Contribution from smoking to PM2.5, PM1 particles and VOCs concentrations in residential houses in Athens, Greece

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Abstract

The objective of this study was to investigate the indoor and outdoor air quality at two residences in a suburban area of Athens, based on different human activities (smoking and non-smoking, open and closed windows). For this purpose, two apartments in the same area were equipped with particulate matter samplers with PM1 and PM2.5 impactors and VOCs samplers for benzene, toluene, m,p-xylene, o-xylene measurements. Both apartments had 4 inhabitants, while one smoker was living in the second one, smoking on average 10 cigarettes per day. Daily activities were also recorded to questionnaires.

The results indicated that for the non-smokers apartment, the main source of PM2.5 indoor concentration seems to be PM2.5 outdoor concentration, while PM1 and VOCs concentrations followed a corresponding variation. On the other hand, the main source of indoor pollution in the smoker's apartment seems to be smoking since PM2.5, PM1 and benzene indoor concentrations were found 2.5, 3.5 and 1.4 times higher than the ones observed in the non-smokers house. In addition, during two days of smoker's absence, PM2.5, PM1 and VOCs indoor concentrations were decreased but still over the outdoor concentrations.
Keywords: indoor air quality, PM2.5, PM1, VOCs, cigarette smoke.

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1 Introduction

On average, people spend 90% of their life indoors where their health may be affected by significant pollutants' concentrations. Both indoor and outdoor sources contribute to the concentration and composition of pollutants in indoor air while ventilation plays a crucial role in relation to the indoor pollution levels.

Quantitative assessment of indoor source emission characteristics in real situations is a complex task, and therefore only qualitative information about the contribution of many indoor sources is available. Emissions from tobacco smoking have attracted considerable attention and as a result there is more information available on emission rates from this, compared to other indoor sources [1].

Environmental tobacco smoke (ETS) is a complex mixture of more than 4500 chemical compounds that are caused by the burning of tobacco products and are distributed as particles, vapours and gasses [2]. The concentrations of these substances vary with time, room ventilation and proximity to the source. Some of the more common compounds found in ETS include TVOCs, $PM_{2.5}$, NO_X and CO_2. Mainstream Smoke (MS) is directly exhaled from the smoker and Side Stream smoke (SS) is emitted from smouldering tobacco between puffs.

The importance of indoor smoking for contributing to human exposures and adverse health outcomes has motivated substantial scientific inquiry over the past few decades. ETS can cause adverse health problems as eye, nose, throat irritation and allergies, asthma, respiratory tract illnesses and lung cancer [3–5].

According to Schlitt and Knoppel [6], a passive smoker at a distance of 50cm from a cigarette may inhale more than 10 times the amount of carbonyl compounds compared to the smoker himself. Another study (Jones et al. [7]) indicated that cooking and smoking were determined to be major indoor sources of PM2.5 and PM1 whilst cleaning and general activity had little influence on concentrations within this size range. Furthermore, He et al. [8] investigated the relation among 21 different types of indoor activities and particle concentrations and found that PM2.5 concentrations could be up to 3, 30 and 90 times higher than the background levels during smoking, frying and grilling, respectively.

The scientific community has also been preoccupied with the measurement of certain VOCs in indoor air while smoking took place. A tobacco smoking simulation experiment [9] has indicated that VOCs concentrations emitted by tobacco smoking were linearly associated with the number of cigarettes consumed and different behaviors were observed in closed indoor environment, of which ETS markers, d-limonene, styrene, trimethylbenzene, etc decayed fast, whereas benzene, toluene, xylene, ethylbenzene, etc decayed slowly and even increased in primary periods of the decay. In an other study [10] aimed at investigating cigarette-smoke indoor pollution in a controlled environment, the results indicated that when windows were kept closed and smoking took place TVOCs concentrations increased by an order of 10 times and decreased returning to initial levels after 1 or 2 hours.

2 Sampling

Two apartments in the same suburban area of Athens (Aghia Paraskevi) were employed for the purposes of this study. The first one is on the 3rd floor of a 25 year-old, four-store apartment house, covers an area of 120m^2 and has four non-smokers inhabitants. During the experimental campaign, the apartment was ventilated daily using natural ventilation, i.e. from open windows and the balcony, which faces a low traffic street. Also, 300m away from the house, is the high traffic density Mesogion Avenue. Finally, evergreen trees and other plants cover the area between the houses.

