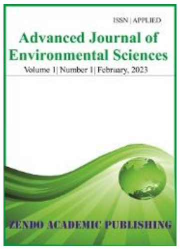

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ASSESSMENT OF INDOOR PARTICULATE MATTER CONCENTRATION IN OFFICES: IMPACTS OF OCCUPANCY AND OUTDOOR PARTICULATES

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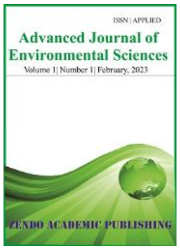
Abstract: Exposure to indoor particulates has been linked to serious health problems. This research aimed to measure the mass concentration of inhalable particles in four offices experimentally, focusing on three airborne particle sizes (PM1, PM2.5, and PM10) during occupancy and non-occupancy periods at the Qassim University Campus, KSA. Results revealed that most activities in the offices significantly affected PM10 and PM2.5, but not PM1, except for vacuuming. Outdoor particles had a significant impact on indoor air quality, especially for PM1 and PM2.5 size fractions. The study concludes that the concentration level of particle fractions (PM10 and PM2.5) during occupancy periods does not satisfy the air quality standards. This study sheds light on the importance of assessing indoor air quality in offices, given the impact on productivity and human health, especially among the elderly, people with heart and/or lung diseases, children, and women. The study also emphasizes the significance of outdoor particulates on indoor air quality and the urgent need to improve office environmental parameters to enhance productivity and limit health risks related to insufficient fresh air.

Keywords: Indoor air quality, particulate matter, PM1, PM2.5, PM10, occupancy, outdoor pollutants, Sick Building Syndrome

INTRODUCTION

Exposure to airborne particulate matter is a global public health concern that has been associated with various health problems such as cardiovascular and respiratory diseases, cancer, and premature death (1-3). Particulate matter (PM) is a complex mixture of tiny solid and liquid particles suspended in the air. These particles can be classified into various sizes, with PM1, PM2.5, and PM10 being the most commonly studied sizes. PM1 and PM2.5 are considered to be more hazardous due to their ability to penetrate deeply into the lungs, while PM10 is less harmful as it is typically deposited in the upper respiratory tract (4-7). Exposure to high concentrations of PM, particularly fine and ultrafine particles, has been associated with short-term and long-term health effects, depending on the duration and level of exposure (8,9).



While outdoor PM has been extensively studied, indoor air quality has recently received attention, given that people spend the majority of their time indoors, especially in urban areas where outdoor air quality is often poor (10,11). Indoor particulate matter concentrations are influenced by several factors, including outdoor air quality, building design and ventilation, and human activities such as cooking, smoking, cleaning, and other indoor activities (12-14).

Poor indoor air quality has been linked to a range of health problems, particularly among vulnerable groups such as the elderly, children, and people with pre-existing health conditions (15-17). Sick Building Syndrome (SBS) is a term used to describe the adverse health effects experienced by occupants of buildings with poor indoor air quality (18). It is estimated that the economic cost of SBS-related health problems is substantial, with productivity losses and healthcare costs running into billions of dollars annually (19,20).

The quality of indoor air in office buildings is particularly important, given that workers spend a significant amount of time in these environments (21). Poor indoor air quality in offices has been associated with decreased productivity and increased absenteeism and health problems among workers (22-24). Besides, airborne particles in office rooms could cause discomfort and health problems to office workers, and their concentration is rapidly changing due to several sources (25). Indoor particulate matter concentrations can be influenced by office equipment such as printers, copiers, and other sources (26,27).

The Middle East, including Saudi Arabia, is home to some of the most polluted cities globally, with outdoor particulate matter being a significant concern (28). However, limited studies have been conducted to investigate indoor air quality in this region, including the concentration of particulate matter (29). Therefore, this study aimed to measure the mass concentration of inhalable particles of different sizes in several offices at the Qassim University Campus in Saudi Arabia. Specifically, the study investigated the impact of outdoor pollutants on the concentration of airborne particles in the offices, as well as the effect of human activities on indoor particulate matter concentrations during occupancy and non-occupancy periods. The results of this study could inform indoor air quality management strategies, particularly in office buildings in Saudi Arabia, to reduce the health risks associated with exposure to indoor particulate matter.

