California Environmental Protection Agency

Air Resources Board

Evaluation of Ozone Emissions From Portable Indoor Air Cleaners: Electrostatic Precipitators and Ionizers

Staff Technical Report

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ACRONYMS and UNITS

ACRONYM	**DEFINITION**
AAQS	ambient air quality standard
AER	air exchange rate
ANSI	American National Standards Institute
ARB	California Air Resources Board
CO_2	carbon dioxide
ESP	electrostatic precipitator
FDA	U.S. Food and Drug Administration
GP	germicidal protection
NO	nitric oxide
NO_2	nitrogen dioxide
NO_X	oxides of nitrogen
MLD	Monitoring and Laboratory Division
O_3	ozone, three atoms of oxygen (reactive)
OG	ozone generator; air cleaners that intentionally produce ozone
OSHA	U.S. Occupational Safety and Health Administration
RH	relative humidity
T	temperature
UL	Underwriters Laboratories, Inc.
UV	ultraviolet
VOCs	volatile organic compounds

UNITS

ft^2	square feet
g	gram
hr	hour
L	liter
m^2	square meter
m^3	cubic meter
m/s	meters per second
m^3/s	cubic meters per second
mole	6.022×10^{23} molecules
µg	microgram (one-millionth of a gram)
µg/s	micrograms per second
$µg/m^3$	micrograms per cubic meter (concentration)
mg	milligrams (one-thousandth of a gram)
mg/hr	milligrams per hour
%	percent
ppb	parts per billion by volume (e.g., one grain of sand in a billion grains of sand)
ppm	parts per million by volume (e.g., one grain of sand in a million grains of sand)
s	second

EXECUTIVE SUMMARY

Public concern about indoor air has resulted in a growing market for the sale of indoor air cleaning devices to improve indoor air quality. The numerous indoor air cleaning devices that are currently available use a variety of technologies to remove unwanted contaminants from users' indoor environments. Some of these technologies emit ozone as a by-product of their operation. Two types of portable air cleaning devices that may emit ozone as a by-product include ionizers and electrostatic precipitators (ESPs). The limited studies available indicate that the resultant levels of ozone are generally low and not likely to be harmful to health. However, while not producing as much ozone as "air purifiers" that intentionally emit ozone, some by-product air cleaners may produce indoor ozone levels that approach or exceed the California health-based standard of 0.070 parts per million (ppm) 8-hour average, or the Underwriters Laboratories, Inc. industry emission test standard of 0.050 ppm. To assess the potential health impacts of ozone from current models of ionizers and ESPs, the California Air Resources Board (ARB) staff performed three different tests of several models of ESPs and ionizers.

Staff tested five models of ESPs and ionizers that are widely marketed in California. Room ozone concentrations were measured in a small room furnished with a desk and chair, at temperature, humidity, and air exchange conditions common in California homes while the devices were operated according to manufacturers' instructions. Prior to the room concentration tests, measurements were made at 2, 6, 12, and 24 inches from the face of each device to locate the major output stream for each and identify the range of emissions in preparation for the room concentration tests. After the room concentration tests were completed, ozone emission rates were measured using non-reactive ducting.

The results presented in Table ES-1 show that all of the ESPs and ionizers tested produced ozone at levels that are below health-based standards for all the tests conducted. None of the devices produced ozone concentrations above 45 ppb during the face tests, and all produced room concentrations below 16 ppb in the room test. All of the devices examined produced less than 3 mg/hr of ozone. When compared to previous measurements of intentional ozone-generating air cleaners (OGs) performed by ARB staff, the ozone levels from ESPs and ionizers were substantially lower for all tests. The lower ozone levels produced by ESPs and ionizers are expected, because ozone generation is not the intended result of their operation.

While these tests reveal that ozone emissions from ESPs and ionizers are generally much lower than those from OGs, there is still a need to exercise caution. The tests described in this report were conducted under a very limited set of conditions that do not cover the full range of conditions in which air cleaners are used. Longer periods of use than the 2-3 hour periods tested here, lower relative humidity, and lower air exchange rates would all be expected to increase the concentrations of ozone produced in actual environments by these devices. In fact, a few other investigators have reported ozone emissions from ESPs and ionizers measured under a variety of test methodologies, and found several devices produced ozone concentrations in excess of 0.050 ppm, with a few devices even exceeding 0.070 ppm. The findings of this previous research also indicate that while some ESPs and ionizers may emit elevated levels of ozone, these devices should be able to meet all relevant emission standards with small design adjustments.

Caution also is warranted because introduction of any amount of ozone into indoor spaces may result in increased levels of formaldehyde, ultrafine particles, and other pollutants due to the reaction of ozone with terpenes (fragrance compounds such as pinene and limonene) and other chemicals emitted from modern consumer products and building materials. Additionally, operation and maintenance practices of air cleaner owners have the potential to significantly impact the amount of ozone produced. Recent survey results indicate that most California air cleaner owners operate their indoor air cleaning devices continuously and year round; however, owners typically do not maintain their devices as instructed by the manufacturer. This can lead to excess ozone generation and greater ozone emissions than observed in the tests reported here.

In the future, test conditions need to be optimized to ensure the most repeatable measurements possible to accurately characterize the true ozone emissions from these devices. Room tests should be of longer duration and chamber performance should be carefully specified. The effects of device age and maintenance need to be better characterized, and inter-unit variability needs to be addressed. In short, close attention to the methods of emission characterization is necessary to assure these devices can be continuously operated in occupied spaces without concern over possible elevated ozone exposures leading to potential health effects.

Table ES-1. Summary Results

	Maximum Ozone Level			
Unit	**Face Emission Concentration (ppb)**	**Room Concentration 1-min avg.[a] (ppb)**	**Room Concentration 60-min avg.[a] (ppb)**	**Emission Rate (mg/hr)**
Oreck Super Air 8	18	8.2	6.9	1.4
Sharper Image™ Ionic Breeze® GP[b]	44	10.5	9.0	2.9
Sharper Image™ Ionic Breeze® Quadra® Pro	35	15.1	14.1	2.7
Sharper Image™ Ionic Breeze® Quadra® Compact	27	10.6	9.5	1.3
Sharper Image™ Ionic Breeze® Air Freshener	NA [c]	2.2	1.7	NA

[a] Not corrected for background ozone concentration; [b] GP = germicidal protection; [c] NA = not available.

1. INTRODUCTION

The market for portable air cleaning devices advertised for residential use has expanded substantially as public concern over a variety of airborne pollutants has increased. Recent figures indicate that annual national sales of these products have surpassed $400 million (Consumer Union, 2005a). The numerous indoor air cleaning devices available use a variety of technologies to remove unwanted contaminants from users' indoor environments. Some of these technologies have the potential to emit ozone as a by-product of their operation. The limited studies available indicate that the resultant levels of ozone are generally low and not likely to be harmful to health. However, while not producing as much ozone as purported "air purifiers" that intentionally emit ozone, some by-product air cleaners may produce indoor ozone levels that approach or exceed health-based standards or industry test standards, especially when the air cleaners are used for 24 hours or continuously around the clock (Britigan *et al*., 2006; Consumers Union, 2005b; Niu *et al*., 2001a; Tung *et al*., 2005).

Ionizers and electrostatic precipitators are two types of portable air cleaning devices that may emit ozone as a by-product. Ionizers release electrons into the air forming ions with airborne molecules which then a) attract particles to form agglomerates possessing a greater tendency for deposition, or b) charge airborne particles, increasing the likelihood of attraction to surfaces and subsequent deposition. Electrostatic precipitators (ESPs) utilize a corona to charge airborne particles and collect them with charged metal plates of opposite polarity. The magnitude of ozone emissions from ESPs and ionizers appears to be linked to certain design characteristics and operational methods, the discharge voltage, polarity of the discharging electrode, the arrangement and effective surface area of the electrodes, and the overall geometry of the air cleaner.

To assess the potential health impacts of current models of ionizers and ESPs, the California Air Resources Board (ARB) staff performed three different emissions tests on several models of ESPs and ionizers. This report presents and discusses the results of those tests and their implications. A May 2006 ARB report on the ozone concentrations and emissions produced by intentional "ozone generators" (OGs), is available at http://www.arb.ca.gov/research/indoor/o3g-rpt.pdf.

2. BACKGROUND

Ozone is a highly reactive molecule composed of three oxygen atoms. Human exposure to ozone can damage the respiratory system. Ozone inflames and irritates respiratory tissues, and can worsen asthmatic symptoms in individuals with asthma. Ozone exposure can produce symptoms such as coughing, chest tightness and impaired breathing. Elevated exposures have the potential to induce permanent lung damage, and exposure can even increase the risk of premature death in persons with poor health. Ozone can also damage plants, fabrics and building materials, such as paint, walls, and flooring. Ozone is a primary component of photochemical smog, and has been recognized and regulated as a serious outdoor air pollutant for many years.

To protect public health from exposure to outdoor ozone, ARB has established a health-based ambient ozone standard of 0.09 parts per million (ppm) for a one hour average and 0.070 ppm for an eight hour average (ARB, 2005). The U.S. Food and Drug Administration (FDA) established a 0.05 ppm ozone emission concentration limit for medical devices in the 1970s. Underwriters Laboratories, Inc. (UL), a consumer product testing and certification organization, developed Standard 867 for testing electrostatic air cleaning devices. Section 37 of the standard provided a test for ozone emissions that limits room ozone concentrations to 0.050 ppm at two inches from the face of the device after 24 hours of operation. The usefulness of the test methodology in protecting health was questioned due to the lack of specificity of some aspects of the test protocol. This allowed for variability in how the test protocol was interpreted which allowed some high-emitting air cleaners that produce unhealthy ozone levels to pass the test (Niu *et al.*, 2001a,b; Chen and Zhang, 2004; Mullen *et al.*, 2005). Accordingly, UL convened an *ad hoc* committee in 2006 to revise the Section 37 test protocol. The revised Section 37 has been approved through the American National Standards Institute (ANSI) standard revision process, and was published on December 21, 2007 (ANSI/UL, 2007).

A handful of investigators have reported ozone emissions from ESPs and ionizers measured under a variety of test methodologies (Consumer Union, 2005a,b; Chen and Zhang, 2004; Niu *et al*., 2001a,b; Mullen *et al*., 2005; Britigan *et al*., 2006; Tung *et al*., 2005). These studies found varying effectiveness and ozone emissions for ESPs and ionizers. Several devices were observed to produce ozone concentrations in excess of 0.050 ppm, with a few devices even exceeding 0.070 ppm, the California 8-hour ambient air quality standard (AAQS) for ozone.

