# Indoor air quality implications of using ion generators in residences

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## SUMMARY

Portable air cleaners are popular and heavily marketed devices that are sold to improve indoor air quality. One prominent air cleaning technology is ion generation, which can emit up to 5 mg/hr of ozone as a byproduct of its operation. The ozone emitted by ion generators can react with unsaturated organic compounds to form ultrafine and fine particles, as well as aldehydes and free radicals. This research experimentally characterizes the indoor air quality implications of an ion generator in a 27 $m^3$ residential room, with a matrix of four different room test configurations. Two of the tests had carpet (a likely ozone sink) in the room, and for one test with and without carpet, a popular plug-in air freshener was used as a source of terpenes. Each experiment lasted at least four days: two days of background measurements, and two days with an operating ion generator. Measurements included airborne sampling of size-resolved particulate matter (0.015–20 μm), $C_1$-$C_{10}$ aldehydes and terpenes, ozone concentrations, and air exchange rates. This study finds that the use of ion generators in the presence of a common air freshener can lead to a net increase in fine and ultrafine particulate matter (<0.5 μm) and ozone, as well as formaldehyde and nonanal. This research allows exposure and health professionals to make justified recommendations about the use of these ozone-generating devices.

## KEYWORDS

Portable ion generators, Secondary organic aerosol, Ozone/terpene reactions, Field study

## INTRODUCTION

Portable ion generators are popular devices in the U.S. that are sold as air cleaners to remove particles from the indoor air. They are marketed to predominately residential customers, can be set on a floor or table-top, and are meant to clean a room-sized space. These devices use a corona to generate negative ions and charge nearby particles, and the corona generates ozone as a byproduct of its operation. The California Air Resources Board (2007) reports that 10% of California households own an air cleaner that produces ozone.

Portable ion generators can have both positive and negative impacts on indoor air quality (IAQ). Positively, ion generators remove the charged particle contaminants to collector plates in the device or indoor surfaces. Removal by the device itself can be quantified by the clean air delivery rate (CADR), which is the effective volumetric flow of particle-free air delivered by an air cleaner ($m^3$ $h^{-1}$). CADR for portable ion generators range from 0–90 $m^3$ $h^{-1}$ (Offermann et al., 1985; Niu et al., 2001a; Mullen et al., 2005; Waring et al., 2008), an order of magnitude less than high efficiency particulate air (HEPA) cleaners (Offermann et al., 1985; Mullen et al., 2005; Waring et al., 2008).

However, ion generators also emit ozone with rates that range from 0.056 –13.4 mg $h^{-1}$ (Niu et al., 2001a, 2001b; Tung et al., 2005; Mullen et al., 2005; Waring et al., 2008). These rates are significant, and Weschler (2006) provides indirect evidence of a link between morbidity and mortality and exposures to indoor ozone and its oxidation products. Ozone is a primary driver of indoor chemistry (Weschler, 2000), and it reacts with terpenes to form oxygenated gases and secondary organic aerosol (SOA) in the ultrafine (< 0.1 μm) and fine (0.1–2.5 μm) range (e.g., Weschler and Shields, 1999). Terpenes are common indoors and are emitted from consumer products such as air fresheners, surface cleaners, perfumes, and colognes (Singer et al., 2006; Corsi et al., 2007).

Thus an ozone-generating air cleaner with a low CADR could operate as a net producer of particles and deleterious gases in the presence of terpenes. Alshawa et al. (2007) operated an ion generator in an office and injected 15 and 45 mg of d-limonene into the air. Transient elevations in ultrafine particle concentrations were observed. Other studies have observed the particle forming effects of dedicated ozone generators, which typically emit at least an order of magnitude more ozone than ion generators, in real environments (Weschler and Shields, 1999 and 2003; Hubbard et al., 2005). Waring et al. (2008) observed steady-state net particle and formaldehyde formation when five ion generators were operated separately in a 14.75 $m^3$ stainless steel chamber with a terpene-emitting air freshener. The purpose of this study was to extend this chamber work to a residential space, since real indoor spaces typically have larger volumes and surface-to-volume (S/V) ratios, as well as have sources of particles and other pollutants. The goal of this investigation was to determine the comprehensive impacts of using a portable ion generator on IAQ in real indoor environments.

