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AIR IONIZER AND INDOOR PLANTS INTERACTION IMPACT ON ION CONCENTRATION

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Abstract
The plants emit different types of volatile organic compounds (Bio VOC's) and can improve air quality: they effectively remove organic pollutions and reduce the number of microorganisms in the air by releasing phytoncides. The lack of negative ions in the air can cause deterioration of the health of humans breathing it. At the same time, an air saturated with negative ions can improve the state of health and provide a comfortable environment. In this article, the influence of the plants (*Cupressus macrocarpa*) on the number of ions is proved, based on a series of experiments performed with applying high-voltage pulses (air ionizer). This work is devoted to the elaboration of the mathematical relationship between the air ions concentration and the factors influencing it. For this purpose an experimental stand was made, consisting of two equal compartments: one contained the plants while another one was used as a control without plants. It was concluded that the plants, in general, are able to stabilize the ion concentration and to reduce its fluctuations. The plants help to increase the concentration of negative ions and to decrease the concentration of positive ones.
Key words: air ions, plants, microclimate, high-voltage pulses.

Introduction

Aerosol is a collective term for the myriad of particles present in the atmosphere. The size spectrum of these suspended particulates ranges from the smallest cluster ions to relatively large organic matter with radii of order 10^{-4} m (Pruppacher & Klett, 1998). Atmospheric ions are frequently classified into large ions (r > 3 nm), intermediate ions (1 > r > 3 nm), and small ions, which are typically 0.5 nm in radius. Large ions are often classified as charged aerosol particles and have a distribution of electrical charges, whereas intermediate and small ions have a unit charge (Hõrrak *et al*., 2000). Atmospheric particles with small diameters transform in different layers of the atmosphere. Atmospheric particles have an important role in cloud formation and global radiation processes. The most recent studies on the formation of atmospheric particles and their impact on the human organism are based on the importance of these processes (Kulmala *et al*., 2000).

Data on the presence of small charges in the layers of the atmosphere prompted a study of the causes and effects of air ionization. Several causes of formation of these charges need to be noted: free electrons, their deficit or excess, the presence of particles in the air to which atoms attach (Griffin *et al*., 1962).

The variable chemical composition of negative ions reduces the mean number of water molecules attached to the central cation. Consequently, the negative ions are slightly smaller than positive ones, and can move faster in the electric field. A schematic diagram of the atmospheric ion production mechanism is given in Figure 1 (Aplin, 2000).

The topic of many discussions was the impact of air ions on the human organism. The formation of negative air ions in the atmosphere has a beneficial effect. Whereas, migraines, nausea and ill health can be caused by the presence of positive ions. In the natural environment, air ions are found near waterfalls, with the presence of particular atmospheric currents, radioactivity fluctuations or cosmic rays (Clements-Croome, 2004).

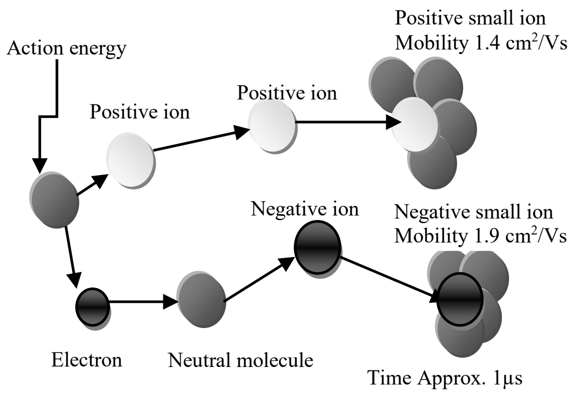

Figure 1. Schematic illustration of the production of atmospheric small ions from neutral molecules (Aplin, 2000).

