Air Ionization
Clinical Evaluation Report

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Clinical Evaluation Report

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Review Table

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1. General concepts

Air ions are electrically charged molecules or atoms in the atmosphere which are generated by cosmic radiation, waterfalls, friction forces in storms and by ultraviolet lightning. Generally speaking, an ion is formed when a molecule or an atom receives sufficiently high energy to eject an electron. Ions which lose an electron are positive and they are called also cations, while ions which gain an electron are negative and known also as anions [1-2].

The atmosphere which surrounds the Earth is subjected to a natural electric field characterized by an intensity that changes constantly due to local and global influences. Local influences are geographical location and weather conditions, while global influences mean daily electric field variations. The corona discharge, a basic principle of ionization, occurs in the presence of high intensity electric fields generated by natural phenomena such as thunderstorms or lightning.

High concentrations of negative ions are found near waterfalls or at seashores. They are generated by Lenard's effect, which is also called spray electrification [1,3]. In particular, negative ions are generated from the surrounding air molecules by charging themselves when water drops collide with each other.

Artificial corona discharge is an efficient way to generate negative ions by applying a high negative voltage to a conductor. The intensity of the corona discharge depends on the size and shape of the conductor [1]. The main difference between corona discharge and Lenard's effect is that the former charges negatively every substance in the air and generates ozone, the latter produces only superoxide ions [4].

The first reported information of air ions dates back to the 19th century. According to many studies, high concentrations of negative air ions have a positive influence on human health, stress and cognition [4-16].

2. Effects of air ionization on psychophysiological health

Perez et al. [16] conducted a comprehensive literature review to sum up the effects of air ionization on depression, anxiety and mental well-being. They reported several studies in which the effects of positive and negative ions were highlighted.

In one study, 10 healthy adults and 2 subjects with chronic neurologic conditions were involved [17]. They analyzed the electroencephalogram and they found a consistent decrease in alpha activity in ten subjects during air ionization (9 healthy and 1 pathologic). Another study focused on the impact of negative ions on mood, and they found a significant improvement due to negative air ionization, as well as benefits in memory [18].

Perez et al. reported a study on 112 patients with mental disorders and their aim was to analyze if air ionization was able to mitigate symptoms of the disease after a treatment from 10 to 30 days. The results of the study indicated that in the majority of patients there was an attenuation of anxiety, depressive reactions and insomnia [19].

Summarizing, their main findings were two:

- Consistent beneficial effects of air ionization on studies of anxiety, mood, relaxation, sleep and personal comfort;
- Reduction of symptoms in depression, but significant reduction of clinical depression was not reported in any study.

The evidence of the effect of negative ions on psychophysiological state and performance was reported also by Pino et al. study [4]. They focused on 28 female patients with asthma divided into two groups, one subjected to negative ions treatment and the other one to placebo effect. People involved in the study were instructed to measure their peak of expiratory flow (PEF) with a flow meter and to record all symptoms. Females who received negative ions treatment showed lower depression and anxiety condition together with a reduction on asthma symptoms and use of corticosteroids, prednisolone and antibiotics. Additional studies have also suggested good results for the treatment of depression and seasonal disorders [2].

3. Positive ion effects on human health

Perez et al. [16] reported a study on the effects of positive air ions on mood of 85 subjects in which significantly greater tension and irritability in subjects' mood was found [20]. In particular ion-sensitive people showed increased reaction times and decreased activation, while non-sensitive subjects showed increased activation and no effects on reactions time. Another study [21] in which 14 volunteers were involved, saw an increase of anxiety, excitement and suspicion, however, they found opposite response to negative ions exposure.

Another study [17] exposed subjects to negative and positive ions for 30 minutes. 10 healthy subjects and 2 patients with chronic stationary neurologic conditions were involved to evaluate the effect of air ionization on human electroencephalogram. They found a decreased alpha activity for both negative and positive ions exposure in 10 subjects (1 pathologic and 9 healthy subjects). Half of the subjects reported relaxation and sleepiness with ionization, more frequent for negative than positive ion exposure.

Better results were also obtained with negative air ions, than with positive ones, as reported by Cernecky et al. [22] who stated that when there is a higher number of positive ions in the air people may suffer of headache, insomnia, fatigue, nervousness, joint aches, high blood pressure and decreased work activity.

Ionizers produce a specific ratio between negative and positive ions, in particular increasing the number of negative ones that are almost equal to zero in indoor environments, making them healthier and more natural. Not all ionizers produce a balanced ration of negative and positive ions.

4. Effects of air ionization on airborne and surface bacteria

To ensure food quality and safety, food manufacturers have to implement quality management systems to prevent air and surfaces contamination. Manufacturers have to guarantee storage hygiene and food safety by using innovative technologies and methods to prevent bacterial contamination which may occur in the food preparation area. One of this method is air ionization that destroys micro-organisms or inhibits their growth.

Some forms of the ionization process is accompanied by the release of ozone [4] , which is a potent oxidizer with an antimicrobial activity. Commercial ionizers, which often produce high levels of ozone, must not exceed the threshold limit of ozone (between 50 and 100 ppb) [23] since it is harmful to humans and food products at higher concentrations. NOTE: Periso AERSwiss Pro units do not produce ozone as part of their operation [24].

Kampmann et al. [25] investigated the antimicrobial effect on three different material:

- Sterile plastic material to simulate refrigerator inner liners;
- Sterile glass plates to simulate glass shelves;
- Agar plates to simulate food products.

Each material was put in a Petri dish and the test was done with and without the ionizer. The investigation showed that ionization is an effective method for reducing airborne bacteria in domestic refrigerators.

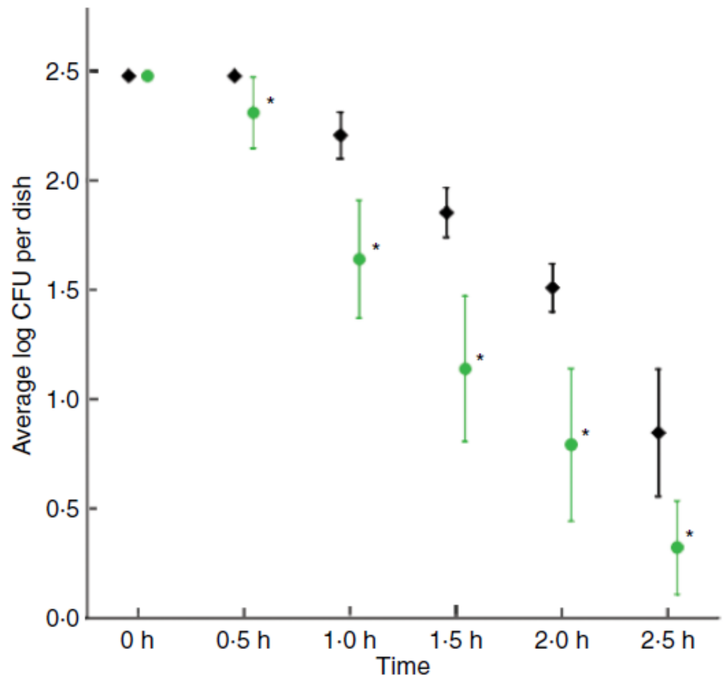


Figure 1 Average airborne bacteria per dish in static refrigerators with (green lines) and without (black lines) ionizer. [25]

In figure 1, the time evolution of the concentration of bacteria per dish in static refrigerators (without ventilation) is reported. It is evident that ionization is able to reduce the amount of bacterial almost completely within few hours.

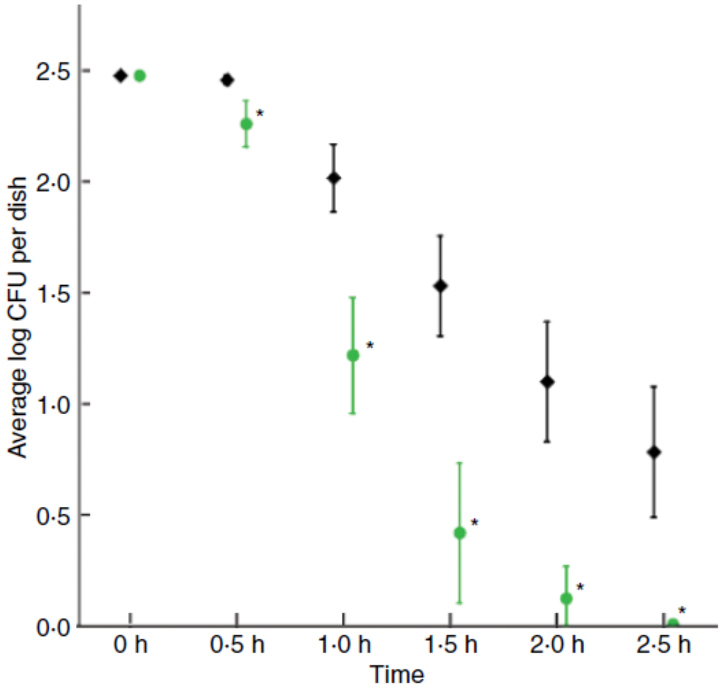


Figure 2 Average airborne bacteria per dish in dynamic refrigerators with (green lines) and without (black lines) ionizer. [25]

In figure 2, the time evolution of the concentration of bacteria per dish in dynamic refrigerators (with ventilation) is reported. In both cases, bacterial reduction is much higher when the ionizer is switched on. In addition, air circulation in refrigerators had a better influence on antimicrobial activity and airborne bacteria, maybe due to the increased mobility through the use of ventilator.

Kampmann et al. [25] found that the surface material and structure influence the antimicrobial activity. In particular they observed a reduction of bacteria on plastic and glass surfaces with respect to agar samples since the latter is more porous. They concluded that ionization is not indicated for reduction of bacteria on food but only on plastic and glass surfaces.

Fletcher et al. [26] studied the bactericidal effect of air ions on seven bacterial species exposed to positive and negative ions. The experiments were made in an ambient room conditions for 5, 10, 15 minutes. The results of negative and positive ion exposure is presented in figure 3 in which the survival fraction of bacteria versus the exposure time is shown. For each type of bacterial species there was a remarkable reduction in colony count with negative ions. The effect of ionization on bacterial species with positive ions was different. In particular, except for Mycobacterium parafortuitum, the bactericidal effect produced by the exposure to positive ions was much less than the case of negative ones.

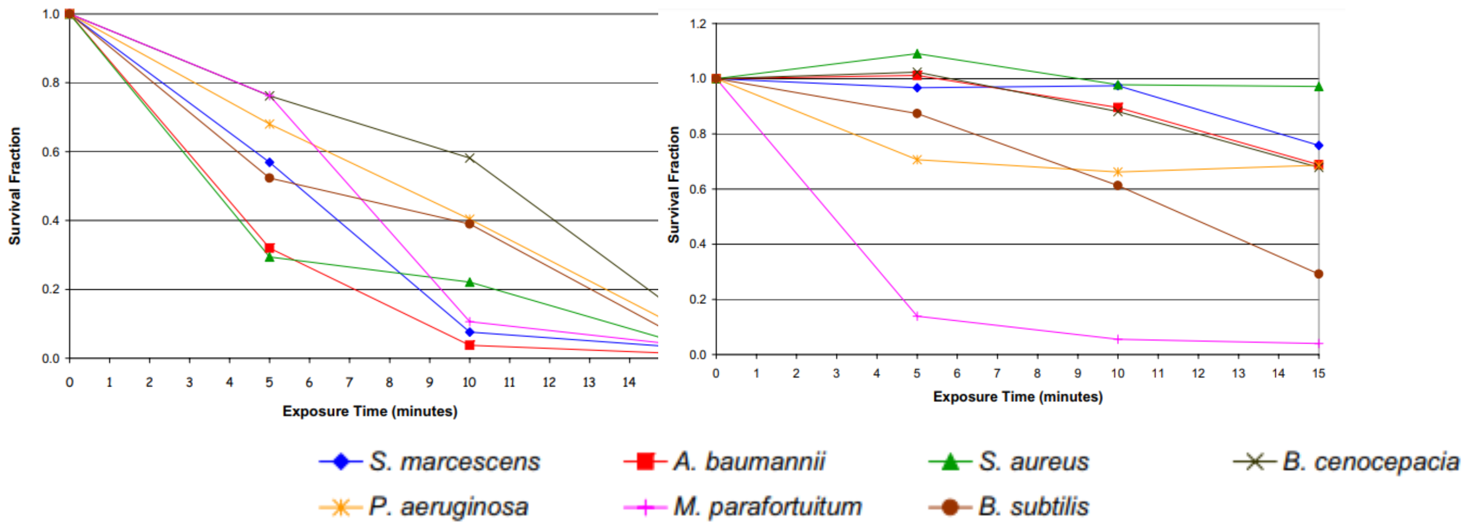


Figure 3 Bactericidal effect due to exposure to negative (on the left) and positive (on the right) ions. [26]

The principal bactericidal mechanism, in this research instance, related to negative air ions seems to be oxidation damage due to exposure to ozone, however did not isolate the negative ion concentration from the amount of ozone produced.

