Indoor and outdoor formaldehyde concentrations in homes in residential areas in Greater Cairo

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Indoor and outdoor measurements of formaldehyde were conducted at seven flats located in residential areas in Greater Cairo, during spring and summer seasons 1999. The mean daytime formaldehyde concentrations in kitchens, bedrooms and living rooms were 89, 100 and 100 ppb, respectively, in the seven flats. Significant positive correlations were found between the concentrations of formaldehyde found in these three rooms. On the other hand, no significant differences were found between the mean formaldehyde concentrations in these three rooms. The maximum mean concentration of formaldehyde (147 ppb) was recorded in a new flat, while the minimum concentration (43 ppb) was observed in an old flat. The maximum hourly and daytime concentrations were 350 and 225 ppb, respectively. Air temperature, relative humidity and the age of the flat are factors affecting the emission and concentration of formaldehyde. The maximum indoor and outdoor formaldehyde concentrations were recorded during the summer season. During the spring, 38% of the samples indicated that the concentration of formaldehyde in the seven flats exceeded 0.1 ppm, the American Society of Heating, Refrigerating, and Air Conditioning Engineers' (ASHRAE) standard; in the summer, this figure increased to 53%.

Introduction

Formaldehyde is known to be toxic at high concentrations and to be irritating to the respiratory tract, eyes and skin.[1,2] Moreover, there is increasing concern about the potential of formaldehyde to act as a human carcinogen.[3] Construction materials, modern furnishings and consumer products contaminate indoor air with numerous vapour phase organic compounds. Indoor formaldehyde is emitted from a variety of sources, including particle-board, plywood, glues and resins in furniture, carpets and panelling, urea formaldehyde foam insulation, various treated fabrics, tobacco smoking and combustion processes.[4–8] Carpet shampoos can leave enough formaldehyde residues to cause health complaints.[9] Formaldehyde has been measured in office buildings[10] and residential houses.[11,12] Formaldehyde levels up to 3 ppm in new homes and 0.2 ppm in 10-year-old homes have been recorded.[13] The indoor formaldehyde level was measured at a mean value of 0.5 ppm in 600 mobile homes in Washington.[14] In addition, the average of 1-week formaldehyde values ranged between 70 and 90 ppb inside mobile homes in California.[15] Moreover, formaldehyde levels were found to be in the range 0.01–0.1 ppm in offices and homes.[16] Formaldehyde was recorded at higher levels in indoor air (54.56 ppb) compared to that found in outdoor air (12.53 ppb) at residential houses located in a suburban area of New Jersey.[17]

Atmospheric formaldehyde is directly emitted from mobile and stationary sources. It is also formed in the atmosphere by photochemical reactions involving virtually all classes of hydrocarbon pollutant.[18] Atmospheric concentrations of formaldehyde have been reported to range from under 0.005 ppm to 0.6 ppm near industrial outlets or in areas of heavy smog.[19]

The present study aims to evaluate the indoor formaldehyde concentrations in the kitchens, bedrooms and living rooms at different flats, with different characteristics. The indoor/outdoor ratio of formaldehyde levels and the factors that have an effect on the formaldehyde concentration were measured.

Materials and methods

Indoor and outdoor measurements of formaldehyde concentrations were made at seven different flats in residential areas in Greater Cairo. Each flat was occupied by a single family. Information concerning the sampling sites is shown in Table 1. Air samples were collected from the kitchens, bedrooms and living rooms and outdoors. The indoor samples were collected at approximately 1.5 m above the floor and in the centre of each room. The samples were taken hourly from 08.00 to 19.00 local time during spring (March–May) and summer (June–August) seasons (1999) and the mean daytime concentration was calculated. The mean concentration of formaldehyde in each flat was calculated from the concentration found in the kitchens, bedrooms and living rooms.

Chemical analysis

Absorbing solution was prepared from 3-methyl-2-benzothiazolone hydrazone hydrochloride (MBTH) (Merck). Oxidizing solution was prepared from sulfamic acid (Fluka) and ferric chloride (Sigma). Spectrophotometry (Coleman, Junior II spectrophotometer model 6/20) was used for the determination of absorbance.

