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Formaldehyde Risk Assessment in Indoor / Outdoor Environment in Cairo, Egypt

Inas A. Saleh*, Aliaa A. Ezzo, Nasser M. Abdel-Latif and Atef M.F. Mohammed

Air Pollution Research Department, Environmental Research Division, National Research Centre, Giza, Egypt

Abstract

Acute and chronic health problems are expected due to exposure to high levels of formaldehyde. The aim of the current study was to evaluate the outdoor and indoor levels of formaldehyde in Cairo in order to assess the carcinogenic and non-carcinogenic risks as a result of exposure to formaldehyde. Formaldehyde concentrations were measured outdoors and indoors at five residential sites in Cairo, Egypt. The samples were taken during the day (8 AM to 6 PM) and at night (8 PM to 6 AM) for 10 hours during winter and summer seasons of 2018/2019. Chronic daily intakes (CDI), cancer risk (R) and hazard quotient (HQ), were estimated to assess health risks from exposure to formaldehyde. Outdoor average concentrations of formaldehyde at the selected sites were 24.6 and 22.8 µg/m³ in summer and winter, respectively, which exceeded the value of 15 ppb (18.3 µg/m^3) set as an indicator for urban environment. Indoor HCHO concentrations are still far lower than the effective short-term exposure levels of HCHO between 0.5 and 1 ppm (0.62-1.23 mg/m3) which could lead to irritation of throat, nose and eyes. Newly apartments with newly furnished can be a stronger source for formaldehyde emissions than the ambient sources. The I/O ratios of formaldehyde were above one which demonstrated that the sources in the indoor environment are prevalent at the investigated sites. The outdoor cancer risk values did not exceed the “alarm level” ($R > 1 \times 10^{-4}$) for formaldehyde, while in living rooms and kitchens they exceeded the “alarm level” by 30% and 55% in winter and summer, respectively. The results indicated that the levels of airborne and inhaled formaldehyde in Cairo residences should not be underestimated. The current study can help regulatory agencies to establish guidelines for formaldehyde concentration in indoor air.

Keywords: Formaldehyde, indoor/outdoor, Hazard quotient, Cancer risk.

1. Introduction

Air pollution, whether indoor or outdoor, is a critical global health problem [1-4]. The quality of air is influenced by high use of fossil fuels, improper combustion techniques, lack of green space and traffic loads, as well as terrain and meteorological conditions. Many adverse health effects on human health are observed for long-term exposure to air pollution, e.g., respiratory, cardiovascular, neurological system… etc. [4, 5-7]. Formaldehyde (HCHO) is the most abundant carbonyl compound in the urban atmosphere [8-11]. HCHO has been reported as a hazardous indoor organic pollutant with high oxidation capacity [12-16], and is considered as one of the free radical precursors in the atmosphere [4, 17-18]. On the other hand, HCHO have an important role in the industry as an important organic base chemical, with an annual production capacity of over 30 million tons worldwide [19].

Ambient formaldehyde is produced through the photochemical oxidation of some reactive organic gases in the atmosphere [4, 16, 20-23]. In addition, many industrial processes (e.g. Oil refining, copper plating, incinerators, etc.) and fuel combustion in urban and industrial activities are the main emission sources of formaldehyde [24-25].

Indoor air quality is liable to influence human health more than outdoor air quality as people spend most of their time in indoor environments [26-28]. HCHO is considered the most common indoor pollutant [29-31]. Indoor sources of formaldehyde include wood-based materials, flooring, insulation materials, paints, residential cooking activities, and smoking [32-34]. Moreover, electronic equipment, paper, fabric dyes, inks, cosmetics, cleaning products, air fresheners, etc. are other potential sources of formaldehyde in the indoor environment [30, 35-37].

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*Corresponding author e-mail: inas_alisaleh@yahoo.com; (Inas A. saleh).

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HCHO is known to be a human carcinogenic agent according to the International Agency for Research on Cancer (IARC) under Group 1 [30, 38-39]. Moreover, the US. Environmental Protection Agency (EPA) identified formaldehyde as the most important carcinogen in outdoor air among the 187 hazardous air pollutants (HAPs). It has been estimated that up to 6600–12500 people in the United States would develop cancer over their lifetimes by exposure to outdoor HCHO [40]. Because of the toxic nature of formaldehyde, some international agencies have established maximum exposure levels in residential environments. According to the American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE) and most of the European countries, the standard limit set was 0.1 ppm (123 µg/m3) [41-43].

Nose tumor, irritation of the eyes, respiratory, and skin are the main effects of HCHO over short term exposure [16, 21, 44-46], while liver toxicity, neurotoxicity, reproductive impairment, and abortion in women are the expected chronic effects after long-term exposure. Furthermore, the International Agency for Research on Cancer (IARC) and the US national toxicology organization registered HCHO to be a leukemia agent [4, 47].

As in the case of many other developing countries, the most important contributions to air pollution in Egyptian cities originate from uncontrolled urbanization and industrialization. Cairo is a metropolitan megacity with a rapid increase in population to around 19 million. The major urban activities within and around Cairo City have a great influence on Cairo's atmosphere which is accompanied by a high emissions rate of pollution, resulting from the intensity growing in human activities like transportation and industry. This high emission rate in the presence of low wind speed leads to high pollution load in the atmosphere [48-50].

However, the studies analyzing formaldehyde in Egypt are still rare and are important to set a proper control strategy in the future. Therefore, the main objective of the current study is to evaluate the levels of formaldehyde outdoor and indoor apartments located in different sites in Cairo, in order to assess carcinogenic and non-carcinogenic risks of exposure to formaldehyde in Cairo.

2. Experimental work

Five sampling sites were chosen in Cairo City, Egypt, as shown in Fig. 1. The sampling sites are located in residential areas (El-Maadi, El-Haram, Nasr City and Masr Al Gadidah and Madinity) with moderate population and moderate traffic density, except the area of Madinity which with low population and traffics. Apartments were selected in the sites to cover different age, different areas and different floors. Table 1 shows information concerning the sampling sites.

Air samples were collected simultaneously indoor (from kitchens and living rooms) and outdoor. Sampling was performed during the day (8 AM to 6 PM) and at night (8 PM to 6 AM) for 10 hours during winter (December, January and February) and summer (June, July and August) of the years 2018/2019. A total of three hundred and sixty samples were taken during this study. Indoor measurements were measured in smoking-free apartments and natural ventilation in all apartments was by opening windows, not air conditioners.

Table 1: Information concerning of sampling sites in Cairo City

Site	Age	Size (m^2)	Floor	Comment*
El-Haram	30	80	1st	
El-Maadi	22	130	3rd	
Masr Al Gadidah	20	180	6 th	
Nasr City	17	90	1st	
Madinity	8	160	4th	With new paints and furniture

*Smoking not allowed in all the investigated apartments

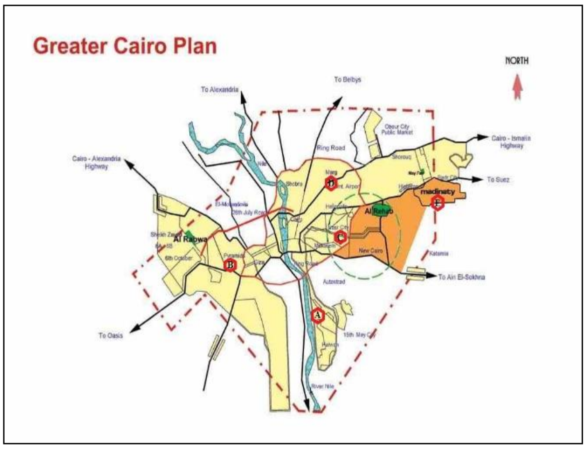

Figure 1: Sampling sites in Cairo.
A: El-Maadi, B: El-Haram, C: Nasr City, D: Masr Al Gadidah, E: Madinity

