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VOCs Levels in Indoor and Outdoor Residential Homes in Helwan, Egypt

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VOCs measurements in indoor and outdoor residential homes, located in four residential sectors of Helwan city, south Cairo, Egypt, were conducted during 2010-2011. VOCs samples were collected according to a standard method developed by NIOSH using activated charcoal tubes and analyzed by GC/FID. The highest ambient VOCs level was determined in site 2 (Helwan city center/commercial/residential area) reaching 102.63 µg/ m^3. The highest VOCs levels were recorded in winter and autumn seasons, while the lowest values were found in summer. The maximum VOCs levels in indoor air were measured at site 1 (Helwan city center/residential area) reaching 77.3 µg/m^3. The highest indoor VOCs levels were observed in winter, while the lowest values were found in summer. Indoor annual mean concentration of total VOCs was higher than outdoor (I/O ratio) at sites 1 and 4 (Torra/ popular residential area), more than 1.5 which indicates the role of both indoor and outdoor sources at these sites. I/O ratio for annual mean concentration for individual VOCs was higher than 1 for most VOCs which indicates that the air inside Egyptian homes is affected by both indoor and outdoor sources. For some VOCs, I/O ratio was higher than 10 (*e.g.* Toluene and 1,3,5 Trimethylbenzene at site 1) which indicates dominant indoor sources for these pollutants at site 1. This study shows the impact of indoor and outdoor sources on air inside homes and indicates that the high levels of VOCs in indoor air are sufficient to represent a degree of risk to the residence population .

High proliferation of urban life style has given rise to indoor air pollution and thereby has become a public concern in the past few decades. Indoor air pollution may has a greater impact than outdoor pollution because people spend about 90% of their time within enclosed environments (living, working and studying) such as homes and workplaces, which means that ambient air concentrations may not reflect accurate personal exposures [(1-8)]. This evaluation is more pronounced on inactive people (*e.g.* old age persons, infants, children and the disabled) [(9)].

Volatile organic compounds (VOCs) are among the most abundant chemical pollutants in the indoor air [(10-12)]. VOCs are a group of chemicals that have

attracted particular scientific attention due to the number and diversity of their sources as well as their potential harmful effects on human health [13-15]. Some VOCs are associated with sick building syndrome (SBS) including mucous membrane irritation, headache, fatigue, dizziness, and vertigo [16-18,7]**.** Others are known carcinogens (*e.g.,* formaldehyde, benzene, acrolein)[19]. Concentrations of many VOCs are consistently higher indoors (up to ten times higher) than outdoors[7].

This study is designed to characterize the distribution and variability of 13 VOCs in indoor and outdoor residential homes located in four residential sectors of Helwan city.

Materials and Methods

Area under investigation

Helwan is a city in Egypt on the bank of the Nile river. It is situated about 24 km south east of Cairo city. It had a population of 643,327 at the 2006 population[20]. Helwan is a residential area surrounded from its north and south by industrial activities; about 32 establishments for manufacturing of cement, automobiles, iron and steel, lead and zinc smelting, foundries, ceramics, chemicals, coke, fertilizers, spinning and weaving, starch, and other miscellaneous activities. In addition, there are two big power stations, one in the north and the other in the south of Helwan city. Helwan is impacted by emissions from nearby industrial activities.

Site characterization and sampling strategy

Homes were chosen in order to adequately cover the various sections and activities taking place in the area under investigation. Participants were recruited on a voluntarily basis. According to building surroundings and road configuration, four residential buildings in Helwan city were selected, and represented as sites 1, 2, 3 and 4 as shown in Table 1 and Fig. 1. Table 2 represents Questionnaire items defining the factors affecting presence of pollutants and their levels at homes under investigation.

Sampling of VOCs

Thirteen VOCs (Benzene (B), Toluene (T), Ethylbenzene (E), Styrene (S), Bromobenzen (BrB), m-Xylene (m-X), 1,3,5-Trimethylbenzene (1,3,5 TMB), 1,2,4-Trimethylbenzene (1,2,4 TMB), Isopropyltoluene (IPT), n- Butylbenzen (nBB), 1,2.4 Trichlorobenzen (1,2,4 TCB), 1,2.3 Trichlorobenzen (1,2,3 TCB) and Naphthalene (NAP)) were detected in all sites under investigation.

Sampling was carried out at all investigated sites in both indoor and outdoor, simultaneously. Two daytime samples were collected monthly at each of the sampling locations (indoor and outdoor, simultaneously), starting from September 2010 to August 2011 (96 samples per year).Indoor samples were collected at about 1.5 meters height from the floor of living room, while outdoor

samples were taken at a height of 1.5–2m in the buildings balconies and at least 1 m away from the wall. The heights of the balconies were 4-10 m from street ground level.

VOCs samples were collected according to a standard method developed by NIOSH using activated charcoal tubes (ORBOTM-32 activated coconut charcoal (20/40)) [21]. The collecting tubes (Supelco, Inc., Bellefonte, PA) contained 150 mg of coconut charcoal sub-divided into two portions of 100 mg and 50 mg; the front portion of 100 mg was used to collect the VOCs, while the 50 mg backup section was intended to determine if solvent breakthrough occurred from the front section. The breakthrough volume is the volume of gaseous sample that can be drawn through a sample tube before an analyte is eluted from the tube. Air was drawn through the charcoal tubes, using a pump calibrated to draw 0.20 L/min. After sampling time, the charcoal tube was removed from the sampling train and two open sides were tightly closed using special caps to avoid any desorption. During the sampling procedure, one charcoal tube was opened at the sample site and then the ends capped, which served as a blank. The samples and blanks tubes were put into special plastic bags that were tightly closed and kept at -10 °C in a freezer until processed, not more than 15 days.

