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Effects of atmospheric ions on human well-being in indoor environment

Levente Herczeg* and **Norbert Érces**

Department of Building Service Engineering and Process Engineering
Budapest University of Technology and Economics
Műegyetem rkp. 3, H-1111, Budapest

**Corresponding author E-mail: l.herczeg@hfhc.hu*

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Abtract—People spend a significant part of their days in buildings or in a box within some kind of means of transport. It is one of the main issues in our fast-paced world that typifies the twentieth and twenty-first centuries. Consequently, suitable environment creation plays an increasingly important part, which has significant influence on human comfort, health, and productivity as well. It turns out in pursuance of developments in various heating, ventilation and air conditioning (HVAC) systems that human comfort is affected not only by air temperature, humidity, and draught but also by meteorological, physiological, and psychological parameters. Airborne particles, so-called atmospheric ions assessments have been carried out in the course of these investigations. This paper presents effects of atmospheric ions on indoor environment and the occupants.

Key-words: atmospheric ions, human well-being, air quality, comfort spaces, measurement technique

1. Introduction

The comfort in closed spaces is usually understood as thermal, air quality, acoustical, and illumination engineering comfort. The office plays a special role in providing adequate comfort as workers spend a longer time in closed spaces performing intellectual work. In the air-conditioning of comfort spaces, the primary task is to provide a pleasant indoor microclimate for the people staying in the room. In addition to thermal comfort, air quality is also regulated by international requirements and standards. In the occupied zone, a sufficient amount of fresh air of appropriate quality must be provided for the people staying in the room. Hungarian technical regulations do not fully cover these aspects yet, hence the complaints frequently heard from employees working in air-conditioned spaces are the air has an unpleasant ‘smell’, they experience ‘lack of air’ or perhaps have headaches (*Kajtár* and *Hrustinszky*, 2001, 2002, 2003; *Kajtár* and *Herczeg*, 2012; *Kalmár* and *Kalmár,* 2013) In addition to the impact on human’s health- and comfort factors, extensive studies were carried out on the effect of atmospheric ions.

2. Physical attributes of atmospheric ions

According to Henri Hess (1802–1850), a Swiss chemist, every type of gases contains electrically – positively or negatively – charged particles called ions. One singular ion carries 4.77·10-10 electrostatic values (ESV) charge. Under this force, ions will migrate in an electric field according to the type of their charge. Basically, two types of ions are distinguished: small or molecular ions and large, i.e., Langevin ions. Certainly dimensional differences can be observed in regard to ion velocity as well. Under normal air conditions, small ions are moving at 1–2 cm/s, and large ones at 0.01–0.005 cm/s, depending on their size. Velocity of negatively charged ions is usually higher than in case of positive ones.

In nature, ions are formed because of the radiation of sun, cosmic rays, and fluctuations of radioactivity within the lithosphere on the Earth. Highly ionized gases are approaching the Earth surface due to a capillary action generated by wind suction. Considering the total number of ions in the air, it is in the order of 60%. Stage of atmospheric ionization is simultaneously influenced by other natural processes which attempt to destroy or neutralize the ions.

The most important factors and processes are:

- bonds between oppositely charged ions,
- neutral ions creation, aggregation with condensation centers,
- large ions creation, and
- absorption by solid or liquid conductors (*Kérdő et al.,* 1972).

2.1. Determination of the number of atmospheric ions

Positively and negatively charged atmospheric ions in the air usually measured with the Ebert counter or with a modified version of that. The examined air sample is forced trough a cylindrical condenser with an electrode pole fitted in the middle. This electrode is oppositely charged than ions which should be measured, and only sufficiently high-speed ions are able to reach it. In the course of collision, pole subtracts electrons equally to the charge of ions. Based on the quantity of electrical discharges and the airflow measured by a damping plate, the number of ions can be determined in a given amount of air.

The ion concentration depends significantly on the time of day, weather conditions, and location, moreover the number of occupants and their activity (*Yaglou,*1935).

3. Effects of atmospheric ions on human physiology

First interdisciplinary study of biological and medical influents of ionized air was published by *Dessauer* in 1931. In the course of their assessments, ionized air was conducted directly on the face of participants through a funnel. Exposure had been taking 15–60 minutes, at concentration of 10^6 ions/cm^3. It was clearly established that positive and negative ions had different effects on human health, amongst healthy participants and inpatients too. Positive ions induced discomfort, headache, rising blood pressure and respiratory rate. Moreover, they generate occasionally a feeling of being sick. Negative ions had opposite influences which led to sense of refreshment and decreased blood-pressure.

