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PARTICULATE POLLUTION IN URBAN RESIDENTIAL BUILT ENVIRONMENTS DURING WINTER AND SUMMER SEASONS IN LAHORE, PAKISTAN

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ABSTRACT

Indoor air pollution in urban residential areas of developing countries is of growing public health concern. The seasonal variation in mass concentration of PM_1, $PM_{2.5}$ and $PM_{10}$was investigated in a residential built environment in Lahore, Pakistan by two DustTrak aerosol monitor (model 8520, TSI Inc.) during the winter and summer season. The measurements were carried out in the kitchen and living room simultaneously.The 24-hr meanconcentrationsfor PM_1, $PM_{2.5}$ and PM_{10}in the kitchen and living room during the winter season were 157µg/m^3 (±54), 733 µg/m^3(±243), 409 µg/m^3(±177) and 135µg/m^3 (±39), 240 µg/m^3 (±87), 300 µg/m^3 (±115), respectively.During the summer the 24-hr mass concentration, for the same size fraction, in the kitchen and living room fell to 37µg/m^3 (±4), 74µg/m^3 (±11), 100 µg/m^3 (±22) and31µg/m^3 (±4), 71 µg/m^3 (±19), 190 µg/m^3 (±21), respectively. Apart from a higher concentration in winter than summer, a vast variation in 24hr and hourly mean concentration was also observed in the latter than in the former.Moreover background concentrations (hourly minimum) were also higher in winter than summer. These clearly highlight the impact of ventilation on indoor particulate matter as the sampling spaces (kitchen and living room) were more ventilated in summer than winter. The higher concentrationof the coarse size fraction in the living room than in the kitchen during summer time also shows the contribution from outdoor sources. These findings highlightthe impact of location, use and management of a residential built environment on exposure to indoor air pollutants.

Key words: PM, Urban, Seasonal variation, Residential, Lahore.

INTRODUCTION

Indoor air quality has emerged as an issue of great concern since in urban areas, people tend to spend most of their times indoors. The built environmentmay seem safe from the pollutants, nonetheless, indoor air could be more polluted than that outdoors due to diverse pollutant sources and use/management practices. The air we breathe indoors may be laden with a number of pollutants. Of these particulate matter (PM) is of great concerndue to its association with many respiratory problems, lung diseases, allergic diseases, headaches, and hypertension (Goyal and Khare, 2010; Lee *et al.* 2014).

The origin and concentration of PM indoors varies with the location of the building, its design, construction material, air intake, furnishing and also with different activities such as cooking, smoking, cleaning, movement of people and above all infiltration from the outside (Lee *et al.* 2001; Ferro, 2004; Hänninen*et al.* 2004; He *et al.* 2004; Bi *et al.* 2005; Zuraimi*et al.* 2006; Chunram*et al.* 2007). However, climate and ventilation also play their part in defining the indoor air quality (Saksena and Uma, 2008).The concentration of PMindoors is also dependents upon on outdoor sources and may vary seasonally(Nitta *et al.* 1994).

Studies on seasonal variations of PM in residential buildings showed higher levels in winter than summer (Massey *et al.* 2012).Since the windows and doors are mostly kept closed during winterPM concentrations were found to be higher than the summer (Leaderer*et al.* 1999; Chunram *et al.* 2007; Massey *et al.* 2012; Sidra *et al.* 2015). In another study comparing PM concentrations during monsoon and winter season, higher concentrations were observed in the winter (Tiwari *et al.*2012).These results clearly highlight the role of ventilation in defining indoor air quality.In fact, the operation of residential built environments (e.g. activities, ventilation behaviour of the occupants) can be greatly influenced by many socio-economic, socio-demographic, political, cultural values and outdoor environmental/climatic conditions. Hence there would be substantial variation in the concentration of indoor PM and subsequent exposure in various residential micro environments within and across different geographic regions. It is reasonable to argue that in order to identify potential intervention strategies to mitigate indoor air pollution knowledge on venue and scenario specific PM concentrations and their determinantsis prerequisite.

Worldwide, the use of solid fuels as household cooking fuel is one of the biggest source of indoor air pollution and currently responsible for 4 millionpremature deaths (WHO, 2014). The use of these fuels is highest in low income countries especially in rural areas. However, in urban areas where clean fuels (natural gas/ electric, liquefied petroleum gas) are usedthe deterioration of air quality due to rapid urbanization and associated growth in vehicles, transport infrastructure and industryalong with poor air quality management is likely to impact onindoor air quality.Little work has been done on indoor particulate pollution in Pakistan so far (Nasir *et al.* 2013). There is lack of knowledge regarding indoor air quality and how the changing seasons affect it in Pakistan, particularly in urban areas. The current study was conducted toinvestigate the indoor concentrations of PM (PM_1, $PM_{2.5}$ and PM_{10}) in both summer and winter seasons in a house in Lahore, Pakistan to investigate the effect of seasonal variations on indoor air quality in an urban residential environment.

