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Efficiency of ionizers in removing airborne particles in indoor environments

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ABSTRACT

Air ionizers are increasingly being used to clean indoor environments of particle pollution. We tested the efficiency of a small negative ion generator (Aironic AH-202) in removing ultrafine particles from indoor environments. A high-flow air filter fitted with a HEPA filter was used to compare the removal efficiencies. We estimated the percentage of particles removed when the ionizer was operated within a closed chamber of volume 1 m^3, in a closed unventilated room of volume 20 m^3 and in three force-ventilated rooms of volume 32, 45 and 132 m^3. The closed chamber studies were conducted with ambient particles and with smoke at particle number concentrations of 5×10^3 and 7×10^4 cm^{-3}, respectively. In both cases, 70% of the particles were removed by the ionizer in 15 min. In general, the particle removal efficiency of both the ionizer and the air filter decreased as the room size increased. Both devices were also more effective in unventilated rooms than in ventilated rooms. The most important finding in this study was that, while the air filter was more effective than the ionizer in the two small rooms, the ionizer was clearly more effective than the air filter in the three largest rooms. We conclude that air ionizers are more suited than high-flow air filters in removing ultrafine particles from rooms larger than about 25 m^3. The investigation also showed that small ions produced by the ionizer, placed in one room, were carried through the air conditioning system into other rooms, effectively removing particles from the air in these rooms in the process.

1. Introduction

Air ions are naturally formed in the atmosphere by ionization of neutral air molecules or atoms by cosmic rays from space and natural radioactivity on the earth. Ionization results in free electrons and positively charged simple molecules or atoms (positive ions). The free electrons instantaneously attach to neutral molecules or atoms, forming negative ions. Negative air ions are generally O_2^- molecules with an excess of electrons and positive air ions are generally N_2^+,O_2^+, N^+ and O^+ molecules with a deficiency of electrons. Positive ions occur in high concentrations in both indoor and outdoor polluted environments such as industrial and highly populated areas. Ions of both signs are naturally found in large numbers near the coastline, in the mountains, in forests [1] and near waterfalls [2].

Outdoor air pollutants are mainly produced from motor vehicle emissions, industrial emissions and construction activities. The reported indoor sources of air pollutants include smoking [3], candle burning [4], cooking [5], vacuum cleaning [6] and from modern appliances such as printers, copy machines, LD monitors, TV sets and mobile phones [7]. At the same time, the high level of indoor air pollutants has become an important concern because people spend most of their time (> 80%) indoors [8].

Ions can be artificially generated by electrical devices such as air ionizers (also known as ion generators), ozone generators and electrostatic precipitators. Most of these devices produce ions using “corona discharge” produced through a high-voltage. When these ions are released into the atmosphere, they soon attach to airborne particles, leading to the removal of particles from the air in two mechanisms. Firstly, it results in an enhancement of the aggregation process as charged particles are increasingly attracted to neutral particles due to image forces. Larger particles settle faster than smaller particles. Secondly, charged particles have a greater mobility than neutral particles and are transported and deposited more effectively on nearby surfaces due to image charges.

A number of studies have demonstrated that air ionizers are efficient at various levels in removing aerosol particles from indoor environment [9–14]. These studies have found a significant reduction in concentrations of airborne particles due to the presence of ions. For example, Grabarczyk [10] used corona ionizers in a 50 m^3 unventilated, unoccupied room and found that the particle number concentrations (PNC) reduced by up to two orders of magnitude after 2 h, for the size range 0.3–2.5 µm. Lee et al. [11] tested corona ionizers in a 24.3 m^3

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chamber and found that particle removal efficiency was 97% for 0.1 µm particles and 95% for 1 µm particles, after 30 min. Grinshpun et al. [12] tested commercially available ionic air cleaners in a 2.6 m^3 chamber and found that the most powerful unit showed a particle removal efficiency of 90% within 5–6 min and 100% within 10–12 min for particle sizes between 0.3 and 3 µm. Both those studies concluded that the particle removal efficiency was not significantly affected by the particle size, while it increased with increasing ion emission rate. Wu et al. [13] studied the influence of the wall surface material on the removal of particles with negative air ions in an indoor environment. They used different wall surface materials such as stainless steel, wood, polyvinyl chloride (PVC), wallpaper and cement paint as the inner surface of a chamber and concluded that the removal of particles from the air was more efficient when the walls were of wood and PVC than of any other materials. Further, Shiue et al. [14], studied particle removal efficiency by measuring PNC at different heights and distances from the negative ion source in a closed chamber. They observed the highest particle removal efficiency at a height of 60 cm from the floor. They also found that particle removal efficiency decreased with increase in distance from the negative ion source due to limited horizontal diffusion of ions. Sawant et al. [15] used corona discharge to test the possibility of reducing the concentration of fog and smoke in a 72 cm^3 closed unventilated glass container. They found that a particle removal efficiency of 93–97% in the chamber within 6 min. This study demonstrated that it is possible to reduce the concentration of fog and smoke to a significant degree using negative air ions resulting in improved visibility in a closed chamber.

