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Air ionizers case study

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Abstract- Fresh air is essential for humans' physical and mental health, and it helps us relaxed and relieve stress. Air ionizers can remove harmful gases in the air and absorb suspended particles in the air, especially various bacteria and viruses. This report investigates the nature and working principles of air ionizers and discusses their application in the indoor environment and the protection of human exposure. We used the ozone emission test, particle removal rate and clean air delivery rate to analyze the effectiveness of four selected air ionizers. Simultaneously, this report identifies the side effects of air ionizers and advice more further studies about air ionizers before promoting them into daily-life use.

1. Introduction

Air pollution has become more severe as industrialization has progressed. Researchers found nine harmful chemicals in the air that can cause severe health problems in human. A few household materials produce indoor air pollution: cement, paints, lacquers, furniture, and heating and cooking operations. As people spend most of their time in an indoor environment, it is essential to create a pollution-free environment for long-term well-being.

This paper will discuss the nature and operation of air ionizers through a series of examples and explain how air ionization technology in air purification, VOC, and PM treatment can minimize human exposure. Second, this study offers three methods for determining the efficacy of air ionizers. Additionally, the paper will also reveal the negative impacts of air ionizers.

2. Nature and working principles of Air Ionizers

An air ionizer is a device that ionizes air molecules by applying a high voltage to eliminate airborne pollutants [1]. Electrostatic attraction draws charged particles in the air to an ionizer. These particles are subsequently drawn to any grounded conductors in the vicinity, whether deliberate plates in the air filter or the adjacent walls and ceilings.

Air Ionization systems operate by deluging positive and negative ions into the atmosphere. The term "electrostatic charge" refers to the accumulation of ions with a particular charge on a nonconductive surface until it neutralizes. Cosmic Rays, Gamma Rays, Lighting, and Solar Ultraviolet Radiation are all-natural sources of ionization. Alpha/gamma radiation from radioactive minerals in the Earth's crust is also considered part of background radiation [2].

In essence, a solid electrostatic field surrounding a sharp edge causes a discharge of high-energy electrons [3]. These high-energy electrons will combine with neutral air molecules, forming exciting neutral air molecules or primary positive ions that also include sluggish secondary electrons. In a parallel plate free-air ionization chamber, these sluggish secondary electrons are quickly heated and undergo the attachment of termolecular electrons to O_2 to form superoxide anions O_2 [4].

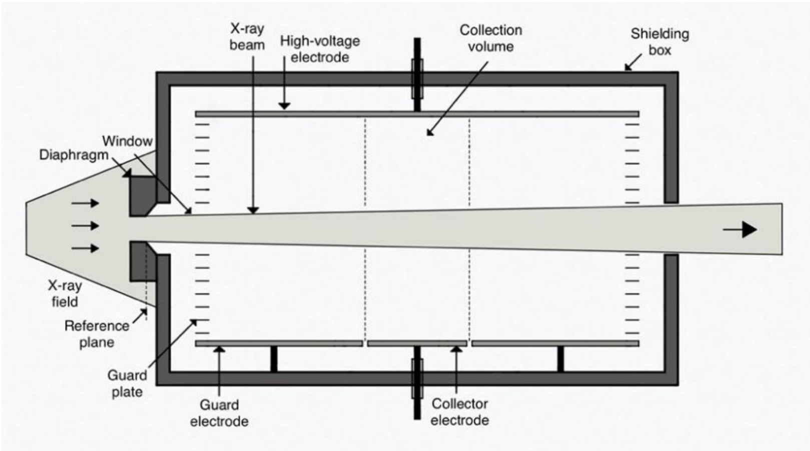

Figure 1. A free-air ionization chamber with a parallel plate [4].

High electrostatic fields generate positive and negative ions and fast attain steady-state concentrations. Ion-ion and ion-electron recombination processes will create ions with a range of 10^5 to 10^6 ions per cm^{-3} [5].

3. The applications of Air Ionizers in indoor environment

For illustrating the application of Air Ionizers in the indoor environment, we used ionair ® Air Ionization System (LK Luftqualität Air Quality, Inc., Luzern, Switzerland) (See Figure 2) as an example of an autonomously regulated ionization system. It provides a pleasant atmosphere by eliminating and removing volatile and particulate components from the interior air environment, reducing microbial contamination and neutralizing odors.

In addition to sensors for monitoring air quality (VOCs and PM), electronic monitoring of air ions, and ionization modules that generate ions on demand. The test also used the air ionization treatment system in various locations, including enclosed spaces and central air handling units (AHU).