The aldehydes in air were collected in a 0.05% aqueous

Table 1 Identification of sampling sites in Greater Cairo[a]

Site	Age	Size/m^2	Floor	City	Smoking allowed
Flat 1	6 months	120	2nd	Giza	No
Flat 2	1 year	110	2nd	Giza	Yes
Flat 3	2 years	65	Ground	Giza	Yes
Flat 4	4 years	140	5th	Giza	No
Flat 5	8 years	60	3rd	Cairo	Yes
Flat 6	15 years	55	4th	Cairo	No
Flat 7	43 years	35	2nd	Giza	No

[a]Note: all flats use liquefied petroleum gas and have natural ventilation.

solution of MBTH.[20] The resulting azine is then oxidized by ferric chloride–sulfamic acid solution, which can be measured at 628 nm using spectrophotometry. The concentration of total aldehydes is calculated in terms of HCHO. This method is relatively free from interference and its collection efficiency is 84%.[20]

Air samples were collected in glass bubblers with a coarse fritted inlet containing 35 ml of 0.05% MBTH solution, using a pump calibrated to draw 1 l min^{-1}. The samples were taken hourly (60 l air sample). After each sampling time, the volume of the absorbing solution was made up to exactly 35 ml with distilled water (to compensate for evaporation losses) and allowed to stand for 1 h. Ten millilitres of the sample solution were transferred into a clean glass stoppered tube washed with distilled water, and an equal volume of unexposed reagent was placed in a second clean tube to serve as a blank. Two millilitres of oxidizing solution (1.6 g sulfamic acid and 1.0 g ferric chloride dissolved in 100 ml distilled water) was added to the sample solution and blank, and mixed well. After allowing to stand for at least 12 min, the absorbance was determined at 628 nm against the reagent blank. The aldehyde content (expressed as μg ml^{-1} HCHO) was determined from the calibration standard curve. The air concentration of total aliphatic aldehyde (as HCHO) was calculated.[20]

To prepare the calibration solution, a freshly prepared standard HCHO solution containing 10 μg ml^{-1} HCHO was used. Replicate samples and blanks were handled and analysed in the same manner as mentioned previously. The calibration curve was constructed as absorbance against μg ml^{-1} HCHO of the solutions. From 0.03 to 0.7 μg ml^{-1} HCHO can be measured in colour developed solution (12 ml), with a detection limit of 0.03 μg ml^{-1}. This corresponds to a minimum detectable concentration of about 14 ppb aldehyde (as HCHO) in a 60 l air sample, absorbed in 35 ml MBTH. Ten replicate field samples were collected in the bedroom of one flat for 1 h. The relative standard deviation (RSD) for replicate analyses of the field samples was 5% ($n=10$). However, the RSD for replicate analyses of the calibration standard was 2% ($n=12$).

Meteorological parameters

During every sampling, the temperature and relative humidity were measured using a Sigma-II thermohygrograph (No. 7210), SK Sato Keiryoki MFG-Co., Ltd., Japan.

Statistical analysis

The correlation coefficient (r) and the correlation significant t-test were determined using the alternative method of calculation.[21]

Results and discussion

The surface area of materials (wood products, carpet and insulation), smoking and combustion may be important factors that determine the indoor formaldehyde concentration in each flat and its rooms. There is a small difference in the formaldehyde concentrations in the kitchen, bedroom and living room (Table 2). Slightly higher concentrations were recorded in the bedroom and living room as compared with the kitchen, except in flat 7 where relatively higher concentrations were recorded in the kitchen. Based on the data from the seven flats, the mean concentrations of formaldehyde were 89, 100 and 100 ppb in the kitchens, bedrooms and living rooms, respectively, during the study period (Table 2). However, no significant differences were found between the mean concentrations of formaldehyde in these three rooms. This is in agreement with Brown *et al.*[22] who found no significant differences between the concentrations of formaldehyde in the living rooms and bedrooms. Significant positive correlations were found between the formaldehyde concentrations in the kitchens, bedrooms and living rooms during the spring and summer seasons (Table 3). This may be because the formaldehyde is mixed throughout the flats. This is in agreement with Sexton *et al.*[15] who found a consistent and statistically significant relationship between the formaldehyde measurements in the kitchen and bedroom. They also suggested that formaldehyde is relatively well mixed throughout the structure.

The maximum indoor formaldehyde concentration (147 ppb) was found in flat 1; this flat was only 6 months old (Fig. 1). On the other hand, the minimum indoor formaldehyde concentration (43 ppb) was recorded in flat 7; this flat was 43 years old (Fig. 1). The higher formaldehyde concentration in flat 1 probably reflects the higher emission rate from new building materials. A significant negative correlation (-0.85, $p=0.05$) was found between the formaldehyde concentrations and the age of the different flats. These results are in agreement with many studies[7,23] that have reported an inverse relationship between home age and formaldehyde levels. The release of formaldehyde from pressed wood products and other sources inside mobile homes is known to

Table 2 Mean daytime concentrations of indoor formaldehyde (ppb) in the kitchens, bedrooms and living rooms during the spring and summer seasons (1999) in the seven different flats[a]

