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ASSESSMENT OF AIRBORNE PARTICULATE MATTER ($PM_{2.5}$) IN UNIVERSITY CLASSROOMS OF VARRYING OCCUPANCY

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ABSTRACT

Air pollution is a major concern in Pakistan. Levels of particulate matter ($PM_{2.5}$) in educational built environments, have not yet been studied comprehensively in Pakistan. This study was conducted to assess relationships between indoor and outdoor particulate matter in classrooms of the University of the Punjab, Lahore, using a DUSTTRAK Aerosol Monitor (TSI Model 8520). Sampling for $PM_{2.5}$ concentrations was carried out simultaneously outdoors and indoors in different classrooms on the campus. According to the level of occupancy three classrooms were selected i.e. Classroom I: low occupancy, Classroom II: medium occupancy and Classroom III: high occupancy. Simultaneous outdoor measurements were carried out at rooftop of each classroom. A tracer method was used to measure the air change per hour in each classroom. The 24 hour average concentrations of $PM_{2.5}$ in Classrooms I, II and III were observed to be 282 µg/m³, 75 µg/m³ and 673 µg/m³ whereas 24 hour average outdoor levels were 324 µg/m³, 121 µg/m³ and 998µg/m³ respectively. Results showed a significant impact of ambient air and occupancy level on $PM_{2.5}$ levels inside classrooms and all observed values exceeded the WHO limits.

Keywords: Particulate Matter, $PM_{2.5}$, Classrooms.

INTRODUCTION

Air pollution, both ambient and indoors, is a major global public health issue, particularly in developing countries. In these countries ambient air quality is deteriorating due to excessive increase in emission sources, energy use and unplanned urbanization, while use of solid fuels as household energy source by vast majority of population is responsible for poor indoor air quality. Exposure to both indoor and outdoor air pollution results in many health effects which range from lung cancer to chronic obstructive pulmonary disease, cataracts to tuberculosis, cardiovascular diseases and respiratory infections. According to World Health Organization (2014 a,b) worldwide, premature deaths attributable to indoor air pollution from solid fuel use and ambient air pollution are estimated to be 4.3 million and 3.7 million, respectively.

Urban areas and their dwellers in developing countries are affected by air pollution disproportionately due to their likely long term exposure to excessive ambient as well as indoor air pollutants. A large proportion of time by urban population is spent in different enclosed environments and knowledge of indoor air quality in these locations is vital to estimate total human exposure to different air pollutants. Additionally, ambient concentration of air pollutants may not accurately reflect the degree, frequency and nature of exposure to them. Therefore it is vital to gather knowledge on levels of exposure to air pollutants in different microenvironments.

The state of air quality in educational built environments is important, not only because of amount of time spent there, but also due to high occupant density. As compared to other indoor microenvironments, classrooms do not contain sources of indoor pollutants such as smoking and cooking but high levels of particulate matter can be observed (Janssen *et al.*, 2001). Among the range of air pollutants particulate matter is of great significance due to its association with cardiovascular and pulmonary ailments.

Sources of particulate matter and other pollutants inside the classrooms can be varying. One of the chief potential sources of indoor pollution is activities of the inhabitants (Huang *et al.*, 2007). Blondeau *et al.* (2005) concluded that the airborne pollutants of non-ambient source are strongly influenced by the re-suspension, deposition and generation of particles by the occupants. Thus in classrooms, activities of students play a major role in the variation of PM levels. The presence of large number of students in a relatively small classroom can result in the generation and re-suspension of particles (Diapouli *et al.*, 2008). Branis *et al.* (2005) conducted a study comprising of 12 hours mass concentration analysis of PM_{10}, $PM_{2.5}$ and PM_1 in a lecture room during the absence and presence of the students along with day and night analysis. The results showed a strong correlation between the students and $PM_{2.5}$ levels i.e. presence of the students in the lecture room caused an elevation in the concentration of fine particulate matter.

Apart from student activities, ventilation rate also effects the particulate matter concentrations in classrooms. Fromme *et al*. (2008) concluded that cleaning and inadequate ventilation results in elevated levels of particulate matter. Daisey *et al*. (2003) stated as a result of reduced and improper ventilation various health related issues were reported.

Indoor air quality in education built environment in urban centres of developing countries is likely to be influenced by excessive levels of ambient air pollution. Studies have shown that infiltration of the particles from outdoor caused an increase in the concentration of $PM_{2.5}$ in classrooms (Guo *et al*., 2010) and that construction and traffic activities were major outdoor sources which influenced indoor air quality (Liu *et al*., 2004).

