Environment Protection Engineering

Vol. 45 2019 No. 3

DOI: 10.5277/epe190307

KAROLINA KUSKOWSKA[1], WIOLETTA ROGULA-KOZŁOWSKA[1], KAMILA WIDZIEWICZ[2]

A PRELIMINARY STUDY OF THE CONCENTRATIONS AND MASS SIZE DISTRIBUTIONS OF PARTICULATE MATTER IN INDOOR SPORTS FACILITIES BEFORE AND DURING ATHLETE TRAINING

The mass size distribution of five fractions of particulate matter inside most popular types of closed sports facilities before and after athlete training were compared. In all the facilities, the concentrations of particles were higher during the training than before it. Their values depended on the type of flooring and cubic capacity of the rooms. Particle mass size distribution importantly affects the particle deposition rate in the respiratory tract. The results of the work indicate the necessity of further investigating the relations between the physical properties of particles and the effects of inhaling them during training in various sports facilities.

1. INTRODUCTION

Even short-term intense breathing air saturated with particulate matter (PM) is harmful – it can cause inflammation of the lower respiratory tract and raise the level of fibrinogen in blood [1, 2]. Particulate matter deposited in lungs can stimulate the formation of anionic hydroxyl radicals and superoxides, reactive oxygen compounds that can cause lung tissue necrosis by damaging lipids, proteins, or DNA in the cells. The chronic presence of these compounds in the lungs can cause pneumonia, pulmonary fibrosis, chronic obstructive pulmonary disease, and asthma [3, 4].

At the same elevated PM concentrations, the health hazard from PM to training athletes is greater than it is to people at rest. In intensively training humans, the greater oxygen demand enhances mouth breathing [5, 6] and, consequently, inhalation and then

[1]The Main School of Fire Service, ul. Słowackiego 52/54, 01-629 Warsaw, Poland, corresponding author K. Kuskowska, e-mail address: kkuskowska@sgsp.edu.pl

[2]Institute of Environmental Engineering, Polish Academy of Sciences, ul. Skłodowskiej-Curie 34, 41-819 Zabrze, Poland.

deposition of PM in the lower respiratory tract [1, 7]. The fine PM deposits in alveoli impair gas exchange between the lungs and blood [8, 9] and reduce the training effectiveness. Active athletes breath more intensively not only while doing exercise. Their general oxygen demands are greater and their respiratory minute volume can be even twenty times greater than the one in an average person [9, 10].

During the last two decades, the awareness greatly increased in the society of the role physical exercise plays in keeping the body in good physical shape and health. Various sports facilities have arisen, and both the new and old ones are now important elements of the local social infrastructure. The number of people visiting those facilities has been growing significantly. They spent there several hours several days a week. Being at strenuous effort, they are exposed to uncontrolled indoor PM concentrations.

The goal of the present work is to determine the mass size distribution of PM. This feature of PM is decisive for the efficiency of the PM deposition in the respiratory tract, in various kinds of closed sports facilities before and during athlete training. According to our knowledge, this is the first approach to comparing the indoor PM mass size distributions in such facilities before and during training.

2. MATERIALS AND METHODS

The concentrations of five PM fractions, PM_1, $PM_{2.5}$, PM_4, PM_{10}, and PM_{100}, were measured in 8 closed sports facilities: athletic gym, covered school gym, fitness room, fencing room, wrestling rooms 1, 2, and 3, and tennis court (under a bubble dome). The facilities differed greatly from each other in cubature, floor area, floor surface finish, ventilation, etc. (Table 1). In each facility, in March 2017 and in October 2017, 25 consecutive measurements of one-minute concentrations of each PM fraction were done both before and during athlete training. The concentrations were measured at about 1.5 m above the floor, not closer than 2 m to training people, each time at the same place inside. In this way, for each fraction, two 50-element sets of one-minute concentrations were received at each site: the fraction concentrations before and during training. The arithmetic means and standard deviations for all these PM concentration sets are presented in Table 2.