## METHODS

Field experiments were conducted to assess the impact of an ion generator on indoor pollutant concentrations in a residence. Experiments were performed in a 27 $m^3$ unoccupied room in an approximately 475 $m^3$ three-floor duplex town home in Austin, Texas, from May to August in 2007. The room was furnished with a futon, bookshelf, desk with a computer, television, and curtains covering a sliding glass door that lead outdoors. The walls and ceiling were painted with flat latex paint, and the flooring was sealed/stained concrete. One HVAC duct supplied the experimental room, and the HVAC system was switched off during each day of testing from 11 p.m. to 9 a.m.. A ceiling fan was operated on its lowest setting to aid in air mixing.

Four different room configurations were measured in the 2×2 matrix shown in Table 1. The original flooring of stained concrete was used for two configurations, and carpet with padding was installed for two others. There was not a terpene source present for two configurations, and a "Hawaiian" scented plug-in air freshener on its highest setting was used as a terpene source for two others (total emission rate = 1.5 g $day^{-1}$). This same type of air freshener was used in Waring et al. (2008), and the primary terpene emitted was d-limonene. The room air for each configuration was sampled for at least one two-day period without an ion generator operating and at least one two-day period with an ion generator operating on its highest setting in the center of the room. The ion generator was a tower model (with collector plates and no fan) and was cleaned according to its instructions before each two-day test. It had an ozone emission rate of 3.3 ± 0.2 mg/h, a count average CADR (± one standard deviation) for particles (12.6–514 nm diameter) of 41 (11) $m^3$/h, and was IG 1 in Waring et al. (2008).

Table 1. Experimental matrix for the four room configurations.

| | |
|---|---|
| Stained concrete floor, No terpene source | Carpet with padding floor, No terpene source |
| Stained concrete floor, Terpene source | Carpet with padding floor, Terpene source |

The experimental measurements and instrumentation are listed in Table 2. Instruments were located within the room itself, and all samples were taken near the center of the room 2 m from the floor. Indoor temperature and relative humidity (RH) were monitored as well as the temperature at the supply duct register, which indicated when conditioned air was supplied to the room. Air exchange rates were measured by the decay of sulfur hexafluoride ($SF_6$) and were calculated as the best fit slope of the natural log of the ratio of the concentration of $SF_6$ to the initial concentration versus time. This method assumes that the air is well-mixed and that air exchange rate was constant over time.

Table 2. Measurements taken and instruments used in study and their characteristics.

| Measurement | Instrument | Brand/Operator | Model # | Detection Limit/Range |
|---|---|---|---|---|
| Indoor Temperature | Thermistor | TSI | Q-Trak 8551 | 0-50 °C |
| Indoor RH[a] | Resistance | TSI | Q-Trak 8551 | 5-95% |
| Supply Duct Temperature | Thermistor | Onset | Hobo U10/U12 | -20-70 °C |
| $SF_6$ | Gas Chromatograph; Electron Capture Detector | Lagus | Autotrac ATGM | 0.05 ppb (linear range) |
| Indoor Ozone | Dual Beam UV-Absorbance | 2B Technologies | 205 | 1 ppb or 2% |
| PM (0.015-0.533 µm) | Scanning Mobility Particle Sizer | TSI | EC 3080, DMA 3081, WCPC 3785 | 1 #/cm$^3$ |
| PM (0.542-20 µm) | Aerodynamic Particle Sizer | TSI | APS 3321 | 0.001 #/cm$^3$ |
| Light Aldehydes (C1-C4) | DNPH Focus Liners; HPLC | SKC; Waters | 226-120; 600 | 0.03 µg |
| Heavy Aldehydes (C6-C10) and Terpenes | Focus Liners with Tenax GR 60/80; TD/GC/MS | Atas; TENAX MANUF; HP | A100094; Tenax #; Optic 2; HP5890; HP5971A | |

The ozone monitor drew indoor samples through 3 m of 6 mm OD Teflon tubing, averaged over one minute. Hourly outdoor ozone concentrations were taken from a nearby monitoring station 9 km from the residence. Indoor size-resolved particle concentrations were measured in the range of 0.015–0.661 µm diameter with the Scanning Mobility Particle Sizer (SMPS) and in the range of 0.542–20 µm diameter with the Aerodynamic Particle Sizer (APS), both every five minutes. Thirty minutes of outdoor particle measurements were taken three times each day of testing, with sampling lines that accessed the outdoors via the sliding glass door. The indoor and outdoor particle sampling lines were similar in length and orientation.

