California Environmental Protection Agency
Air Resources Board

Evaluation of Ozone Emissions From Portable Indoor "Air Cleaners" That Intentionally Generate Ozone

Staff Technical Report
to the
California Air Resources Board

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ACRONYMS

ACRONYM	DEFINITION
AAQS	ambient air quality standard
AER	air exchange rate
ARB	California Air Resources Board
CADR	clean air delivery rate
Cal/EPA	California Environmental Protection Agency
CO	carbon monoxide
CO_2	carbon dioxide
DHS	California Department of Health Services
FDA	U.S. Food and Drug Administration
NO_2	nitrogen dioxide
NO_X	oxides of nitrogen
O_2	oxygen molecule, two atoms of oxygen (stable)
O_3	ozone, three atoms of oxygen (reactive)
RH	relative humidity
RSD	relative standard deviation
T	temperature
U.S. EPA	U. S. Environmental Protection Agency
UV	ultraviolet

UNITS

ft	feet
ft^2	square feet
l/min	liters per minute (flow rate)
m^2	square meter
m^3	cubic meter
µm	micron; a unit of length equal to one millionth of a meter; a micrometer
µg	microgram (one-millionth of a gram)
µg/s	micrograms per second
$\mu g/m^3$	micrograms per cubic meter (concentration)
mg	milligrams (one-thousandth of a gram)
mg/hr	milligrams per hour
%	percent
ppb	parts per billion (such as one grain of sand in a billion grains of sand)
ppm	parts per million (such as one grain of sand in a million grains of sand)

EXECUTIVE SUMMARY

Public concern about indoor air has resulted in a growing market for the sale of devices to reduce indoor pollution and improve indoor air quality. Several manufacturers are marketing ozone generators ─ appliances labeled as indoor "air purifiers" or "air cleaners" that intentionally generate ozone, the primary component of smog. The limited research available shows that these devices can emit large quantities of ozone that result in indoor ozone concentrations well above the health-based state and federal ambient air quality standards for ozone. At elevated levels, ozone can cause difficulty breathing, exacerbate asthma, and damage the lungs in sensitive individuals. Due to concern about potential unhealthful ozone exposures, Air Resources Board (ARB) staff tested four models of ozone generators in order to measure the room concentrations that would result through the use of these devices, and to obtain current emissions data.

Several manufacturers of ozone generators have stepped up the marketing of their products in California and the U.S. in recent years, taking out full page advertisements in major city newspapers, and developing extensive websites. They generally claim that their products produce "safe" levels of ozone that remove indoor air pollutants such as particles, gases, allergens, viruses, odorous compounds, mold, and bacteria. In fact, ozone has no effect on most pollutants, kills mold only at much higher levels, and reacts with some gases to produce significant increases in other pollutants, such as formaldehyde and ultrafine particles, which are also harmful to health.

Staff tested four models of ozone generators that are widely marketed in California. The room tests were conducted in a small room furnished with a desk and chair, under temperature, humidity, and air exchange conditions common in homes. The devices were operated according to manufacturers' instructions, with a few adjustments due to facility limitations. 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, emission rates were measured using non-reactive ducting.

The results (Table ES-1) show that all of the models tested produce room concentrations that exceed health-based standards and can pose a serious risk to health. The Biozone® 500, the Prozone® Whole House, and the Prozone® Compact produced room concentrations that substantially exceed both the California Ambient Air Quality Standards (CAAQS) of 90 parts per billion (ppb), 1-hour average, and 70 ppb, 8-hour average, for ozone. They also would exceed the U.S. Food and Drug Administration (FDA) standard of 50 ppb that applies to medical devices (devices for which the manufacturers make health-related claims). In addition, the Alpine Air XL-15 / LA Lightning Air RA 2500 unit exceeded the 70 ppb CAAQS and the FDA standard of 50 ppb when set at a medium setting (ozone output for a 1,000 square foot area). This unit was not tested at its highest setting, but has been shown in other studies (e.g., Mason *et al*., 2000) to produce room levels over 300 ppb at its highest settings.

The Prozone® Whole House unit produced the highest room concentrations measured when operated in the continuous mode – over 400 ppb, more than four times the 1-hour CAAQS of 90 ppb. Although the continuous mode is designed for an unoccupied home with greater volume than the test room in this study, consumers could naively operate the unit in this mode when their home is occupied, which would result in extremely high ozone exposures. Additionally, when operated for 15 minutes per hour as recommended by the manufacturer for occupied spaces, the Prozone® still produced unhealthy ozone levels: concentrations reached 90 ppb within 7 minutes, and the maximum 60-minute average was 119 ppb, well above the CAAQS.

The face test results and the emission test results correlate reasonably well with the room concentration results. The face test results at 2 inches from the face of the air cleaners range from 379 to 1287 ppb across the four models tested. At 24 inches from the face, the Alpine Air/Lightning Air unit and the Prozone® Whole House device clearly exceed health-based standards, with levels well over 300 ppb. Emission rates ranged from 0.29 to 94 mg/h.

The results of this study demonstrate that the use of "air cleaners" that intentionally emit ozone can result in room concentrations that exceed state and national health-based standards. California agencies currently do not have regulatory authority to address the problem of ozone emissions from ozone generators, and current federal and industry standards have not been effective in addressing this problem.

Table ES-1. Summary Results

Manufacturer and Model	Operational Setting	Maximum 60-minute average room concentration (ppb)	Minutes to reach 70 ppb (8-hr std)	Minutes to reach 90 ppb (1-hr std)
Alpine Air XL-15 / LA Lightning Air RA 2500	Low	1[a]	NA[b]	NA
	Medium	88	28	NA
Biozone® 500	Low	96	42	135
	High	99	111	162
Prozone® Whole House	Intermittent	119	6	7
	Continuous	435	6	7
Prozone® Compact A	On	109	18	31
Prozone® Compact B[c]	On	149	15	20

a) Unit was set at low fan, with Ozonator turned to lowest setting.
b) NA: unit never reached the level indicated.
c) A second Prozone® Compact unit was purchased to test for between-unit variability.

1. INTRODUCTION

A number of manufacturers are marketing appliances labeled as “air purifiers” or “air cleaners” that intentionally generate ozone, the primary component of smog. These devices, called “ozone generators”, most often use metal plate electrodes or needle electrodes to create electrical discharges that produce ozone, typically in large quantities. Operation of these devices in the confined spaces of homes and commercial buildings has long been known to cause unhealthful ozone exposures ─ elevated room ozone concentrations above the health-based state and federal ambient air quality standards for ozone. The current California Ambient Air Quality Standards (CAAQS) for ozone are 90 parts per billion (ppb) for a 1-hr averaging time, and 70 ppb for an 8-hr averaging time; the parallel federal standard is 80 ppb for an 8-hr average.

However, few measurements have been obtained from current models of ozone generators, which have proliferated in recent years. Also, manufacturers have made further claims that these products emit safe levels of ozone. Accordingly, to obtain data from current models, Air Resources Board (ARB) staff tested several models of ozone generators currently marketed in California. The results are presented below, along with background information on ozone generators.