The PM concentrations were measured using a DustTrak 8534 DRX Aerosol Monitor, a sampler allowing simultaneous real-time measurements of mass concentrations of PM_1, $PM_{1–2.5}$, $PM_{2.5–4}$, $PM_{4–10}$, and $PM_{10–100}$ in the range of 0.001–150 mg/m^3. The sampler was calibrated systematically using a standardized dust sample (Arizona dust); zero calibration was performed using high-efficiency particle air filter before each measurement. The accuracy of the sampler was 5%. A more detailed description of the used measuring technique is available in [11].

The mass median aerodynamic diameter (MMAD) and the geometric standard deviation (GSD), two parameters characterizing the particle size distribution (PSD), were determined. If d_p denotes the diameter for which p% of the total mass of particles are smaller than d_p, then MMAD for a PSD is d_{50}. The GSD is computed as the ratio $d_{84.1}/d_{50} = d_{50}/d_{15.9}$ for unimodal PSDs and as square root of the ratio $d_{84.1}/d_{15.9}$ for bimodal PSDs [12, 13]. MMAD and GSD were calculated using regression lines from the log-probability graph of PM size versus cumulative mass distribution [12].

Table 1

Characteristics of sampling sites

Facility	Description[a]	Coordinates
Athletic gym	floor area of ca. 3665 m^2 divided into four sectors differing with surface coat: team games – synthetic surface, tracks for long and high jumps, pole vault – tartan, throwing – tartan, six-lane, 100 m long running tartan track ending with two pits for long jump, natural ventilation, stands for about 300 people on the mezzanine; PM concentrations measured before and after training of 16 volleyball players	52°17′11.13″ N 20°57′29.15″ E
School gym	floor area of ca. 600 m^2, wooden parquet; natural ventilation, stands for about 150 people on the mezzanine; PM concentrations were measured before and during gym classes of 25 and 28 pupils	52°16′18.45″ N 20°58′34.15″ E
Fitness room	floor area of ca. 80 m^2, synthetic floor, natural ventilation; PM concentrations measured before and during training of 6 and 5 students in March and October 2017, respectively	52°16′20.57″ N 20°58′43.34″ E
Fencing room	floor area of ca. 243,6 m^2, carpet-like floor covering, natural ventilation, PM concentrations measured before and during fencing training of 6 persons on wheelchairs	52°17′09.32″ N 20°57′2.92″ E
Wrestling room 1	floor area of ca. 176 m^2, floor covered with mats, natural ventilation; PM concentrations measured before and during the training of 11 wrestlers	52°17′09.32″ N 20°57′24.92″ E
Wrestling room 2	floor area of ca. 231 m^2, taekwondo mats on wooden parquet floor, natural ventilation; PM concentrations measured before and during the training of 8 wrestlers	52°17′09.32″ N 20°57′24.92″ E
Wrestling room 3	Floor area of ca. 46.8 m^2, martial art mats on wooden parquet floor, natural ventilation; PM concentrations were measured before and during the training of 10 wrestlers	52°17′09.32″ N 20°57′24.92″ E
Indoor tennis court	6 courts under bubble dome, floor area of ca. 5000 m^2, floor covered with brick powder; PM concentrations were measured before and during tennis training of 4 and 5 players	52°12′47.04″ N 20°57′44.82″ E

[a]All measurements were taken in March and October 2017.

Based on PM concentrations, the average 25-minutes inhaled doses of particles in the respiratory tract (RT) were calculated using the Eulerian multiple path particle dosimetry model (MPPD V2.11, ARA, Inc.).