Integrated gas-phase samples were taken each morning, usually between 1 and 3 am. Light aldehydes ($C_1$–$C_4$) were sampled in focus liners packed with dinitrophenylhydrazine (DNPH) coated silica gel, with a potassium iodide (KI) ozone trap. Sample flow rates were 0.5 L/min and sample volumes 30 L. The DNPH-filled focus liners were prepared based on EPA method TO-11A (US EPA, 1999) and analyzed with an HPLC. Heavy aldehydes ($C_6$–$C_{10}$) and terpenes were sampled onto two side-by-side Tenax-GR-filled focus liners, for quality assurance. Samples were collected without ozone scrubbers, since indoor concentrations were always below 15 ppb. Sample flow rates were 21 cm$^3$/min and sample volumes 1.3 L. Heavy aldehydes and terpenes were analyzed with GC/MS/TS with the method outlined in Waring et al. (2008) and quantified using an internal standard of 1-bromo-4-fluorobenzene. The measurement uncertainty was taken as the percent ratio of one standard deviation over the mean of the standard variation and was 15%.

## RESULTS AND DISCUSSION

A summary of the room environmental conditions for each test is presented in Table 3. Each test ID represents a unique two-day test. The first letter in the test ID represents the air cleaner status (N = no air cleaner; I = ion generator present), the second letter the flooring (S = stained concrete; C = carpet, padding), the third letter the terpene source (N = no terpene source; A = air freshener present), and the number the test iteration. The temperature and RH in the room were relatively constant across all tests, which is important since both influence SOA formation rates (Sarwar et al., 2003; Weschler and Shields, 2003). Three air exchange rates were measured: the rate when the HVAC system was off ($\lambda_{off}$), when cycling on/off during its duty cycle ($\lambda_{cycle}$), and when on ($\lambda_{on}$). At least one type of air exchange rate was measured for each two-day test except NSN-1, during which the HVAC system remained off.

Table 3. Room environmental conditions for each unique two-day test.

| | | HVAC On (9am-11pm) | | HVAC Off (11pm-9am) | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Test ID** | **Dates of Test[a]** | **T[b](SD) (°C)** | **RH[c](SD) (%)** | **T[b](SD) (°C)** | **RH[c](SD) (%)** | **$\lambda_{off}$[d] ($h^{-1}$)** | **$\lambda_{cycle}$[e] ($h^{-1}$)** | **$\lambda_{on}$[f] ($h^{-1}$)** | **Air Cleaner** | **Floor** | **Terpene Source** |
| NSN-1 | 5/22-5/24 | - | - | 27.9 (0.8) | 55 (2) | 0.62[g], 0.65[g] | - | - | None | Stained Concrete | None |
| NSN-2 | 6/14-6/16 | 27.4 (0.6) | 47 (3) | 28.0 (0.4) | 51 (3) | 0.55[g], 0.58 | 1.5[g] | 5.5 | | | |
| ISN-1 | 5/27-5/29 | 27.0 (0.3) | 46 (2) | 27.3 (0.2) | 48 (2) | 0.64 | 1.2[g] | 4.7 | IG[h] | | |
| ISN-2 | 6/5-6/7 | 27.4 (0.7) | 51 (3) | 27.7 (0.2) | 48 (1) | 0.75 | 1.2[g] | 3.6 | | | |
| ISN-3 | 6/17-6/20 | 27.9 (0.5) | 47 (3) | 28.7 (0.3) | 48 (2) | 0.51[g], 0.55 | 1.4[g] | 5.0 | | | |
| NCN-1 | 6/27-6/29 | 27.6 (0.7) | 48 (2) | 28.6 (0.5) | 52 (2) | 0.52 | 1.1[g] | 2.1 | None | Carpet, Padding | None |
| ICN-1 | 7/1-7/3 | 28.4 (0.6) | 47 (2) | 29.2 (0.2) | 49 (1) | 0.51 | 1.3[g] | 3.7 | IG[h] | | |
| NSA-1 | 7/31-8/2 | 27.2 (0.5) | 47 (2) | 28.1 (0.4) | 50 (2) | 0.18 | 0.7[g] | 1.8 | None | Stained Concrete | Air Freshener |
| NSA-2 | 8/9-8/11 | 27.7 (0.5) | 44 (1) | 28.7 (0.3) | 47 (2) | 0.32[g], 0.68 | 1.2[g] | 2.7 | | | |
| ISA-1 | 8/4-8/6 | 27.5 (0.6) | 46 (2) | 28.4 (0.5) | 49 (2) | 0.40[g], 0.66 | 1.2[g] | 2.9 | IG[h] | | |
| ISA-2 | 8/6-8/8 | 28.0 (0.4) | 44 (1) | 28.8 (0.4) | 47 (1) | 0.51[g], 0.66 | 1.5[g] | 3.2 | | | |
| NCA-1 | 7/7-7/9 | 29.3 (0.6) | 46 (2) | 30.1 (0.4) | 48 (2) | 0.69 | 1.4[g] | 3.4 | None | Carpet, Padding | Air Freshener |
| ICA-1 | 7/10-7/12 | 29.5 (0.5) | 42 (1) | 30.6 (0.5) | 45 (1) | 0.44[g], 0.63 | 1.9[g] | 5.6 | IG[h] | | |