MATERIALS AND METHODS

Study area: Particulate matter mass concentrations of PM_1,
$PM_{2.5}$ and PM_{10} were monitored for 5 months (September, 2018-February, 2019) at Qassim University Campus, KSA. Four offices were investigated. The offices selected were listed in Table 1.

Methodology: Particulate matter fractions in the offices and outdoors were monitored using two units of Grimm Portable Laser Aerosol Spectrometer model 1.108 (GRIMM Aerosol Technik, Ainring GmbH and Co. KG, Germany). This device uses a light-scattering technique for measuring particle concentration and gives real-time measurements of different particle size ranges. The air sampled was continuously drawn into the instrument by a pump with a flow rate of 0.0012 m^3 minG^1.

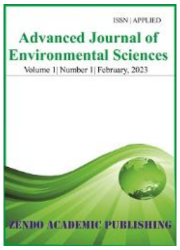


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Table 1: Demonstrate the specification of the office rooms selected for the study*

Room	ID	Volume (m^3)	Windows Number	Windows Size (m)
Director	D	72.12	4 double glazing	0.3×0.9
Secretary	S_1	27.80	2 double glazing	0.3×0.9
Secretary	S_2	42.49	0	-
Meeting	M	53.82	0	-

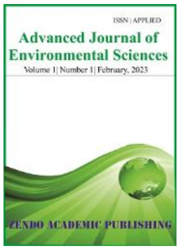
*All offices are ventilated during working hours (5.00 am-17.00 pm) by a central ventilation system

Measurements of airborne particle mass concentrations at the Qassim University Campus, KSA were made during weekdays (daytime and night). The purpose of the daytime and night measurements was to assess the impact of occupant's related activities and the impact of outdoor particles on the Particulate Matter (PM) in the offices respectively. The particle monitoring units were set to simultaneously measure PM_1, $PM_{2.5}$ and PM_{10} fractions (particles with an aerodynamic diameter equal or less than 1, 2.5 and 10 µm, respectively) in the selected offices. Work time is usually from 08:00 am-2:30 pm and the measurements cover the occupied and unoccupied periods. The optical particle sampler was placed in the middle of the offices at a height of 1.30 m above floor level, which represents the breathing level of a sedentary seated adult of average height. The measuring unit was set to a 1 min data logging interval (each reading was an average of 1 min) because with such short intervals activities showed a clear influence on the indoor concentration, but for longer intervals, this effect could not be captured. Outdoor measurement of airborne PM mass concentrations was conducted simultaneously.

RESULTS AND DISCUSSION

The data of Table 2 shows the dates of the sampling periods for the particulate matter fractions measured in the office rooms and average daily airborne particle mass concentration levels. It can be noted from the table that the average daily PM is not consistent, particularly for larger particles (e.g., PM_{10} in the director (D) and secretary (S_1) offices). The average mass concentration for PM_{10} ranges between 8.70-47.65 and 12.83-52.31 µg mG^3 for D and S_1 offices respectively. While PM_1 and PM $_{2.5}$ the average ranges between 3.96-8.70 and 5.12-13.46 µg mG^3, respectively for office D. For office S_1, the average of PM_1 and $PM_{2.5}$ ranges between 6.52-9.36 and 7.98-14.52 µg mG^3, respectively. On the other hand, the average daily particulate matter concentrations for office S_2 and office M is not significantly varied for most of the particle fractions monitored.