Park et al. [27] studied the bactericidal effect of ionizers under low concentration of ozone. Tests were made in a sealed plastic chamber at room temperature and 60-70% of relative humidity. Four different species of bacteria were placed on Petri dishes and exposed to air ionization. The research confirmed that the ionization was effective with no or low levels of ozone, in removing specific strains of bacteria.

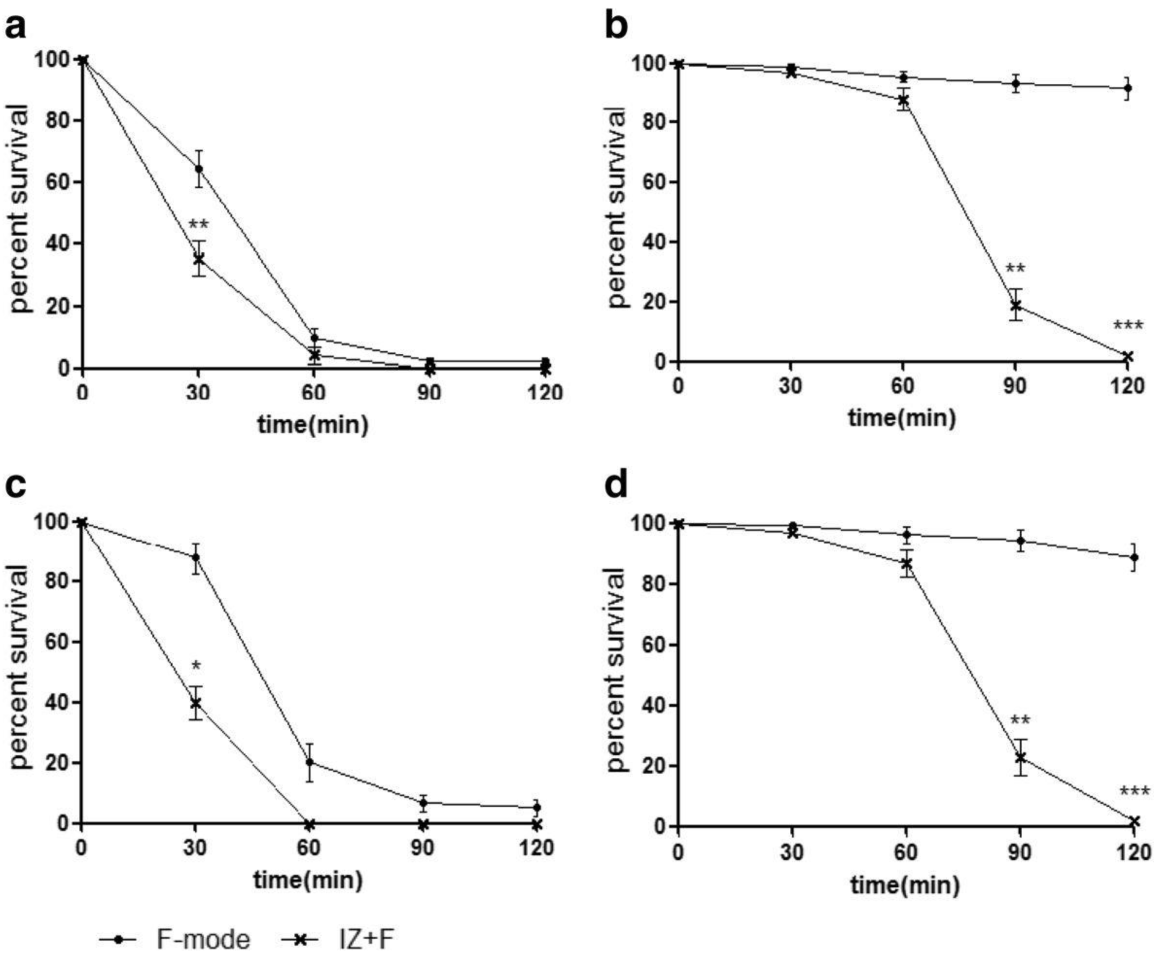


Figure 4 Percentage of survival bacteria during air ionization tests. For each type of bacteria two tests were made: ionization with ventilation (IZ+F) and ventilation only (F-mode). ***a*** *E.coli,* ***b*** *E. faecalis,* ***c*** *B.subtilis,* ***d*** *S.aureus.* [27]

With ventilation mode there was a decrease of *E. faecalis* and *S. aureus* but not of *E. coli* and *B subtilis*. This means that the effect of ionization depends on the type of bacteria. Indeed *E. coli* and *B. subtilis* were reduced almost to zero only if ionization was switched on. In addition, if ionization was switched on the time needed to reduce the percentage of bacteria was lower.

5. Effect of air ionization on viruses

Hagbom et al. [28] studied ionizers and viruses. The spread of infectious diseases is a crucial aspect, and today no simple validated technology exists which is able to collect viruses from the air. The device used in this study works at 12V and generates negative ions in an electric field. The study used several types of viruses of clinical importance, such as calcivirus, rotavirus and influenza virus. The main result of the study indicated that the ionization of air lead to loss of infectivity of viruses.

The researchers conducted a focused study on influenza A [28] (Panama virus infection between guinea pigs). In particular 4 infected guinea pigs were placed in cage A and four uninfected guinea pigs in cage B. They performed two experiments: the first one with the ionizer switched on between the cages and the second one with the ionizer switched off. The results showed that in the first case the active ionizer prevented 4 of 4 exposed pigs from developing influenza virus, in the second case, with the inactive ionizer, 3 of 4 pigs were infected. It was demonstrated that an ionizer may be able to prevent spread of airborne transmitted viral infection between animals, and destroy viruses from the environment.

Additional studies have also found positive results with unipolar and bipolar ionization and reducing viral infectivity [29-33].

6. Effect of air ionization of fine particulates

Jiang et al. [1] studied air ionization benefits on human and animal health, and microorganism growth. They reported that exposure to negative ions induced wide effects on animal/human health, plant growth and against microorganisms. On humans and animals, the main results were improvements on the cardiovascular system, respiratory system and mental health. They reported another positive benefit of air ionization: rapid precipitation of particulate matter (PM), both PM_{10} and $PM_{2.5}$.

PM is the major pollutant substance which seriously affects human health [34-38]. Particulate matter penetrates into the lungs, and damages the alveolar wall, and as a result, respiratory functions. The World Health Organization (WHO) has quantified the effects of exposure to PM_{10} and $PM_{2.5}$ in the form of air pollution, and has determined the symptoms to include: Acute symptoms (wheezing, coughing, phlegm production, respiratory infections), irritation of the eyes, nose and throat, headaches, dizziness, rashes, muscle pain and fatigue, respiratory and cardiovascular hospital admissions, emergency department visits and primary care visits, days of restricted activity, work and School absenteeism, physiological changes (e.g. lung function), inflammation, death due to cardiovascular and respiratory disease, chronic respiratory disease incidence and prevalence (infections, asthma, COPD, chronic pathological changes), chronic changes in physiologic functions, intrauterine growth restriction in women (low birth weight at term, intrauterine growth retardation, small for gestational age), pneumonia, lung cancer, chronic cardiovascular disease and stroke [39]. In fact, according to the United Nations, up to 7 million people die each year due to air pollution, which contains PM_{10} and $PM_{2.5}$ [40].

Negative ions electrically charge PM which precipitate more rapidly than uncharged ones. Sawant et al. [41] studied how a negative electric discharge voltage generator can reduce fog and smoke. They did tests in a dark room with two identical glass containers. They found that in absence of ions emission the particulate matter decreased slowly with time, due to the natural sedimentation and diffusion. By opposite, the reduction of particles concentration with negative ions generator was faster and results are reported in the figure below.

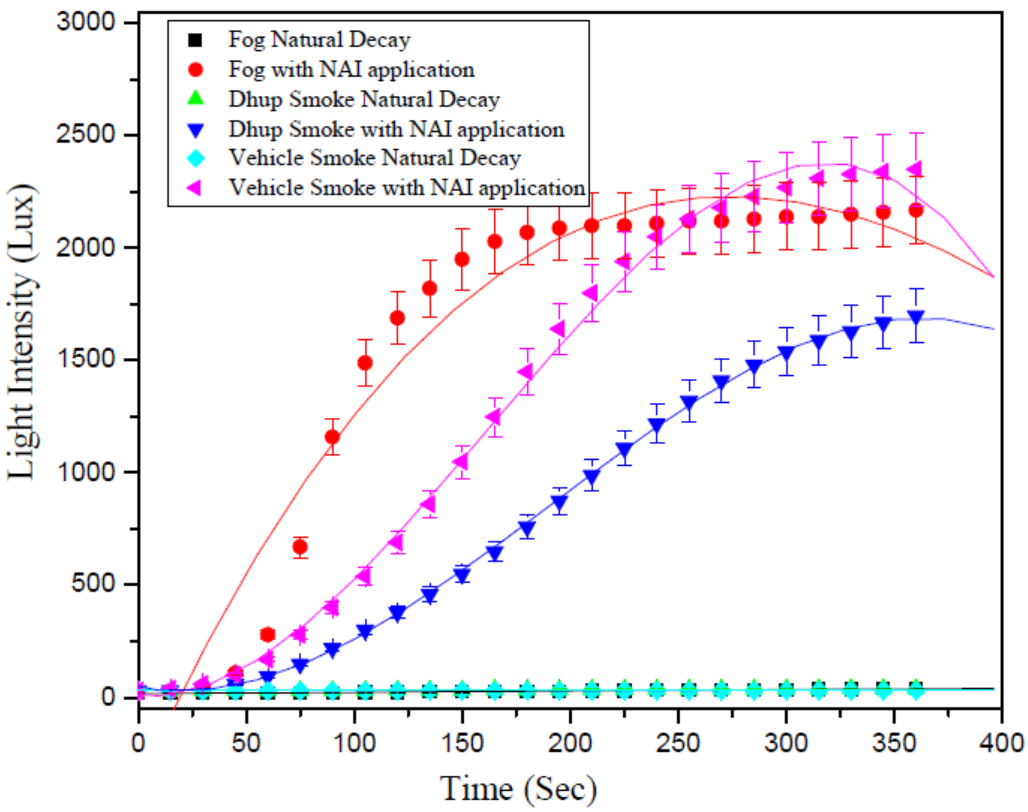


Figure 5 Particle concentration decay.

In figure 5, the natural versus ionizer induced decay of particulate is shown. The results showed that negative air ions can almost completely remove pollutants from air in a closed chamber in short time. The rate of fog removal is higher than smoke. Hence, the particle removal depends on the type of substance, ion emission rate and time of emission.

7. Effect of air ionization on dust mites

The study of Abidin et al. [42] demonstrated the increased mortality of dust mites due to negative ions generated by an ionizer. Mites are the main source of allergens in humid areas and they are a potential risk for rhinitis, asthma and atopic dermatitis. Nowadays, there are several ways to reduce allergic symptoms induced by mites which include chemical substances, the use of allergen impermeable covers for mattress and pillows and the maintenance of room humidity lower than 50%.

