Relationships between Personal, Indoor, and Outdoor PM_{10} in the Residential Environment in Damietta, Egypt

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Abstract: The relationship between indoor and outdoor air pollution levels is important as people spend about 90% of their time indoors. This may underline the importance of particulate as an environmental health risk and the consequence need for monitoring them particularly in indoor microenvironment. The current study measured the concentrations of PM_{10} in the personal (P), indoor (I), and outdoor (O) air of buildings located in three residential areas at Damietta Governorate, Egypt, during the summer and the winter of 2009. Twenty- four homes were included in this study. The outdoor PM_{10} concentrations ranged from 975.9 – 512 μgm^3 in summer and from 1184 to 555.6 μgm^3 in winter. The indoor PM_{10} concentrations ranged from 997.1n to 65302 μgm^3 in summer and from 1198.8 to 705.6 μgm^3 in winter. The personal PM_{10} concentrations ranged from 1008.4to 334.52 μgm^3 in summer and from 1164.48 to 642.6 μgm^3 in winter. It was apparent that there is a general pattern of increasing levels from winter to summer, and similarly from indoor to outdoor air PM_{10} measured in this study. The indoor/outdoor (I/O) ratios varied between in summer (1–1.5) and winter (1–1.3). The I/O ratios obtained were linked to the indoor activities using occupant's diary entries. Results from the regression analysis showed a relatively strong correlation between the indoor and personal concentrations, between personal and outdoor PM_{10} concentrations and between indoor and outdoor concentrations at both summer and winter. The only exception was the correlation between the concentrations in summer season. Whereas statistically significant correlations were observed between outdoor and personal concentrations in winter, the correlations observed in summer were relatively low. The strongest correlations were found between indoor and personal concentrations, indicating that personal PM_{10} exposures were significantly affected by indoor PM_{10} than by ambient PM10. This shows that the contribution of outdoor pollutants to indoor pollution is higher in winter than summer. The estimated F_{inf} of the studied homes in summer and winter were 0.65 and 0.89, respectively.
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1. Introduction

Particulate air pollution has become a growing concern after the association between exposure particulate matter and adverse health effects. Many studies have shown a correlation between particulate concentrations in ambient air and the health risks caused by exposure to these particles (Oberdorster et al., 1995; Schwartz et al., 1996; Peters et al.,1997; Brunekreef et al., 1997; Duhme et al., 1998). Some investigations demonstrated the adverse effects of particles on health (Jansen et al., 2005; Adgate et al., 2007) while others reported the importance of finer particles since they are easily respired and deposited in the lungs, causing problems with the respiratory system and increased mortality (Seaton et al., 1995; Schwartz et al., 1996).

The relationships between indoor and outdoor levels of particulate air pollutants vary between cities, regions and countries due to differences in factors that can influence the indoor levels, e.g. climate, building characteristics, human activity, ventilation and heating systems (Wallace, 1996; Monn, 2001; Nazaroff, 2004; Ashmore and Dimitroulopoulou, 2009). The concentration of indoor particles is governed by the indoor particles generation, the outdoor concentration of particles, the air exchange rate and the depositional characteristics of the particles (Kamens et al., 1991; Thatcher and Layton, 1995).

Many studies investigated the contribution of outdoor particles to the indoor particle concentration levels (Colome et al., 1992; Abt et al., 2000; Koponen et al., 2001; Monn, 2001; Morawska et al., 2001; ; Riley et al., 2002; Franck et al.,2003 ; Allen et al.,2003; Cyrys et al., 2004; Maston, 2005; Hoek et al., 2008) as well as the contribution of indoor and outdoor sources to indoor pollutant levels (e.g., Thatcher and Layton, 1995; Abt et al., 2000; Jones et al., 2000; Kopperud et al., 2004; Meng et al., 2005).It is important to assessing the indoor air quality and to determine the pollution sources within the indoor environment for understanding the impact of particle pollution on human heath as people spend most of their times indoor (Jenkins et al., 1992; Klepeis et al., 2001; Monn, 2001). Certain population groups such as seniors, elderly, and children are most susceptible to particle pollution. Personal exposure measurement can provide

insight into the routes and amounts of the pollutants to which the human is directly exposed.

Fuel combustion processes in transportation and energy production are major contributors to particulate urban air pollution (Gertler et al., 2000; Martuzevicius et al., 2008), while cooking (Kamens et al., 1991;Chao et al., 1998) smoking (Spengler et al., 1981; 1985; Guerin et al., 1987; Chao et al., 1998;) and indoor combustion sources (Moschandreas et al., 1987; Allen and Miguel, 1995) were the predominant activities associated with elevated concentrations of the indoor particulate levels. Large particles are generated within homes from activities such as household cleaning (vacuuming and sweeping) (Chao et al., 1991; Kamens et al., 1991) which can lead to the re-suspension of deposited particles from horizontal surfaces such as floors, carpets and furniture (Miguel et al., 1995; Byrne, 1998).