A family of four members, one of whom is a smoker, live in the second home. This apartment is situated on the 1st floor of a similar (in age, size, building materials, and surroundings) four-store apartment house. This apartment was daily naturally ventilated from a large balcony facing a low traffic road while the new constructed Hemittos mountain peripheral highway is located 600m away from it.

Finally, in order to examine the possible different indoor sources, we note that both families use electricity for heating and cooking and had a similar daily schedule while there is a pet in the non-smokers house.

3 Instrumentation and methodology

Twenty four-hour PM samples were collected during the period between 13th and 19th May 2005 in the non-smokers home and between 20th and 27th May 2005 in the smoker's home. Two identical low volume controlled flow rate (2.3m^3/h) samplers were used indoors for PM1 and PM2.5 measurements (SEQ 47/50, Integrated LVS3, SVEN Leckel INGENIEURBURO GmbH) while another one (TCR Tecora Bravo) measured PM2.5 outdoors.

Particles were collected on 47mm Glass Fiber filters, which were protected in plastic filter holders before and after sampling. Each filter was inspected from its integrity prior to its use.

Particle mass concentrations were determined gravimetrically using an electronic microbalance (Mettler Toledo MX-5) with a resolution of 10^{-6} g, which was placed in a "weighing room". In order to create the appropriate conditions in the weighing room (T= 20 ± 1°C, R= 50 ± 5%), temperature and relative humidity were automatically controlled with the use of an air-conditioner operating in continuous basis.

Indoor and outdoor 30-minute VOC samples were collected simultaneously, twice a day. The first was at 8:00-8:30 in the morning and the second at 8:008:30 in the evening. All VOC samples were analyzed within 1 day after sampling.

Finally, the measurements procedure included daily recording of all necessary details of the habitats' activities, such as the duration and kind of cooking, cleaning or the quantity of cigarettes smoked.

4 Results and discussion

4.1 $PM_{2.5}$ & PM_1 concentrations

4.1.1 Non-smokers' house

Most studies show that indoor activities affect indoor particle concentration levels, with the degree of effect depending on the type of the source and on house characteristics. This study concentrates on the examination of the role of smoking in $PM_{2.5}$ and PM_1 formation by comparing the values measured in two apartments in correlation with $PM_{2.5}$ outdoor measurements.

The daily variations of indoor $PM_{2.5}$ and PM_1 and outdoor $PM_{2.5}$ concentrations for the non-smokers' house are shown in fig. 1.

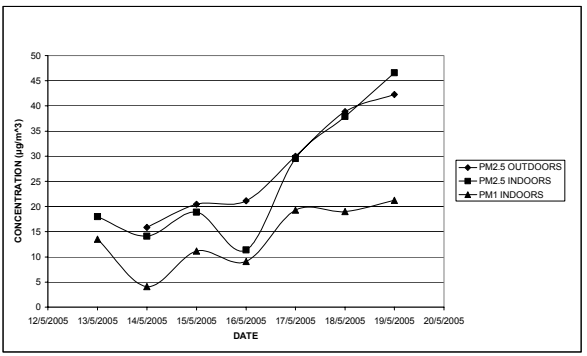

Figure 1: Indoor $PM_{2.5}$ and PM_1 and outdoor $PM_{2.5}$ concentrations for the non-smokers' house.

As it is shown, indoor $PM_{2.5}$ and PM_1 levels were lower than the outdoor ones, but their variations seem to be quite similar to the outdoor $PM_{2.5}$ variation, indicating that the main PM source was the outdoor one. Furthermore, the correlation coefficient between indoor and outdoor $PM_{2.5}$ was found R=0.97, and between outdoor $PM_{2.5}$ and indoor PM_1 was R=0.93. This strong correlation between indoor and outdoor values amplifies the assumption that the outdoor environment mainly contributes to the indoor PM levels. Additionally, quite strong correlation between indoor $PM_{2.5}$ and PM_1 (R=0.89) was estimated, implying common sources for both particulate pollutants. As far as the indoor/outdoor (I/O) concentrations ratio for $PM_{2.5}$ is concerned, I/O average value is lower than unity (I/O=0.89). Quackenboss and Lebowitz [11] found a similar result, with I/O average value equal to 0.63 for homes without reporting smoking.