To understand the variation of the average daily particulate matter mass concentration in the office rooms, the measurement campaigns were divided into two different periods. One period represented sampling during working hours (daytime; 8:00 am-3:30 pm) and the other one represented sampling during night time (8:00 pm-5:00 am). The data of Table 3 illustrates the concentration of different particulate fractions during daytime and



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nighttime monitoring periods. From the table, it is clear that daytime samplings have higher particle mass concentrations than night time for most of the particle fractions measured. This suggested that the particle concentrations in the offices could be influenced by activities that took place in these rooms during working hours.

Particle mass concentrations for PM_1, $PM_{2.5}$ and PM_{10} during working hours for occupied and unoccupied offices are shown in Table 4. It can be seen that during occupancy samplings particles concentration levels are higher than those

Table 2: Dates of the sampling measurements and average daily particle mass concentration monitored in the office rooms

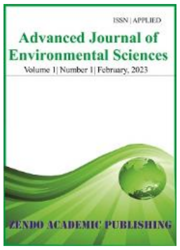
	Monitoring		Particle fractions (µg mG^3)		
Office	Start	End	PM_1	$PM_{2.5}$	PM_{10}
D	24/10/2018	13/2/2019	3.96-8.70	5.12-13.46	8.70-47.65
S_1	6/11/2018	14/2/2019	6.52-9.36	7.98-14.52	12.83-52.31
S_2	7/11/2018	22/1/2019	5.29-5.45	6.77-7.76	12.95-17.46
M	24/10/2018	22/1/2019	3.85-5.18	5.34-6.66	10.06-12.99

Table 3: Average range s of particle mass concentration (ıg mG^3) e office rooms durin riods

	Day time			Nighttime		
Office	PM_1	$PM_{2.5}$	PM_{10}	PM_1	$PM_{2.5}$	PM_{10}
D_1	3.43-8.70	4.19-13.46	7.79-47.65	2.95-9.22	3.81-12.29	5.60-22.43
S_1	5.36-9.21	6.40-14.52	9.81-52.31	8.15-11.14	11.06-17.34	18.59-35.89
S_2	6.39-7.28	8.64-13.32	20.06-40.42	3.96-5.69	4.68-6.63	5.31-7.43
M	3.83-6.24	5.36-8.53	11.53-20.09	3.71-4	4.51-4.93	4.88-6.10

Table 4: nass concentrations particle frac
Average µg m G3) ed and unocc upied periods in t ne selected offices

	Occupancy	Non-occupancy



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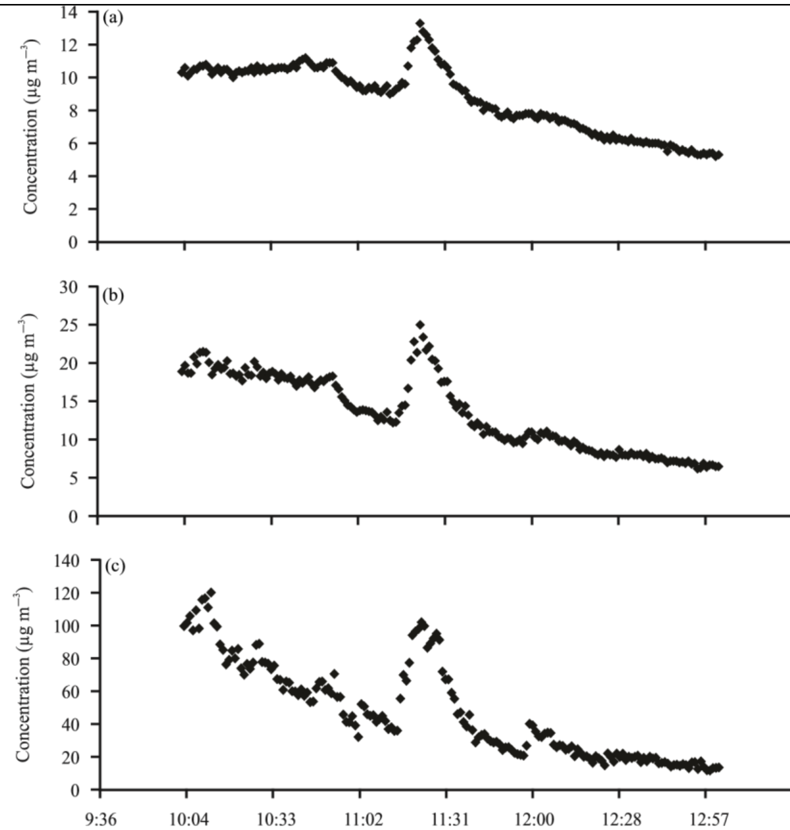
Office	PM1	PM2.5	PM10	PM1	PM2.5	PM10
D_1	8.70	13.46	47.65	4	5.09	10.43
S_1	9.21	14.52	52.31	5.96	6.73	10.47
S_2	7.28	13.32	40.42	6.39	8.64	20.06
M	N/A	N/A	N/A	5.23	6.84	14.63



