Monitoring of Indoor Ultrafine Particulate Matter at the Sites of the Czech Armed Forces

Eva KELLNEROVÁ[1], Zbyněk VEČEŘA[2], Josef KELLNER[1], Tomáš ZEMAN[1]

[1] Department of Emergency Management, Faculty of Military Leadership, University of Defence, Kounicova 65, 662 10 Brno, Czech Republic; email: kellnerova.eva@seznam.cz, josef.kellner@unob.cz, tomas.zeman2@unob.cz
[2] Department of Environmental Analytical Chemistry, Institute of Analytical Chemistry CAS, Veveří 967/97, 602 00 Brno, Czech Republic; email: vecera@iach.cz

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Abstract

Ultrafine particles and nanoparticles in the air are evaluated as a risk factor for the development of respiratory and other health symptoms due to their inhalation from the ambient air. The Czech Army professionals are expected to have frequent presence in a polluted environment and regular exposure to air with increased concentration of airborne pollutants. The report evaluates the presence of ultra-fine particles (in the range of about 7.6–299.6 nm) in rooms often used by soldiers during their working hours when they are not deployed. The purpose is to assess whether the presence of troops in these workplaces is safe and does not pose a risk of adverse health effects in itself. Testing took place in three military rooms (classroom 1, classroom 2 and exercise flight simulator room). Seven samples of air were analysed in time by the scanning mobility particle sizer in succession. Mean particle concentrations were found at 1.79×10^4, 7.53×10^3 and 8.39×10^3 $N\cdot cm^{-3}$ for the classroom 1, classroom 2 and exercise flight simulator room. Conclusions of the research have shown that particle concentrations in the places of the Czech Army can reach values that border the immission limits stated by the World Health Organisation.

Keywords: ultrafine particle, indoor air, air quality, health risk

Introduction

Some pollutants are naturally occurring since time immemorial, and their amount is usually increased by human activity. This type of pollutants also includes ultrafine particles (UFP) of less than 100 nm (Viana et al., 2015), which are released into the atmosphere mainly by various types of combustion, transport, industrial activity, etc.

Health Risks from Inhalation of Ultrafine Particles

Particle size is critical for nanoparticle penetration and deposition in the respiratory tract. The finest submicrometric fraction of the particles passes through the lungs (Ministry of the Environment, 2015). Nanoparticles, especially those smaller than 30 nm, cause oxidative stress and are the most dangerous form of air pollution. The surface properties of nanoparticles, including their surface charge, play an important role in this process because UFP exhibit high activity in the lungs (Večeřa et al., 2012).

Immission Limits of Ultrafine Particles in the Air

Nanoparticles in the air are referred to as so-called particulate matter (PM). For example, the World Health Organization (WHO) recommends that a quantity of nanoparticles smaller than 2.5 μm (PM2.5) in the atmosphere is at a maximum level of 10 $\mu g.m^{-3}$ per year and not more than 25 $\mu g.m^{-3}$ per 24 hours (WHO, 2005). In the Czech Republic, air quality is assessed on the basis of requirements of Act No. 201/2012 Collections, on air protection. Here is a requirement for a maximum permissible PM2.5 limit of 20 $\mu g.m^{-3}$ per year (Czech Republic, 2012).

Air Quality Inside Buildings of Military Departments

UFP exposures inside buildings are often divided into two parts that differ significantly in composition, time regime and their relation to patterns of human activity in time. The first part refers to particles from outside air that can significantly affect PM levels inside buildings and transport-related microenvironments. The second part refers to particles from internal sources that have the potential to generate very high levels of PM that do not correlate with external levels of particles on a temporary basis (McAuley et al., 2010; Morawska et al., 2013).

Czech Armed Forces (CAF) belong among the components of the Integrated Rescue System, whose personnel is at risk of higher UFP loads from the air. In military environments, air pollution is often caused by using combat techniques and weapons, combat vehicles, guns, and a number of special weapons and military equipment in field conditions. In these activities, a large amount of airborne particles is released (Nindl et al., 2013).