Table 2

Concentrations of 9 PM fractions before and during training in 8 sport facilities [μg/m^3]

Sampling site	Status	PM_1	$PM_{1–2.5}$	$PM_{2.5}$	$PM_{2.5–4}$	PM_4	$PM_{4–10}$	PM_{10}	$PM_{10–100}$	PM_{100}	REPI[b] $PM_{2.5}$	REPI[b] PM_{10}
Athletic gym	before training	40.9±9.5	1.1±0.6	42.0±9.7	0.8±1.0	42.9±10.1	2.9±4.7	45.8±13.4	6.3±25.9	52.1±36.8	40.9	46.2
	during training (16)[a]	47.7±10.5	1.2±0.5	49.0±10.5	1.2±0.8	50.1±10.7	6.9±5.9	57.1±13.7	18.8±19.6	75.9±28.6	32.3	43.5
School gym	before training	39.2±30.3	0.8±0.7	39.9±30.6	0.8±0.6	40.7±30.5	3.3±3.5	44.1±30.0	4.7±9.3	48.8±30.3	51.5	64.5
	during training (25 or 28)[a]	53.8±46.3	1.4±1.5	55.3±47.1	1.6±3.3	56.8±48.1	8.2±13.3	65.1±53.0	19.7±23.6	84.8±62.6	41.6	52.1
Fitness room	before training	39.5±3.3	0.4±0.5	39.9±3.3	0.3±0.5	40.2±3.4	0.4±0.7	40.6±3.4	2.5±9.2	43.1±10.4	44.5	56.1
	during training (5 or 6)[a]	63.5±1.4	0.7±0.5	64.2±1.4	1.0±0.6	65.2±1.4	3.2±2.8	68.3±3.6	0.0±0.0	68.3±3.6	42.6	56.0
Fencing room	before training	40.5±15.2	0.9±0.4	41.4±15.2	0.9±0.7	42.3±15.1	3.6±3.8	45.9±15.1	7.6±18.0	53.4±23.5	45.2	53.1
	during training (6)[a]	60.5±24.2	1.7±0.7	62.2±24.3	3.2±1.5	65.4±24.4	17.2±9.9	82.6±27.1	39.5±34.2	122.1±50.3	43.4	51.7
Wrestling room 1	before training	42.1±18.8	0.8±0.5	42.9±18.9	0.8±0.6	43.7±19.1	2.8±2.9	46.6±19.8	3.1±9.3	49.6±20.9	46.0	53.1
	during training (11)[a]	46.9±37.3	1.6±1.7	48.5±38.7	2.6±2.7	51.1±40.9	12.3±13.8	63.4±52.4	51.3±74.0	114.7±117.8	42.6	51.0
Wrestling room 2	before training	41.5±18.3	0.9±0.4	42.4±18.4	0.9±0.6	43.3±18.5	2.5±2.9	45.8±18.8	2.9±9.3	48.6±20.2	45.1	54.7
	during training (8)[a]	54.1±16.4	1.4±0.8	55.5±16.5	2.5±1.7	58.0±16.8	13.2±10.0	71.5±21.5	71.2±62.3	142.3±76.5	43.7	52.1
Wrestling room 3	before training	65.6±2.8	0.3±0.5	65.8±2.8	0.9±0.7	66.7±3.0	2.0±2.3	68.7±4.0	2.1±5.7	70.7±8.6	29.1	76.7
	during training (10)[a]	139.0±49.3	4.3±0.8	143.3±49.6	8.4±1.9	151.7±50.5	58.1±21.1	209.7±66.9	298.7±131.1	508.4±189.0	28.9	44.1
Indoor tennis court	before training	54.6±8.6	2.4±2.4	57.0±10.6	4.4±4.5	61.4±14.5	14.5±12.6	75.9±25.8	6.6±10.3	82.5±27.3	32.4	64.1
	during training (4 or 5)[a]	54.5±16.4	1.6±1.9	56.1±17.2	2.7±3.2	58.8±19.1	12.6±13.4	71.4±30.6	14.9±25.5	86.3±50.4	33.8	65.2

[a]Number of persons exercising during PM measurement.

[b]Arithmetic means from 50 one-min concentrations (Warsaw center, Regional Environmental Protection Inspectorate automated station, one-min optical measurements)

The deposited mass of PM was calculated for one breathing cycle including only inspiration (without expiration). The deposition was calculated using adults-specific symmetric lung model. The following exposure scenario was considered: upright body orientation, nasal breathing under conditions of normal physiological activity and oral breathing under conditions of training, 14 breaths/min before training and 28 breaths/min during training [13].