Infiltration of ambient respirable particulates into interior spaces occurs readily due to the aerodynamic diameter and long atmospheric residence times of tiny suspended particles, (Ozkaynak et al., 1996; Wallace and Williams, 2005). It is also important to note that physical characteristics of dwellings, such as interior volume, window draftiness, and ambient temperature and humidity, have an impact on both the build-up of particles generated indoors and the penetration of outdoor particles (Wallace, 1996).

The relations between ambient PM_{10} concentrations and adverse health effects suggest that outdoor concentration may be an indicator for personal PM10 exposure, and outdoor PM_{10} should correlate well with indoor and personal PM10 concentrations (Wilson and Suh, 1997). However, studies have shown incompatible correlations between outdoor, indoor, and personal PM10 levels, with correlation coefficients (R) ranging from below zero to close to one (Wallace, 1996; Watson et al., 1997; Wallace, 2000;Wilson et al., 2000; Goswami et al., 2002; Allen et al., 2003). The large range of R-values, reflects that personal PM2.5 exposure is impacted by individual lifestyles (e.g. sedentary indoor vs. active outdoor type) and the characteristics of the microenvironment (e.g. poor vs. good ventilation), where the subjects spend time (Wallace, 1996 and Wallace, 2000). personal PM_{10} exposure estimation is measured by a personal exposure monitor worn by the subject or obtained by averaging the time-weighted concentration of different microenvironments (Wilson et al., 2000).

There are relatively few personal PM monitoring studies and most focus on subjects presumed to be more sensitive to PM health effects (Janssen et al., 1998; 2000; Ebelt et al., 2000; Rojas-Bracho et al., 2000; Sarnat et al., 2000). Relatively few studies monitored healthy adults (Ozkaynak et al., 1996; Brauer et al., 2000; Adgate et al., 2002; Adgate et al., 2007).

The relationship between indoor and outdoor particles can be assessed through three different parameters: The ratio between indoor and outdoor particles concentrations, infiltration factor and penetration factor (Chen and Zhao, 2010). Penetration factor, *P*, is defined as the fraction of particles in the infiltration air that passes through the building shell. it is the most relevant parameter for the particle penetration mechanism through cracks and leaks in the building envelope (Chen and Zhao, 2010).

The ratio between indoor and outdoor concentrations of particles represents the relationship between indoor and outdoor particle concentrations, which is very easy to understand and widely used. It gives an indication as to whether particles found indoors are the result of indoor generation. The variation in the indoor/outdoor ratios that has been reported in the literature is largely the result of the variation in activity within the home (Monn et al., 1997).

There have been many studies concerning measurements and data analysis for I/O ratio in the USA (Geller et al., 2002, Polidori et al., 2007, Lunden et al., 2008, Martuzevicius et al., 2008; Parker et al., 2008 and McAuley et al. 2010), UK and Europe (Jones et al., 2000, Koponen et al., 2001; Götschi et al., 2002, Cyrys et al., 2004, Hänninen et al., 2004, Blondeau et al., 2005, Fromme et al., 2008, Hoek et al., 2008; Stranger et al., 2008, Stranger et al., 2009 and Pekey 2010), Australia (Morawska et al., 2001a; b)and elsewhere (Lee et al., 1997; Lee and Chang, 2000, Ho et al., 2004, Gupta and Cheong, 2007; Zuraimi et al., 2007; Massey et al., 2009; Tippayawong et al., 2009). Wallace (1996) and Monn (2001) summarized I/O results from the 1970s to 1990s.

Infiltration factor, which avoids the influence of indoor sources, is quite useful for interpreting the fraction of ambient particles that penetrate indoors and remain airborne (Chen and Zhao, 2010). The infiltration of outdoor particles the indoor environment can be estimated by linear regression analysis; the slope can be interpreted as the infiltration factor and the intercept as indoor generated particles (Long et al., 2001; Götschi et al., 2002; Cyrys et al., 2004; Hänninen et al., 2004; Ho et al., 2004; Meng et al., 2005; Polidori et al., 2007; Hoek et al., 2008; Massey et al., 2009; Wichmann et al., 2010).

To assess the relationships between personal, indoor, and outdoor exposures to particulate matter in the residential environment in Damietta, Egypt, this study was undertaken with the following objectives: (1) to investigate the relationship between personal, indoor and outdoor particle concentration measured simultaneously in 24 residential houses located in 4

residential areas in Damietta during winter and summer, (2) to determine indoor/outdoor ratios and correlations between indoor and outdoor pollution levels, as well as seasonal changes in particles concentrations, and (3) to investigate the indoor infiltration of particles of outdoor origin.