Time (hrs min)[1]

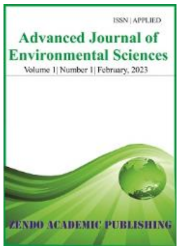
Fig. 1(a-c):Variations in particulate fractions for a typical day of measurement in the director's office (D) during occupancy

(a) PM_1, (b) $PM_{2.5}$ and (c) PM_{10} concentration

during unoccupied periods for the majority of the monitoring campaigns and human-related activities (e.g., walking around, vacuuming, etc.) the only factor that could be suggested to explain the increasing particulate mass levels during such periods (e.g., occupied periods). When the employees occupied the offices, resuspension of particles larger than 1 µm is significant, which leads to higher levels than those when they were not attended. This finding is consistent with previous findings in other situations. A previous study was carried out in three different indoor environments (e.g., office, café and home) reported that particle concentration increased when the indoor environments were occupied due to resuspension from people's movement and other activities indoor that emitted particles such as cooking[34]. Another investigation carried out in a house reported that human activity increased the concentration levels of particles with an aerodynamic diameter equal or less than 10 µm[45]. On the other hand, in general, the effect of occupancy periods on the small fraction (e.g., PM_1) in this study is insignificant. This result agrees well with the results shown by a previous study conducted in classrooms[28].

The influence of human-related activities on the concentrations of particles in offices during working hours is demonstrated in Fig. 1a-b. The figure shows sampling measurements that were taken in office D on day 4/12/2018. It should be noted that the office was occupied by one employee (e.g., the director) and on some occasions, one or two persons enter the office to meet the director. The activities recorded on that day were several people entering and leaving the office (movement levels) and vacuuming. Concerning the small fraction (e.g., PM_1), see Fig. 1a, the spectrum of the particle concentration was slightly different than those for $PM_{2.5}$ and PM_{10}. The effect of level of movement was insignificant for PM_1. Whereas, the impact of vacuuming on PM_1 fraction concentration was significant and gave a similar trend to observed in $PM_{2.5}$ and PM_{10} (e.g., the period between 11:10 am and 11:20 am). This suggested that vacuuming emitted fine particles (<1 µm).

It is clear from the figure that larger particulates (e.g. $PM_{2.5}$ and PM_{10}) show a similar trend which suggested that both size fractions were influenced by the activities made in the office (people movements and vacuuming). Looking at the