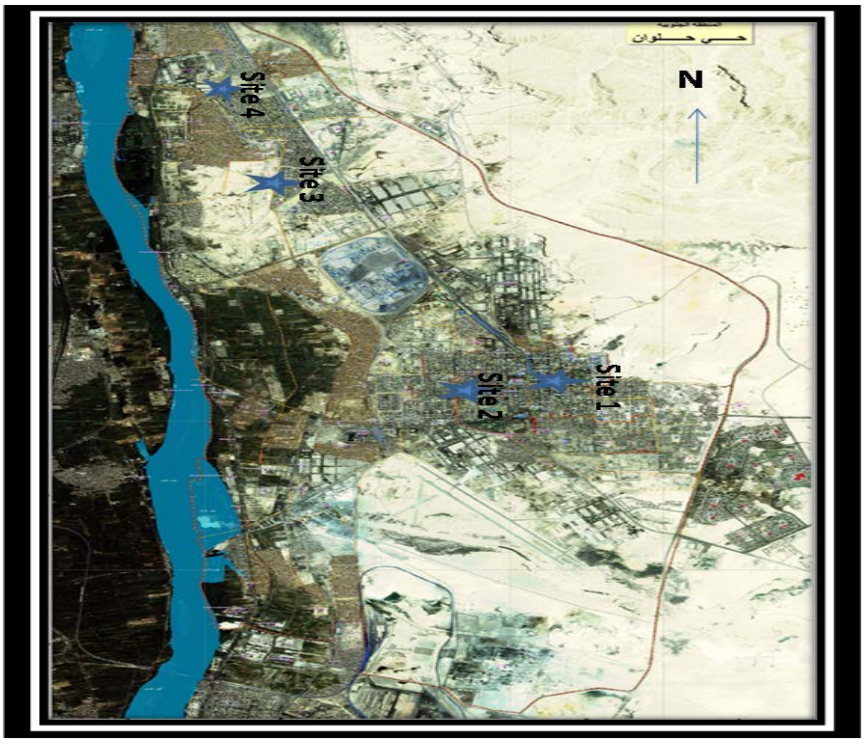


Fig. 1. Map of Helwan city showing sampling sites.

TABLE 1. Description of sampling locations and characteristics.

Site	Description
Site 1	❖ Located in Helwan city center ❖ A flat in the fourth floor with about 16 m high from ground level. ❖ With medium road traffic. ❖ Was built in 1975. ❖ Downwind of Cairo city. ❖ Represents residential area.
Site 2	❖ Located in Helwan city center. ❖ A flat in the second floor with about 5 m high from ground level. ❖ Adjacent to a busy road with heavy traffic. ❖ Was built in 1972. ❖ Downwind of Cairo city. ❖ Was about 900m away from site1. ❖ Represents commercial /residential area with high traffic.
Site 3	❖ Located in Wady Hoff at the north of Helwan city. ❖ A flat in the second floor with about 5 m high from ground level. ❖ There were no main traffic roads, but the relatively narrow lanes for residents and private cars in and out. ❖ Was built in 1989. ❖ Downwind of Cairo city. ❖ Represents residential area with light traffic.
Site 4	❖ Located in Torra (cement factory located close to residential area) at the northern part of Helwan city. ❖ A flat in the first floor. ❖ Was built in 1985. ❖ Downwind of Cairo city. ❖ Represents a popular residential area (buildings are close to each other).

TABLE 2. Questionnaire items defining the factors affecting presence of pollutants and their levels.

Questions	Site 1	Site 2	Site 3	Site 4
Cooking (hour)	4	2	3	6
Using ventilation fan	Yes	No	Yes	Yes
Type of fuel	natural gas	natural gas	natural gas	*LPG
Presence of smokers	Yes (1)	No	No	No
Floor type of living room	Carpet	Carpet	Carpet	Carpet
Use of air conditioner	Yes (only bed room)	No	Yes (only bed room)	No
Duration of opening windows in living room (hour)	5	1	3	0.5
Use of pesticides	Few	No	No	No

* Liquefied Gas

Extraction of VOCs

Before analysis, all samples and blanks were taken from the freezer, contents of both sections of the adsorbing tubes were transferred to glass test tubes containing 2.00 ml of distilled carbon disulfide (CS_2). The tubes were shaken using a mechanical shaker for half an hour and were left to settle for at least 1 hr to obtain the final sample solution. 2 ml aliquot was then withdrawn from the samples, including the blank and injected into a gas chromatography (GC)**.**

Analysis of VOCs

Qualitative and quantitative determination of individual VOCs were undertaken using Hewlett-Packard gas chromatography (GC) (Model HP6890), fitted with a flame ionization detector (FID). A HP-5 (30m×320 µm ×0.25 µm) capillary column was used with hydrogen as carrier gas and temperature programming from 30 °C (5 min) to 250 °C at 10 °C min^{-1}. The instrument was checked on daily basis based on the drift in retention times and responses of selected compounds in the standard calibration mixture injection. The concentrations of the target VOC species were quantified by an external standard calibration. The peaks in the chromatogram were identified by comparing retention times (from GC chromatogram) with those of standards and they were quantified by comparing the integrated peak area with that of the nearest standard**.** The concentrations of individual VOCs were calculated and expressed in µg/m^3. GC was calibrated with a diluted standard solution of 13 VOCs mixture compounds (2000 µg/ml for each) (Supleco, Inc., Bellefonte, PA). Standard solution was prepared by injection of aliquot portion of the standard into 2 ml of the same distilled carbon disulfide (CS_2) as used for the

sample vials. The detection limit of each compound was calculated from the data of duplicate measurements of low concentration samples and observed from their standard deviation. The method detection limits ranged from 0.02 to 0.2 μg/m^3 for the target VOCs.

Quality assurance and quality control (QA/QC)

The quality assurance and quality control (QA/QC) procedure included laboratory and field blanks, parallel samples and duplicate measurements of samples. Five laboratory blanks and five field blanks were tested with no significant contamination found for any of target VOCs. The VOCs recovery after extraction with CS_2 was determined by injecting a known amount of the compounds selected for study directly onto the 100 mg portion of charcoal in five unused tubes. The sealed vials containing the charcoal were allowed to stand overnight to ensure complete absorption of the VOCs onto the charcoal. A parallel blank of 100 mg charcoal was handled in the same manner except that no compound was added to it. The 100 mg portion of charcoal was then removed and placed in a septum sealed vial for analyses as above.

Results and Discussion

Outdoor VOCs

Concentration of individual VOCs

Table 3 shows a comparison between annual mean concentration of individual VOCs in all investigated sites in this study and in other literatures. From this table it can be noticed that the most abundant VOCs in Helwan city were Benzene > m-Xylene > Ethylbenzene > Bromobenzene>1,2.4 Trichlorobenzen > Styrene.

Benzene concentration exceeded the level of other countries, for example it is about eleven times that recorded in Brisbane, Australia [22]; nine times that in Eskişehir, Turkey[7]; and about four times the concentration recorded in Northern Spain [23]. Benzene is a carcinogenic compound causing leukaemia. The WHO has estimated that a life time exposure of 1 μg/m^3 of benzene leads to about six cases of leukaemia per million inhabitants [4]. According to EC Directive the annual mean benzene concentrations in ambient air must not exceed 5 μg/m^3 [24]. The annual mean concentration of Benzene recorded in the recent study is more than twice this limit.