[a] Tests started and stopped about approximately 12:00 p.m.; [b] Temperature; [c] Relative humidity; [d] Air exchange rate when the HVAC system was off; [e] Air exchange rate when the HVAC system was set on duty cycle; [f] Air exchange rate when the HVAC system was on; [g] At least an hour of data was used to calculate these air exchange rates; [h] Ion generator.

A sample of the continuous particle and ozone measurements is shown in Figure 1, for the tests (a) NSA-2 (no ion generator) and (b) ISA-1 (operating ion generator). The duration during which the HVAC system was switched off (11 p.m. to 9 a.m.) is demarcated by thin vertical lines on the plot. The room configuration for these two tests were both stained concrete flooring and an active plug-in air freshener. Thus, the impact of operating a portable ion generator in a terpene-rich environment on indoor particle concentrations is illustrated by Figure 1b. When the HVAC system was operating on its duty cycle (9 a.m. to 11 p.m.), the air exchange rate measured for test NSA-2 was $\lambda_{cycle}$ = 1.2 $h^{-1}$. This loss rate was high enough relative to the reaction rate that there was no evidence of SOA formation. However, when the HVAC system was switched off and the air exchange rate decreased ($\lambda_{off}$ = 0.32 and 0.68 $h^{-1}$ for the two nights), the reaction rate was fast enough relative to the air exchange rate to yield substantial SOA formation. The largest particle number increases can be observed in the smallest size range (0.015 – 0.05 µm), and increases can be observed for all size bins less than 0.533 µm. Figure 1a shows the same room condition without an operating ion generator. Without the ozone emitting air cleaner present, particle concentrations did not increase when the air exchange rate decreased during the HVAC off period. The only particle formation observed was at approximately 12 p.m. on the second day of test NSA-2, most likely owing to the infiltration of high outdoor ozone concentrations.

