Particulate matter and polycyclic aromatic hydrocarbons in a selected athletic hall: ambient concentrations, origin and effects on human health

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Abstract. The paper presents the results of research on the concentration of 16 polycyclic aromatic hydrocarbons (PAHs) associated with total suspended particles (TSP) and their respirable fraction (PM_4) in one of the Warsaw sports halls. Samples of dust were collected for 15 days simultaneously inside and outside (atmospheric air) of the sports hall. The obtained data allowed calculating diagnostic ratios indicating the origin of the PAHs and selected indicators of cumulative exposure to the PAH mixture. Both PM and PAH in the surveyed area were derived from the combustion of solid fuels; this involved pollution both in the atmospheric air and in the air inside the sports hall. It has been shown that the exposure of sports hall users to PAHs is significantly higher than the exposure resulting from concentrations recorded in the atmospheric air.

1. Introduction

In recent years society's awareness of the necessity of maintaining one's physical condition as the most important parameter regulating the proper functioning of the body has increased considerably. As a result, the use of various sports facilities, both open (stadiums, playgrounds, outdoor tennis courts) and closed (gyms, gymnasiums, sports halls) has also increased. The quality of air in sports facilities is particularly important for regular trainers, who spend several hours per day in these buildings, several times a week.

Meteorological parameters and the air quality in open facilities are almost the same as in atmospheric conditions, so the air quality in open facilities can be assessed by comparing the concentrations of the different pollutants to the relevant standards (reference values, limit values, etc.).

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But in closed sports facilities there are no standards for air quality. Here, the sanitary condition of the air is regulated mainly by the efficiency of the air-supply system, which affects the values of many parameters, including the concentrations of volatile organic compounds (VOCs) in the air, airborne biological concentrations, and particulate air pollution [1, 2]. This last parameter seems to be the most important in the assessment of the health exposure because quantitative and qualitative analysis of dust provides additional information on other dust-bound substances (e.g. polycyclic aromatic hydrocarbons (PAHs), heavy metals) which may have adverse health effects.

The results of epidemiological studies show that both short-term and long-term exposure to high concentrations of particulate matter (PM) increase the risk of respiratory, blood and nervous system diseases [3]. PM particles settling on the walls of the pulmonary alveoli impede the gas exchange. For those who train in the room, this means that high PM concentrations during training will decrease the athletic performance [4]. In addition, oral breathing usually occurs during intense exercise [5–7]. Nasal respiration allows stopping most of the inhaled PM particles with diameters above 2 μm. Breathing through the mouth causes the omission of the natural respiratory filtration mechanisms in the upper part of the respiratory system. As a result, the amount of particles reaching the deeper parts of the respiratory system is increased [8, 9]. The high intensity of breathing while exercising causes not only fine (i.e. less than 2 μm in general) but also larger particles to be transferred into the air passages. The increased intensity of breathing occurs in people who regularly train not only during training. Oxygen consumption in people who regularly train is considerably higher than in the average person. Moreover the per minute breathing volume in physically active persons is greater than the per minute breathing volume in non-athletes [10]. This means that trainees will be exposed to more PM and PM-bound substances and pollutants in all conditions than those who do not regularly practice a sport.

A brief overview of enclosed sports facilities shows that most sports buildings in Poland are buildings equipped with gravitational ventilation and lacking internal facilities to improve indoor air quality. These are most frequently urban sports halls and halls of various sports clubs. New buildings equipped with modern installations to replace and clean the air are reserved mostly for professional athletes; their use by amateur athletes is associated with high (too high) costs. Due to this, people prefer sports facilities free of charge but of poorer quality. Regular school workouts and a variety of sports activities for children and young people are offered in public sports halls. These are usually rented by the instructors conducting the classes and are heavily used from early morning to late evening.

The first research in Poland into PM concentrations and 16 PM-bound PAHs within a Warsaw sports hall is that presented here. PAHs are classified as priority substances in the air due to their proven carcinogenic and mutagenic effects [11–14]. The main sources of PAHs in the air in urbanized areas are the following: processes related to energy consumption (burning solid and liquid fuels), incomplete combustion of organic compounds, chemical processes, waste incineration, forest fires, tobacco smoke, and chemical reactions in the atmosphere [15]. The most common and the most often examined PAHs in the environment are: acenaphtene (Acn), acenaphthylene (Acnl), anthracene (An), benzo[a]anthracene (BaA), benzo[a]pyrene (BaP), benzo[b]fluoranthene (BbF), benzo[ghi]perylene (BghiP), benzo[k]fluoranthene (BkF), chrysene (Ch), dibenzo[ah]anthracene (DahA), fluoranthene (Flt), fluorene (Flu), indeno[1,2,3-cd]pyrene (IP), naphthalene (Na), phenanthrene (Phen) and pyrene (Pyr) [16, 17].