Similarly, m-Xylene concentration is about eleven times that recorded in Brisbane, Australia[22]; and about 18 times that recorded in Eskişehir, Turkey[7]; and about twice the concentration recorded in Northern Spain[23].

Furthermore, Ethylbenzene concentration is highly exceeding the concentration recorded in previous studies, it is about 26 times that recorded in Brisbane, Australia[22]; and about 30 times that recorded by in Eskişehir, Turkey[7]; and about 3 times the concentration recorded in Northern Spain[23].

Concentration of total VOCs

The maximum concentration of total VOCs was found at site 2 (Fig. 2) reaching 102.63 μg/m^3. It is about 8 times the concentration (12.85μg/m^3) recorded in southeast Michigan, USA[25]; and about 10, 3 and 3.7 times the geometric mean concentration reported in summer and winter in Japan and in China, respectively[26]. Moreover, this concentration is more than the mean concentration measured for outdoor air of Brisbane, Australia (5μg/m^3)[22]. High concentration at site 2 may be due to the impact of industrial activities on the air. Elevated VOCs concentrations have been found near large industrial facilities and complexes[27]. The higher concentration of VOCs may be also due to the impact of traffic emissions and fuel evaporations at this site. The increase in traffic density increases both exhaust and vehicle evaporative emission. VOCs emissions could not only be resulted from the industrial source but also be affected by surrounding traffic sources[28]. In addition to urbanization/ industrialization and seasons, proximity to traffic can also strongly affect VOC concentrations, especially for aromatic compounds[29].

TABLE 3. Comparison between annual mean concentration of individual outdoor VOCs (μg/m^3) in the present study and in other literatures.

		(USA) [25]	(Australia) [22]	(Turkey) [7]	(Spain) [23]	Present study annual mean concentratin in all sites
1	**Benzene**	1.13	0.9	1.23	2.84	11.19
2	**Toluene**	2.61	2.3	6.11	13.26	3.24
3	**Ethylbenzene**	0.52	0.3	0.26	2.15	7.84
4	**m-Xylene**	1.98	0.8	0.47	3.38	8.70
5	**Styrene**	0.04	0.1	-	-	3.88
6	**Bromobenzene**	-	-	-	-	4.70
7	**1,3,5 Trimethylbenzene**	0.23	-	-	-	1.78
8	**1,2,4 Trimethylbenzene**	0.66	-	-	-	1.81
9	**m-Isopropyltoluene**	-	-	-	-	2.34
10	**n- Butylbenzene**	0.01	-	-	-	1.00
11	**1,2,4 Trichlorobenzene**	-	-	-	-	4.08
12	**Naphthalene**	0.28	0.1	-	-	3.69
13	**1,2,3 Trichlorobenzene**	-	-	-	-	3.49

Fig. 2. Annual mean concentrations of total volatile organic compounds (VOCs) (µg/m^3) in outdoor air at sites under investigation and over Helwan city.

Seasonal variation of VOCs in outdoor air

Figure 3 shows the seasonal mean concentration of VOCs at the investigated sites. It can be noticed from these figures that, the mean concentrations of total VOCs were varied seasonally as the highest VOCs levels were measured in winter and autumn while the lowest value was recorded in summer almost at all sites under investigation. This is in agreement with other studies [23,30-34]. The highest VOCs levels during the winter season may be attributed to an increase in the emission of VOCs, due to the use of fuel during cold season, beside higher atmospheric stability, which lead to increase the accumulation of VOCs in the atmosphere during winter, in addition to lower temperature, lower solar radiation and lower photochemical reactions during that season. Meanwhile, VOC removal is faster in summer than in winter as more sunlight and higher temperatures increase the chemical removal reaction rates, especially by OH radicals [23], as well as the low atmospheric stability and higher atmospheric dispersion during summer decrease VOCs [35].

BTEX concentration ratio

VOCs concentration ratios have been taken as an indicator to compare the BTEX emission sources [34,36,37]. Because of the varying reaction rates of VOCs with hydroxyl radical (OH.), these ratios provide information about the VOCs sources. The abundance of highly reactive VOCs species usually decreases in daylight time due to photochemical reactions. On the other hand, the abundance of relatively less reactive species gradually increases during daylight time due to accumulation [34]. So that, they are used as indicators of the age of the air mass and tracers for emission sources. Evaluation of benzene/toluene (B/T), toluene/benzene (T/B), m-xylene/benzene (m-X/B), and m-xylene/ethylbenzene (m-X/E) concentration ratios is useful for characterizing the distance of vehicular emission sources and for estimating the photochemical age of the air mass [38,39].

