Original scientific article

The impact of ultrafine particles on daily counts of deaths from respiratory diseases in the Municipality of Ljubljana: A temporal variability study

Natalija **KRANJEC**[1], An **GALIČIČ**[1], Ivan **ERŽEN**[1,2], Andreja **KUKEC**[1,2*]

ABSTRACT

Ultrafine particles are outdoor air pollutants, the exposure to which is associated with morbidity and mortality for respiratory and cardiovascular diseases. The purpose of this study is to assess the temporal variability of ultrafine particle number concentrations in outdoor air and daily counts of deaths from respiratory diseases. Epidemiological ecological temporal variability study lasted 731 days. The observed population included residents of the Municipality of Ljubljana, who died of respiratory diseases in the observed period. Descriptive statistics was implemented. The highest daily counts of deaths from respiratory diseases in 2012 were in the periods February-April, May-June, and October. The next periods with the highest daily counts of deaths from respiratory diseases repeated again in the periods December 2012-April 2013, May-July 2013, and October 2013. These periods coincide with the periods of increased levels of ultrafine particle number concentrations. We concluded that there was a temporal variability association between the periods with higher daily counts of deaths from respiratory diseases and heightened levels, of ultrafine particle number concentrations. Research of the ultrafine particles' effect in outdoor air on public health is a new scientific field in public health, which because of its complexity needs an interdisciplinary approach.

Key words: ultrafine particles, respiratory diseases, health effect

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[1] National Institute of Public Health, Centre for Environmental Health, Zaloška 29, SI-1000 Ljubljana, Slovenia

[2] University of Ljubljana, Faculty of Medicine, Public Health Centre, Zaloška 4, SI-1000 Ljubljana, Slovenia

[*] *Corresponding author*

Andreja Kukec, Public Health Centre, Faculty of Medicine, University of Ljubljana, Zaloška 4, Ljubljana, Slovenia, e-mail: andreja.kukec@mf.uni–lj.si

INTRODUCTION

Particulate matter is besides nitrogen dioxide (NO_2), sulfur dioxide (SO_2), ozone (O_3), carbon monoxide (CO), heavy metals, volatile organic compounds and pesticides one of the most common outdoor air pollutants in Slovenia and in Europe [1, 2]. The division of particulate matter is most commonly based on aerodynamic diameter, including particles with aerodynamic diameter less than 10 μm (PM_{10}), less than 2.5 μm ($PM_{2.5}$), less than 1 μm (PM_1), and less than 0.1 μm ($PM_{0.1}$), with the last group also labeled as ultrafine particles (UFPs). Taken from the report Air quality in Slovenia 2014 [1], the main source of PM_{10} (62 %) and $PM_{2.5}$ (74 %) are small furnaces.

Nitrogen dioxide (NO_2), sulfur dioxide (SO_2), ozone (O_3), carbon monoxide (CO), heavy metals, volatile organic compounds and pesticides one of the most common outdoor air pollutants in Slovenia and in Europe.

UFPs are particles of outdoor air pollution, with aerodynamic diameter less than 0.1 μm. Chemical compounds and physical shape of UFPs is dependent on the source of formation and secondary formations in outdoor air. Primary UFPs are formed directly at the emission source, whereas secondary UFPs are formed as a homogenous nucleation of gases [3-5]. The distribution and the type of UFPs are strongly dependent on the type of diesel exhaust, as traffic is counted as one of the main UFPs formation sources [6, 7]. Sources of emission of UFPs are also small furnaces, biomass boilers, and emissions from industrial coal fueled power plants [8-10]. Concentrations of ultrafine particle (UFP) number concentrations in the environment, where there are no anthropogenic sources of formation, vary between few to twenty thousand particles on cm^3 [10]. Even though UFPs have high particle number concentrations on cm^3, they add very little to total mass of particles of different sizes (total mass concentration of particles of various sizes) [11]. Variation of UFP number concentration is dependent on location and seasonal and daily temporal variability of meteorological and ecological parameters [4]. The formation of UFPs is also strongly associated with pollutants, which are formed in combustion processes, like nitrogen oxides (NO_x) and carbon monoxide (CO) [12].