The authors of many articles reviewed agree on the fact that most live organisms, including humans and plants, are affected by the balance and concentration of particles in the atmosphere (Smallwood, 1999). Any change in the proportions of air ions can affect biological organisms (Jovanic & Jovanic, 2001). Not only do air ions affect vegetation processes but plants themselves can generate ions, including negative ions under certain conditions (Nemeryuk, 1970). Therefore, not only temperature, pressure, humidity, daylight and the amount of minerals, but also the concentration of air ions in the atmosphere can be considered an integral factor for the organization of the ecological microclimate of plants.

Negative and positive air ions are generated from different sources like lightning, the aerosols present in the atmosphere (Jagadesan *et al*., 2016). The presence of negative air ions (NAI) in the inhaled air is essential for normal functioning of human and animal organisms (Charry *et al*., 1987).

However, the NAI level is too small to be detected by conventional methods. In this paper, we propose that the generation of NAI by plants could be enhanced by electrization by high voltage pulses, thus providing for the high level of NAI. It has been proven that the production of air ions by plants and soil is observed under natural conditions. In particular, it occurs after a prolonged accumulation of air condensate near the plant, despite the fact that the formation of NAI is very slow (Tikhonov *et al*., 2004).

Some countries have already elaborated legal framework concerning the concentration of air ions in the work-rooms. On 16 June 2003, sanitary and epidemiological rules and regulations 'Hygienic Requirements for the Air-Ion Level of Industrial and Public Facilities SanPin 2.2.4 1294-03' (Санитарно-эпидемиологические правила и нормативы 'Гигиенические требования к аэроионному составу воздуха производственных и общественных помещений СанПин 2.2.4 1294-03') entered into force in the Russian Federation. According to these Requirements, optimal concentration of light negative ions amounts to 3000 – 5000, while concentration of positive ions should be half as much. However, in most cases, the concentration of favorable light, NAI indoors does not exceed few dozens, while the concentration of harmful positive ions is growing rapidly, especially if there are people, TVs, computer monitors and similar devices in the room. Besides, practical field testing reveals that the somnolence, apathy, headaches, etc. ascribed to the 'dead' air in enclosed spaces can be conquered effectively by supplying moderate concentrations of negative ions (Krueger, 1985). Air ions may be healing or they may harmfully affect human health. This effect depends on the ion concentration in the air and on the proportions of positive and negative ions. These proportions are characterized by unipolarity coefficient where:

$$K = \frac{N^{+}}{N^{-}} \tag{1}$$

N^{+} and N^{-} are mean concentrations of positive and negative cluster ions.

Sanitary-hygienic characteristics of plants include their ability to release a special volatile organic compound called phytoncides. Most plants emit different types of volatile organic compounds (Bio VOCs) and even micro-amounts of Bio VOC have a great impact on the processes of formation of cluster ions (Duddington, 1969). This effect is reinforced when volatile compounds are emitted from the plant in the ionic form, e.g., Bio VOCs emitted from the needles of conifers are ionized because of charges accumulated on the sharp tips of the needles. To a certain extent, most of the plants are air ion generators. Despite that, aeroionizers are always present in places with artificial atmosphere, e.g. in submarines, and long-term space stations. With this, the saturation of the air we breathe at work and at home with the air ions is nowadays becoming a more urgent problem (Ponomarenko, 2015). We have tried to model the artificial air ionisation using indoor plants. For this purpose, a special experimental stand was constructed (Fig. 2). It would be perspective to develop technology for artificial greening that would ensure an optimal air ion concentration for human organism and indoor microclimate conditions. In order to develop such a technology, it is necessary to assess the changes in air ion concentration depending on indoor plants and microclimate. The aim of this research is to explore the impact of indoor plants and microclimate on air ion concentration in order to find opportunities to use the plants for air quality improvement. Studies with sciophytes and carbon filters have shown that they can improve the parameters of microclimate while removing organic pollutants in buildings. This combination can be considered one of the best means for fighting the symptoms of the sick building syndrome (Wolverton *et al*., 1989).