In order to investigate the role of air change between the internal and external environment and if the latter influenced the indoor PM concentrations, a test of isolating the outdoor sources was done during two days of the sampling period. In particular, all windows and balcony doors were kept closed during the period

between the 15th May (8:00 am) and the 16th May (8:00 am). As it is shown in fig. 1, although PM2.5 outdoor levels stayed almost constant (there was a small increase of 3.81%), indoor $PM_{2.5}$ and PM_1 were decreased by 39.7% and 18.6% respectively. After the isolation period all doors and windows were opened and indoor PM levels followed the outdoor variations. To be more specific, outdoor $PM_{2.5}$ values presented an increasing trend of 41.3% and $PM_{2.5}$ and PM_1 indoor values were increased by 159.8% and 112.3% respectively. He et al. [8] had a similar result as they recorded an increase of 20% in $PM_{2.5}$ levels due to opening the outside door. Also these results are in agreement with the assumption that the main PM source is the outdoor environment.

4.1.2 Smoker's house

A different picture of PM concentrations was found in the smoker's apartment (fig.2).

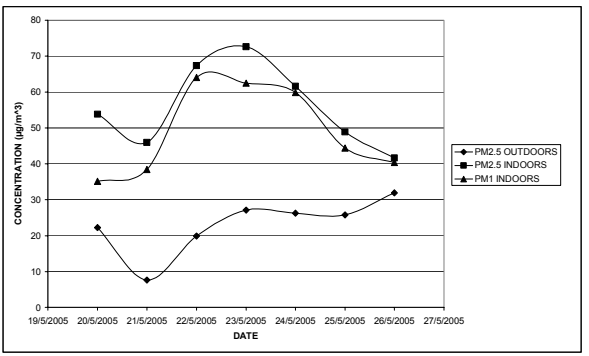

Figure 2: Indoor $PM_{2.5}$ and PM_1 and outdoor $PM_{2.5}$ concentrations for the smoker's house.

In this case, indoor values were higher than the outdoor ones, indicating cigarette smoking as a significant indoor source. This conclusion is in agreement with the observation that no significant correlation was noted neither between indoor and outdoor $PM_{2.5}$ (R=0.11) nor between outdoor $PM_{2.5}$ and indoor PM_1 (R=0.22) concentrations. On the other hand, strong correlation between $PM_{2.5}$ and PM_1 indoor values, was recorded (R=0.87) whereas the I/O ratio for $PM_{2.5}$ was found to be higher in the smoker's house (I/O=2.27) as compared to the non-smokers' house (I/O=0.89), indicating a large elevation of the indoor $PM_{2.5}$ levels in homes with the presence of smoking [12, 13].

It is worth to mention that during the last two days of the experimental campaign the smoker was absent. As a result a corresponding decrease in $PM_{2.5}$ and PM_1 indoor levels (32.5% and 32.4% respectively), was observed while the outdoor $PM_{2.5}$ presented an increasing trend of 21.5%.

Statistics of measurements of both houses are given in the comparative table 1.

Table 1: Statistics of PM measurements.

	PM1 INDOORS (μg m^-3)		PM2.5 INDOORS (μg m^-3)		PM2.5 OUTDOORS (μg m^-3)	
	NON-SMOKERS	SMOKERS	NON-SMOKERS	SMOKERS	NON-SMOKERS	SMOKERS
avg	13,9	49,3	25,2	56,9	28,1	22,9
max	21,2	64,1	46,6	72,6	42,2	31,9
min	4,09	35,1	11,4	41,7	15,8	7,60
stdev	6,27	12,4	13,2	11,5	10,7	7,77
	CORRELATION				I/O (PM2.5)	
		NON-SMOKERS	SMOKERS		NON-SMOKERS	SMOKERS
	PM2.5 IN-PM2.5 OUT	R=0,97	R=0,11	avg	0,89	2,27
	PM1 IN-PM2.5 OUT	R=0,93	R=0,22	max	1,10	2,43
	PM1 IN-PM2.5 IN	R=0,89	R=0,87	min	0,27	1,30

4.2 VOCs concentrations

4.2.1 Non-smokers' house

There are many factors which can affect the VOCs concentrations, such as the cigarette brand, the mainstream smoke or side stream smoke, the indoor miscellaneous pollution sources, the absorption and desorption of the building materials to VOCs and the indoor air change rate.

Table 2 summarizes the statistics, concerning four VOCs (benzene, toluene, m,p-xylene, o-xylene) for both apartments.