The state of health protective equipment used against inhalation of pollutants and the safety and protection of soldiers' health is a topic closely monitored. In particular, efforts are made to avoid excessive pollution by air pollutants even in situations where these persons do not directly participate in their own field activities. The aim of this paper is to propose a comprehensive image of the burden of selected interior spaces of military buildings with ultra-fine particles in the range of 7.6–299.6 nm. On the basis of these data, it will be possible to assess whether the presence of exposed professionals in these workplaces is safe and does not in itself pose a risk of adverse health effects.

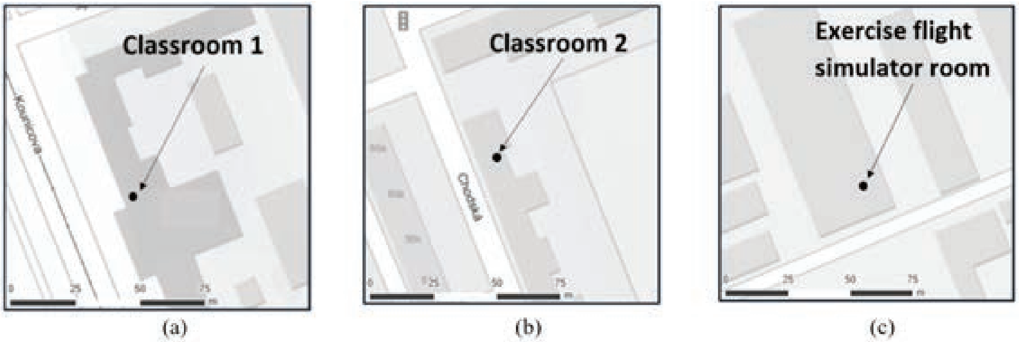


Fig. 1. Illustration of the sampling places in the examined buildings: (a) classroom 1, (b) classroom 2, (c) flight simulator room (source: own)
Rys. 1. Miejsca pobierania próbek w badanych budynkach: (a) klasa 1, (b) klasa 2, (c) sala symulatora lotu (źródło: własne)

Methods

The methods used for the evaluation of selected indicators were introduced at the Institute of Analytical Chemistry of the Academy of Sciences of the Czech Republic. The numerical concentrations of UFP aerosol particles were measured in the interior of the three rooms of military departments (classroom 1, classroom 2 and exercise flight simulator room). All buildings are located in the suburban part of Brno (Czech Republic). The scanning mobility particle sizer (SMPS, model 3936L72, TSI) was used to measure the particle size ranged from 7.6 nm to 299.6 nm. In all cases, measurements were made in empty room oriented to a high-traffic street. Seven samples of air were immediately analysed in succession (one sample time was approximately 5 minutes, so the total measurement time in one school was approximately 35 minutes). All doors and windows in rooms were closed during the measurement. Illustrations of measured rooms are in the Figure 1.

Experimental Part

Because research studies suggest (McAuley et al., 2010) that sources of nanoparticles from the external environment (in the first instance the traffic situation) have a great influence on the concentrations inside the adjacent buildings, the characteristics of the nearest UFP sources from heavy traffic are given in the Table 1. For this purpose, dimensionless coefficient K was calculated, where a is the traffic intensity of the nearest thoroughfare [number of vehicles per day], e is Euler's number and x is the distance of the nearest frequent thoroughfare [in 100 m]:

$$K = \frac{a}{e^x}$$

Description of Meteorological Conditions at the Time of Measurement

The highest values of pollutant concentrations are usually achieved during unfavorable dispersion conditions outside the transport sites (Ministry of Environment, 2015; Morawska et al., 2013). For each room investigated, the values of the basic meteorological indicators that were reported in Brno at the time of the measurements were subsequently surveyed in the archive (see Table 2).