Ionizers represents a simple and efficient solution to reduce allergen concentration in domestic environments. Abidin et al. [42] investigated the efficacy of a commercial ionizer on two types of mites: Dermatophagoides pteronyssinus and Dermatophagoides farinae. The results showed increasing mite mortalities on exposed surfaces like floors, clothes, curtains, etc, with increasing exposure time. The mean mortality of mites after 24, 36, 48, 60 and 72 hours was higher for D. farinae. The better result obtained for D. farinae indicates that different species respond in a different way.

8. Ions interaction with surfaces

Shepherd et al. [43] studied the effect of air ionization on bacterial contamination of plastic medical equipment. Several studies reported the positive action of ions in air but the role of ionizers on bacterial dissemination and deposition on materials surfaces has largely been ignored. Shepherd et al. reported a study in which a significant reduction of *Acinetobacter* infection was measured in presence of negative air ionizers. *Acinetobacter* is a microorganism responsible of respiratory tract infections associated to contamination of ventilators and other respiratory therapy equipment.

The authors hypothesized that negative ions charge plastic medical equipment which then repel, instead of attract, airborne bacterial. The study was conducted in a mechanically ventilated room characterized by ambient conditions. Their aim was to measure the changes in surface potential of plastic medical equipment exposed to negative ions produced by a unipolar air ionizer.

The ion count measured less than 1000 ions/cm^3 when the ionizer was switched off and 28800-85600 ions/cm^3 when the device was switched on. The results indicated that negative ions significantly alter the surface potential of many plastic equipment which developed a negative charge as shown in figure 6 and 7.

When the ionizer is switched on, the airborne particles gain negative charge and the electrostatic repulsive force ensures that particles are repelled from the surface of medical equipment. The result is a lower contamination of the surfaces.

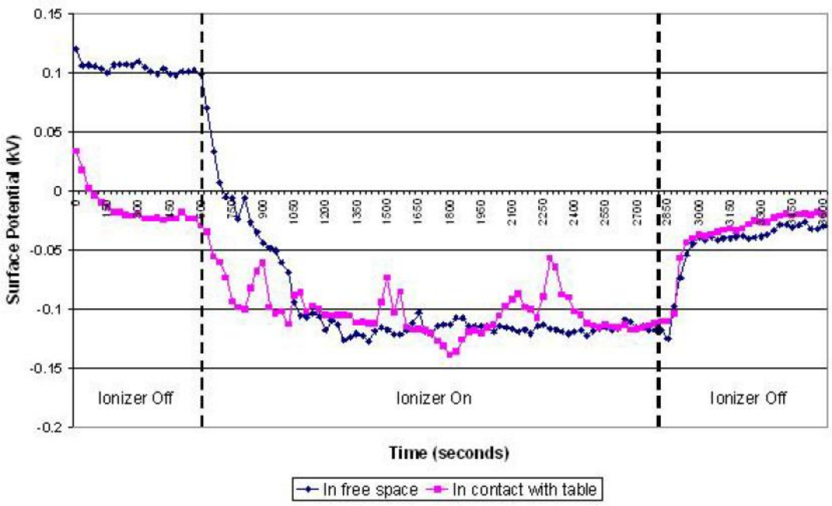


Figure 6 Change in surface potential over time on the surface of the face mask in presence of negative air ions. [43]

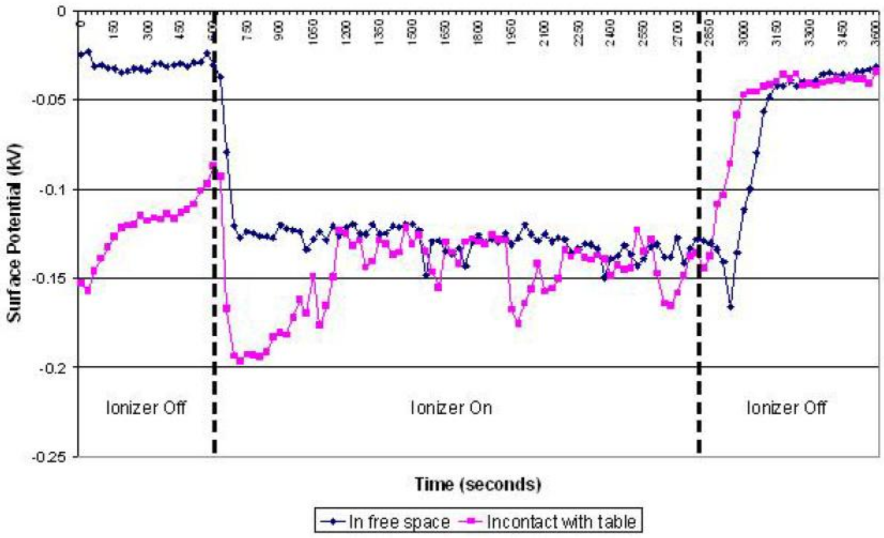


Figure 7 Change in surface potential over time on the surface of the nebulizer tubing in presence of negative air ions. [43]

The results obtained for the Unometer were very different from the other medical equipment and shown in figure 8. This is because it was made of styrene acrylonitrile which is more positive triboelectric than PE or PVC. Indeed, Styrene acrylonitrile is a polymer able to hold both negative and positive charges for hours due to its high electrical resistivity. Thus, the results found indicated that air ions could change the surface potential of material with benefits against air particles contamination depending on the triboelectric properties on the material itself.

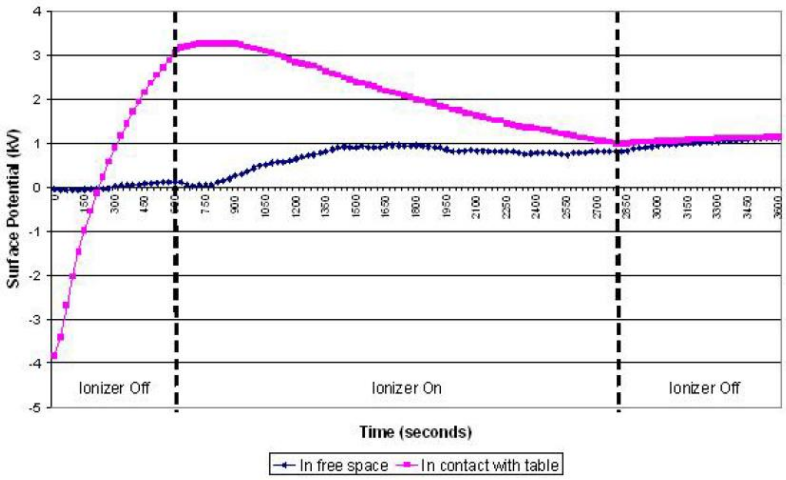


Figure 8 Change in surface potential over time on the surface of the Unometer measuring chamber in presence of negative air ions. [43]

9. Air ion decay

Jiang et al. [1] reported that generated negative ions are not stable and they gradually decay. If negative ions are combined with water their life is longer. For example, the average life of negative oxygen ions generated by the Lenard effect is around 60 seconds while ions produced by corona discharge can survive only for few seconds.

Forney et al. [44] reported that air ions are short lived, in particular they highlighted that positive ions have a longer life than negative ones. Indoors the life of an ion is much shorter due to the increased probability of interaction with walls and surfaces. They stated that in confined spaces, ions may live only for about 30 seconds. In addition, high humidity and air pollution are factors which increase ion precipitation.

According to Jiang et al. [1] the intensity of the electric field has a huge impact on ion life, and this is way different lifetimes may be reported by several studies. This is confirmed also by Bailey et al. [45] who underlined that the concentrations of air ions in natural or experimental environment may be similar, but lifetimes of these ions may not be the same.

10. Ion measurement

Sinicina et al. [46] studied the mathematical relationship between air ions concentration and the factors influencing it. Negative ions are smaller than positive ones and they can move faster in the electric field. As shown in figure 9 negative ions are characterized by a mobility of about 1.9 cm^2/Vs while positive ions of about 1.4 cm^2/Vs.

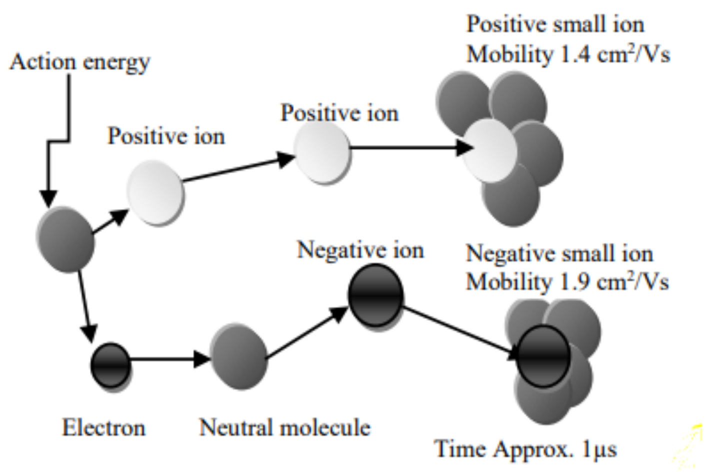


Figure 9 Illustration of negative and positive air ions. [46-47]

The effect of air ions on human health depends on their concentration, in particular the unipolarity coefficient (K) describes the proportion between them:

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

Where N^+ and N^- refer to the mean concentrations of positive and negative ions. The authors compared air ions concentrations in indoor environment (118 x 110 x 94 cm) with plants and air ionizer against plants only. Measurements were made with bipolar air ion counter "Sapfir-3M" with a minimal resolution of 10 ions per 1 cm^3. The results are reported in table 1. Measurements of air ions concentrations indicated that in 3 cases the number of positive ions was higher than negative ones: 41% with plants, 5% with an air ionizer and 52% in an empty box. In case of air ionizer and plants the number of negative ions was greater than positive ones. However the higher concentration of ions was measured in the experiment with the air ionizer only (N^+_{max} = 199292, N^-_{max} = 201821).

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	

Table 1. Air ions measurements in 4 cases: plants only, air ionizer only, plants and air ionizer, empty box. [46]

As shown in figure 10, the maximum number of ions detected was during night, while the concentration decreased during the day. The author explained this result as follow: negative charged surfaces are characterized by electrons which flow through the dielectric surface. When an electron separates the surface becomes positively charged and lead to a change in air ion concentration.