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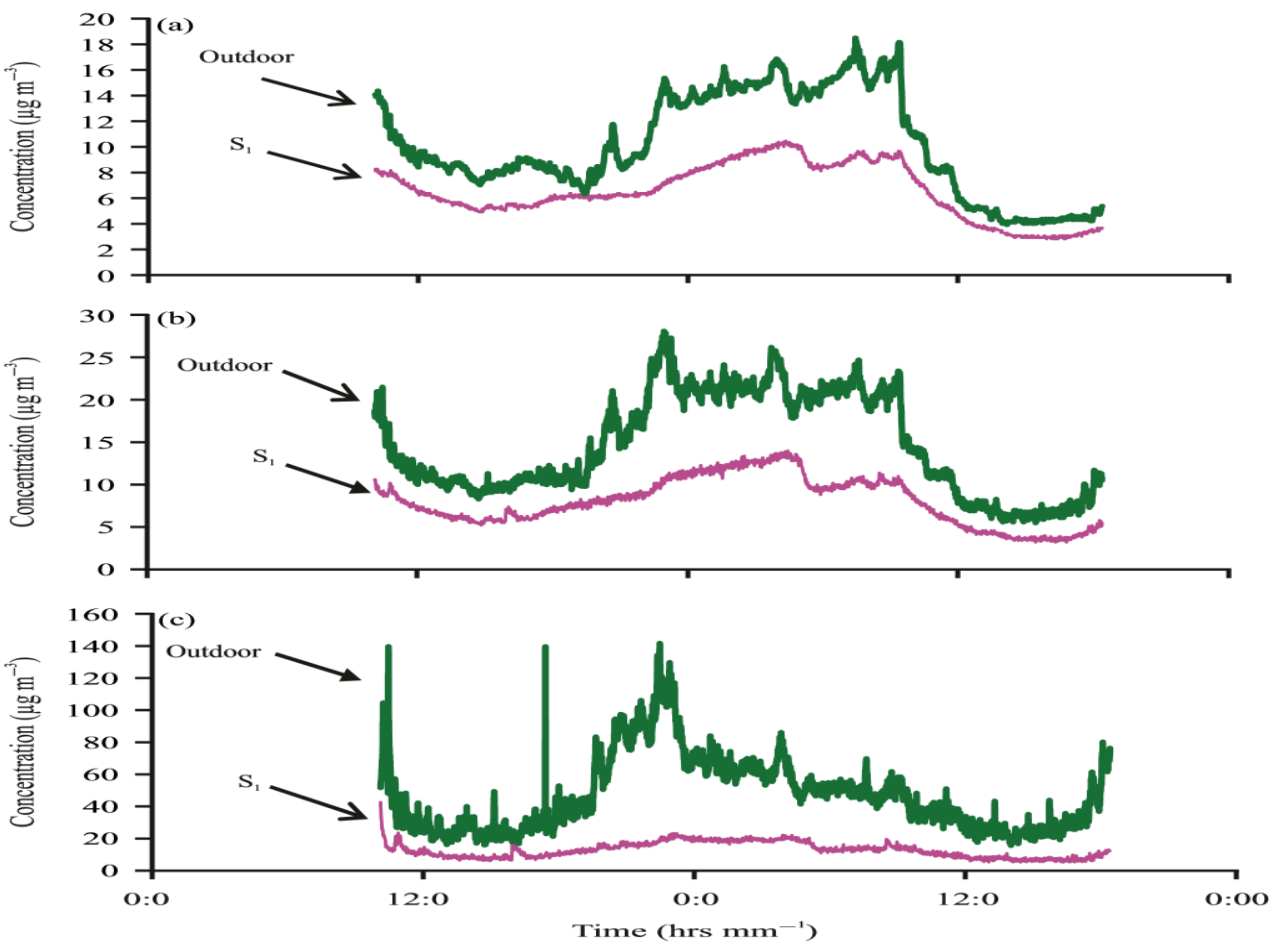

Fig. 2(a-c): Secretary office (S_1) and outdoor PM concentrations (date of measurements; 13/2/2019-14/2/2019)

(a) PM_1, (b) $PM_{2.5}$ and (c) PM_{10} concentration

concentration profiles of $PM_{2.5}$ and PM_{10} (Fig. 1b-c), high concentration levels were observed which are related to high activities. For example, high concentration levels at the beginning of the measurements (10:00 am) were thought to be partly due to the presence of two persons before 10:00 am to install the instrumentation before the start of samplings which caused a high level of movement. The concentrations started to decay after finishing the installation due to low activity levels. However, several small peaks were found (e.g., at 10:30, 10:55 am and 12:00 pm) which were related to a person (visitor) entered the office (low level of movement). When the visitor was seated, the movement stopped and the decay started. The particle concentrations rapidly rose during the period between 11:10 and 11:20 am and vacuuming was the only factor recognized to describe the increasing particle fraction concentration levels.