The air exiting the space can be vented directly to the atmosphere, or it can be combined with outside air before returning to space [6].

Users can adjust the position of the air ionization device depending on the source and severity of VOCs and PM. The air ionization device can be mounted directly on the central monobloc HVAC unit to treat the whole airstream. Furthermore, air ionization modules can be placed downstream of the central HVAC system in the existing ducting. To meet emergency demands, freestanding air ionization devices can be put in a separate room area.

There are seven proof factors to measure if an air ionization system has enhanced air quality. We placed the process control unit in the center. The inputs can be configured manually based on situation design parameters or automatically depending on monitoring demand factors. Three manual inputs allow for adjusting the desired ionic strength level, power capacity, and airflow area. Additionally, four electrical inputs allow for the measurement of airflow, humidity, air quality, and ozone [6].

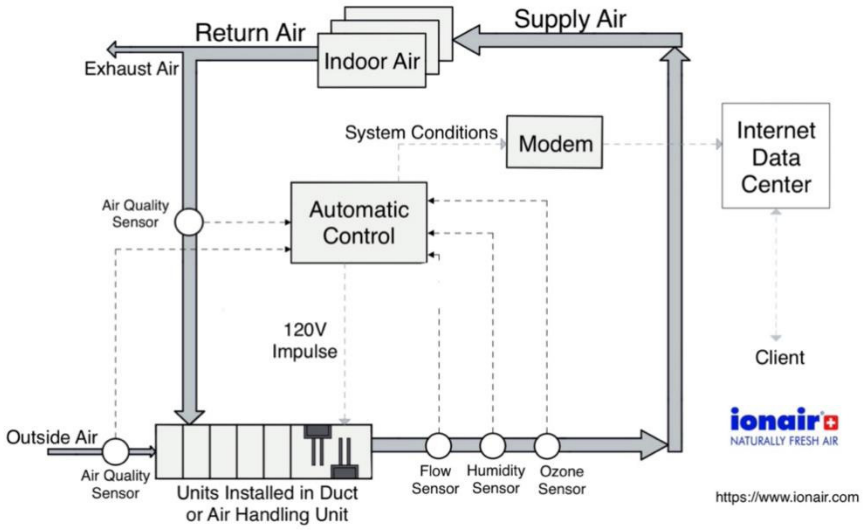

Figure 2. Air ionization - process schematic [6].

4. The effectiveness of Air Ionizers and corresponding evaluation methodologies

The results of ozone emission and ionization, particle removal and secondary organic aerosol formation, and clean air delivery rate are the indicators to identify air ionizers' effectiveness. The following table showed the comparison of the effectiveness of four air ionizations based on the three methodologies below.

Table 1. Characteristics of the four selected air ionizers [7].

Air Ionizer	Manufacturer description	Description	Dimensions (cm)	Weight (g)
AI 1	Cleaner air is directed toward the mouth and nose using electronic propulsion.	The electron kinetic transducer generates negative ion airflows by corona discharge using metallic cathodes. There is no fan and particulate filter.	11.4 x 8.4 x 3.8	86
AI 2	Mate personal ionic air purifier produces ions and 0.028 ppm ozone. Viruses, germs, odors, chemical pollutants, and dust are all targets.	Corona discharge with metallic cathodes generates negative ions. A positively charged metal grid removes the particles with negative charges. There is no fan or particulate filter.	6.4 x 3.8 x 2.0	81
AI 3	Neck air purifier: Emits negative ions. Target: odors, virus, particles	Negative ions are produced via a high-voltage corona discharge using metallic cathodes. There is no fan or particulate filter.	6.1 x 3.8 x 3.3	54
AI 4	Air purifier for travel emits a steady stream of negative ions. Viruses, bacteria, pollen, dust, and other microorganisms are among the targets.	Corona discharge using carbon fiber cathodes produce negative ions. A positively charged metal ring collects particles with negative charges. There is no fan or particulate filter	7.6 x 3.3 x 2.8	50

4.1. Ozone emission test

The indoor ozone concentration with the specified air ionizers is depicted in Figure 3. The indoor ozone concentrations in AI 3 and AI 4 remained at a background level of 0 ppb after three hours of operation. However, when AI 1 and AI 2 were operational, indoor ozone concentrations increased to 410 ppb and 32 ppb, respectively. This discovery suggests that AI 1 and AI 2 produce substantial amounts of ozone. Researchers can calculate the ozone emissions from household ionized air purifiers using steady-state ozone concentrations according to a prior study [7]. However, even after ten hours of operation, the steady-state ozone concentrations in the room were not attained for AI 1 and AI 2.