One of the most important UFP characteristics, influencing public health, is chemical properties of particles, mostly elemental composition, inorganic ions and carbonaceous compounds [5, 13]. Considering bigger relative surface area of UFPs in comparison to coarse particles, it is predicted that UFPs have bigger toxicological effect on health; small particle size diameter is enabling them to enter into the bloodstream and thus spread in the whole organism through penetration into the lung tissue compartments [5, 11].

UFP deposition in the respiratory tract can be affected by physical activity, entryway – oral versus nasal breathing, disease status, and individuals age [9]. UFP deposition importantly affects the development of respiratory and cardiovascular diseases and functioning of other internal organs [11].

Exposure to total deposited fraction of UFPs is higher in asthmatic than in non-asthmatic children [14]. Health risk is also associated with heightened immune response, which may lead to the formation of blood clots and can cause myocardial infarction and stroke [10]. Heightened risks of sudden asthma exacerbation, induced allergy response, thrombosis, and endothelial dysfunction have also been confirmed [9, 15]. In patients with asthma, exposure to UFPs has a more significant effect on exacerbation of acute respiratory diseases [16]. Exposure to UFPs in outdoor air can reduce vascular reactivity and can significantly reduce venous nitrate (NO) concentrations [17]. The impact of the delayed and cumulative effects of UFPs pollution has also been discussed. Cumulative effects of 5-day UFPs pollution levels are stronger than health effects which appear right after the exposure [17]. Exposure to UFPs is associated with the decrease of electrical activity of the heart, which may lead to myocardial infarction [18, 19]. Exposure to UFPs exerts proinflammatory effects through oxidative stress response, and with the formation of reactive oxygen spices (ROS) stimulates the progression of atherosclerosis and precipitation of acute cardiovascular response, which involves all responses from the increased blood pressure to myocardial infarction [20]. Besides the effect on the development of respiratory diseases and cardiovascular system, UFPs have other effects on human health. Exposure to UFPs increases the levels of biomarkers for neutrophilic inflammation [21]. In patients with chronic respiratory diseases, exposure to UFPs can induce immune response of the white blood cells (monocytes) [22]. UFPs can change the structure of DNA [23]. Contradictory effects of UFPs partly come from the increased oxidative stress in the tissue and their subsequent impairment of the phagocytic ability of alveolar macrophages and phagocyte activity [20, 24].

Traffic is counted as one of the main UFPs formation sources. Sources of emission of UFPs are also small furnaces, biomass boilers, and emissions from industrial coal fueled power plants.

Confirmation for the association between exposure to UFPs and other acute health outcomes (such as mortality and dysfunction of the central nervous system) and chronic health outcomes (mortality and respiratory system dysfunction, reproductive and developmental effects, cancer, genotoxicity and mutagenicity) were conducted as inconsistent [19, 25–28].

Epidemiological studies at the population level, because of inconsistencies in their conclusions, still cannot firmly ascertain the association between exposure to UFPs in outdoor air and morbidity and mortality for either cardiovascular or respiratory diseases [9–11]. Lanki et al. [19] have confirmed positive and statistically significant temporal variable association between UFP number concentrations in outdoor air and daily number of hospital admissions because of acute myocardial infarction. Positive and statistically significant temporal variable association was proven between UFP number concentration in outdoor air and number of daily hospital admissions and daily counts of deaths because of stroke; UFP number concentrations in warmer seasons have been proven by Kettunen et al. as well [29]. Leitte et al. [16] have proven positive and statistically significant temporal variable association between daily number of emergency room visits for respiratory diseases and UFP size fraction between 0.05 in 0.10 μm. This association has not been proven for UFP size fraction smaller than 0.05 μm. Spirometric lung function was found to be non-significantly associated with concentrations of ultrafine particle (UFP) number concentrations [28, 30].

The aim of this study is to assess the temporal variable association between UFP number concentrations in outdoor air and daily counts of deaths from respiratory diseases in the Municipality of Ljubljana (MOL).

METODOLOGY

Study type and observed population

For the observation of association between UFPs and daily counts of deaths from respiratory diseases in MOL, an epidemiological ecological temporal variability study was implemented. The unit of observation was represented as a single day in the period between January 1st, 2012 and December 31st, 2013. In total, there were 731 days of observation in this period. The observed population was represented by residents of MOL aged 1 year or older, who died of respiratory diseases in the period of observation.

Area of observation

An area of observation in our study is an administrative unit of the Municipality of Ljubljana. In the first year (2012), MOL consisted of 280,278 residents; in the second year (2013) MOL consisted of 282,741 residents. Population density in 2012 counted as 1,019.2 m^2 and in 2013 as 1,028.1 m^2 [31].