3. RESULTS AND DISCUSSION

In each facility, except Tennis Court, the concentrations of all the PM fractions were higher during the training than before it (Table 2). Especially high they were during training in wrestling rooms 1, 2, and 3, reaching 114.7, 142.3, and 508.4 μg/m^3, respectively, for PM_{100}. All these indoor concentrations strongly depended on how effectively the indoor activities stirred up and maintained particles airborne, but even stronger on the type of the flooring [14, 15]. The floor in wrestling rooms was padded with foam mattresses, what made it harder to clean than the floors in the other facilities because of slits between the mattresses from where the accumulated dust was easily stirred up during training. The equally obvious factor that significantly affects indoor PM concentrations was building ventilation [16, 17]. There was natural ventilation in all the facilities, but they were also aired by the frequent opening of windows (during training, too). The facilities differed in numbers of windows. The most numerous windows were in the athletic gym, less numerous in the school and fitness gyms, and least numerous in wrestling rooms situated in a basement. In the wrestling room 3, 10 persons could exercise by only one narrow window opened, while 4 windows could be opened when 5 persons exercised in the fitness gym.

The number of simultaneously training persons during sampling, different in various facilities (Table 2), does not seem to have affected the PM concentrations so significantly as the type of exercise, floor finish, ventilation, and the cubic capacity of the rooms. Wrestling rooms where the PM concentrations were highest were smallest, they were only about 2.2 m high. In the wrestling room 3, the PM concentrations (even those of PM_1) exceeded 60 μg/m^3 before training and the PM_{100} concentrations reached almost 500 μg/m^3 during training. The training on the tennis court did not affect the PM concentrations under the dome much, moreover, packing the court surface with clay powder before a training caused sometimes higher PM concentrations than the training itself.

The rapidity of movements of exercising people caused rapid changes in all the PM fraction concentrations in all the facilities, but the concentrations of the coarser fractions ($PM_{4–10}$, $PM_{10–100}$) varied more dynamically during training than those of the fine ones (PM_1, $PM_{1–2.5}$). The greatest standard deviations were computed for the $PM_{10–100}$ one-minute concentrations occurring during training in the wrestling rooms 2 and 3. However, the greater health hazard arises from the high one-minute PM_1 concentrations

($PM_{2.5}$ and PM_4, too) because of the enhanced oxygen demands and breath intensity in exercising people [6].