2.1. Sampling and chemical analysis

MBTH (3-methy-2-benzothiozolone hydrazone hydrochloride) Method is used for the determination of formaldehyde in air. HCHO is collected in glass bubblers with a coarse fritted inlet containing 50 mL of MBTH solution by using a calibrated pump to draw air (one liter/minute) through absorbing solution (0.5 gm of MBTH in one liter of distilled water) [51]. Figure 2 shows the sampling equipment for formaldehyde collection. 10 ml of sample and 2 ml of oxidizing reagent (1.6 gm of sulfamic acid and 1 gm of ferric chloride dissolved in 100 ml of distilled water) is reacted for 12 minutes to oxidize the azines formed during samples. Then HCHO is determined by the colorimetric method at 628 nm using UV/VIS 1800 Spectrophotometer, Shimadzu. Standard solution (2.7 ml of formaldehyde (35-37 %) diluted into one liter by distilled water, where 1000 µg HCHO/ml) is used for blank measurement. HCHO in blank solution is determined by the same manner like samples. The concentration of HCHO (expressed as $\mu g/m^3$) was calculated from the standard curve and the volume of air.

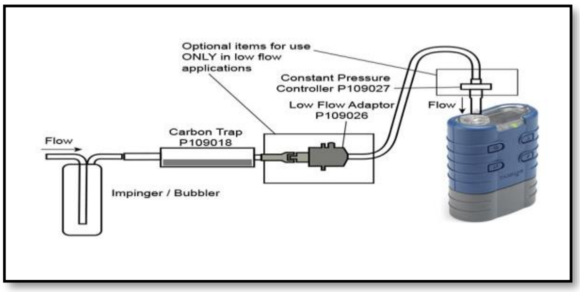

Figure 2: Sampling equipment for formaldehyde collection

2.2. Statistical Analysis

SPSS Statistical program version 16 was used to investigate the day-time and night-time relationship of formaldehyde concentrations that measured in each season at outdoor and indoor sites. It was used to estimate the significant difference between the mean concentrations of formaldehyde in different seasons, and between daytime/nighttime concentrations.

2.3. Carcinogenic Risks Calculation

Carcinogenic risks were calculated for chronic exposure to formaldehyde in the investigated residential apartments. Exposure duration and frequency, body weight, and lifetime of the receptor are critical parameters for computation of chronic daily intake (CDI) for a carcinogen [52], which is calculated by Eq. 1:

$$CDI = \frac{C \times IR \times ET \times EF \times ED}{BW \times AT \times 365} \qquad \text{Eq. 1}$$

Where C is the concentration of carcinogenic substance ($mg.m^{-3}$), IR is the rate of inhalation ($m^3.hour^{-1}$), ET is the time of exposure ($hour\ day^{-1}$), EF is the frequency of exposure ($day.year^{-1}$), ED is the duration of exposure (years), BW is the average body weight of receptor's (kg), and AT is the average lifetime (years) [53]. The standard BWs and ATs for adults and children have been defined by the United States Environmental Protection Agency (USEPA) [54-55]. Risk assessment for formaldehyde was expressed in terms of the probability of developing cancer assuming continuous lifetime exposure to HCHO. In further, based on the CDI values, the cancer risk (R) is thus estimated by Eq. 2 [54],

$$\mathbf{R = CDI \times PF} \qquad \textbf{Eq. 2}$$

Where PF is the cancer potency factor for a particular carcinogen ($kg.day^{-1}.mg^{-1}$), which is available from the open access in Integrated Risk Information System (IRIS) [56]. Certain assumptions were made to estimate the risk, e.g. exposure frequency, exposure duration, average lifetime and average body weight. An average of 300 days per year of exposure and 40 years of exposure duration were assumed. Also, average body weight of 70 kg for man and 70 years of lifetime were considered, according to USEPA [54-55]. To calculate the daily intake of formaldehyde, EPA indicated an inhalation rate of 0.63 m^3h^{-1} and 10 h per day for residential exposure [57]. For carcinogenic potency, a slope factor of 0.045 ($kg.day^{-1}.mg^{-1}$) for formaldehyde was used according to the IRIS system [58-60]. The inhalation cancer risk of formaldehyde is the output of the multiplication of daily intake and slope factor.

Non-cancer risk is expressed in terms of the hazard quotient (HQ), which is the inhalation dose (I) divided by the reference exposure level (REL) for a single substance and a particular endpoint (Eq. 3A and Eq. 3B).

$$HQ = I / REL \qquad \textbf{Eq. 3A}$$

Where

$$\text{Inhalation dose } (I) = (C \times ET \times EF \times ED) / AT \qquad \textbf{Eq. 3B}$$

The REL is the chronic inhalation exposes levels, at or below it, no non-cancer adverse health effect is anticipated to occur for population exposed for a specific duration (REL is 94 $\mu g/ m^3$). Generally, no health effects are likely at a HQ value less than or equal to 1 ($HQ \leq 1$), however at a HQ value greater than 1 ($HQ > 1$), there is a possibility that adverse health effect will occur [61].

1. Results and Discussion

3.1. Outdoor Formaldehyde concentrations

Figure 3 shows that, outdoor formaldehyde concentrations in winter varied between the five sites, ranging from 7.4 to 53.9 $\mu g/m^3$ in day time and from 7.6 to 69.9 $\mu g/m^3$ at night time. Meanwhile, in summer the outdoor concentrations ranged from 7.2 to 52.7 $\mu g/m^3$ and from 6.1 to 68.9 $\mu g/m^3$ in day and night times, respectively. No significant difference was found between the values of day and night outdoor formaldehyde concentrations over the sites. Figure 4 shows the ambient average concentrations of formaldehyde at the selected sites in winter and summer seasons. The total mean of formaldehyde concentrations for the five sites were 24.6 and 22.8 $\mu g/m^3$ in summer and winter, respectively. These concentrations exceeded the value of 15 ppb (18.3 $\mu g/m^3$) set as an indicator for urban environment [13].

Ambient levels of formaldehyde in the current study are lower than the values of 40.0 µg/m^3 and 33.0 µg/m^3 found in Cairo by Khoder et al. (2000) [41] and Khoder (2006) [62]; which means that there may be an improvement in the formaldehyde concentrations in the air of Cairo.

Table (2) compares the ambient formaldehyde concentrations of the current study with that determined by others around the world, taking into consideration the different sampling strategies followed in each study.

3.2. Indoor Formaldehyde concentrations

Figures (5 and 6) show average, maximum and minimum indoor (living rooms and kitchens) formaldehyde concentrations in apartments selected in the five sites in winter and summer. Figure (5) shows that, average formaldehyde concentrations determined in living rooms in winter varied between the ranges of 12.3 - 87.5 µg/m^3 and 8.6 - 103.2 µg/m^3 for day and night times, respectively. Meanwhile, in summer the average concentration ranged from 14.2 to 184.1 µg/m^3 and from 14.8 to138.3 µg/m^3 for day and night times, respectively. Formaldehyde concentration determined in kitchens during winter was 13.6 - 84.0 µg/m^3, for the day times and 15.7 - 161.4 µg/m^3 for the night times (Fig. 6). Meanwhile during the summer, the average concentrations ranged from 28.5 to114.4 µg/m^3 and from 27.7 to 230.2 µg/m^3 for day and night times, respectively.

Table 2: Outdoor formaldehyde levels determined in different studies around the world.