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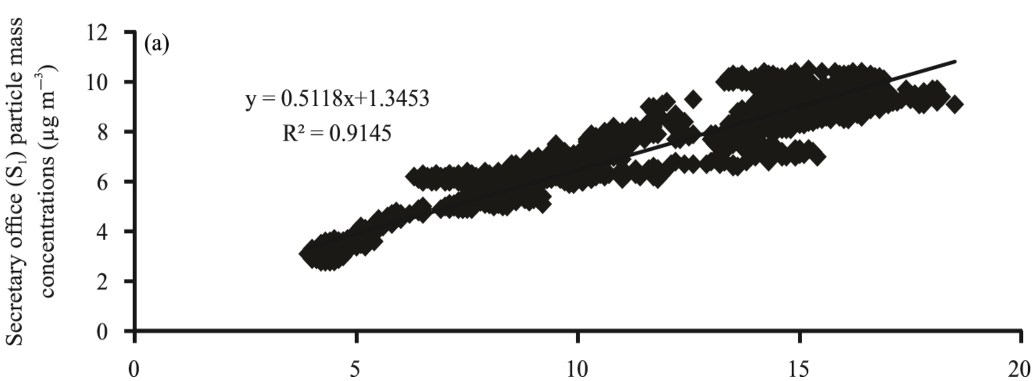
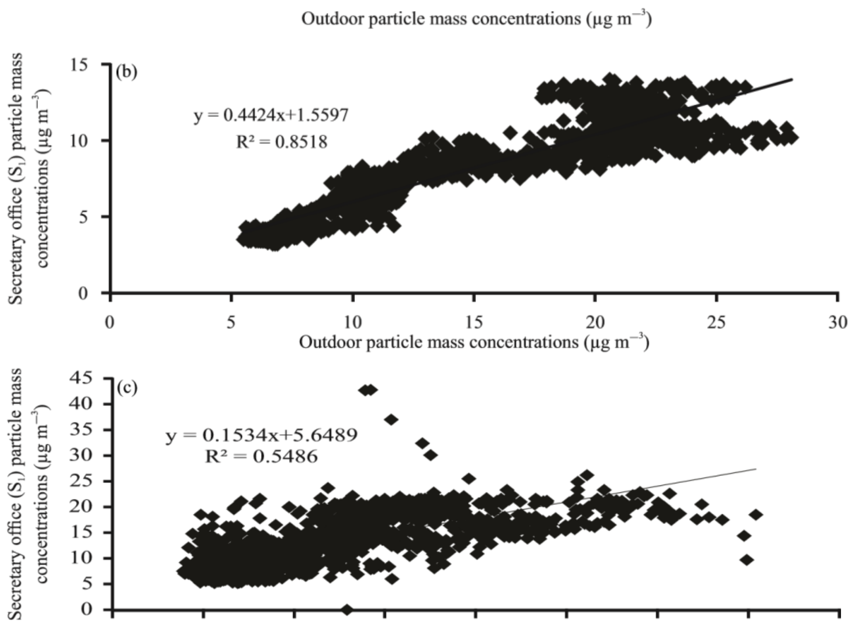
The result of Fig. 2a-c shows the concentration profiles of the three-particle fractions (PM_1, $PM_{2.5}$ and PM_{10}) during the sampling campaigns in the secretary office (S_1) and outdoor. The purpose of this measurement was to study the impact of outdoor particles on the concentration levels of particulate in the office air. To investigate this impact the concentration levels in S_1 were obtained from the measurements carried out during unoccupied periods to avoid the influence of any indoor activities on such investigation. It is clear from the figure that PM_1 and $PM_{2.5}$ followed the concentration spectrum of outdoor suggesting that both fractions were influenced by outdoor concentrations (Fig. 2a-b). On the other hand, PM_{10} seems to be independent of the particle concentrations outdoor (Fig. 2c). this result agrees with another study in Poland concluded that there significant correlations between indoor and outdoor PM concentrations[46].

