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Comparison of Indoor and Outdoor Air Quality in Children Homes at Prenatal Period and One Year Old

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***Abstract*—**Indoor air (VOCs) samples were collected simultaneously from variety of indoors (e.g. living rooms, baby's rooms) and outdoor environments which were voluntarily selected from the houses in which pregnant residents live throughout Ankara. This is the first comprehensive study done in Turkey starting from prenatal period and continued till the babies had one year old. VOCs levels were measured over 76 homes. Air samples were collected in Tenax TA sorbent filled tubes with active sampling method and analyzed with Thermal Desorber and Gas Chromatography/Mass spectrometry (TD-GC/MS). At the first sampling period in the baby's rooms maximum concentration of toluene was measured about 240.77µg.m^{-3} and in the living rooms maximum concentration of naphthalene was 180.24µg.m^{-3}. At the second sampling period in the baby's rooms maximum concentration of toluene was measured about 144.97µg.m^{-3} and in the living rooms maximum concentration of naphthalene was 247.89µg.m^{-3}. Concentration of TVOCs in the first period was generally higher than the second period.

***Keywords*—**Indoor Air, Volatile Organic Compounds (VOCs), Gas Chromatography.

I. Introduction

VOLATILE Organic Compounds (VOCs) are a large group of carbon-based chemicals that easily evaporate at room temperature. They have been associated with a number of health problems that include cancer [1], [2] and the induction of acute and chronic health pathologies [3].

There are hundreds of VOCs in the air, which increases the complexion of indoor air pollution. VOCs emitted from various sources such as building materials [4]-[9] household materials [10] and combusted materials [11]-[14]. VOCs are widely used in many household products and are emitted by paints [15]-[17] adhesives [18] waxes, solvents, detergents, woods [19]-[20] and items containing them, including carpets [21] vinyl flooring [22], [23] air-conditioners [24] newspapers [25] printers and photocopiers [26].

Combined indoor/outdoor air quality measurements have shown that there exist significant VOC sources indoors.

People spend 80–90% of their time in enclosed spaces (e.g., houses, office buildings, and schools). Several researches have demonstrated that babies and children are more sensitive to environmental pollution than adults. Babies spend about 95% of their time in indoor environment. The time spend in indoor might be more during winter times. The health effects of indoor air pollutants are not fully understood, but indoor air quality has been linked with a wide array of health outcomes including deficits in lung function, chronic respiratory disease, lung cancer, heart disease, developmental disorders, and damage to the brain, nervous system, liver, or kidneys [27], [28].

Benzene, toluene, ethyl benzene, ortho, meta, and para-xylene (BTEX) are mono aromatic hydrocarbons belonging to the family of volatile organic compounds (VOCs) [29]. Ambient air concentration of some of these compounds, most notably benzene, is regulated by law due to their toxicity [30]. Benzene (C6H6), Toluene (C7H8) and xylene (C8H10) are found in the vapor of products such as gasoline, oils, paints, glues, inks, plastics, and rubber, where they are used as solvents. These three pollutants also enter into the composition of detergents, explosives, pharmaceuticals, foams and dyes.

II. Material and Method

A. Study Site and Sampling Strategy

The study undertook at the 76 houses in which pregnant woman and their babies live in. The sampling was conducted in spring, during two periods from May 2011 and from May 2012. Indoor and outdoor levels of volatile organic compounds (VOC) were determined. The measurements are done in two periods, during the third three-master of pregnancy, and when the babies are one year old in different areas of Ankara.

The questionnaire about building conditions and household characteristics (e.g., type of heating fuel) and number of occupants in homes was completed by the participants during the sampling period.

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B. Sampling

The air sampling tubes was placed in the middle of the sampled rooms in the 50cm above the floor on a horizontal surface.

Previously to sampling or calibration, all sampling tubes were conditioned at 280°C by forcing pure nitrogen gas through the tubes at a flow rate of 75ml min^{-1} for 5h and then analyzed to certify that no target pollutants were present.