Country		Sampling location	Conc. (µg/m^3)	Comments	Reference
Egypt	Cairo - five sites	Urban sites	7.4 - 53.9	Mean winter - day time	The present study
			7.6 - 69.9	Mean winter - night time	
			7.2 - 52.7	Mean summer - day time	
			6.1 - 68.9	Mean summer - night time	
	Cairo- seven sites	Residential areas	33.0	Mean spring and summer	[41]
	Cairo- six sites	Suburban areas	40.0	Mean winter	[62]
	Cairo - Shoubra El-Kheima	Residential areas	10.7	-	[76]
	Cairo - Helwan	Residential areas	16.7	-	
Algeria	Algiers	Urban sites	5.2-27.1	-	[77]
Saudi Arabia	Makkah	Urban sites	1.2 - 18.9	-	[78]
Spain	Madrid	-	4.7 - 20.0	-	[79]
	Catalonia	Residential areas	0.9 –3.0	-	[46]
Finland	Eastern	Urban sites	13.2	-	[78]
	Kuopio	Highway	38.0	-	
Greece	Athens	Urban sites	39.0	-	
India	Kolkata	-	19.7	-	[78]
China	Hong Kong	Urban sites	4.0	-	
Japan	Osak	Urban sites	2.3	-	[77]
Iran	Tehran	High-traffic areas	21.0 - 28.0	-	[4]
USA	Chicago	Urban sites	2.5	-	[20]
	Los Angeles	Urban sites	8.8	-	
	St. Louis	Urban sites	5.4	-	
	Houston	Urban sites	9.7	-	
Brazil	Salvador	Urban sites	1.5 – 18.0	-	[16]
	Rio de Janeiro	Roadside sites	18.3	-	[79]
		Urban sites	66.0	-	
Mexico	Mexico City	Urban sites	63.0	-	[77]

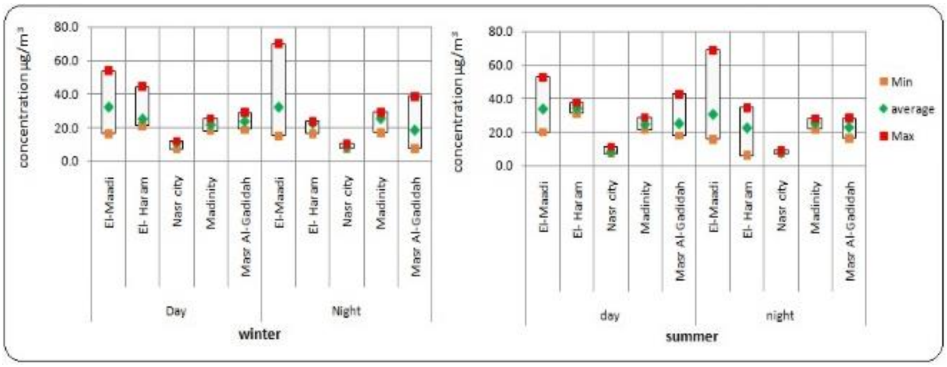

Figure 3: Average, maximum and minimum outdoor concentrations of formaldehyde at the selected sites in winter and summer seasons (as µg/ m^3).

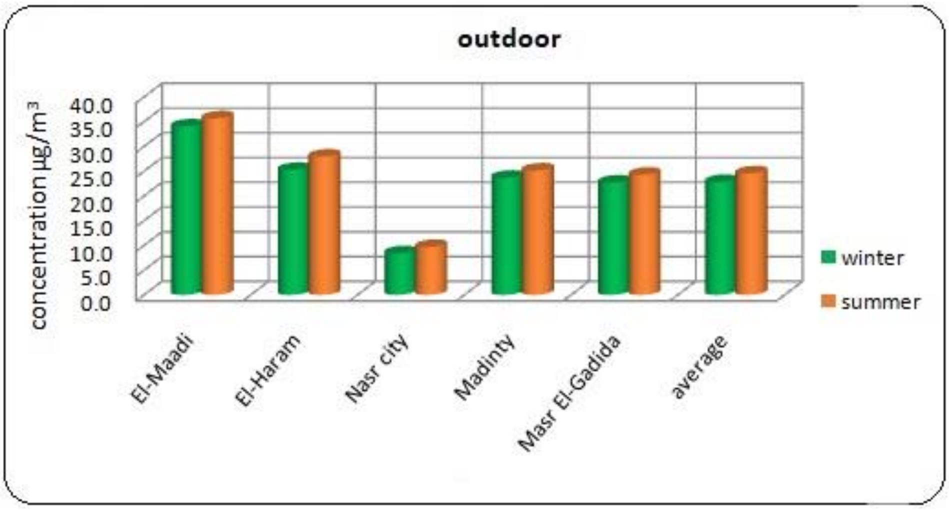

Figure 4: Outdoor average concentrations of formaldehyde at the selected sites in winter and summer seasons (as µg/ m^3).

The results show an increase in the levels of formaldehyde in kitchens more than in living rooms which reflect the effect of cooking processes in kitchens on the increase of indoor HCHO concentrations; these results are in agreement with Tang and Wang (2018) [63].

No significant difference was found between the values of day and night indoor HCHO concentrations for living rooms or kitchens in either summer or winter. The absence of variation between day and night HCHO concentrations could be attributed to air circulation over monitoring time. Opening windows and allowing fresh outdoor air to replace indoor air can be as an effective way to decrease formaldehyde concentration inside homes [64].

Most of indoor formaldehyde concentrations in the investigated apartments had values higher than the recommended exposure limit of 20.0 µg/m^3 over 8-hours [65], but lower than the limit set by the Egyptian law 4/1994 (0.37 mg/m^3 = 370.0 µg/m^3) [66]. However, these concentrations are still far lower than the effective short-term exposure levels of HCHO between 0.5 and 1 ppm (0.62-1.23 mg/m3) which could lead to irritation of throat, nose and eyes [39, 43]. HCHO is a sensitizer and can cause allergic contact dermatitis and asthma [53].

Figure (7) shows average concentrations of indoor formaldehyde (living rooms and kitchens) in the investigated apartments in summer and winter. The highest indoor HCHO concentrations, in living rooms or kitchens, were found in Madinity site of low population density; which could be due to the apartments in that site are newest buildings with newly furnished. These findings indicate that newly buildings can be a stronger source for formaldehyde emissions than the ambient sources.

Average indoor concentration of formaldehyde, for both living rooms and kitchens, in summer was found about 1.6 times higher than that found in winter. This result is in agreement with Dehghani et al. (2017) [4]

who found a strong correlation coefficient of 0.58 between temperature increase and formaldehyde. Moreover, Liu et al. (2017) [67] stated that the higher air temperature is, the faster the formaldehyde is released. Feng et al. (2017) [68] also revealed the reduction of formaldehyde concentration with the temperature decrease.

Table (3) compares the indoor formaldehyde concentrations of the current study with that determined by others around the world, taking into consideration the different sampling strategies followed in each study.