2. BACKGROUND

Ozone, a highly reactive compound composed of three oxygen atoms, can damage the lungs and airways. It inflames and irritates respiratory tissues, and can worsen asthma symptoms in persons with asthma. It causes symptoms such as coughing and chest tightness, and impairs breathing. Elevated exposures can cause permanent lung damage, and repeated exposure can even increase the risk of premature death in persons with poor health. Ozone also damages plants and materials, such as paint, walls, and flooring. Ozone is the primary component of smog, and has been recognized and regulated as a serious outdoor pollutant for many years.

The manufacturers of ozone generators often claim that “safe” levels of ozone can remove indoor air pollutants such as particles, gases, allergens, viruses, odorous compounds, mold, and bacteria. In fact, ozone only reacts with some gases of concern (aromatic hydrocarbons such as benzene) and with terpenes, such as limonene and pinene. These reactions produce significant increases in other pollutants such as formaldehyde and ultrafine particles, which can be harmful to health (Boeniger, 1995; Nazaroff and Weschler, 2004; Hubbard *et al*., 2005). While ozone reduces a few odorous compounds, more importantly it fatigues the olfactory sense and reduces one’s ability to smell odors; thus ozone masks odors more than removes them. Finally, ozone is effective against mold and bacteria on building material surfaces only at extremely high levels ─ well over 5,000 ppb ─ and even those levels do not denature or remove microbial residues and spores in building materials (Foarde *et al*., 1997).

Ozone generators are typically sold through the internet and by independent distributors, not via retail establishments. Each year, the ARB and the California Department of Health Services receive numerous calls from the public concerning the safety and effectiveness of ozone-emitting air cleaners, and questions regarding the claims made by the manufacturers or distributors.

Data on currently available models of ozone generators are limited to a small number of scientific journal articles, U.S. Environmental Protection Agency (U.S. EPA) test reports, and manufacturers' product test data. A test home study by researchers at the U.S. EPA found that an ozone generator could produce indoor ozone levels up to three times the CAAQS of 90 ppb averaged over one hour (Mason *et al*., 2000). In a full-scale test chamber at relatively high air exchange rates of five air changes per hour, Chen and Zhang (2004) found that two ozone generator models produced ozone concentrations above 100 ppb within 4-6 hours of use. These limited data indicate that ozone generator emissions in confined areas elevate room concentrations of ozone above threshold health values, and thus pose substantial health risks.

State agencies currently do not have regulatory authority to address the problem of ozone emissions from ozone generators, and current federal and industry programs have not been effective at preventing the production and continued sale of ozone generators. Since the late 1970s, the U.S. Food and Drug Administration (FDA, 2005a) has had an ozone standard for air cleaners that are medical devices, i.e., those marketed with health claims. The FDA standard for medical devices is a maximum of 50 ppb ozone in the air circulating through the device or in an enclosed space that is designed for human occupancy, but the specific test protocols are not well defined. Non-compliant devices cannot be used in hospitals, medical offices, or other occupied spaces. The FDA (2005a,b) requires listing and labeling for these devices, including the smallest room area allowed when using the device. However, the FDA has conducted very little enforcement concerning health and germicidal claims and product labels for air cleaners. The U.S. Consumer Product Safety Commission can potentially regulate air cleaners that are marketed without health claims; it has not developed any regulations in this area (Thomas, 2005).

Underwriters Laboratory, Inc. (UL), a product-testing organization, has developed Standard 867 for testing electrostatic air cleaners. Section 37 of the standard provides a test for ozone that limits room ozone concentrations to 50 ppb at 2 inches from the face of the device after 24 hours of operation, but the test method includes a faulty background calculation that allows some high-emitting air cleaners that produce unhealthy ozone levels to pass the test (Niu *et al*., 2001a,b; Chen and Zhang, 2004; Siegel, 2005). This is of concern for some electrostatic precipitators and ionizers, devices which remove particles from the air using electronic technology that emits ozone as a by-product, usually in much lower levels than purposeful ozone generators. Also, air cleaners can be approved under UL 867 without the ozone emissions test completed. UL standards are voluntary, so manufacturers of ozone generators and some other air cleaners do not pursue UL certification.

Ozone treatment is recognized as an effective means of purifying water, but not as a means of cleaning indoor air. Extensive expert testimony in the successful lawsuit by the federal government against Alpine Air and Living Air, two ozone generator manufacturers, confirmed the almost complete lack of effectiveness of ozone for indoor air treatment (FTC, 2002). More recently, Chen and Zhang (2004) confirmed that the two ozone generators did not effectively remove volatile organic compounds from a test room, except for limonene, which reacts quickly with ozone to produce formaldehyde. ARB, the California Department of Health Services (DHS), the U.S. EPA, and other public health agencies and groups have strongly warned against using so-called air cleaners that intentionally emit ozone.

3. OBJECTIVES AND TECHNICAL APPROACH

The goal of this project was to determine the potential impact of popular ozone generators on indoor ozone levels, particularly under common conditions most 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 ozone generators are operated per manufacturers' directions.

2. Determine ozone emission rates from those appliances.

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 ozone generators on indoor air quality and human health.

We selected four models of ozone generators for testing (see Table 1). Because reliable sales data for ozone generators (and most air cleaners) are not 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: manufacturers' websites, and a distributor's website on e-Bay. We included a second unit of model no. 4 (Prozone® Compact) to test the variability between units of the same model. The purchase price of these models ranged from $190 to $497.

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, we developed three test protocols 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 ozone generator unit to identify the primary emission point and direction for ozone, and to roughly characterize the near-source dispersion of the ozone.

2. Room Test. Measure ozone concentrations for a few hours with the ozone generator 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 ozone generator unit using inert ductwork attached to the unit.

The specific methods, results, and discussion for each of these three tests of each ozone generator model are presented below. For all tests, ozone concentrations were measured with an API 400 Ozone analyzer. Its ozone sample probe is made of stainless steel, which is connected to a glass manifold, which is then connected to the ozone analyzer via Teflon® tubing. A second API ozone analyzer was used to measure background ozone concentrations in the building for the room and emission rate tests.

Table 1. Ozone Generator Model Descriptions

Unit #	Model	Purchase Price ($)	Floor Space or Time Rating; Recommended Settings [a]	Additional Features [a]
1	Alpine XL-15 / Lightning Air RA 2500	495	100-2500 ft^2. Hospitals, nursing homes, day care centers, and doctors' offices included. Adjust to meet user needs, sensitivities; reduce setting if user smells ozone. Normally keep ozone at modest levels, adjust to higher levels to remove odors. Users sensitive to ozone can use a timer and operate at higher setting when they are away from home.	Ionizer
2	Biozone® 500	190	Up to 500 ft^2. If ozone smell is too strong, lower the fan speed or run time, increase room air circulation, move the unit to other location. Do not place directly in the face of a person or pet.	Negative ion generator
3	Prozone® Whole House	497	No more than 15 min/hr in continuously occupied rooms. Use continuous mode only in unoccupied rooms. Cleans 400 ft^2 room in one hour. Consult physician first if user has a respiratory problem such as asthma.	Ultraviolet Lamp
4A, 4B	Prozone® Compact, duplicate units A & B	227 [b]	Use 30 minutes or less initially if sensitive to ozone. Contact physician first if user has a respiratory problem such as asthma.	None

a. From product brochures that came with appliances. The instruction items selected are those most pertinent to ozone production and human exposure.
b. This item was discounted when it was bought with the Prozone® Whole House unit (Unit 3).

