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INDOOR AIR QUALITY ASSESSMENT IN SPACES DESIGNED FOR OFFICE ACTIVITIES: PAHs AND PHENOLS

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Abstract. A big number of studies prove that there is a strong relation between the quality of indoor air in office environments and the health and productivity of people who work in these environments. The paper presents the results of a sampling campaign conducted in the autumn of 2014 in an office building in Bucharest, located in an area characterised by a low level of pollution, in order to determine the concentrations of PAHs and phenols from particulate matter. Parallel samplings have being conducted both indoor and outdoor (I/O): in an office, a smoking place and outside the building. The highest concentrations of particulate matter were found in outdoor air, 89.41 ± 40.44 μg/m^3; at the semi-opened smoking place the concentration was 70.89 ± 26.24 μg/m^3, and inside the office, 45.89 ± 19.65 μg/m^3. The average I/O ratio was 0.53, indicating a good isolation of the building against particulate matter infiltration from outdoor and the absence of indoor sources of particulate matter. In samples taken from outdoor and from the smoking place have been identified a number of 13 PAHs with chrysene and benzo(a)pyrene being the most abundant and *m*, *p*-cresol and 2–3 xylenol among phenols. The results indicated that smoking places can have a big impact on indoor air quality if they are not properly located in order to avoid the infiltration of PAHs inside offices.

Keywords: indoor air, PAHs, phenols, particulate matter, I/O ratio.

AIMS AND BACKGROUND

Recent studies proved that we are spending an average of 80% of our time inside different building: homes, offices, schools and other spaces with non-industrial destination, given that most of the time the quality of air is worse than outdoor[1].

Indoor air can contain, depending on the activity developed, the characteristics of the ventilating system, occupancy and the level of outdoor air pollution, a wide range of compounds that can influence the health of the people starting with temporary effects like the irritation of eye and mucus membrane of nose, dizziness and headache, to serious conditions like lung cancer or cardiovascular and brain diseases[2–5].

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Particulate matter and organic/inorganic compounds absorbed on their surface are among the pollutants omnipresent outside buildings in most of the big cities[6–8]. Semi-volatile organic compounds such as PAHs and phenols adsorbed on the surface of particulate matter amplify the harmfulness because of their carcinogenic and mutagenic effect[9]. In case of the people who work in offices, a bad quality of air can affect not only their health but also the efficiency and the quality of work. This is the reason why in the last years it could be observed a bigger attention regarding the optimum parameters of air in office spaces.

Through the case study we intended: (i) assess the level of air pollution with particulate matter, PAHs and phenols from particulate matter in a space designed for office activities, (ii) establish the correlations between indoor and outdoor air pollution, and (iii) identify the sources of air pollution from an office space.

The assessment of air pollution with particulate matter, PAHs and phenols inside the office E3-13 was based on the results obtained from the parallel monitoring of pollutants concentrations in indoor and outdoor air. The results of monitoring were used to establish the correlations between indoor and outdoor and to identify the sources of pollution through calculation of I/O ratio and of the infiltration factor (F_{in}); more information regarding the emission sources were obtain from statistical analysis, using Pearson correlation test and linear regression analysis. Thus, the gradient of the linear regressive curve represents F_{in}, and the value of the intercept gives information regarding indoor sources[11], according to the relation:

$$C_{in}=F_{in}C_{out} + C_s \quad (1)$$

where C_s is the concentration of pollutants from indoor sources and C_{in} and C_{out} are the indoor and outdoor concentration of particles, respectively.

It can be seen that in the situation where there are no indoor sources of pollution F_{in} is equal with the value of the I/O ratio. In this situation, big differences between F_{in} and I/O ratio indicate the presence of internal sources of pollution.

EXPERIMENTAL

The tests performed by this study were conducted in a new building located on the outskirts of Bucharest (Fig. 1), one of the most polluted European capitals with particulate matter[10]. Between 1–11.11.2014 were taken simultaneously samples of total suspended particles from air in a space located on the 3rd floor of the building (office E3-13) which holds office activities (writing, printing and copying documents), from the smoking area located on the same floor with the office and from outside the building.

The building is equipped with air conditioning with recirculation without refreshing or air purification; air exchange is ensured by opening windows. Normally in the office operates 6 persons (occupancy: 6.5 occupants/100 m^3) for about 8 h/day.