As far as the non-smokers' house is concerned, the average I/O ratio was lower but close to unity (except for the benzene morning concentration which was 1.02) as expected [14]. Furthermore, the correlation co-efficient between indoor and outdoor morning, evening (not shown) or daily values were quite high for all VOCs measured (table 2) indicating the outdoor environment (vehicles, trees etc) as a significant source for indoor VOCs levels. In addition, all VOCs presented higher values in the morning possibly because windows and balcony doors were closed all night, resulting to pollutants' accumulation since human activity in this house were not intense during the early morning hours.

Table 2: Statistics of VOCs measurements.

			non- smokers	smokers				non- smoke	smokers
benzene	daily indoor concentration (μg m^-3)	average	5,06	6,85	m,p-xylene	daily indoor concentration (μg m^-3)	average	9,63	8,14
		max.	8,91	12,0			max.	18,4	18,2
		min.	1,80	4,59			min.	2,51	4,49
		stdev	2,72	3,01			stdev	6,29	4,96
	daily I/O ratio	average	0,91	1,73		daily I/O ratio	average	0,93	1,34
		max.	1,30	3,21			max.	1,81	2,01
		min.	0,64	0,16			min.	0,45	0,31
		stdev	0,21	0,95			stdev	0,35	0,49
	R (indoor-outdoor)	daily	0,98	0,53		R (indoor-outdoor)	daily	0,90	0,68
			non- smokers	smokers				non- smoke	smokers
toluene	daily indoor concentration (μg m^-3)	average	18,6	23,3	o-xylene	daily indoor concentration (μg m^-3)	average	3,56	4,25
		max.	36,4	57,9			max.	6,93	7,65
		min.	3,91	10,8			min.	1,36	2,68
		stdev	12,5	16,9			stdev	2,18	1,71
	daily I/O ratio	average	0,90	1,41		daily I/O ratio	average	0,92	1,51
		max.	1,20	2,74			max.	1,72	2,28
		min.	0,58	0,30			min.	0,23	0,47
		stdev	0,22	0,62			stdev	0,35	0,57
	R (indoor-outdoor)	daily	0,94	0,85		R (indoor-outdoor)	daily	0,97	0,42

Figure 3 presents the morning and evening indoor and outdoor variation of benzene, toluene, m,p-xylene, o-xylene for the non-smokers' apartment. As it is shown, indoor variations were similar to the outdoor ones.

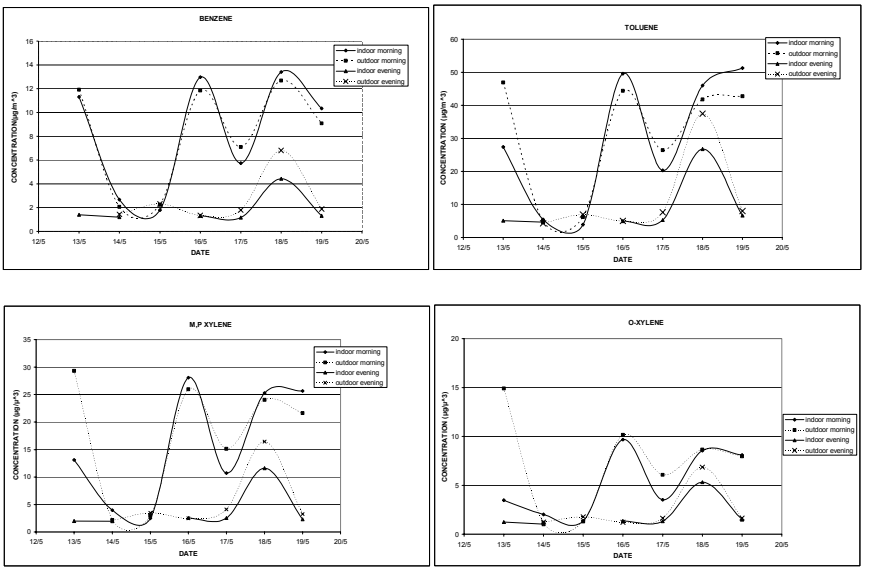

Figure 3: Benzene, toluene, m,p-xylene and o-xylene concentrations for the non-smokers' house.