Commonly accepted quality control and quality assurance procedures were followed. All monitoring equipment and data acquisition equipment underwent a system audit by ARB's Monitoring and Laboratory Division (MLD) audit staff before testing began. 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 at the same settings were not conducted due to time and resource limitations; however, results for the various settings for each unit were reviewed to identify any inconsistent results.

4. FACE TESTS

A. Face Test Methods

In preparation for the room and emissions tests, ozone concentrations were measured at all faces of each appliance's face vent(s) 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 appliance settings for ozone output, as described in Table 2. Some of these settings differ from those used in the later room and emission tests.

B. Face Test Results

Summaries of the face test results are presented in Table 2 and Figure 1. All of the ozone generators had face ozone concentrations in excess of 375 ppb at a distance of 2 inches from the exhaust face, and three units (1, 3 and 4) exceeded 1,000 ppb at a distance of 2 inches, when operated at the high settings. Despite the added dilution at 6 inches distance, concentrations remained at or in excess of about 700 ppb for Units 1, 3 and 4. Concentrations at the 12 inch distance decreased by about 50% or more for all units except Unit 1. The measurements made at 24 inches from the unit's face still resulted in ozone concentrations in excess of 370 ppb for Units 1 and 3. It should be noted that the "Ozonator" setting for Unit 1 during these tests was for 2,500 ft^2, the highest ozone setting, which was adjusted to a lower setting for the room tests to follow.

C. Face Test Discussion

This quick screening approach easily identified the ozone generator models with the largest emissions, the primary point of ozone emissions from each unit, the major flow direction, and the range of concentrations that might be encountered in the room and emission tests. The results at 2-12 inches clearly identified Units 1, 3 and 4 as high emitters when operated at the high settings for ozone production, but only Units 1 and 3 were identified as such by the results at 24 inches. Variability, expressed as percent

relative standard deviation (RSD), was less than 10% for most of the ozone generators examined at the four different distances. The Biozone® 500 was a major exception, under both fan settings at 6, 12 and 24 inch distances, where the variability ranged from 11-60%. Additionally the Prozone® Compact also exceeded 10% variability at 24 inches, with a RSD of 44%. This suggests that more than 10 minutes of sampling may be necessary to get a precise measurement in this test, in order to characterize inherent fluctuations in the ozone generating device itself and fluctuations in the air currents and dispersion near the ozone monitor probe.

The face test measurement results at 2-24 inches showed that the ozone concentrations dropped off rapidly with distance. The one exception was that for Unit 1 with the fan on high speed and the ozonator set at 2,500 ft^2 ozone concentrations did not decline noticeably until 12 inches away. This suggests that fan speed can be important in increasing near-source exposure.

This screening approach worked well to locate the peak emissions near the face of the units and characterize the decline in ozone concentrations with distance from the face. The face test results indicate that at their high settings, and after just a few minutes of operation, the Alpine Air/Living Air and the Prozone® Whole House devices produce ozone levels that clearly exceed CAAQS and FDA standard levels at a distance of 24 inches from the face.

Table 2. Results from Exploratory Ozone Generator Face Testing

			Ozone Concentration at Varying Distances from Unit Face (ppb) [b,c]			
Test ID	**Model**	**Operational Setting**	**2”**	**6”**	**12”**	**24”**
1LH [a]	Alpine XL-15 / Living Air 2500	2,500 ft^2; Fan at Low speed	1287	1171	907	567
1HH [a]		2,500 ft^2; Fan at High speed	781	718	580	373
2L	Biozone® 500	Fan at Low speed	438	95	11	11
2H		Fan at High speed	379	144	43	13
3H	Prozone® Whole House	Continuous mode (System on; Timer inactive; UV on)	1030	815	577	389
4	Prozone® Compact B	On mode (no user-defined controls)	1134	695	304	61

a. The 2,500 ft^2 Ozonator setting was also used in the emission rate tests, but not in the room tests.
b. Concentrations are 10-minute averages after the unit has been operating for at least 10 minutes.
c. For the face tests, values have not been adjusted for differences in background ozone levels, which ranged from 0-25 ppb during the testing.

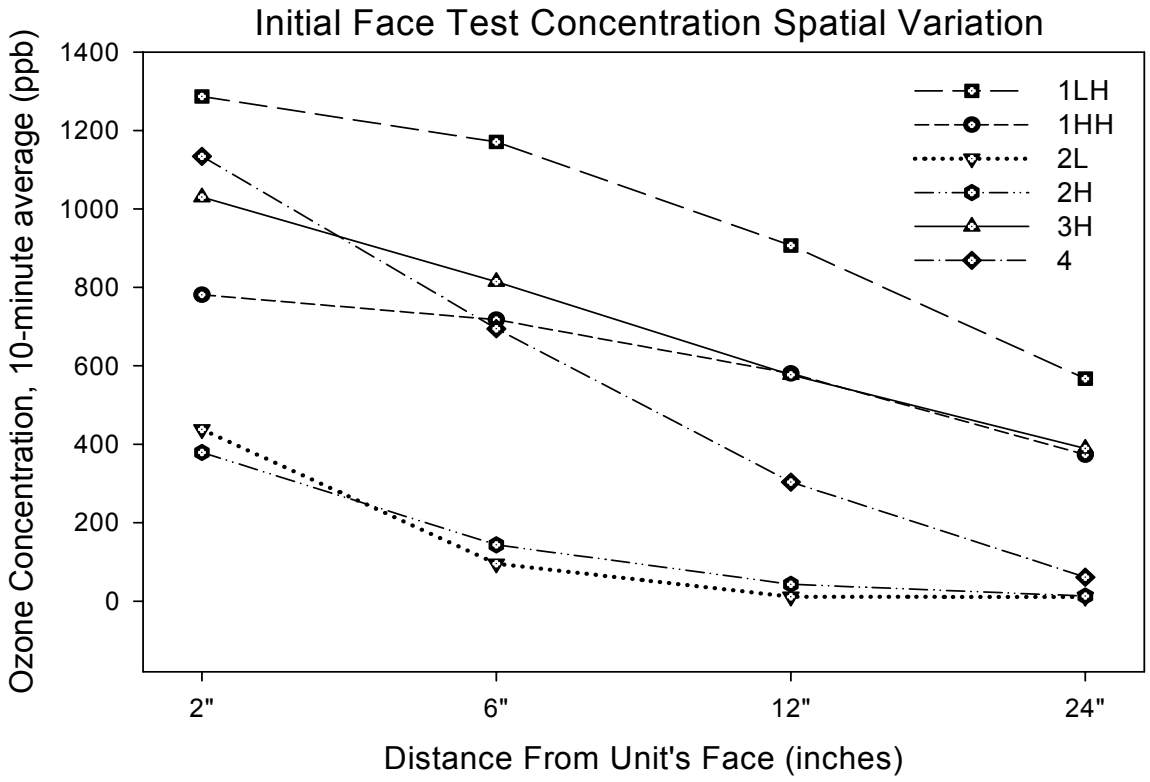


Figure 1. Concentration Profiles for Face Tests

5. ROOM TESTS

A. Room Test Methods

1. Test Room Characteristics

The test room was a small office approximately 8 ft. wide, 11 ft. long, and 8 ft. high (88 ft^2, volume of about 20 m^3), the size of a small bedroom or home office. The room is located in a warehouse building in Sacramento, California, about 1,000 meters from any major freeway or surface street. The room was furnished with an office desk made of hard wood and laminated composite wood, and one upholstered desk chair with a high back. The room had linoleum flooring, and painted wallboard construction for the walls and ceiling. A 6-foot fluorescent light fixture was mounted in the ceiling. The room had no air supply or return registers, and no large openings other than the door. All power cords and air sampling lines were run through an 8-inch hole in the door's center, which was sealed with duct tape. The adjoining warehouse space was conditioned, and its doors were kept closed during the tests in this study. Two adjoining bathrooms had automatic exhaust fans, which were turned off during the testing.