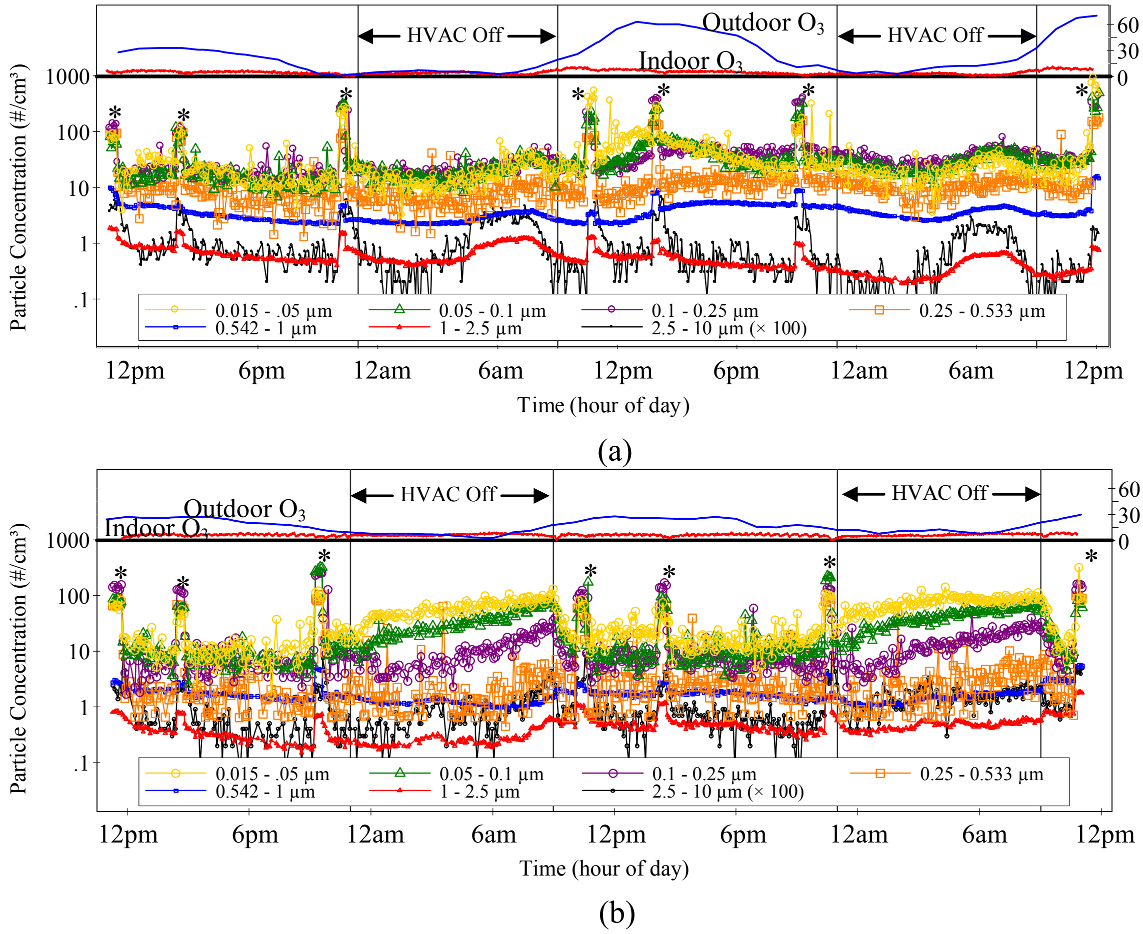

Figure 1. Ozone and particle concentrations versus time, for the room configuration with stained concrete flooring and an air freshener as a terpene source, both (a) with and (b) without an operating ion generator. The HVAC system was switched off from 11 p.m. to 9 a.m. * denotes outdoor particle samples.

The continuous measurements for every test are not shown for brevity, but Figure 2 displays summary results for particle, ozone, formaldehyde, and nonanal room concentrations. Formaldehyde is a product of ozone surface reactions (Wang and Morrison, 2006), ozone gas-phase reactions with air freshener constituents, and is emitted from the air freshener (Singer et al., 2006). Nonanal is also a product of surface reactions, particularly with carpet (Wang and Morrison, 2006). The ion generator had a negligible effect on other sampled concentrations. Displayed particle number concentrations are the mean for the last two hours of the HVAC off period (7 to 9 a.m.), and ozone concentrations are for the entire HVAC off period (11 p.m. to 9 a.m.). The particle averaging time of 7 to 9 a.m. was chosen so as to compare particle concentrations as close to steady-state values as possible, though as shown in Figure 1, steady-state was not always reached by the end of the HVAC off period. The entire HVAC off period was chosen as an averaging time for ozone concentrations because ozone reached steady-state within an hour of the reduction in the air exchange rate associated with the system turning off. Formaldehyde and nonanal concentrations are the integrated results from the test sample times (1 to 3 a.m.). The solid lines separate the results into the four different room configurations, and within those, the dashed lines separate the results into no operation and operation of an ion generator.