2. Experimental

2.1. Description of the sampling sites

Samples of dust were collected inside and outside of the sports hall of the Sports and Recreation Center (OSiR) of the Targówek district located in Warsaw at 25 Ossowskiego Street (52◦16'19 N, 21◦02'42 E) (Fig. 1). Targówek district is split into two parts: industrial and residential. This hall is located in the residential part of the district. It adjoins on its south side a one-story residential building; on the north, the buildings of a school complex; on its west side is an Orlik-type playground; on its east side is Ossowski Street, with relatively low traffic due to the closure of part of the street in May 2016 to build a subway. Approximately 100 meters in a straight line to the west there passes Saint Vincent Street with the highest traffic in the area (according to the Association for the integration of capital communications (SISKOM) data, about 1900 cars/hour). There is a lot of open space around the hall. In the surroundings of the hall, especially on the northeast side, low-rise buildings are dominant.

OSiR is a multifunctional facility that allows training in many sports, such as handball, basketball, football, volleyball, table tennis, etc. It has two stories. On the ground floor is a sports hall with a parquet floor (measuring 44 m x 24 m) and washrooms. On the upper floor is an auditorium for 200 persons and offices. Only gravity ventilation is used in the building. During working days, the hall is used by students of the neighboring school and in the afternoons and on weekends the hall is used for training and inter-school competitions.

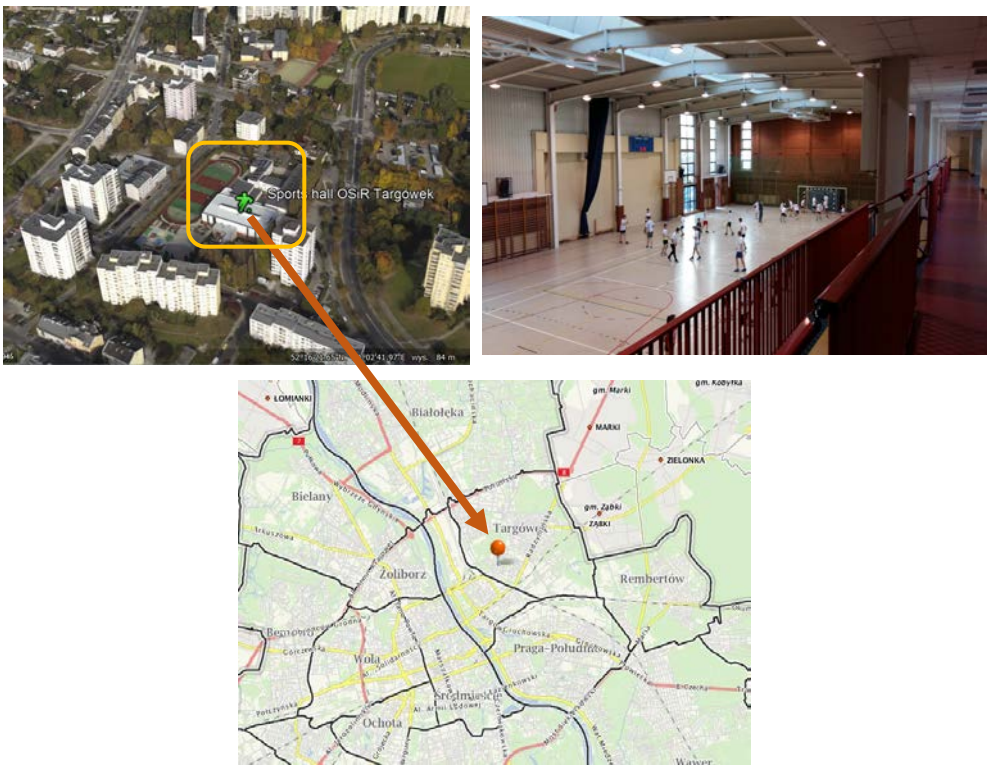

Fig. 1. Location of sampling place.