Samples of VOCs were collected by drawing air through a stainless steel tube containing 500mg of Tenax TA using a personal air sampling pump (SKC Pump) at a flow rate of 80-85ml min^{-1} for a period of 45min.

C. Chemical Analysis

7 VOCs were selected for chemical analysis in this study. The description of sampling and species analysis methods is shown in Table I.

TABLE I
SAMPLING AND SPECIES ANALYSIS

sampler	Active Tenax tube
Target compounds (7 compounds)	Benzene, Toluene, m,p,o-Xylene, Ethyl benzene, Naphthalene
Sampling method	Active sampling for 45min
Desorption method	Solvent desorption (Tenax disulfide)
Analytical method (TD-GC/MS)	Thermal Desorber-Gas chromatography/Mass Spectroscopy Column: DB-1 (Agilent J&W Columns, part number 123-1063) ID: 0,32mm, length:60m, film 1µm

Air samples were collected in Tenax TA sorbent filled tubes with active sampling method and analyzed with Thermal Desorber (Tekmar Dohrmann AERO Trap6000)-Gas chromatography (Agilent 6890N)/Mass Spectroscopy (Agilent 5975C) Detector (TD-GC/MS). The sum of the concentration of the 7 target VOCs was defined as TVOC.

III. RESULTS AND DISCUSSION

A. Indoor Concentrations

Monitoring for indoor air quality was conducted in the rooms in which the infant spends the most time for 76 homes in Ankara. Tables II and III summarize the mean, median and TVOCs levels in each home in the May 2011.

TABLE II
THE MEAN MEAN± STD, MEDIAN, MAXIMUM, MINIMUM, AND TVOCS[1] IN MAY 2011 (PRENATAL PERIOD)

Area	Living Room I ($\mu g.m^{-3}$)				
Sample	N	AVE	MAX	MIN	MED
Benzene	59	1.27±1.71	10.89	0.18	0.72
Toluene	58	23.56±22.41	91.65	0.36	13.59
Eth.benzene	59	4.36±9.49	68.05	0.01	2.10
m,p.xylene	59	6.63±6.24	35.07	0.21	4.73
o.xylene	59	5.90±7.23	45.82	0.23	3.77
Naphthalene	59	22.45±34.22	180.24	0.54	10.62
TVOCs[1]	59	63.77±52.44	224.18	2.42	50.45
Area	Living + Baby`s Room I[2] ($\mu g.m^{-3}$)				
Sample	N	AVE	MAX	MIN	MED
Benzene	10	1.12±1.12	4.07	0.14	0.75
Toluene	10	39.04±50.78	142.38	4.55	17.57
Eth.benzene	10	1.99±1.44	4.69	0.37	1.55
m,p.xylene	10	5.94±3.92	13.86	1.03	5.25
o.xylene	10	2.60±1.77	5.19	0.55	2.15
Naphthalene	10	11.23±12.88	42.42	1.84	5.63
TVOCs[1]	10	61.93±64.87	207.78	9.64	35.77

1. Total Volatile Organic Compounds ($\mu g.m^{-3}$)
2. living room and baby`s room is the same

Mean of toluene 39.04$\mu g.m^{-3}$ at houses without baby`s room and ethyl benzene 4.36$\mu g.m^{-3}$ in the living (Table II), m+p+o-xeylene 7.96 and 6.88$\mu g.m^{-3}$ and naphthalene 25.18$\mu g.m^{-3}$ in the baby`s rooms were the highest concentration (Table III).