Effects of atmospheric ions were evaluated in a more cautious way in a research had been carried out by Harvard School of Public Health in 1933. In the course of investigations, ions formed by small molecules were dispersed into the experimental space with a velocity of 1.3 cm/s. Concentrations of positive and negative ions were continuously varying between 5000–1 500 000 ions/cm^3. Applied ionizer could produce simultaneously positive and negative ions. Temperature in the experimental room was set according to the personal demands. Air-change rate was 35, without usage of a humidifier.

Examination series were divided into three groups:

- normal ground state,
- 2–4 hours after breakfast, and
- 3–5 hours after an easy lunch.

During the investigation, variations in metabolism, breathing, pulse rate, blood pressure, and body temperature were recorded in regard to each test persons, who aged from 10 to 68 years. The group of 60 participants was observed during 141, one or more hour long experiments under influence of ionized air. It was established that intake air can normalize body processes, i.e., accelerate physiological changes if personal results are above or below the normal rate. Significant influences of positive and negative charges could not be determined. However, based on evaluation of subjective physiological effects, the following statements can be made: exposure to positive ionization causes headache, nose and throat irritation. Negative ionization led to a feeling of being calm. A small group of test persons reported sense of freshness, especially affected by negative ionization (*Yaglou et al.,* 1933).

4. Measuring investigations of atmospheric ions

4.1. Description of measurements

To purpose of this chapter is to present how ion number is varying and what the influence of that is on occupants being in different places. Since 1930s, several measurements have been taken in areas in towns, subway stations, and residential enclosures, in order to answer these questions.

Under conditions of natural ion climate which is beneficial to health, numbers of positive and negative ions are equal to each other in terms of scale, and concentration of biological effective ions is in the range of 500–4000 ions/cm^3. Due to changes generated by civilisation, atmospheric ion concentration rates scattered in cities and industrial areas are fundamental. Number of large ions will be significantly increased by polluted air. Consequently small, biological effective, negatively charged ions are almost completely disappearing. Several studies were carried out by *Yaglou* and *Benjamin* between 1930 and 1934 in relation of various meteorological parameters. Seasonal phenomena, influences of temperature, humidity, clouds, precipitation, and changes in atmospheric pressure were also taken into consideration. Results from the three-year-long assessments show adequate similarity, presenting definite minimum ion concentration in winter, and maximum in summer. Winter of 1930–31 was extremely cold. Therefore, results for this period had been deleted afterwards. Indoor level of ionisation was lower than in outdoor air during winter and springtime of 1932–33. In summertime this deviation could not be observed. In comparison with measurements at Pacific, Atlantic, and Indian Oceans (1915–16), corresponding variation in ion concentrations was established. However, comparing results had not been considered sufficient to provide an adequate basis in regard to both land and water surface measurements. Related to the connection between yearly changes and ionization, no conclusions were made as further measurements had been considered inaccurate. Ion concentration influenced by air temperature and humidity was evaluated in a more adequate way. Increased wind velocity leads to a consequent decrease in ion concentration at any time of the year, independently from temperature levels. Low concentration of small ions starts to be appreciable below air temperature of 21 °C. Thus, minimal concentration in winter becomes out of question as the humidity is at the highest level and temperature is at the lowest level simultaneously. Presence of high ion concentration can be noticed at relative humidity of 75%, independently of temperature parameters. Ion concentration level is varied with both cloudy and partly cloudy weather. In fact, clouds which cover the sky completely or partly will decrease ion concentration significantly. There is similar effect both of light and moderate rain. Heavy rain and storms accompanied by lighting and very heavy precipitations will increase the level of negative ion concentration definitely. If storm approaches its peak, this can reach the level of the zenith point of ion concentration 3000–3150 ions/cm^3. Indoor ion concentration depends considerably both on the amount and duration of precipitation and the direction of the wind. A few hours of light or moderate rain has no major impact on indoor ion concentration.

Number of ions formed by surface radioactivity is influenced by barometric effect which can be measured near the ground. If Earth's capillaries are under a decreased pressure, more ions will be released. This kind of "ground breathing" becomes heavy at an increased level of pressure. However, these are not significant changes.