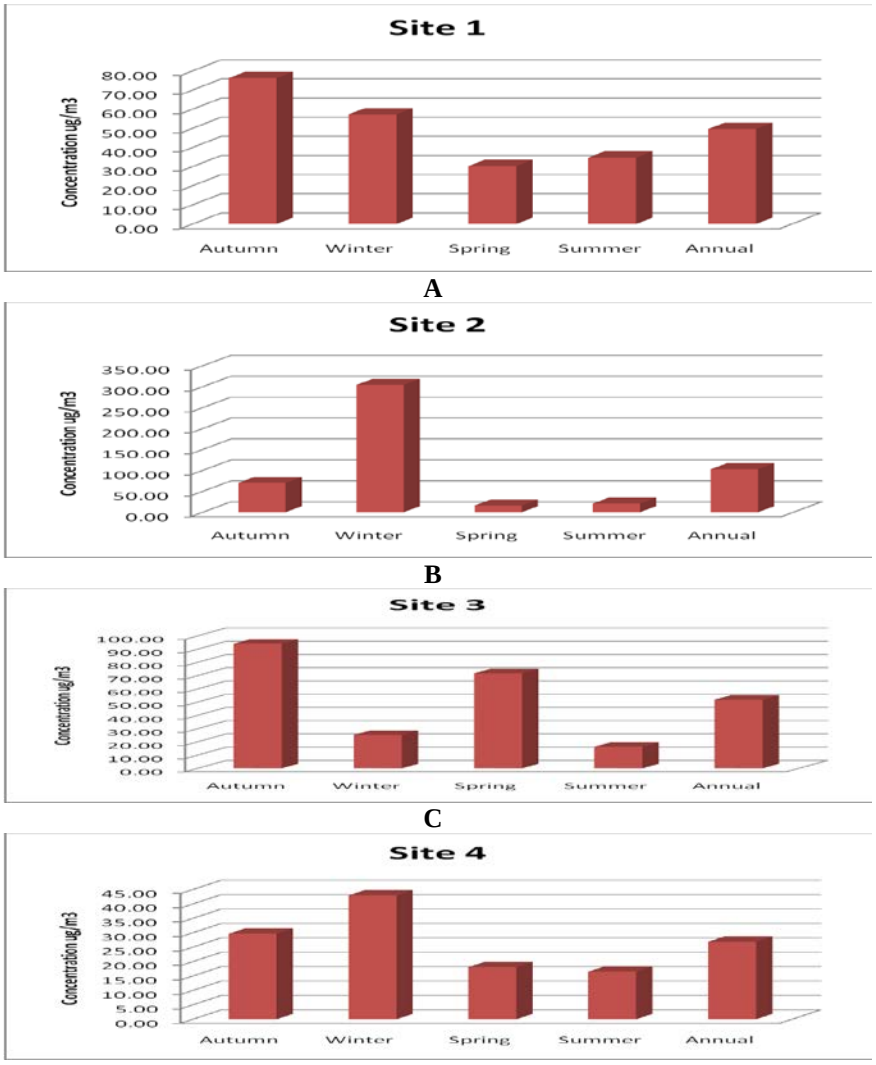


Fig.3. Seasonal and annual mean concentrations of total volatile organic compounds (VOCs) (µg/m^3) in outdoor air of sites under investigation.

Table 4 shows a comparison between BTEX ratios in this study and those recorded in other studies. The maximum annual mean concentration ratios of (T/B) and (m-X/B) were found to be at site 1 followed by site 2, while the maximum (m-X/E) ratios were found at site 3 followed by site 2. Site 2 is suffering from existence of an intense traffic, so higher concentration ratios of (T/B) and (m-X/B) may be due to traffic emission, this is in agreement with other studies [38,39].

TABLE 4. Comparison between outdoor BTEX ratios in this study and in other studies.

Country	Area characteristic	Ratio			Reference
		T/B	m-X **/B**	m-X **/EB**	
Egypt, Helwan	Site 1	0.55	3.12	0.76	**Present study**
Egypt, Helwan	Site 2	0.52	1.83	1.15	**Present study**
Egypt, Helwan	Site 3	0.19	0.25	2.35	**Present study**
Egypt, Helwan	Site 4	0.23	0.35	1.14	**Present study**
Japan	Industrial	4.5	2.7	1.24	**(34)**
Japan	Urban	4.8	1.9	1.13	**(34)**
Taiwan	Urban	9.49	1.11	0.6	**(28)**
Taiwan	Industrial	14.2	0.92	0.38	**(28)**
Taiwan	Industrial	2.3	4.05	1.3	**(40)**
Japan	summer Industrial	7.7	1.61	1.16	**(41)**
Japan	winter Industrial	5.74	1.15	0.94	**(41)**
Italy	Industrial	3.6	1.1	NA	**(42)**
China	Urban	1.27	1.17	4.68	**(43)**
Turkey	Urban	1.59	1.09	2.22	**(44)**

BTEX correlations

Table 5 shows correlation coefficients (r) between individual outdoor air BTEX at sites under investigation. From this table it can be seen that there was a positive significant correlations ($p<0.001$) at site 1 between the concentrations of B and T and E, and for T with E. Site 2 showed a significant positive correlations between the concentrations of all of BTEX with each other except for B, which suggest that all measured BTEX at site 2 (except B) are originated from similar sources, *i.e.* traffic emissions. Benzene content is minor compared with TEX in the petrol fuel; therefore, the evaporation of benzene to the atmosphere from vehicular is the lowest [23,35,45]. Site 3 showed a significant positive correlations ($p<0.001$) between the concentrations of B with T and with E, and for T with E. Site 4 showed significant positive correlations ($p<0.001$) between the concentrations of E with T and with m-X which may indicate that they are originating from the same source (vehicular emission).

TABLE 5. Correlation coefficients (r) between individual outdoor BTEX at sites under investigation.

	Benzene	Toluene	Ethyl benzene	m-Xylene
Site 1 (N=12)				
B	1			
B	1			
T	0.98*	1		
E	0.97*	0.93*	1	
m-X	-0.37	-0.49	-0.14	1
Site 2 (N=12)				
B	1			
T	0.50	1		
E	0.27	0.97*	1	
m-X	0.15	0.93*	0.99*	1
Site 3 (N=12)				
B	1			
T	0.96*	1		
E	0.75*	0.90*	1	
m-X	0.25	0.37	0.61	1
Site 4 (N=12)				
B	1			
T	-0.46	1		
E	0.17	0.79*	1	
m-X	0.65	0.32	0.75*	1

N: number of samples in statistical analysis.
*Significant ($p<0.001$)

Difference in concentration of VOCs in ambient air of the investigated sites

Table 6 shows the difference in concentration of VOCs in ambient air of the investigated sites (between sites). As seen from this table, there was significant difference between site 2 and sites 1, 3 and 4, also there was significant difference between site 2 and site 4.

Table 7 shows difference in concentration of VOCs between seasons in ambient air of the investigated sites, there was significant difference between autumn and spring at site 1, while there was significant difference between autumn and winter and all other seasons at site 2, also there was significant difference between autumn season and winter and summer seasons at site 3, while site 4 showed significant difference between autumn and spring and summer seasons.

TABLE 6. Difference in concentration of VOCs in ambient air of the investigated sites (between sites).

	site 1	site 2	site 3	site 4
site 2	0.01**	0.5		
site 3	0.4	0.04*	0.5	
site 4	0.06*	0.0003***	0.1	0.5
site 4	0.06*	0.0003***	0.1	0.5

* Significant at P <0.05
** Significant at P <0.01
*** Significant at P <0.005

TABLE 7. Difference in concentration of VOCs in ambient air of the investigated sites (between seasons) .

	Autumn	Winter	Spring	Summer
Autumn	0.5			
Winter	0.3	0.5		
Spring	0.09*	0.1	0.5	
Summer	0.1	0.2	0.4	0.5

Site 1

	Autumn	Winter	Spring	Summer
Autumn	0.5			
Winter	0.002***	0.5		
Spring	0.01**	0.0002***	0.5	
Summer	0.02*	0.0002***	0.3	0.5

Site 2

	Autumn	Winter	Spring	Summer
Autumn	0.5			
Winter	0.03*	0.5		
Spring	0.35	0.18	0.5	
Summer	0.01**	0.27	0.13	0.5

Site 3

	Autumn	Winter	Spring	Summer
Autumn	0.5			
Winter	0.26	0.5		
Spring	0.09*	0.11	0.5	
Summer	0.09*	0.10	0.43	0.5

Site 4

Indoor VOCs

Concentration of individual VOCs

Table 8 shows a comparison between annual mean concentration of individual indoor VOCs in all investigated sites and other literatures. The most abundant mean concentration of VOCs compounds over sites under investigation were m-Xylene > Benzene > Ethylbenzene > Toluene.