For particulate matter sampling were used quartz filter with a diameter of 45 mm and automatic samplers model SVEN LECKE Ingenieurbüro GmbH. Samplings were carried out for 24 h with a flow rate of 2.3 m^3/h. Inside the office and the place of smoking, particulate sampling equipment was installed in the middle of the room and the extraction system was placed at 1.5 m above the ground. Outside, sampler was placed in an area located at 20 m from the building and the main road (Fig. 1). Filters were conditioned at 20°C and 50% humidity for 48 h without light, in a climatic chamber, were weighed before and after exposure using an AG 135 analytical balance (Mettler-Toledo GmbH, Greifensee, Switzerland) with a 10-µg resolution.

Fig. 1. Sampling site

Weight gain is the mass of particulate matter retained from the volume of samples air. The concentration of particulate matter in µg/m^3 was calculated by dividing the mass of particulate matter retained on the filter to the volume of air sampled. After collection, the filters were wrapped separately in aluminum foil and stored in a freezer until analysis.

For PAHs and phenols adsorbed on particulate matter determination each filter was cut in two halves and analysed separately. Extraction was performed in an ultrasonic bath, for 30 min, in cold conditions, using 10 ml of toluene for PAHs and 10 ml of methanol for phenols. For PAHs the extracts in toluene were combined and concentrated in nitrogen atmosphere up close dryness, and taken with 1 ml acetonitrile. For phenols analysis the combined extracts in methanol were concentrated until 1 ml in a nitrogen atmosphere. The concentrates were kept in cold and dark conditions until they were analysed using GC/FID for phenols and HPLC/FLD for PAHs. Before analysing, the extracts were filtered through 0.45-µm nylon Acrodisc syringe filters (Pall Corp., Port Washington, NY, USA).

For PAHs analysis we used an Agilent 1200 high-performance liquid chromatograph with a fluorescence detector (Agilent Technologies Inc., Santa Clara, CA, USA) with a Phenomenex Envirosep-PP-PAH column (125 mm long, 3.2 mm i.d.; Phenomenex Inc., Torrance, CA, USA), with a flow rate of 1 ml/min. LGC Standards PM-613APAH mixture, which contains 16 PAHs between 5 and 10 μg/ml in acetonitrile, were used to calibrate the instrument.

The separation and quantification of phenols was performed using a Varian 3800 GC with FID detector and CP-SIL 5CB, 25 m × 0.25 mm ID column; a certified reference material was used for calibration curves (PHM 804 Phenols Mixture) containing 17 phenols in methanol with concentrations of 100.4 ± 0.5 μg/ml.

Chromatographic-quality water, toluene, methanol and acetonitrile were used throughout the extraction and analysis procedures.

RESULTS AND DISCUSSION

PARTICULATE MATTER

The results of monitoring, the concentration of particulate matter in outdoor air, indoor air (E3-13 office) and the smoking place from the 3rd floor, during 1–11.11.2014 are presented in Table 1 and Fig. 2. The outdoor air concentration of particulate matter varies widely from a minimum of 44.36 μg/m^3 up to a maximum of 134.11 μg/m^3, with an average concentration of 89.41 ± 35.46 μg/m^3, values located below the daily limit of 150 μg/m^3 imposed by Romanian legislations (STAS 12574-87 Air in protected areas. Quality conditions.)

Table 1. Particulate matter in air concentration indoor (E3-13), outdoor and smoking place

Parameters	Particulate matter concentrations (μg/m^3)			I/O ratio
	indoor	outdoor	smoking place	
Number of daily samples	10.00	10.00	10.00	–
Mean (μg/m^3)	45.94	89.41	70.89	0.53
SD (μg/m^3)	13.25	35.46	36.39	–
Minimum (μg/m^3)	25.66	44.36	30.93	0.38
Maximum (μg/m^3)	65.42	134.11	115.19	0.69
Difference min./max. (μg/m^3)	39.76	89.75	84.26	–
I/O the Pearson correlation coefficient, *r*	0.86			

For the measurements performed in the office E3-13 the concentration of particulate matter was in the range [25.66–65.42 μg/m^3] with an average of 45.94 ± 13.25 μg/m^3.