MOL is situated in a basin, for which winter temperature inversion is characteristic, which causes long-term fog. Temperature inversion also creates poor airing of the basin, which further causes decreased dilution of pollutants. In the year 2013 in MOL, 17 industrial sources were presented, which yearly produce over 100 kg of total dust from combustion sources. The total dust mass of 17 industrial sources in MOL in 2013 was 62,096 kg [32].

Data collection

Health and environmental data for this temporal variability study was collected within the European project UFIREG (Ultrafine particles – cooperation with environmental and health policy). UFIREG project started in July 2011 and finished in December 2014 in four European countries – Dresden and Augsburg (Germany), Prague (Czech Republic), Ljubljana (Slovenia) and Chernivtsi (Ukraine) [33].

Daily counts of deaths from respiratory diseases

Health data was collected from death register, kept by the National Institute of Public Health. In the study, daily counts of deaths from respiratory diseases (ICD-10 (The International Statistical Classification of Diseases and Related Health Problems, 10th Revision), code J00 – J99) were recorded [34]. From the death register, the date of death, diagnosis of deaths, age at death, and gender were collected.

Ultrafine particles in outdoor air

UFP number concentrations were measured depending on the size (angl. Particle Number Concentration – PNC) in the time interval from 5 to 20 minutes, which were calculated to daily average concentrations. 24-hr average UFP number concentrations were calculated for five size ranges: UFP size from 0.01 to 0.02 μm, from 0.02 to 0.03 μm, from 0.03 to 0.05 μm, from 0.05 to 0.07 μm and from 0.07 to 0.10 μm as particle number/cm^3.

UFP number concentration was collected on measuring sites, on the location at The National Institute of Chemistry, Hajdrihovaulica 19, Ljubljana. Kindergarten, primary school and multistorey buildings are situated in the vicinity of the measuring site. Measuring site is situated 50 m from the nearest road. In the vicinity of the measuring site, the railway station is situated (approximately 1 km). The measuring site is situated in the urban environment, and measurements are representative for MOL [33].

Statistical analysis

Distribution and temporal variability of daily counts of deaths from respiratory diseases and daily UFP number concentrations in outdoor air are represented in tabular form with statisticaly significant parameters: mean, standard deviation, minimum and maximum value, quartile 1, median, quartile 3, total number of observed days, and total number of missing data. Temporal variability of daily counts of deaths from respiratory diseases and UFP number concentrations for each particle size diameter is displayed with sequence diagrams. For description of the observed variables and temporal variability, a statistical programme SPSS version 21.0 (SPSS Inc., Chicago, IL, ZDA) was used.

RESULTS

Data description

Daily counts of deaths from respiratory diseases

Daily counts of deaths from respiratory diseases were collected for 731/731 (100 %) observed days. Statistically significant values for data variability of daily counts of deaths from respiratory diseases for the years 2012 and 2013 are displayed in Table 1.

Ultrafine particles in outdoor air

Data for individual UFP size ranges ($UFP_{0.01\text{-}0.02}$, $UFP_{0.02\text{-}0.03}$, $UFP_{0.03\text{-}0.05}$, $UFP_{0.05\text{-}0.07}$ and $UFP_{0.07\text{-}0.10}$) was in the observed period measured for 435/731 (59,5 %) days. In total,this presents 296 (40,5 %) missing entries of UFP number concentration measurements. The chosen typical statistical values for distribution of average 24-hr UFP number concentrations for individual UFPs size ranges are displayed in Table 2.

Table 1: Distribution of statistical values data for daily counts of deaths from respiratory diseases in the Municipality of Ljubljana in years 2012 and 2013

Year	Mean	SD	Min.	Q_1	Median	Q_3	Max.	N	MD
2012	0.37	0.64	0	0.00	0.00	1.00	3	366	0
2013	0.31	0.52	0	0.00	0.00	1.00	2	365	0

Legend: SD – standard deviation; Q_1 – quartil 1;Q_3– quartil 3; N – total number of oberved days; MD– number of missing data

Table 2: Distribution of chosen typical values of average 24-hr number concentrations of $UFP_{0.01\text{-}0.02}$, $UFP_{0.02\text{-}0.03}$, $UFP_{0.03\text{-}0.05}$, $UFP_{0.05\text{-}0.07}$ and $UFP_{0.07\text{-}0.10}$ in the Municipality of Ljubljana in years 2012 and 2013