Pakistan is one of the most urbanized countries in South Asia and reports have shown that the levels of particulate pollution, especially in urban areas, are considerably higher than limits proposed by WHO and other developed countries (Sanchez-Triana *et al*., 2014). Recently the state of indoor air quality in the country has gained attention and studies have been carried out in residential and transport settings (Siddiqui *et al*., 2009; Colbeck *et al*., 2010 a,b; Colbeck *et al*., 2011; Nasir *et al*., 2013; Nasir *et al*., 2015; Sidra *et al*., 2015). However knowledge on indoor quality in education built environments is rare. Hence the study was conducted to assess the concentration of $PM_{2.5}$ in classrooms to demonstrate the impact of occupancy and related activities in university classrooms.

MATERIALS AND METHODS

Study Site: Simultaneous measurements of indoor and outdoor $PM_{2.5}$ were carried out at the University of the Punjab located in new Lahore area. This city is capital of Punjab with a total population of 11,000,000 and a total area of 1772 km^2. The university spreads over an area of 1800 acres. The location of Department of Zoology was determined by using GPS i.e. N 31 30´04.90´´ E 74 18´24.79´´.

For sampling three classrooms in the Zoology department were selected on the basis occupancy i.e. low, medium and high strength, and size. Rooftops relevant to the indoor classroom were selected as ambient sampling locations. The classrooms and respective outdoor sites were designated as:

Classroom I: low occupancy (less than 25 students), 79.15m^3 (Small Size) and Outdoor I

Classroom II: medium occupancy (25 to 50 students), 142.09m^3 (Medium Size) and Outdoor II

Classroom III: high occupancy (more than 50 students), 403.79m^3 (Large Size) and Outdoor III

All three classrooms had windows and fans and were air conditioned. Windows of the classrooms were permanently closed. Thus the only source of infiltration of the particulate matter from outdoors was the door. As the sampling was done during the winter season the fans and air conditioner were switched off. In the outdoor sampling site, the instrument was placed on an elevated surface and covered with an umbrella in order to protect it from rain, moisture and dew during the sampling hours.

Sampling for Particulate Matter: Simultaneous indoor and outdoor sampling of $PM_{2.5}$ was undertaken for 24 hours. Average concentrations of all the sampling sites were obtained. The data logging interval was set at 1 minute.

Ventilation: The air change rate per hour (ACH) of the selected classrooms was determined using CO_2 as a tracer gas. The doors and windows were closed and the initial concentration of CO_2 was noted. CO_2 was injected and air was mixed by switching on the fans. When the level of CO_2 reached a steady state the concentration was recorded after every five minutes. The decrease in CO_2 level was monitored until the concentration dropped back to the initial levels. The same procedure was repeated with the doors and windows opened. Natural log of CO_2 concentration was plotted against time, air change per hour was calculated by drawing a straight line through the curves attempting a best fit.

RESULTS AND DISCUSSION

Table 1 summarizes the indoor and outdoor levels of $PM_{2.5}$ in all classrooms and respective outdoor sites. The 24 hour average concentrations of $PM_{2.5}$ in Classroom I and Outdoor I was found to be 282 $\mu g/m^3$ and 324 $\mu g/m^3$ with an indoor/outdoor (I/O) ratio of 0.87. The average levels of fine particulate matter in Classroom II were 75 $\mu g/m^3$and Outdoor II were 121 $\mu g/m^3$; the I/O ratio was found to be 0.62. The 24 hour average concentrations of $PM_{2.5}$ in Classroom III and Outdoor III were 673$\mu g/m^3$ and 998 $\mu g/m^3$ with an I/O ratio of 0.67.

Table 1: Indoor and outdoor average concentrations of $PM_{2.5}$ in all classrooms and respective outdoor sites.

	24 Hours			Hourly Maximum			Hourly Minimum		
	Indoor	**Outdoor**	**I/O**	**Indoor**	**Outdoor**	**I/O**	**Indoor**	**Outdoor**	**I/O**
Classroom I	282	324	0.87	469	794	0.59	127	107	1.2
Classroom II	75	121	0.62	141	350	0.4	55	61	0.9
Classroom III	673	998	0.67	892	1343	0.66	442	598	0.74

The average concentrations of all indoor and outdoor sampling sites show that the concentration of $PM_{2.5}$ was higher in the ambient air as compared to inside the classrooms. The indoor to outdoor ratios also show the impact of outdoor air on indoor levels of PM in the classrooms. The hourly maximum and minimum levels of PM show the same trend in all classrooms and outdoor sampling sites i.e. levels of PM were higher in ambient air as compared to indoor except for the hourly minimum values observed in Classroom I. These minimum levels of PM were observed during the non-activity hours in the classroom I, when the door was closed.