The magnitude of ozone emissions from ESPs and ionizers appear to be linked to various design characteristics and operational methods. According to Tung *et al*. (2005) important design factors related to potential ozone production include the discharge voltage, polarity of the discharging electrode, the arrangement and effective surface area of the electrodes, and the overall geometry of the air cleaner. The previous work of Liu *et al*. (2000) showed that ozone emissions were dependent upon the overall geometry of the air cleaner and the temperature of the corona wire surface. The findings of these studies indicate that ESPs and ionizers that emit elevated levels of ozone should be able to meet all relevant standards with small design adjustments.

An added concern with the introduction of ozone into modern indoor spaces is the possible health impact of secondary emissions from reaction of ozone indoors with chemicals such as terpenes, which can produce pollutants such as formaldehyde and ultrafine particles (Weschler, 2000; Nazaroff and Weschler, 2004; Singer *et al*., 2006). Pinene and limonene, two common terpenes that provide pine and citrus fragrance, respectively, are present in many consumer products; thus, increased concentrations of reaction products is likely in indoor spaces where ozone is present. Increased exposure to formaldehyde is a concern because it was upgraded to a Group I, or known human, carcinogen in 2004 by the International Agency for Research on Cancer.

3. OBJECTIVES AND TECHNICAL APPROACH

The goal of this project was to determine the potential impact of popular electrostatic precipitator and ionizer portable air cleaners on indoor ozone levels. Product testing was conducted under common conditions likely to result in elevated ozone levels, and to assess the results for their potential impacts on human health. The specific objectives were to:

1. Determine short-term indoor air concentrations of ozone in a room where ESP and ionizer air cleaners are operated per manufacturers' directions.
2. Determine ozone emission rates from those devices under different operational settings.
3. Compare the results to health-based ozone standards, and where feasible, to industry test standards, literature results, and other information to assess the potential impact of ESPs and ionizers on indoor air quality and human health.

Five models of ESP and ionizer air cleaners were selected for evaluation (see Table 1). Because reliable sales data for portable air cleaning devices are not readily available for California or the U.S., the models most often mentioned in public inquiries to ARB and widely marketed in California were selected for testing. The models were obtained through normal marketing channels, retail and the Internet. A second unit of model number 8 (Sharper Image™ Ionic Breeze® Quadra® Compact) was included to test the variability between units of the same model.

Existing test methods for ozone emissions from air cleaners have various limitations, and government agencies in North America have neither certified these methods nor developed their own. Consequently, three test protocols were selected after reviewing the scientific literature and consulting researchers in this field, as follows:

1. Face Test: Measure ozone concentrations near the exterior exhaust face of each air cleaner unit to identify the primary emission point and direction for ozone exhaust, and roughly characterize the near-source dispersion of the ozone.
2. Room Test: Measure ozone concentrations for a few hours (ideally until steady state is reached) with the air cleaner operated at different settings, in a small, partly furnished test room to simulate conditions in a small room in a home.
3. Emission Test: Measure ozone emission rates directly from the air cleaner unit using inert ductwork attached to the unit.

The specific methods, results, and discussion for each of these three tests of each air cleaner model are presented briefly. For all tests, ozone concentrations were measured with an API 400 Ozone analyzer. A second API ozone analyzer (outside the chamber) was used to monitor the background ozone concentrations in the building during the device emission measurements. Additional details are available in an earlier report (ARB, 2006).

Table 1. Model Descriptions of ESP and Ionizer Portable Air Cleaners

Unit #	**Model**	**Floor Space or Time Rating; Recommended Settings** [a]	**Features** [a]
5	Oreck Super Air 8	High setting for maximum cleaning. Medium setting for normal operation. Silent setting for quiet operation. Utilize louvers to direct unit output as desired. Prolonged arcing indicates collector cell needs cleaning and complete drying. Optimal efficiency from continuous operation.	ESP, Ionizer
6	Sharper Image™ Ionic Breeze® GP	One unit per 500 ft^2. Operational setting dependent on room size. Operate unit continuously. Position at least 12” from nearest wall. Avoid UV exposure if in excess of 60 min/day. Using Boost/Ion button will increase soot production. Clean collection plates, grill and ionization wires every 2 weeks, or if arcing sound is produced by the unit. Avoid scrubbing ionization wires on front grill. Do not operate near heavy particulate sources such as fireplaces, candles or oil lamps.	ESP, Ionizer, Ultraviolet Lamp
7	Sharper Image™ Ionic Breeze® Quadra® Pro	One unit per 500 ft^2. Operational setting dependent on room size. Operate unit continuously. Clean collection plates every 2 weeks, or if arcing sound is produced by the unit. Do not operate near heavy particulate sources such as fireplaces, candles or oil lamps.	ESP, Ionizer
8	Sharper Image™ Ionic Breeze® Quadra® Compact	Operational setting dependent on room size. Operate unit continuously. Position at least 12” from nearest wall. Reduce operational setting if noticeable odor is produced. Clean collection plates every 2 weeks, or if arcing sound is produced by the unit, allow 24 hr. drying time afterwards. Do not operate near heavy particulate sources such as fireplaces, candles or oil lamps.	ESP
9	Shaper Image™ Ionic Breeze® Air Freshener	Plug into electrical wall outlet. If unit produces a “humming” sound, clean the ionization wires by shaking the unit.	Ionizer

[a] From product brochures that came with appliances. The instruction items selected are those most pertinent to ozone production and human exposure.

Commonly accepted quality control and quality assurance procedures were followed. The monitoring equipment received daily zero and span checks by MLD staff during testing, in accordance with standard ARB methods. To minimize contamination of the air cleaners, they were stored in their shipping boxes in the warehouse except when they were being tested or being fitted for the custom duct adaptor at a fabrication shop. Two duplicate units of one air cleaner model were obtained to identify between-unit variability. Repeated tests on the same unit under the same operational setting were conducted on units 5 and 7 to examine the reproducibility of the results obtained.

4. FACE TESTS

A. Face Test Methods

In preparation for the room and emissions tests, ozone concentrations were measured at all of the face vents for each device (except for unit 9, the air freshener) in order to locate the major air stream output and direction for each appliance. Measurements were made at 2, 6, 12, and 24 inches away from the vertical or horizontal face. The measurements were made for 10 minutes at the different operational settings shown in Table 2. Note that these concentrations were corrected by subtracting background ozone levels, which were measured in an adjacent portion of the warehouse.

B. Face Test Results

Summaries of the face test results are presented in Table 2 and Figure 1. None of the electrostatic precipitators/ionizers examined produced face ozone concentrations that exceeded 45 ppb for the 10-minute average measurements. Additionally, only units 6 and 7 emitted ozone concentrations that were 30 ppb or greater. As expected, the highest measured concentrations were observed at the 2 inch distance. The added dilution provided by measurement at 6 inches did not result in a reduction of ozone concentration of more than 20% for any of the units, while operated under high setting. Measurements taken at a distance of 12 inches were below 25 ppb for all units and operating conditions. Ozone concentrations at 24 inches did not exceed 20 ppb, and were less than 50% of the 2 inch levels for the high setting operation of units 6, 7 and 8. Unit 5 under high setting did not exhibit 50% reduction between the 2 and 24 inch distances; however, the ozone levels were below 5 ppb for all distances measured, and dilution across space was likely affected by local air currents or other factors.

Table 2. Results from Exploratory Face Tests of ESP and Ionizer Air Cleaners

			Ozone Concentration at Varying Distance (inches) from Unit's Face (ppb) [a]			
Test ID	**Manufacturer and Model**	**Operational Setting**	**2"**	**6"**	**12"**	**24"**
5L	Oreck Super Air 8	Silent setting, Ionizer on	18	18	13	5.4
5H		High setting, Ionizer on	3.3	4.9	1.7	2.3
6L	Sharper Image Ionic Breeze GP [b]	Low setting, GP on, Boost off	44	5.1	3.0	2.0
6H		High setting, GP on, Boost on	42	36	24	19
7L	Sharper Image Ionic Breeze Quadra Pro	Low setting, Boost off	31	14	3.9	1.9
7H		High setting, Boost on	35	29	24	16
8L	Sharper Image Ionic Breeze Quadra Compact	Low setting	3.5	4.0	2.0	0
8H		High setting	27	27	21	10

[a] Reported concentrations are 10-minute averages, corrected for background ozone levels.
[b] GP = germicidal protection

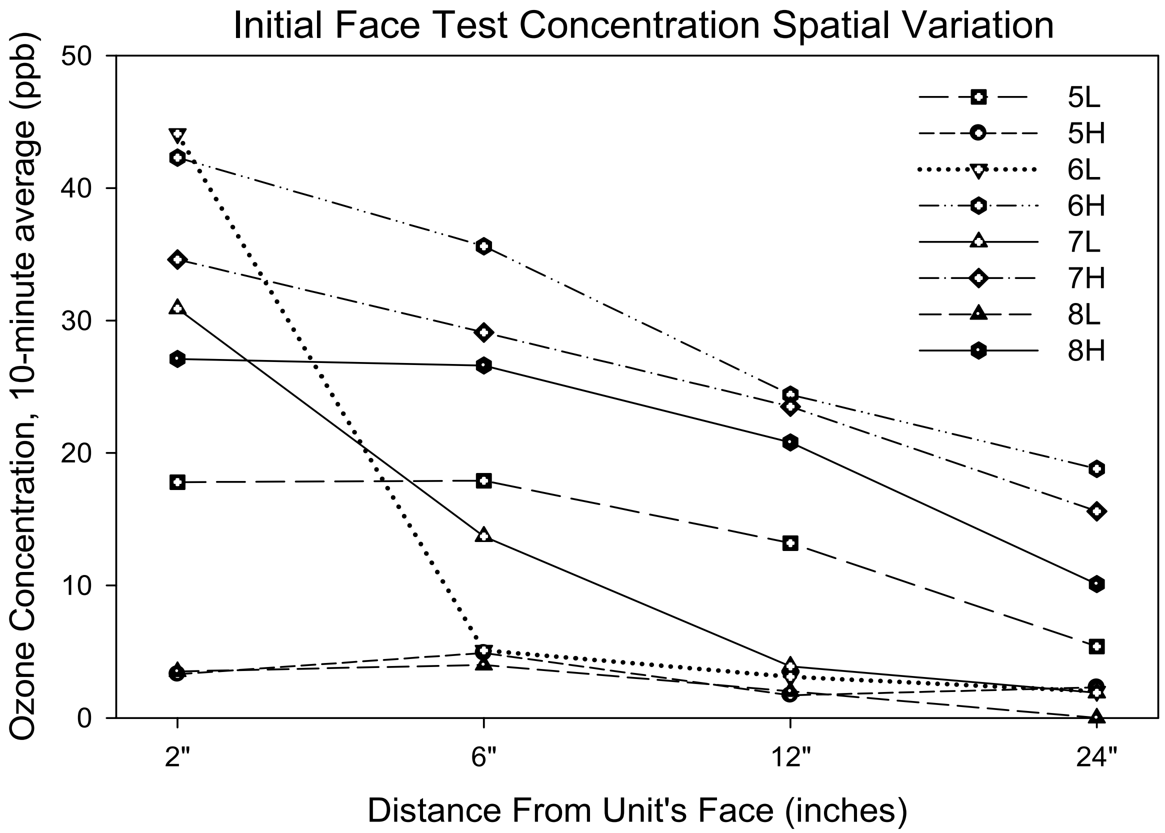

Figure 1. Ozone Concentration Profiles for Face Tests of ESP & Ionizer Air Cleaners