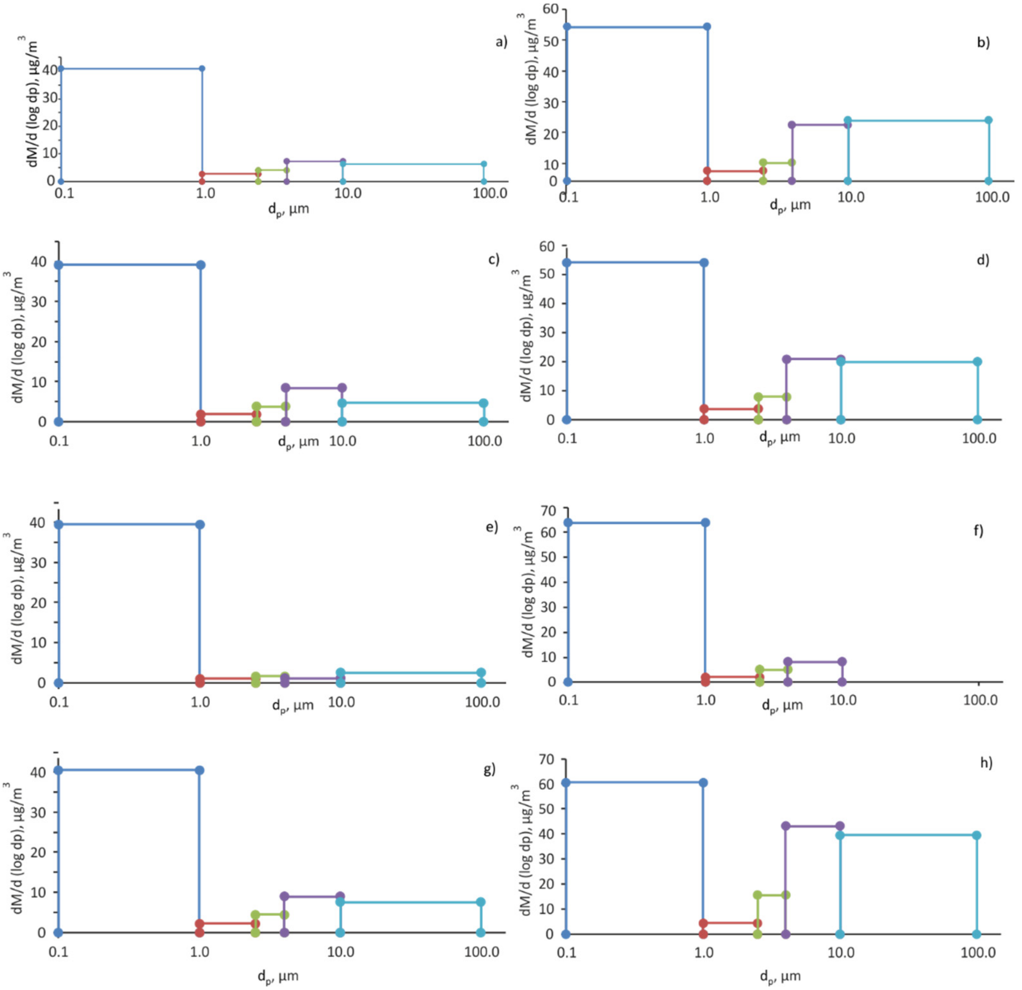

Fig. 1. PM mass size distribution in some sports facilities before and during training:
a) athletic gym before training, b) athletic gym during training, c) school gym before training,
d) school gym during training, e) fitness room before training, f) fitness room during training,
g) fencing room before training, h) fencing room during training

The PM concentrations in the athletic gym before training were comparable with and during training a little higher than the outdoor $PM_{2.5}$ and PM_{10} concentrations at the Warsaw center. In the school gym, fitness room, fencing room, wrestling rooms 1 and 2, they were lower before and higher during training than those at the Warsaw center. In the wrestling room 3, the PM_{10} concentrations were lower than those at the Warsaw center before and higher during training, and the $PM_{2.5}$ concentrations were higher both before and during training (Table 2).