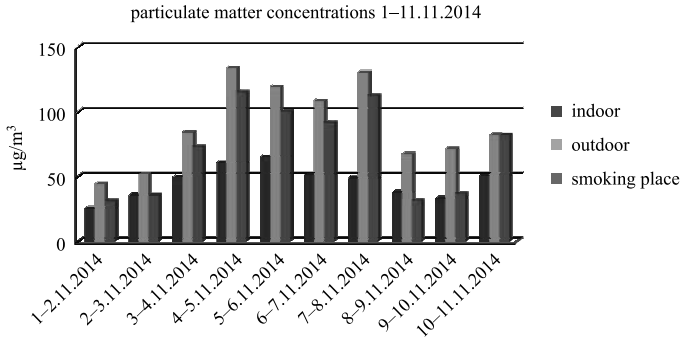

Fig. 2. Variation in time for particulate matter in air concentration: indoor, outdoor and smoking place

In general, there are recognised two types of pollution sources for indoor air: (i) outdoor air that comes in through infiltration and/or penetration, and (ii) indoor sources of particulate matter[11].

The I/O ratio is the most used indicator to characterise the contribution of the outdoor air pollution to indoor air quality. The I/O ratio value (0.53) indicates a good building insulation, that does not allow easy penetration of particles from outside, and the absence of major indoor pollution sources with particulate matter. More information can be obtained from the results of statistical treatment of the monitoring data by applying the Pearson correlation test and the linear regression analysis (Table 2). The slope provides information regarding particle infiltration from outside and the intercept about the possibility of existence for indoor pollution sources[12,13].

Table 2. Results of the Pearson correlation test (r) and linear regression analysis (r^2, slope, intercept) for particulate matter concentration inside and outside the building

Linear regression			The Pearson correlation	I/O ratio
intercept	slope (F_{in})	r^2	r	
		Indoor/outdoor		
15.81	0.337	0.74	0.86	0.53

The correlation between the concentration of particulate matter from indoor and outdoor was very good (r = 0.86) which confirms that the outdoor air is an important source of pollution for the indoor air; different values of I/O ratio (0.53) and infiltration factor F_{in} (0.337) indicate the presence of indoor sources of particulate matter, too.

Activities like printing and copying documents can represent an important source of pollution with particulate matter for indoor air; the staff (occupancy: 6.5 occupants/100 m^3) can be also a source of pollution by transfer of dust from clothing or shoes. These hypotheses are also sustained by the variation of the concentration

in time for E3-13 office; it can be noticed that during the week-end (1–3.11.2014 and 8–10.11.2015) the concentrations are smaller than during working days.

Another source of pollution can be represented by the smoking place located nearby; here, the concentration of particulate matter is smaller compared with the outdoor air but bigger compared with the indoor air, with a period average of 70.89 ± 36.39 μg/m^3. This fact is explained by the construction particularities of the smoking place: located at the 3rd floor with an open side.

Also, because of the height, the influence of the traffic is reduced compared with the point where the concentration was measured, outside the building.

PAHS AND PHENOLS IN PARTICULATE MATTER

As shown in Table 3, that comprises the values resulted from the PAHs and phenols determination, the highest concentrations of PAHs, expressed in sum of PAHs, ng/m^3, are found outdoor (36.30 ng/m^3) and the lowest indoor (21.82 ng /m^3).

The most abundant PAH are benzo(a)pyrene, indoor and chrysene outdoor and at the smoking place.

The ratio between indoor and outdoor (I/O) calculated for the sum of PAHs is approximately equal with the I/O ratio for particulate matter, indicating a common source of pollution; the analysis of I/O ratios for individual compounds reveals a concentration variation between 0.14 and 1.03, which indicates a different distribution for PAHs in indoor air compared with outdoor, or the existence of other indoor sources for PAHs or particles containing PAHs.

Highest ratio values can be observed for anthracene and its derivate, benzo(a)anthracene and dibenzo(ah)anthracene; the presence of these compounds in high concentration may be due to an internal source of pollution with PAHs (with three rings), compounds that are found also in cigarette smoke[14,15].