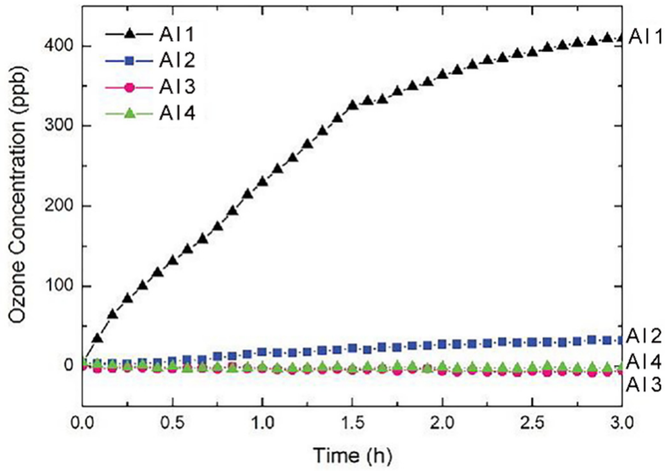

Figure 3. The concentration of ozone in the chamber with an air ionizer operating [8].

Corona charging is a standard ionizer charging method that produces ozone as a by-product [9]. We used the following two phases to describe ozone production:

$$O_2 + e \rightarrow 2O + e; \quad (1)$$

$$O + O_2 + M \rightarrow O_3 + M \quad (2)$$

The reaction rate in Equation (1) is proportional to the intensity of the electron current, where M might be an O2 or N2 molecule. As the surface of the corona line heats, the air temperature rises, and the surrounding air temperature rises, the reaction rate in Equation (2) drops. As a result, the electron current strength and the temperature of the corona line surface would affect the ozone emission rate.

The intensity of ozone generation is determined not only by the cathode material [10] but also by other ion generators design factors such as applied voltage and cathode diameter [11]. In this experiment, AI1 and AI2 used metal corona discharges to generate ions, whereas AI3 and AI4 used carbon fiber ion generators. The metal corona discharge mechanism can produce significant ozone [11,12]. This might explain the high levels of ozone detected in AI1 and AI2 in this research. Carbon fiber ion generators usually require lower voltages than metal cathodes for corona discharge to achieve the same amount of ionization, as the diameter of carbon fiber is considerably less than that of metal cathodes (5-10 mm). As demonstrated in equations (1) and (2), the lower voltage supplied to the carbon fiber is adequate to begin ionization at the tip of the carbon fiber cathode; nevertheless, the electric field created by the applied voltage is insufficient to initiate undesired ozone reactions [13,14]. This may account for AI3 and AI4's low ozone emissions.

4.2. Particle removal rate

Figure 4 shows the overall particle count removal rates (h^{-1}) for the four chosen air ionizers tested in the size range of 18.1 to 289 nm. The AI4 had the most effective total particle count removal rate of 27.9 h^{-1} in the measured size range among the four air ionizers tested, while the AC2 had the lowest value of 0.52 h^{-1}.

Figure 5 shows the mass removal rates of the four chosen air ionizers for PM2.5. AI1, AI2, AI3, and AI4 had PM removal rates of 1.85 h^{-1}, 0.48 h^{-1}, 1.52 h^{-1}, and 5.37 h^{-1} correspondingly.

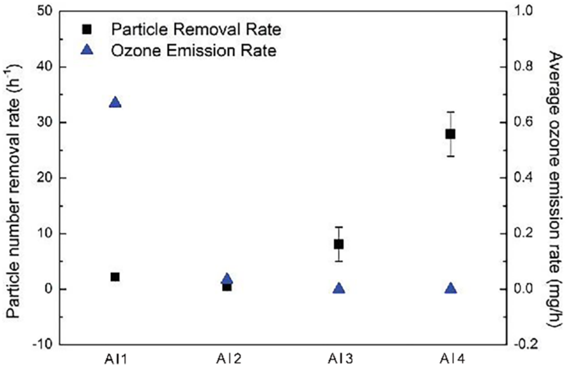

Figure 4. Total particle removal rates and time-averaged ozone emission rates of four air ionizers in the measured size range [8].