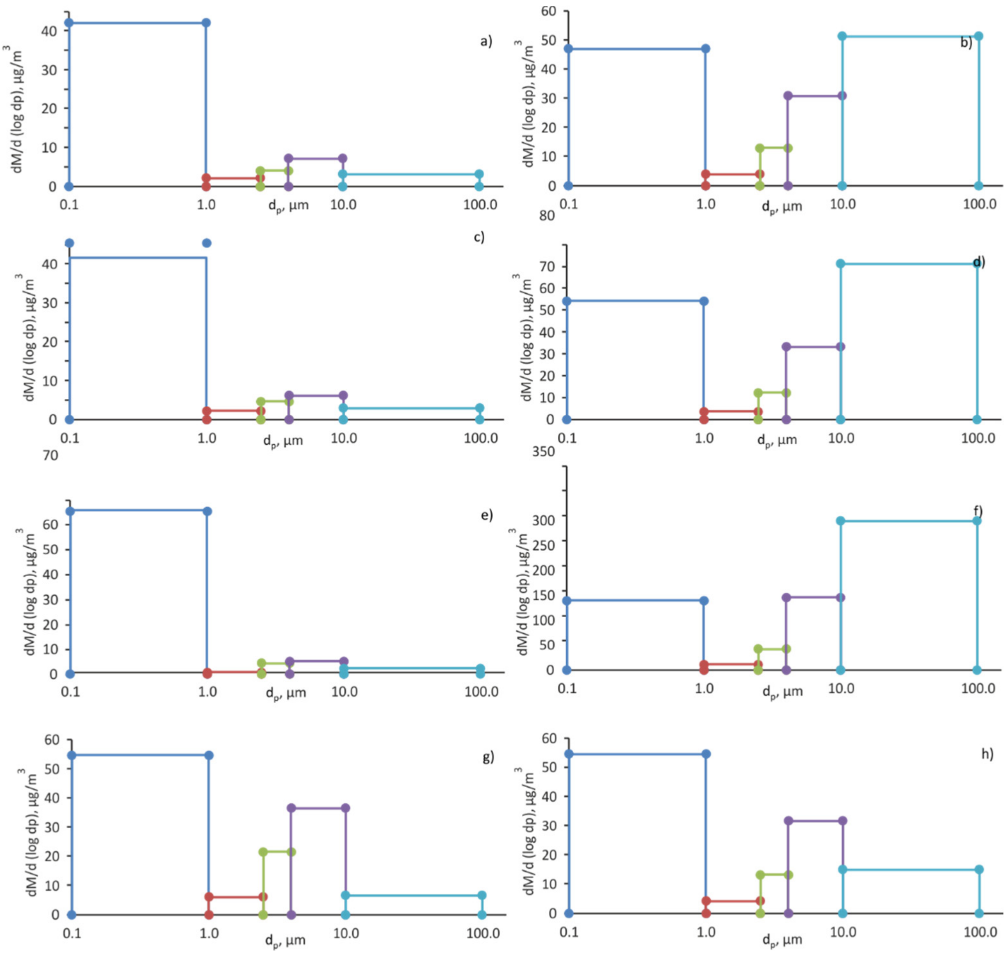

Fig. 2. PM mass size distribution in some sports facilities before and during training: a) wrestling room 1 before training, b) wrestling room 1 during training c) wrestling room 2 before training, d) wrestling room 2 during training e) wrestling room 3 before training, f) wrestling room 3 during training g) indoor tennis court before training, h) indoor tennis court during training

The PM_1 and $PM_{2.5}$ concentrations during training in all the sports facilities were high compared to indoor PM concentrations of these PM fractions in some teaching rooms at Warsaw universities [18].

Although the measurement methods applied at the station at the Warsaw center and in the teaching rooms differed from those applied in this study, although the distances between the station and the facilities differed, and although a university teaching room is hardly comparable to a closed sport facility hall, the data in Table 2 can give some view on how the intense human activity in closed sport objects affects the indoor air quality. The health hazard from indoor PM that is stirred up by exercising people in closed sports facilities proves to be high.

The PM mass size distributions before training were similar in all the facilities and they differed extremely during training (Figs. 1, 2). In all the facilities, the indoor PM mass size distributions before training were the same as the outdoor ones (the effect of natural ventilation). All the before-training PM distributions were bimodal and their MMADs were between 0.89–2.21 µm. Their smaller modes were between 0.1–1.0 µm and the greater ones between 2.5–10 µm; the indoor PM mass size distributions resembled the distributions in atmospheric air in Polish urban areas [19, 20]. Later, during training, the different indoor conditions caused different indoor PM mass size distributions [21]. The physical activity of exercising people caused resuspension of settled down coarser PM, what changed the PM distributions, therefore their MMADs and GSDs, too (Table 3).

Table 3

Mass median aerodynamic diameter (MMAD) and geometric standard deviation (GSD) of particle mass size distributions (PSD) in examined sports facilities

Facility	Before training		During training	
	MMAD	GSD	MMAD	GSD
Athletic gym	1.45	8.97	3.06	12.54
School gym	1.36	8.44	2.92	11.83
Fitness room	0.9	8.11	0.89	7.03
Fencing room	1.65	9.4	1.45	8.97
Wrestling room 1	1.16	7.88	15.06	28.4
Wrestling room 2	1.13	7.81	24.4	41.47
Wrestling room 3	0.89	7.57	98.29	82.21
Indoor tennis court	2.21	7.32	2.76	9.48

The PM mass size distributions during training were bimodal, too. Their MMADs were between 0.89 and 82.21 µm and, except for the fitness and fencing rooms, they were greater for the PM distributions during training than before it. The maxima of the density functions at the greater modes were greater than at the smaller ones, the smaller mode for the fencing room was between 0.1 and 1.0 µm and the greater one was between 10 and 100 µm. In the wrestling rooms, the PM mass size distributions are typical of resuspended PM [22, 23].