C. Face Test Discussion

Minimal previously published research is available for comparison of the results obtained in this study. Previous work published in Consumer Reports® (Consumer Union, 2005a) examined one similar air cleaner by a comparable testing method. The authors measured ozone emission concentrations of 48 ppb and 18 ppb for the Sharper Image Ionic Breeze Quadra Professional Series at distances of 2 inches and 36 inches respectively. These values compare favorably to the results obtained in this study for the Sharper Image Ionic Breeze Quadra Pro of 35 ppb and 16 ppb at 2 inches and 24 inches respectively for operation at the high setting. The good agreement observed adds confidence to the results obtained for the air cleaner face tests.

Recently the devices marketed by Sharper Image have included an ozone exhaust control device named Ozone Guard. Consumers who purchased their air cleaner prior to the release of the Ozone Guard can purchase the control device separately. At the time of purchase of the Sharper Image models examined in this testing, they were not outfitted with the ozone emission control device. Thus, for the testing described in this report, none of the units utilized the Ozone Guard, and it is not known how this device might have performed under our test conditions.

In comparison to face test ozone emission concentrations from OGs, the results for ESPs and ionizers were substantially lower (ARB, 2006). None of the ESP and ionizer units exceeded 45 ppb, while OGs yielded ozone concentrations well in excess of 100 ppb with several tests measuring ozone above 1000 ppb. For each of the ESPs and ionizers tested, the measured concentration at 24 inches was at least 50% less than the ozone level measured at 2 inches, excluding unit 5 under high setting. This reduction is consistent with the previous results with OGs.

5. ROOM TESTS

A. Room Test Methods

A complete description of the room testing methodology utilized in this research is available elsewhere (ARB, 2006). Briefly, each device was operated in a test room located within a warehouse in Sacramento, California, located about 1000 meters from any major freeway or surface street. The room dimensions were similar to that of a home office or small bedroom (88 ft^2, volume of ~20 m^3). An air exchange rate (AER) of 0.3-0.5 was targeted for the testing. The AER was verified using a CO_2 tracer decay methodology. A summary of the actual AERs during the room tests is provided in Table 3 below.

Table 3. Air Exchange Rates for Room Tests of ESP and Ionizer Air Cleaners

Date	**Room Test #**	**AER (air exchange rate; air changes per hour)**
6/23/05	Pre-test	0.27
6/24/05	Pre-test	0.25
6/27/05	Pre-test	0.28
Pretest Average		**0.27**
7/12/05	5L, 5LA	0.28
7/19/05	5H, 6L, 6LA, 6H, 7L, 7LA	0.26
7/25/05	7LAR, 7H, 8L	0.25
9/7/05	5LAR, 8LD, 8H, 9	0.27
Test Average		**0.27**

Room tests were conducted during daytime hours on weekdays between July 8 and September 12, 2005. Prior to appliance testing, ozone concentrations were monitored in the test room and the adjacent warehouse open area for 30 minutes to characterize initial background conditions. At the completion of background ozone monitoring, appliance testing began. The appliance was placed in a central location in the room on top of a desk, 3 feet from the wall, at a height of approximately 2.5 feet off the floor. User instructions from the manufacturers were considered in selecting the location and settings for each appliance. The room-sampling probe for ozone was situated four feet above the floor to approximate the average "breathing zone height" for adults, and located about 3 feet from the device.

The appliance was remotely started at one of the pre-selected settings. Actual operational settings for each test are described in Table 4. For each test, the appliance was operated until ozone levels in the room reached steady-state (defined as maintenance of a constant ozone level of ± 5% for 30 minutes), or for 3 hours if steady-state was not achieved. After steady-state or 3 hours was reached, the appliance was turned off by remote switch, and the monitoring was continued until the room ozone level returned to ambient levels. In addition, the test room was monitored before and during the room tests for NO, NO_2, NO_x, room temperature (T), and relative humidity (RH). After each test period, room air was fully vented out of the building.

B. Room Test Results

Results from the room tests for the electrostatic precipitators/ionizers are summarized in Table 4 and in Figures 2 and 3. Background ozone levels were NOT subtracted from the room measurements. The steep declines at the right end of the tracings of elevated concentrations in the figures indicate the rapid decay of ozone that occurred after the devices were turned off. Figure 2 displays the room ozone concentration profile for the units while operated at their high setting. Figure 3 displays the results for operation at the low setting. None of the units produced room concentrations above 50 ppb; in fact, room concentrations were generally very low, usually just a few ppb and reaching 16 ppb at most. Most of the room concentrations show a slight initial rise in the room ozone level once the unit was turned on. Several of the room tests showed no change in the ozone concentration after the unit was energized.

The maximum concentrations measured were less than 10 ppb for all tests, with the exception of units 6, 7 and 8 when operated at the high setting. This result is in agreement with the 2 inch face tests for these units in which the 2nd, 3rd and 4th highest ozone concentrations were measured at the 2 inch distance. The only test to produce a 60-minute average concentration exceeding 10 ppb was the high setting operation of unit 7. It should be noted that the average background levels for all the unit 8 tests and the 5L and 5LAR tests were higher than the observed room concentrations. This is attributable to the tightness of the room and its associated low air exchange rate, plus the relatively short test time of 2 - 3 hours. This would seem to indicate that little, if any, of the ambient ozone entered the chamber during the tests; thus, the chamber ozone concentrations are essentially the result of emissions from the devices tested.

A steady-state concentration was not reached by any of the electrostatic precipitator/ionizer units when operated on their high setting. This is likely attributable to the low, measured ozone levels in conjunction with the tight variability allowance in our definition of a steady-state concentration.

Room test results for unit operation at their respective low settings produced ozone concentrations below 10 ppb for all of the units tested. In test 8L at about 105 minutes, a break in the door seal allowed background ozone to penetrate the test chamber after the unit had been turned off, creating a spike of about 9 ppb. Another anomaly is present in test 8LD in that the ozone level at the start of the test is higher than at any point later in the test. Both units 6 and 7 were observed to have initial spikes in the room ozone concentration that eventually decreased to less than 2 ppb.

Table 4. Ozone Concentration Results from Room Tests of ESP and Ionizer Air Cleaners

			Ozone Concentration (ppb)			
Test ID	**Manufacturer and Model**	**Operational Setting**	**Max 1-min AVG** [a]	**Max 60-min AVG** [a]	**Back-ground AVG**	**Relative Humidity (RH)**
5L	Oreck Super Air 8	Fan at low speed, Ionizer off	6.9	6.6	8.3	38.4
5LA		Fan at low speed, Ionizer on	4.5	3.8	0.6	47.6
5LAR		Repeat of test 5LA	8.2	6.9	8.9	32.9
5H		Fan at high speed, Ionizer on	2.5	2.1	0.8	43.1
6L	Sharper Image Ionic Breeze GP [b]	Low setting, GP off, Boost off	8.1	3.7	2.2	39.2
6LA		Low setting, GP on, Boost off	5.5	2.5	2.2	40.9
6H		High setting, GP on, Boost off	10.5	9.0	0.3	38.4
7L	Sharper Image Ionic Breeze Quadra Pro	Low setting, Boost off	3.8	1.6	2.2	39.9
7LA		Low setting, Boost on	6.8	3.7	6.1	37.0
7LAR		Repeat of test 7LA	9.0	4.6	8.3	42.5
7H		High setting, Boost on	15.1	14.1	7.1	36.3
8L	Sharper Image Ionic Breeze Quadra Compact	Low setting	2.1	1.2	9.1	37.6
8LD		Test 8L performed using duplicate unit	8.8	6.1	17.9	36.0
8H		High setting	10.6	9.5	17.2	36.1
9	Sharper Image Ionic Breeze Air Freshener	On (no user defined controls)	2.2	1.7	0.6	32.9

[a] Background concentration not subtracted from measured room value.
[b] GP = germicidal protection