Statistical Evaluation of Results

To evaluate the signal from the SMPS, Aerosol Instrument Manager (TSI, 2010) was used to calculate the particle size distribution by dividing the particle size range into 64 identical channels. In addition, the total number of particles C_N [N·cm^{-3}] was calculated, where n is the total number of channels and C_i [N·cm^{-3}] is the number of particles in the i-th channel:

$$C_N = \sum_{i=1}^{n} C_i$$

The total particle volume V [nm^3·cm^{-3}], where Ri is the radius of the particles measured in the i-channel was then estimated.

$$V = \frac{4}{3}\pi \sum_{i=1}^{n} R_i^3 C_i$$

Furthermore, on the basis of measured data, approximate total mass concentration of particles C_M [μg·m^{-3}] according was estimated. In this equation, ρ stands for average:

$$C_M = V\rho$$

The corresponding value of particle density ρ = 1.5 g·cm-3 to urban aerosol from various studies was used (Zhao, et al., 2016).

Results

The measured results are presented in Table 3 that summarizes the main data and statistical calculations of measured UFP in the examined rooms. The highest particle volume was measured in the exercise flight simulator room (7.93·109 nm³·cm^{-3}). The particle volume acquired in military classroom 2 and classroom 1 was 2.22·109 and 3.98·109 nm³·cm^{-3}.

Acquired results show different values of the nanoparticles in the monitored spaces within the distinct sites of the Czech Armed Forces. At the CAF classroom 1, the average concentration was detected at 1.79×10⁴ N·cm^{-3}, which corresponds to the average weight of the nanoparticles at the level of 5.97 μg·m^{-3} of air. Mean particle diameter of nanoparticles was at the size of about 36.61 nm as the lowest observed diameter within the tested rooms.

In the classroom 2, the average nanoparticle concentration measured was 7.53×10³ N·cm^{-3}, which corresponds to the average weight of nanoparticles at the level of 3.32 μg·m^{-3}. Mean particle diameter of nanoparticles was at the mean size of 41.97 nm.

In the exercise flight simulator room, the average nanoparticle concentration measured was 8.39×10³ N·cm^{-3},

Tab. 1. Characteristics of investigated CAF rooms during air sampling (source: own) [Note: SE – southeast; NW – northwest; N – north; *) RNDr. Jiří Huzlík, PhD. Transport Centre in Brno [interview], 2012; **)Traffic Slope 2016 – Transport Research Centre, 2016]

Tab. 1. Charakterystyka badanych pomieszczeń CAF podczas próbkowania powietrza (źródło: własne) [Uwaga: SE – południowy wschód; NW – północny zachód; N – północ; *) RNDr. Jiří Hužlík, PhD. Transport Center w Brnie [wywiad], 2012; **) Nachylenie ruchu 2016 – Centrum Badań Transportu, 2016]

Tested rooms	Description of the sampling place	Usual activities performed inside the tested rooms	Description of the building	Distance, location and traffic intensity of the nearest known thoroughfare	K
Classroom 1	Room on the 1st floor, with the size about 50 m^2, unventilated	Theoretical teaching of military students	Five floor Public Military School, built in 1936–1937	260 m, SE, 17 000 vehicles per day in average *)	1262.65
Classroom 2	Room on the 2nd floor, with the size approximately 50 m^2	Theoretical teaching of military students	Three floor Public Barracks, built in 1904	805 m, NW, 30 066 vehicles per day in average **)	9.59
Exercise flight simulator room	Hall on the ground floor, with the size approximately 200 m^2	Practical training of military students in handling with military aircraft technology	Two floor Public Barracks, built in 1927	560 m, N, 45 682 vehicles per day in average **)	168.93

Tab. 2. The values of the basic meteorological indicators recorded in Brno at the time of measurement at the monitored sites of CAF (source: Meteocentrum.cz, 2018) [Note: T_{atm} – air temperature, T_{dp} – dew point temperature, P_{atm} – atmospheric pressure, w – wind speed, PWD – prevailing wind direction, N – north, E – east, NE – northeast]