We selected a target range of 0.3-0.5 indoor-outdoor air changes per hour for the air exchange rate (AER) for the room tests. This range reflects common conditions for older single-family homes in California without open windows or mechanical ventilation in operation. Compared to newer homes in California, older single-family homes tend to have less airtight exterior shells, and they often have additional air exchange when the central heating or cooling system is operating because the system has substantial air leakage in its ductwork. This range does not reflect comparable "closed" conditions for new homes, which can have indoor-outdoor air exchange rates of 0.1 air changes per hour or less when closed up. Thus, the target AER range is realistic for California homes, and does not provide conditions that would result in an overestimation of ozone concentrations from the ozone generators tested.

In order to provide the target AER of about 0.3-0.5 air changes per hour, any suspected air leakage paths were sealed. The door frame was sealed with one-half inch wide, closed cell foam weather-stripping. In addition, two-inch wide duct tape was used to seal the edges of the door, the gap around the ceiling light fixture, and both horizontal edges and vertical gaps of the baseboard vinyl coving.

2. Air Exchange Rate Testing

The AER of the test room was measured on three consecutive days prior to the start of the room tests. Once the ozone generator room tests began, the room AER was measured once a week. The room AER was measured using the single zone tracer gas decay method of ASTM Standard E741, with carbon dioxide (CO_2) gas as the tracer gas (Persily, 2000). CO_2 gas from a cylinder was injected into the room center with the door closed. CO_2 concentrations were measured inside the test room, and in the warehouse during the pre-tests, using a TSI QTrak Plus. Once the CO_2 concentration reached more than 3,000 ppm (usually much higher) in the test room, the CO_2 source was turned off. The decay of measured CO_2 concentration over time was used to calculate the dilution (by room ventilation) with "replacement" air using the empirical equation shown below. A decay period of 30 minutes was chosen to obtain an accurate measurement.

The initial and end concentrations of CO_2 were used to calculate the AER of the test room as follows, assuming no change in CO_2 concentrations in the adjoining space:

AER = Air exchange rate (number of air exchanges per hour, h^{-1})
$= [\ln C(t1) - \ln C(t2)] / (t2 - t1)$ (Persily, 2000)

where:
ln = Natural log
C = Concentration (dimensionless)
t1 = Time at start of measurement period (hours in decimal fraction form)
t2 = Time at end of measurement period (hours in decimal fraction form)

The results of the AER testing are shown in Table 3. Both the initial AERs on the three days prior to the room tests of the ozone generators and the AERs measured during the test periods were stable – they ranged from 0.25 to 0.28 AER. The measured AERs during the test periods averaged 0.27 air changes per hour. This AER was slightly below our target level of 0.3-0.5 per hour. This method assumes no significant change in CO_2 concentrations in the adjoining space during the testing, and that the concurrent CO_2 concentrations were much less in the adjoining space than those utilized for the AER measurement. The adjoining space did not contain any combustion sources or other notable sources of CO_2, so levels were assumed to be near the average of 358 ppm measured in the warehouse during the pre-tests, a reasonably low amount relative to the room CO_2 concentrations, which ranged from about 2,900 ppm to 4,900 ppm.

Table 3. Summary of Room Air Exchange Rate Tests

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	1L, 3L, 3LA, 3H, 4, 4D	0.28
7/25/05	1H, 2L, 2H	0.25
Test Average		**0.27**

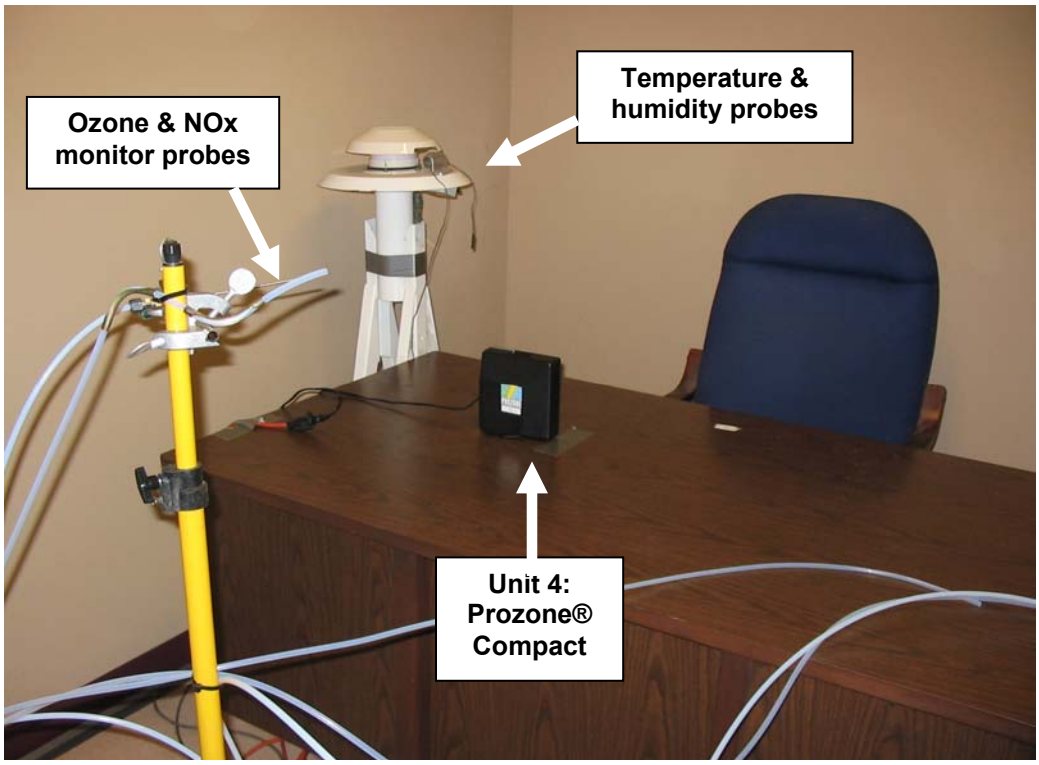
3. Appliance Set-up and Room Air Measurements

Room tests were conducted during daytime hours on weekdays between July 5 and August 1, 2005. Prior to appliance testing, background ozone concentrations were monitored in the test room and the adjacent 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. Photographs were taken showing the placement of appliances during room testing. 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 either sitting or standing. The probe was located about 3 feet from the appliance, toward the center of the room,

to simulate the position of a room occupant who is sitting or sleeping near the air cleaner.

