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Research Article

Evaluation of the Relationship Between Outdoor Environment and Indoor Air Quality in Arid Condition

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Abstract

Background and Objective: Several research studies have found a relationship between exposure to indoor particulates and serious health problems. In this research, the mass concentration of inhalable particles in four offices is measured experimentally. **Materials and Methods:** Three airborne particles sizes (PM_1 , $PM_{2.5}$ and PM_{10}), were monitored in the offices during occupancy and non-occupancy periods, Qassim University Campus, KSA. **Results:** The results show that most activities made in the investigated offices are a strong factor affecting PM_{10} and $PM_{2.5}$. However, the influence of such activities on PM_1 was not strong except for vacuuming where the concentration level increased during cleaning activity. The impact of outdoor particles on the air inside was significant for PM_1 and $PM_{2.5}$, while its effect on PM_{10} was moderate. **Conclusion:** Particulates generated outdoor contributed significantly to the particle concentrations in the offices, particularly for PM_1 and $PM_{2.5}$ size fractions. The concentration level of the particle fractions (PM_{10} and $PM_{2.5}$) during the occupancy period does not satisfy the World Health Organization (WHO).

Key words: Airborne particle, air quality, health problems, occupancy, arid condition, indoor, outdoor environment

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Competing Interest: The author has declared that no competing interest exists.

Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

Several studies have reported that exposure to indoor and outdoor airborne particles are associated with health problems¹⁻³. In particular, particulates with small sizes (e.g. PM₁ and PM_{2.5}) are known to have a bigger health effect⁴⁻⁷. These sizes can reach deeper portions of the respiratory tract^{8,9}. Other previous studies have also considered the risk resulting from short-term exposure to airborne pollutants¹⁰⁻¹². It has been documented that exposure to a concentration of 200 µg m⁻³ of fine particles for 2 hrs could cause serious health problems to the respiratory system^{13,14}.

Lack of sufficient fresh air increases the concentration of indoor particulate matter¹⁵. Therefore, failure to improve the quality of indoor air could influence human health, especially among the elderly, people with heart and/or lung diseases, children and women^{16,17}. It is referred to as the Sick Building Syndrome (SBS) and this has recently been given attention to limit the health risk related to insufficient fresh air.

Although people spend between 10-15% only of their time outdoors, the majority of time is spent indoors. Many studies have given attention to the concentration of outdoor particulate matter¹⁸⁻²¹. However indoor studies are relatively new while indoor particulate concentrations are often higher than outdoor concentrations^{22,23}. Thus, recently, much consideration has been invested in examining air quality in different indoor environments²⁴⁻²⁹.

Generally, airborne indoor particle concentrations are considered to be dependent on the outdoor particulate matter³⁰. The paths of transporting ambient particles into indoor areas are via indoor openings (e.g., windows and doors), cracks and ventilation systems. However, several human activities take place in indoor environments such as walking, cooking, dusting, vacuuming, smoking that result in elevated particulate matter concentrations³¹⁻³³. Therefore, exposure to particulate matter in indoor air can change rapidly due to the rapid changes in occupant activities and sources³⁴.

Previous studies have reported that poor quality environments in offices decrease productivity^{35,36}, thus increasing productivity could be achieved by improving office environmental parameters³⁷. The study carried out by Ponsoni and Raddi³⁸ showed a positive correlation between occupancy and airborne bacteria in a public office building.

Poor building ventilation and indoor air contaminants increased health conditions among workers in office rooms³⁹. Mendell *et al.*⁴⁰ reported that building-related symptoms in the United States could increase the annual loss of productivity (from 7-75\$ billion/year). Particles suspended in room air could be responsible for discomfort and health problems to office workers and their concentration is

changing rapidly⁴¹. A previous study conducted by Molhave⁴² documented that 5 hrs of exposure to office dust could influence healthy people. The sources which increase the concentration levels of airborne particulates in office rooms vary. Besides, they could emit pollutants that are more hazardous compared to those in the ambient air. Several research studies have investigated the impact of office devices (e.g., printers, photocopiers, etc.) on the concentration of particulate matter in office microenvironments^{43,44}. The results showed that those devices are important sources for an airborne particle in the size range <0.1 µm.

There is an important knowledge gap in the airborne indoor particle concentrations in Saudi Arabia. Therefore, investigating different particle size classes in different indoor environments could be very important for indoor personal exposure studies in Saudi Arabia. This study reported data on the diurnal variations of airborne mass concentrations for different particulates including PM₁, PM_{2.5} and PM₁₀ in several offices at the Qassim University Campus, KSA. The concentration levels of such fractions during occupancy and non-occupancy periods were investigated. Besides, the impact of outdoor pollutants on the concentrations of airborne particles in the offices was studied.

MATERIALS AND METHODS

Study area: Particulate matter mass concentrations of PM₁, PM_{2.5} and PM₁₀ 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 m³ min⁻¹.