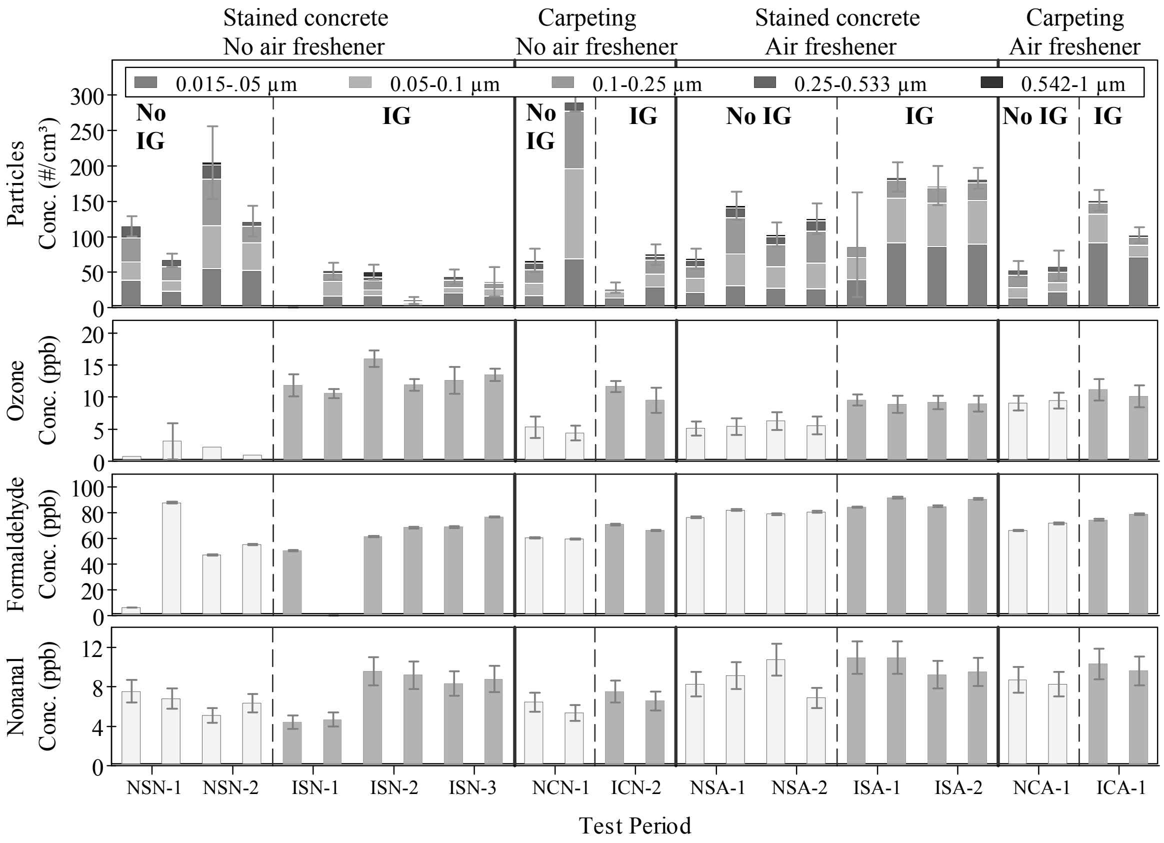

Figure 2. Summary of particle, ozone, formaldehyde, and nonanal room concentrations. Particles are averaged over last two hours of HVAC off period, ozone the entire HVAC off period, and formaldehyde and nonanal are integrated results from sampling period.