Annual mean concentration of indoor Benzene was more than twice the concentration reported by Jia [25], and about three times that recorded by Hamidin and Demirel [22,7].

Annual mean concentration of benzene exceeded the EC Directive [24] for annual mean benzene concentration in ambient air (5 μg/m^3). Annual mean concentration of benzene is considered to be high since there is no safe level of exposure can be recommended and the unit risk of leukemia per 1 μg/m^3 air concentration is 6×10^{-6} [4]. The concentrations of airborne benzene associated with an excess lifetime risk of 1/10000, 1/100000 and 1/ 1000000 are 17, 1.7 and 0.17 μg/m^3, respectively as suggested by WHO [4]. As benzene concentration in this study was 7.3 μg/m^3, the excess lifetime risk expected in the investigated study is over 1/100000.

Indoor benzene is associated with human activities such as cleaning, painting, the use of consumer products, mosquito repellents, photocopying and printing, the storage and use of solvents, and smoking tobacco [4,16,33,46-48].

Similar to benzene m-Xylene annual mean concentration in indoor air is more than that reported by Jia [25], and more than twice that recorded by Hamidin [22]; about eight times concentration reported by Demirel [7] and about 21 times concentration measured by Maisey [49] (Table 6).

Moreover, Ethylbenzene indoor annual mean concentration is more than three times that recorded by Jia and Hamidin[25,22]; about nine times concentration measured by Demirel[7] and about 34 times concentration measured by Maisey[49].

Concentration of Total VOCs

The highest annual mean concentration of total VOCs in indoor air was detected at site 1 (77.3 μg/m^3) as shown in Fig. 4 . The maximum concentration at site 1 may be due to the use of incense and pesticides besides opening of windows for long time daily. Indoor concentrations are also affected by climatic conditions and air exchange rate due to forced or natural ventilation[4]. This recorded concentration is about twice the median concentration of VOCs measured by Maisey[49] in Western Australia (38.1 μg/m^3); about three times the maximum TVOCs in indoor 0.5-22.4 μg/m^3 recorded by Sexton [50] and more than 0.31-28; 1.39-13.91 and 0.5-58.6 μg/m^3 measured by Gustafson; Kuntasal and Schlink, respectively[51-53].

On the other hand this concentration is less than the annual mean concentration (Arithmetic mean) 247 µg/m^3 recorded by Järnström in Finland[55]; 0.1 – 99.3 µg/m^3 reported by Kim [16]; 143 µg/m^3 measured by Langer and Bekö in Sweden[56]; 138 µg/m^3 measured by Rehwagen in Germany[57]; 202 µg/m^3 recorded by Raw in England (measured in bedrooms)[58]; 0.2–159 µg/m^3 measured by Sinha[59]**;** 123 µg/m^3 average concentration for 53 VOCs recorded by Jia in southeast Michigan, USA[25] and 2-137 µg/m^3 recorded by Hamidin in residential indoor air of Brisbane, Australia[22].

TABLE 8. Comparison between annual mean concentration of individual indoor VOCs in this study and in other literatures.

		Gallego [54]	**Jia** [25]	**Hamidin** [22]	**Demirel** [7]	**Maisey** [49] **median concentration**	**Present study annual mean concentration of all sites**
1	**Benzene**	0.49-8.7	2.84	2.4	2.29	BDL	7.32
2	**Toluene**	14.4-50.9	15.56	10.7	26.55	2.62	5.92
3	**Ethylbenzene**	1.84-8.8	2.17	1.9	0.73	0.2	6.97
4	**m-Xylene**	3.47-30	7.93	3.7	1.13	0.42	8.83
5	**Styrene**	0.22-1.5	0.5	1.5	-	0.07	2.10
6	**Bromobenzene**	-	0.01	-	-	-	3.42
7	**1,3,5 Trimethylbenzene**	n.d.-2.2	0.93	-	-	-	4.62
8	**1,2,4 Trimethylbenzene**	1.3-3.9	3.07	-	-	0.32	1.68
9	**m-Isopropyltoluene**	-		-	-	-	5.61
10	**n- Butylbenzene**	-	0.25	-	-	-	0.56
11	**1,2,4 Trichlorobenzene**	-		-	-	-	1.38
12	**Naphthalene**	0.01-0.05	3.49	2.3	-	-	1.84
13	**1,2.3 Trichlorobenzene**	-	-	-	-	-	1.45

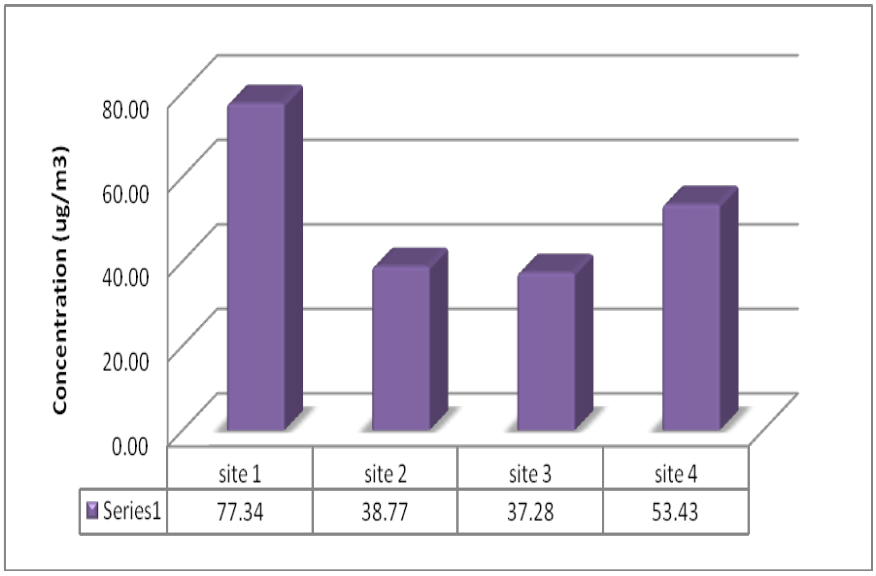


Fig. 4. Annual mean concentrations of total volatile organic compounds (VOCs) (µg/m^3) in indoor air at sites under investigation.