A specially selected combination of plants and appropriate soil content can remove and absorb VOCs in the buildings, which are harmful for humans. Many scientific papers published by Dr. Wolverton confirm the effectiveness of such biosystems for improving indoor microclimate. The articles describe how the pumping action created during transpiration near the plant roots, removes air pollution to have it converted into plant food. The charges between the Earth and the ionosphere are transferred by air ions. The carriers of negative charges rush to the ionosphere, while positive air ions move to the surface, where they enter into contact with the plants. The higher the negative charge of the plant, the more positive ions it absorbs. There can be assumed that the plants react to change the electric potential of the surrounding environment (Wolverton, 1999). More than two hundred years ago, scientist Grando concluded that for the normal growth and development of plants they need constant contact with the external electric field. Chizhevskii developed the first devices for artificial generation of NAI – Chizhevsky's chandelier (Chizhevskii, 1989).

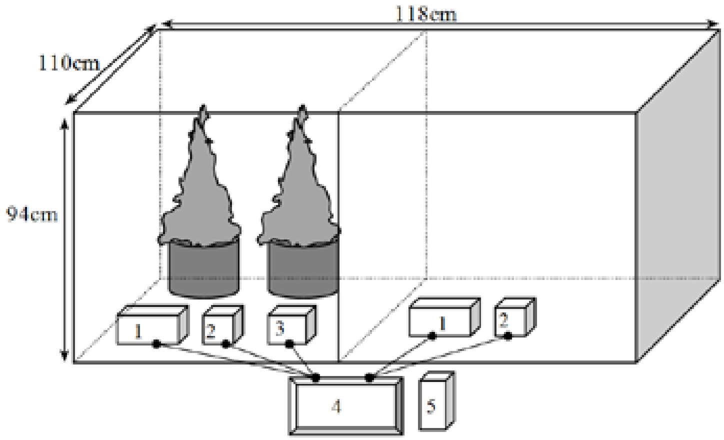

Figure 2. Schematic drawing of the experimental stand, consisting of two equal sectors. First sector houses the plants and air ionizer, the other one is empty. 1 – Air ion counter, 2 – microclimate multi-meter, 3 – air ionizer, 4 – laptop computer, 5 – radioactivity meter.

Materials and Methods

In our previous work (Sinicina *et al*., 2013; Sinicina *et al*., 2015; Sinicina *et al*., 2016) we studied the same plant samples as in the article by Tikhonov *et al*. (2004) and concluded that generation of NAI differs by the type of plant. Apparently, NAI are emitted from the pointed parts of the leaves. After conducting a series of experiments with five species of plants, it was concluded that the best among them, by the ability to generate negative ions, was *Pinus mugo*. This means that the *Pinus Mugo* could be used as a source of negative air ion. Unfortunately, this species of plants cannot grow in indoor conditions, where for them it is too warm and dry. Meanwhile, there are conifers, which are able to grow in the indoor microclimate, for example- Cypress *(Cupressus macrocarpa)* (Van der Neer, 2012), which was selected as the object of this study.

The aim of the experiments was to prove that plants are able to generate NAI to stabilize ion concentration and to reduce its fluctuations in response to the electrical stimulation. The main task was to create conditions with the least influence of external factors on the concentration of air ions (lighting, air streams *et al*.).

In order to quantify the influence of plants on the indoor ions concentrations, we have constructed an experimental stand made of 10 mm thick plywood. The general dimensions of the box are 118 cm × 110 cm × 94 cm. The box is divided by the partition into two equal compartments. A plant and air ionizer was placed in one compartment while the other one stayed without any plants. Every sector contained the devices for measuring the microclimate parameters. The box itself was placed in the basement type premises with natural air ventilation, without any windows, the walls covered with processed concrete. In addition, the radiation background was measured outside the box. During the experiment, there were no people in the premises. The premises were entered only to change plants and to retrieve the meters data. Air ion concentration was measured with the portable bipolar air ion counter 'Sapfir-3м'. This device provides simultaneous measuring of positive and NAI with minimal resolution of 10 ions per 1 cm^{-3}. The device measures air ion concentration in the air (mobility $k \geq 0.4\ cm^2\ V^{-1}\ s^{-1}$). This mobility interval is close to the class of cluster ions. During the measurements and according to their polarities, the air ions are channelized to positive or negative aspiration collector in aspiration chamber and, after entering into contact with the collector, the ions are discharged. Afterwards, the charge is sent to amplifiers and then the impulses are counted and displayed. The device counts the unitary charges of air ions, therefore if a ion is repeatedly charged, it is counted as several mono-ions.