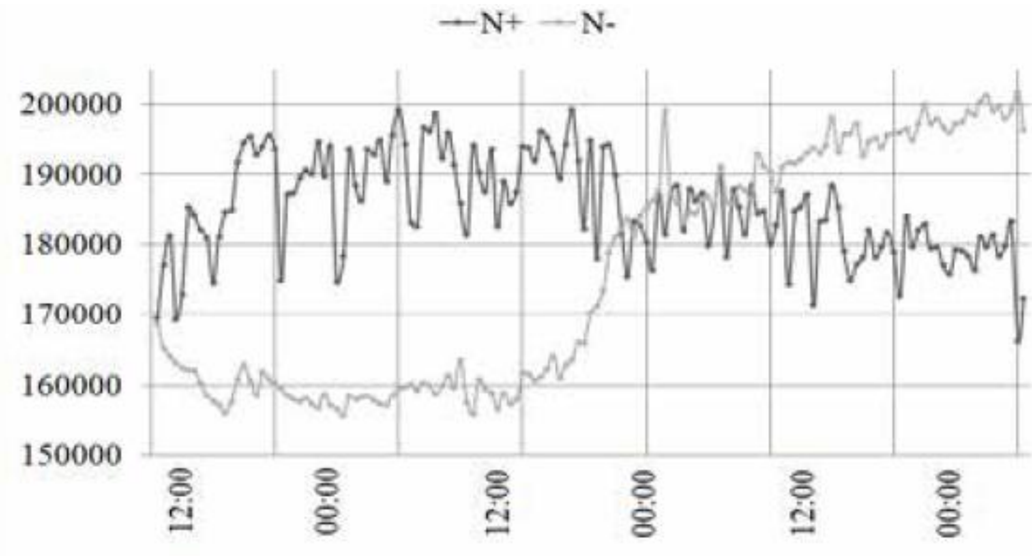


Figure 10 Illustration of the concentration of negative and positive ions generated by air ionizer with respect to time. [46]

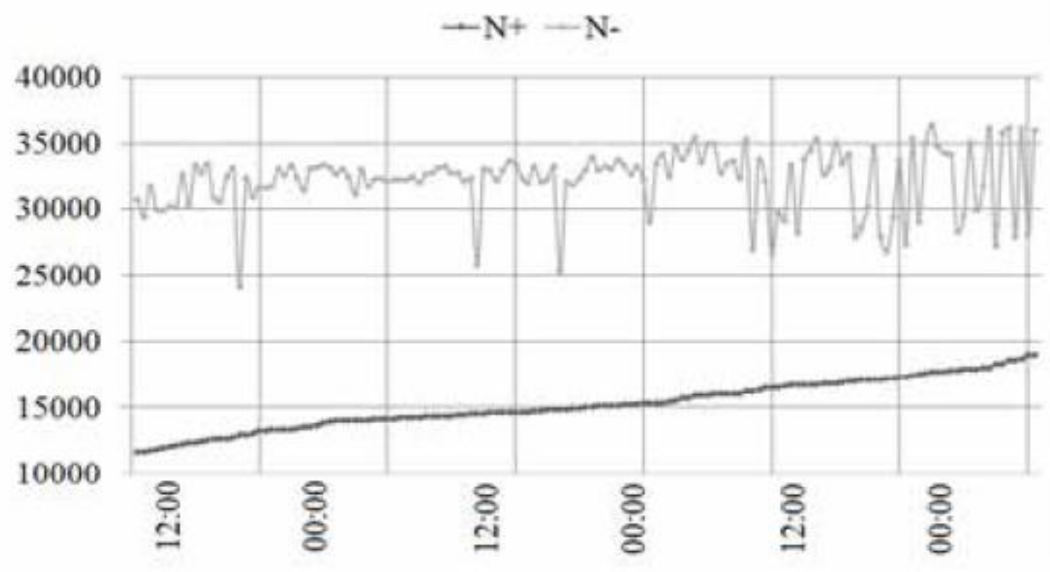


Figure 11 Illustration of the concentration of negative and positive ions generated by air ionizer and plants with respect to time. [46]

The presence in the indoor environment of both the ionizer and plants resulted in a constant concentration of positive ions and a slightly increasing concentration of negative ones (figure 11). However, the number of ions was lower with respect to the air ionizer only.

Hirsikko et al. [48] explained different instruments for air ion measurements:

Integral aspiration counter

It was introduced in the first studies of air ions and it is called Gerdien condenser because it became popular after Gerdien's publications [49-50]. The instrument is characterized by a steady voltage applied across two coaxial electrodes of an integral aspiration condenser and the space between the electrodes is ventilated with an air flow. The air ion concentration is fluctuating in the atmospheric ground layer due to turbulence and the atmospheric electric field. This instrument is characterized by a very low mobility resolution, hence it allows to distinguish only a few groups of air ions in a wide mobility range.

Single-channel differential aspiration spectrometers

With this type of measurement, ions are collected into a collector ring or plate. The effect of ions concentration fluctuations is partially suppressed with respect to integral aspiration counter. Ions are collected inside the condenser and the electric current generated by ions is measured with an electrometer connected to the electrode. Hewitt [51] replaced the divided electrode in the differential aspiration condenser with a divided output air flow. This type of device is also known as a Differential Mobility Analyzer. The number of ions is measured with a condensation particle counter (CPC) which can be used in case of large ions.

Multichannel aspiration spectrometers

In this case, the collector electrode is divided into many rings, and ions are measured simultaneously. This allows shorted time to obtain the whole spectrum, in addition to other advantages. First of all, data is collected simultaneously with several electrometers and the full distribution is measured directly when the signal from a single channel becomes available. Additionally, simultaneous measurements allow to avoid errors associated to fluctuations of air ion concentrations. The major disadvantage of this type of instrument is the construction and calibration, which leads to high costs and complex maintenance.

Patil et al. [52] presented an effective method for measurement of air ions of different size using a Gerdien condenser. A potential difference was applied across the Gerdien, air ions of the same sign of the voltage were repelled from the outer electrode and attracted to the central electrode. These ions generated a small current which was measured to obtain ion concentration. Different bias voltages were needed since air is characterized by different sizes of ions according to atmospheric changes. The authors used a new programmable ion counter which allowed to measure automatically results for small (radius ~ 0.5nm), intermediate (radius between 1 and 3 nm) and large (radius > 3nm) ions. They found that the concentration of large and small ions during the day was more or less the same, with diurnal and night variations. In contrast intermediate ions were characterized by a much regular trend during the day.

They compared the concentration of negative ions in February and in October in Pune (India), as reported in figure 12.

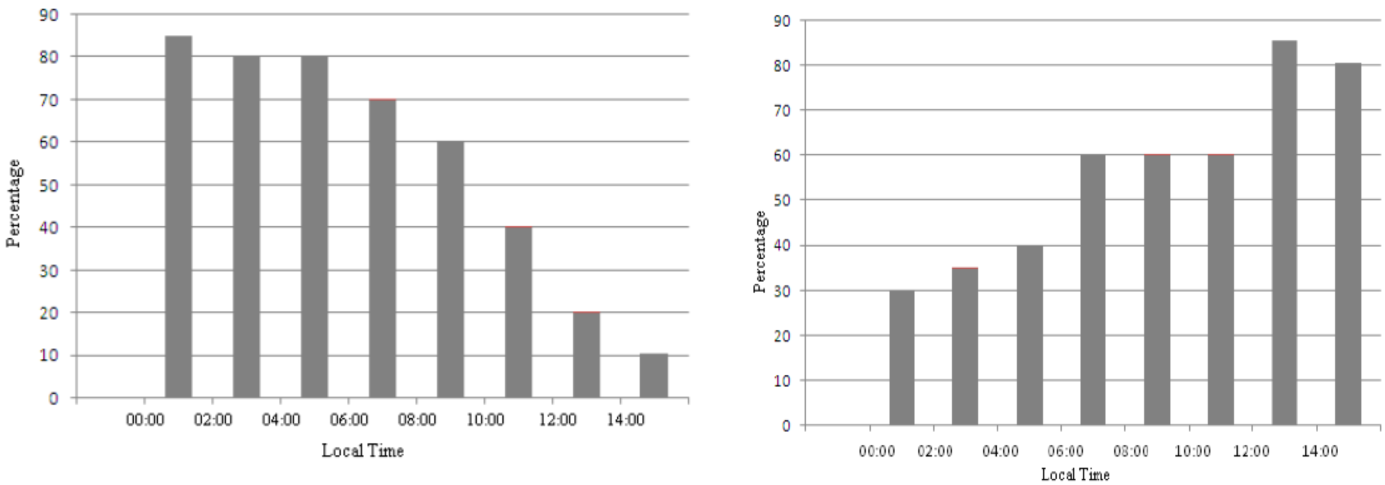


Figure 12 On the left negative ion concentration in February; on the right negative ion concentration in October. [52]

The trend of these graphs explained that air ion concentration depends on climatic condition and the purity of air. In February, low concentration of ions during the day was measured and it was probably related to the intense traffic and the presence of pollutant particles. In October the air ion concentration was higher during the day thanks to wind and rain which characterized the monsoon season, while it was lower during night hours since wind speed and solar radiation intensity decreased.

Lehtimäki et al. [53] studied air ion concentration with the aspiration condenser method. This method is based on the measurement of the electric current generated by ions drifting from the sample air flow to the measuring electrodes:

$$I_p = e \cdot F \left[\int_{k_0}^{\infty} f_p(k)dk + \left(\frac{1}{k_0}\right) \int_{0}^{k_0} k f_p(k)dk \right]$$

Where *e* is the elementary charge, *F* is the sample air flow, *k* is the ion mobility, k_0 is the critical mobility of the aspiration condenser, $f_p(k)$ is the mobility distribution of positive ions. The same expression can be written for negative ions (I_n) by using the mobility distribution of negative ions.

In figure 13, the relationship between ions and aerosol particles concentration is reported. It can be notice that ion concentration is strongly dependent on particle concentration, in particular it decreases when particles number increases. The concentration of air ions for different corona voltage was measured at a distance of about 1.3 meters.

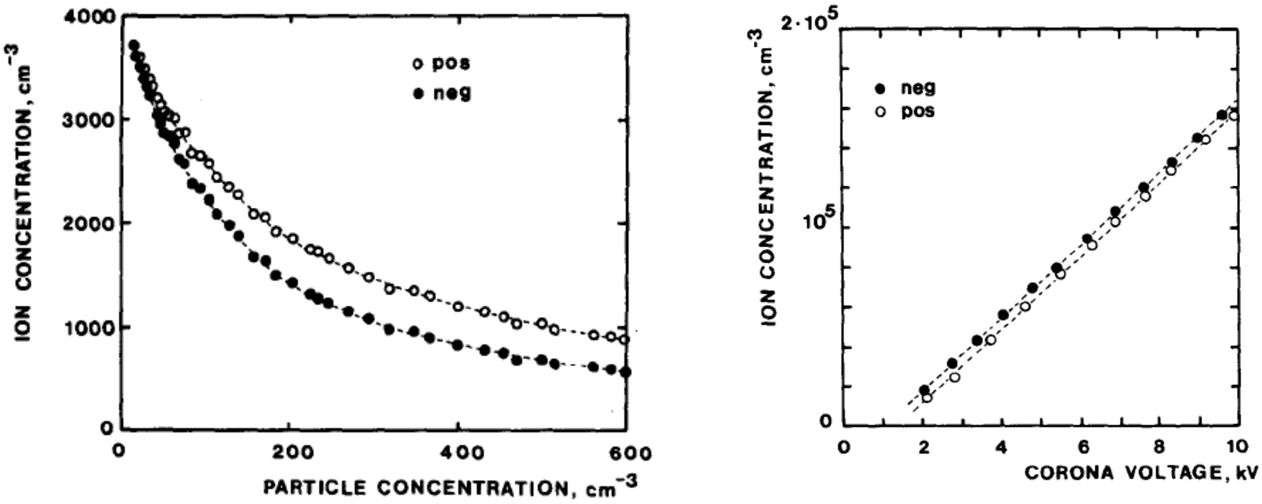


Figure 13 On the left ion concentration versus particles concentration; on the right ion concentration versus corona voltage. [53]

Hirsikko et al. [54] measured air ion size distribution using an air ion spectrometer (AIS) in the size range of 0.34-40.3 nm in Finland, both indoors and outdoors. They studied also particle number concentrations and size distributions. The device they used consisted of two identical cylindrical aspiration-type differential mobility analysers, one for positive and the other one for negative ions. They measured the indoor total particle number concentrations with two Condensation Particle Counters (CPC). The authors found that the concentration of small, intermediate and large air ions had a different daily cycle between the working days and weekends, both indoors and outdoors. As shown in figure 14, ion concentrations were quite stable throughout the day during the weekend and indoor concentrations are 2-3 times higher than outdoors.