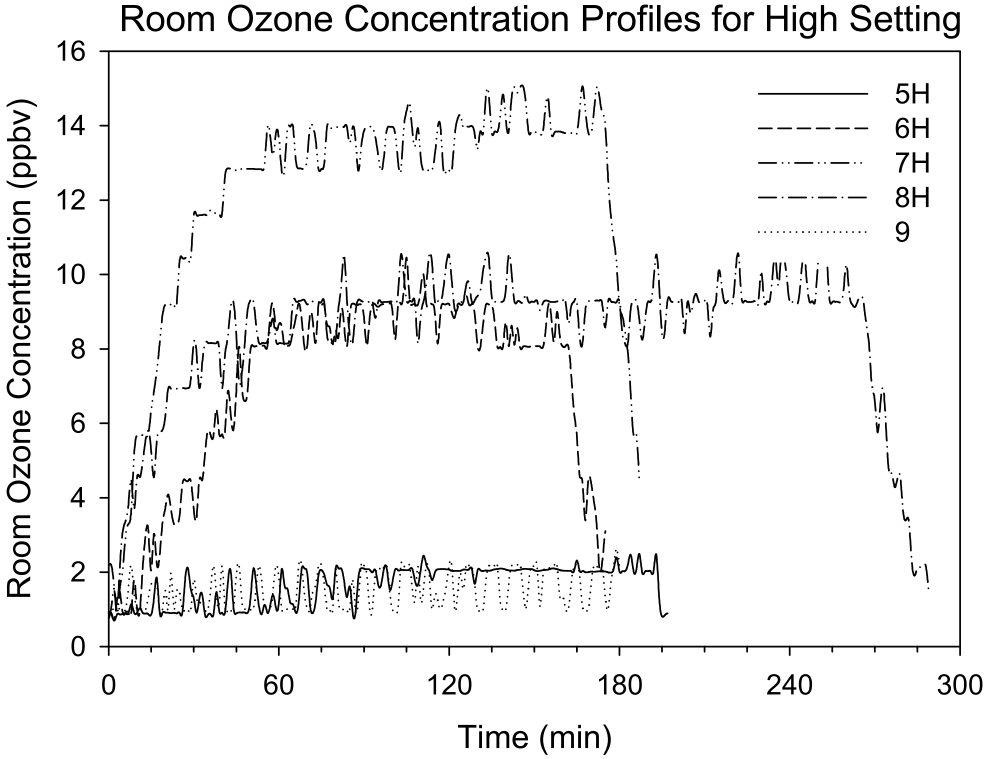

Figure 2. Ozone Room Concentration Profiles for High Setting

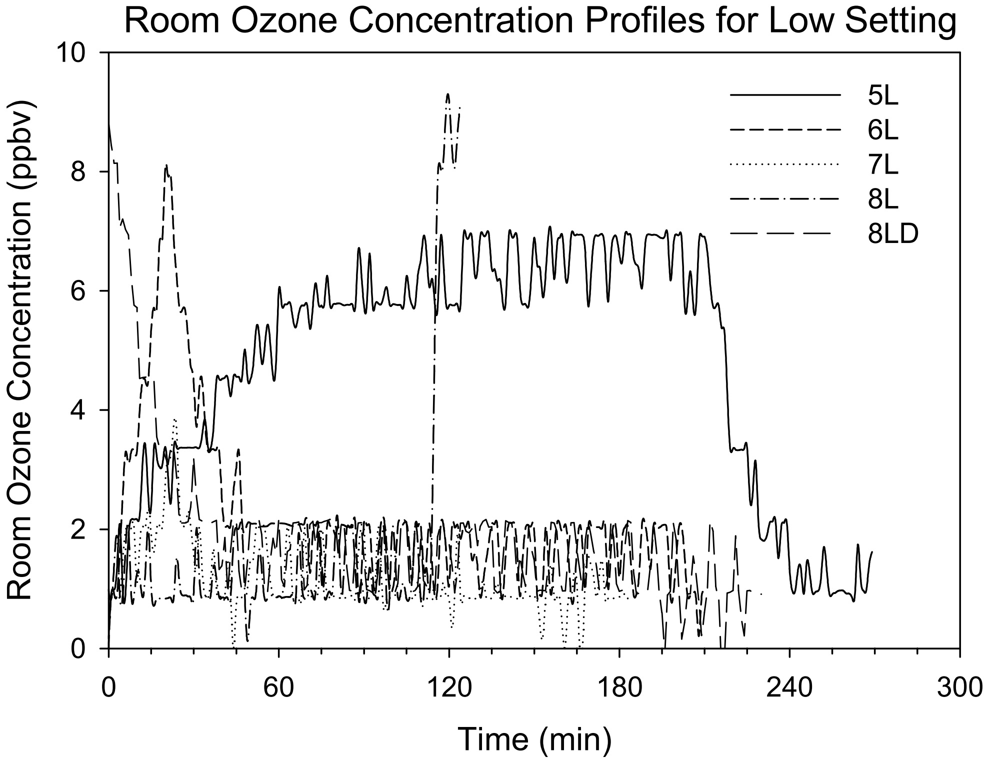

Figure 3. Ozone Room Concentration Profiles for Low Setting

1. Oreck Super Air 8

The observed maximum room ozone concentration for unit 5 was more than 2 times higher for the low versus the high setting, as shown in Figure 4 (background not subtracted). This result is consistent with the higher ozone concentrations measured for the low setting during the initial face emissions tests. But, greater average background ozone levels observed during the low versus high setting, 8.3 ppb and 0.8 ppb respectively, may also have contributed to this result.

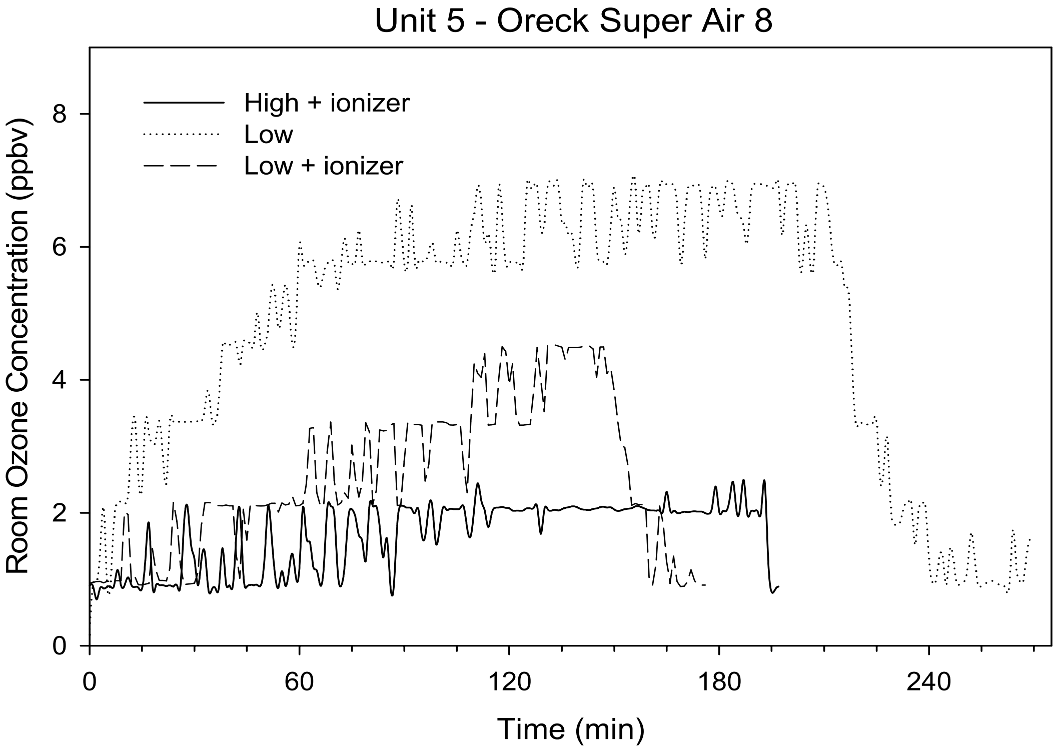

Figure 4. Ozone Room Concentration Profiles for Unit 5

The impact of operation of the ionizer feature on observed ozone concentrations was unable to be ascertained. In test 5LA the measured room ozone concentrations were less than those observed in 5L when the ionizer was not used. One observed difference between 5L and 5LA is the substantially lower background levels during the 5LA test (0.6 vs. 8.3 ppb average; see Table 4). In contrast, the room ozone levels in the replicate test, 5LAR, were higher than those observed in test 5L, when background levels were comparable (8.9 vs. 8.3 ppb averages). However, the lower RH in test 5LAR may also have contributed to the higher levels measured. Comparing 5LA to 5LAR (the repeat test), 5LAR showed nearly twice the ozone level as 5LA; the higher background ozone and lower RH likely account for this difference.

2. Sharper Image Ionic Breeze GP

The room ozone concentration results for unit 6 are displayed in Figure 5 (background not subtracted). Operating unit 6 under its low setting produced a small initial room ozone concentration spike of 5-8 ppb, both with and without the operation of the germicidal protection (GP) function, peaking at 20-22 minutes. However, in both cases the room concentrations decreased to a background ozone level of about 2 ppb within about 45 minutes. Operation of unit 6 with the GP function produced lower room concentrations, with a difference of about 1 ppb for the maximum 60-minute average concentration.

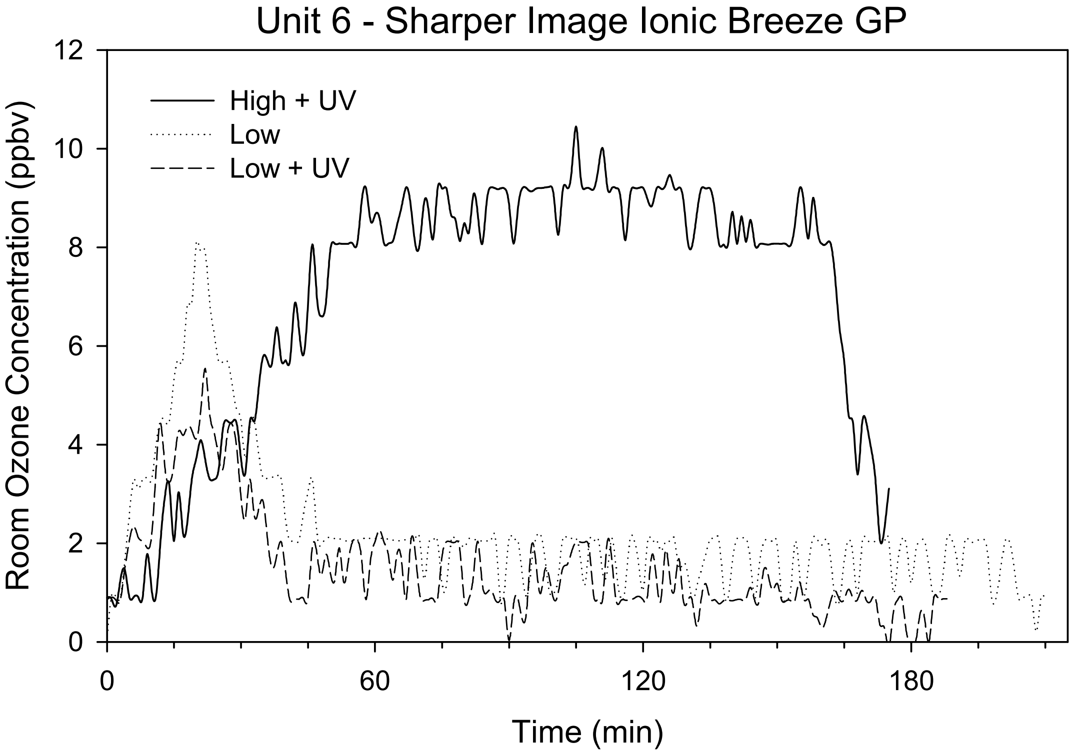

Figure 5. Ozone Room Concentration Profiles for Unit 6

No concentration spike was observed for operation at the high setting. Room ozone concentrations measured in test 6H rose steadily to 9 ppb over the first 60 minutes, with a maximum concentration of 10.5 ppb observed at 105 minutes. Steady-state concentrations as defined for these tests were not observed in any of the unit 6 tests. However, the observed concentrations after 60 minutes typically varied by approximately ± 1 ppb, and can be considered essentially steady-state.