Particulate matter mass size distributions changed during training in the tennis court, fitness and fencing rooms the least and in the wrestling rooms the most (Figs. 1, 2, Table 3). These changes reflect the differences between PM deposition in RT of athletes before and during training, in total RT (Fig. 3).

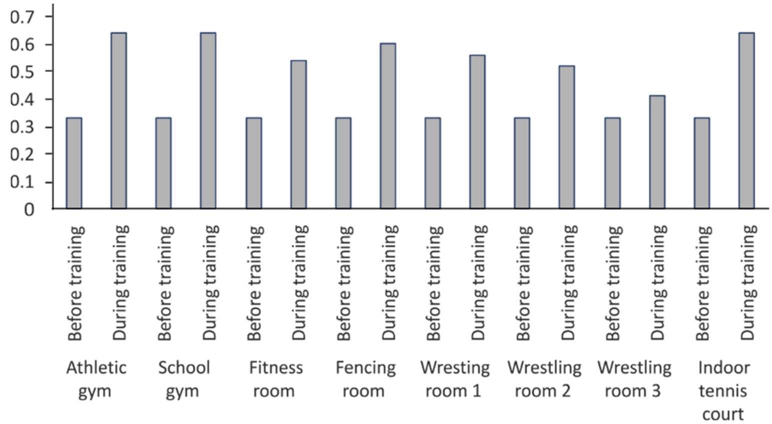

Fig. 3. PM deposition coefficients in the respiratory tract of users of selected sports facilities, including periods before and during training

In almost all sports facilities, the mass of dust deposited in the airways was at least two times higher during physical exertion than before it. Most probably, these changes themselves cause an increase in the deposition of PM in the upper respiratory tract [6, 24]. The greater maxima of the density functions in the diameter interval 0.1 to 1.0 μm during training suggest that more PM reach the deeper parts of RT during than before training, also because the frequency and depth of the breath of exercising people are greater than those of the breath in normal circumstances [25].

4. CONCLUSION

The presented results only signal the necessity of addressing the problem of air pollution in sports facilities. Using a sampler measuring only 5 PM size fractions, we have shown that the PM mass size distributions before and during training differ and that they also differ among various facilities (types of exercise). A more comprehensive approach would need more advanced equipment and cover wider spectrum of sports activities and training conditions (e.g., the numbers of exercising people, here not differing much but seaming to matter). Although much more advanced study is needed to properly predict the health effects of PM inhalation in sports facilities, the presented study shows that rather adverse ones should be expected.

REFERENCES

[1] ABELSOHN A., STIEB D.M., *Health effects of outdoor air pollution. Approach to counseling patients using the air quality health index*, Can. Fam. Phys., 2011, 57, 881.

[2] KI-HYUN K., EHSANUL K., SHAMIN K., *A rewiew on the human health impact of airborne particulate matter*, Environ. Int., 2015, 74, 136.

[3] DE KOK T.M.C.M., DRIECE H.A.L., HOGERVORST J.G.F., BRIEDÉ J.J., *Toxicological assessment of ambient and traffic-related particulate matter: A review of recent studies*, Mutat. Res., 2006, 613, 103.

[4] RAASCHOU-NIELSEN O., *Particulate matter air pollution components and risk for lung cancer*, Environ. Int., 2016, 87, 66.

[5] CAKMAK S., DALES R., LEECH J., LIU L., *The influence of air pollution on cardiovascular and pulmonary function and exercise capacity: Canadian Health Measures Survey (CHMS)*, Environ. Res., 2011, 111, 1309.

[6] SRACIC M.K., *Modeled regional airway deposition of inhaled particles in athletes at exertion*, J. Aerosol Sci., 2016, 99, 54.