The appliance was then remotely started at one of the pre-selected settings. These settings included a low output setting, a high output setting, and a low output setting plus the use of an additional operating feature, if appropriate, as shown in Table 4. For each test, the appliance was run until ozone levels in the room reached steady state (defined as the maintenance of constant ozone levels within ± 5% for 30 minutes), or for 3 hours if steady state was not achieved at each setting. 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, NOx, room temperature, and relative humidity. After each test period, room air was fully vented out of the building.



Test room set-up with Prozone® Compact

B. Room Test Results and Discussion

The results of the room tests for the four different units at different operational settings are summarized in Table 4 and Figures 2, 3 and 4, and discussed below for each unit. Figure 2 shows all test results on one graph; Figures 3 and 4 show those same results for the high vs. low tests separately, so that the results for the lower settings can be

shown on a lower scale. Figures 5-8 present the results for each model of ozone generator individually. All of these figures show the minute-by-minute ozone concentrations measured during each test. The rapid increase in ozone levels is seen on the left hand side of the figures, and the rapid decline when the ozone generator is turned off at the end of each test is clearly seen on the right hand side of the figures. The figures also show the duration of the steady-state or near steady-state levels throughout the center of the figures, except for one unit which was operated on a 15-minute per hour intermittent cycle. This is discussed further below.

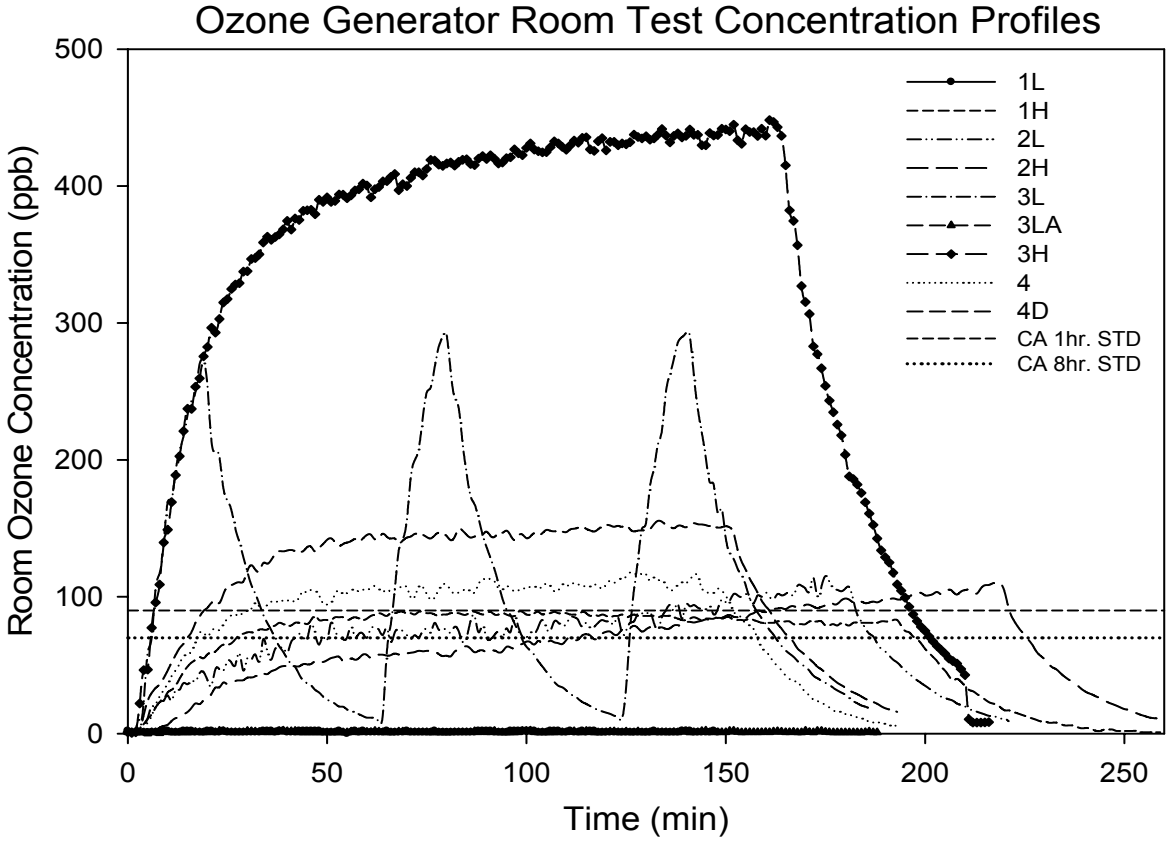


Figure 2. Concentration Profiles for Room Tests

Figures 2-4 show that all but two of the tests (1L and 3LA) produced ozone concentrations that exceeded at least one of the CAAQSs, and one device, the Prozone® Whole House model, produced exceptionally high levels of ozone. Figure 3, with the results from tests using the medium or high operational settings only, shows that the three Prozone units all exceeded the CAAQS quickly, within about 30 minutes, while the Biozone® 500 and Alpine/Lightning Air units exceeded the CAAQS after a longer period of time. Figure 4, with the results from the low operational setting tests, shows that "low" is a relative term only: the two Prozone devices clearly exceeded the CAAQS, one very quickly.

Table 4. Ozone Concentration Data for Ozone Generator Room Tests

			Room O_3 Concentration (ppb)		Time (min)				Background Ozone Concentration (ppb)
Test ID	**Manufacturer and Model**	**Operational Setting**	**Max 1-min AVG**	**Max 60-min AVG**	**To Reach 90 ppb**	**Above 90 ppb (1hr STD)**	**To Reach 70 ppb**	**Above 70 ppb (8hr STD)**	**Entire Test AVG**
1L	Alpine XL-15 / Living Air 2500	100 ft^2; Fan at Low speed [a]	2	1	NA	NA	NA	NA	5.3
1H [d]		1,000 ft^2; Fan at high speed [b]	89	88	NA	NA	28	170	0.8
2L	Biozone® 500	Fan at Low speed	115	96	135	48	42	146	3.4
2H		Fan at High speed	110	99	162	60	111	115	4.6
3L	Prozone® Whole House	Timed output mode (System on; Timer mode at 15 min/hr) [c]	291	119	7	27, 29, 31	6	31, 32, 37	11.8
3LA		UV mode only (Germicidal UV on; Timer inactive)	2	1	NA	NA	NA	NA	1.0
3H [d]		Continuous mode (Timer inactive)	448	435	7	190	6	196	3.0
4 [d]	Prozone® Compact A	On (no user-defined controls)	118	109	31	121	18	140	3.3
4D [d,e]	Prozone® Compact B	On (no user defined controls)	155	149	20	141	15	152	11.6

a. Ozonator dial setting of 100 ft^2 was the lowest possible setting.
b. Ozonator dial setting of 1,000 ft^2 was the mid-range setting.
c. Manufacturer recommends no more than 15 minutes of operation per hour for occupied areas. The series of three values represents values for the three 1-hour cycles of operation observed.
d. Ozone concentration reached “steady-state” in these 3-hour tests.
e. Duplicate test of Unit 4B, under the same operating conditions as for Unit #4A in Test 4.