Size ranges of UFPs	Year	Average	SD	Min.	Q_1	Median	Q_3	Max.	N	MD
$UFD_{0.01\text{-}0.02}$	2012	1549.84	503.63	361	1200.28	1499.37	1903.08	3203	147	219
	2013	1303.19	518.48	29	939.32	1222.0	1584.80	3564	288	77
$UFD_{0.02\text{-}0.03}$	2012	1203.00	405.15	190	907.47	1158.59	1433.03	2462	147	219
	2013	1113.33	433.37	92	838.40	1063.84	1346.27	3360	288	77
$UFD_{0.03\text{-}0.05}$	2012	1571.23	571.64	183	1150.06	1537.13	1887.38	3897	147	219
	2013	1483.22	628.58	267	1102.01	1392.05	1752.15	4164	288	77
$UFD_{0.05\text{-}0.07}$	2012	1029.51	418.72	191	763.63	939.05	1226.13	3127	147	219
	2013	994.42	472.69	232	659.13	897.34	1189.20	3447	288	77
$UFD_{0.07\text{-}0.10}$	2012	1032.09	488.27	292	743.18	924.83	1188.02	3610	147	219
	2013	1029.71	575.63	281	683.59	886.20	1195.85	4208	288	77

Legend: SD – standard deviation; Q_1 – quartil 1;Q_3– quartil 3; N – total number of data; MD – number of missing data

Temporal variability of health and environmental data

Temporal variability of daily counts of deaths from respiratory diseases of MOL population and UFP number concentration in outdoor air for each UFP size range in the years 2012 and 2013 is displayed with sequence diagrams in Figure 1.

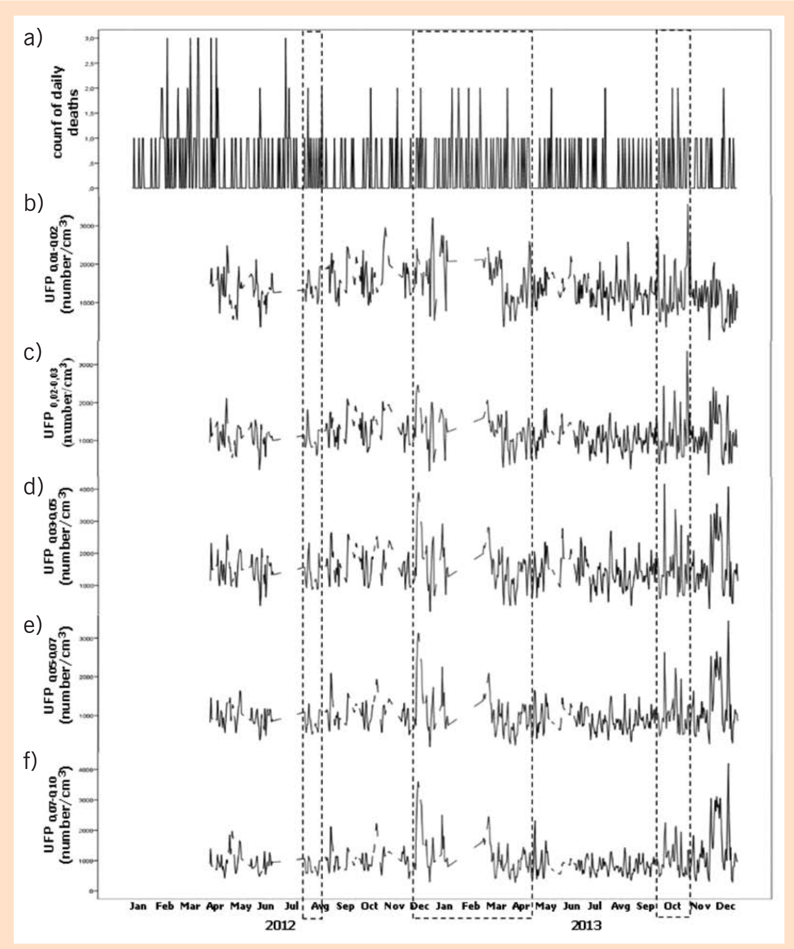

Figure 1:
Temporal variability:
a) daily counts of deaths from respiratory diseases,
b) average 24-hour number concentration of $UFP_{0.01\text{-}0.02}$(number/cm³),
c) average 24-hour number concentration of $UFP_{0.02\text{-}0.03}$ (number/cm³),
d) average 24-hour number concentration of $UFP_{0.03\text{-}0.05}$ (number/cm³),
e) average 24-hour number concentration of $UFP_{0.05\text{-}0.07}$ (number/cm³) and
f) average 24-hour number concentration of $UFP_{0.07\text{-}0.10}$ (number/cm³) in the Municipality of Ljubljana in years 2012 and 2013.