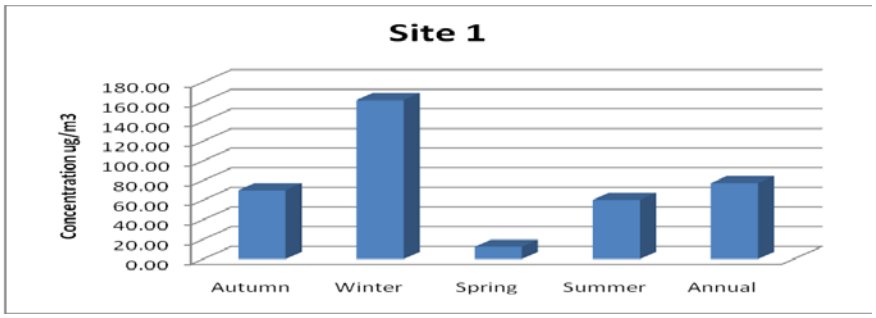
Seasonal variation of VOCs in indoor air

Figure 5 showed seasonal variation of the mean concentrations of total volatile organic compounds. The maximum seasonal concentrations were recorded during winter season, while the lower seasonal concentrations of total volatile organic compounds were recorded during summer at almost all of sites under investigation. Concentrations are tending to increase in cold weather, mainly due to lower ventilation and air exchange rates [(57)]. In winter season, door and windows are not opened as much as in summer and spring seasons [(60)]. Cooler temperatures slow the rates of photochemical reactions with a simultaneous increase in the emissions from heating sources which could be a reason of the elevated VOCs concentration [(29)].

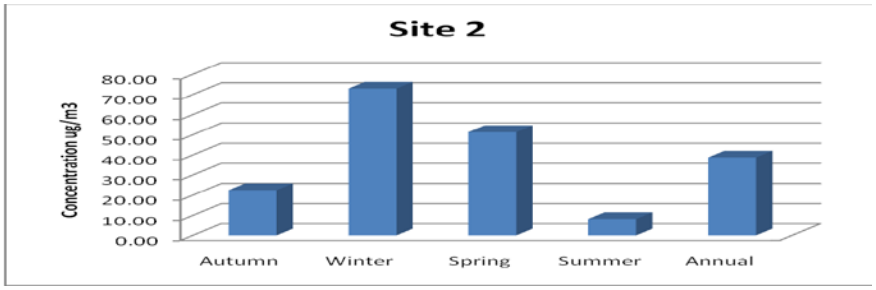
The maximum concentration of VOCs was found during winter at site 1 (161.7 µg/m^3), which may be attributed to the presence of smoker and the lower ventilation during winter at this site. However, it is lower than that recorded by Raw in English residences (208 µg/m^3) during winter season[(58)].

BTEX concentration ratio

Table 9 shows comparison between diagnostic ratios of indoor VOCs in the investigated sites and in previous studies. The maximum annual mean concentration ratios of (T/B) and (m-X/B) were found at site 1, while the maximum (m-X/E) ratios were found at site 4. (T/B) and (m-X/B) annual mean concentration ratios in outdoor air of site 1 were the maximum too; which may indicate that the indoor of site 1 may be affected by outdoor pollutants sources.



A



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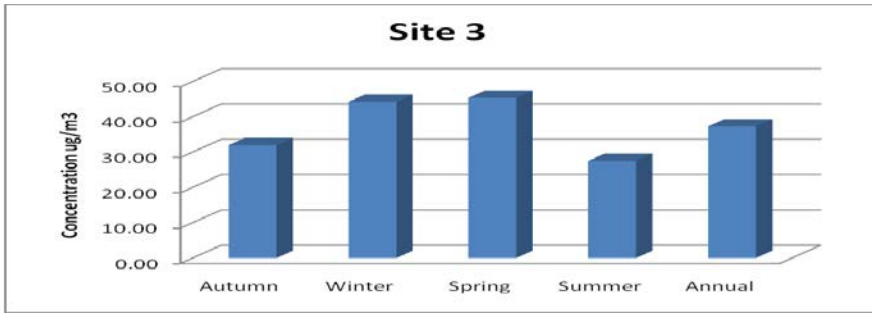

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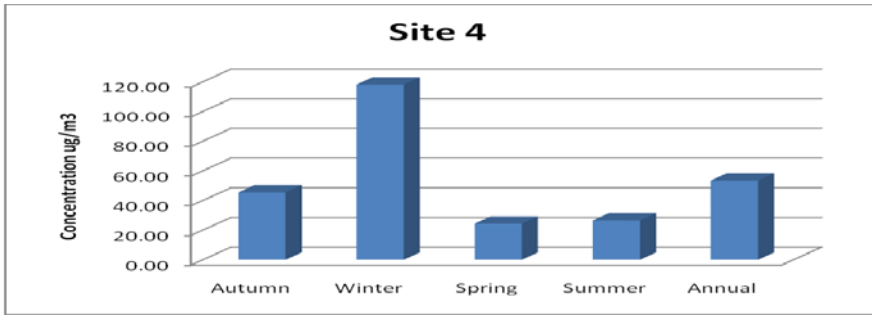

D

Fig.5. Seasonal and annual mean concentrations of total volatile organic compounds (VOCs) (µg/m^3) in indoor air of sites under investigation.

BTEX correlations

There were excellent positive correlations ($p<0.001$) between the concentrations of Benzene with the concentration of Ethylbenzene; and for Toluene with m-Xylene at site 1 (Table 10). Site 2 showed significant positive correlations ($p<0.001$) between the concentrations of Benzene with Toluene; and for Ethylbenzene with m-xylene. which suggest that these VOCs at site 2 are originated from the same source. There were excellent positive correlations ($p<0.001$) between the concentrations of Benzene with the concentration of m-Xylene; and for Ethylbenzene with m-Xylene at site 4, which may indicate that they are originated from the same source.

TABLE 9. Comparison between diagnostic ratios of indoor VOCs in this study and in other studies.

Country	Area characteristic	Ratio			Reference
		T/B	X/B	X/EB	
Egypt,	Site 1	4.97	3.30	0.84	**Present study**
Egypt,	Site 2	0.12	0.36	0.90	**Present study**
Egypt,	Site 3	0.87	1.67	1.33	**Present study**
Egypt,	Site 4	0.40	1.55	2.50	**Present study**
Japan	Industrial	4.5	2.7	1.24	**(34)**
Japan	Urban	4.8	1.9	1.13	**(34)**
Taiwan	Urban	9.49	1.11	0.6	**(61)**
Taiwan	Industrial	14.2	0.92	0.38	**(61)**
Taiwan	Industrial	2.3	4.05	1.3	**(40)**
Japan	summer Industrial	7.7	1.61	1.16	**(62)**
Japan	winter Industrial	5.74	1.15	0.94	**(62)**
Italy	Industrial	3.6	1.1	NA	**(42)**
China	Urban	1.27	1.17	4.68	**(43)**
Turkey	Urban	1.59	1.09	2.22	**(44)**

TABLE 10. Correlation coefficients (r) between individual indoor BTEX at sites under investigation.