2- Materials and methods

2-1- Site description

Damietta Governorate or Domyat is one of the governorates of Egypt. It is in the north of the country. Its capital is the city of Damietta. It is 210 km (131 miles) northeast of Cairo and 15 km from the Mediterranean. The governorate's area is 1.029 km² or about 5% of the Delta's area, and about 1% of the Egypt area. The modern city has a population of about 1,093,580 (2006).

Mostly Damietta is an industrial center known for its furniture, leathers, textile and sweets industries in addition to dairy products and rice mills and for its agricultural heritage. It is also a fishing industry town, with one of the largest fleets on the Mediterranean which accounts for fully half of the fishing boats of Egypt. Finally, it is well known for the port.

Meteorological parameters including ambient temperature, and relative humidity were measured both indoors and outdoors (Table 1). The average indoor and outdoor temperatures in summer were 29.5 ºC (varied between 26–32 ºC) and 32.4 ºC (varied between 28.3- 38ºC), respectively while the average indoor and outdoor temperatures in winter were 27 ºC (varied between 25–29 ºC) and 17.6 ºC (varied between 16.5-19 ºC), respectively. The average indoor and outdoor relative humidity in summer were 50.8 % (varied between 47.3- 56.2%) and 51.7% (varied between 46.3- 60.6%), respectively while the average indoor and outdoor relative humidity in winter were 62.7% (varied between 59- 69%) and 60.6 % (varied between 54- 63.9%), respectively.

2-2 Study design

The current study measured the concentrations of PM_{10} in the personal (P), indoor (I), and outdoor (O) air of buildings located in three residential areas at Damietta Governorate, during the summer and the winter of 2009. Twenty- four homes were included in this study. Seven locations were in Asenania designated AS1- AS7, thirteen in Damietta City designated D1- D13, and four in Shata designated SH1 – SH4. The sampling sites are shown in Fig. 1.

All the homes were occupied during the periods of sampling and the residents performed their normal activities during the entire study period. Apartment buildings fulfilled to an experimental criterion and their residents granted permission to measure the indoor and outdoor air concentrations within their apartments

An effort was made to balance the residences with respect to building type and cooking practices to make sure the indoor/outdoor measurements were representative for the study area. Of the three residential areas, Damietta City residential area used gas for cooking. Household ventilation was provided through open windows and doors as the occupants thought necessary. The pollution outdoors is mainly from the emission of automobile and the dust from the furniture workshops. The most prevalent indoor source was cooking, and smoking. Most of the residents cooked at least once per day. Other significant indoor aerosol sources included cleaning, dusting by furniture spray, using chemicals as pesticides, cosmetics and hair spray. The willingness of the residents to participate in the air sampling campaign (refusal rate was about 40%) were considered when selecting homes for this study. Brief details of the houses and their locations are provided in Table 2.

The residents were asked to complete a time-activity diary (TAD), recording activities such as cooking, cigarette smoking, window openings, cleaning, dusting, vacuuming and possible indoor and outdoor pollution sources. Analysis of The time activities diaries showed that all volunteers spent more than 80% of their time indoors.

2-3 Sampling protocol

Personal, indoor, and outdoor PM_{10} concentrations were measured concurrently at all sites using Whatman 37, 47, and 47 mm Teflon filters with 2-µm pores size, respectively. Identical sampling equipment was positioned inside (on the ground floor) and outside sampled homes (except for the flats, at street level and generally at the front of the house).

For subject convenience and logistical reasons I, P, and O samplers were distributed and collected from subject homes in the evening (usually between 5 and 9 p.m.). Start times for P, I and O monitors were always within a few minutes of each other, so comparisons between these measurements have essentially complete temporal overlap.

2-3-1 Personal $PM_{2.5}$ measurements

Subjects carried the personal samplers in small foam-insulated bags with a shoulder strap that had the inlet mounted on the front. During sampling sessions, subjects were asked to wear or carry the sampler as closely as possible, but they were allowed to place the sampler beside them while seated and to take it with them as they went about their activities. At night they were instructed to place it beside their bed. One Subject in each house wore a personal sampler and was representative of the personal exposure level of the entire home.

2-3-2 Indoor PM_{10} measurements

The sampling equipment was housed such that it was as compact as possible and positioned indoors to cause minimal intrusion to the occupants. Inlets for Indoor instruments were placed in each subject's residence at least 2 m away from doors, windows, and potential indoor sources; more than 20 cm away from a wall and never above a heating source in the living room or dining room but never directly in a kitchen. Sampling pumps were housed in specially designed foam-insulated boxes. Inlet heads were positioned at a height of 1.0–1.5 m above the ground in each residence in order to avoid potential interferences from excessive resuspension of particles due to residential activities and to also sample aerosol concentrations in the breathing zone of a seated person.

2-3-3 Outdoor PM_{10} measurements

The outdoor equipment was housed in a weather-proof cabinet was placed right outside the home, usually in the front yard, in the garden, or on a balcony. Outdoor sampling locations were chosen to avoid significant point sources of pollution, such as building exhaust vents.