The I/O ratios for each location on per minute data are given in figures 1, 2 and 3. Higher I/O ratios can be observed in the classrooms during the activity hours thus indicating that both the level of occupancy and ambient air effects the indoor air quality. Whereas I/O ratios less than 1 can be observed when classrooms were unoccupied and doors were closed during non-activity hours.

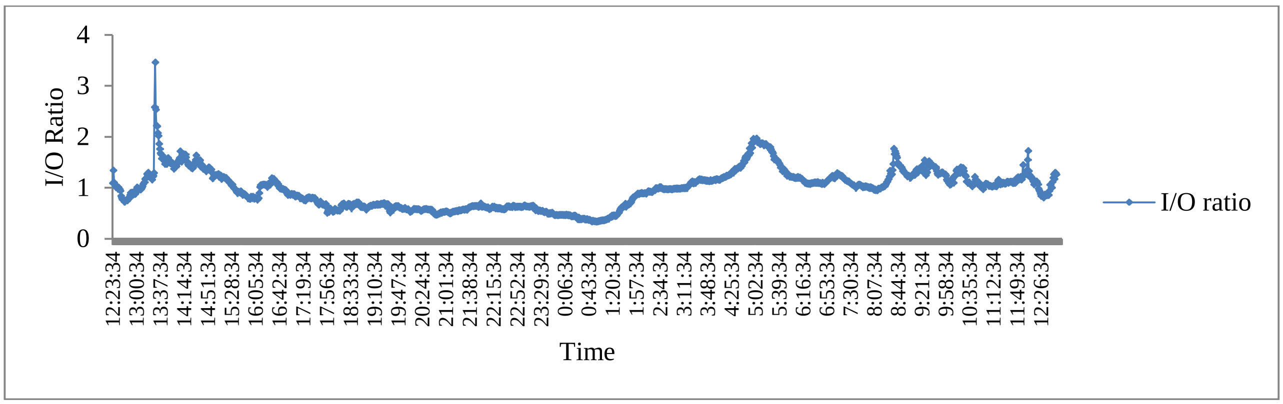

Fig. 1. I/O ratio of $PM_{2.5}$ for Classroom I and Outdoor I

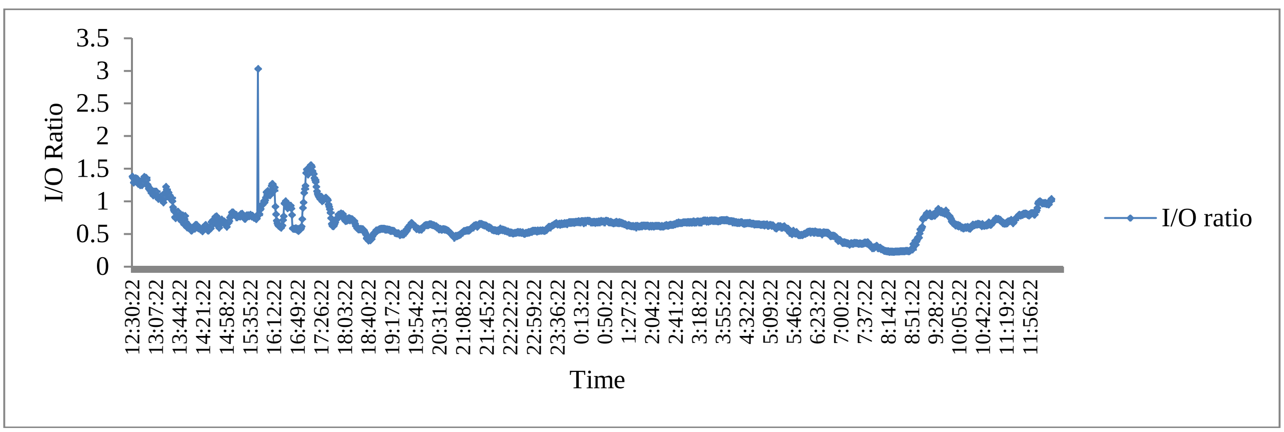

Fig. 2. I/O ratio of $PM_{2.5}$ for Classroom II and Outdoor II

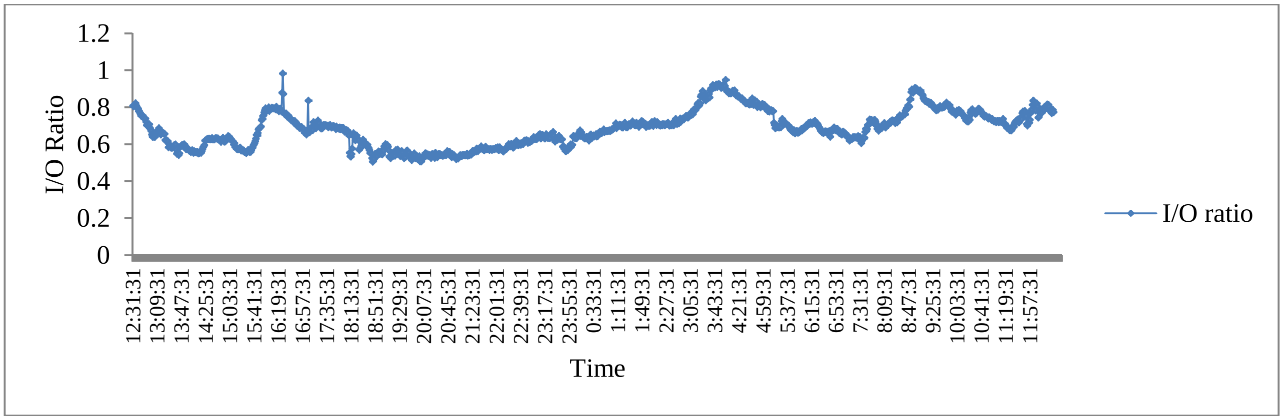