	B	**T**	**E**	**m-X**
Site 1 (N=12)				
B	1			
B				
T	0.56	1		
E	0.96	0.29	1	
m-X	0.33	0.97	0.05	1
Site 2(N=12)				
B	1			
T	0.95*	1		
E	0.27	-0.03	1	
m-X	0.07	-0.23	0.98*	1
Site 3(N=12)				
B	1			
B				
T	-0.48	1		
E	-0.66	0.16	1	
m-X	-0.51	0.37	-0.31	1
Site 4(N=12)				
B	1			
B				
T	0.53	1		
E	0.78	0.21	1	
m-X	0.89*	0.22	0.96*	1

N: number of samples in statistical analysis.
*Significant ($p<0.001$)

Difference in concentration of VOCs in indoor air of the investigated sites

Table 11 shows the difference in concentration of VOCs in indoor air of the investigated sites (between sites). As seen from this table, there was a significant difference between site 1 and sites 2 and 3.

TABLE 11. Difference in concentration of VOCs in indoor air of the investigated sites (between sites) .

	site 1	site 2	site 3	site 4
site 2	0.05*	0.5		
site 3	0.03*	0.4	0.5	
site 4	0.15	0.2	0.1	0.5

Table 12 shows difference in concentration of VOCs between seasons in indoor air of the investigated sites, there was significant difference between winter and all other seasons at site 1, while there was significant difference between summer and all other seasons at site 2, also there was significant difference between winter season and all other seasons at site 4.

TABLE 12. Difference in concentration of VOCs in indoor air of the investigated sites (between seasons) .

	Autumn	Winter	Spring	Summer
Autumn	0.5			
Winter	0.08*	0.5		
Spring	0.03*	0.005***	0.5	
Summer	0.4	0.09*	0.1	0.5

Site 1

	Autumn	Winter	Spring	Summer
Autumn	0.5			
Winter	0.1	0.5		
Spring	0.1	0.3	0.5	
Summer	0.02*	0.06*	0.02*	0.5

Site 2

	Autumn	Winter	Spring	Summer
Autumn	0.5			
Winter	0.2	0.5		
Spring	0.2	0.4	0.5	
Summer	0.3	0.2	0.1	0.5

Site 3

	Autumn	Winter	Spring	Summer
Autumn	0.5			
Winter	0.04*	0.5		
Spring	0.1	0.01**	0.5	
Summer	0.1	0.01**	0.4	0.5

Site 4

* Significant at P <0.05
** Significant at P <0.01
*** Significant at P <0.005

Indoor/outdoor relationship

The indoor/outdoor VOC concentration ratio gives an idea about VOCs sources. Indoor/outdoor ratios near unity (1±0.5) indicate that VOCs rise primarily from outdoor sources; ratios from about 1.5 to 10 indicate the impact of both indoor and outdoor sources. Ratios exceeding about 10 reveal primarily or exclusively indoor sources [25, 60].

From Table 13 and Fig. 7 it can be observed that the indoor annual mean concentration of total VOCs is higher than outdoor at sites 1 and 4; I/O ratios are more than 1.5 and less than 10 at these sites which indicate the effect of both indoor and outdoor sources on the indoor air at these sites; this is in agreement with Jia and Aslan[25, 60]. I/O ratios at sites 2 and 3 were lower than 1, indicating the effect of outdoor sources on the indoor air. Indoor/outdoor ratios for individual VOCs as seen from Fig. 6 varied from 1 to 10 for most VOCs, however these ratios were 10.34 and 14.33, at site 1, for toluene and 1,3,5 Trimethylbenzene, respectively.

TABLE 13. Ratio between indoor and outdoor (I/O) VOCs annual mean concentrations at sites under investigation.

VOCs		Site 1	Site 2	Site 3	Site 4
1	**Benzene**	1.15	1.39	0.18	0.99
2	**Toluene**	10.34	0.31	0.80	1.69
3	**Ethylbenzene**	1.10	0.35	2.08	1.99
4	**m-Xylene**	1.22	0.27	1.17	4.37
5	**Styrene**	1.01	0.09	6.67	3.09
6	**Bromobenzene**	3.59	0.08	0.78	3.04
7	**1,3,5 Trimethylbenzene**	14.33	0.52	0.50	2.63
8	**1,2,4 Trimethylbenzene**	1.78	0.40	0.64	2.81
9	**m- Isopropyltoluene**	2.11	0.97	9.65	4.40
10	**n- Butylbenzene**	0.81	0.41	0.31	1.65
11	**1,2.4 Trichlorobenzene**	0.09	0.22	2.25	0.54
12	**Naphthalene**	0.39	0.35	0.94	0.76
13	**1,2.3 Trichlorobenzene**	0.50	0.14	0.14	3.11
Annual Mean		**1.55**	**0.37**	**0.71**	**1.98**

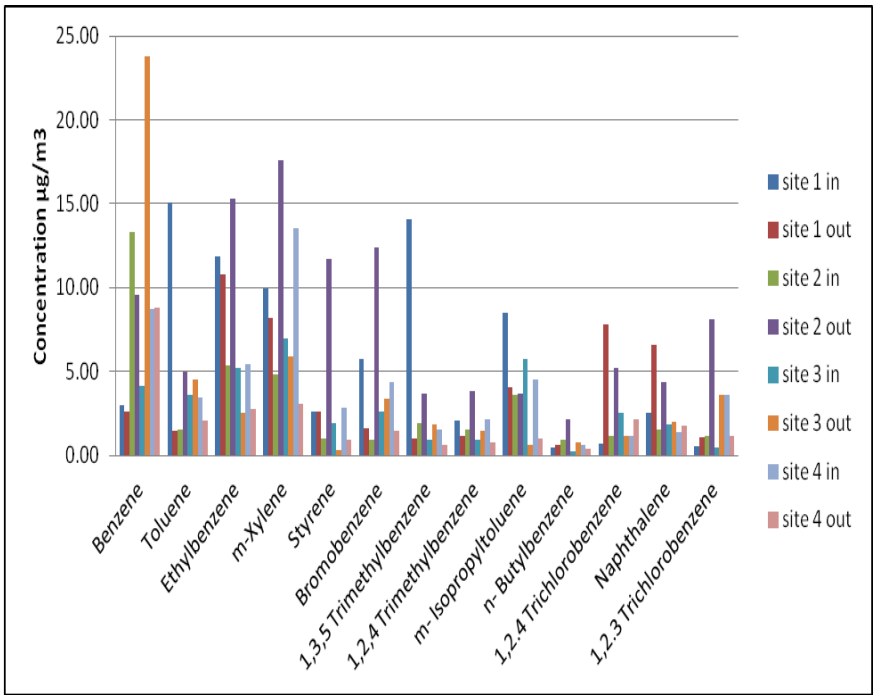

Fig. 6. Comparison between indoor and outdoor individual VOCs annual mean concentrations in 4 sites under investigation .