3. Sharper Image Ionic Breeze Quadra Pro

Results from the room tests conducted on unit 7 are provided in Figure 6 (background not subtracted) and Table 4. Three of the four tests conducted (repeat test not shown in

Figure 6) showed a low initial spike of 6-8 ppb in the room ozone concentration, which peaked at about 20-25 minutes. The two tests with the low + boost operational settings peaked at ozone levels of 9 ppb (not shown in figure) and 6.8 ppb, while the low setting alone peaked at 3.8 ppb. The spike in initial room ozone concentration for the low setting operation mimicked the background levels (8.3, 6.1 and 2.2 ppb averages, respectively). In all three of these tests the room ozone concentration then decreased to less than 3 ppb within 60 minutes. Under high setting unit 7 showed a steady increase in the room ozone concentration to 14 ppb within 60 minutes. Near the end of the test the concentration had increased to 15 ppb. It is possible that the room levels would have continued to increase slightly if the unit were not turned off at 180 minutes. In general the behavior of unit 7 was very similar to that of unit 6 for all the operational settings. Again, steady-state concentrations as defined for these tests were not achieved. However, the observed concentrations after 60 minutes typically varied by approximately ± 1 ppb, and can be considered essentially steady-state.

As shown in Table 4, the repeat test conducted for unit 7, test 7LAR, showed slightly higher ozone concentrations compared to test 7LA. The slightly higher background ozone during test 7LAR may account for this difference; however, average RH was notably higher for test 7LAR, which would be expected to have a dampening effect on ozone emissions during that test. In general, ozone levels were very low in both tests, and the results are reasonably consistent for tests conducted under different, relatively uncontrolled, environmental conditions.

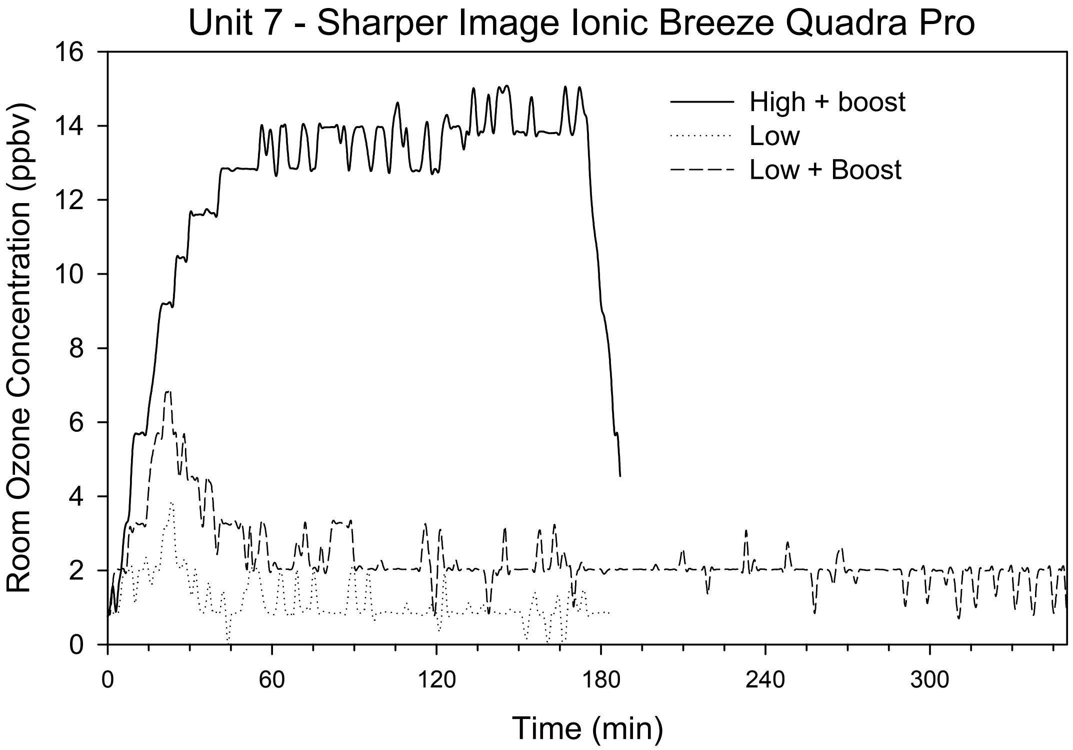

Figure 6. Ozone Room Concentration Profiles for Unit 7

4. Sharper Image Ionic Breeze Quadra Compact

Ozone room concentration profiles (background not subtracted) are displayed in Figure 7 for all operational settings of unit 8. Operation at the low setting produced a very low room concentration of 1-2 ppb. A spike in the concentration profile was observed at 115 minutes, but the unit had already been turned off. The likely source was the ambient ozone that entered the chamber due to a breach of the test chamber door seal.

Test results for a duplicate unit (data not presented in Figure 7; see Table 4) operated under low setting showed a much different concentration profile. The room ozone concentration was the highest at the start of the test (8.8 ppb), and slowly decreased to about 2 ppb over 45 minutes. The background ozone showed the highest average during this test; thus it is possible that the background ozone was highest at the beginning of the test and decreased over the course of the test. The difference in results between test 8L and the test of the duplicate device (8LD) may totally be explained by the fact that the background ozone (for 8LD) was about twice that for test 8L (17.9 vs. 9.1 ppb). It is also possible that oil residue from the manufacturing process or volatile organic compounds (VOCs) off-gassing from the device may have acted as an ozone sink. Based on the observed results, it is likely that the output from unit 8 under the low setting was not sufficient to raise the room ozone concentrations above 2 ppb.

Results for unit 8 using the high operation setting were similar to those observed for units 6 and 7 under high setting. The room ozone levels reached an apparent steady-state at 9 ppb within 60 minutes. A steady-state concentration as operationally defined for this project was not observed as the room ozone level varied by about 20%. However, the ozone concentration during test 8L was ± 1 ppb for the first 100 minutes of the test, and room levels varied by only ± 2 ppb for test 8H. Thus the room concentrations essentially reached a steady-state.

5. Sharper Image Ionic Breeze Air Freshener

As shown in Figure 8, the room ozone concentration (background not subtracted) did not exceed 2.6 ppb at any time during the test for unit 9, the air freshener. This device did not contribute significantly to the room ozone concentration. A steady-state concentration according to the operational definition was not reached during the test. However, since the room levels fluctuate by less than ± 1 ppb, the room concentration can be essentially considered to have attained steady-state.