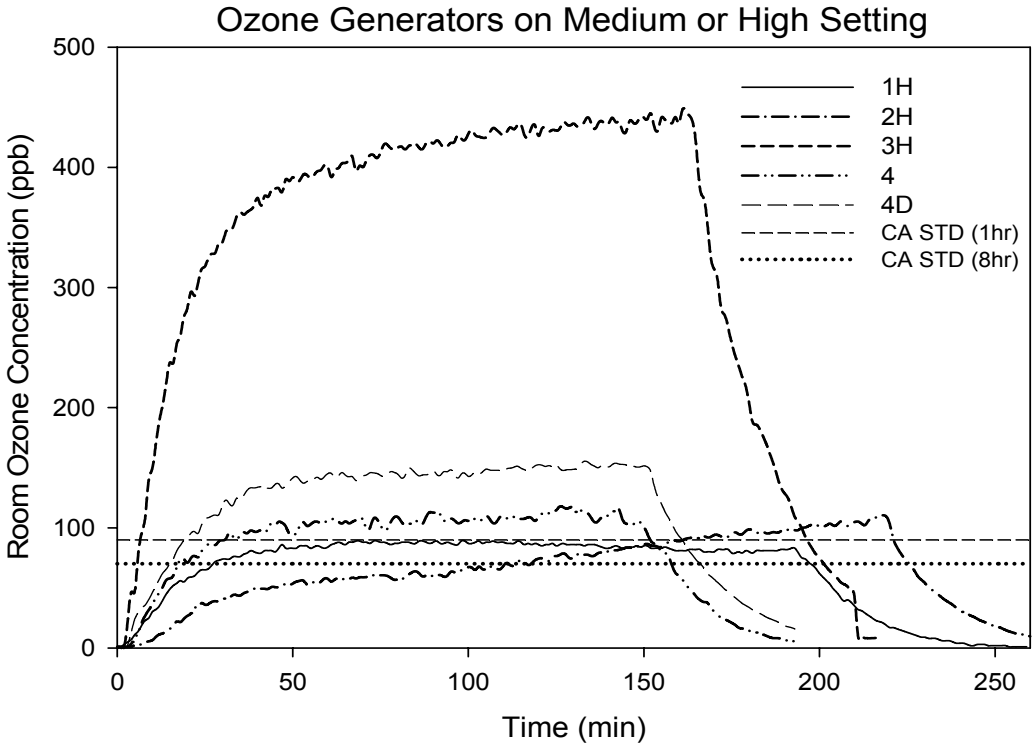


Figure 3. Room Concentration Profiles for Medium and High Settings

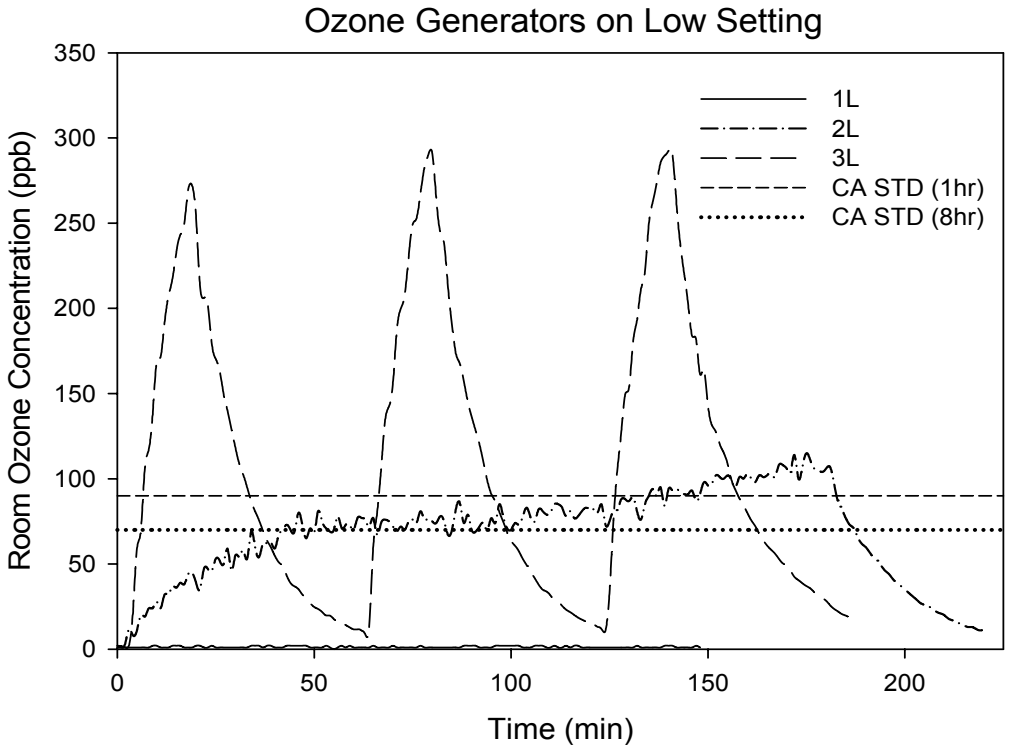


Figure 4. Room Concentration Profiles for Low Settings

Before discussing the individual units, it should be noted that steady-state concentrations within the three hours of testing were only attained in four of the nine room tests, as noted in Table 4. The failure of the tests to reach a steady-state room concentration was mainly in the tests with lower ozone concentrations and was likely due to several contributing factors. The first factor is the narrow operational definition of a steady-state concentration (less than $\pm$ 5% variability for 30 minutes) that was chosen at the beginning of the project. This small variability is difficult to attain when the accuracy of the ozone monitor alone is 2% RSD, when the background ozone concentrations begin to increase markedly (as in Test 3L), or when the monitoring time is limited (as it was in this study) and the air exchange rate is low. When the definition of steady state is expanded to ± 10%, then Test 2H met this criterion, and Test 2L nearly met the criterion. Other factors affecting room concentration variability may include slight short-term variability in AERs, differing ozone reaction/sorption loss rates (due to the condition of the room surfaces and furnishings at the time of each test), and background concentrations.

Additionally, steady state conditions were not attainable by design for Test 3L because the unit was cycling on for just 15 minutes per hour. Nonetheless, 1-minute maximum averages were nearly identical for the 2nd and 3rd cycles, and within $\pm$ 5% of each other (291 vs. 293 ppb), indicating a consistent oscillation in ozone concentrations. The first peak's value was 272 ppb, which was well within 10% of the other peak values.

1. Unit 1: Alpine Air Enhanced XL-15 / LA Lightning Air RA 2500

The time-resolved room concentration profiles for Unit 1, the Alpine Air XL-15/LA Lightning Air RA 2500, are shown in Figure 5. Unit 1 was examined at two different operational settings for the room tests: 100 ft^2 Ozonator setting with a low fan speed (Test 1L); and 1,000 ft^2 Ozonator setting with a high fan speed (Test 1H). The maximum 1-minute and 60-minute average ozone concentrations were similar in Test 1H: 89 vs. 88 ppb (see Table 4). This suggests that the short-term variation in ozone output for Unit 3 at this setting was small.

Room concentrations for Tests 1L and 1H were quite different. Test 1H attained a steady-state room concentration of 88 ppb within about 70 minutes. This concentration is very near the CAAQS level of 90 ppb for one hour. Under real-world conditions that occur in a number of California's larger cities during summer, with higher background ozone concentrations from outdoor air, room concentrations could exceed 90 ppb. The room concentrations in Test 1H exceeded the level of the 8-hr CAAQS of 70 ppb within about 30 minutes, as shown in Table 4. Had the testing time been extended, it is likely that the 1H setting would clearly have exceeded this standard. In addition, Test 1H concentrations exceeded the FDA room air standard of 50 ppb within about 20 minutes.