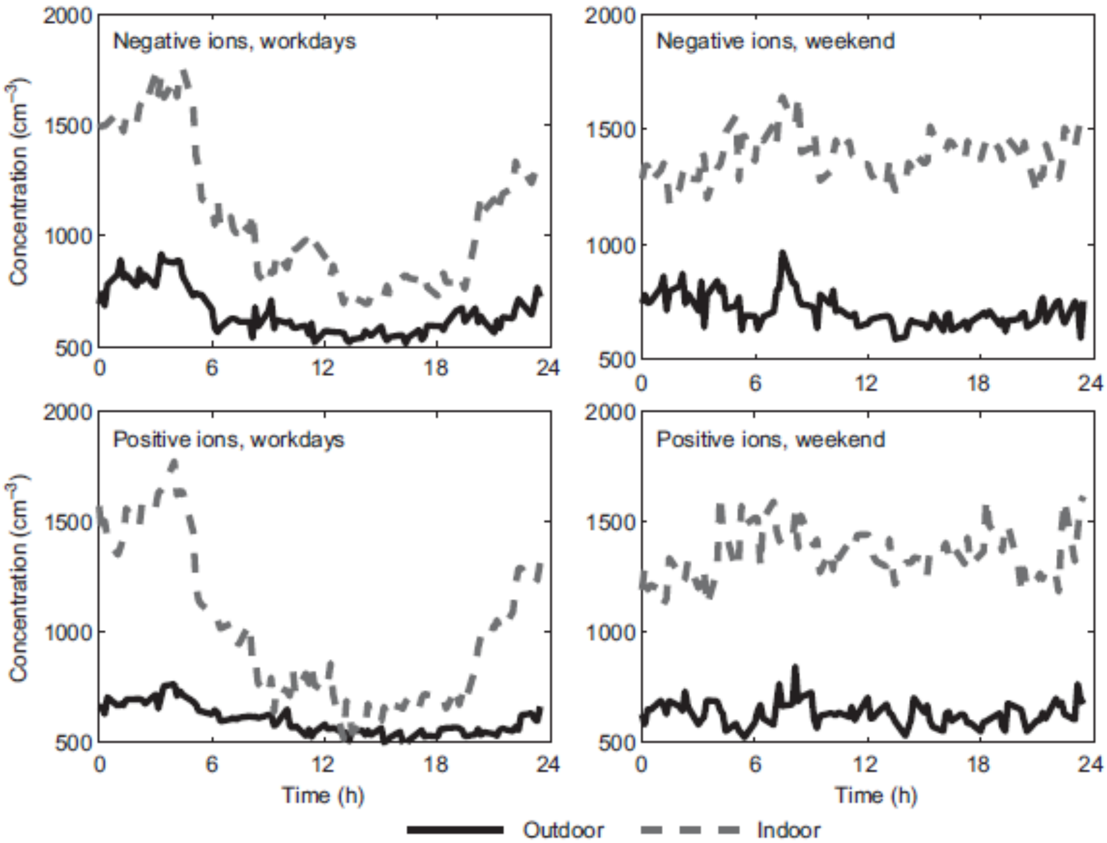


Figure 14 Positive and negative air ion concentration during the day on workdays and on weekend. [54]

Aplin [47] described the Gerdien device (figure 15) for measurement of air conductivity. The hollow cylinder known as the outer electrode contains a thinner central electrode which is frequently a solid wire. When a potential is applied across the electrodes and the tube is ventilated, air ion with the same sign of the voltage are repelled from the outer electrode and attracted to the central one.

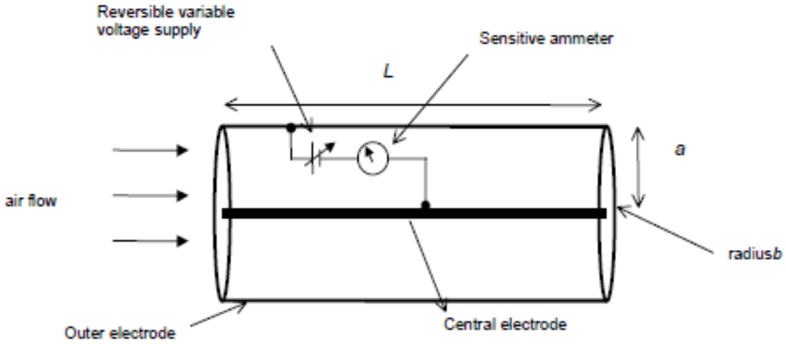


Figure 15 Illustration of the Gerdien condenser. [47]

The author reported the study of Chalmers [55] in which the charge decay was computed. In particular:

$$Q = Q_0 \exp\left(-\frac{\sigma t}{\varepsilon_0}\right)$$

Where σ represents the conductivity, ε_0 the permittivity of free space and *Q* the charge. The formula indicates that the charge will decay exponentially with time t from the original value Q_0. The rate of the decay is related to ion concentration.

Patil et al. [56] developed an ion counter based on Gerdien condenser using an operational amplifier AD549JH with low input current and low input offset voltage. The instrument allowed to detect ions with diameter lower than 1.45 nm and mobility range > 0.77 10^{-4} m^2/Vs.

Bartusek et al. [57] studied air ion concentration using a Gerdien condenser characterized by inner and outer electrodes of elliptical shape. This allowed to had laminar air flow and the results showed a reduction of systematic error of measurement. It allowed measuring air ion concentration with a sensitivity > 100 ions/cm^3.

Alonso et al. [58] investigated air ion mobility using a Differential Mobility Analyzer (DMA) of high resolving power. The sketch of the DMA is presented in figure 16.

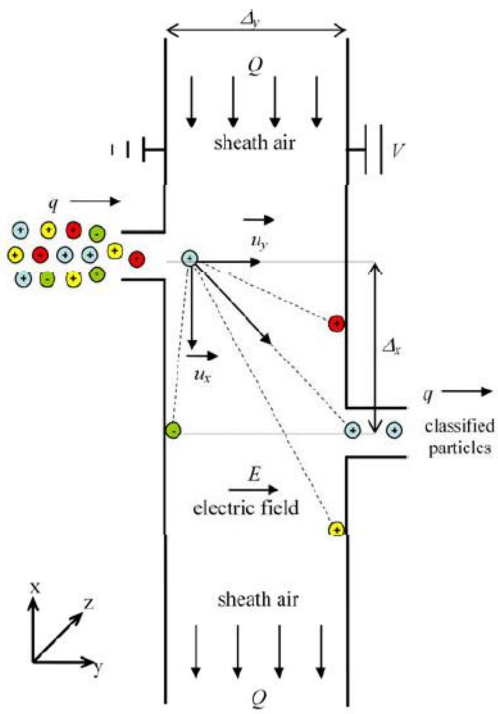


Figure 16 Sketch of DMA. [58]

The core of the DMA is the classification region where the electric field is perpendicular to sheath flow. Ions, which enter in the classification region through the inlet, move under the influence of the electric field and the sheath flow. The authors reported the mobility distribution of negative and positive ions generated by corona discharge for different corona voltages, as shown in figure 17.

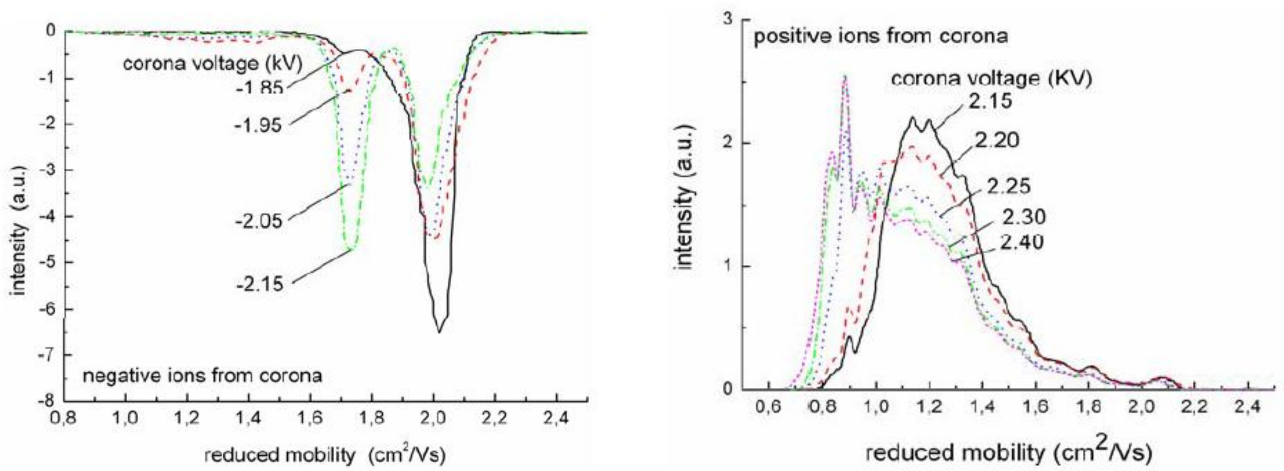


Figure 17 On the left mobility spectra of negative air ions as a function of the corona voltage, on the right mobility spectra of positive air ions as a function of the corona voltage. [58]

Mirme et al. [59] presented a new multi-channel air ion spectrometer (AIS) characterized by high resolution, low instrumental background for concentrations and stable and long operation time. The authors described the design of the AIS, its main specifications, instrument calibration and testing. The devices allowed to detect the presence of ions with a diameter smaller than 1 nanometre.

10. Periso SA Ions measurement

The study of Guerra [60] describes how Periso SA assess air ion concentrations. Periso SA developed the Meteoline uP-2000 series which consists of:

- Ion meter PN-2001 to measure positive and negative ions simultaneously;
- EEP – 2002 Electrometer for measuring the electric earth potential;
- AGC – 2003 Picoammeter to measure the air-to-earth current;
- DA – 2004 Data acquisition system for traditional atmospheric parameters;
- E – 2005 Expander to interface and manage complex systems.

As reported in several works in literature, the air contains a large number of electrically charged oxygen, water particles, and/or air ions, which are classified into three groups: small, medium and large.

Small ions are composed of electrically charged clusters of air gas molecules of considerable mobility (1 cm/s), small dimensions (0.001-0.003 μm diameter), and electrical charge (1.6×10^{-19} coulomb); they decay within a few seconds.

Medium ions contain larger clusters (0.003— 0.03 μm diameter) with slower mobility (0.5 cm/s). Lifetime is in the order of hours.

Large ions are sluggish ions with charges attached to dust particles, the hygroscopic particles, on which moisture condenses when clouds are formed. Mobility (0.005- 0.00005 cm/s); dimensions (0.001 mm). Lifetime is in the order of hours.

The most important natural sources of air ionization are the radioactive emanation from the earth's surface, different cosmic and meteorological influences, and ultraviolet solar radiation. Secondary sources are electrical charges created during storms, pollution, friction of winds, the Lenard waterfall effect, and so on.

Ions remain in the monomolecular state for a relatively short period. Thanks to the electrostatic forces involved, they will be regrouped to other molecules, forming aero-ions of different size as per the above-mentioned subdivisions. Measurement of the quantity and quality of air ions has not always been correct in the past, due mainly to difficulties incurred in measuring and because of problems in managing correctly the output data of a parameter with variations caused by different atmospheric physical factors.

Periso SA has therefore developed the 3rd generation of the Meteoline uP-2000 instruments, giving priority to the greatest accuracy, easy portability, ultra-sensitivity and reliability of the device.

Ion meter PN-2001 description

The instrument measures natural and artificial ion concentrations in gases and in the air. In figure 18 the system configuration of PN-2001 ion meter is shown. The system has been optimized for the stable measurement and recording of ultralow currents from very high source impedances, with very good protection against extraneous signals. The essential analog part of this instrument is a highly sophisticated low-noise circuit composed of an electrometer amplifier capable of measuring currents in the range of femtoamperes (10-15 A), and the 12-bit [+sign] analog to digital converter with excellent signal resolution enabling the measurement of concentrations as low as 10 ions/cm^3.

The PN-2001 unit uses a Z80-A microprocessor that performs all the functions of absolute and differential measurement, data storage and processing, data display and controls for unattended operation. The zero point is recalibrated automatically with every measurement cycle by the main program and by the sophisticated sensing and feedback control circuits.