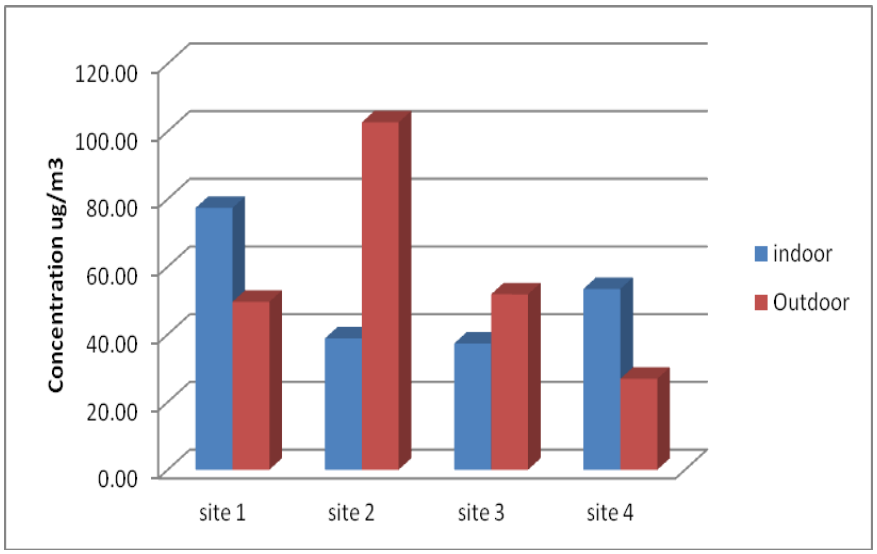

Fig. 7. Comparison between indoor and outdoor total VOCs annual mean concentrations at sites under investigation.

Conclusions

Information regarding concentrations of indoor volatile organic compounds (VOCs) in Egypt is limited in terms of the number and types of the measured compounds. This study characterizes thirteen volatile organic compounds (13 VOCs) inside and outside of four residential sectors of Helwan city, south Cairo, Egypt during four seasons that represent a gradient of population density and affected by nearby emissions of industrial activity, and also to identify indoor/outdoor relationships. Monitoring was conducted in one year (starting from September 2010 to August 2011). The most abundant VOCs compounds in ambient air at area under investigation as annual mean concentration were Benzene, m-Xylene, Ethylbenzene, Bromobenzene, 1,2.4 Trichlorobenzen and Styrene. Concentrations were elevated in winter. Meanwhile, the most abundant indoors VOCs compounds as annual mean concentration were m-Xylene, Benzene, Ethylbenzene and Toluene. Indoor/outdoor ratios (I/O ratio) for annual mean concentration of individual VOCs varied from 1 to 10 for most compounds, and up to 10.34 and 14.33 at site 1 for toluene and 1,3,5 trimethylbenzene, respectively, which indicates that the air inside Egyptian homes is affected by both indoor and outdoor sources. The study shows the importance of both indoor and outdoor sources on the concentration of indoor VOCs.

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مستويات المركبات العضوية المتطايرة داخل وخارج المنازل بمدينة حلوان – مصر

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قامت هذه الدراسة بقياس المركبات العضوية المتطايرة فى الهواء داخل و خارج منازل تقع في أربعة قطاعات سكنية مختلفة بمدينة حلوان – جنوب القاهرة – بمصر خلال سنة كاملة (من سبتمبر 2010 حتى اغسطس 2011). تم جمع عينات المركبات العضوية المتطايرة وفقا للطريقة القياسية التي وضعتها NIOSH باستخدام أنابيب الفحم المنشط وتحليلها بواسطة GC./FID. تم تحديد أعلى مستوى للمركبات العضوية المتطايرة فى الهواء الخارجى في الموقع 2 (وسط مدينة حلوان / منطقة تجارية / سكنية) حيث وصل التركيز إلى 102.63 ميكروغرام / م^3. سجلت أعلى مستويات المركبات العضوية المتطايرة خلال فصلى الشتاء والخريف، في حين تم قياس أدنى القيم في الصيف. تم قياس أعلى مستويات المركبات العضوية المتطايرة في الهواء داخل المنازل في موقع 1 (وسط المدينة حلوان / منطقة سكنية) حيث وصل التركيز إلى 77.3 ميكروغرام / م^3. وقد لوحظت أعلى مستويات المركبات العضوية المتطايرة في الهواء داخل المنازل خلال فصل الشتاء، في حين تم تسجيل أدنى القيم خلال فصل الصيف. تركيز المتوسط السنوي للمركبات العضوية المتطايرة في الهواء داخل المنازل كان اعلى منه في الهواء خارج المنازل (نسبةالداخل\ الخارج) في كلا الموقعين 1 (وسط المدينة حلوان / منطقة سكنية) و 4 (طرة / منطقة سكنية شعبية), حيث كانت النسبة اكبر من 1.5 مما يشير إلى دور كلا من المصادر الموجودة داخل وخارج هذه المواقع. وكانت نسبة الداخل\ الخارج للتركيز المتوسط السنوي لافراد المركبات العضوية المتطايرة أعلى من 1 لمعظم المركبات العضوية المتطايرة مما يشير إلى أن الهواء داخل المنازل المصرية يتأثر بكلا من مصادر التلوث الداخلية والخارجية. كانت نسبة الداخل\ الخارج لبعض المركبات العضوية المتطايرة أعلى من 10 (مثل ال طولوين و1،3،5 تراى مثيل بنزين (TMB) في الموقع رقم 1) مما يشير الى ان مصادر التلوث المهيمنة لهذه الملوثات في موقع 1 هى مصادر داخلية. تعرض هذه الدراسة تأثير كلا من المصادر الداخلية والخارجية على الهواء داخل المنازل وتشير إلى أن وجود مستويات عالية من المركبات العضوية المتطايرة داخل هذه المنازل كافية لتشكل خطر على السكان القانطين فى هذه المنازل.