TABLE III
THE MEAN MEAN± STD, MEDIAN, MAXIMUM, MINIMUM, AND TVOCS[1] IN MAY 2011 (PRENATAL PERIOD)

Area	Baby`s Room I ($\mu g.m^{-3}$)				
Sample	N	AVE	MAX	MIN	MED
Benzene	59	1.05±1.21	7.90	0.07	0.63
Toluene	59	36.12±43.09	240.77	0.22	23.37
Ethbenzene	58	3.28±2.89	17.01	0.06	2.93
m,p.xylene	59	7.96±11.05	80.36	0.20	6.42
o.xylene	59	6.88±6.42	36.91	0.09	6.17
Naphthalene	59	25.18±30.83	165.92	0.05	14.08
TVOCs[1]	59	80.42±64.75	264.31	2.08	57.78
Area	Outdoor I ($\mu g.m^{-3}$)				
Sample	N	AVE	MAX	MIN	MED
Benzene	76	1.68±2.01	17.06	0.03	1.26
Toluene	76	22.08±44.89	296.18	0.28	6.72
Eth.benzene	76	1.65±1.70	11.56	0.04	1.15
m,p.xylene	76	4.16±5.32	34.51	0.05	2.50
o.xylene	76	1.62±2.20	12.84	0.06	0.89
Naphthalene	76	5.69±10.52	72.95	0.16	2.97
TVOCs[1]	76	36.88±57.63	383.00	0.97	16.69

1. Total Volatile Organic Compounds ($\mu g.m^{-3}$)

Tables IV and V summarize the mean, median and TVOCs levels in each home in the May 2012.

TABLE IV
THE MEAN MEAN± STD, MEDIAN, MAXIMUM, MINIMUM, AND TVOCS[1] IN MAY 2012 (BABIES ONE YEAR OLD)

Area	Living Room II (µg.m^{-3})				
Sample	N	AVE	MAX	MIN	MED
Benzene	67	2.93±1.85	8.49	1.04	2.36
Toluene	67	28.15±31.54	137.35	0.11	12.24
Eth.benzene	67	7.14±7.30	51.13	0.97	5.42
m,p.xylene	67	10.74±10.89	62.99	0.78	8.19
o.xylene	67	9.32±9.54	48.44	0.79	6.12
Naphthalene	67	25.94±41.13	247.90	2.10	12.92
TVOCs[1]	67	84.21±64.53	308.86	6.87	64.74
Area	Living + Baby`s Room II[2] (µg.m^{-3})				
Sample	N	AVE	MAX	MIN	MED
Benzene	7	2.30±0.35	3.00	2.05	2.10
Toluene	7	12.37±18.36	50.62	0.56	2.87
Eth.benzene	7	3.77±2.12	7.50	1.32	3.60
m,p.xylene	7	5.72±4.57	14.02	0.78	5.19
o.xylene	7	4.55±3.11	9.02	0.73	4.20
Naphthalene	7	19.59±26.92	78.22	2.16	9.06
TVOCs[1]	7	48.30±52.07	161.43	8.54	34.70

1. Total Volatile Organic Compounds (µg.m^{-3})
2. living room and baby`s room is the same

TABLE V
THE MEAN± STD, MEDIAN, MAXIMUM, MINIMUM, AND TVOCS[1] IN MAY 2012 (BABIES ONE YEAR OLD)

Area	Baby`s Room II (µg.m^{-3})				
Sample	N	AVE	MAX	MIN	MED
Benzene	69	3.40±2.23	9.74	1.00	2.37
Toluene	69	27.69±35.53	144.98	0.14	9.98
Eth.benzene	69	7.46±10.77	79.30	1.31	4.80
m,p.xylene	69	9.62±10.79	58.59	0.75	7.19
o.xylene	69	8.21±9.77	62.54	0.80	5.82
Naphthalene	69	21.94±33.02	204.20	1.60	11.41
TVOCs[1]	69	78.32±61.97	291.58	7.28	52.74
Area	Outdoor II (µg.m^{-3})				
Sample	N	AVE	MAX	MIN	MED
Benzene	76	3.14±2.20	15.65	1.88	2.29
Toluene	76	11.2±16.58	92.33	0.12	5.29
Ethbenzene	76	3.03±1.73	11.42	1.27	2.63
m,p.xylene	76	3.71±2.98	15.76	0.76	2.99
o.xylene	76	3.04±2.31	12.76	0.70	2.40
Naphthalene	76	5.41±7.74	53.25	2.04	3.27
TVOCs[1]	76	29.53±26.35	158.45	6.80	20.30

1. Total Volatile Organic Compounds (µg.m^{-3})

In Table IV and V mean of toluene 28.15µg.m^{-3}, m+p+o-xylene 11.23 and 9.56µg.m^{-3} and naphthalene 25.9µg.m^{-3} in the living rooms were highest. Warmer temperatures during the summer time will obviously increase the evaporation of VOCs from vehicle fuel tanks.