Fig.3. I/O ratio of $PM_{2.5}$ for Classroom III and Outdoor III

Analysis of $PM_{2.5}$ in Classroom I (Low Occupancy) and Outdoor I: Figure 4 shows the diurnal variation in $PM_{2.5}$. According to activity and non-activity time it was seen that students occupied the classrooms from 7 A.M. to 4 P.M. and from 5 P.M. to 6 A.M. the classroom was unoccupied. The air exchange rate in the classroom with doors closed and opened was found to be $0.48h^{-1}$ and $2h^{-1}$.

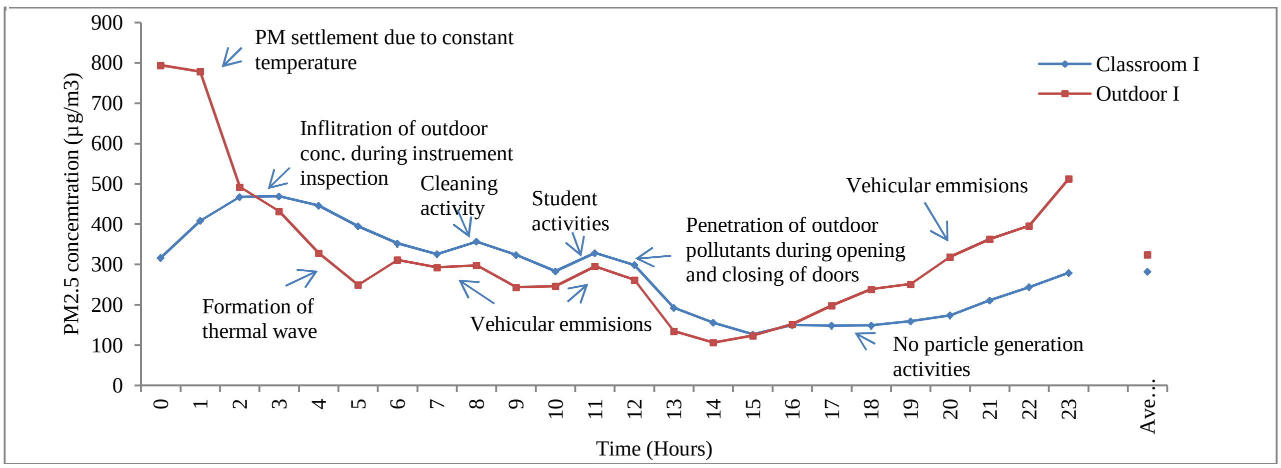

Fig.4. $PM_{2.5}$ average concentrations for 24 hours in Classroom I (Low Occupancy) and Outdoor I

