ACH to 2.48 and 2.41 ACH respectively when air conditioners were switched on and doors and windows kept closed. On the contrary, the ACH in living room of B3 remained at a rate of 5.42 air changes per hour for most part of the day with slight variations.

Table 3a. *Fine particulate concentration in the indoor micro–environments of category–A houses (Ave=Average, Max=Maximum, Min=Minimum, St Dev=Standard deviation)*

Study Site	PM2.5 in Kitchen (µg/m³)											
	24 Hours				Hourly Maximum				Hourly Minimum			
	Ave	Max	Min	St Dev	Ave	Max	Min	St Dev	Ave	Max	Min	St Dev
A1	188.8	200.6	168.2	17.9	336.4	396.1	289.1	54.5	75.4	91	63.8	14
A2	69.9	92.4	56.1	19.7	206.9	399.1	81.2	169.1	34.0	38.7	24.9	7.9
A3	202.3	296.4	131.8	84.8	1 787.4	3 666.4	233.8	1 739.3	53.4	66.1	29.2	20.9
A4	422.7	576.2	259.4	158.7	1 256.6	1 817.7	847.1	502.5	86.2	129.9	64.1	37.8
A5	456.7	488.8	409.8	41.5	1 697.2	2 639.4	1 208.5	816.1	153.6	212.4	99.7	56.5
	PM2.5 in Living Room (µg/m³)											
A1	149	168.4	123.1	23.3	265.3	309.1	239.5	38.2	69	89.8	57.9	17.9
A2	119.9	127.4	113.9	7.0	231.2	281.8	173.3	54.6	66.7	73.1	58.8	7.2
A3	123.4	140.2	109.7	15.5	231.3	295.4	187	56.8	54.7	71.4	29.7	22
A4	509.3	660.4	419.5	131.7	1 671.5	2.626.2	1 065.1	836.8	75.4	76.4	74.9	0.8
A5	383.2	433.3	290.6	80.3	874.8	1 077.8	745	178.1	187.9	235.7	117.9	61.9

Table 3b. *Fine particulate concentration in the indoor micro–environments of Category B houses (Ave=Average, Max=Maximum, Min=Minimum, St Dev=Standard deviation)*

Study Site	PM2.5 in Kitchen (µg/m³)											
	24 Hours				Hourly Maximum				Hourly Minimum			
	Ave	Max	Min	St Dev	Ave	Max	Min	St Dev	Ave	Max	Min	St Dev
B1	445.6	681.5	237.5	223.3	1 588.5	3 383.4	542.3	1 561.5	126.9	150.6	80.6	40.1
B2	250.5	368.5	162.2	106.3	2 013.7	2 991.8	775.5	1 130.8	51.0	57.1	45.4	5.8
B3	199.6	269.4	143.5	64.1	508.0	823.1	247.7	291.6	92.6	113	56.1	31.7
B4	440.3	556.3	289.4	136.8	1 073.1	1 586.6	582.6	502.4	115.1	165.7	70.4	47.9
B5	383.5	452.1	344.8	59.6	643.0	706.7	600.3	56.2	193.6	217.5	170.4	23.5
	PM2.5 in Living Room (µg/m³)											
B1	227.4	310.1	165.5	74.5	512.9	681.1	336.6	172.4	91.5	131.6	71.2	34.7
B2	114.6	119.0	106.5	7.0	282.1	348.6	179.4	90.2	53.8	64.1	47.4	8.9
B3	213.6	282.6	154.1	64.8	499.9	697.9	278.1	210.9	102.5	125.9	62.5	34.8
B4	476	589.3	306.7	149.4	1 192.3	1 638.7	577.9	550	132.6	179.2	89.9	44.8
B5	657.2	1 068.7	439.2	356.6	4 744.1	12 291.2	823	6 537.7	223.7	282.3	188.1	51.2

Table 3c. *Fine particulate concentration in the indoor micro–environments of Category C houses (Ave=Average, Max=Maximum, Min=Minimum, St Dev=Standard deviation)*

Study Site	PM2.5 in Kitchen (µg/m³)											
	24 Hours				Hourly Maximum				Hourly Minimum			
	Ave	Max	Min	St Dev	Ave	Max	Min	St Dev	Ave	Max	Min	St Dev
C1	342.6	441.5	256.7	93.1	1 721.7	2 365.5	1 156.4	608.4	87.1	96.9	71.0	14.1
C2	79.6	107.3	61.7	24.3	193.7	323.2	94.0	117.4	38.5	52.8	29.1	12.6
C3	136.8	165.3	113.8	26.2	319.8	404.0	214.5	96.5	52.3	60.3	43.7	8.3
C4	321.4	355.8	299.4	30.1	1 053.3	1 290.6	745.7	279.1	75.2	102.8	43.0	30.1
C5	504.8	536.9	456.5	42.6	916.2	1.083	722.7	181.6	218.7	253.7	194.3	31
	PM2.5 in Living Room (µg/m³)											
C1	193.6	228.6	151.6	39.0	502.7	626.5	277.3	195	85.4	93.6	69.1	14.1
C2	68.4	77.3	58.8	9.2	116.1	151.2	86.1	32.8	41.3	50.7	35.0	8.3
C3	137.6	163.4	112.7	25.3	283.4	334.3	195.0	76.9	51.2	66.0	35.2	15.4
C4	388.5	423.7	327.9	52.7	1 067.6	1.235	812.7	224.3	112.9	180.9	53.5	64.1
C5	729.7	803.1	674	66.3	1 230.1	1 466.1	906.4	290	437.7	685.9	278.2	217.8

5. Conclusions

Particulate matter concentrations were observed to be affected by shifting seasons with lowest averages obtained during the summer season, slightly increasing during the rainy season, and further during the fall. Indoor environments were reported to accumulate highest levels of particulate matter during the winters which fell considerably during the spring season. The variations were statistically significant. The air exchange rate was directly correlated with PM concentrations in the living rooms while no correlation was observed in the kitchens. This could most probably be due to the influence of increased activity in kitchens generating higher PM concentrations. Different activities were identified to cause fluctuations in PM levels throughout the day. The results were in agreement with many other studies associating the elevated levels of particulate matter in residential settings resulting from various routine activities such as cooking, floor sweeping, presence of people, smoking and space heating. The impact of household activities, ventilation rates, and changing seasons upon the particulate matter in the indoor environments was concluded to be substantial.

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