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

Z. Ali1, F. Naz1, Z. A. Nasir2, S. Sidra1,3 and I. Colbeck4

1Environmental Health and Wildlife, Department of Zoology, University of the Punjab, 54590, Lahore, Pakistan
2School of Energy, Environment and Agrifood, Cranfield University, Cranfield, Bedfordshire MK43 0AL, UK
3Department of Wildlife and Ecology, University of Veterinary and Animal Sciences, Lahore, Pakistan
4School of Biological Sciences, University of Essex, Colchester, Essex, CO4 3SQ, UK

Corresponding email: zali.zool@pu.edu.pk

ABSTRACT

Indoor air pollution in urban residential areas of developing countries is of growing public health concern. The seasonal variation in mass concentration of PM1, PM2.5 and PM10 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 mean concentrations for PM1, PM2.5 and PM10 in the kitchen and living room during the winter season were 157 μg/m³ (±54), 733 μg/m³ (±243), 409 μg/m³ (±177) and 135 μg/m³ (±39), 240 μg/m³ (±87), 300 μg/m³ (±115), respectively. During the summer the 24-hr mass concentration, for the same size fraction, in the kitchen and living room fell to 37 μg/m³ (±4), 74 μg/m³ (±11), 100 μg/m³ (±22) and 31 μg/m³ (±4), 71 μg/m³ (±19), 190 μg/m³ (±21), respectively. Apart from a higher concentration in winter than summer, a vast variation in 24-hr 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 concentration of the coarse size fraction in the living room than in the kitchen during summer also shows the contribution from outdoor sources. These findings highlight the 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 environment may 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 concern due 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; Hämminenet al. 2004; He et al. 2004; Bi et al. 2005; Zuraimiet 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 PM indoors is also dependent upon 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 winter, PM concentrations were found to be higher than the summer (Leaderet 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 determinantis 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 million premature 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 used the deterioration of air quality due to rapid urbanization and associated growth in vehicles, transport infrastructure and industry along with poor air quality management is likely to impact on indoor 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 to investigate the indoor concentrations of PM (PM$_{10}$, PM$_{2.5}$ and PM$_{1}$) 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 73,514 m$^2$. 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 set at 1.7 L/min and was adjusted every 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$_{2.5}$ and PM$_{1}$ in kitchen and living room during winter and summer. It is clear that 24-hr mean concentrations 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 higher in comparison to mean background values (hourly minimum) (Table 1). 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 (Bhangare 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.

---

*Proceedings of The National Conference and Training Workshop “Wildlife and Aerobiology” held on February 6-7, 2015 Lahore, Pakistan*

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/m³.

<table>
<thead>
<tr>
<th></th>
<th>KITCHEN</th>
<th></th>
<th></th>
<th>LIVING ROOM</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>PM₁</td>
<td>PM₂₅</td>
<td>PM₁₀</td>
<td>PM₁</td>
<td>PM₂₅</td>
<td>PM₁₀</td>
</tr>
<tr>
<td></td>
<td>PM₁</td>
<td>PM₂₅</td>
<td>PM₁₀</td>
<td>PM₁</td>
<td>PM₂₅</td>
<td>PM₁₀</td>
</tr>
<tr>
<td></td>
<td>Mean</td>
<td>PM₁</td>
<td>PM₂₅</td>
<td>PM₁₀</td>
<td>PM₁</td>
<td>PM₂₅</td>
</tr>
<tr>
<td></td>
<td></td>
<td>SD</td>
<td>54</td>
<td>243</td>
<td>177</td>
<td>115</td>
</tr>
</tbody>
</table>

For coarse particles (PM₁₀) winter time levels were higher compared to the summer. The values of PM₁₀ 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 PM₁₀ 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 PM₁₀ due to cleaning activities in the morning together with a PM₂₅ 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 PM₁₀ in the evenings 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, PM₂₅ won’t be shown in the PM₁₀ data.

An important factor to be noted is that indoor particulate concentration was dominated by PM₂₅. 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 PM₂₅ i.e. 25 µg/m³ and for PM₁₀ i.e. 50µg/m³. 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 PM₁, PM₂.₅ and PM₁₀. The concentrations of PM₁₀, PM₂.₅ and PM₁ 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 PM₁, PM₂.₅, PM₅ and PM₁₀ 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 from outdoor PM, especially in urban areas with poor air quality. Ventilation plays an important part in defining outdoor PM, 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 (Häninnen et al. 2011). During the current study higher concentrations of PM₁₀ during summer in living room than kitchen was most probably due to the coarse size PM contribution from outdoors.

![Graph 1](image1.png)

**Figure 1.** Representative hourly average mass concentrations of PM₁₀, PM₂.₅ and PM₁ in the kitchen during summer and winter.

![Graph 2](image2.png)

**Figure 2.** Representative hourly average mass concentrations of PM₁₀, PM₂.₅ and PM₁ in the living room during summer and winter.

*Proceedings of The National Conference and Training Workshop “Wildlife and Aerobiology” held on February 6-7, 2015 Lahore, Pakistan*
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. Factors responsible for these comparable differences include low ventilation due to closed windows, more space heating, indoor activities and more time spent indoors by the occupants during 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 these is required to understand the existing and emerging pathways of exposure to PM and to inform the policy and intervention strategies.

REFERENCES


Hänninen, O., E. Lebret, V. Ilacqua, K. Katsouyanni, N. Künzli, R.J. Srám and M. Jantunen (2004). Infiltration of ambient PM$_{2.5}$ and levels of indoor generated non-ETS PM$_{2.5}$ in residences of four European cities. Atmospheric Environment. 38: 6411-6423.


continuous mass and size monitors. J. Air and Waste Management Association 50: 1236-1250.

Massey, D., A. Kulshrestha, J. Masih and A. Taneja (2012). Seasonal trends of PM$_{10}$, PM$_{2.5}$, PM$_{5.0}$ and PM$_{1.0}$ in indoor and outdoor environments of residential homes located in North-Central India. Building and Environment. 47: 3e231.


Tiwari, S., D. Chate, P. Pragya, K. Ali and D.S. Bisht (2012). Variations in mass of the PM$_{10}$, PM$_{2.5}$ and PM$_{1}$ during the monsoon and the winter at New Delhi. Aerosol and Air Quality Research 12: 20-29.