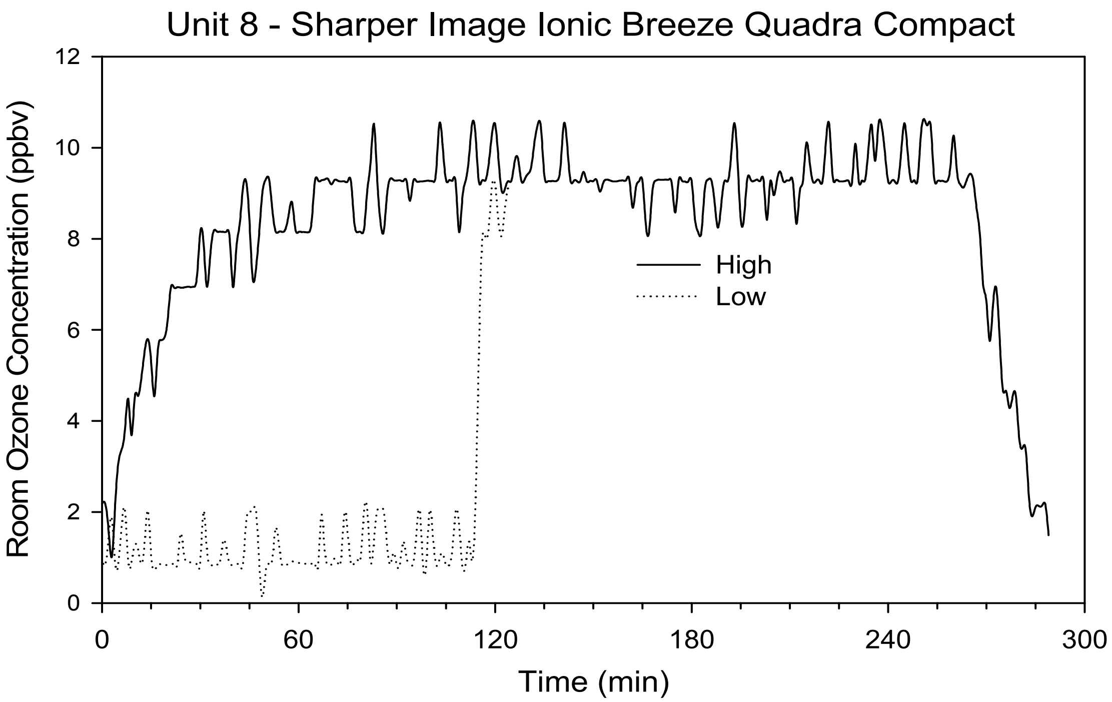

Figure 7. Ozone Room Concentration Profiles for Unit 8

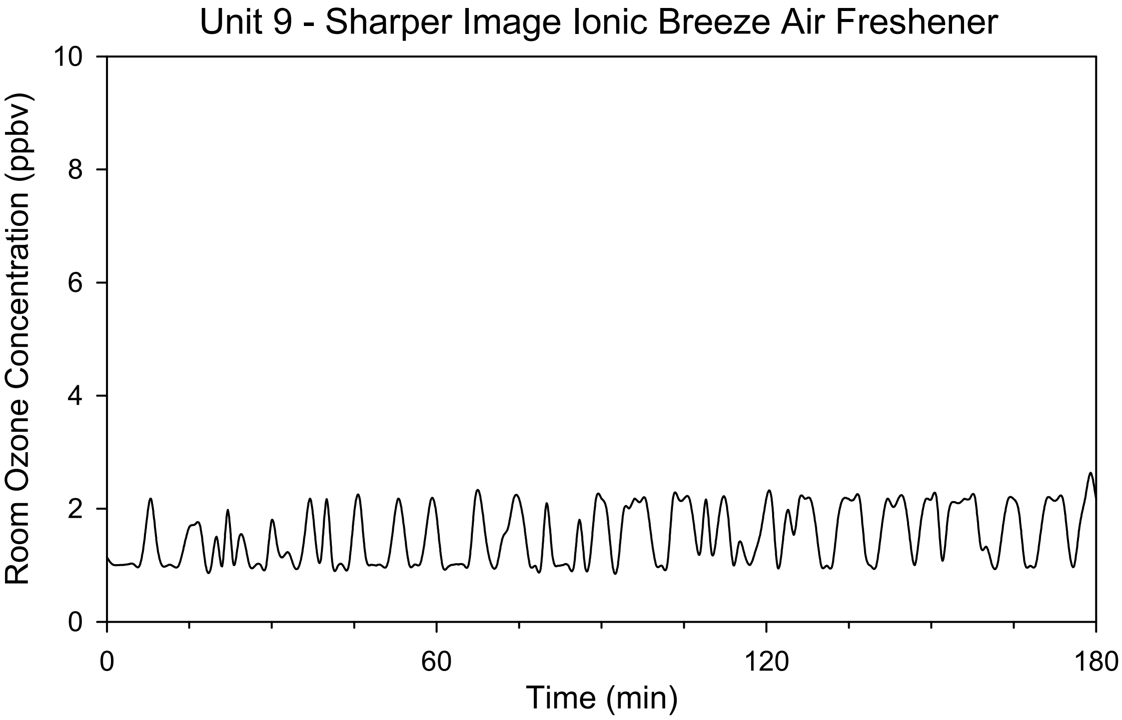

Figure 8. Ozone Room Concentration Profile for Unit 9

C. Room Test Discussion

Room ozone concentrations measured during the operation of ESP and ionizer air cleaners were substantially lower than previously observed during similar testing of OGs (ARB, 2006). None of the room ozone concentrations measured from the ESPs and ionizer exceeded 20 ppb. However, for OGs, numerous room tests measured ozone concentrations well in excess of 50 ppb, with several OG tests well above 100 ppb. Most importantly, the ozone room concentrations measured from the ionizers and ESPs did not exceed health-based standards such as the California AAQS, NAAQS, U.S. Occupational Safety and Health Administration (OSHA) permissible exposure limit, FDA medical device emission limit or the UL electrostatic air cleaner emission limit.

However, because these standards typically use averaging times or test methods greater than 2-3 hours and/or a sampling location nearer the device, it is possible that some of the devices tested could produce room concentrations that exceed these standard levels if the devices were operated for a longer time period, as required by those standards. Additionally, although RH was relatively low for most of these experiments (ranging from 33 to 48%), desert areas of California experience even lower RH during portions of the year, so ozone emissions in those areas could be expected to be higher than those measured in our tests. And, perhaps most important, preliminary review of the detailed data collected indicates that our test room likely had substantial ozone sinks. That is, it appears there may have been greater loss of ozone through reaction with the wall and furniture surfaces in the room than anticipated. This will be further explored in a future paper, but if correct would indicate that ozone emission rates would be expected to be higher for these devices when tested in a more rigorous test chamber under more controlled conditions.

There is minimal previously published research against which to compare the results obtained in these room tests. Britigan *et al*. (2006) examined a Sharper Image Quadra that is similar to the Quadra Pro evaluated in this research. The authors measured room concentrations of 9 and 12 ppb in office environments of 35.2 and 27.1 m^3. These results are similar to the 3.8-15.1 ppb room concentration range obtained for various settings in this study. This level of agreement for the Quadra units provides additional confidence in the results obtained from the room tests. Lack of additional previous research hinders comparison of our results for the other units examined.

7. EMISSION TESTS

A. Emission Test Methods

A thorough description of the methodology utilized for the determination of the ozone emission rate from ESP and ionizer air cleaners is available in ARB's previous report on ozone generators (ARB, 2006). Briefly, in March of 2006, after completion of the room tests each device was tested to ascertain its ozone emission rate. Exhaust from each device was directed into Teflon® ductwork custom designed to fit tightly over each unit's vent face. The duct was designed to direct the unrestricted exhaust flow to an ozone emissions sampling port.

Standard source test methods from ARB (1999) were used as a guide for the emission rate measurements. Ozone emission concentrations were measured using an API 400 ozone analyzer, while a second API 400 ozone analyzer was used to monitor background ozone concentrations in the adjacent area of the building. The cross-section of the duct was traversed by sampling at eight pre-set locations within the duct (total of eight sampling points), with the probe kept perpendicular to the air flow. Temperature and relative humidity were monitored in the appliance exhaust within the ductwork.

Measurements in the duct were taken at different appliance settings once the ozone concentrations and air velocity reached a maximum level and maintained stability. One-minute measurements of ozone were taken for five consecutive minutes at each of eight locations, and all 40 data points were averaged. Air velocity measurements taken at each sampling point also were averaged.

The emission rates, expressed in units of emitted ozone mass per unit time, were calculated by converting the measured ozone concentration in ppb units to mass/volume units, multiplying that value by the air flow rate through the duct, and converting the mass/volume units to units of milligrams/hour (mg/hr). All ozone concentrations were first corrected by subtracting the background (warehouse) ozone concentration. Assuming standard temperature and pressure, the conversions from concentration (ppb) to emission rate (mg/hr) were accomplished using the following equations:

$$O_3\ (\mu g/m^3) = (X\ \text{ppb}\ O_3\ \text{measured in the duct}) \times (10^{-9}) \times (1\ \text{mole of gas}/24.46\ \text{liters}) \times (48.00\ \text{g}\ O_3/\text{mole}) \times (1000\ \text{liters}/m^3) \times 10^6\ \mu g/g$$

$$\text{Air Flow Rate}\ (m^3/s) = (X\ \text{m/s duct air velocity}) \times (0.0081\ m^2\ \text{duct area})$$

$$O_3\ \text{Emission Rate} = (X\ \mu g/m^3\ O_3) \times (Y\ m^3/s\ \text{flow rate}) = \mu g/s$$

$$O_3\ \text{Emission Rate in mg/hr} = \mu g/s \times (0.001\ mg/\mu g) \times (3600\ s/hr) = \text{Mass/time in mg/hr}$$

B. Emission Test Results

The results from the emissions tests conducted on the ESPs and ionizers are summarized in Table 5 and Figures 9 and 10. As shown in Table 5 all of the measured linear velocities from the electrostatic precipitators/ionizers were within the range observed for the OGs examined previously (ARB, 2006), with the exception of unit 5 when operated on high. This higher flow rate is likely the reason for the decreased ozone levels observed for unit 5 during the face tests and room tests when operated on high versus low setting.

Table 5. Ozone Emissions Determined from ESP and Ionizer Air Cleaners

Test ID	**Manufacturer and Model**	**Operational Setting**	**Measured Velocity (m/s)**	**Volumetric Flow Rate (m^3/s)**	**Corrected O_3 Emission Concentration (ppb) [a]**	**Calculated O_3 Emission Rate (mg/hr)**
5L	Oreck Super Air 8	Fan at low speed, Ionizer off	1.19	0.0096	16	1.1
5LA		Fan at low speed, Ionizer on	1.17	0.0095	18	1.2
5LAR		Repeat of test 5LA	1.17	0.0095	21	1.4
5H		Fan at high speed, Ionizer on	3.55	0.0288	8	1.6
6L	Sharper Image Ionic Breeze GP [b]	Low setting, GP off, Boost off	0.74	0.0060	47	2.0
6LA		Low setting, GP on, Boost off	0.73	0.0059	51	2.1
6H		High setting, GP on, Boost off	0.73	0.0059	70	2.9
7L	Sharper Image Ionic Breeze Quadra Pro	Low setting, Boost off	0.94	0.0076	33	1.8
7LA		Low setting, Boost on	1.02	0.0083	47	2.7
7LAR		Repeat of test 7LA	1.02	0.0083	16	0.94
7H		High setting, Boost on	1.01	0.0082	44	2.6
8L	Sharper Image Ionic Breeze Quadra Compact	Low setting	0.70	0.0057	13	0.50
8LD		Test 8L performed using duplicate unit	0.75	0.0061	17	0.72
8H		High setting	0.70	0.0057	32	1.3

[a] Concentrations are the measured value minus the average background concentration on the day of testing