Indoor climate parameters were determined using the multi-meter 'Easy Sense Q'. Systematic measurement error of this device for temperature is ± 0.3 °C, whereas error for relative humidity is ± 5%. Error for lighting is not specified. The total amount of radioactive α, β and γ radiation was measured in μSvh^{-1} with the portable device 'Gamma-Scout' with systematic measurement error less than 5%. For all devices, the average value of each measurement point was 10 minutes. Each time the measuring devices were placed in a distance of approximately 40 cm from the plants. The measurements were carried out in automatic mode for each *species* of plants individually, constantly during a 70 hrs time span.

Results and Discussion

The experimental data (Table 1) show that the number of positive air ions in the box is higher than the number of negative air ions: 41% with plants, 5% with air ionizer and 52% in an empty box, but in the sector with plants and air ionizer the number of negative air ions in the box is higher than the number of positive air ions: 110%. The maximum number of positively and negatively charged air ions was found in the sector with the ionizer: 199292 cm^{-3}/20182cm^{-3}. Whereas the minimum value of the same particles was observed with the presence of plants: 59 cm^{-3}/ 44 cm^{-3}. These data reveal that, based on the air ion concentration and unipolarity coefficient (Fig. 2), the air on the box that used to the experiments is not recommended for human health (if not ventilated), in case of if in the box houses only plants or air ionizes and empty sector.

The box in this sector has an unacceptable concentration of positiveand negative air ions and inadequate unipolarity coefficient, because, basing on the SanPin 2.2.4 1294-03, admissible concentration of positive air ions is 400-50000 cm^{-3}, concentration of negative air ions should amount to 600-50000 cm^{-3}, while admissible values of unipolarity coefficient are $0.4<K<1.0$. In the box sector with plants and air ionizer, in turn, concentration of positive and negative air ions was stabilized and was in the permissible limits. During the experiment, the temperature and relative humidity in the box increases. The measured average ambient temperature in the box with plants is about 0.5 °C higher than in the box without plants.

The average humidity is up to 15% higher in the room with plants than in the room without plants. It means that plants increase the air humidity (the water is evaporated through leaf pores). As the natural radiation level fluctuates chaotically around the average value of 0.14 μSvh^{-1} and the amplitude of these fluctuations is less than 10%, the level of radiation can be considered as constant; fluctuations of radioactive background do not affect daily changes of air ion concentration.

Table 1

Average ions concentration and Indoor climate parameters

Conditions/ Parameters	*Plants*		*Air ionizer*		*Plants and Air ionizer*		*Empty box*	
	N^+, cm^{-3}	N^-, cm^{-3}	N^+, cm^{-3}	N^-, cm^{-3}	N^+, cm^{-3}	N^-, cm^{-3}	N^+, cm^{-3}	N^-, cm^{-3}
$N^{(min)}$	59	44	166262	155521	11685	24052	124	102
$N^{(max)}$	900	646	199292	201821	19024	36335	3240	2083
$N^{(average)}$, cm^{-3}	448	317	185273	175758	15262	32198	917	602
K	1.49		1.07		0.48		1.40	
*Category of working conditions	1.level, harmful		1.level, harmful		allowable level		1.level, harmful	
T, °C	25.3-26.1		24.5-25.1		25.3-26.3		24.1-24.5	
RH, %	22.3-27.2		21.3-25.2		22.3-25.3		21.1-24.2	
Sv, μSvh^{-1}	0.10		0.14		0.12		0.10	

*16 June 2003, sanitary and epidemiological rules and regulations 'Hygienic Requirements for the Air-Ion Level of Industrial and Public Facilities SanPin 2.2.4 1294-03' (Санитарно-эпидемиологические правила и нормативы 'Гигиенические требования к аэроионному составу воздуха производственных и общественных помещений СанПин 2.2.4 1294-03').