	Spring			Summer			Mean		
Site	K	B	L	K	B	L	K	B	L
Flat 1	(120) [100–168]	(129) [101–178]	(140) [121–183]	(154) [130–192]	(163) [135–213]	(178) [150–225]	(137) [100–192]	(146) [101–213]	(159) [121–225]
Flat 2	(105) [85–153]	(125) [100–168]	(114) [90–163]	(133) [110–172]	(157) [125–196]	(142) [113–190]	(119) [85–172]	(141) [100–196]	(128) [90–190]
Flat 3	(91) [73–133]	(105) [83–153]	(121) [93–163]	(109) [90–147]	(125) [105–170]	(141) [114–176]	(100) [73–147]	(115) [83–170]	(131) [93–176]
Flat 4	(89) [70–130]	(102) [74–146]	(95) [72–143]	(99) [79–136]	(122) [94–157]	(111) [91–146]	(94) [70–136]	(112) [74–157]	(103) [72–146]
Flat 5	(69) [51–95]	(77) [61–105]	(73) [60–110]	(80) [63–105]	(94) [77–136]	(87) [68–133]	(74.5) [51–105]	(85.5) [61–136]	(80) [60–133]
Flat 6	(50) [38–70]	(50) [40–70]	(58) [48–83]	(55) [45–73]	(58) [46–80]	(69) [52–94]	(52.5) [38–73]	(54) [40–80]	(63.5) [48–94]
Flat 7	(47) [35–68]	(41) [30–60]	(35) [28–50]	(51) [37–73]	(45) [31–63]	(39) [28–56]	(49) [35–73]	(43) [30–63]	(37) [28–56]
All flats	(82) [35–168]	(90) [30–178]	(91) [28–183]	(98) [37–192]	(109) [31–213]	(110) [28–225]	(89) [35–192]	(100) [30–213]	(100) [28–225]

[a]K, kitchen; B, bedroom; L, living room; parentheses, mean; square brackets, range.

Table 3 Correlation coefficients between formaldehyde concentrations found in the kitchens, bedrooms and living rooms inside the seven flats during the spring and summer seasons

Season	Location	Kitchen	Bedroom	Living room
Spring ($n=49$)	Kitchen	1	0.90[a]	0.85[a]
	Bedroom		1	0.91[a]
Summer ($n=49$)	Kitchen	1	0.92[a]	0.88[a]
	Bedroom		1	0.93[a]

[a]Significant ($p \leqslant 0.05$). *n*, number of samples in statistical analysis.

decrease exponentially with time.[24] Formaldehyde levels are always highest in new buildings.[25,26]

The comparison between indoor and outdoor formaldehyde concentrations is presented graphically in Fig. 1. The indoor formaldehyde concentrations are always higher than the outdoor concentrations, especially at the new flat. The maximum indoor/outdoor (I/O) ratio of formaldehyde concentration (4.43) was found at flat 1 (Fig. 1). On the other hand, the minimum ratio (1.08) was observed at flat 7. Moreover, the mean ratio of formaldehyde concentration for the seven flats was 2.95.

The indoor mean daytime concentrations of formaldehyde were 87.60 and 105.60 ppb during the spring and summer seasons, respectively, in the seven flats (Table 4), and the difference was statistically significant ($p \leqslant 0.05$). The higher concentration of formaldehyde during the summer season may be due to the higher emission rate of formaldehyde from its indoor sources at relatively higher temperatures and relative humidity. The highest formaldehyde concentrations were observed during the summer season.[27,28] Significant positive correlation coefficients were found between the formaldehyde concentration and relative humidity and temperature during both seasons in this study (Table 5). This may be attributed to a greater emission of formaldehyde from material surfaces as the air temperature and relative humidity increase. Formaldehyde concentration increases with increasing temperature and relative humidity.[6,29] In addition, ozone forms formaldehyde and other aldehydes after reaction with olefins in vinyl wallpaper, latex paint, plywood, fitted carpets, plaster and

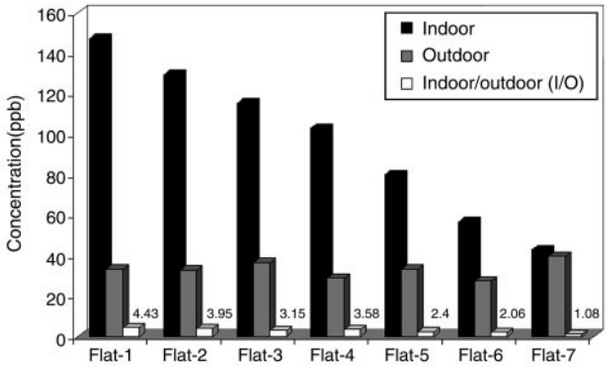

Fig. 1 Indoor and outdoor mean daytime concentrations of formaldehyde and their I/O ratios at different flats during the period of study.