Tab. 2. Wartości podstawowych wskaźników meteorologicznych zarejestrowanych w Brnie w czasie pomiaru w monitorowanych miejscach CAF (źródło: Meteocentrum.cz, 2018) [Uwaga: T_{atm} – temperatura powietrza, T_{dp} – temperatura punktu rosy, P_{atm} – atmosfera ciśnienie, w – prędkość wiatru, PWD – dominujący kierunek wiatru, N – północ, E – wschód, NE – północny wschód]

	Date and time	T_{atm} [°C]	T_{dp} [°C]	P_{atm} [hPa]	w [$km \cdot h^{-1}$]	PWD
Classroom 1	18.1.2018 10:00	-1	-4	1008	7	N
Classroom 2	18.1.2018 9:00	-1	-3	1008	9	NE
Flight sim. room	25.1.2018 8:30	-1	-2	1024	11	E

Tab. 3. Acquired concentrations of particles (source: own) [Note: NA – not measured]

Tab. 3. Stężenia cząstek (źródło: własne) [Uwaga: NA – nie mierzone]

Ci [$N \cdot cm^{-3}$] / Mi [$\mu g \cdot m^{-3}$]	Flight simulator room	Classroom 2	Classroom 1
1. measure	7029.74 / 11.91	6064.23 / 3.15	16400.62 / 5.78
2. measure	8053.28 / 11.89	6186.8 / 3.18	16054.02 / 5.78
3. measure	8499.84 / 11.79	6575.07 / 3.24	17356.14 / 5.87
4. measure	8750.78 / 11.91	7626.17 / 3.34	17825.85 / 6.10
5. measure	8982.19 / 12.00	8348.68 / 3.37	19123.94 / 6.01
6. measure	8812.34 / 12.00	8546.88 / 3.50	20484.68 / 6.26
7. measure	8621.25 / 11.76	9393.46 / 3.48	NA
C_N [$N \cdot cm^{-3}$] / C_M [$\mu g \cdot m^{-3}$]	8392.77 / 11.89	7534.48 / 3.32	17874.21 / 5.97
Average std. deviation [%]	30.77	46.19	128.54
V [$nm^3 \cdot cm^{-3}$]	$7.93 \cdot 10^9$	$2.22 \cdot 10^9$	$3.98 \cdot 10^9$

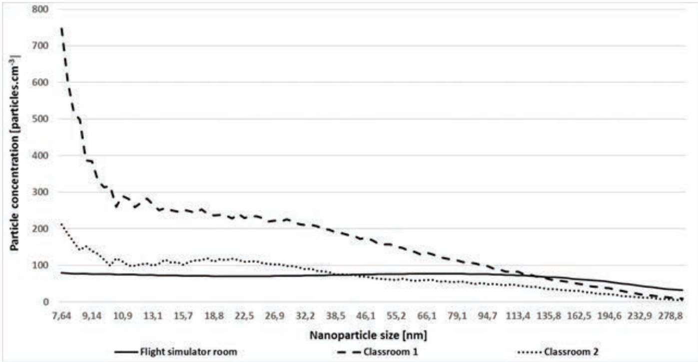
which corresponds to the average weight of nanoparticles at the level 11.89 $\mu g \cdot m^{-3}$. This is probably because there was a higher number of larger particles with the mean diameter about 100 nm. Mean particle diameter of nanoparticles was at the size of about 70.01 nm.

Discussion

Due to easy permeability of UFP smaller than 30 nm through respiratory tract, they may increase health risks more easily in comparison with other tested rooms (Večeřa et al., 2012). Highest levels of such particles were found in the classroom 1. However, amount of particulate matter in the air of flight simulator room (11.89 $\mu g \cdot m^{-3}$) exceeded the limit recommended by the WHO (maximum annual mean of $PM_{2.5}$ on the level of 10 $\mu g \cdot m^{-3}$). In the case that in the air of the flight simulator room are achieved similar values of UFP particles regularly, long-term inhalation of such air may pose a health risk (WHO, 2005). Figure 2 shows mean C_i values of performed measurements ordered by their size for tested rooms.