[7] LIPPI G., GUIDI G.C., MAFFULLI N., *Air pollution and sports performance in Beijing*, Int. J. Sports Med., 2008, 29, 696.

[8] RUNDELL K.W., CAVISTON R., *Ultrafine and fine particulate matter inhalation decreases exercise performance in healthy subjects*, J. Strength Cond. Res., 2008, 22, 2.

[9] CUTRUFELLO P.T., SMOLIGA J.M., RUNDELL K.W., *Small things make a big difference: particulate matter and exercise*, Sports Med., 2012, 42, 1041.

[10] PHALEN R.F., *Inhalation studies: Foundations and techniques*, Informa Healthcare, New York 2009.

[11] WANG X.L., CHANCELLOR G., EVENSTAD J., FARNSWORTH J.E., HASE A., OLSON G.M., SREENATH A., AGARWAL J.K., *A novel optical instrument for estimating size segregated aerosol mass concentration in real time*, Aerosol Sci. Technol., 2009, 43, 939.

[12] HINDS W.C., *Aerosol technology. Properties, behavior, and measurement of airborne particles*, 2nd Ed., Wiley, New York 1998.

[13] NAG S., GUPTA A.K., MUKHOPADHYAY U.K., *Size distribution of atmospheric aerosols in Kolkata, India and the assessment of pulmonary deposition of particle mass*. Indoor Built. Environ., 2005, 14(5), 381.

[14] CHENG K., GOEBES M.D., HILDEMANN L.M., *Association of size-resolved airborne particles with foot traffic inside a carpeted hallway*, Atmos. Environ., 2010, 44, 2062.

[15] NASIR Z.A., COLBECK I., ZULFIQAR A., SHAKIL A., *Indoor particulate matter in developing countries: A case study in Pakistan and potential intervention strategies*, Environ. Res. Lett., 2013, 8, 1.

[16] DIMITROULOPOULOU C., *Ventilation in European dwellings: A review*, Build. Environ., 2012, 47, 109.

[17] WIDDER S.H., HASELBACH L., *Relationship among concentrations of indoor air contaminants, their sources, and different mitigation strategies on indoor air quality*, Sustainability, 2017, 9 (7), 1149.

[18] ROGULA-KOZŁOWSKA W., KOZIELSKA B., MAJEWSKI G., KOCIESZEWSKA K., *Submicron particle-bound polycyclic aromatic hydrocarbons in the Polish teaching rooms: concentrations, origin and health hazard*, J. Environ. Sci., 2018, 64, 235.

[19] ROGULA-KOZŁOWSKA W., *Size-segregated urban particulate matter: mass closure, chemical composition, and primary and secondary matter content*, Air Qual. Atm. Health, 2016, 9 (5), 533.

[20] WIDZIEWICZ K., ROGULA-KOZŁOWSKA W., *Urban environment as a factor modulating metals deposition in the respiratory track and associated cancer risk*, Atm. Poll. Res., 2018, 9 (3), 399.

[21] GUO M., LYU Y., XU T., YAO B., SONG W., LI M., YANG X., CHENG T., LI X., *Particle size distribution and respiratory deposition estimates of airborne perfluoroalkyl acids during the haze period in the megacity of Shanghai*, Environ. Poll., 2018, 234, 9.

[22] ALVES C.A., CALVO A.I., CASTRO A., FRAILE R., EVTYUGINA M., BATE-EPEY E.F., *Air quality in sports venues with distinct characteristics*, Int. J. Environ. Chem. Ecol. Geol. Geophys. Eng., 2013, 7, 298.

[23] RAMOS C.A., WOLTERBEEK H.T., ALMEIDA S.M., *Exposure to indoor air pollutants during physical activity in fitness centers*, Build. Environ., 2014, 82, 349.

[24] BEZEMER G., *Particle deposition clearance from respiratory tract*, Institute for Risk Assessment Sciences, Utrecht 2009.

[25] WHO, *Health effects of particulate matter. Policy implications for countries in eastern Europe, Caucasus and central Asia*, Copenhagen 2013.