[b] GP = germicidal protection

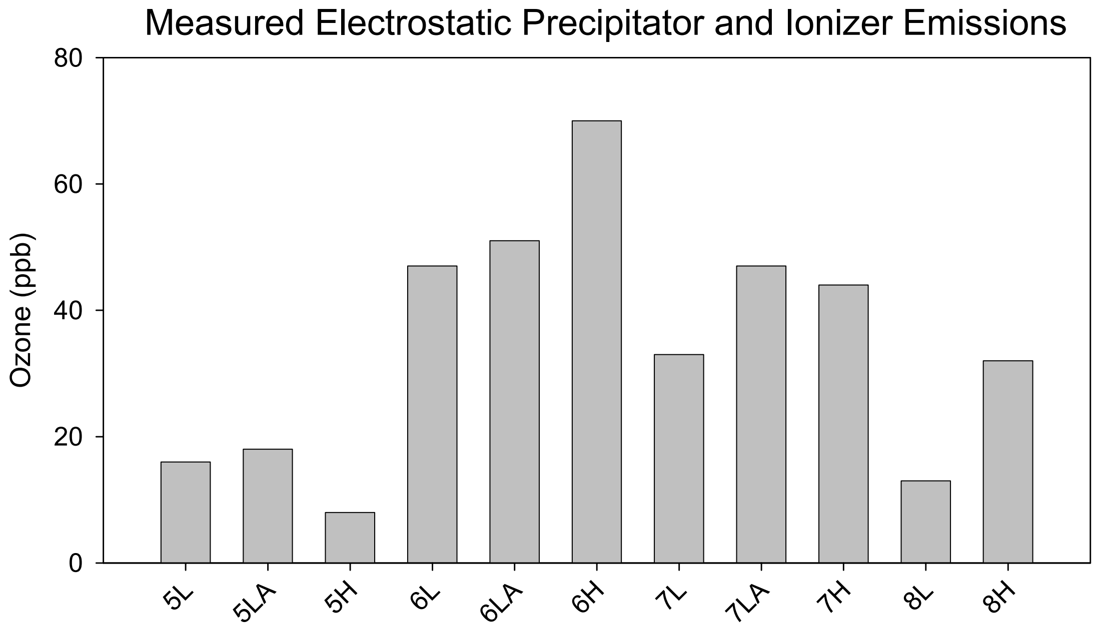

Figure 9. Ozone Emission Concentrations from ESP and Ionizer Air Cleaners

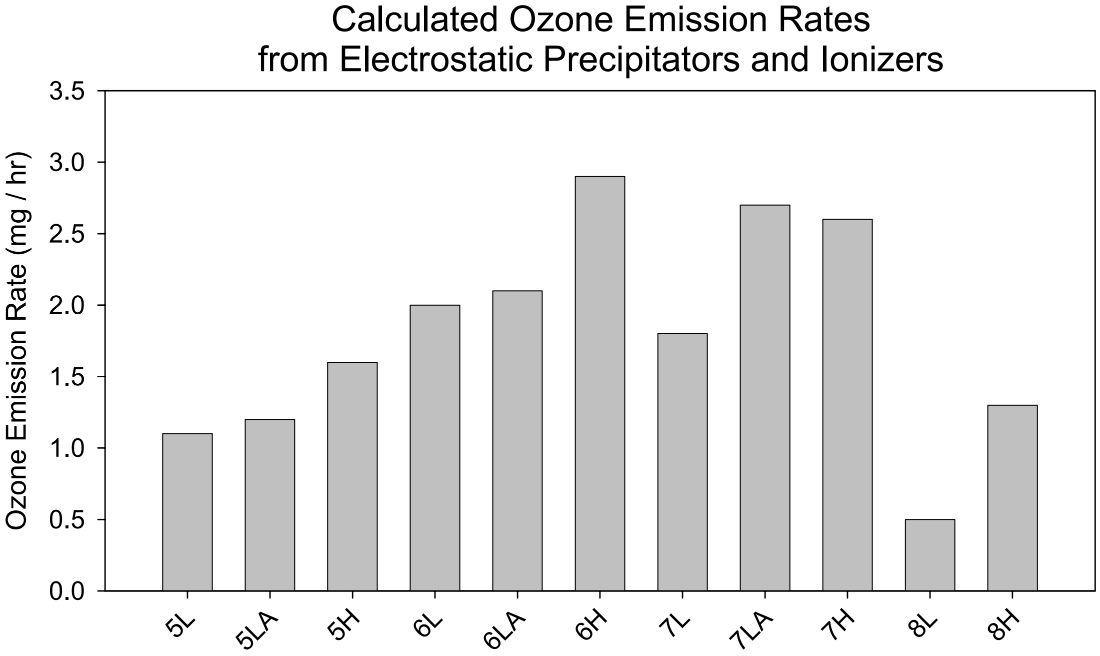

Figure 10. Calculated Ozone Emission Rates from ESP and Ionizer Air Cleaners

The results in Figure 9 show that only five of the emission tests measured in-duct ozone concentrations in excess of 40 ppb, which included all tests of unit 6. Each of the four units examined had at least one setting where a concentration at or above 20 ppb was observed. As shown in Figure 10, none of the units emitted greater than 3 mg/hr of ozone under any operation condition.

Examination of the replicate and duplicate emission tests performed on these devices, presented in Table 5, yielded several interesting observations. The replicate test of unit 7 under low + boost setting did not agree closely with the first measurement. Calculated emission rates for 7LA and 7LAR were 2.7 and 0.94 mg/hr. Additionally the emission rate observed in 7LA is the highest measured for this unit under any operational setting. The reason for this discrepancy was not immediately discernable. The duplicate test conducted on unit 8 under the low setting yielded considerably different emission rates, with the duplicate being 44% higher. The repeat test on unit 5 showed much better agreement, with the repeat test yielding an emission rate less than 20% higher than the first test. These results show that there is potential for substantial inter-unit variability, at least for new, lightly-used devices.

C. Emission Test Discussion

Ozone emission rates determined for the ESP and ionizer air cleaners (0.5 – 2.9 mg/hr) were generally much lower than for the OGs examined previously (0.079 – 94 mg/hr) (ARB, 2006). All of the ESP and ionizer devices examined, with the exception of unit 8, have emission rates for the high setting operation that are less than 50% greater than the units’ corresponding low setting operation.

Comparison of the emission rates determined in this study with those obtained in previous research is provided in Table 6. The results obtained in this study compare favorably with previous findings, but tend to be slightly lower. For a similar device, Sharper Image Ionic Breeze Quadra, the emission rate range determined in this work (1.8-2.7 mg/hr) compares very favorably with that previously measured by Britigan *et al.* (2006) of 2.2 mg/hr. All of the determined ozone emission rates from the devices examined in this work (0.5-2.9 mg/hr) fall within the range of emission rates measured previously by other researchers (0.065-4.1 mg/hr). The observed close agreement with previous results adds additional confidence to the data obtained in this work.

8. DISCUSSION

A. General

Overall, the ozone emissions and room concentrations measured from ESPs and ionizers were low compared to those from intentional ozone generators (ARB, 2006) and compared to available health-based standards. None of the ESPs and ionizers examined exceeded 45 ppb during the 2 inch face test measurements, while OGs face emissions were all above 379 ppb at the 2 inch distance. This measurement approach

(2 inches from the face) is similar to the UL test protocol, although air cleaners were tested only for a matter of minutes rather than for 24 hours.

Table 6. Comparison of ESP and Ionizer Ozone Emission Rates

Device	Ozone Emission Rate (mg / hr)	Reference
Oreck® Super Air 8	1.1 – 1.6	this study
Sharper Image™ Ionic Breeze® GP	2.0 – 2.9	this study
Sharper Image™ Ionic Breeze® Quadra® Pro	1.8 – 2.7	this study
Sharper Image™ Ionic Breeze® Quadra® Compact	0.5 – 1.3	this study
Sharper Image™ Quadra® Silent	2.2	Britigan *et al.,* 2006
Ion Generator	2.7	Mullen *et al.,* 2005
Ion Generator	2.7	Mullen *et al.,* 2005
Ion Generator	0.75	Mullen *et al.,* 2005
Ion Generator	4.1	Mullen *et al.,* 2005
Ion Generator	4.0	Mullen *et al.,* 2005
Misc. Air Cleaners	0.065 – 2.8	Niu *et al.,* 2001

Similar to the face tests, the results from the room concentration and emission rate tests found ESPs and ionizers to have much lower ozone output than OGs (ARB, 2006). The room concentrations measured from the ESP and ionizer devices examined were below health effect thresholds of 70 ppb and 90 ppb for 8-hour and 1-hour exposures, respectively. Room ozone levels from ESPs and ionizers were all below 16 ppb, while ozone levels from OGs were typically well above 70 ppb, the 8-hour California AAQS. Likewise the calculated emission concentrations and rates for ESPs and ionizers were much lower than those measured for OGs. All of the ESPs and ionizers produced ozone at emission rates below 3 mg/hour, while each OG emitted ozone above 9 mg/hour for at least one operational setting. The much lower ozone levels produced by ESPs and ionizers is encouraging and expected, as ozone generation is not the intended result of their operation.

Given our findings it is unclear whether most of the ESPs and ionizers examined would meet the FDA and UL emission concentration limit of 50 ppb. Caution needs to be exercised because three of the four devices produced concentrations in excess of 30 ppb at a distance of 2 inches in the face tests. If levels increase over time as the device is used continuously (as directed), or if the device is used when background ozone is high or RH is low, the resulting ozone levels could pose a health concern for near source exposure. As discussed in the earlier Room Test Discussion section, our tests were conducted in a chamber different from standard chambers used in the UL test, and conditions such as temperature, RH, and ozone background were not controlled. Thus, the results presented here may differ from those that would be obtained using the revised UL 867 (Section 37) test protocol.

An additional consideration is the possible health impact of secondary emissions from reaction of even low levels of ozone indoors with terpenes and certain other chemicals, which can produce pollutants such as formaldehyde and ultrafine particles (Weschler, 2000; Nazaroff and Weschler, 2004; Singer *et al*., 2006). Pinene and limonene, two common terpenes, are widespread in modern day products; thus the likelihood of increased indoor formaldehyde and ultrafine particles is high with any indoor source of ozone, even when emissions are relatively low and below the 50 ppb standard. While levels of formaldehyde and other reaction products that result from indoor ozone chemistry may be low relative to direct emissions from primary indoor sources, caution is warranted to avoid unanticipated health impacts, especially for formaldehyde, a known human carcinogen and mucous membrane irritant.

The results obtained from the testing of ESP and ionizer portable air cleaners raise several questions. These include: a) How does the age of the device and owner operation affect room concentration and resulting exposure, b) Is a 3-hour room test adequate for these devices, c) How would these levels affect indoor exposures in areas containing high outdoor ozone infiltration, and d) Do inter-product variability and test chamber performance fluctuations warrant more rigorous emissions test protocols or quality control measures? The following discussion examines these points.

B. Age and Maintenance Effects

Accompanying each ESP and ionizer device is an owner's manual which outlines the operational directions for the device as deemed appropriate by the manufacturer. For the devices examined in this work, the manufacturers' instructions are summarized in Table 1. Of the five units tested, all four of the Sharper Image models instructed the owner to operate the unit continuously. In a recent survey of California homes, conducted by Piazza *et al*. (2006), the authors found that, in residences containing portable air cleaners, the unit was operated every day in nearly 80% of the households year round, with 60% of the owners operating their devices continuously throughout the day and night. Based on the survey results, it appears that most owners are adhering to the manufacturer recommendations for operation of their air cleaners and typically operate their air cleaning devices 24 hours/day, 7 days/week.