Table 4 Mean daytime formaldehyde concentrations measured indoors and outdoors the seven different flats during the period of study[a]

	Indoors			Outdoors		
Season	*n*	Mean	*s*	*n*	Mean	*s*
Spring	147	87.6	37	49	29	7.1
Summer	147	105.6	47	49	37	9.5
Average	294	96.6	43	98	33	8.6

[a]*s*, standard deviation; *n*, number of samples.

Table 5 Correlation coefficients between temperature, relative humidity and formaldehyde concentration inside the seven flats during the spring and summer seasons

Season	Temperature	Relative humidity
Spring ($n=147$)	0.93[a]	0.78[a]
Summer ($n=147$)	0.95[a]	0.85[a]

[a]Significant ($p \leqslant 0.05$). *n*, number of samples in statistical analysis.

other materials.[30–32] In Cairo, the maximum outdoor ozone concentration was recorded during the summer season.[33] It is suggested that the penetration of outdoor ozone to indoor air during the summer season and its reaction with different indoor surfaces and building materials may lead to an increase in the formation of indoor formaldehyde. In the present study, the average concentration of formaldehyde inside the seven flats during the period of study was 96.6 ppb (Table 4). This average concentration was lower than that reported by Carbone.[14] In contrast, the result in the present study was relatively higher than that reported in comparative studies.[15,17]

The outdoor mean concentrations of formaldehyde were 29 and 37 ppb during the spring and summer seasons, respectively (Table 4), and the difference was statistically significant ($p \leqslant 0.05$). The higher outdoor concentration of formaldehyde during the summer may be due to the higher prevalence of photochemical reactions and greater ozone concentration. Aldehydes in polluted air, during the summertime, are mainly generated from complicated atmospheric oxidation of hydrocarbons (HC) by various free radicals which are formed through photochemical reactions.[34] Similar concentration patterns were observed for outdoor ozone and outdoor formaldehyde, and a significant correlation was found between these two compounds.[17]

The indoor formaldehyde concentration in non-industrial settings should not exceed 0.1 ppm [American Society of Heating, Refrigerating, and Air Conditioning Engineers (ASHRAE)].[35] The frequency percentage distribution of mean daytime concentrations of formaldehyde measured inside the seven flats is presented graphically in Fig. 2. From this figure, 38% and 53% of the concentrations during the spring and summer seasons, respectively, exceeded the maximum formaldehyde concentration (0.1 ppm) set by ASHRAE.

Conclusions

Formaldehyde measurements inside the seven flats indicate that no significant differences were found between the concentrations of formaldehyde in the kitchens, bedrooms and living rooms. This indicates that formaldehyde concentrations were well mixed throughout the flats. Formaldehyde concentrations decreased with flat age, and a significant negative correlation was found between the flat age and formaldehyde concentration. This is probably a result of the increased emission rate of formaldehyde from new buildings. The maximum I/O ratio of formaldehyde concentration was

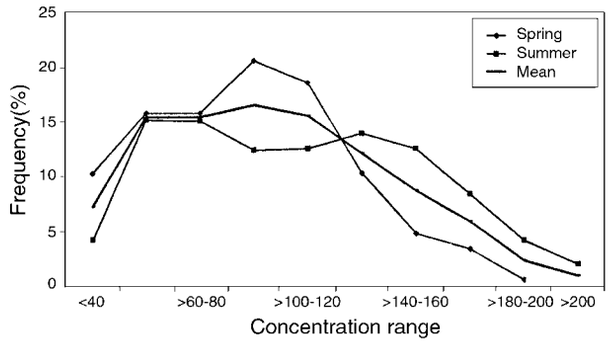

Fig. 2 Frequency percentage distribution of mean daytime formaldehyde concentrations measured inside the seven flats.

observed in a new flat (flat 1), while the minimum I/O ratio was recorded at an old flat (flat 7).

Significant differences were found between the formaldehyde concentrations during the spring and summer seasons outdoors and indoors, with the maximum concentration during the summer and the minimum during the spring. Also, significant positive correlations were found between formaldehyde concentration and air temperature and relative humidity. Based on the formaldehyde concentration measured inside the seven flats, 38% and 53% of the mean daytime concentrations during the spring and summer seasons, respectively, exceeded the maximum concentration of 0.1 ppm formaldehyde recommended by ASHRAE. This may suggest the need to use building materials which emit less formaldehyde.

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