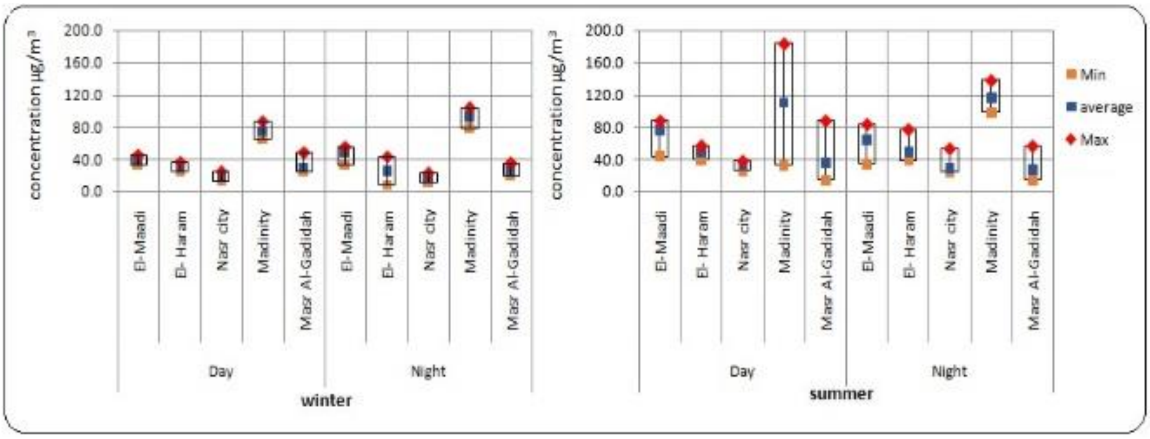

Figure 5: Average, maximum and minimum indoor (living rooms) formaldehyde concentrations (as µg/ m³) in apartments selected in the five sites in winter and summer.

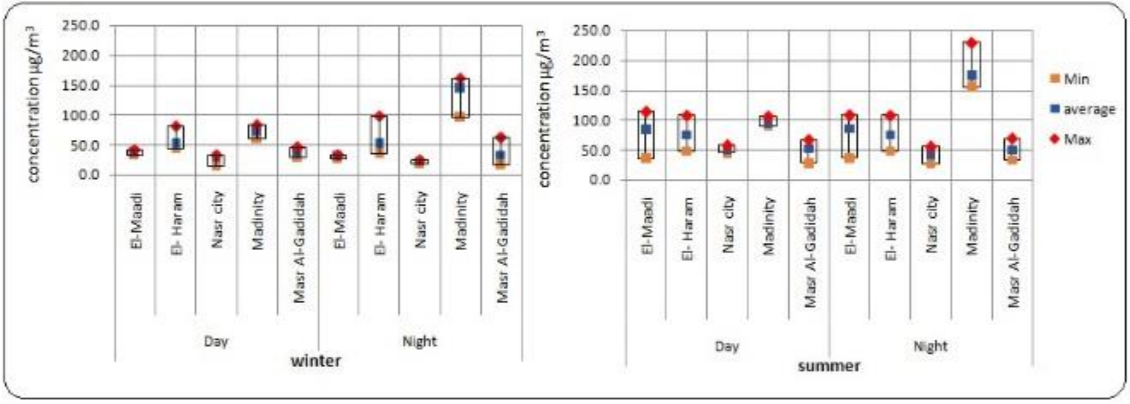

Figure 6: Average, maximum and minimum indoor (kitchen) concentrations of formaldehyde (as µg/ m³) in apartments selected in the five sites in winter and summer.

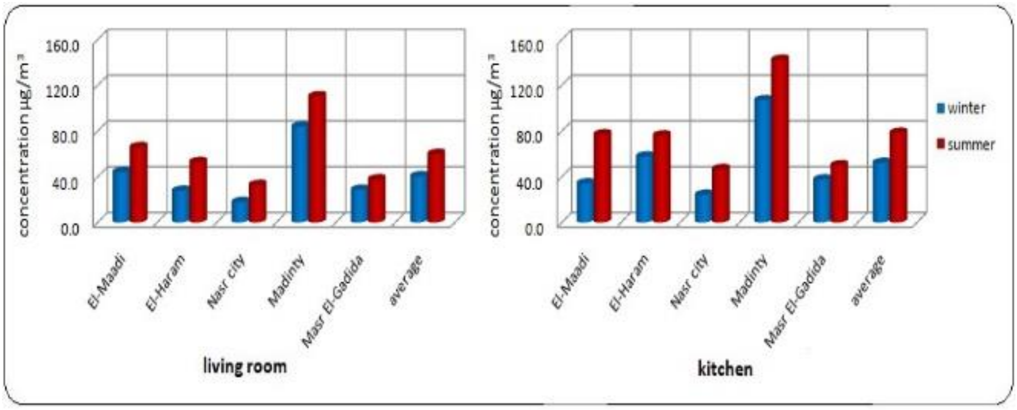

Figure 7: Average concentrations of indoor formaldehyde (living rooms and kitchen) in the investigated apartments in winter and summer (as µg/ m³).

Table 3: Indoor formaldehyde levels determined in different studies.

Country		**Sampling location**	**Conc. (µg/m^3)**	**Comments**	**Reference**
Egypt	Greater Cairo	Living room Kitchen	40.3 , 59.7 51.9, 78.3	Mean (winter, summer)	The present study
	Cairo (Spring & summer)	New Apartments Old Apartments Kitchen Living rooms	180.0 52.0 109.0 123.0	Mean (daytime)	[41]
China	Harbin	Bedroom Living room Kitchen	50.0 (20.0-100.0) 100.0(80.0-130.0) 30.0 (20.0-40.0)	Mean (Range)	[80]
	Dailan	Bedroom Kitchen	29.0 (13.0 -272.0) 31.0 (13.0-167.0)	Median(Range)	[81]
	Hangzhou	2324 rooms in residential homes	107.0	Annual mean	[81]
	Chinese cities	Renovated rooms	12.5	Median	[82]
	China	Indoor northern china Indoor southern china	56.0 40.0	Median	[27]
	Beijing	Remodelled dwellings Indoor	131. 0 1.3–86.0	Mean range	[1] [83]
Spain	Catalonia	Bedrooms living room Houses in industrial city	10.0 - 47.0 96.0 - 37.0 55.0	Range Median	[46] [84]
Sweden	Sweden	single-family houses apartments	22.0 13.0	Median	[49]
Lithuania	Lithuania	11 newly residential buildings.	3.0 –52.0	Range	[85]
Australia	Australia	Forty dwellings	15.0	Annual mean	[86]
	Perth	Bedroom Lounge-room Domestic indoor	5.0 , 22.0 4.0 , 24.0 16.0 (ND-46.0)	Median, Max Median, Max Mean (Range)	[87-88]
Italy	Italy	20 homes	9.3-12.9	Range	[89]
Japan	Minamisoma	Temporary houses	29.0	Mean	[90]
USA	Boston	Indoor Mobile homes	43.0 70.0	Geo Mean	[91-92]
France	France	24 student rooms	21.0	Average	[93]
Korea	Korea	Three types of residential units	52.0 - 99.0	range	[94]

3. 3. Indoor/Outdoor (I/O) ratios

Generally, the concentrations of formaldehyde indoors and outdoors in summer were higher than in winter. (Fig. 4, 7). Increasing the air temperature in summer in Egypt indicates an important role of temperature parameter in the chain of photochemical reactions, which lead to increase the formaldehyde production. Average daily high temperature in Cairo, Egypt, were above 90°F (32.2 °C) in hot season and below 72°F (22.2 °C) in cold season [69].

Average indoor/outdoor (I/O) ratios of formaldehyde concentrations are shown in Table (4). Generally, the measured I/O ratios of formaldehyde were above one; this means that, average indoor formaldehyde levels are still higher than outdoor levels in Cairo. (I/O) ratios demonstrated that sources in the indoor environment are prevailing for all the investigated sites. The high

I/O ratios at the Madinity site reflect the high internal emissions inside the new apartments. Average values of I/O ratio of formaldehyde were 1.79 and 2.74 in winter and summer, respectively.

In general, the indoor exposure to formaldehyde, in residential locations in Cairo, is higher than the outdoor exposure, mainly due to the presence of stronger sources inside the buildings such as cooking and the emissions from furniture, flooring, insulation and coating materials as well as the entry of the outdoor air of the building, which leads to the accumulation of additional pollutants inside, and it may be another source of indoor air pollution with formaldehyde.