MATERIALS AND METHODS

Lahore is the second most populous city of Pakistan and provincial capital of Punjab province. During the summer (May, June, and July) the temperature can exceed 45°C, whereas it may drop below 0°C during winter (December, January and February). The monsoon brings heavy rain during the month of August. The size of the house was 73,514m^2. The number of residents was same in both seasons i.e. 7. Some visitors and guests were also present in house during the study period. The entire house was naturally ventilated; however there was an exhaust fan in the kitchen where two natural gas stoves were used for cooking. Movement of people was low in the kitchen as compared to that in the living room. During the time of study, the exhaust fan was mostly off in the kitchen during the winter, while in summer it was on during the cooking times. In addition a ceiling fan was on during the whole study period in the kitchen and living room during the summer. The windows and doors were closed in the winter while left open during summer time. There were few periods of electric load shedding but no kerosene lamps were used in this house during period of study.The building was constructed of concrete and the surroundings had low traffic density and trees close by.

The levels of PM_1, $PM_{2.5}$ and PM_{10} were measured in both the kitchen and living simultaneously to investigate diurnal and seasonal variations. Two DustTrak aerosol monitors (model 8520, TSI Inc.)were used to record mass concentrations of in the kitchen and living room during winter (January, 2012) and summer (May, 2012) season. The sampling period was of 72 hours duration for each size fraction. The air flow was setat 1.7 L/min and was adjustedevery time the inlet nozzle was changed.Data logging interval was set at 1 minute.The measurements were made at height of 1m. The time/activities diaries of the occupants were kept during the sampling periods.Information on number of residents in the house, cooking activities, and ventilation in the kitchen and living room was also documented. The data was further analyzed hourly to investigate the effect of various activities(hourly maximum) and background concentrations (hourly minimum) on PM levels and 24-hour mean concentrations were calculated for each setting.

RESULTS AND DISCUSSION

Table 1 presents 24-hr, hourly maximum and hourly minimum mass concentration of PM_{10}, $PM_{2.5}$ andPM_1 in kitchen and living room during winter and summer.It is clear that 24-hrmeanconcentrations for all size fractions in both the kitchen and living room were higher in the winter compared to the summer. Summer concentrations were around 70% than in the winter time except for $PM_{2.5}$ in the kitchen (90% decrease) and PM_{10} in the living room (37% decrease).Hourly maximum concentrations reflect impact of various activities on indoor PM and mean hourly maximum levels were more than three times higherin comparison to mean back ground values (hourly minimum)(Table1).

There were 7 residents in the house performing different activities. The sources of PM_1 were identified to be cooking and a higher concentration of PM_1 was found both in the kitchen and living room during the winter than in the summer. The PM concentrations in the kitchen were elevated due to cooking in both winter and summer. Cooking is generally identified to be the major source of ultrafine particles (PM_1) in kitchens (Bhangar*et al.* 2011). The mean 24-hr value for $PM_{2.5}$ during the winter in the kitchen was over three times higher than that in the summer. However in the summer these were almost same in the kitchen and living room. The maximum concentration of $PM_{2.5}$ in the kitchen was observed during cooking. Cooking and frying were identified to be the major sources of the emission of $PM_{2.5}$. This is in agreement with previous studies where the estimated $PM_{2.5}$ emission rate from frying, grilling, cooking pizza, and smoking was reported to be the highest among the indoor particle emission sources investigated. Similarly cooking was found to be the dominating factor in $PM_{2.5}$ accumulation in the indoor environment while human activities and infiltration from outdoor were the second major contributors (Chao and Cheng, 2000). Abt*et al.* (2000) reported that oven cooking and toasting contributed primarily to sub micrometer particles and cleaning to super micrometer particles while frying contributed to both. Similarly Jones *et al.* (2000) found that fine particles smaller than 2.5µm were mainly generated from activities such as smoking and cooking. Colbeck and Nasir (2010) have also noted that specific indoor activities, such as cooking, cleaning and smoking, lead to high concentrations of indoor air pollutants.

Table 1. Summary of levels of particulate pollution in kitchen and living room during summer and winter. Concentrations in µg/m^3.