2.2. PM sampling

Measurements were carried out from December 2016 to January 2017. Fifteen parallel measurements of the concentrations of PM_4 and TSP were made simultaneously inside and outside the sports hall. The average time of the PM sampling was 436 minutes. The PM concentration was examined by the gravimetric method (PN-91/Z-04030/06, PN-91/Z-0430/05). For this purpose, two GilAir 3 aspirators and glass filters (Cat. no. GF1-025, 25 mm in a diameter) were used. The PM sampling was performed at a height of 2 m from the floor/ground level. The procedures for conditioning and weighing of pure filters and PM sample filters were the same as in [18,19].

2.3. PAH analysis

The samples prepared for the PM_4 and TSP analysis were extracted using dichloromethane in an ultrasonic bath. The resulting extract was filtered, washed and concentrated in a helium atmosphere. The crude extract was diluted with propanol-2 and redistilled water until a propanol-2:water equivalent ratio of 15:85 (V/V) was reached. Next, the samples were subjected to an extraction to solid phase (SPE) using the columns c-18 with stationary phase. A Perkin Elmer Clarus 500 gas chromatograph with flame-ionisation detector (FID) was used to analyse the extracts. An RTE-5 capillary column (30 m x 0.32 mm x 0.25 μm) from the Restek company was used for the separation of the components. Helium was used as the carrier gas with a flow rate of 1.5 cm^3/ min. The quantitative analyses were based on the calibration curves for 16 standard PAHs. The linear correlation of dependence between the peak area and the PAH concentrations was tested for a range of concentrations from 1 to 20 ng/μl. The correlation coefficients for this concentration range were between 0.98 and 0.99. The samples were fed into the dispenser. The evaporation temperature was 240°C and the detector temperature was 280°C. The analysis was carried out using a programmable temperature increase in the operating column. The initial temperature of the analysis for up to 4 minutes was 60°C, then increased by 10°C/min to reach 280°C. At this temperature the column was soaked for 14 minutes. The total analysis time was 40 minutes. The FID was powered by hydrogen (flow rate 45 cm^3/min) and air (450 cm^3/min) [14].

3 Results and discussion

The average concentrations of PM_4 and TSP in the indoor and outdoor air of the sports hall during the whole of the sampling period are presented in Table 1.

Table 1. The average concentrations of PM_4 and TSP indoor and outdoor the hall.

Concentration	Indoor [μg/m^3]	Outdoor [μg/m^3]	I/O
PM_4	74.2 ± 21.5	22.3±8.2	3.3
TSP	115.1 ± 9.6	65.2±34.7	2.1

The concentrations of PM_4 and TSP were significantly higher (three times for the PM_4 and two times for TSP) inside the hall than in its surroundings. In outdoor air only about 33% of the TSP mass was PM_4 particles whereas in the indoor air of the sports hall the analogue PM_4 proportion exceeded 60%. It seems that the reason for maintaining high concentrations of PM inside the hall is the accumulation of PM particles in the indoor air. Probably PM particles reach the indoor air of hall with atmospheric air and due to the limited ventilation they are not removed to an adequate extent to balance the PM migration.

A similar phenomenon was observed in air quality studies in university teaching rooms in Gliwice and Warsaw [20, 21]. Over time, the particles inside the hall create larger agglomerates and they are added to the mass of the coarse dust (in this case, the aggregate mass of the particles in the 4100 μm range). Then the particles settle on the ground and undergo permanent resuspension during the movement of the air in the hall until they are mechanically removed (cleaning, vacuuming). For these reasons the difference in PM_4 concentration indoor and outdoor of the hall were clearly higher than the difference in TSP concentrations.

Fig. 2 shows that the concentrations of 16 PM_4- and TSP-bound PAH both in the indoor and outdoor air of the sports hall recorded during the study period were very high. In atmospheric air they exceeded values previously quoted in Warsaw several times [22], and were similar to those that were recorded only in heavily polluted areas of Poland in the heating period (increased emissions from burning coal and biomass in household furnaces) [15].

The main reason for the high concentrations of PAHs was doubtless the season in which the measurements took place: the heating season. The research was conducted in the Targówek district, where over 1000 buildings (according to the statistical data of city office of Warsaw are not connected to the municipal central heating network. These buildings are individually heated, usually with solid fuels (coal, wood). The quality of the air in the district is also affected by air migration from neighboring districts (Białołęka, Marki, Ząbki), which are characterized by low buildings with individual fireplaces also.