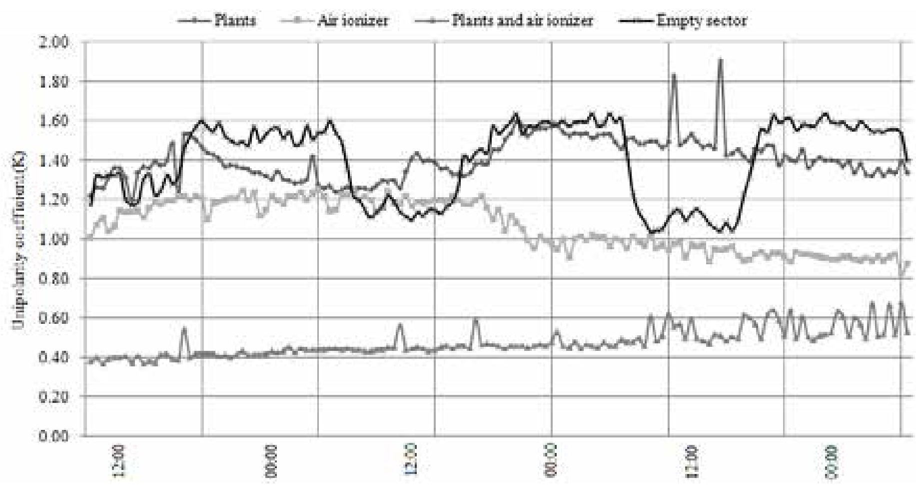

Figure 2. Changing in the unipolarity coefficient.