(I/O) ratios of formaldehyde concentrations in the present study are almost similar to that found in Beijing, in which indoor/outdoor ratios were 1.6 –6.3 for the summer months [70], and in Mexico City in which I/O ratios were 1.4 – 4.4 [71].

Table 4: The average ratios of the indoor/outdoor (I/O) formaldehyde concentrations.

Site		Winter I/O	Summer I/O
El Maadi	Day	1.20	2.10
	Night	1.26	1.75
El Haram	Day	1.03	1.47
	Night	1.17	2.43
Nasr City	Day	1.71	3.68
	Night	1.99	4.10
Madinity	Day	3.43	4.08
	Night	3.63	4.68
Masr Al Gadidah	Day	1.28	1.53
	Night	1.21	1.57
Average I/O		1.79	2.74

1. 4. Carcinogenic and Non-Carcinogenic Risks

Carcinogenic and non-carcinogenic risks were calculated for chronic exposure to formaldehyde at the investigated residential sites in Cairo. The present study quantified the chronic daily intake (CDI) and the cancer risk (R); their average values are illustrated in Tables (5). Table (5) shows that daily intake of inhaled and cancer risk of HCHO varies from site to site according to HCHO concentrations. Outdoor values showed minimal inhalation intake and cancer risk of HCHO, while maximum values were found indoors in kitchens.

The daily outdoor cancer risk (R) ranged from 1.5E-05 to 6.4E-05 in winter and from 1.8E-05 to 6.7E-05 in summer. While the indoor values were in the range 3.3E-05 - 1.5E-04 and 6.1E-05 - 2.1E-04 for living rooms, and in the range 4.5E-05 - 2E-04 and 8.7E-05 - 2.6E-04 for kitchens in winter and summer, respectively. The highest cancer risk values were detected in the kitchens in Madinity site during summer. Exposure to HCHO may cause worse symptoms in people who have asthma or who are particularly sensitive to chemicals. Chronic effects due to high levels of HCHO include an increased risk of cancer and damage to the kidneys, liver, and central nervous system [72].

In typical, R value of $< 1 \times 10^{-6}$ represents below the "concern level", while R value of $> 1 \times 10^{-4}$ is an indication for the "alarm level"; which implies an urgent necessity to take appropriate action to protect human health [73-74].

All cancer risk (R) values for formaldehyde in the current study (either indoors or outdoors) are above the "concern level". However, outdoor cancer risk values (R) did not exceed the "alarm level" for formaldehyde; while in living rooms and kitchens they exceeded the "alarm level" by 30% and 55% in winter and summer, respectively.

Hazard Quotients (HQ) for non-cancer risk were also illustrated in Table (5). HQ values for external formaldehyde ranged between 0.15 - 0.65, between 0.44 - 2.59 for kitchens and 0.32 - 2.01 for living rooms. HQ values for outdoors were less than 1 (HQ < 1); indicating that no adverse health effects occur due to external exposure to HCHO in the investigated sites. Whereas, about 30 - 50% of the (HQ) values, due to indoor exposure in living rooms and kitchens, were greater than 1; indicating the potential for adverse health effects indoors. These results agree with Du et al. (2014) [75] who stated that about 70% of the risk is due to exposures occurring in homes.

The results of the present study showed that the levels of airborne and inhaled formaldehyde in Cairo residences should not be underestimated. Undoubtedly, formaldehyde is a relevant indoor pollutant in Cairo. The current study can help regulatory agencies to establish guidelines for formaldehyde concentration in indoor air. The use of low-emitting building materials and products, ventilation and keeping temperature moderate can reduce the indoor exposure to formaldehyde and minimize its related risk.

2. Conclusions

Average concentrations of outdoor formaldehyde (HCHO), at the selected sites, exceeded the value of 15 ppb (18.3 $\mu g/m^3$) set as an indicator for urban environment. Indoor formaldehyde concentrations in the investigated apartments were higher than the recommended exposure limit set by OSHA, but lower than Egyptian standards. Moreover, indoor concentrations are still far lower than the effective short-term exposure levels of (0.62-1.23 mg/m3) which could lead to irritation of throat, nose and eyes. Newly furnished apartments could be a stronger source for formaldehyde emissions than the ambient sources. Formaldehyde levels increased in kitchens more than living rooms, reflecting the effect of cooking processes.

Table 5: Average chronic daily intake (CDI), cancer risk (R) and hazard quotient (HQ) of formaldehyde for the different sites.

Site	CDI		R		HQ	
	winter	summer	winter	summer	winter	summer
Indoor (living rooms)						
El-Maadi	0.0018	0.0027	8.2E-05	1.2E-04	0.80	1.20
El-Haram	0.0011	0.0022	5.1E-05	9.9E-05	0.50	0.96
Nasr City	٠.0007	0.0013	3.3E-05	6.1E-05	0.32	0.60
Masr Al-Gadidah	0.0011	0.0015	5.2E-05	7.1E-05	0.51	0.68
Madinity	0.0034	0.0046	1.5E-04	2.1E-04	1.51	2.01
Indoor (kitchens)						
El-Maadi	0.0014	0.0032	6.4E-05	1.4E-04	0.62	1.40
El-Haram	0.0024	0.0031	1.1E-04	1.3E-04	1.05	1.35
Nasr City	0.0010	0.0019	4.5E-05	8.7E-05	0.44	0.85
Masr Al-Gadidah	0.0015	0.0020	7.1E-05	9.4E-05	0.68	0.91
Madinity	0.0044	0.0059	2.0E-04	2.6E-04	1.95	2.59
Outdoor						
El-Maadi	0.0014	0.0015	6.4E-05	6.7E-05	0.62	0.65
El-Haram	0.0010	0.0011	4.7E-05	5.2E-05	0.46	0.51
Nasr City	0.0003	0.0004	1.5E-05	1.8E-05	0.15	0.18
Masr Al-Gadidah	0.0009	0.0010	4.2E-05	4.5E-05	0.41	0.44
Madinity	0.0009	0.0010	4.4E-05	4.7E-05	0.43	0.46

There were no significant diurnal variations, however there was a seasonal variation, where concentrations in summer were higher than in winter indicating the important role of temperature. I/O ratios of formaldehyde were above one demonstrated that sources in the indoor environment are prevailing for all the investigated sites.

The Calculated carcinogenic health risks due to HCHO exposure demonstrated that outdoors show minimal values of inhalation intake (CDI) and cancer risk (R), while maximum values were found indoors in kitchens. All cancer risk (R) values for formaldehyde in the current study (either indoors or outdoors) are above the "concern level" ($R < 1 \times 10^{-6}$), while the outdoor cancer risk did not exceed the "alarm level" ($R > 1 \times 10^{-4}$), however in living rooms and kitchens they exceeded the "alarm level" by 30% and 55% in winter and summer, respectively. "Alarm level": implies an urgent necessity to take appropriate action to protect human health.

Hazard Quotients (HQ) for outdoors were less than 1 ($HQ < 1$); indicating that no non-carcinogenic adverse health effects occur due to external exposure to HCHO. Whereas, about 30 - 50% of the (HQ) values, due to indoor exposure in living rooms and kitchens, were greater than 1; indicating the potential for adverse health effects indoors.

The results indicated that the levels of airborne and inhaled formaldehyde in Cairo residences should not be underestimated. Undoubtedly, formaldehyde is a relevant indoor pollutant in Cairo. The current study can help regulatory agencies to establish guidelines for formaldehyde concentration in indoor air.