2-4 Gravimetric measurements

Each filter, along with filter blanks, was weighed in duplicate—both before and after sampling using a Sartorius analytical microbalance (MC5 UL), with a readability of 1 µg, under controlled relative humidity and temperature conditions. Laboratory and field blanks were used for quality assurance. Flow rates for the 24 hrs P and I/O samples were 4 and 10 l/min, respectively, and pump times (median 22:38 h; range 20 –24 h) were used to calculate sample volumes.

Field blanks, consisting of approximately 10% of the total samples, were used to evaluate the potential contamination during the process of filter assembly, disassembly, and transport. Field blanks were loaded into the sampler inlet in an identical manner as the sample filter, but then removed immediately and stored at the sampling site for 24 h before returning to the lab with the sample filters. Mean field blank weights were subtracted from all sample weights prior to calculation of concentrations.

Filter-based $PM_{2.5}$ concentrations were computed using the mass difference between the filter's initial and final weight obtained from gravimetric measurements. Units PM_{10} concentrations are reported in microgram per cubic meter ($\mu g/m^3$).

2-5 Data validation and analysis

The descriptive statistical parameters (i.e. arithmetic means, standard deviations, maxima and minima) were used to present the data. Temporal analysis (i.e. seasons of the year) of the variations of PM_{10} concentrations was also conducted. Linear regression was performed to determine the relationships between personal, indoor, and outdoor concentrations. The indoor/outdoor ratio were calculated to indicate the effect of significant indoor sources of particulates and/or outdoor particle concentrations on indoor levels.

The infiltration factor can be interpreted as the fraction of ambient particles that penetrate indoors and remain airborne. the infiltration of outdoor particles can be estimated from the linear regression analysis: the slope can be interpreted as the infiltration factor and the intercept as indoor generated particles (Meng et al., 2005 ; Hänninen et al., 2004; Ho et al., 2004).

3- Results and Discussion

3-1- Outdoor, indoor, and personal $PM_{2.5}$

Summary statistics for the concentrations of PM_{10} in outdoor, indoor and personal air are given in Table 3. The sample size is 24 homes. The mean PM_{10} concentrations measured in outdoor, indoor and personal in two seasons are presented in Fig. 1. The outdoor PM_{10} concentrations ranged from 975.9 – 512 μgm^3 in summer and from 1184 to 555.6 μgm^3 in winter. The indoor PM_{10} concentrations ranged from 997.1n to 65302 μgm^3 in summer and from 1198.8 to 705.6 μgm^3 in winter. The personal PM_{10} concentrations ranged from 1008.4to 334.52 μgm^3 in summer and from 1164.48 to 642.6 μgm^3 in winter.

As shown in Fig. 2, outdoor, indoor, and personal PM_{10} concentrations tended to have higher values in winter than in summer for all sites. High indoor concentrations suggest high transport rates from outdoor to indoor environments for these elements. For all three sites, the mean indoor and personal PM_{10} concentrations were consistently higher than the outdoor concentrations.

As shown in Table 2, arithmetic means are higher than the medians, indicating that the concentration data are log-normally distributed. This distribution is typical of indoor air quality data and air pollutants in general (Cohen et al., 1989).

The higher standard deviations and maximum and minimum values for imply that under some circumstances indoor sources can have a considerable impact on the local indoor concentrations. Also, this indicates that the indoor PM_{10} is highly subjective to the individual's activity patterns and the ventilation conditions of where the individual spends time. Several reports have documented human activity as being responsible for high indoor and personal PM concentrations when no apparent indoor source exists (Long et al., 2000; Wallace, 2000; Vette et al., 2001).of specific pollutants indicating the effect of human activity on indoor air quality.

Almost all participants with the highest measured personal concentrations recorded tobacco exposures during their daily activities (Table 2), and many recorded occupational exposures to dusts or fumes on their time-activity diaries.

3-2- Seasonal variations

In order to investigate the effect of seasonality on indoor and ambient air quality, winter to summer median ratios were calculated, and the results are shown in Table 4. It was apparent that there is a general pattern of increasing levels from winter to summer, and similarly from indoor to outdoor air PM_{10} measured in this study. Seasonal differences were noted most probably due to the effects of increased fuel consumption, and meteorological factors.

S/W ratios lower than 1 could be attributed to several factors, such as increasing fossil fuel combustion for residential heating and industrial processes, high motor vehicle emissions because of the effect of low temperatures, high atmospheric stability, and strong low-level morning temperature inversions causing low mixing height conditions during winter, all of which resulted in winter concentrations that were higher than those of summer.