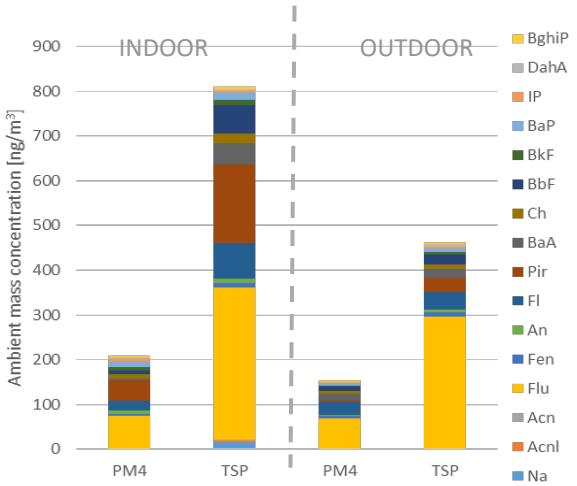

Fig. 2. Average ambient concentration of 16 PAH related to PM_4 and TSP in indoor (athletic hall) and outdoor (atmospheric) air.

To confirm the above theses and establish the origin of the PM_4- and TSP-bound PAHs, we used Diagnostic Ratios (DR). Diagnostic ratios are the mutual proportions of the ambient concentrations of a single PAH or groups of PAHs that have similar physicochemical properties and impact in the environment [14, 17–19]. From the many known diagnostic ratios [17], several were selected (Table 2). Their values indicate that the PAH mixture both in the indoor and outdoor air of the sports hall was mainly connected with the burning of solid fuels (coal, wood) and with engine exhaust gases (with the predominant ones being diesel engines).

Table 2. PAH diagnostic ratios for the indoor and outdoor sampling points.

Diagnostic ratio	Indoor		Outdoor		Source of PAHs [17]
	PM_4	TSP	PM_4	TSP	
CPAH/TPAH	0.820	0.845	0.748	0.866	~ 1 - combustion
Flu/(Flu+Pir)	0.620	0.659	0.948	0.905	> 0.5 - petrol emissions
An/(An+Fen)	0.692	0.523	0.322	0.298	> 0.1 - petrogenic; 0.24 - coal burning
Flt/(Flt+Pir)	0.323	0.312	0.886	0.571	< 0.4 - unburned petroleum; 0.57 - coal burning; > 0.5 coal, grass, wood
BaA/(BaA+Ch)	0.434	2.145	2.181	1.918	0.46 - coal burning
BaP/(BaP+Ch)	0.558	0.405	0.547	0.447	0.5 - diesel
IP/(IP+BghiP)	0.536	0.517	0.427	0.452	0.2–0.5 - petroleum combustion; > 0.5 - grass, wood, coal combustion
IP/BghiP	1.156	1.070	0.746	0.824	~1 - diesel
BaP/BghiP	3.057	3.342	3.125	1.832	> 1.25 - coal/coke

The measured concentrations of 16 PAHs clearly showed that the average concentration of the PAH mixture (ΣPAH) inside the sports hall is almost twice as high as the concentration of the PAH mixture in the surroundings of the hall. This applies both to PM_4- and TSP-bound PAHs. Particularly high contents of PAHs were found in the TSP fraction inside the sports hall (809.435 ng/m^3). The values of the concentrations of individual compounds from the group of TSP-bound PAHs in the indoor air of the hall were within the range of values from those values not exceeding the detection threshold (Na, Acnl, Acl) to the value 340 ng/m^3 (Flu). The concentrations of individual compounds from the group of TSP-bound PAHs in the outdoor air was as follows: from the detection limit (Na, Acnl, Acl) to 296 (Flu) ng/m^3. In the indoor air the concentration of individual PM_4-bound PAHs ranged from the detection limit (Na, Acnl, Acl) to 75 ng/m^3 (Flu) and outside from the detection limit (Na, Acnl, Acl) to 70 ng/m^3 (Flu).

Table 3 presents the individual compounds that had the largest contribution to the average ambient concentrations of PM4.0- and TSP-bound PAHs in the indoor and outdoor air. Similar PAH profiles in the indoor and outdoor air also indicate the infiltration of atmospheric air (by slots, open windows and doors) as the main source of PAHs inside the sports hall.

An important substance, due to its adverse health effects, is BaP, for which its PM_4-bound average concentration in the sampling period in the indoor air (12.668 ng/m^3) was two times higher than in the atmospheric air (6.929 ng/m^3). This result may indicate an internal source of this compound in the sport hall.