Reference

[1] Huang G, Lee D, Scott M (2015). An integrated Bayesian model for estimating the long-term health effects of air pollution by fusing modelled and measured pollution data, a case study of nitrogen dioxide concentrations in Scotland. Spat Spatiotemporal Epidemiol 14: 63–74

[2] Zhu Z, Sun X, Zhao F, Meixner FX (2015) Ozone concentrations, flux and potential effect on yield during wheat growth in the Northwest- Shandong Plain of China. J Environ. Sci. Health A 34: 1–9Anger S, Bekö G (2013) Indoor air quality in the Swedish housing stock and its dependence on building characteristics. Building and Environment 69: 44-54

[3] Fouladi FR, Naddafi K, Yunesian M, Nabizadeh NR, Dehghani MH, Hassanvand MS (2016) The assessment of health impacts and external costs of

natural gas-fired power plant of Qom Enviro Sci Pollut Res Oct 23(20): 20922-20936

[4] Dehghani MH, Salari M, Naddafi K, Nazmara S, Ehsan Ahmadi E, Prashant Kumar P (2017) Evaluation of formaldehyde concentration in the ambient air of a most populated Iranian city, Tehran. Air Qual Atmos Health 10: 763–772

[5] Shahsavani A, Naddafi K, Haghighifard NJ, Mesdaghinia A, Yunesian M, Nabizadeh R, Arhami M, Yarahmadi M, Sowlat MH, Ghani M, Jafari AJ, Alimohamadi M, Motevalian SA, Soleimani Z (2012) Characterization of ionic composition of TSP and PM10 during the Middle Eastern Dust (MED) storms in Ahvaz, Iran. Environ.Monit. Assess 184: 6683–6692

[6] Bertazzon S, Johnson M, Eccles K, Kaplan GG (2015) Accounting for spatial effects in land use regression for urban air pollution modelling. Spat. Spatiotemporal Epidemiol 14 (15): 9– 21

[7] Moghadam FM, Heidari M, Farhadkhani M, Sadeghi M, Forouzandeh S, Ahmadi A & Ghasemi EK. (2020) TSP, PM_{10}, $PM_{2.5}$, and PM_1 in ambient air of Shahr-e Kord, Iran's rooftop; levels, characterisation and health risk assessment of particles-bound heavy metals, International Journal of Environmental Analytical Chemistry, DOI: 10.1080/03067319.2020.1796992.

[8] Cheng Y, Lee SC, Huang Y, Ho KF, Ho SSH, Yau PS, Louie PKK, Zhang RJ. (2014). Diurnal and seasonal trends of carbonyl compounds in roadside, urban, and suburban environment of Hong Kong. Atmospheric Environment, 89: 43-51.

[9] Ezzo AA (2014) Monitoring and emission assessment of organic Toxic Air Pollutants in Greater Cairo", Ph.D. Thesis, Faculty of Science, Cairo University, Egypt

[10] Luecken DJ, Napelenok SL, Strum M, Scheffe R, and Phillips S (2018) Sensitivity of Ambient Atmospheric Formaldehyde and Ozone to Precursor Species and Source Types Across the United States. Environ Sci Technol 52 (8): 4668–4675

[11] ECHA (European Chemicals Agency). (2019). Report on Worker exposure to formaldehyde and formaldehyde releasers. EC NUMBER: 200-001-08 (Formaldehyde).

[12] Liu Y, Shao M, Lu S, Chang CC, Wang JL, Fu L (2008) Source apportionment of ambient volatile organic compounds in the Pearl River Delta, China, Part II. Atmospheric Environment 42(25): 6261-74

[13] Salthammer T (2013) Formaldehyde in the Ambient Atmosphere, From an Indoor Pollutant to an Outdoor Pollutant. AngewandteChemie International Edition 52: 3320 – 3327. DOI: 10.1002/anie.201205984, (2013).

[14] Zheng J, Zhang R, Garzón JP, Huertas ME, Levy M, Ma Y, Torres-Jardón R, Ruiz-Suárez LG, Russell L, Takahama S, Tan H, Li G, Molina LT (2013) Measurements of formaldehyde at the US–Mexico border during the Cal-Mex 2010 air quality study. Atmos. Environ. 70: 513–520

[15] Szulejko JE, Kim KH (2016) A practical approach to estimate emission rates of indoor air pollutants due to the use of personal combustible products based on small-chamber studies. Chemosphere 144: 1451– 1458

[16] Santana FO, Vânia P, Campos VP, Cruz LP, Luz SR (2017) Formaldehyde and acetaldehyde in the atmosphere of Salvador-Brazil, using passive sampling. Micro chemical Journal 134: 78–86

[17] Roman CP, Fernández M, Martín LG, Cuevas E, Ojeda MG, Marusczak N, Puentedura O, Sonke JE, Lopez AS. (2020). Atmospheric formaldehyde at El Teide and Pic du Midi remote high-altitude sites, Atmospheric Environment,Volume 234, 2020, 117618.

[18] Liu Z, Cui Y, He Q, Guo L, Gao X, Feng Y, Wang Y, Wang X. Seasonal Variations of Carbonyls and Their Contributions to the Ozone Formation in Urban Atmosphere of Taiyuan, China. *Atmosphere*. 2021; 12(4):510. https://doi.org/10.3390/atmos12040510

[19] Tang X, Bai Y, Duong A, Smith MT, Li L, Zhang L (2009) Formaldehyde in China, Production, consumption, exposure levels, and health effects. Environment International 35: 1210-1224

[20] Lei W, Zavala M, de Foy B, Volkamer R, Molina MJ, Molina LT (2009) Impact of primary formaldehyde on air pollution in the Mexico City Metropolitan Area. Atmospheric Chemistry and Physics 9: 2607–2618

[21] Wang L, Sakurai M, Kameyama H (2009) Study of catalytic decomposition of formaldehyde on Pt/TiO_2 alumite catalyst at ambient temperature. J Hazard Mater 167: 399–405

[22] CARB (2013). California Almanac of Emissions and Air Quality - 2013 Edition. California Air

Resources Board. Appendix B: County Level Emissions and Air Quality by Air Basin.

[23] Su W, Liu C, Hu Q, Zhao S, Sun Y, Wang W, Zhu Y, Liu J and Kim J. (2019). Primary and secondary sources of ambient formaldehyde in the Yangtze River Delta based on Ozone Mapping and Profiler Suite (OMPS) observations. Atmos. Chem. Phys., 19, 6717–6736, 2019.

[24] Kohse-Hçinghaus K, Osswald P, Cool TA, Kasper T, Hansen N, Qi F, Westbrook CK, Westmoreland PR (2010) Angew Chemosphere 122: 3652 – 3679

[25] Mendoza C, Rivera C, Espinosa C, Gonzalez Abad G, Stremme W, Grutter M. (2019). Study of Formaldehyde Abundance Trends in Mexico City Using Remote Sensing. American Geophysical Union, Fall Meeting 2019. 2019AGUFM.A11T2838M.

[26] Anderson AA, Cheung AY, Lei MW. (2014). Report on: Evaluation of Hong Kong'S Indoor Air Quality Management Programme: Certification Scheme, Objectives, and Technology. In Collaboration with Business Environment Council Limited. Worcester Polytechnic Institute (WPI). http://www.wpi.edu/Academics/Projects.

[27] Dai X, Liu J, Yin Y, Song X, Jia S (2018) Modelling and controlling indoor formaldehyde concentrations in apartments, On-site investigation in all climate zones of China. Building and Environment 127: 98-106

[28] Gawande S, Tiwari RR, Narayanan P, Bhadri A. (2020) .Indoor Air Quality and Sick Building Syndrome: Are Green Buildings Better than Conventional Buildings?. Indian J Occup Environ Med. 2020; 24(1):30-32. doi:10.4103/ijoem.IJOEM_148_19.