Acquired data are in accordance with the calculated coefficient K, which was the highest in the classroom 1 (1262.65), suggesting that frequent traffic in the nearest surroundings contributes to high number concentrations of ultrafine particles in classroom 1. Regarding research studies focused on the traffic as the main source of nanoparticles with sizes lower than 100 nm (Gong et al., 2009), our results indicate that the main source of UFP in classroom 1 is related to the frequent traffic (number of particles increased with the decreasing size of particles in general). In the classroom 2 and

Fig. 2. The concentration of nanoparticles in the tested military rooms (source: own)
Rys. 2. Stężenie nanocząstek w badanych pomieszczeniach wojskowych (źródło: własne)



exercise flight simulator room, with the coefficients K 9.59 and 168.93 respectively, the traffic was the probably source of nanoparticles to a lesser extent.

Conclusion

The paper monitored the presence of UFP in the size range from 7.6–299.6 nm in rooms often used by troops of the Czech Armed Forces (classroom 1, classroom 2 and exercise flight simulator room). The general characteristics (average particle count, mean standard deviation, corresponding mass and size distribution) were evaluated and consequently statistically evaluated (mean particle diameter, total particle number and mass concentration, particle surface, specific surface area and particle volume). Average particle counts of 1.79×10^4, 7.53×10^3 and 8.39×10^3 $N\cdot cm^{-3}$ were determined for the classroom 1, classroom 2 and exercise flight simulator room. This concentrations correspond to the mean particle weight of 5.97, 3.32 and 11.89 $\mu g\cdot m^{-3}$ for the classroom 1, classroom 2 and exercise flight simulator room. The concentration found in flight simulator room border with the immission limit stated by the WHO (maximum annual mean of $PM_{2.5}$ particles is recommended to be lower than 10 $\mu g.m^{-3}$). Such concentrations may pose a health risk when inhaled for a long time. However, the measured range did not include other particle sizes than 7.6–299.6 nm. Therefore, it is possible to expect that the number of particles smaller than 2.5 μm was higher than we found. Moreover, duration of our measurements was 35 minutes and UFP at the annual horizon is unknown. Expert studies focused on the occupational health symptoms of troops highlighted that military staff should increase the use of breathing masks in all hazardous situations as much as possible (Nindl et al., 2013).

Acknowledgements

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Monitorowanie ultradrobnych cząstek w pomieszczeniach na terenach czeskich sił zbrojnych

Najdrobniejsze cząstki i nanocząsteczki w powietrzu są oceniane jako czynnik ryzyka dla dróg oddechowych i innych objawów zdrowotnych spowodowanych ich wdychaniem z otaczającego powietrza. Oczekuje się, że specjaliści z czeskiej armii będą często obecni w zanieczyszczonym środowisku i będą regularnie narażeni na kontakt z powietrzem o zwiększonej koncentracji zanieczyszczeń. Raport ocenia obecność ultradrobnych cząstek (w zakresie około 7,6–299,6 nm) w pomieszczeniach często używanych przez żołnierzy w godzinach pracy. Celem jest ocena, czy obecność wojsk w tych miejscach pracy jest bezpieczna i sama w sobie nie stwarza ryzyka negatywnych skutków zdrowotnych. Testowanie odbyło się w trzech pomieszczeniach wojskowych (sala 1, sala 2 i sala do ćwiczeń). Siedem próbek powietrza analizowano w czasie przez separator cząstek. Stwierdzone średnie stężenia cząstek 1,79 × 104, 7,53 × 103 i 8,39 × 103 [N · cm^{-3}] w sali lekcyjnej 1, klasie 2 i sali do ćwiczeń. Wnioski z badań wykazały, że stężenia cząstek w wybranych pomieszczeniach czeskiej armii mogą osiągnąć wartości graniczące z limitami imisji podanymi przez Światową Organizację Zdrowia.

Słowa kluczowe: ultradrobne cząstka, powietrze w pomieszczeniach, jakość powietrza, ryzyko dla zdrowia