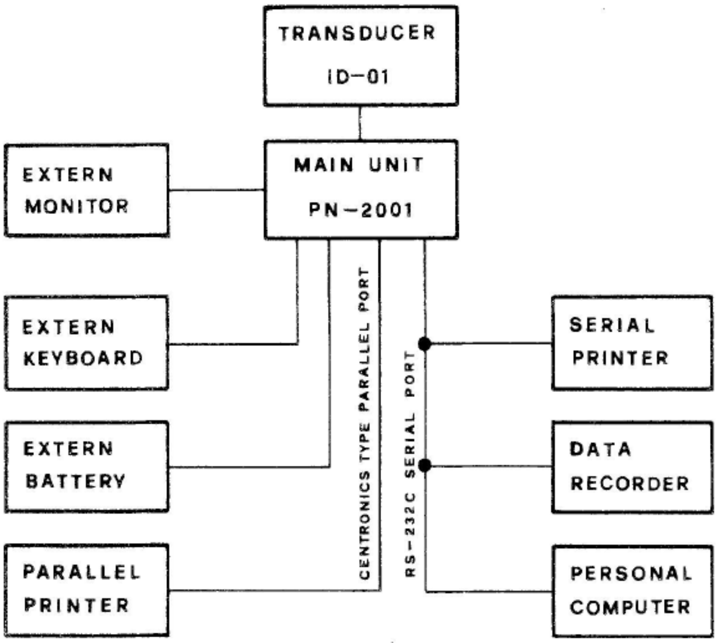


Figure 18 System configuration of PN-2001 ion meter.[60]

System components

The PN-2001 ions measuring system consists of two interconnected units: the control unit PN-2001 (figure 19) and the remote transducer module ID-01 (figure 20). The control unit consists of a compact lightweight console with a self-contained main power supply, rechargeable standby battery and the "intelligence" of the system. The keyboard allows the user to communicate with the system, the measured data and the status of internal functions.

Figure 19 View of the Control unit PN-2001.[60]

Figure 20 View of the remote Transducer module ID-01. [60]

The PN-2001 control unit is contained in a standard 19-in. enclosure and is perfectly shielded against random electrical noise.

The ID-01 transducer module (figure 20) contains two identical air-intake tubes that house the measuring electrodes and fans, all rigidly mounted in a shielded and sealed 19-in. metal casing, equipped with water splash-proof connectors. The entire ID-01 assembly is ruggedly constructed and weather protected, so it is capable of operating for a long period in high-humidity environments without particular attention.

Cylindrical aspiration tubes are used to minimize air flow turbulence and to satisfy our miniaturization needs for the most exact method for the determination of ion concentrations in gases or in the air. Ambient air is forced to flow continuously through the electrically charged coaxial capacitor with a precise speed of 1 m/s, with the fans controlled through an arithmetic program to ensure constant velocity.

The proper ions contained in this gas or air sample are deflected by the polarizing cylinder to the collecting electrode in which they neutralize themselves and generate a very small current proportional to the quantity of ions present. The resulting signal is delivered to the main unit to show the exact content of ions in a cubic centimeter. This cylindrical aspiration system is based on: the laws inherent to the mechanics of fluids, which are also applicable to gases; the ionic mobility, which means the drift speed that an ion can assume under normal conditions (20° C and 760 torr) in an electric field with an intensity of 1 V/cm; the speed of an ion submitted at a determined electric field E.

Considering the basic hypothesis for the aspiration system development, which allows us to state 1 liter/second the quantity of air or gas that must undergo the transformation process (namely to give up its charge), we can obtain this last parameter n with the well-known formula, which gives the ionic current as a function of the electron elemental charge e, the transformed air quantity Q, and the ions quantity n:

$$I = e \cdot Q \cdot n$$

The input signal delivered from the detector is applied to the first amplifier used in the inverting application as a current to voltage converter, through high-quality Teflon insulators. To realize the full potential of the electrometer amplifier and to obtain optimum circuit performances, particular components are used and special design rules are respected. The electrometer amplifier has a very low bias current, 0.2 femtoamperes/° C over a wide temperature range (0°-70° C). Minimizing the bias current is the only important consideration for our delicate first stage because in the inverting application, a DC error is produced at the inverting input of the amplifier. The value of such error is given from the multiplication of the bias current by the feedback impedance.

It appears that the bias current flow through the feedback impedance causes an output voltage error. The bias current limits the ultimate resolutions of current measuring circuits and causes an output drift.

$$Eo = -I_{in} \cdot Rf + (DC\ error)$$

$$DC\ error = I_{bias} \cdot Rf + Eos\ \left[1 + \frac{Rf \cdot (Rs + Rd)}{Rs \cdot Rd}\right]$$

$$Eos = input\ voltage\ off - set = \pm 5\ mV$$

Periso SA optimized the circuit performance by using: Teflon capacitors, precision glass encapsulated resistors, special reed relays, and a PC board in a guard-ring configuration to prevent current loops. The voltage off-set zero circuit managed and calibrated by the digital to analog converter card guarantee the zero point of the electrometer amplifier.

The main unit PN-2001 is provided with connectors for linking to other external system components controlled by the CPU:

- parallel port output, standard Centronics type, to connect a parallel type of dot matrix printer
- serial port output, RS-232C type, to connect a serial type of dot matrix printer, data recorder, and modem interface board or to allow communication between the PN-2001 and any computer system. The baud rate is selectable via key board by a proper escape sequence.
- composite video output: BNC plug, enabling the user to connect a professional monitor with a minimum bandwidth of 16-18 Mhz
- 12 Vdc input sockets: The user has the option to connect a 12-V external battery if required.

The electrical conductivity λ (lambda) of the atmosphere varies directly with both the concentration (n) and mobility (k) of ions present:

$$\lambda = e \cdot (n^{+}k^{+} + n^{-}k^{-})$$

where:

e = elementary charge = 1.6 × 10-19 coulomb;

n+ | n - = number of positive and negative ions per cubic centimeter;

k+ | k - = mobility factor of positive and negative ions, which is defined as the drift speed of an ion under standard conditions (20° C and 760 torr) in an electrical field intensity of 1 V/cm. In the measurement system, the ionic current on the electrodes is given by:

$$I = n \cdot e \cdot Q$$

where:

n = number of ions,

e = 1.6 x 10 -19 A/s,

Q = air or gas measured volume in cubic centimeters per second.

From the above-mentioned formula, the outcome will be:

$$n = \frac{I}{e \cdot Q} = \text{ions per cubic centimeter.}$$

The drift speed (vd) is expressed in centimeter per second and the electric field intensity (E), or gradient, is expressed in volts per centimeter, such as:

$$v_d = k \cdot E$$

Therefore, ion mobility is indicated by:

$$\frac{cm/s}{V/cm} = \frac{cm^2}{V \cdot s}$$

This may vary somewhat with the mass and charge of the ion as well as the physical and chemical properties of the medium. Moreover, charge-carrying particles vary in size and mass and, therefore, in mobility values. However, these variables are less significant for ions in the small-ion category, which have higher mobility factor values (k) which, by definition of “small ions” is always equal to, or greater than k = 0.85. The PN-2001 system is designed to measure only those ions with a mobility or drift speed of at least:

$$0.85 \, \frac{cm/s}{V/cm}$$

in the small-ion category.

Some of the ions in the immediately adjacent mobility range (medium ions) may also be measured, but such error is very small because the population of medium ions in a sampling environment is quite low since they aggregate very rapidly into large ions.

The mobility factor of the PN-2001 has been calculated with the following formula:

$$k = \frac{(r_2^2 - r_1^2) \cdot \ln\left(\frac{r_2}{r_1}\right)}{2 \cdot V \cdot l} \cdot V_L$$

where:

r1 =	Intern electrode radius
r2 =	Extern aspiration cylinder radius
l =	Cylindrical condenser length
ln =	Natural logarithm
V =	Voltage applied on extern aspiration cylinder
VL =	Intake air speed
right :	Intern
	Extern

Condensed technical specifications

PN-2001 Main unit

Range of measurement	From 0 to 400 millions of ions/cm^3, continuously, with auto-ranging system
Resolution	1000 ions out of 2.5 million (Analog to Digital Converter resolution)
Zero point	Automatic zero set
Warm-up	15 min to rated accuracy
Environmental limits	Operating from 0°-50° C at 80% non-condensing relative humidity
Power requirement	110/220 V, 50/60 Hz. Selectable with an external switch. The power supply is fan-cooled. Built-in 12 V/6.5 Ah battery for network-free operations
Power consumption	30 VA (typical)
Dimensions	46 × 48 × 15 cm
Accessories soon available	Memory and real-time clock expansion card

ID-01 Remote transducer

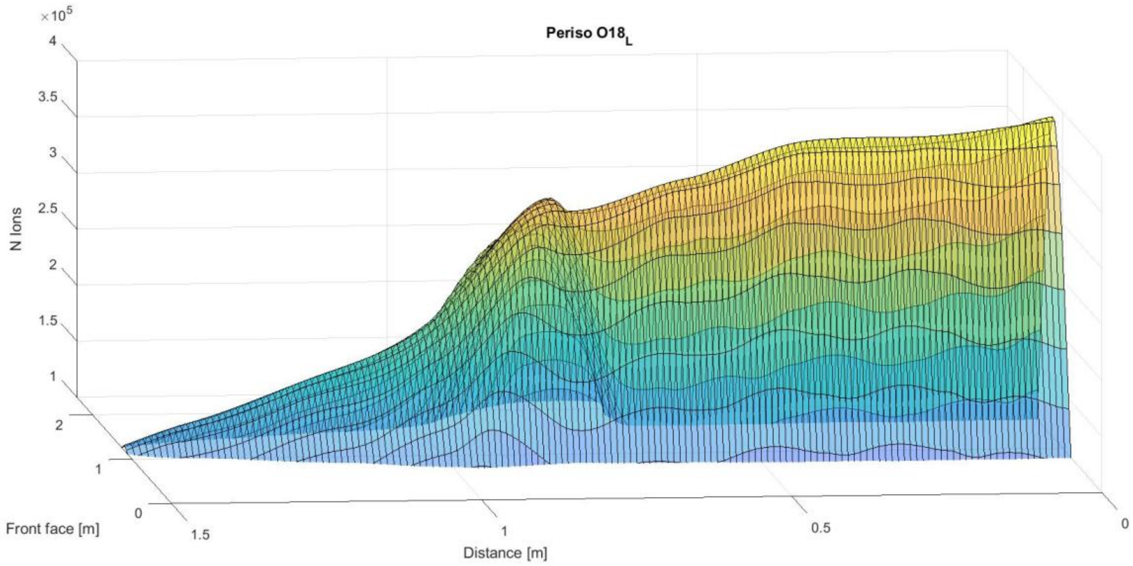
Measurable ions	
Polarity	Positive and negative independently and simultaneously
Size category	Small (0.001-0.003 μm diameter)
Threshold mobility	0.85 $\frac{cm^2}{V \cdot s}$
Intake air or gas	
Throughout volume	1.4 l/s
Measured volume	1 l/s
Controlled velocity	1 m/s
Output connectors	Water splash-proof type, Teflon-insulated
Dimensions	
Weight	7 kg
Size	48 × 15 × 26 cm
Accessories supplied	Cables (2), Special coax, 150 cm, for interconnection with PN-2001 Cable, control, 150 cm, for interconnection with PN-2001 Kit, cleaning, for dismounting electrodes and cleaning Teflon insulators
Optional accessories	90° rigid plastic elbows for outdoor use, to protect aspirated airstream from wind and rain, trolley for indoor applications, aluminium tables set for outdoor measurements, aluminium bags for easy and safe transport

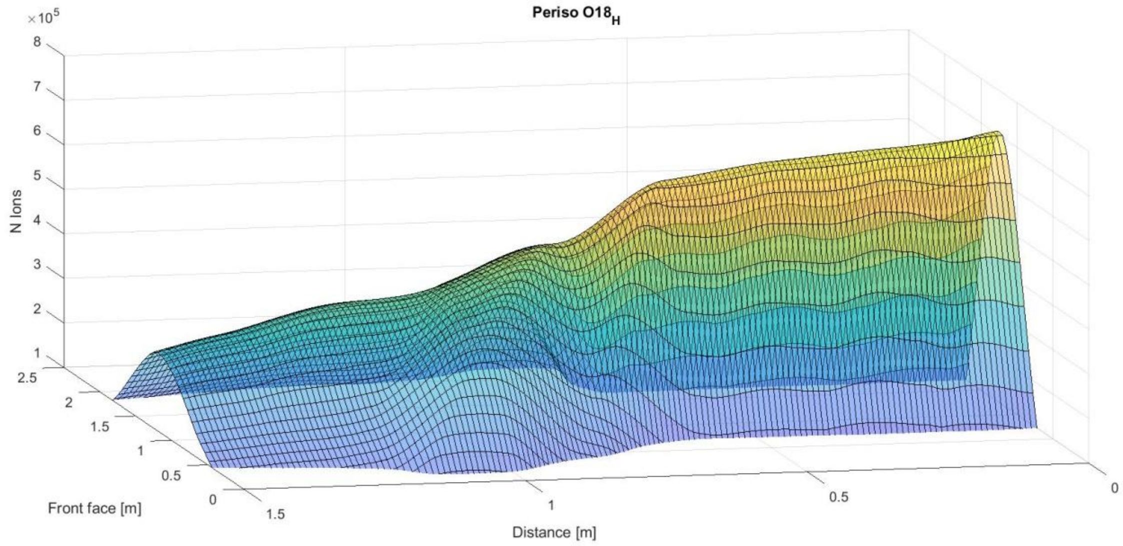
11. AERSwiss Pro Ion measurement results