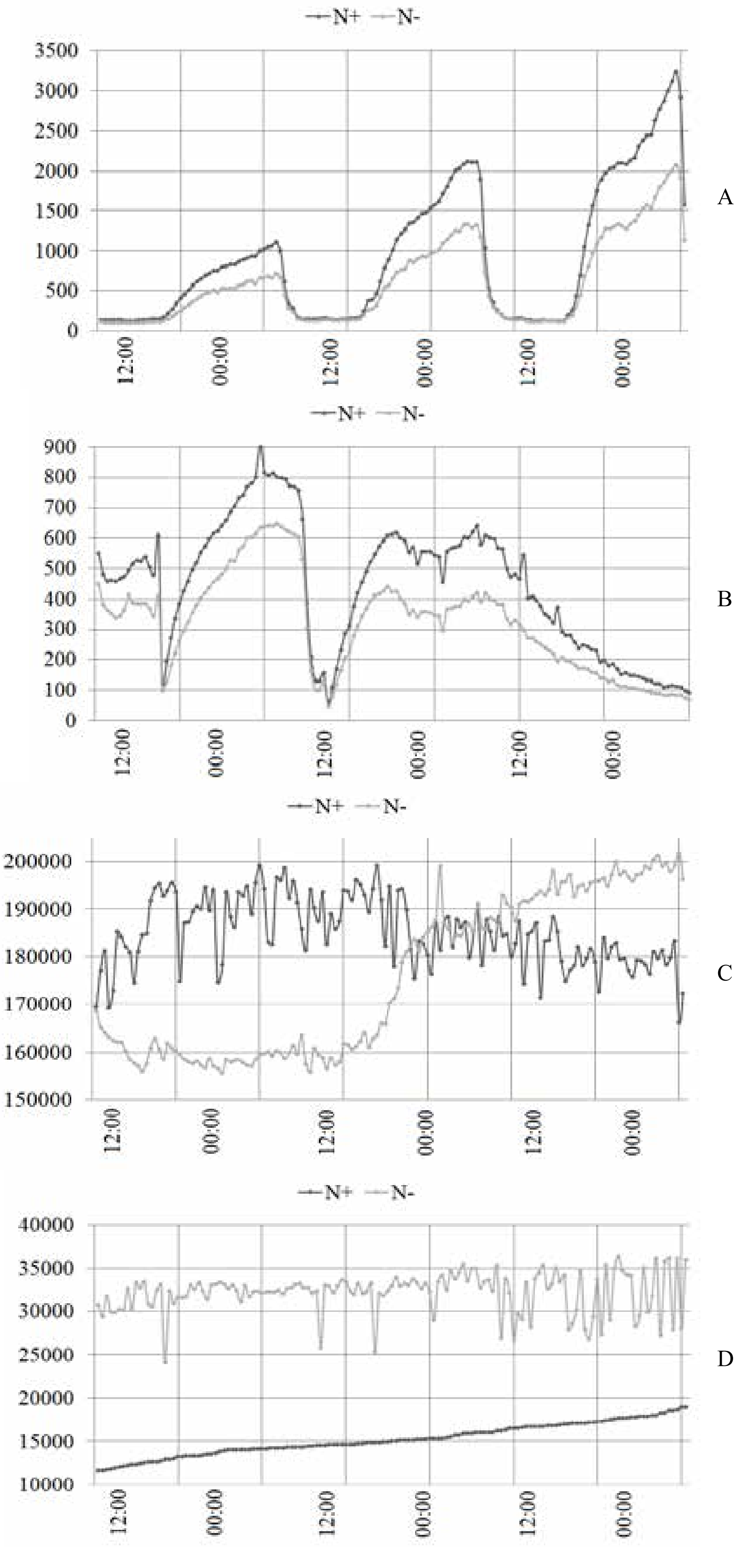

Figure 3. Concentration of negative and positive ions in the air in box cm^{-3}: A – Empty sector, B – Plants, C – Air ionizer, D – plants and air ionizer.

The indicated concentration of air ions in the presence of plants and in the empty sector (Fig. 3) allows us to conclude that fluctuation in the number of ions depends on the time of the day.

The maximum number of ions was observed in the night (01:00-05:00 a.m.), at the same time the decline of the ions was observed during the day (9:00-01:00 p.m.), although the experiment was conducted under conditions of complete darkness, i.e. without the influence of daylight or artificial light.

It can be explained as follows: negatively charged surface areas are mostly formed by free electrons flowing through dielectric adsorbent surfaces. An electron separates, leaving a positively charged area. Such positively charged surface areas lead to a change in air ion concentration. The number of air ions was decreasing during the day too. At night-time the action stops – the charged areas disappear with time and adsorption decreases, which leads to an increase of the number of air ions.

The room has a good ventilation. Air ions penetrate from the outside into the experiment room. The measurements in the box without plants points to the quantity of the ion outside air. If ventilation would be completely turned off in the room, it is possible that there would not be any cyclical changes in the graphs. Comparing the graphs with and without plants, it is possible to draw conclusions on how plants change the ion number in the diurnal period.

Conclusions

The positive and negative air ions concentration indoors varies periodically within the period of twenty-four hours – sector with plants (Fig. 3, B) and empty sector (Fig. 3, A): during the daytime it decreases, while during the nighttime it increases. In some cases, there are identified deviations from the periodicity. It is possibly related to the changes of Solar radiation activity.

In the box with plants, the concentration of positive and negative air ions is lower than in the empty sector or in the sector with air ionizer. However, at the same time, an unacceptable concentration of ions and inadequate unipolarity coefficient was experimentally recorded in these sectors.

The present study has shown that in the box with plants and air ionizer the concentration of negative ions remains almost constant during the twenty-four hour period. This means that this combination could be used as a source of support for acceptable concentration of positive and negative air ions.

Further experiments could be related to changes in air ion concentration depending on electrization of soil by high voltage pulses, thus providing for the high level of air ions.

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