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

Room	ID	Volume (m ³)	Windows	
			Number	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 PM₁, PM_{2.5} and PM₁₀ 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., PM₁₀ in the director (D) and secretary (S₁) offices). The average mass concentration for PM₁₀ ranges between 8.70-47.65 and 12.83-52.31 µg m⁻³ for D and S₁ offices respectively. While PM₁ and PM_{2.5} the average ranges between 3.96-8.70 and 5.12-13.46 µg m⁻³, respectively for office D. For office S₁, the average of PM₁ and PM_{2.5} ranges between 6.52-9.36 and 7.98-14.52 µg m⁻³, respectively. On the other hand, the average daily particulate matter concentrations for office S₂ 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 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 PM₁, PM_{2.5} and PM₁₀ 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

Office	Monitoring		Particle fractions (µg m ⁻³)		
	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 ranges of particle mass concentration (µg m⁻³) monitored in the office rooms during the day and night periods

Office	Day time			Nighttime		
	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: Average mass concentrations (µg m⁻³) for different particle fractions during occupied and unoccupied periods in the selected offices

Office	Occupancy			Non-occupancy		
	PM ₁	PM _{2.5}	PM ₁₀	PM ₁	PM _{2.5}	PM ₁₀
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

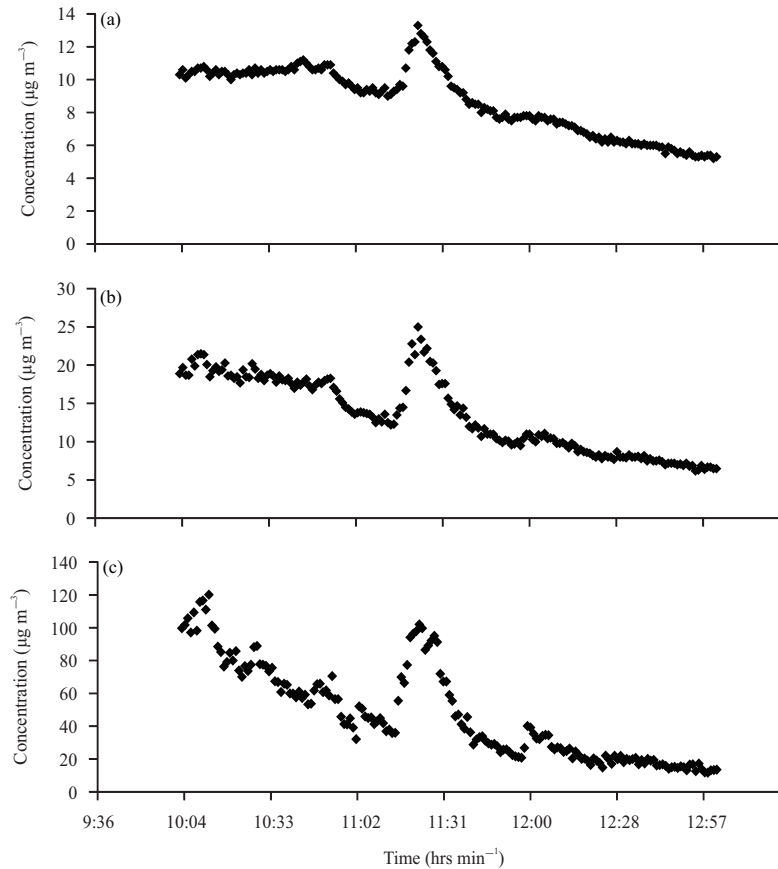


Fig. 1(a-c): Variations in particulate fractions for a typical day of measurement in the director's office (D) during occupancy (a) PM_1 , (b) $PM_{2.5}$ and (c) PM_{10} concentration

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 $1 \mu m$ 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 cooking³⁴. 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 $10 \mu m$ 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 classrooms²⁸.

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 ($<1 \mu m$).