A simple linear correlation was employed to determine the correlation between the concentration levels inside and outside. The result of Fig. 3a-b illustrates the relationship between the Secretary Office (S_1) and outdoor particle fractions. There was an influence of outdoor concentrations, particularly for fine fractions (PM_1 and $PM_{2.5}$). The correlation between indoor airborne particles and those found outdoor is much stronger, particularly for PM_1 and $PM_{2.5}$ (R^2 = 0.91 and 0.85, respectively), see Fig. 3a-b. A relatively good correlation was determined for indoor and outdoor PM_{10} concentrations (R^2 = 0.55), see Fig. 3c. In our study only mechanical ventilation was used. In general, the correlation is stronger when the outdoor concentration varies (increasing or decreasing), a sufficient air change between indoor and outdoor exists and during the absence of indoor sources. This examination was able to show a strong positive correlation between the outdoor fine fractions levels and those in the offices recorded. This suggested that small particles are influenced strongly by outdoor ones but large particles are affected strongly by human activity. It has previously been found that indoor fine particles are well correlated with ambient concentrations because they have higher penetration efficiency than larger ones[47,48]. The concentration levels of the particle indoor were higher than the World Health Organization (WHO) standard for annual average which has been set at 20 µg mG^3 for PM_{10} and 10 µg mG^3 for $PM_{2.5}$[14]. The impact of outdoor particle concentrations on the air quality indoor must be taken into account when



designing buildings in dry areas, as well as reducing the impact of various activities on indoor air quality.



0 20 40 60 80 100 120 140 160

Outdoor particle mass concentrations ($\mu g\ m^3$)

Fig. 3(a-c): Secretary office (S_1) and outdoor PM concentrations relationship with an unoccupied period

(a) PM_1, (b) $PM_{2.5}$ and (c) PM_{10} concentration

CONCLUSION

The results obtained from the monitoring instruments showed that the most significant parameters for generating particles in the offices were human-related activities. Walking generated substantial amounts of larger particulates (e.g., PM_{10}). Particulates generated outdoor contributed significantly to the particle concentrations in the offices, particularly for PM_1 and $PM_{2.5}$ size fractions. The concentration levels of the particle fractions (PM_{10} and $PM_{2.5}$) during the occupancy period do not satisfy the World Health Organization.

SIGNIFICANCE STATEMENT

This study discovered the diurnal variations of airborne mass concentrations for different particulates including PM_1, $PM_{2.5}$ and PM_{10} by high precision technic using Grimm Portable Laser Aerosol Spectrometer was to assess the impact of occupants related activities and the impact of outdoor particles on the particulate matter in indoor. This study will help the researchers to uncover the critical areas of environmental change especially in an arid land that many researchers were not able to explore.

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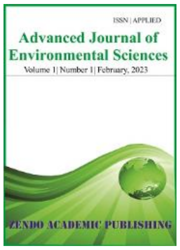

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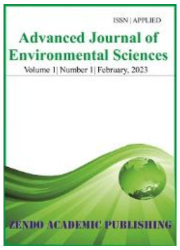

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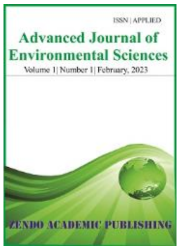

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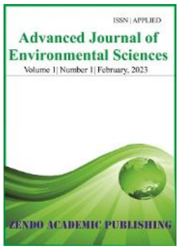

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