An unusual increase in the indoor concentration of $PM_{2.5}$ during the first few hours of monitoring could be observed. This is most probably due to the door being opened for the inspection of the instrument. Cleaning of the classrooms followed by student activities during the activity hours resulted in a variation in PM levels. Within this period there was a higher chance of penetration of outdoor pollutants inside the classroom due to opening and closing of the door. Infiltration of the particles from outdoor causes an increase in the concentration of $PM_{2.5}$ in the classrooms (Guo *et al*., 2010). Vehicular emissions are the most likely cause of the ambient $PM_{2.5}$ variations.

Analysis of $PM_{2.5}$ in Classroom II (Medium Occupancy) and Outdoor II: The diurnal variation indoors and outdoors for Classroom II is shown in figure 5. This classroom was occupied from 7 A.M. to 1 P.M. and empty the rest of the time. The air exchange rate in the classroom with doors closed and opened was found to be $0.34h^{-1}$ and $1.71h^{-1}$.

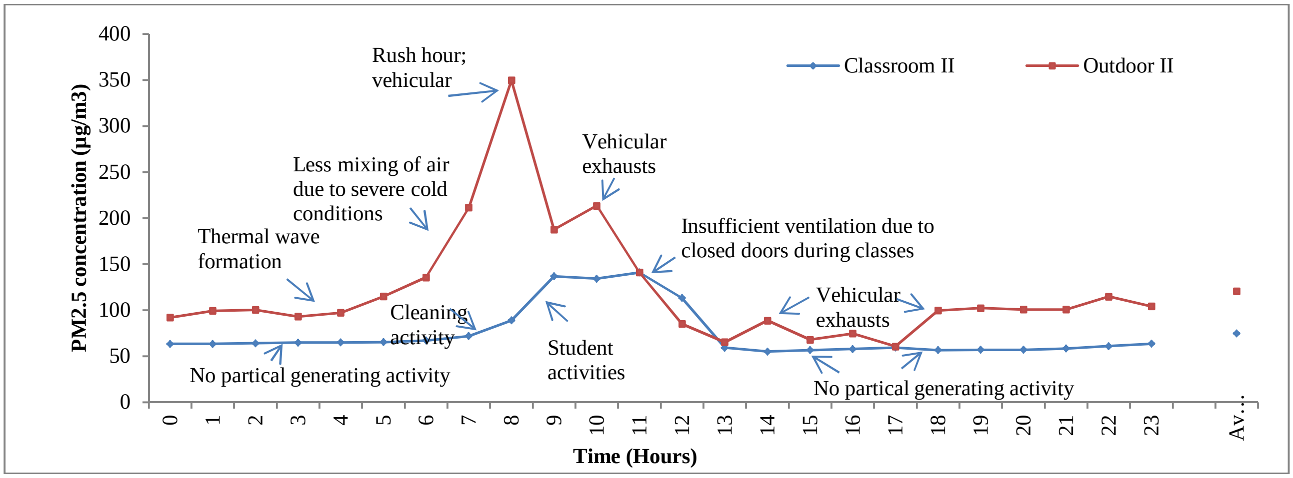

Fig.5. $PM_{2.5}$ average concentrations for 24 hours in Classroom II (Medium Occupancy) and Outdoor II.

No additional source of aerosol was present as the door of the classroom was shut thus the constant value in the first hours of monitoring was observed. Along with insufficient ventilation, cleaning of the classrooms, opening and closing of doors and student activities are the chief factors causing the rise in the concentration once activities had commenced. Heudorf *et al*. (2009) studied indoor air quality using classrooms as a sampling site for the impact of cleaning and ventilation on particulate matter. Their study concluded that infrequent cleaning and insufficient ventilation results in higher levels of particulate matter. Once classes had finished a decrease in concentration can be observed.Severe cold conditions were observed during the sampling of $PM_{2.5}$ outdoors of classroom II. Increased concentrations were observed during the peak traffic rush hours.