	24 Hour			Hourly Maximum			Hourly Minimum		
WINTER									
KITCHEN	**PM_1**	**$PM_{2.5}$**	**PM_{10}**	**PM_1**	**$PM_{2.5}$**	**PM_{10}**	**PM_1**	**$PM_{2.5}$**	**PM_{10}**
Mean	157	733	409	308	1639	903	57	160	111
Max	215	906	611	402	1984	1328	69	164	179
Min	108	561	284	180	1295	553	45	156	67
SD	54	243	177	115	487	393	12	6	60
LIVING ROOM									
Mean	135	240	300	288	454	667	47	134	96
Max	177	302	433	362	656	1085	54	144	156
Min	100	179	230	170	252	397	43	125	54
SD	39	87	115	104	286	367	6	13	53
SUMMER									
KITCHEN									
Mean	37	74	100	111	164	161	11	45	44
Max	41	86	121	159	223	176	17	55	57
Min	34	66	78	66	116	136	8	39	35
SD	4	11	22	46	54	22	5	9	12
LIVING ROOM									
Mean	31	71	190	86	144	372	11	43	75
Max	34	91	205	113	175	457	16	54	96
Min	26	53	166	54	113	298	8	34	51
SD	4	19	21	30	31	80	4	10	23

For coarse particles (PM_{10})winter time levels were higher compared to the summer. The values of PM_{10}, during summer time, were higher in the living room as compared to kitchen. This is most probably result of increased household activities and an outdoors contribution due to enhanced ventilation.Movement of people can also cause variation in the concentration of PM and there can be changes in the concentration of PM_{10} within the same house due to varying life style/activities of the occupants. Long *et al.*(2000) found that cleaning and indoor work had a significant effect on coarse mode particles.

Overall, the concentration of PM in all the size fractions was higher during the winter season than the summer in both kitchen and living room and these were higher in kitchen than living room in both winter and summer. Ventilation rates were presumably low in winter as windows and doors were closed for most of the time. But in summer higher ventilation rates are very likely due to open windows and doors and use of exhaust and ceiling fans. In the present study, ventilation behavior of the occupants was recorded and it was found that opening time for windows and doors was double in summer than winter time

Adiurnal variation, in all size factions is much more evident in the kitchen in winter than in the summer. There is a peak in PM_{10} due to cleaning activities in the morning together with a $PM_{2.5}$ peak from cooking. Due to increased ventilation any diurnal variation is small.In the living room the diurnal variation is again much more evident in the winter. However there is an increase in summer time PM_{10} in the eveningas a result of social activities. It should be noted that all size fractions were not recorded simultaneously. Each size fraction was recorded for 72 hours so a peak in, for example, $PM_{2.5}$ won't be shown in the PM_{10} data.

An important factor to be noted is that indoor particulate concentration was dominated by $PM_{2.5}$. Although the concentration of PM was low in the summer season, these values were found to exceed the permissible limits specified by World Health Organization (WHO) for $PM_{2.5}$ i.e. 25 µg/m^{3}and for PM_{10} i.e. 50µg/m^3. Studies carried out in other regions have also found higher concentrations in winter than summer.

Tiwari *et al*. (2012) conducted a study in Delhi during August to December 2007 to measure the mass concentrations of PM_1, $PM_{2.5}$ and $PM_{10.}$ The concentrations of $PM_{10,}$ $PM_{2.5}$ and PM_1 ranged from 20 to 180µg/m³ during the monsoon and from 100 to 500 µg/m³ during the winter. Similarly Massey *et al*. (2012) observed the concentration of PM_1, $PM_{2.5}$, PM_5 and PM_{10} to be highest in winter season. This increased concentration in winter is most probably due to increased human activities indoors and reduced ventilation. Household activities such as cooking on stoves, indoor smoking and outdoor vehicular traffic, and garbage burning were found to be the major sources of particulate emissions indoor as well as outdoor (Massey *et al.* 2012). Recently, Sidra *et al.* (2015) also observed a significant impact of seasons upon PM levels in the indoor residential environments of Lahore, Pakistan.

It is of note that enhanced ventilation in summer due to opening of windows and doors for long duration may also lead to increased contribution form outdoor PM, especially in urban areas with poor air quality. Ventilation plays an important part in defining the indoor air and infiltration from outdoor sources can have a prominent impact on the indoor air quality. The highest infiltration levels are typically observed in the summer and lowest values in winter (Hänninen*et al.* 2011). During the current study higher concentrations of PM_{10} during summer in living room than kitchen was most probably due the coarse size PM contribution from outdoors.