3-3- Indoor–outdoor ratio

Fig. 7 shows the I/O ratio for different size range of particles in naturally ventilated spaces. The indoor/outdoor (I/O) ratios varied between in summer (1–1.5) and winter (1–1.3). The indoor/outdoor ratio is an indicator of whether indoor levels are influenced by significant indoor sources of particulates or if indoor levels are the result of outdoor particle concentrations. However, although RSP levels tended to be reduced in the air-conditioned buildings, I/O ratios were still greater than 1.0, indicating that indoor levels were higher than outdoors.

The indoor–outdoor ratio is dependent on several factors, including the tightness of the building envelope, ventilation conditions, the strength and variability of the sources, the selected averaging period, and the fate and transport of the infiltrated particles, including deposition and volatilization rates. Therefore, high variability in the I–O ratio is expected among different residences and during different daily and seasonal time periods. In addition, the I–O ratio is difficult to use as a predictor of particle infiltration when indoor sources are not controlled

Gupta and Cheong, 2007 concluded that temperature plays the most significant role in affecting the I/O ratio followed by relative humidity and wind speed. It is observed that with increase in ambient temperature there is a relative increase in I/O ratio, which implies more particles migrating indoors. This may be attributed to the temperature gradient that is established between the indoor and outdoor locations, which favors the motion of the particles.

Similar results were reported by other studies. Tippayawong et al., 2009 were found to be well below a value of 1. Crist et al., 2008 concluded that the mean I/O ratios ranged from 1.71 to 2.98 during school days, while they ranged from 0.80 to 1.27 during non-school days. Gupta and Cheong, 2007 found the I/O ratio varied from 0.8 to 1.0 for particles. In nine homes in the Boston area, (Long et al., 2000) reported the mean I/O ratios for PM2.5 as 2.4±14 for daytime while 0.74±0.41 for nighttime.

A study by Jones et al. (2000) showed that mean daily I/O ratios of PM10 in the homes of smokers in the UK were greater than unity (2.7 ± 6.7). Monn et al. (1997) reported that indoor smoking had the highest influence on I/O ratios during an investigation of 17 houses in Zurich, Switzerland. They reported that in houses with smokers the daily mean I/O ratio of PM10 was in the range 1.84–2.07. The indoor concentrations were generally higher than those outdoors. Studies (e.g. Wallace, 1996) also found that I/O ratios are typically less than or equal to 1 in the absence of indoor sources.

The current study's I/O ratio is relatively similar to that from a study in Southern California (1.03) (Geller et al., 2002), in Stockholm (1.02) (Wichmann et al., 2010) and in Birmingham (1.00) (Jones et al., 2000), but somewhat higher than that previously reported in Stockholm (Westerlund and Sjövall, 1997), in Hong Kong (0.80) (Ho et al., 2004) and Singapore (below 1.00) (Zuraimi et al., 2007).

3-4- Correlations between outdoor, indoor and personal air quality

A number of studies have demonstrated that outdoor air quality can have a significant impact on indoor air (Yocom, 1982; Daisey et al., 1994; Perryb and Gee, 1994). To investigate relationships between indoor and outdoor air quality, correlation coefficients were calculated for the summer and winter data sets separately (Table 6).

The values of the regression parameters slope, intercept and coefficient of determination (R^2) are shown in Table 7. The regression of personal, indoor, and outdoor for PM_{10} is shown in Fig 5. Results from the regression analysis showed a relatively strong correlation between the indoor and personal concentrations, between personal and outdoor PM_{10} concentrations and between indoor and outdoor concentrations at both summer and winter. The only exception was the correlation between the concentrations in summer season. Whereas statistically significant correlations were observed between outdoor and personal concentrations in winter, the correlations observed in summer were relatively low. This shows

that the contribution of outdoor pollutants to indoor pollution is higher in winter than summer.

The results of poor personal–outdoor correlations from this study and other related studies (Lai et al., 2004; Mohammadyan and Ashmore, 2005) indicate that personal PM_{10} exposure is more closely affected by indoor PM2.5 levels than the ambient PM_{10} correlations. Pellizzari et al. (1999) found low personal–outdoor correlations (R=0.19), moderate indoor–outdoor correlation (R=0.21–0.33), and strong personal–indoor concentrations (R=0.79). Abt et al. (2000), found that indoor activities, such as vacuuming, dusting, washing and carpet cleaning, contributed from 50% to 80% of the indoor particles concentrations. Crist et al.,(2008) .

3-5- Indoor and outdoor concentration relationship: F_{inf}, and C_{ig}

Indoor air pollution concentrations are affected by infiltration of outdoor pollutants into the home and indoor sources. The infiltration factor can be interpreted as the fraction of ambient particles that penetrate indoors and remain airborne. A better approach is to estimate the infiltration factor (F_{inf} which is dimensionless) from the slope of an indoor–outdoor regression model (Eq. 2). Consequently, the infiltration of outdoor particles can be estimated by linear regression analysis: the slope can be interpreted as the infiltration factor and the intercept as indoor generated particles (Hänninen et al., 2004; Meng et al., 2005; Polidori et al., 2007). In the regression model the indoor-generated level of the pollutant (Ci_g) can also be controlled for, which may result in the slope of the regression model (i.e. F_{inf}) to be smaller than the crude I/O ratio. The estimated Ci_g is the intercept of regression model.

$$Ci_{it} = F_{inf} Co_{it} + Ci_g \quad \text{(Eq. 2)}$$

where *it* refers to the location and time.