These studies clearly demonstrated that ionizers were efficient in reducing aerosol particles in indoor environments. However, most of these studies were conducted in closed chambers and not in real life environments. In this study, in addition to a closed chamber, we estimated the particle removal efficiency by a small negative ion generator (Aironic AH-202) in a number of different indoor environments such as unventilated and ventilated rooms, also investigating the effect of room size.

2. Methods

2.1. Instrumentation

2.1.1. Ionizer (negative ion generator)

A small commercially available negative ion generator (Aironic AH-202) was used to ionize air molecules. This device is mains powered, contains four corona needles and emits approximately 1×10^6 negative ions s^{-1}.

2.1.2. Air filter

An air filter fitted with a HEPA filter, provided by Healthway (New York, USA) was tested in this study. The filter has three settings: high mode (air flow rate-5660 l/min), medium mode (air flow rate-3540 l/min) and low mode (air flow rate-2400 l/min). The estimated particle removal efficiency by this device (based on the specifications reported by the manufacturer) is 99.99% at of all particles as small as 0.007 µm in size.

2.1.3. P-trak ultrafine particle number monitor

A TSI model 8525 P-Trak ultrafine particle monitor was used to measure the number concentration of particles in the size range 0.02–1 µm in real-time. The P-trak uses high-grade ethyl alcohol as its working liquid in the condensation particle counting technique to count ultrafine particles by means of laser scattering and detection. Data is stored on the instrument and later downloaded to a computer using the software provided. This instrument has a measurement range of 0–500,000 particles per cm^{-3}. The time resolution was set to 1 s.

2.1.4. Scanning mobility particle sizer (SMPS)

A scanning mobility particle sizer (SMPS), consisting of a TSI 3936 differential mobility analyser and a TSI 3781 condensation particle counter, was used to determine the particle size distribution in the range 10–400 nm.

2.2. Experimental methods

The experiments were carried out in a range of different indoor environments at the Garden Point campus of the Queensland University of Technology in Brisbane. The indoor environments were chosen to represent different volumes and ventilation systems. The experiments in each environment were repeated three times.

2.2.1. Chamber experiments

These experiments were conducted with ambient air in a closed chamber of volume 1 m^3. The initial PNC in the chamber was about 5×10^3 cm^{-3}. The P-track was placed at a height of 30 cm above the floor while the ionizer was placed on the floor of the chamber with its power switch accessible from outside to control its operation time. In each experiment, before the ionizer or the air filter was turned on, the conditions were allowed to reach an equilibrium state with the P-trak readings steady for at least 5 min. At that time, the ionizer or the air filter was turned on for a fixed period, as required, while the PNC was continuously monitored. Throughout this study, the air filter was used in the high mode setting. Particle size distribution was measured by the SMPS, in order to determine any changes in particle size during the particle charging process.

In order to study the effect at high PNC values, the experiment was repeated with a controlled quantity of smoke introduced into the chamber by inserting a lighted match into the chamber for a very short time of less than 1 s. After a few minutes, this gave a mean PNC of about 7×10^4 cm^{-3}. The ionizer was turned on and left on for a period of 25 min.

2.2.2. Unventilated room

These experiments were conducted in a closed unventilated room of volume 20 m^3. The ionizer and P-trak were placed approximately 1.5 m apart. In each experiment, the ionizer or the air filter was turned on after it was observed that the P-trak recorded an approximately constant PNC reading for 5 min. Next, the ionizer or the air filter was turned on for a period of 15 min. When the ionizer or the air filter was turned off, the P-trak continued recording for another 10–15 min. Air filter was used in its high mode setting. The vertical distribution of PNC was also investigated by placing the P-trak at different levels in the room.

2.2.3. Ventilated rooms

These experiments were conducted in three ventilated rooms of volume 30 m^3, 45 m^3 and 130 m^3. The ionizer or the air filter and the P-trak particle monitor were placed at the same level, approximately 1.5 m apart. In each experiment, after ensuring that the PNC was steady, the ionizer or the air filter was turned on for a period of 15 min, after which, the P-trak continued recording for another 10–15 min. The air filter was used at the high mode setting during all experiments. The air flow rate through the ventilated rooms was approximately 30 l s^{-1}.

2.2.4. Ventilated system

A further set of experiments were conducted with the ionizer and the P-trak particle counter in different rooms. The rooms were physically separated from each other but connected via the central air conditioner ventilation system. In this system, air was circulated through a HEPA filter and temperature control system and approximately 20% of air from outside the building was filtered and mixed with the circulating air on each cycle. This meant that 80% of the air in the building was being filtered and recirculated. The aim was to investigate if ions