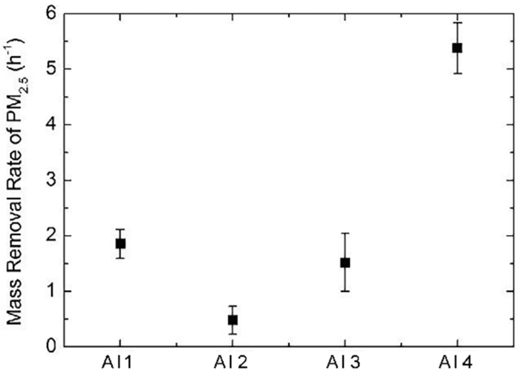

Figure 5. Mass removal rates of PM2.5 by four air ionizers [8].

4.3. Clean air delivery rate

The clean air delivery rate (CADR) may be calculated directly from the particle removal rate obtained by air ionizers that do not emit ozone:

$$CADR = R \times V \quad (3)$$

V = volume of the Chamber (m^3).

Researchers compared the CADRs of the four selected air ionizers to those of other air ionizers in prior research in Table 5. The CADRs of and for pm 2.5 mass concentration are significantly lower than those of the air ionizers evaluated by Chen and Cheng [15]. When it comes to the cumulative removal rate of size-resolved particle number concentrations in the measurement range, AI4 has a considerably higher removal capacity than AI3.

Table 2. Comparison of CADR and ozone emission rate between the selected air ionization and other air ionization from reference [8].

Air Ionizer	CADR for size- resolved number concentration of ultrafine particles ($m^3 \cdot h^{-1}$)	CADR for mass concentration of fine particles ($m^3 \cdot h^{-1}$)	Ozone emission rate ($mg \cdot h^{-1}$)
AI 1			0.669
AI 2			0.034
AI 3	1.09 – 5.20	0.70	0.00
AI 4	2.24 – 19.7	2.47	0.00
Phillips et al. 1999			0.102 – 0.114
Britigan et al. 2006			0.3 – 0.5
Chan and Cheng 2006		53.58	
Mølgaard et al. 2014	46–119		
Zuraimi et al. 2011	5–45		
Waring et al. 2008	16–76		3.3 ± 0.2
Niu et al. 2001			0.065 – 2.76
Britigan et al. 2006			0.16 – 220

5. The side effects of Air Ionizers

As time passed, the technology improved and alternative methods of cleaning air without traditional filters gradually increased. For example, the manufacturers remove filter replacements to reduce costs and cleaning time, frequency, and duration of environmental impact. This improvement led to creating air purifiers without filters instead of using ionizers to clean the air.

Air purifiers that utilize ionizers are very effective and can capture organisms and particles that may escape from conventional filters. Despite this, consumers still question the level of safety of ionizers and their possible side effects on humans.

5.1. Clean of dirt
Due to the working principle of the air ionizer, it is not drawing air into itself, and the ionizer works by releasing charged ions into the atmosphere, thereby binding to harmful contaminants and making them too heavy to float. Therefore, the heavy harmful contaminants will be dragged to the ground or anywhere nearby. Surfaces that should ultimately be wiped clean by the users.

In other words, air ionizers typically only knock particles out of the atmosphere. However, these particles remain in the surrounding environment. For instance, after releasing charged ions into the apartment's air with contaminants, they will fall onto household surfaces. To remove the dirt, users need to dust off the exposed surfaces or clean electrostatic plates. Otherwise, the dirt will circulate back into the atmosphere.

Therefore, the ionizer only has the prospective ability as the cleaning habits of the individual using the ionizer. So, the effectiveness of air ionizers used to remove airborne contaminants depends on users' cleaning habits.

5.2. Emission of ozone
Emissions of ozone are a side effect of air ionizers. The powerful oxidizer can be hazardous to health due to long-term or high-dose exposure. Factors associated with high ozone levels include longer exposure times, higher energy loss rates and the use of bipolar ions [16]. Bipolar ions can release up to 30 ppb of ozone than monopolar ions, which have ozone concentrations of 2-10 ppb [17]. Ozone exposure is negligible for 2 hours but increases significantly to > 77 ppb after 8 hours of exposure [18].

An ion ionizer with too-tight space can produce more ozone concentrations than the safety requirement. Ozone is a high level of lung irritant. Breathing in ozone can cause throat irritation, chest discomfort, and coughing. Ozone can also exacerbate symptoms of asthma and bronchitis.