From Table 7, the estimated F_{inf} of the studied homes in summer and winter were 0.65 and 0.89, respectively. Many studies measured F_{inf}, (Long et al., 2001; Hänninen et al., 2004; Emenius et al., 2004; Meng et al., 2005; Meng et al., 2009, Wichmann et al., 2010). These studies reported F_{inf} for PM_{10}: 0.59 (Helsinki), 0.61 (Prague), 0.63 (Basle), 0.69 (Houston, Los Angeles and Elizabeth), 0.70 (Athens) 0.74, (Boston, during night time), and 0.42 (Stockholm).

These indoor emissions of $PM_{2.5}$ (in the absence of assumed major sources) might be due to the movement of people, the chemical formation of $PM_{2.5}$ from numerous gaseous air pollutants due to cleaning, cooking on electrical stoves, or from ozone (infiltration from open windows) that reacts with limonenes present in many household cleaning products and toiletries (Abt et al., 2000).

Table 1: Meteorological parameters both indoors and outdoors the study homes

	Summer				Winter			
	Outdoor		Indoor		Outdoor		Indoor	
	Temp. °C	%H	Temp. °C	%H	Temp. °C	%H	Temp. °C	%H
Mean	32.4	51.7	29.5	50.8	17.6	60.6	27.0	62.7
SD	2.8	3.5	1.5	2.5	0.6	2.7	1.2	2.9
Max	38.0	60.6	32.0	56.2	19.0	63.9	29.0	69.0
Min	28.3	46.3	26.0	47.3	16.5	54.0	25.0	59.0
Median	31.5	51.5	29.9	50.0	17.5	61.0	27.0	62.0

Table 2: Main characteristics of homes used in the study area

area	ID	No. of occupants	ventilation	fuel	air conditioning	smoking	pollution sources
Asenania	AS1	2	Natural, frequent window opening	LPG	no	yes	outdoor furniture workshop, cooking, cleaning
	AS2	6	Natural, frequent window opening	LPG	no	no	outdoor furniture workshop, cooking, cleaning
	AS3	5	Natural, frequent window opening	LPG	no	yes	outdoor furniture workshop, cooking, cleaning
	AS4	4	Natural, rare window opening	LPG	no	no	outdoor furniture workshop, cooking, cleaning
	AS5	4	Natural, rare window opening	LPG	no	no	outdoor furniture workshop, cooking, cleaning
	AS6	1	Natural, frequent window opening	LPG	yes	no	outdoor transportation, cooking, cleaning
	AS7	4	Natural, frequent window opening	LPG	yes	no	outdoor transportation, cooking, cleaning
Damietta City	D1	5	Natural, frequent window opening	Gas	yes	no	outdoor transportation, cooking, cleaning
	D2	5	Natural, no window opening	Gas	yes	no	outdoor transportation, cooking, cleaning
	D3	3	Natural, no window opening	Gas	no	yes	outdoor furniture workshop, cooking, cleaning
	D4	5	Natural, frequent window opening	Gas	no	no	outdoor furniture workshop, cooking, cleaning
	D5	4	Natural, frequent window opening	Gas	no	no	Outdoor transportation, cooking, cleaning
	D6	2	Natural, frequent window opening	Gas	no	no	Outdoor transportation, cooking, cleaning, cosmetics
	D7	1	Natural, frequent window opening	Gas	no	no	outdoor transportation, cooking, cleaning, pesticides,
	D8	5	Natural, rare window opening	Gas	yes	yes	outdoor transportation, cooking, cleaning, hair spray, cosmetics
	D9	6	Natural, frequent window opening	Gas	no	no	outdoor transportation,, cooking, cleaning
	D10	4	Natural, no window opening	Gas	yes	no	outdoor transportation, cooking, cleaning, cosmetics
	D11	5	Natural, frequent window opening	Gas	no	no	outdoor furniture workshop, cooking, cleaning
	D12	2	Natural, no window opening	Gas	no	no	cooking, cleaning, pesticides, cosmetics
	D13	1	Natural, frequent window opening	Gas	yes	no	cooking, cleaning, pesticides
Shata	SH1	4	Natural, frequent window opening	LPG	no	no	outdoor furnature workshop, cooking, cleaning
	SH2	3	Natural, frequent window opening	LPG	no	yes	cooking, cleaning
	SH3	2	Natural, frequent window opening	LPG	no	yes	cooking, cleaning
	SH4	2	Natural, frequent window opening	LPG	no	yes	cooking, cleaning

Table: 3 Summary of personal, indoor, and outdoor PM_{10} measurements ($\mu g/m^3$).