Concern over continuous air cleaner usage arises when these units are not properly maintained. Previous research observed a sharp spike in the emission concentration from an ionizer when sprinkled with house dust (Phillips *et al*., 1999). Other previous work by Dorsey and Davidson (1994) examined the effect of operating ESPs in an environment containing 60 $\mu g/m^3$ of Arizona Road Dust for seven consecutive days. Their results found that ozone emissions from the ESP increased from 70 ppb on day 1 to 355 ppb on day 7. The authors were able to determine that the increase in ozone emissions was due primarily to soiling of the collection plates, rather than contamination of the corona wire. Understanding this effect, air cleaner manufacturers currently provide the device owner with suggested cleaning instructions. The units examined in this research were recommended for cleaning every two weeks, or if an arcing sound was being emitted from the device. This places significant responsibility on the device owner to properly adhere to the recommended cleaning intervals to keep the unit operating properly and to minimize ozone emissions and subsequent exposure.

Survey results obtained by Piazza *et al*. (2006) also revealed that most air cleaner owners do not follow the recommended cleaning intervals. Piazza *et al*. found 60% of the households utilizing portable air cleaners owned units that contained collection plates for electrostatic removal processes. Results indicated that nearly 20% of the device owners cleaned their collection plates ‘as needed’, possibly when the arcing sound is heard as indicated for the Oreck Super Air 8 in Table 1. However, only 2% of portable air cleaner owners responded that they never cleaned the collection plates. The balance of the air cleaner owners responded that they clean the collection plates monthly (34%), quarterly (12%), biannually (6%), annually (4%) and other (20%). Based on the substantial increase in the ozone emissions observed by Phillips *et al*. (1999) and Dorsey and Davidson (1994), the maintenance habits of more than half of the portable air cleaner owners in California are possibly contributing to unnecessary ozone exposure levels. These levels may be much higher than those measured in these tests because the units were not operated for longer than one day prior to testing. Thus, the low levels reported here for ESP and ionizer air cleaners may not reveal the actual ozone exposure levels created by real-world operation of these devices over time.

C. Operation Time

Because of time and resource constraints, the testing methodology for this work used a maximum duration of 3 hours for the room tests, unless a steady-state ozone concentration was attained sooner. While this approach appeared adequate with OGs (ARB, 2006), the lower emission rates of the ESPs and ionizers appear to necessitate a longer test to accurately obtain the room concentrations that would result with continuous use. Since the lower ozone levels from ESPs and ionizers are more affected than OGs by any ozone sinks present in the test chamber, a longer test would help to ensure that any potential sinks have been saturated and would more likely produce a true steady-state ozone concentration. Given the largely continuous operation of air cleaners by owners in California (Piazza *et al*., 2006), a 3-hour test would not be truly representative of the operation of these devices in residential applications, and the resultant ozone exposure concentrations.

Other test methodologies exist that utilize other time periods of product testing. As indicated earlier, the Section 37 of UL Standard 867 testing approach examines the ozone emissions from air cleaners during a 24-hour continuous operation period (ANSI/UL, 2007). Another approach for testing electronic equipment, ECMA Standard 238 (ECMA, 2006), monitors the ozone output from a device for at least 1 hour or until the maximum concentration is reached. Based on the Piazza *et al*. (2006) survey of usage patterns, it appears that the room tests for these devices should be conducted using a 24-hour test to ensure the most accurate representation of the possible room concentrations, similar to the approach of UL.

D. Outdoor Ozone Contribution and Effect

Assessing the actual ozone exposures that occur indoors is not possible solely from the measurements performed in this research, due to seasonal contributions from outdoor ozone infiltration, differences in RH, differences in housing design and operation, and other factors. Previous work by Avol *et al*. (1998) found that 10% of the southern California homes examined experienced 24-hour ozone concentrations above 32 ppb indoors. Given this level, an indoor air cleaner should not emit ozone at levels that would raise the concentration by 40 ppb, because this would lead to an indoor level exceeding the California 8-hour ozone ambient air quality standard. Although the room concentrations measured in this research did not exceed 40 ppb, the possibility still exists to have sustained ozone exposures above 70 ppb with operation of these air cleaners, depending on the individual's proximity to the device, the contribution of outdoor ozone infiltration, the relative humidity of the area, and other factors.

E. Product Variability and Chamber Performance

Throughout the testing of ESPs and ionizers, two units, 5 and 7, were subjected to repeat testing under identical operation conditions. Additionally, a duplicate of unit 8 was also tested at its low setting. Room test measurements showed higher ozone levels for both repeat tests and also for the duplicate unit test. The repeat tests were approximately two times higher for unit 5 and 1.25 times higher for unit 7, with the duplicate of unit 8 nearly four times greater. One possible explanation for these discrepancies would be the differences observed in the background levels during the respective tests.

However, if the observed differences were solely due to the differences in the background ozone levels between the tests, the results of the emission rate measurements should find closer agreement because the background levels were subtracted prior to the emission rate calculations. The unit 5 repeat emission rate measurements show less than 20% difference between the two measurements. The unit 7 repeat emission rate is only approximately 33% of the original measurement. These results would indicate the need for more stringent controls for surface losses, background ozone, and RH within the test chamber. However, variability was observed not only in the repeat tests, but also in the testing of a duplicate device. The unit 8 duplicate emission rate is approximately 50% greater than its counterpart. This discrepancy illustrates that the differences observed between the primary and repeat room test results may not be solely due to the performance of the test chamber, and that inter-product variability may be substantial and should not be ignored. Considering both of these contributions to the measured ozone levels indicates that, in addition to having the ability to strictly control the test chamber conditions, the accurate determination of the true device emissions may necessitate measurement from several duplicate devices, possibly including replicate measurements from each device.

9. SUMMARY AND CONCLUSIONS

This study reports ozone emission measurements from electrostatic precipitator and ionizer portable air cleaning devices. Five different air cleaner models were tested from two different manufacturers. Ozone emissions from these devices were measured using three different methods: units were tested for face concentration emissions, room concentrations, and emission rates. All of the test results showed ozone levels well below levels of health concern, based on comparison to the California health-based standard.

Face test emissions for ESPs and ionizers were typically much lower than the ozone levels previously measured for OGs. Results from the face tests showed that none of the electrostatic precipitators/ionizers examined produced face ozone concentrations that exceeded 45 ppb for the 10-minute average measurements. As expected, the highest measured concentrations were observed at the 2 inch measurement distance. Ozone concentrations at 24 inches did not exceed 20 ppb, and were generally less than 50% of the 2 inch levels, which is consistent with previous tests of OGs.

Room ozone concentrations from the ESPs and ionizers were all below 20 ppb, which is generally much lower than those observed previously for OGs. Most of the units showed an initial rise in ozone concentration upon energizing the unit, but the room concentration generally returned to near background room levels. Typically the maximum 60-minute average concentration was more than 50% of the maximum 1-minute average concentration.

Ozone emission rates determined for the ESP and ionizer air cleaners (0.5 – 2.9 mg/hr) are much lower than for the OGs examined previously (0.079 – 94 mg/hr). Generally the devices examined have emission rates for the high setting operation that are less than 50% greater than the units' corresponding low setting operation. None of the units examined emitted greater than 3 mg/hr of ozone under any operation condition.

The operation and maintenance choices of air cleaner owners have the potential to significantly impact their ultimate ozone exposures. Results from Piazza *et al*. (2006) reveal that most California air cleaner owners operate their units continuously year round, as often instructed by the manufacturer. However, the owners typically do not maintain their devices as instructed by the manufacturer to ensure proper operation, which may promote excess ozone generation. These operational and maintenance practices may ultimately lead to greater ozone emissions from these devices than observed in these tests. Manufacturers would be well advised to emphasize the need for regular and diligent maintenance of their devices in their advertising, literature and owners' manuals.

While these tests reveal that ozone emissions from ESPs and ionizers are much lower than those from OGs, there is still a need to exercise caution because some devices could produce unhealthful levels of ozone in more realistic conditions, and secondary reaction products such as formaldehyde may contribute to the health burden as well. Factors related to the test conditions such as test duration and chamber performance need to be optimized to ensure the most repeatable measurements possible to accurately characterize the true ozone emissions from these devices. The effects of device age and maintenance need to be better characterized for the assurance that the measured emissions are indeed representative of the device output, and ultimate ozone exposure levels. Inter-unit variability needs to be addressed, as it may contribute to unhealthful exposure levels. In short, close attention to the methods of emission characterization is necessary to assure these devices can be continuously operated in occupied spaces without concern over possible elevated ozone exposures leading to potential health effects.

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GLOSSARY

TERM	DEFINITION
Air Changes per Hour, Air Exchange Rate	ACH, AER, the volume of air moved in one hour. One air change per hour in a room, home, or building means that the equivalent of the volume of air in that space will be replaced in one hour, typically with outdoor air.
Air Cleaners	These are devices designed to remove pollutants from a room. Air cleaners can be portable, or part of a central air system. Air cleaners can be mechanical, employing a filter to remove pollutants, or electronic using a small electrical charge to collect particles from air pulled through a device.
Air Fresheners	These devices are promoted to neutralize odors rather than remove pollutants. Products often emit a fragrance which diffuses into the air.
Air Flow Rate	The rate at which air moves into a space. Expressed in units of air changes per hour or cubic feet per minute.
Allergen	A chemical or biological substance (e.g., pollen, animal dander, or house dust mite proteins) that induces an allergic response.
Ambient Air Quality Standard	An acceptable level of air pollution that defines clean air. Standards are designed to protect the public from the harmful effects of traditional pollutants in outdoor air.
Asthma	A chronic disease of lung tissue which involves inflamed airways, breathing difficulty, and an increased sensitivity to allergens and contaminants in the air.
Electrostatic Precipitator	An appliance that utilizes a corona to charge airborne particles and collect them with charged metal plates of opposite polarity.
Ionizer	An appliance that releases charged particles into the air that attract various pollutants to form agglomerates possessing a greater tendency for deposition.
Ozone Generator	An appliance that intentionally emits ozone but is advertised as an “air cleaner” or “air purifier”.
Quality Control	Internal checks on the operation of sample collection and/or sample analysis. Methods for determining the operation include blanks, spiked samples, flow checks, and duplicate samples. QC measures can be used to determine accuracy, bias, and precision of the data reported.

Relative Humidity	The measure of moisture in the atmosphere, expressed as a percent of the maximum moisture the air can hold at a given temperature.
Ventilation	The process of intentionally supplying and removing air by natural or mechanical means to and from any space.