6. Conclusion
In summary, this paper assessed the effectiveness of four different air ionization systems in terms of ozone emission and particle removal. Furthermore, certain air ionizers can remove hazardous gases, and adsorbate suspended particles in the air, including germs and viruses. Air ionizers use an electrostatic charge to generate clean air. However, an issue with air ionizers continues to be that the charged ions they create are not suited for everyone. According to some research, these charged particles might aggravate asthma symptoms, negating the benefits of improved household air quality. The author suggests that further study into the scientific and clinical benefits of air ionizers or even HEPA air purifiers before introducing them into the daily lives of humans.

Reference
[1] Shiue, A., Hu, S.-C., & Tu, M.-L. (2011). Particles Removal by Negative ionic Air Purifier in Cleanroom. Aerosol and Air Quality Research, 11(2): 179–186.
[2] Jokl, M. (2002). Zdravé obytné a pracovní prostředí (Healthy Living and Working Environment). Academia, Prague.
[3] Steinman, A. (2006). The basics of air ionization for high-technology manufacturing applications. Compliance Engineering Annual Reference Guide (2006), 1.
[4] Takata, N. (2010). A free-air ionization chamber with a large aperture diaphragm. Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment, 619(1–3): 216–220.

[5] Kim, K.-H., Szulejko, J. E., Kumar, P., Kwon, E. E., Adelodun, A. A., & Reddy, P. A. K. (2017). Air ionization as a control technology for off-gas emissions of volatile organic compounds. Environmental Pollution, 225: 729–743.
[6] Daniels, S. L. (2002). "On the ionization of air for removal of noxious effluvia" (Air ionization of indoor environments for control of volatile and particulate contaminants with nonthermal plasmas generated by dielectric-barrier discharge). IEEE Transactions on Plasma Science, 30(4): 1471–1481.
[7] Waring, M. S., Siegel, J. A., & Corsi, R. L. (2008). Ultrafine particle removal and generation by portable air cleaners. Atmospheric Environment, 42(20): 5003–5014.
[8] Shi, S., Zhu, S., Lee, E. S., Zhao, B., & Zhu, Y. (2016). Performance of wearable ionization air cleaners: Ozone emission and particle removal. Aerosol Science and Technology, 50(3): 211–221.
[9] Yagi, S., & Tanaka, M. (1979). Mechanism of ozone generation in air-fed ozonizers. Journal of Physics D: Applied Physics, 12(9): 1509–1520.
[10] Boelter, K. J., & Davidson, J. H. (1997). Ozone generation by indoor, electrostatic air cleaners. Aerosol Science and Technology, 27(6): 689–708.
[11] Shi, S., Zhu, S., Lee, E. S., Zhao, B., & Zhu, Y. (2016). Performance of wearable ionization air cleaners: Ozone emission and particle removal. Aerosol Science and Technology, 50(3): 211–221.
[12] Yanallah, K., Pontiga, F., Fernández-Rueda, A., & Castellanos, A. (2009). Experimental investigation and numerical modelling of positive corona discharge: Ozone generation. Journal of Physics D: Applied Physics, 42(6): 065202.
[13] Han, B., Hudda, N., Ning, Z., Kim, H.-J., Kim, Y.-J., & Sioutas, C. (2009). A novel bipolar charger for submicron aerosol particles using carbon fiber ionizers. Journal of Aerosol Science, 40(4): 285–294.
[14] Han, B., Kim, H.-J., Kim, Y.-J., & Sioutas, C. (2008). Unipolar charging of fine and ultra-fine particles using carbon fiber ionizers. Aerosol Science and Technology, 42(10): 793–800.
[15] Chan, M., & Cheng, B. N. (2006). Performance evaluation of domestic ionizer type air cleaners. Architectural Science Review, 49(4): 357–362.
[16] Dones, C. M. (2021). Expanding the role of community colleges with workforce baccalaureate programs. In D. Smith, R. Lewis, & L. Singleton (Eds.), Community Colleges and Workforce Preparation in the 21st Century: Emerging Research and Opportunities. IGI Global., Hershey. pp. 28-58.
[17] Hyun, J., Lee, S.-G., & Hwang, J. (2017). Application of corona discharge-generated air ions for filtration of aerosolized virus and inactivation of filtered virus. Journal of Aerosol Science, 107: 31–40.
[18] Berry, D., Mainelis, G., & Fennell, D. (2007). Effect of an ionic air cleaner on indoor/outdoor particle ratios in a residential environment. Aerosol Science and Technology, 41(3): 315–328.