4.2. Measurement results in Hungary

Obviously, studies on atmospheric ionization have been made in Hungary too. István Kérdő candidates of medicine, and Ferenc Sváb electrical engineer had been performed two assessments, in Budapest on October 12, 1970 and in Stuttgart on July 28, 1972 (*Kérdő et al.*, 1972). Results of their studies are presented in *Table 1*.

Table 1. Variation of atmospheric ion number in urban area (*Kérdő et al.*, 1972)

Location	**Temperature [^{0}C]**	**Relative humidity [%]**	**n+ [ions/cm^3]**	**n- [ions/cm^3]**	**n+/n- [-]**
Budapest, 200 m far from Danube	21–18	56–62	120–130	–	–
North, 14 km far from Budapest	21	60	250–300	120–140	2.08–2.14
Budapest, Nyugati square	21	60	120–140	20–30	6.00–4.67
Budapest, Jászai Mari square	18	–	50–100	10–20	5.00
Budapest, Boráros square	18	–	130–170	20–40	6.50–4.25
Budapest, Nagyvárad square	18	–	100–130	20–30	5.00–4.33
Stuttgart, Entrance of Wagenburg tunnel	20	61	300–500	20	15–25
Stuttgart, Kriegsberg road	20	61	200–220	30–40	6.67–5.50
Stuttgart,Bosch Hospital, 115 m altitude	20	–	270–290	20–30	13.5–9.67
Stuttgart, TV Tower	20	–	110–130	120–130	0.92–1.00

The above mentioned phenomena can be observed, i.e., number of negatively charged ions could be considered negligible or non-measurable in higher polluted environment. However, results measured in the TV tower of Stuttgart verified the theory that unipolarity is near to one in clean environment, so positively and negatively charged ions are dimensionally equated to each other. It shows the importance of negative ions, which can primary affect the physiological parameter, one of the earlier mentioned factors influencing human comfort.

4.3. Recent researches

After the first, remarkable researches in the 1930s which had been processed without achieving a real breakthrough, in the 1960s a new attempt was made in order to define effects of atmospheric ions on occupants in residential spaces. In the course of investigations it was discovered, that a significant amount of positively and negatively charged ions could be generated by humidifiers and vaporizers in the air conditioning devices. As it can be seen in *Table 1*, in case of TV Tower of Stuttgart, natural ions are approximately balanced, but usually more positively charged ions can be found in a cubic centimeter. In general, this number is below 1000 ions/cm^3 in a clean, natural environment. It can be observed that certain human activities, especially ones accompanied by a considerable heat load form positively charged ions. Therefore, man got used to the presence of positive ions more likely. In accordance with the study presented above, this could also give an explanation for the favorable effects of negative ions on human well-being, as the surplus of negatively charged ions could create a perceptible change in well-being. However, this statement was handled with care, even after the study of *Jennings* in 1964 (*Jennings* and *Givoni*, 1964) . As previous investigations, this was also performed in an artificial environment, where ion concentration in air could be increased above the natural level. All the experiments had been performed in the research lab chamber for environmental studies of American Society for Engineering Education (ASEE) which is a room with internal size of 7.5×3.5×2.55 meters. Both indoor air temperature and humidity were controlled by an air conditioning device. In the room, four ion generators were installed. Likewise in the 1930s, adjustable devices could be set for producing or counting either positive or negation ions. The pilot studies showed that there was no direct correlation between the ion concentration in the room and the number of ionizators, since two generators could produce the same high level of ion concentration as the four together. Still simultaneous use of the four devices were considered practical, in order to ensure homogeneity.

In the course of the assessment, 16 people (12 woman and 4 men) were employed as test persons. Before the ionization, each of them has gone through a general physical examination. Initial studies were performed between July 19 and 22, at a relative humidity of 50%. These were reproduced between July 25 and February 2, also at the same humidity level but at a temperature level of 30.5 °C in order to observe the reactions of the same test persons at mild heat stress. Both measurement series were remade between April 19 and May 26. Two groups of 6–8 persons were established and observed in the daytime and at night during each investigation. Three levels of ionization were distinguished:

- basic, when ionizators did not worked,
- negative ionization,
- positive ionization.

In the course of examinations, a special attention was paid to ensure random change in the three levels, in order to avoid any effects of the different ionization statuses. Ionizators had been operating at maximum output which resulted significant increasing in ion concentration day by day. *Table 2* shows the variation of the ion levels in the examination room with respect of different ionization statuses.