Table 3. The contribution of individual compounds to the average ambient concentrations of PM-bound PAH in indoor and outdoor air

Position	**Indoor**		**Outdoor**	
	PM_4	**TSP**	**PM_4**	**TSP**
1	Flu – 36%	Flu – 42%	Flu – 45%	Flu – 64%
2	Pir – 22%	Pir – 22%	Fl – 20%	Fl – 9%
3	Fl – 10%	Fl – 10%	BaA – 8%	Pir – 7%
4	BaP – 6%	Bbf – 8%	BBf – 6%	Bbf – 5%

The high concentration of PM-bound PAHs in the indoor air of the sports hall certainly causes high health risks especially for its users who train in this facility systematically. The level of exposure of persons actively using the analysed sports facility to hazards from the high PM and PAH concentrations can be expressed by indicators of the exposure such as CEQ, MEQ and TEQ [14]. Regardless of the PM fraction, these indicators were significantly higher for the mixture of PAHs in the indoor air (athletic hall) than in the atmospheric air (surroundings). Carcinogenic inhalation exposure to the PAH mixture

(CEQ) in the indoor air reached the values 40 ng/m^3 for the PM_4-bound PAH and 53 ng/m^3 for the TSP-bound PAH (Fig. 3.). These are values several or dozens of times higher than previously recorded in urbanized areas of Europe, including Polish cities [14]. Similar (high) values of the risk indicators were reached during studies in the indoor air of a sawmill in Biskupice (Zabrze; Upper Silesia Agglomeration) where the CEQ for the PM_4-bound PAHs ranged from 6.6 to 69 ng/m^3, MEQ: 6.5–61.39 ng/m^3, TEQ: 53.4–293 pg/m^3 and the CEQ for the TSP-bound PAH mixture, ranging from 41.5 ng/m^3 to 114.98 ng/m^3, MEQ: 32–61.4 ng/m^3, and TEQ: 138–293 pg/m^3 [16]. However, one must keep in mind that almost all activities performed in a sawmill are involved with dust emission and high concentrations of PM and PM-bound PAHs were to be expected; but sports facilities are designed for recreation and improving of one's physical condition, to which is associated the expectation of the appropriate quality of the air.

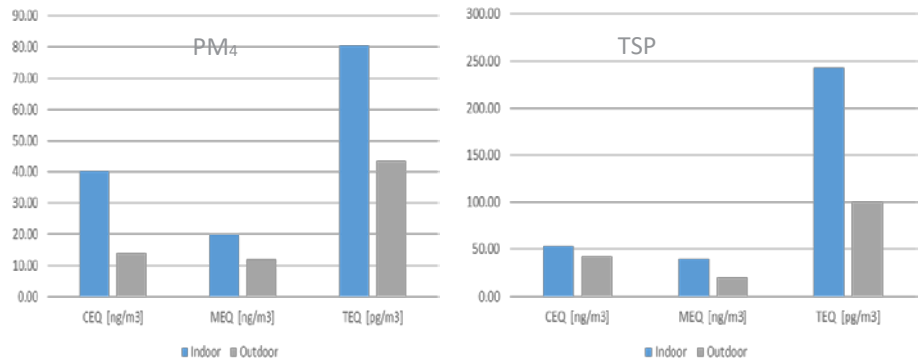

Fig. 3. Mean values of the risk indicators (CEQ, MEQ, TEQ) for PM_4-bound and TSP-bound PAH in indoor (athletic hall) and outdoor (atmospheric) air.

Other important parameters for the assessment of the exposure to PAH are the relations between the average ambient concentration of carcinogenic PAHs and the average mass concentration of the PAH mixture ($\sum PAH_{canc}/\sum PAH$). The average mass share of the sum of carcinogenic compounds in the average ambient concentration of PAH in the indoor air was 25% for PM_4-bound PAH and 20% for PM-bound PAH.

4 Conclusions

The main source of fine PM (PM_4) and PM-bound PAH in the sports hall was atmospheric air. However the poor air exchange in the hall and the related accumulation of PM_4 dust as well as the accumulation of PM-bound PAH resulted in the values of risk indicators for sports hall users as expressed by the selected indicators CEQ, MEQ, and TEQ, being almost twice as high as the values determined at the same time for atmospheric air. On the basis of the selected diagnostic ratios it can be assumed that the source of PM-bound PAHs both in the air of the sports hall and in its surroundings was the burning of fuels, viz. diesel and coal. It seems that the observed high concentrations of PM and PM-bound PAHs in the air of the sports hall are specific to the winter period, when in the vicinity of the hall many different sources of PM and PM-bound PAH emissions associated with the heating of homes and flats are active and in general the consumption of energy is intensified during this period. To draw more general conclusions about the exposure of users of the hall to PM-bound PAH, similar studies should be conducted during the non-heating season.

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