	Summer			Winter		
	outdoor	**indoor**	**personal**	**outdoor**	**indoor**	**personal**
Mean	750.02	858.83	749.14	891.92	970.21	876.35
SD	146.67	116.65	178.95	161.39	152.60	137.30
Max	975.90	997.10	1008.40	1184.00	1198.80	1164.48
Min	512.00	653.20	334.52	555.60	705.61	642.60
Median	744.95	857.70	722.05	882.30	967.71	872.11

Table 4: Summer/winter (S/W) ratios of PM_{10} concentrations ($\mu g/m^3$)

Home ID	outdoor	indoor	personal
AS1	0.9	0.8	0.9
AS2	0.9	0.8	0.7
AS3	0.6	0.9	0.8
AS4	0.7	0.9	0.7
AS5	1.0	1.0	1.1
AS6	0.9	0.8	0.9
AS7	0.9	0.9	0.7
D1	0.7	0.7	0.7
D2	0.7	0.7	0.7
D3	0.7	0.9	0.9
D4	0.9	1.0	1.0
D5	0.8	0.8	0.9
D6	1.0	0.9	1.0
D7	0.9	0.9	0.5
D8	0.9	0.9	0.9
D9	0.8	0.8	0.9
D10	0.8	0.9	0.5
D11	0.9	0.9	0.9
D12	0.7	0.8	0.8
D13	0.6	0.7	0.7
SH1	1.0	0.9	0.8
SH2	0.8	1.0	0.9
SH3	1.3	1.4	1.3
SH4	1.0	1.1	1.1

Table 5: indoor/outdoor (I/O) ratios of PM_{10} concentrations ($\mu g/m^3$)

Home ID	Summer	Winter
AS1	1.0	1.1
AS2	1.1	1.1
AS3	1.5	1.1
AS4	1.3	1.1
AS5	1.0	1.0
AS6	1.0	1.0
AS7	1.2	1.1
D1	1.0	1.1
D2	1.0	1.0
D3	1.3	1.0
D4	1.1	1.1
D5	1.0	1.0
D6	1.0	1.0
D7	1.0	1.0
D8	1.2	1.2
D9	1.2	1.1
D10	1.3	1.1
D11	1.1	1.1
D12	1.4	1.1
D13	1.3	1.1
SH1	1.1	1.2
SH2	1.4	1.1
SH3	1.2	1.3
SH4	1.3	1.1
Mean	1.2	1.1
SD	0.1	0.1
Max	1.5	1.3
Min	1.0	1.0
Median	1.1	1.1

Table 6: **Correlations between outdoor, indoor and personal PM_{10} for summer and winter**

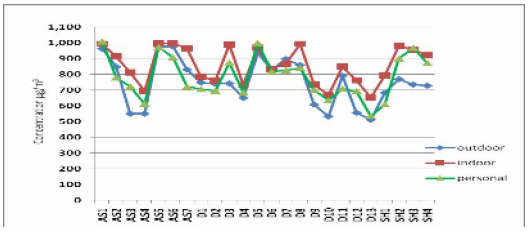
	A: Summer season				B: Winter season		
	outdoor	**indoor**	**personal**		**outdoor**	**indoor**	**personal**
outdoor	-	**0.82**	**0.63**	**outdoor**	-	**0.95**	**0.82**
indoor		-	**0.80**	**indoor**		-	**0.90**
personal			-	**personal**			-

Table 7: Summary of correlations of personal, indoor, and outdoor PM_{10} concentrations ($\mu g/m^3$)

	Summer			Winter		
	Intercept	**slope**	**R^2**	**Intercept**	**slope**	**R^2**
Personal vs Outdoor	**176.38**	**0.7637**	**0.3918**	**256.81**	**0.6946**	**0.6667**
Indoor vs Outdoor	**369.06**	**0.653**	**0.6742**	**172.56**	**0.8943**	**0.8946**
Personal vs Indoor	**-310.21**	**1.2335**	**0.6465**	**91.223**	**0.8092**	**0.8089**

Fig.1: The sampling sites

Summer



Winter

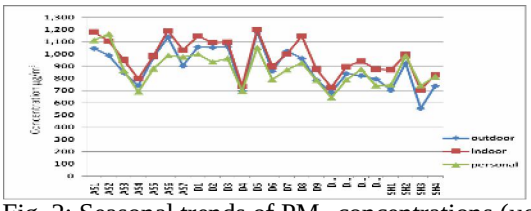


Fig. 2: Seasonal trends of PM_{10}concentrations ($\mu g/m^3$).