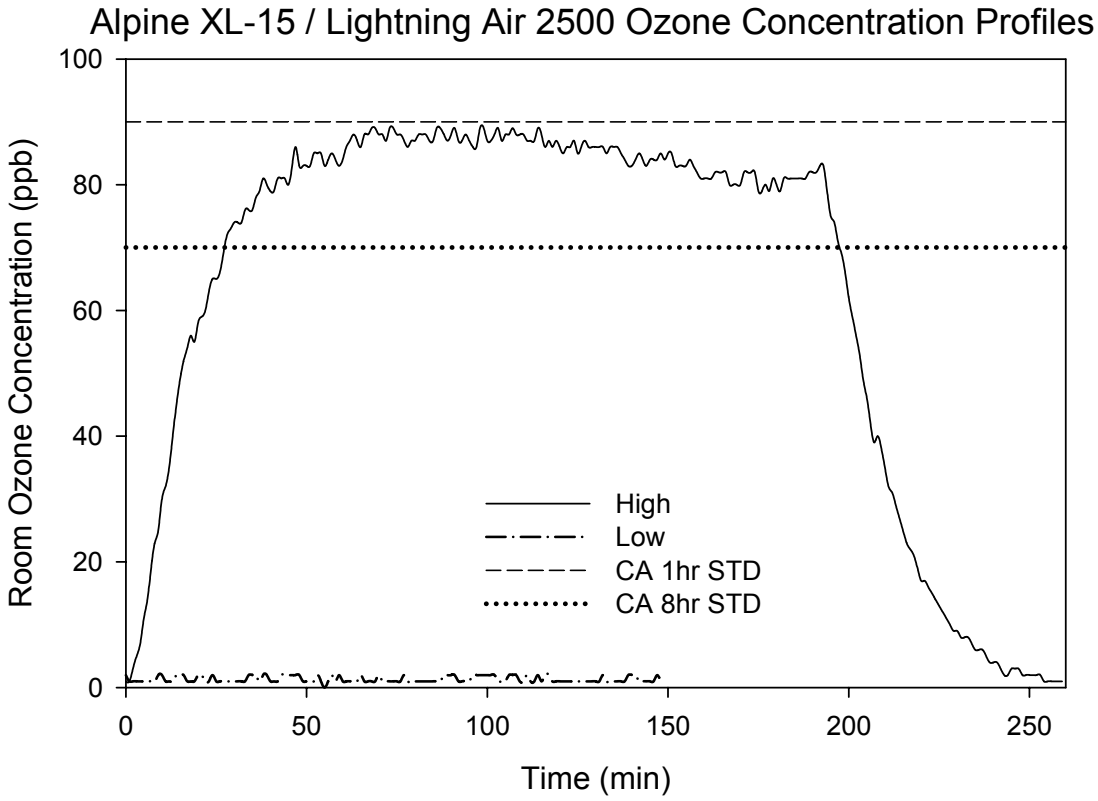


Figure 5. Ozone Concentration Profiles for Unit 1 Room Tests

Room concentrations for Test 1L were 1-2 ppb, below the average background concentration of 5 ppb measured outside the room in the warehouse. This low level was somewhat surprising, but may be attributable to a number of factors. The device may not actually produce any ozone at its lowest ozone setting. More likely, the device produces a very low amount of ozone that reacted quickly with other chemicals or surfaces in the test room.

The Alpine/Lightning Air unit can be operated at a much higher output than the operational settings used in our room tests. Other investigators (e.g., Mason *et al*., 2000) have measured ozone levels above 300 ppb at its highest setting. Despite this, the manufacturer recommends this model for use in hospitals, nursing homes, doctors' offices, and day care settings, as well as other locations. The occupants of these types of buildings are those population groups most likely to be susceptible to the harmful effects of ozone. Further, FDA regulations prohibit the use of ozone generators in these types of buildings.

2. Unit 2: Biozone® 500

The time-resolved room concentration profiles for Unit 2, the Biozone® 500, are shown in Figure 6. Unit 2 was tested at both low (2L) and high (2H) fan speeds. The ozone output for this unit could not be adjusted; thus, the results for the two tests were very similar. The concentration profiles tracked each other fairly closely, with room concentrations rising faster in Test 2L, perhaps due to the lower fan speed, which would result in less air mixing and thus less rapid dilution and less reactivity. Neither test attained a steady-state room concentration, most likely due to the experimental protocol time restriction.

As shown in Table 4, both tests produced room ozone concentrations exceeding the levels of both the 1-hour and 8-hour CAAQS. The maximum 1-min average concentrations of ozone observed in Tests 2L and 2H were 115 ppb and 110 ppb, respectively. The maximum 60-minute averages were 96 and 99 ppb, respectively; both of these averages exceed the 1-hour CAAQS of 90 ppb. This standard was exceeded within 2 - 2.5 hours, and concentrations remained above that level until the end of the tests. Room ozone concentrations reached 70 ppb, the 8-hr CAAQS level, in less than 42 minutes in Test 2L, and 111 minutes in Test 2H. The still-rising room concentrations at the end of the tests suggest that both tests would have exceeded the 8-hr CAAQS if continued long enough. In addition, Test 2L and 2H concentrations exceeded the FDA room air standard of 50 ppb within about 30-50 minutes.