DISCUSSION

Daily counts of deaths from respiratory diseases

Collection of health data did not present any difficulties. Data of daily counts of deaths from respiratory diseases in MOL population was collected for all days within the observed period from January the 1st, 2012 to December 31st, 2013.

The highest daily counts of deaths from respiratory diseases in 2012 were in the period between the middle of February and the middle of April and again from the beginning of May to the middle of July and in October. Daily counts of deaths from respiratory diseases increased again from December 2012 to April 2013. In the year 2013, daily counts of deaths were again higher from the middle of May to the middle of July and in October. High daily counts of deaths in the years 2012 and 2013 coincide with the period of flu epidemic, which was in 2012 between the 4th and 14th week [35] and between the 2nd and 14th week in the year 2013 [36].

The highest daily counts of deaths from respiratory diseases were three deaths per day. The period with the highest daily counts of deaths from respiratory diseases in the year 2012 started at the beginning of February and continued to the beginning of April and repeated again in the first half of July. In the year of 2013, the highest daily counts of deaths from respiratory diseases (three deaths per day) did not repeat.

The highest daily counts of deaths from respiratory diseases were three deaths per day.

Daily counts of deaths from respiratory diseases show a repetitive pattern, which is typically seasonal. Seasonal predisposition is proven in the association with the number of emergency room visits [16] and mortality for myocardial infarction [29, 37]. Leitte et al. [16] report exacerbation of health conditions on weekends and holidays.

Ultrafine particles in outdoor air

Concentration of UFPs was slightly hightened in December and January, which is followed with a slight decrease of concentration in spring and in summer. Slight winter increase of UFP number concentrations can probably be associated with combustion in small furnaces in households. Even though seasonal temporal variability of UFP number concentrations in outdoor air is recognisable, there are still only slight differences in UFP number concentrations in outdoor air. This confirms that UFP number concentrations are mostly conditioned by traffic emissions, because 90 % of the secondary UFP formation in outdoor air is associated with the combustion of dieasel exhaust [7, 38]. In risk management of heightened UFP concentrations and consequently their health effect, it is important to have in mind that environmental indicator in Slovenia "The extent and structure of public transport and traffic" shows that growth of motorized traffic is above the average in comparison to EU [39].

Temporal variability of daily counts of deaths from respiratory diseases and UFP outdoor air pollution

The length of the observed period was conditioned by the European project UFIREG. A 2-year observational period of health and UFP number concentrations data monitoring was medium long observation period. In epidemiological ecological temporal variability studies up until now, health effect of UFPs in outdoor air at the population level was observed both in short and long observation periods. In the study of Penttinen et al. [28, 30], the period of observation was six months long, in the study of Delfinno et al. [27], Brüskeet et al. [22], Leitteet et al. [16], Karakatsaniet et al. [25] and Chung et al. [40] the period of observation was from six months to two years long. Six years and a half [41] and seven-year observation period [29] present long periods of observation.

Figure 1 shows the temporal variability association between periods with higher daily counts of deaths from respiratory diseases and higher daily UFP number concentrations. UFP health effect has already been evidenced in some previous studies. Leitte et al. [16] have proven positive association between $UFPs_{0.05\text{-}0.10}$ and emergency room visits for acute exacerbation of respiratory diseases. Penttinen et al. [30] have proven a positive association between UFP number concentrations and asthma exacerbation.

The observed temporal variability association for longer periods with heightened daily counts of deaths from respiratory diseases and higher daily UFP number concentrations can be contributed to time delayed effects from exposure to the observed health outcome, in the case of this study to the heightened daily counts of deaths from respiratory diseases. In previous studies, it has already been recognized that outdoor air pollution not only on the day of the exposure but also for several preceding days affect daily counts of deaths on a given day [42–45]. It has been discovered that long-term health effects of the outdoor air pollution can persist up until a month [45, 46].