The extracts in methanol of particulate matter analysed by GC/FID revealing the presence of three phenols: *m*+*p*-cresol was found outdoor, at the smoking place and indoor; 2–3-xylenol in outdoor and at the smoking place; highest concentrations where identified in particulate matter sampled from outdoor air: 22.7 ng/m^3 (the sum of phenols) comparative with 17 ng/m^3 at the smoking place and 6 ng/m^3 in indoor air, indicating the outdoor air as a preponderant source of pollution with particulate matter and phenols.

Analysing the results expressed in μg/g, both in the case of PAHs and phenols from particulate matter it can be observed that the particulate matter from indoor contain the biggest mass concentration and, at the opposite, the smaller concentration is outdoor. As recent studies have drawn attention to the potential emissions of small size particulate matter that contain volatile/semi-volatile organic compounds, including PAH, generated by computers and printing machines[16–18], and in the case of the office E3-13 total suspended particles from air contain 91% small size particulate matters[19], one possible explanation may be the different ratio of small

size particulate matters in total suspended particles from indoor and outdoor air. Another possible source can be the smoking place, but the concentration of particulate matter, PAHs and phenols are smaller than the concentration from outdoor air, because of the constructive particularities, which makes us to consider that this source have a smaller importance than we initially estimated.

Table 3. Concentration of PAHs and phenols in particulate matter from indoor air (E3-13), outdoor and smoking place

Compounds	Indoor		Outdoor		Smoking place		I/O
	µg/g	ng/m³	µg/g	ng/m³	µg/g	ng/m³	
Polycyclic aromatic hydrocarbons							
Naphthalene	50.9	2.18	44.7	3.85	46.9	3.02	0.57
Acenaphthene	38.2	1.64	25.4	2.18	30.5	1.97	0.75
Phenanthrene	9.3	0.40	7.3	0.62	13.3	0.86	0.64
Anthracene	1.2	0.05	0.6	0.05	1.6	0.10	0.95
Fluoranthene	5.8	0.25	20.5	1.77	19.5	1.26	0.14
Pyrene	15.1	0.64	18.7	1.61	19.5	1.26	0.40
Chrysene	71.8	3.07	99.7	8.58	107.0	6.91	0.36
Benzo(a)anthracene	16.2	0.69	9.7	0.83	18.0	1.16	0.83
Benzo(b)fluoranthene	62.5	2.68	42.3	3.64	50.8	3.28	0.74
Benzo(k)fluoranthene	33.6	1.44	27.2	2.34	28.1	1.81	0.61
Benzo(a)pyrene	126.2	5.41	82.2	7.07	96.1	6.20	0.76
Benzo(ghi)perylene	31.3	1.34	20.5	1.77	23.4	1.51	0.76
Dibenzo(ah)anthracene	47.5	2.03	23.0	1.98	34.4	2.22	1.03
∑ PAH	509.4	21.82	421.7	36.30	488.9	31.56	0.66
Phenols							
m+*p*-cresol	141.1	6	89.8	8.4	87.4	6.1	0.70
2–3-xylenol	–	–	153.6	14.3	157.2	11.0	–
∑ Phenols	141.1	6	243.4	22.7	244.6	17.0	0.26

CONCLUSIONS

The results of tests performed in the case study demonstrated the presence of particulate matter in the outdoor air in concentrations that are smaller than the daily limit value set by environmental legislation.

Indoor (Office E3-13) the concentration of particulate matter is smaller than outdoor, the I/O ratio being 0.53; thanks to the very good correlation between the concentration from outdoor and indoor (the Pearson correlation coefficient, r = 0.86) and to the type of building ventilation, we can consider that the outdoor air is the most important source of pollution with particulate matter for the indoor air; the particulate matter transfer from personnel clothes and shoes in air can represent

a major source of pollution with particulate matter for the indoor air from the office taking in consideration the high occupancy of the space. Given the results of the tests, outdoor air can also be an important source of indoor air pollution with PAHs and phenols; I/O ratio values indicate the possible presence of an indoor pollution source with particulate matter containing PAHs, too. This indoor source of pollution with particulate matter containing PAHs can be the office activities (printing, coping, drafting documents, etc.); contrary to our initial anticipation, the smoking space influence is reduced due to construction features that ensure rapid dispersal of emissions in the environmental air.

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