[29] EC (European Commission) (2007) Scientific Committee on Health and Environmental Risks (SCHER) Opinion on risk assessment on indoor air quality, European Commission, Brussels

[30] Salthammer T, Mentese S, Marutzky R (2010) Formaldehyde in the Indoor Environment. Chem. Rev. 110: 2536–2572

[31] Liu S (2016) Study on sampling position and control measures of formaldehyde in indoor environment. J Jiangxi Building Material 23: 89-93

[32] Heroux ME, Clark N, Van Ryswyk K, Mallick R, Gilbert NL, Harrison I et al. (2010) Predictors of indoor air concentrations in smoking and non-smoking residences. International Journal of Environmental Research and Public Health 7(8): 3080–3099

[33] Huang Y, Ho SH, Ho KF, Lee SC, Yu JZ, Louie PK (2011) Characteristics and health impacts of VOCs and carbonyls associated with residential cooking activities in Hong Kong. Journal of Hazardous Materials 186(1): 344–351

[34] Guo M, Pei X, Mo F, Liu J, Shen X (2013) Formaldehyde concentration and its influencing factors in residential homes after decoration at Hangzhou, China. Journal of Environmental Sciences 25(5): 908–915

[35] Yu Y, Zhang X (2010) Study of the pollutant emissions from interior wall coating and Fuzzy evaluation. J Build. Mater. 13: 268-271

[36] Wang F, Li Z, Ai Z (2011). New research progress in fiberboard adhesive and their formaldehyde emission. Adhesion 10: 68-71

[37] Zhang H, Qian F, Zhu Q (2012) Emissions characteristics of formaldehyde from block board. Chin. J Process Eng. 12: 335- 339

[38] Jiang C, Li D, Zhang P, Li J, Wang J, Yu J (2017) Formaldehyde and volatile organic compound (VOC) emissions from particleboard, Identification of odorous compounds and effects of heat treatment. Building and Environment 117: 118-126

[39] IARC (International Agency for Research on Cancer). (2020). Indoor burning of biomass and kerosene fuels is associated with higher risk of developing several types of digestive cancers.

[40] Zhu L, Jacob DJ, Keutsch FN, Mickley LJ, Scheffe R, Strum M, Abad G, Chance K, Yang K, Rappenglück B, Millet DB, Baasandorj M, Jaeglé L, and Shah V (2017) Formaldehyde (HCHO) As a Hazardous Air Pollutant, Mapping Surface Air Concentrations from Satellite and Inferring Cancer Risks in the United States Environ. Sci. Technol. 51 (10): 5650–5657

[41] Khoder MI, Shakour AA, Farag SA, Abdel Hameed AA (2000) Indoor and outdoor formaldehyde concentrations in homes in residential areas in Greater Cairo. J Environ Monit 2: 123-126

[42] Papadopoulos A, Mantanis G, Katsinikas K, Michael M. (2013). Formaldehyde in Indoor Air of New Appartments in Drama, Greece. Advances in Forestry Letters (AFL) Volume 2 Issue 2, June 2013.

[43] ASHRAE (The American Society of Heating, Refrigerating, and Air Conditioning Engineers).

(2019). Ventilation for Acceptable Indoor Air Quality. ANSI/ASHRAE Standard 62.1-2019.

[44] Hoshi J, Amano S, Sasaki Y, Korenaga T (2008) Investigation and estimation of emission sources of 54 volatile organic compounds in ambient air in Tokyo. Atmos Environ 42: 2383–2393.

[45] Hasanbeiki O, Miranzadeh MB, Mostafaei GR, Rabbani D, Akbari H (2014) Feasibility of formaldehyde removal from aqueous solutions by advanced oxidation process (UV/H_2O_2). KAUMS Journal (FEYZ) 17: 568–574

[46] Rovira J, Roig N, Nadal M, Schuhmacher M, Domingo JL (2016) Human health risks of formaldehyde indoor levels, An issue of concern. J Environ Sci Health Part A Toxic/ Hazard Subst. Environ. Eng. 51(4): 357-63

[47] Zhang Y, Liu X, McHale C, Li R, Zhang L, Wu Y, Ye X, Yang X, Ding S (2013) Bone marrow injury induced via oxidative stress in mice by inhalation exposure to formaldehyde. PLoS ONE 8(9): e74974. doi:10.1371/journal.pone.0074974

[48] El-Shafie MAM. (2011). Cairo in the Context of Global Cities from Local into Global. MSc. Thesis, Urban Planning and Design, Faculty of Engineering, Ain Shams University, Egypt.

[49] Anger S, Bekö G (2013) Indoor air quality in the Swedish housing stock and its dependence on building characteristics. Building and Environment 69: 44-54

[50] Barakat AO, Khairy MA, Mahmoud MR. (2017). Organochlorine pesticides and polychlorinated biphenyls in sewage sludge from Egypt. J Environ Sci Health A Tox Hazard Subst Environ Eng, 52(8):750-756, 03 Apr 2017.

[51] Harrison RM, Perry R (1986) Handbook of Air Pollution Analysis, 2nd ed., London, New York, Chapman and Hall

[52] USEPA (US Environmental Protection Agency). (2009). Risk Assessment Guidance for Superfund Volume I: Human Health Evaluation Manual (Part F, Supplemental Guidance for Inhalation Risk Assessment. Washington, DC, U.S. EPA, Office of Emergency and Remedial Response.

[53] Ho SH, Cheng Y, Bai Y, Ho KF, Dai WT, Cao JJ, Lee SC, Huang Y, Ho Sai Simon HS, Deng WJ, Guo W (2016) Risk Assessment of Indoor Formaldehyde and Other Carbonyls in Campus Environments in North-western China. Aerosol and Air Quality Research 16: 1967–1980

[54] USEPA (US Environmental Protection Agency) (2014a) Exposure Factors Handbook. Inhalation Route. http,//w ww.epa.gov/ncea/efh/pdfs/efh-chapter05.pdf, Washington, DC, EPA/600/P-95/002Fa., Last Access, 15 May 2014.

[55] USEPA (US Environmental Protection Agency) (2014b) Exposure Factors Handbook. Body Weight Studies. http,//www.epa.gov/ncea/efh/pdfs/efh-chapter07.pdf, Washington, DC, EPA/600/P-95/002Fa, Last Access, 15 May 2014

[56] USEPA (US Environmental Protection Agency) (2012) Washington, DC, Integrated Risk Information System

[57] USEPA (US Environmental Protection Agency). (2011). Exposure Factors Handbook 2011 Edition (Final Report), Office of Health and Environmental Assessment, Washington, DC.

[58] USEPA (US Environmental Protection Agency). (2021a). Integrated Risk Information System (IRIS). IRIS Program Outlook. UPDATE: EPA released an update to the Program Outlook Document in Jun 2021. A Message from the IRIS Program June 2021. (http,//www.epa.gov/iris).

[59] USEPA (US Environmental Protection Agency). (2021b). Integrated Risk Information System (IRIS) Chemical Assessment Summary U.S. Environmental Protection Agency National Center for Environmental Assessment 1 Formaldehyde; CASRN 50-00-0. (http://www.epa.gov/iris).

[60] USEPA (US Environmental Protection Agency). (2021c). Risk Assessment and Modelling - Air Toxics Risk Assessment Reference Library. Risk Assessment and Modelling - Air Toxics. Health Effects Notebook for Hazardous Air Pollutants. Formaldehyde - CAS 50-00-0.

[61] OEHHA (California Office of Environmental Health Hazard Assessment) (2009). California Environmental Protection Agency. Technical Support Document for Cancer Potency Factors, 2009.