The results within each dashed line in Figure 2 were averaged, and the average concentrations without the ion generator operating were subtracted from the average concentrations with it operating. These average *differences* are listed in Table 4. For both room configurations without an air freshener, the use of the ion generator decreased mean particle concentrations, with differences of -95 and -15 #/cm$^3$. In the rooms with an air freshener as a terpene source, the rate of removal due the ion generator and air exchange during the HVAC off period was less than the rate of SOA formation, and a net increase in particle concentrations was observed: 69 and 70 #/cm$^3$. The bulk of this particle growth was in the ultrafine range. Though mean concentrations are not shown during the HVAC on period, particle reductions by and SOA formation due to the ion generator were not as large at those higher air exchange rates. These results imply that ion generators may have a negligible impact on particle concentrations in residences with highly active HVAC systems. However, during periods of time without an operating central HVAC system, both particle removal due to the ion generator and particle formation in terpene-rich environments can be enhanced.

The use of the ion generator caused positive mean ozone concentration differences in all room configurations, ranging from 11 to 1.4 ppb. The concentration increase was the largest in the room configuration with the stained concrete flooring and without the air freshener, implying these conditions consume the least ozone by homogeneous and heterogeneous reactions. The addition of the carpet resulted in a smaller difference of 5.8 ppb, consistent with research that the carpet likely has more available sites for ozone surface reactions than the sealed stained concrete (Klenø et al., 2001). The addition of the air freshener in the room had a larger effect on the ozone concentration difference than adding carpet. The room configuration with both carpet and an air freshener resulted in the smallest ozone concentration difference, likely due to its highly reactive nature. Though the ozone concentration difference due to the ion generator may be smaller with carpet and an air freshener added, these room configurations have substantially higher concentrations of particles. Similar to particles, effects of the ion generator on ozone concentrations were negligible during the HVAC on periods.

Table 4. Mean concentration difference due to operating ion generator in each room configuration during HVAC off period.

| | | **Difference due to ion generator** | | | |
|---|---|---|---|---|---|
| **Flooring** | **Terpene Source** | **Particles ($\#/cm^3$)** | **$O_3$ (ppb)** | **Form. (ppb)** | **Nonanal (ppb)** |
| Stained concrete | None | -95 | 11 | 5.2 | 1.1 |
| Carpet & padding | None | -15 | 5.8 | 8.5 | 1.1 |
| Stained concrete | Air freshener | 69 | 3.5 | 8.3 | 1.4 |
| Carpet & padding | Air freshener | 70 | 1.4 | 7.6 | 1.4 |

Formaldehyde and nonanal concentrations increased with operating the ion generator in each of the configurations. Formaldehyde increases were more substantial than nonanal increases, since formaldehyde is a product of surface and gas-phase reactions and is also emitted by the air freshener. The relatively small increase in nonanal due to the addition of the carpet implies that this particular carpet has few nonanal-producing reaction sites, which has been observed elsewhere (Wang and Morrison, 2006). These samples were not taken during the HVAC on period, so impacts could not be determined.

Though these exact results are dependent on the conditions of the test room and the performance of the particular ion generator, the general effect on IAQ in residences with different environmental conditions can be inferred. For instance, the net measurable effect of the ion generator was a strong function of the air exchange rate. As it decreased, the impact of the ion generator increased, implying that IAQ in similar rooms with lower rates than in our study would be more negatively impacted, as related research has found (Weschler and Shields, 2003; Sarwar et al., 2003). Additionally, the room temperature during the HVAC off period was most often elevated to near 30 °C because of the heat of the instrumentation. Typical room temperatures are between 21 and 24 °C and are often lower. In lower, more common indoor temperatures in the U.S., the SOA formation effect would be more pronounced, as Sarwar et al. (2003) noted a substantial increase formation due to gas-to-particle partitioning of products at lower air temperatures. Taking these factors into account, the operation of an ion generator in a terpene-rich environment could result in more substantial degradation of IAQ than seen in our study.

## CONCLUSIONS

Portable ion generators are common in the U.S., but a comprehensive evaluation of their effects on air quality in residences had not been performed. This study compared the IAQ in four different room configurations without and with the operation of an ion generator. The use of the ion generator increased ozone, formaldehyde, and nonanal concentrations in all tested room configurations. In rooms with an air freshener as a strong source of terpenes, the ion generator also increased steady-state particle concentrations due to SOA formation as the product of ozone/d-limonene reactions. This study finds that ion generators can degrade IAQ, and that their use indoors should be avoided.

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