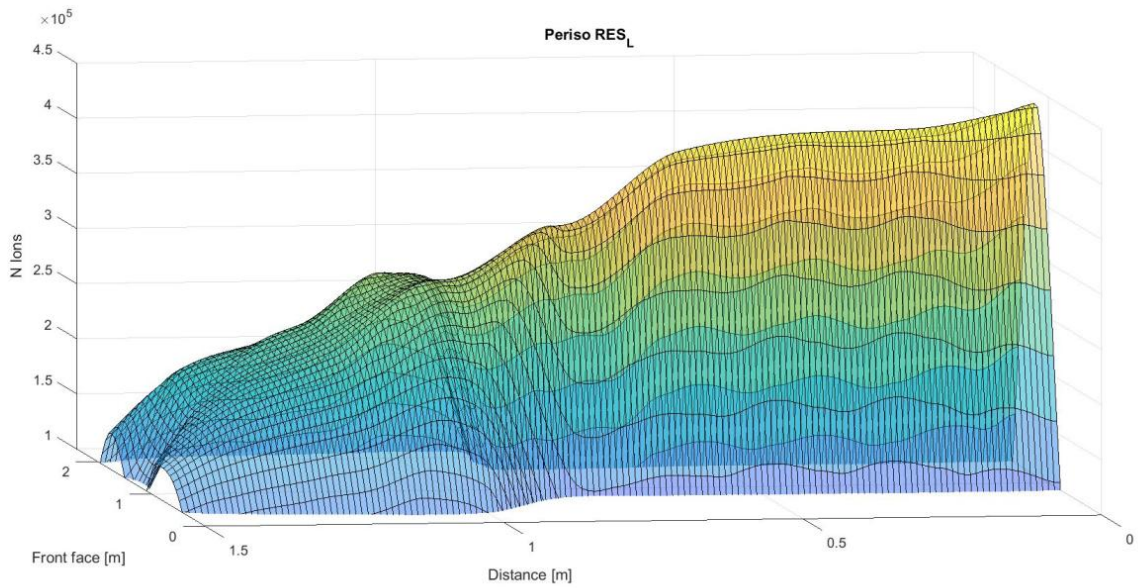
Periso SA measured the ions propagation on three versions of the AERSwiss Pro Blue unit.

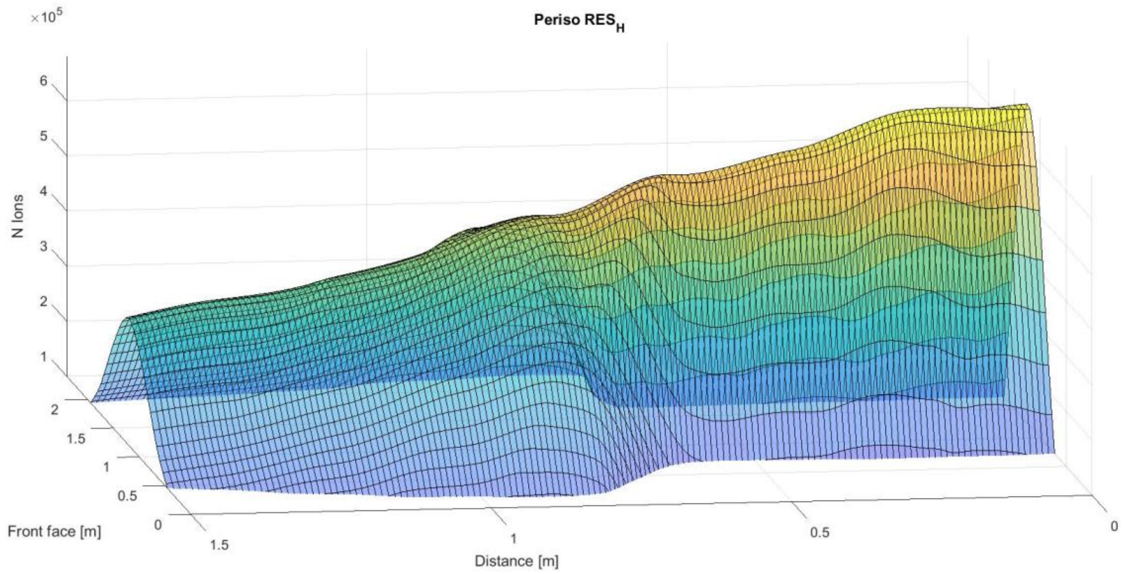
Below it is possible see the ions generated on:

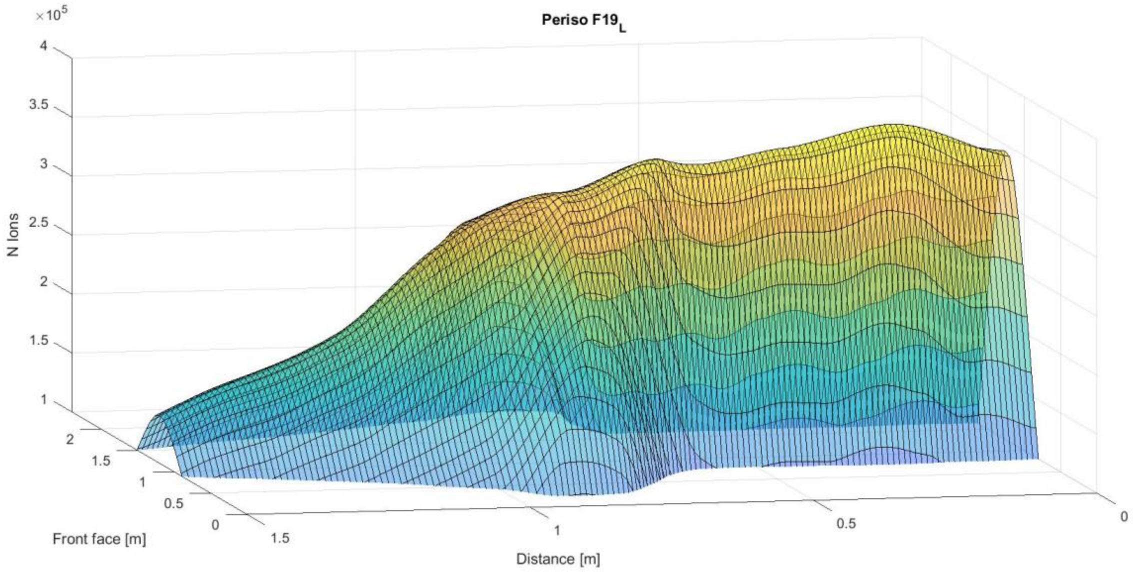
1. Blue unit first version, minimum speed (Periso O18L) and maximum (Periso O18H) speed of the fan.
2. Blue unit resistor version, minimum speed (Periso R18L) and maximum (Periso R18H) speed of the fan.
3. Blue unit version of February 2019, minimum speed (Periso F18L) and maximum (Periso F18H) speed of the fan.

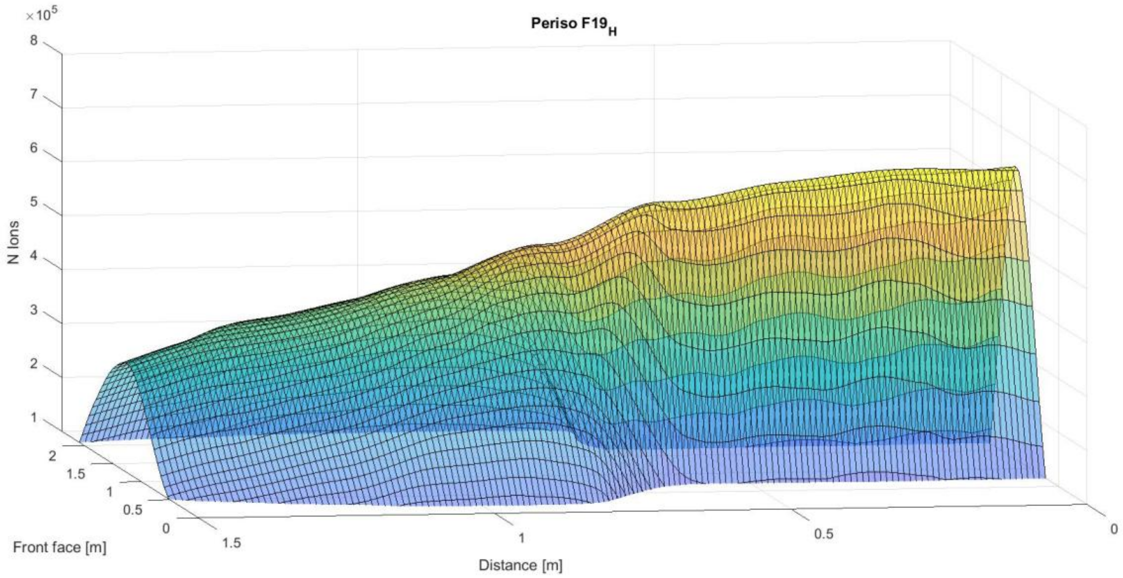



Periso O18$_H$
$\times 10^5$
N Ions
Front face [m]
Distance [m]


Periso RES$_L$
$\times 10^5$
N Ions
Front face [m]
Distance [m]


Periso RES$_H$
$\times 10^5$
N Ions
Front face [m]
Distance [m]





Through the results it is possible to see how the differences in flow rates between the fans affect the number of ions generated.

In particular it is shown that the minor air flow which characterizes the Blue version of February 2019 generated more ions, because there are not turbulences in the fan. Vice versa the previous version of the Blue unit is characterized by higher flow rate but a lower number of generated ions.

The speed of the ions depends only on the chemical bonding between ions and the other particles in the environment.