Analysis of $PM_{2.5}$ in Classroom III (High Occupancy) and Outdoor III: Figure 6 shows the diurnal variation indoors and outdoors of Classroom III. Students occupied the classroom from 7 A.M. to 5 P.M. and the remainder of the time it was empty.The air exchange rate in the classroom with doors closed and opened was found to be $0.43h^{-1}$ and $1.1h^{-1}$. Peaks were observed during the first few hours of sampling in the classroom, occurring due to the infiltration of particles when inspection of the instrument was done. As before cleaning, student activities and insufficient ventilation resulted in an increase in PM. Once activities had finished $PM_{2.5}$ continued to rise probably due to infiltration of outdoor air.A study carried out in five schools of Istanbul concluded that indoor air quality in the respective schools was highly influenced by the anthropogenic activities (Ekmekcioglu and Keskin, 2007).

The results show that ambient air was more polluted as compared to the classrooms (Table 1). This observed impairment in the ambient air quality can be explained as outdoor vary throughout the day. The University of the Punjab is located near a busy road, thus motor vehicle exhausts especially by poorly maintained and ageing automobiles are of the major causes of the elevated levels of $PM_{2.5}$. Guo *et al.* (2010) evaluated the mass concentrations of $PM_{2.5}$ in a primary school. They observed that higher peaks of $PM_{2.5}$ appeared to be consistent traffic rush hours at the outdoor sampling site.
A similar trend was observed in all three ambient samples i.e. the concentration of fine particulate matter increased, following a gradual decrease in concentration. The midnight peaks are possibly due to temperature inversions reducing dispersion and results in a build up of particulate matter. This dissipates in the early morning and so concentrations decrease. Particulate concentrations in winters can be three to five times higher than in other seasons because the dispersion conditions for particulate matter are not good (Goyal and Khare, 2011).

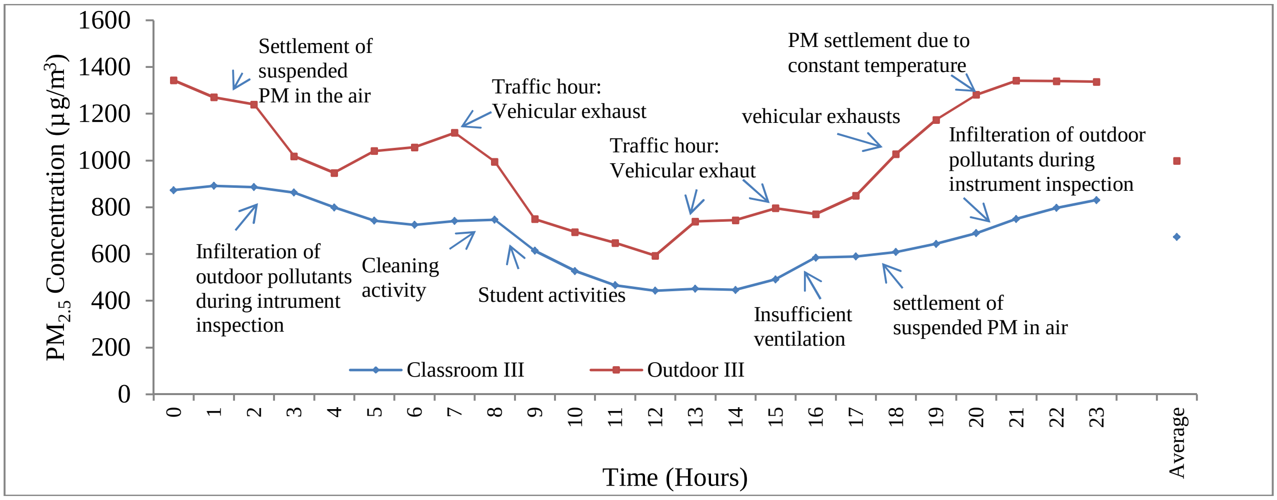

Fig.6. $PM_{2.5}$ average concentrations for 24 hours in Classroom III (High Occupancy) and Outdoor III

Conclusion: The present study is one of the first attempts to monitor and compare the concentrations of indoor and outdoor fine particulate matter ($PM_{2.5}$) in educational built environments in urban areas of Pakistan. In the comparative study, it was observed that ambient air was more polluted as compared to air indoors and had significant impact on the indoor levels of $PM_{2.5}$. Apart from the outdoor sources, student occupancy level also affected the indoor concentrations. Overall the results showed high peaks of $PM_{2.5}$ concentration for all the sampling sites. These concentrations surpassed the guideline levels of World Health Organization (WHO) i.e. 25µg/m^3. Thus strict measures and pollution checks should be undertaken in order to reduce the impairment of the air quality of the classrooms.

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