Concentration of toluene and naphthalene at baby`s room in first sampling periods were higher than other VOCs. Household painting and paint, varnish and lacquer removal, tobacco smoke, and consumer products such as adhesives, floor polish, inks, coatings and solvent-thinned products may contain toluene.

In indoor air, emissions from cooking, tobacco smoking, or moth repellants are expected to be the predominant sources of naphthalene. Available data are inadequate to establish a causal association between exposure to naphthalene and cancer in humans. Adequately scaled epidemiologic studies designed to examine a possible association between naphthalene exposure and cancer was not located.

The results clearly show that baby's rooms are not as safe as we think. Open the windows at least twice a day for 15 minutes at a time to help flush out stuffy air (but if it's cold outside, make sure the child is not in the room or is dressed appropriately).

Concentration of Total Volatile Organic Compounds (TVOCs) at the first sampling were higher than the second period, because in the first sampling they had bought new furniture for baby`s room.

m+p+o-xylene levels in homes with smokers were significantly higher than that in homes without smokers. Xylenes are also emitted from building materials such as carpet adhesives, vinyl cove adhesive, latex caulk, latex paint, and various moldings. Environmental tobacco smoke is also a common indoor source of xylenes [33].

Our results are relevant because they are the first reference values of VOCs exposure levels in two periods be measured in Ankara-Turkey.

Finally, the identification of the determinants that influence both indoor and outdoor pollution levels is vital for designing programs for controlling exposure to household pollution.

Parents can impact the air their infants breathe in several ways. Air conditioners or humidifiers are classic examples, but they may be too harsh for an infant's system or may be inappropriate for the climatic conditions, depending on where the family lives.

B. Indoor and Outdoor Ratio

The indoor (I) to outdoor (O) ratio of the air concentrations of the different compounds (I/O ratio) is a useful tool to assess the importance of indoor versus outdoor sources better than the absolute concentrations. When the I/O ratio is over 1, the presence of indoor sources is considered to be significant. The I/O ratios for each compound are presented in table VI and VII.

TABLE VI
INDOOR AND OUTDOOR RATIOS IN MAY 2011

	B1/L1	L+B1/O1	B1/O1	L1/O1
benzene	0.83	1.77	1.66	2.01
Toluene	1.53	1.77	1.64	1.07
Ethylbenzene	0.75	1.21	1.99	2.65
m,p.xylene	1.20	1.43	1.91	1.59
o.xylene	1.17	1.60	4.24	3.63
Naphthalene	1.12	1.97	4.43	3.95

The indoor levels of VOCs were higher than those registered outdoors (I/O ratios > 1) indicating that the sources of these compounds are located at the indoor environments. In this case, only benzene and ethyl benzene presented lower than 1, and then B1/L1 ratios, so only these compounds are related to outdoor sources.

TABLE VII
INDOOR AND OUTDOOR RATIOS IN MAY 2012

	B2/L2	L+B2/O2	B2/O2	L2/O2
Benzene	1.12	0.76	1.16	1.04
Toluene	0.99	1.38	2.49	2.53
Ethylbenzene	1.01	1.24	2.50	2.46
m,p.xylene	0.86	1.41	2.61	3.02
o.xylene	0.89	1.35	2.81	3.15
Naphthalene	0.87	3.66	4.19	4.81

In Table VII toluene, m+p+o-xylene and naphthalene ratios in baby`s room to living room were lower than 1, then these VOCs sources were from living room.