12. AERSwiss Pro ambient particle removal measurement results

Periso SA measured the dust abatement of the AERSwiss Pro Blue unit. The operator created a saturated environment and measured the particles with:

- Low speed of the Blue unit
  Results:

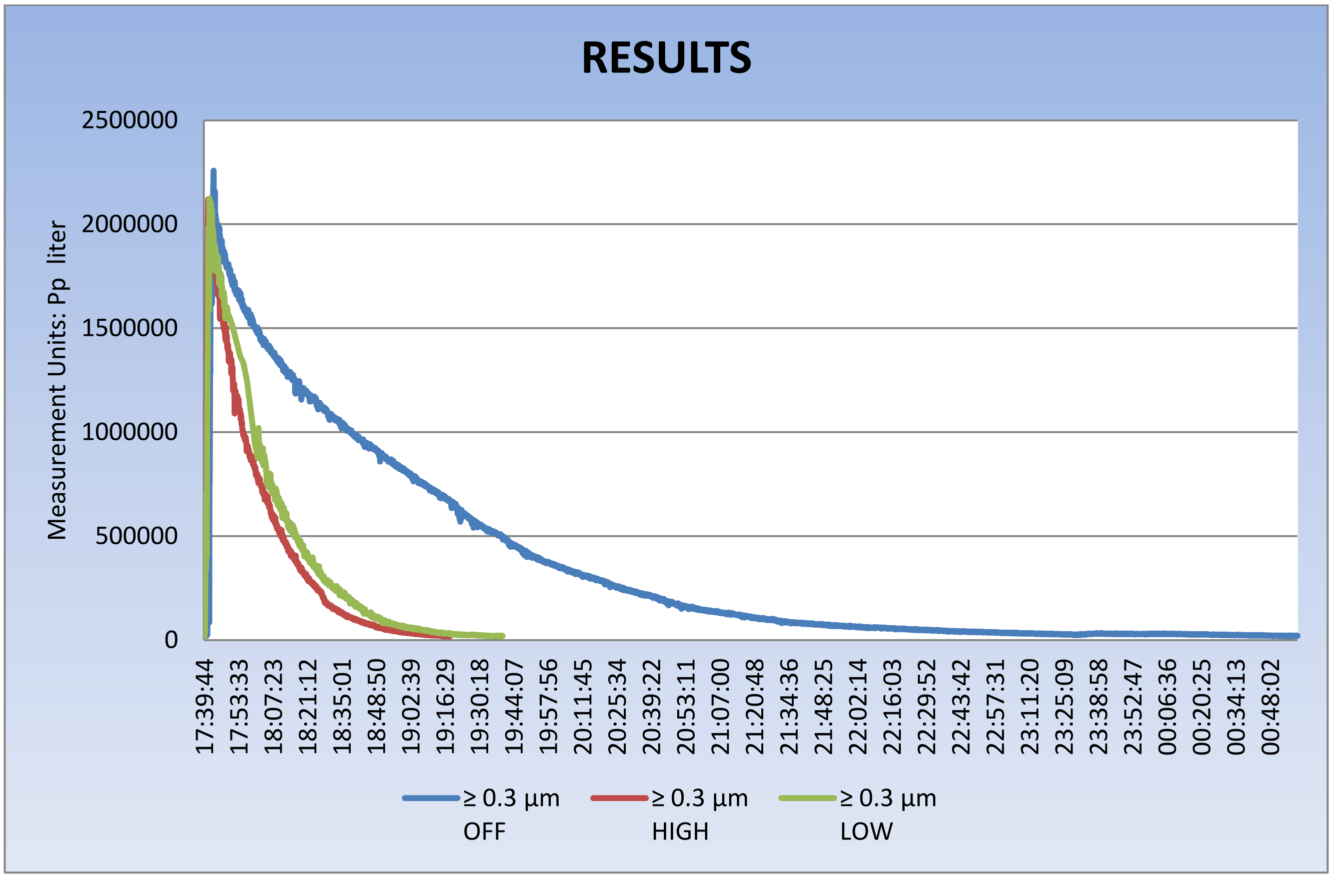
PARTICULATE MATTER			
TIME	**Numbers of particles ≥0.3μm**	**Smoke generator**	**Device AERSwiss Pro Blue**
START	18.216	ON	OFF
After 2 minutes	1.987.427	OFF	ON (Low)
After 120 minutes	19.806	OFF	ON (Low)

- High speed of the Blue unit
  Results:

PARTICULATE MATTER			
TIME	**Numbers of particles ≥0.3μm**	**Smoke generator**	**Device AERSwiss Pro Blue**
START	19.770	ON	OFF
After 2 minutes	2.118.001	OFF	ON (High)
After 100 minutes	20.374	OFF	ON (High)

- Unit off
  Results:

PARTICULATE MATTER			
TIME	**Numbers of particles ≥0.3μm**	**Smoke generator**	**Device AERSwiss Pro Blue**
START	20.012	ON	OFF
After 2 minutes	1.950.369	OFF	OFF
After 100 minutes	666.009	OFF	OFF
After 120 minutes	495.559	OFF	OFF
After 420 minutes	20.374	OFF	OFF



TEST	BREAKAGE TIME PARTICLE (Min)	AERSwiss Pro Blue
1	120	Fan Low
2	100	Fan High
3	420	Fan OFF

Through the results it is possible to see how the device works, in particular the time of abatement with the device is reduced 4 times with respect to a normal situation without the Blue unit.

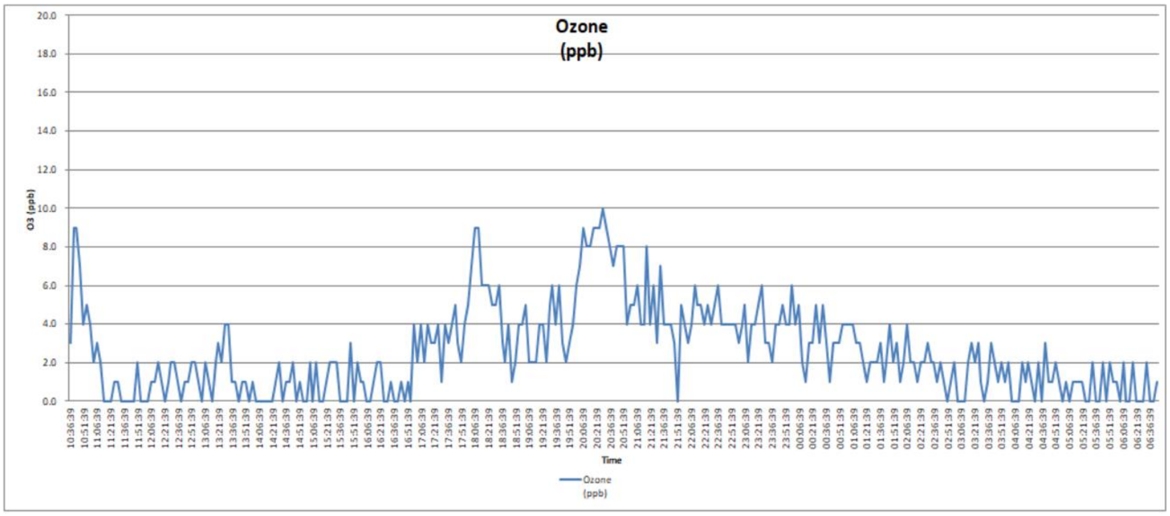
13. AERSwiss Pro zero ozone production measurement results

Periso SA measured ambient ozone levels with the AERSwiss Pro Blue unit, both with the unit running and also with a control room, no unit running:

REPORT DI VALUTAZIONE
EMISSIONI DI OZONO

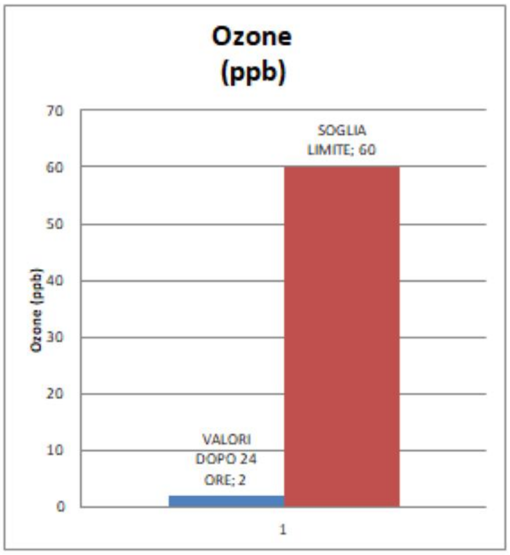
APPARECCHIO MISURATO:	**AERSwiss Pro Blue**
Luogo:	Lab. 2 Pazzallo
Data:	23 luglio 2019
Volume ambiente:	20 m^3
Strumento di misura:	Mod. 106-L Ozone Monitor

MISURAZIONI AMBIENTALI CON APPARECCHIO SPENTO



LIVELLO DI OZONO (ppb)

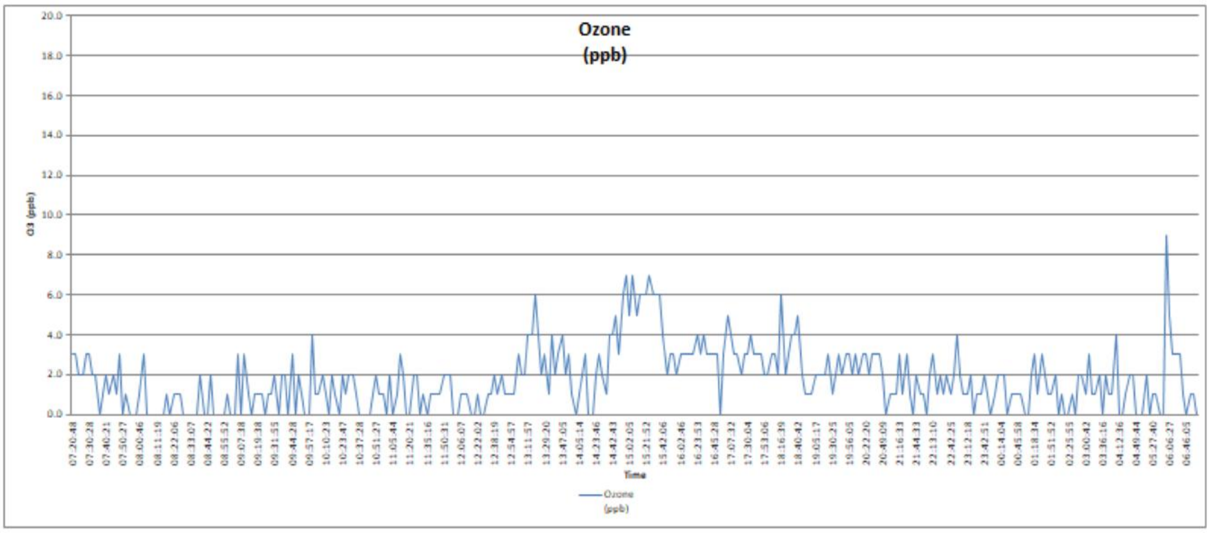
VALORI INIZIALI	VALORI MEDI	VALORI DOPO 24 ORE	SOGLIA LIMITE
5	2.6	2	60



REPORT DI VALUTAZIONE
EMISSIONI DI OZONO

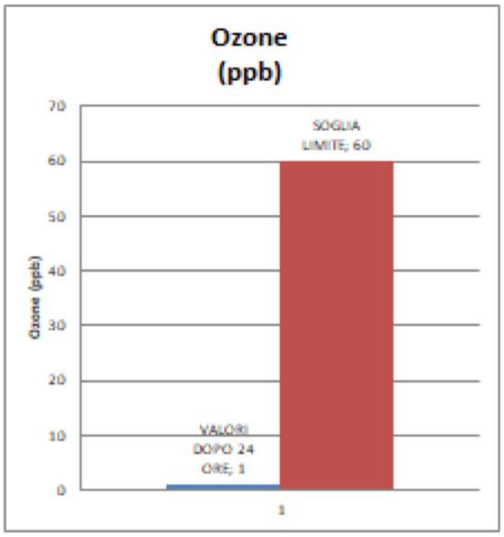
APPARECCHIO MISURATO:	**AERSwiss Pro Blue**
Luogo:	Lab. 2 Pazzallo
Data:	24 luglio 2019
Volume ambiente:	20 m^3
Strumento di misura:	Mod. 106-L Ozone Monitor

MISURAZIONI AMBIENTALI CON APPARECCHIO ACCESO (Vel. 2)



LIVELLO DI OZONO (ppb)

VALORI INIZIALI	VALORI MEDI	VALORI DOPO 24 ORE	SOGLIA LIMITE
3	1.8	1	60



Test eseguito da:

Aldo Volo
(*Product Managar*)

Pazzallo, 24.07.2019

It was determined that the AERSwiss Pro Blue unit does not produce Ozone as part of the ionization process of the unit [24].

PERISO SA
technology that evolves

Pazzallo, 18/09/2019

Subject: Declaration of no ozone production

Dear Customer,

We certify that our devices for air ionization models AERSwiss PRO Blue and AERSwiss PRO Gold do not produce ozone.

This evidence is confirmed by laboratory tests conducted by Periso on 24 July 2019 on the above mentioned devices.

Sincerely,

Alessandro Serra

Quality Manager & Technical Supervisor

PERISO SA
technology that evolves
Via Senago, 42D
CH-6912 PAZZALLO (TI)

TÜV CLUB TÜV Hessen PROFI Member
ISO 9001
ISO 10014
ISO 14001

MADE IN SWISS

bsi. ISO 13485 Medical Devices Quality Management

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