Furthermore, morning indoor and outdoor levels for all VOCs were higher than the evening levels, although human activity was more intense after noon. This, in combination with the assumption that the outdoor environment is the strongest source, can be attributed to the higher morning vehicle circulation.

During the weekend (14th and 15th May) both indoor and outdoor VOCs values were decreased and morning values were too close to the evening (indoor and outdoor) ones. This decrease was detected possibly due to the reduced vehicle circulation during all weekend although human activity in the house was increased compared to the working days.

4.2.2 Smoker's house

Smoker's house presented a different picture, as shown in figure 4. In contrary to the non-smokers' house, VOCs morning and evening indoor variations did not follow the outdoor ones. This observation, in combination with the fact that the indoor-outdoor correlation coefficients were not as high as in the first house (except for toluene), prove that indoor sources such as smoking preserved a more significant role in VOCs concentrations.

Furthermore, I/O ratio was greater than unity (table 2) which also proves the importance of indoor sources, such as smoking. Comparing the VOCs variations in the two different houses, a greater difference was observed during afternoon.

This could be explained by the increased smoking activity during the afternoon and the presence of all family members, according to the information recorded in the questionnaires.

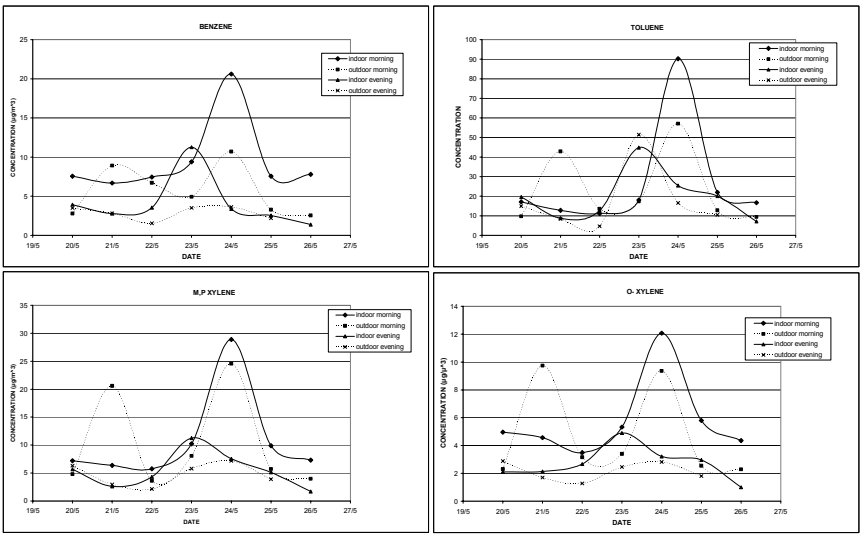

Figure 4: Benzene, toluene, m,p-xylene and o-xylene concentrations for the smoker's house.

On 23rd of May, from 10:00 in the morning until 17:00 there was extensive indoor (living room) and outdoor (balcony) human activity including furniture cleaning and glue usage, while the balcony door was widely open. As shown in fig. 4, the evening measurements showed an increase in all VOCs indoor concentrations possibly due to glue and cleaning products use [15]. Next morning measurement showed that both indoor and outdoor concentrations were elevated. However, all VOCs indoor concentrations present a peak probably not only due to the outdoor levels' increase but also because all doors and windows were kept closed during night.

Finally, in a similar study, Xie et al. [9], there was found that among the four VOCs, which were measured during the experimental campaign, benzene is mainly influenced by environmental tobacco smoke while toluene and xylenes are not evidently correlated with ETS. In the present study, benzene average levels presented the highest increase (1.4 times) in the smoker's house compared to these in the non-smokers' house. Toluene and o-xylene were also elevated by 1.2 times, while the daily average mp-xylene value was lower in the smoker's house.

5 Concluding remarks

- For the non-smokers house, the main source for $PM_{2.5}$, PM_1 and VOCs indoor concentrations seems to be the outdoor environment.

- In the smoker's house, $PM_{2.5}$, PM_1 and benzene indoor concentrations were found 2.5, 3.5 and 1.4 times higher than the ones observed in the non-smokers house, respectively, indicating smoking as the main source.
- During two days of smoker's absence, PM2.5, PM1 and VOCs indoor concentrations were decreased but still over the outdoor concentrations.
- Comparing the VOCs variations in the two different houses, a greater difference was observed during afternoon possibly due to the increased smoking activity during afternoon.

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