C. Questionnaire Survey and Results

The questionnaire containing 30 questions about building conditions, residential life-style and indoor situations was completed by the participants during the sampling period. The questionnaire also asked about the distance of the residence from a street with continuous traffic, type of cooking energy, type of heating used in the home, the parents' smoking habits, whether the parents smoked at home.

In addition, the questionnaire asked about any construction or home improvement projects that had been carried out in the home during the child's first year of life (construction, painting, both), Other questions included how often the house was cleaned (more than once a week, once a week, less than once a week).In tables VIII-XI in different rooms, you can see the statistically significant differences between BTEX and factors.

The possible influence of the building age and proximity to the street, cigarette smoking, number of the family member, number of people during sampling, cooking energy, heating energy, naphthalene tablets and formaldehyde, temperature, relative humidity, CO_2 and CO on the indoor VOCs concentrations in homes was discussed(Table VIII, IX).

TABLE VIII
EFFECT OF FACTORS ON BTEX

	PS	BAY	NFM	HE	CE
Benzene	+	+			+
Toluene					
Ethyl benzene					
o-Xylene					
m-p-Xylene			+		
TVOCs			+	+	
	SAH	NT	VC	NPDS	
Benzene			+		
Toluene		+	+	+	
Ethyl benzene	+		+		
o-Xylene	+		+		
m-p-Xylene	+				
TVOCs			+	+	

+:Statistically significant differences ($p < 0.05$), PS : Proximity to the Street, BAY: Building Age _yr, NFM: Number of the Family Members, HE: Heating Energy, CE: Cooking Energy, SAH: Smokers Area at Home, NT: Naphthalene Tablets, VC: Ventilation Condition, NPDS : Number of people during sampling.

TABLE IX
EFFECT OF FACTORS ON BTEX

	HCHO	CO2	CO	T (˚C)	R_H
Benzene	+			+	
Toluene		+		+	+
Ethyl benzene	+				+
o-Xylene	+		+		+
m-p-Xylene	+		+		+
TVOCs				+	

+: Statistically significant differences ($p < 0.05$), HCHO: Formaldehyde, R_H: Relative Humidity.

Concentration of benzene was higher in homes near to the street and newly built homes and in homes that use gas energy for cooking.

Number of the family members in homes and number of people during sampling may affect the indoor VOCs levels because of the variations of indoor activities, living habits and home volumes [32]. For example, a home with four people frequently used cleaning products and air fresheners when the occupants were at home. On the other hand, a home with one resident had very few indoor activities. Number of people during sampling when >4 in homes, toluene concentration was the highest.

D. Comparison of Our Study and Other Studies

The number of studies that have measured personal BTEX levels in children is scarce. Table X compares VOCs concentrations in Ankara`s homes with those in other countries. It is worth to emphasize that the results were obtained from the measurements in using the same sampling and analytical methods.

TABLE X
COMPARISON OF INDOOR BTEX CONCENTRATIONS WITH OTHER COUNTRIES ($\mu G.M^{-3}$)

	INMA (Valencia, Spain)[1] 2006–2007	Shield (Minneapoli, USA)Spring[2] 1999–2000	This Study (Turkey) May 2011 Living room	This Study (Turkey) May 2012 Living room
	Median	Median	Median	Median
Benzene	1.04	1.5	0.63	2.36
Toluene	10.1	3.1	23.37	12.24
Ethyl benzene	1.3	0.9	2.93	5.42
o-Xylene	1.9	1.0	6.42	8.19
m-*p*-Xylene	1.3	2.9	6.17	6.12

[29][1], [31][2]

Thus, the indoor levels of most VOCs in Ankara regions were higher than the other countries. This difference in methodology may have contributed to the higher levels found in our study.

Our results thus contribute important information with respect to the BTEX exposure levels of Turkish children.

Moreover, we have been able to identify certain sources and factors associated with this exposure, which should facilitate the planning and implementation of measures to reduce it.

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