Table 2. Variation of ion levels in the examination room

Ion polarity	25.5 ^{0}C, 50% relative humidity		30.5 ^{0}C, 50% relative humidity	
	Average level [ions/cm^3]	**Constant deviation [ions/cm^3]**	**Average level [ions/cm^3]**	**Constant deviation [ions/cm^3]**
Basic points				
Positive	277	79	393	46
Negative	118	45	194	30
Measured levels				
Positive	12245	1350	14819	1586
Negative	4766	587	5494	897

It can be observed, that 10 °C rise in temperature causes higher level ion concentration in the room. Approximately, it is increased by 1650 ions/cm^3 in ionized status and by 190 ions/cm^3 in basic. This change was considered a marginal one during the examination. In the course of the examination test persons were allowed to read, play games, and listen to the radio as well. It was permitted to discuss only their well-being. Each test person had to fill a summary questionnaire about well-being during the three-hour-long time of observation, which contained scales of overall thermal comfort, sensible perspiration, pleasantness, tiredness, humidity sensation, air movement, and personal feelings or moods. Sensitivity of estimates is confirmed by the fact that human factors bring individual results. Moreover, subjective sense of human comfort could be influenced by the points of begin and end of the measuring period, the part of the day, and the actual season. If change caused by these "distortive" parameters occurs at the same time as an ionization process, evaluation will be more complicated. It can be said without presenting the enormous amount of results, that neither of test persons prefers the status of negative over-ionization (see *Table 2*) in such a determined way as the basic level of negative ion concentration in the room.

Furthermore, it can be established that if effect of ionization even exists, it must be far too slight to be significant. However, it comes up as a question, how occupants in the room are influenced by this comparatively insignificance (*Jennings* and *Givoni,* 1964).

5. Summary of the measurement results

Researchers could get any definite results in the course of evaluation trough the method of significance analysis. During estimation of pleasantness, some evidence was found in the evening teams for the rejection of the hypotheses.

By taking all the groups into consideration, during the assessments at temperature of 30.5 °C, a probability of P=0.03 was determined. There is a question of how ionization affects the groups at a different level during daytime and at night. Mood votes could not provide adequate information to prove the existence of the ionization effect. This lack of information was obtained also in regard to tiredness votes.

Authors are aware of the fact that the statistical methods which used by them is not the only way to evaluate such an assessment. Nevertheless, effect of ionization probably could not be proved by other methods in a more accurate way either. Influence on different people is not so significant at the measured level of temperature and ion concentration that it should be remarkable from technical point of view.

By summarizing the results it can be declared, that ionization has no significant effect on occupant's well-being and health in residential spaces. All the studies declared that there was some detectable effect, but it was not evaluated exactly. However, air conditioning developers keep on being engaged in this issue, and in the course of technological innovation, more researches were made in the field of ionization in regard to different technologies and building structures.

6. Practical usage of ion air conditioning

It was observed, that filters in air handling devices deionize the air almost completely, but cheaper window air conditioners generate a surplus of positive charge. Reinforced concrete building structures cause further problems, whereas due to the shadow effect of the iron structure, small air ions can not even enter the building or they become neutralized shortly after the entering. This is also caused by that floating condensation seed particles can be separated really gently from the indoor air. Deionization could be generated in that case as well, when plastic parts of the building envelope get electrostatic charge. If the process of air conditioning is assumed optimal from the point of view of ionization, corresponding level of ion concentration should be ensured in an artificial way. It causes further difficulties, that air ionization in central air handling units can not be considered a practical method, whereas ions will be quickly neutralized in the ducts of the distribution system. It was proved by measurements that a three-meter-long metal air duct can completely deionized the air flowing inside. According to the experiences, efficient level of ionization can be achieved if the ioniser is placed into the air inlet. It was a signal result, that number of floating bacteria was decreased significantly by ionizators in the air of bandage, surgical, and operating rooms of hospitals. Surplus of positive ion concentration was measured in an average room with central heating in ten minutes after the room was properly aired. Based on the assessment it can be established, that it is sufficient to provide only the negative ion supplements.

In addition to the buildings, measurements were conducted in different vehicles, in driver cabins of buses and cars, and in cabins of dockyard cranes. Similar results were obtained in regard both to the train set of Budapest Metro and to Russian researches. Rate of unipolarity was not influenced significantly in the course of travelling underground and above ground. Surplus positive ion concentration was measured in the cabins of dockyard cranes even if the window was open. In summertime improved, ion concentration was detected only if a moderate breeze was blowing.

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