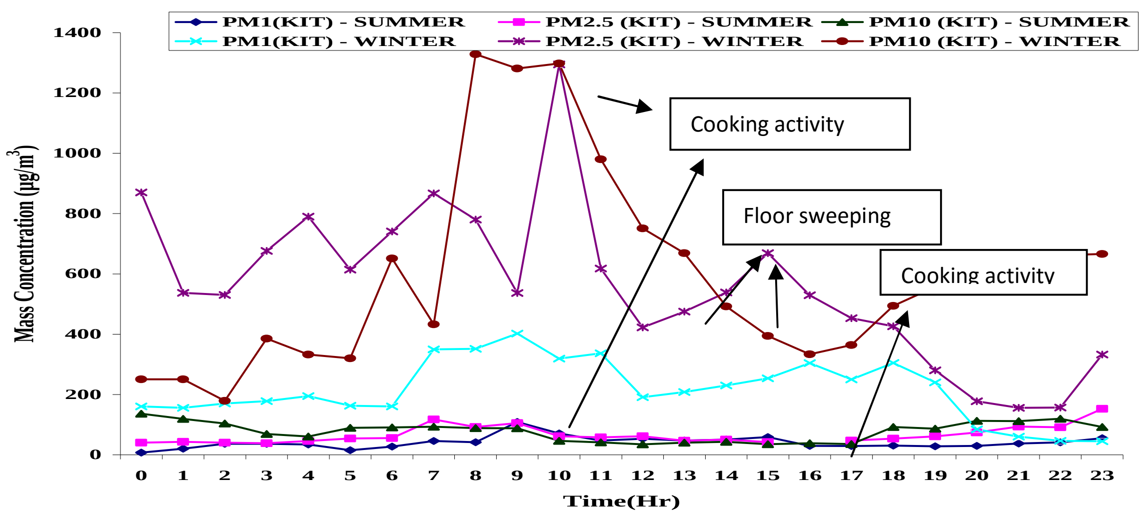

Figure 1. Representative hourly average mass concentrations of PM_{10}, $PM_{2.5}$ and PM_1 in the kitchen during summer and winter.

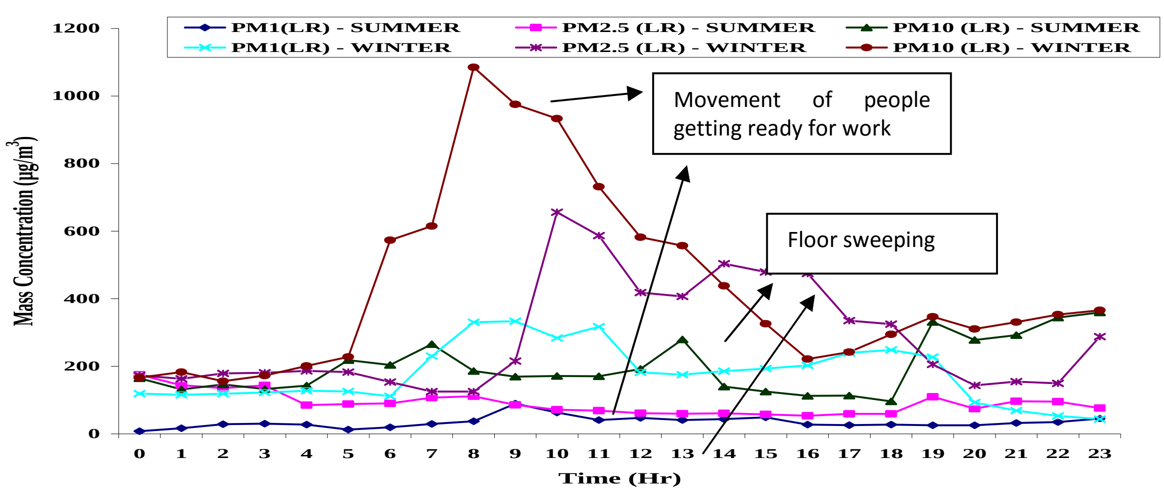

Figure 2. Representative hourly average mass concentrations of PM_{10}, $PM_{2.5}$ and PM_1 in the living room during summer and winter.

Conclusions: The current case study demonstrated that concentration of PM_1, $PM_{2.5}$ and PM_{10} were higher during the winter season than in the summer in both the kitchen and the living room in urban residential environment.Factorsresponsible for these comparable differences include low ventilation due to closed windows, more space heating, indoor activities and more time spent indoors by the occupantsduring the winter season. Windows and door were kept open during the summer season and fans were also on. Increased ventilation decreased the PM concentrations during summer season.However, this increased ventilation may lead to a higher concentration of indoor PM in the case of proximity to PM sources (e.g. heavy traffic, industries, garbage burning). This may have implications in terms of exposure to PM in urban residential built environments. Further studies examining the integrated exposure to indoor and ambient air pollution in a range of residential built environments, for different urban densities along with an evaluation of socioeconomic determinants of use and management of themis required to understand the existing and emerging pathways of exposure to PMand to inform the policy and intervention strategies.

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