Difficulties of data collection

We had some difficulties with collection and preparation of data of daily UFP number concentrations in outdoor air. In the years 2012 and 2013, in total, 40.5 % of data were missing. The biggest part of missing data was in the year 2012 (from January to March 2012 and the first half of July 2012), less data was missing in 2013 (the first half of February 2013). The reason behind the missing measurement data is consequential to the control and validation of measurement equipment and maintenance of measuring equipment [33]. UFPs in outdoor air and UFP health effects present in science a relatively new research field that is why it is important to know that on the European level there is no prescribed method of UFP measurement on the regulatory level [10]. Kukec et al. [47] have already emphasized the complications with the collection of environmental data, which is essential for association with health data at the population level. In the future, the availability and quality of exposure to coarse particles data in outdoor air should be improved. One of the most important challenges in future research still presents the standardization of measuring equipment and technique for UFP measurements as well as the inclusion of UFPs in the routine system of the national network for monitoring air quality [47].

In the literature review of outdoor air pollution and health effect at the population level, Galičič et al. [48] have also concluded that collection of suitable and quality environmental data presents one of the most frequent limitations in epidemiological ecological studies.

Strengths and limitations of our study

Our study is the first study in the field of the investigation of UFP effect in outdoor air on public health in Slovenia, which is why we have come to some limitations of our study. The biggest limitation of our study presents missing the environmental data of daily UFP number concentrations. The second limitation is related to the small population and consequently less daily counts of deaths from respiratory diseases. Nevertheless, our study can be considered as relevant, because the area of observation was not yet investigated in Slovenia. Even though UFP number concentration data was gathered within the UFIREG project, the authors of this study were acquainted with the use of measuring equipment, and that the acquired knowledge would be used in the future for measurements of UFP number concentrations in other parts of Slovenia, which are most burdened with outdoor air pollution.

Future research

Research of the UFP effect in outdoor air on public health is a new scientific field in public health that is why the possibilities for the future research are numerous. Studies up until now on the one hand show statistically significant association between the effect of UFPs of different sizes in outdoor air on public health at the population level [16, 30], and on the other hand the effect is not shown for some UFP sizes ranges [16, 28]. For confirmation of UFPs in outdoor air effect on public health, further temporal and spatial variability epidemiological ecological studies are needed. Galičič et al. [48] and Kukec et al. [49, 50] have already emphasized and recommended the investigation of the effect of outdoor air pollution, also of UFPs, on smaller spatial units with a thick web of the observed units, with the purpose to undertake the exact exposure assessment.

The observed population of studies on the population level was representative for the whole population. In the future, research specific population groups should be considered (children, elderly, ill and poor), because the exposure to outdoor air pollution levels in this population groups has an immense health effect [51].

In the future, research specific population groups should be considered (children, elderly, ill and poor), because the exposure to outdoor air pollution levels in this population groups has an immense health effect.

In the past, UFP number concentrations in outdoor air have been collected only within the UFIREG project. Routine monitoring of UFP number concentrations in outdoor air should be enlisted in the national network for monitoring air quality, which is administered by Slovenian Environment Agency. Within the national network for monitoring air quality, in January 2016 data collection of PM_{10} concentrations was collected on 15 measuring sites, and $PM_{2.5}$ concentrations were measured on 4 measuring sites [50].

The possibilities for future research in the field of UFP health effect in outdoor air on public health also presents chemical and microbiological composition of UFPs and UFP health effect together with other outdoor air pollutants (multiple effects, synergistic and antagonistic interactions). It has been established that UFPs of various sizes also have different chemical composition, which is also associated with the source and age of UFPs [52].

CONCLUSIONS

Temporal variability of daily counts of deaths from respiratory diseases and UFP number concentrations in outdoor air during the year have significant seasonal pattern. UFP number concentrations in outdoor air are slightly higher in winter, when also daily counts of deaths from respiratory diseases are slightly higher. Thus temporal variable association between the periods of higher daily counts of deaths from respiratory disease and higher daily UFP number concentrations has been proven. Research of the UFP effects in outdoor air on public health is a new scientific field in public health, which because of its complexity needs an interdisciplinary approach.

UFP number concentrations in outdoor air are slightly higher in winter.

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