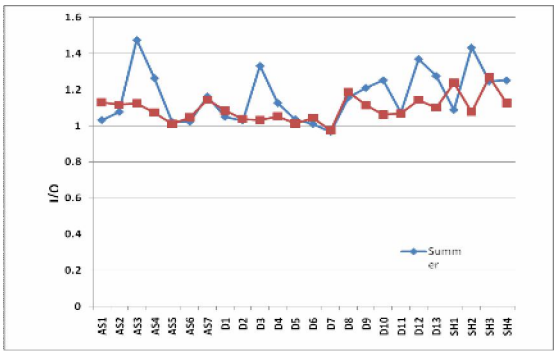


Fig. 3: S/W

4- Conclusion

This study was designed to study personal, indoor, and outdoor levels of PM_{10} concentrations in the personal (P), indoor (I), and outdoor (O) air of buildings located in three residential areas at Damietta Governorate, Egypt, during the summer and the winter of 2009. Twenty- four homes were included in this study. The outdoor PM_{10} concentrations ranged from 975.9 – 512 μgm^3 in summer and from 1184 to 555.6 μgm^3 in winter. The indoor PM_{10} concentrations ranged from 997.1n to 65302 μgm^3 in summer and from 1198.8 to 705.6 μgm^3 in winter. The personal PM_{10} concentrations ranged from 1008.4to 334.52 μgm^3 in summer and from 1164.48 to 642.6 μgm^3 in winter. The result obtained suggested that outdoor sources as well as indoor activities influenced the fine particulate concentrations of indoors in houses located in three different types of microenvironments. At all three residential sites, personal PM_{10} exposures were significantly affected by indoor PM_{10}, presumably the result of re-suspension by human activity. This conclusion was supported by the consistently higher personal and indoor $PM_{2.5}$ concentrations as compared to outdoor levels seen at each site throughout the study. Furthermore, the I/O ratios of $PM_{2.5}$ were greater than unity at all sites. The indoor/outdoor (I/O) ratios varied between in summer (1–1.5) and winter (1–1.3). The I/O ratios obtained were linked to the indoor activities using occupant's diary entries. The highly variable correlations between personal and outdoor concentrations in this study indicate that the ambient PM_{10} may not be a strong indicator for indoor concentration or total personal exposures. The strongest correlations were found between indoor and personal concentrations, indicating that personal PM_{10} exposures were significantly affected by indoor PM_{10} than by ambient PM10.

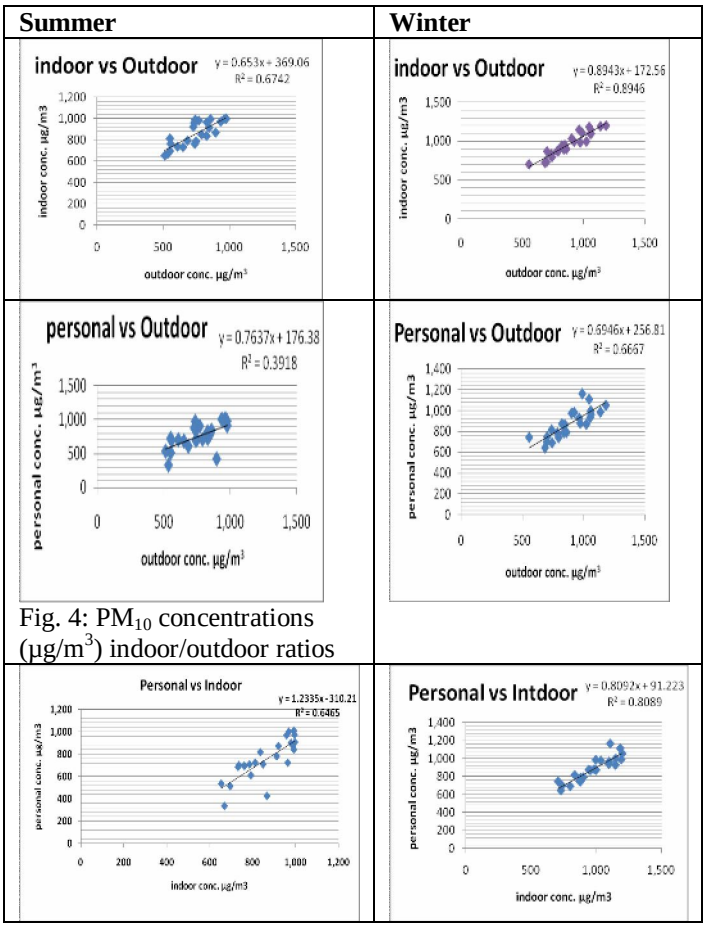


Fig. 4: PM_{10} concentrations ($\mu g/m^3$) indoor/outdoor ratios

Fig. 5: Correlations of personal–outdoor, indoor–outdoor, personal–indoor during summer and winter

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