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

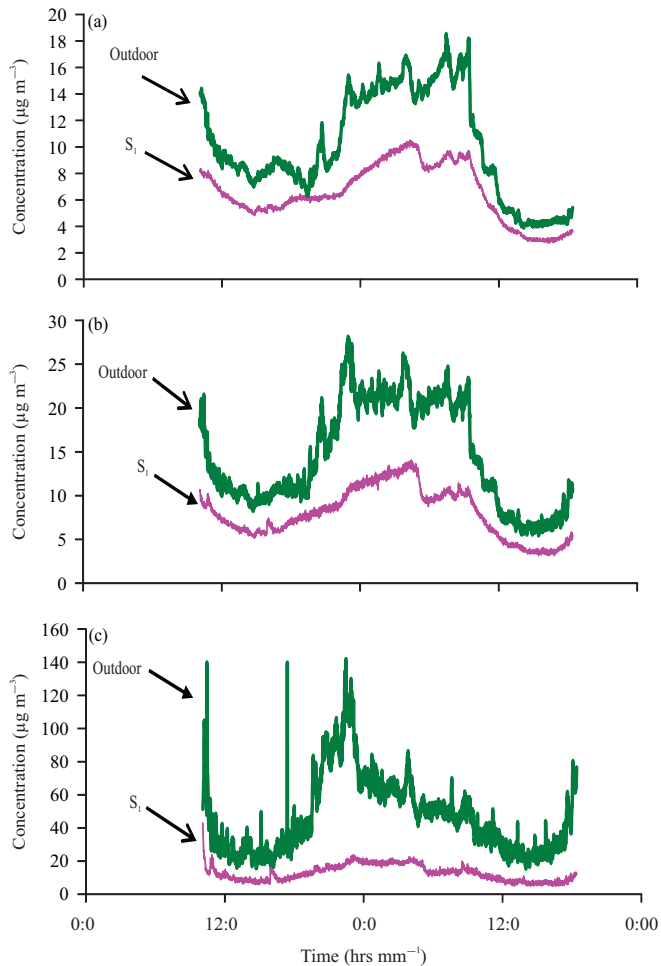


Fig. 2(a-c): Secretary office (S₁) and outdoor PM concentrations (date of measurements; 13/2/2019-14/2/2019)
 (a) PM₁, (b) PM_{2.5} and (c) PM₁₀ concentration

concentration profiles of PM_{2.5} and PM₁₀ (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.

The result of Fig. 2a-c shows the concentration profiles of the three-particle fractions (PM₁, PM_{2.5} and PM₁₀) during the sampling campaigns in the secretary office (S₁) 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 S₁ 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 PM₁ 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, PM₁₀ 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 concentrations⁴⁶.

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 (S₁) and outdoor particle fractions. There was an influence of outdoor concentrations, particularly for fine fractions (PM₁ and PM_{2.5}). The correlation between indoor airborne particles and those found outdoor is much stronger, particularly for PM₁ 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 PM₁₀ 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 $20 \mu\text{g m}^{-3}$ for PM₁₀ and $10 \mu\text{g m}^{-3}$ 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.

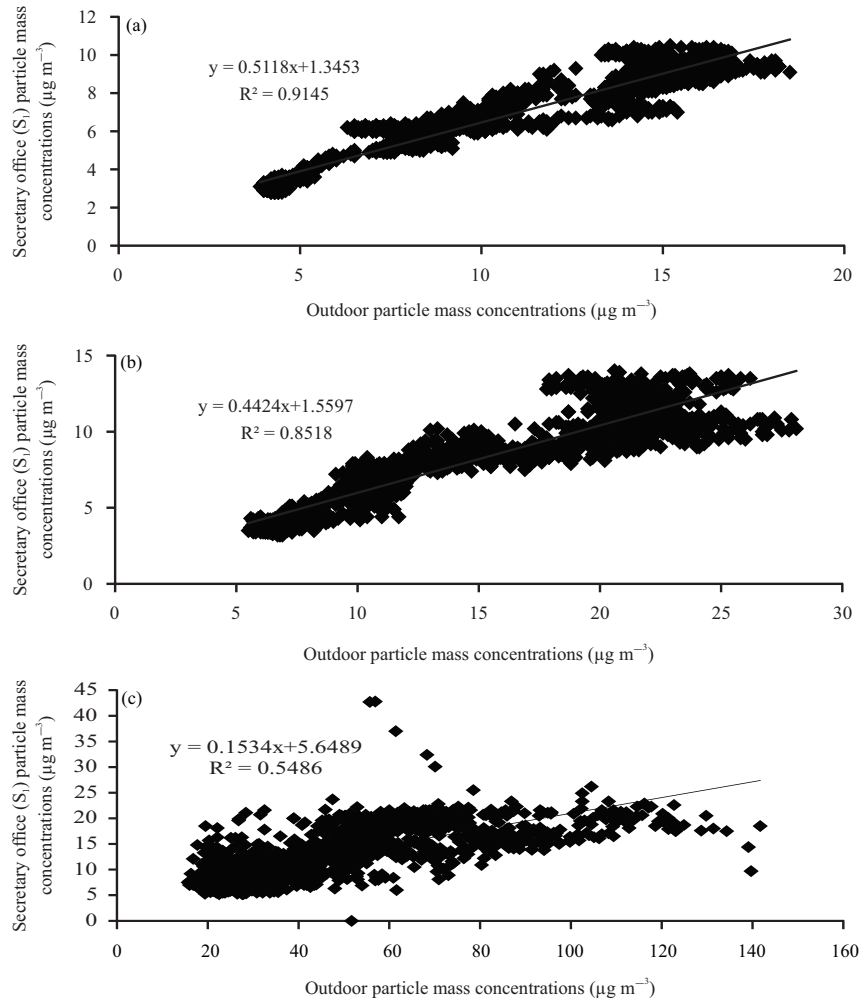


Fig. 3(a-c): Secretary office (S_1) and outdoor PM concentrations relationship with an unoccupied period
(a) PM_1 , (b) $PM_{2.5}$ and (c) PM_{10} concentration

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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