[62] Khoder MI (2006) Formaldehyde and Aromatic Volatile Hydrocarbons in the Indoor Air of Egyptian Office Buildings. Indoor Built Environ 15(4): 379–387

[63] Tang R, Wang Z (2018) Field study on indoor air quality of urban apartments in severe cold region in China. Atmospheric Pollution Research 9 (3): 552-560

[64] Yang T, Clements-Croome DJ (2012) Natural Ventilation in Built Environment. In, Meyers

R.A. (eds) Encyclopedia of Sustainability Science and Technology. Springer, New York, NY

[65] OSHA (Occupational Safety and Health Guideline). (2011). OSHA fact sheets of formaldehyde. Occupational safety and health administration guidelines for chemical hazards. Workers, visit OSHA's web site at www.osha.gov.

[66] EEAA (Egyptian Environmental Affairs Agency) (2011) Egypt Environmental Protection Low. No. 4, 1994, and its amended by the decision of the Prime Minister No. 1095 of 2011

[67] Liu L, Yu X, Dong X, Wang Q, Wang Y, Huang J (2017) The Research on Formaldehyde Concentration Distribution in New Decorated Residential Buildings. Procedia Engineering 205: 1535-1541

[68] Feng G, Jiang B, Huang K, Yu S (2017) Study on Distribution Law of Indoor Formaldehyde Concentration under Natural Ventilation Condition in Severe Cold Area. Procedia. Engineering 205: 724-729

[69] Weather History in Cairo, Egypt, 2018 https://weatherspark.com/h/y/96939/2018/Historical-Weather-during-2018-in-Cairo-Egypt#Figures-Temperature.

[70] Wang B, Lee SC, Ho KF (2007) Characteristics of carbonyls, Concentrations and source strengths for indoor and outdoor residential microenvironments in China. Atmos. Environ. 41: 2851 –2861.

[71] Zhang L. (2018). Formaldehyde: Exposure, Toxicity and Health Effects. Book, Royal Society of Chemistry. Printed in United Kingdom by CPI group (UK) LYd, Croydon, CRo4YY, UK. Print ISBN: 978-1-78262-973-3.

[72] SPA (The Styrene Producers Association). (2018). Styrene Monomer: Safe Handling Guide July 2018. Plastics Europe / Styrenics Chain. Belgium. www.plasticseurope.org.

[73] Lee CW, Dai YT, Chien CH, Hsu DJ (2006) Characteristics and health impacts of volatile organic compounds in photocopy centers. Environ Res 100: 139–149

[74] USEPA (US Environmental Protection Agency) Integrated Risk Information Sys-tem (IRIS) EPA (2013) Washington D.C., 1, 1988a. Available from World WideWeb, http,//www.epa.gov/iri (accessed October 2013).34

[75] Du Z, Mo J, Zhang Y (2014) Risk assessment of population inhalation exposure to volatile organic compounds and carbonyls in urban China. Environment International. 73: 33-45

[76] Mohammed AF (2012) Hazardous air pollutants emitted from fossil-fuel-fired power plants and their impacts on Greater Cairo air quality". Ph.D. Thesis, Faculty of Science, Ain Shams University, Egypt.

[77] Dutta C, Som D, Chatterjee A, Mukherjee AK, Jana TK, Sen S (2009) Mixing ratios of carbonyls and BTEX in ambient air of Kolkata, India and their associated health risk. Environmental Monitoring and Assessment 148(1-4): 97-107

[78] Mohammed AF, Morsy EA, Habeebullah TM, and Munir S (2015) Assessing the Levels and Health Risk of Atmospheric Formaldehyde in Makkah, Saudi Arabia. Environment Asia 8(2): 26-36

[79] Hu M, Wu Z, Slanina J, Lin P, Liu S, Zeng L (2008) Acidic gases, ammonia and water-soluble ions in $PM_{2.5}$ at a coastal site in the Pearl River Delta, China. Atmospheric Environment. 42(25): 6310-20

[80] Zhu X, Liu Y (2014) Characterization and risk assessment of exposure to volatile organic compounds in apartment buildings in Harbin, China. Bull. Environ. Contam. Toxicol. 92(1): 96–102

[81] Guo P, Yokoyama K, Piao F, Sakai K, Khalequzzaman M, Kamijima M, Nakajima T, Kitamura F (2013) Sick building syndrome by indoor air pollution in Dalian, China. Int. J Environ Res Public Health 10(4): 1489–1504

[82] Huang S, Wei W, Weschler LB, Salthammer T, Kan H, Bu Z, Zhang Y (2017) Indoor formaldehyde concentrations in urban China, Preliminary study of some important influencing factors. Science of the Total Environment Jul 15: 394-405. doi, 10.1016/j.scitotenv.2017.02.187. Epub 2017 Mar 11

[83] Liu Q (2014) Source apportionment of personal exposure to carbonyl compounds and BTEX at homes in Beijing, China. Aerosol Air Qual Res 14: 330–337

[84] Villanueva F, Tapia A, Amo-Salas M, Cabañas B, Martínez E (2015) Levels and sources of volatile organic compounds including carbonyls in indoor air of homes of Puertollano, the most industrialized city in central Iberian Peninsula. Estimation of health risk. International Journal of Hygiene and Environmental Health 218: 522-534

[85] Kaunelienė V, Prasauskas T, Stasiulaitienė I, Čiužas D, Šeduikytė L, Martuzevičius D (2016) Indoor air quality in low energy residential buildings in Lithuania. Building and Environment 108: 63-72

[86] Molloy SB, Cheng M, Galbally IE, Keywood MD, Lawson SJ, Powell JC, Gillett R, Dunne E, Selleck PW (2012) Indoor air quality in typical temperate zone Australian dwellings. Atmospheric Environment 54: 400-407

[87] Lazenby V, Hinwood A, Callan A, Franklin P (2012) Formaldehyde personal exposure measurements and time weighted exposure estimates in children. Chemosphere 88: 966–973

[88] Maisey SJ, Saunders SM, West N, Franklin PJ (2013) An extended baseline examination of indoor VOCs in a city of low ambient pollution, Perth, Western Australia. Atmos Environ 81: 546–553

[89] Lovreglio P, Carrus A, Iavicoli S, Drago I, Persechino B, Soleo L (2009) Indoor formaldehyde and acetaldehyde levels in the province of Bari, South Italy, and estimated health risk. J Environ Monit 11(5): 955-61

[90] Shinohara N, Tokumura M, Kazama M, Yoshino H, Ochiai S, Mizukoshi A (2013) Indoor air quality, air exchange rates, and radioactivity in new built temporary houses following the Great East Japan Earthquake in Minamisoma, Fukushima. Indoor Air 23(4): 332–341

[91] Dannemiller KC, Murphy JS, Dixon SL, Pennell KG, Suuberg EM, Jacobs DE, Sandel M (2013) Formaldehyde concentrations in household air of asthma patients determined using colorimetric detector tubes. Indoor Air 23: 285– 294

[92] Murphy MW, Lando, JF, Kieszak SM, Sutter ME, Noonan GP, Brunkard JM, Mcgeehin MA (2013) Formaldehyde levels in FEMA-supplied travel trailers, park models, and mobile homes in Louisiana and Mississippi. Indoor Air 23(2): 134-141

[93] Blondel A, Plaisance H (2011) Screening of formaldehyde indoor sources and quantification of their emission using a passive sampler. Building and Environment 46(6): 1284-1291

[94] Kim HT, Kim TW, Hong WH, and Tanabe SI (2017) Concentration of Formaldehyde, Acetaldehyde, and Five Volatile Organic Compounds in Indoor Air, The Clean-Healthy House Construction Standard (South Korea). Journal of Asian Architecture and Building Engineering 16(3): 633-639