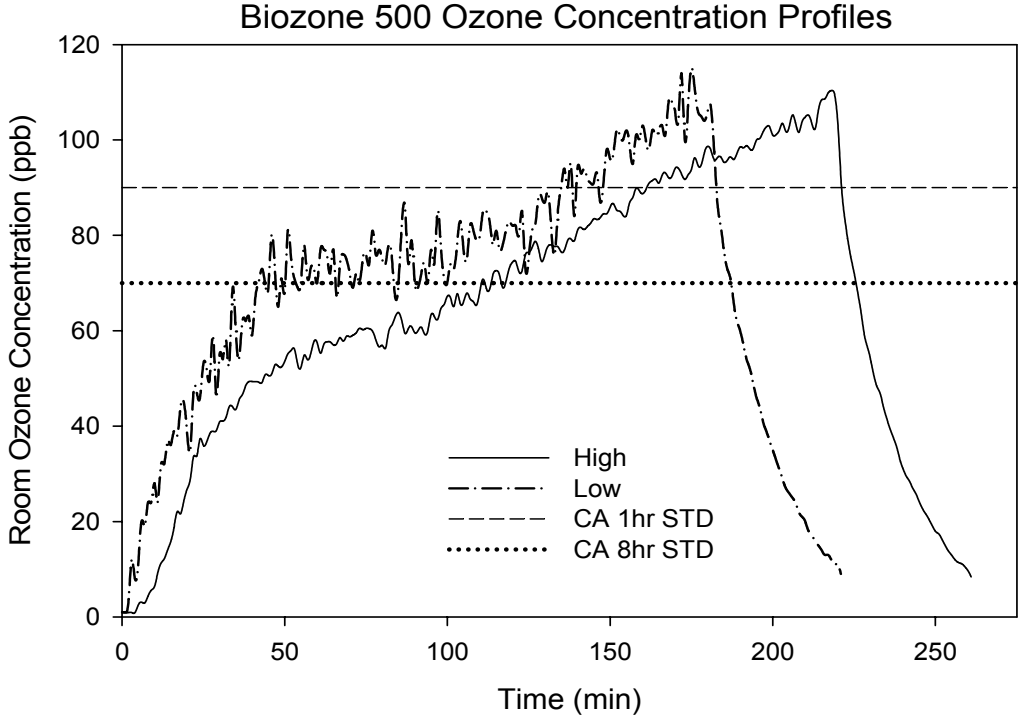


Figure 6. Ozone Concentration Profiles for Unit 2 Room Tests

3. Unit 3: Prozone® Whole House

The room concentration measurements were performed at three different operational settings for Unit 3, the Prozone® Whole House device: an intermittent output (15 min / per hour; Test 3L), germicidal mode (UV-only; Test 3LA), and continuous output (Test 3H). The results are shown in Table 4 and Figure 7. The use of this device on both its intermittent setting and its continuous setting resulted in levels of ozone several times higher than the CAAQS. The use of the germicidal UV function alone showed no ozone production; its ozone concentration in Figure 7 follows the horizontal axis.

The concentrations measured in 3L and 3H were very high. Test 3L had a maximum 1-min average concentration of 291 ppb, and a maximum 60-min average of 119 ppb, while 3H had a maximum 1-min average concentration of 448 ppb and a maximum 60-min average of 435 ppb. The 3H concentrations were the highest observed of all the room tests. Test 3H (continuous mode) produced ozone concentrations nearly 5 times the California 1-hour CAAQS, and exceeded the CAAQS for about 195 minutes of the test, which equates to 90% of the time that the unit was operated. In the 3L test, although the unit was emitting ozone for just 15 minutes of every hour (the left side of each of the three vertical peaks shown in Figure 7), room concentrations nonetheless exceeded the 1-hour CAAQS level within 6-7 minutes of starting the unit, and maintained concentrations above the 1-hour CAAQS for 27-37 minutes of each hour. Additionally, as can be seen on the left hand side of Figure 7, both the 3L and 3H concentrations exceeded the FDA room air standard of 50 ppb within about 5 minutes of starting the units.

The room ozone concentrations in the 3LA test were nearly equal to the average background ozone concentration of 2 ppb, indicating that no ozone was being emitted from the unit during the germicidal (UV) mode operation.

Based on the results obtained during the testing of Unit 3, it is obvious that the operation of this unit in a confined residential setting poses a serious public health risk. Because this particular unit is marketed for both single room coverage as well as whole house coverage, the potential exists for significant ozone exposure for any individual(s) occupying the same room as the unit while it is operating. This unit would violate the 8-hour CAAQS if operated on high for an 8-hour time period. It is also likely that operation in the 15-minute/hr cycling mode, which produced a maximum 60-minute average of 119 ppb in Test 3L, would also exceed the 8-hour CAAQS if the test were continued for 8 hours.

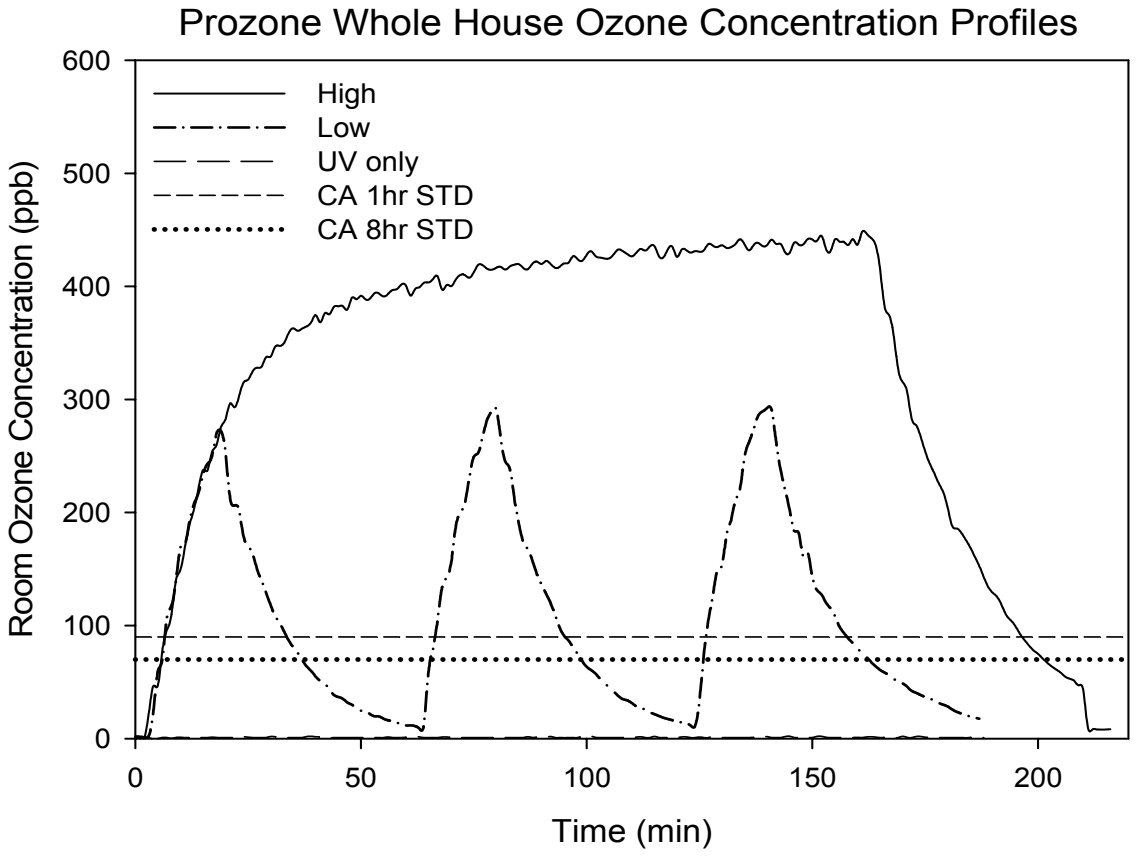


Figure 7. Ozone Concentration Profiles for Unit 3 Room Tests

4. Unit 4: Prozone® Compact

The Prozone® Compact has only an on-off switch and no other controls that are accessible to the operator. Consequently, there were no high or low tests conducted for Units 4A and 4B: the devices were simply turned on. As shown in Figure 8, the general shapes of the concentration profiles for Units 4A (Test 4) and 4B (Test 4D) are very similar. Additionally, the slopes of the ozone increase at the start of the tests are nearly identical until the room ozone concentration reaches 70 ppb at about 15 minutes. At this concentration, the two curves deviate to different steady-state concentration maxima while maintaining a similar shape in their concentration profile.

As shown in Table 4, the maximum 1-min and 60-min average ozone concentrations measured were 118 and 109 ppb, respectively, for test 4, and 155 and 149 ppb, respectively, for test 4D. The measured concentrations exceeded the CAAQS for 2-2.5 hours depending upon the standard and test being considered. This corresponds to

nearly 66% of the time each unit was in operation. Both units exceeded the FDA room air standard of 50 ppb within 15 minutes.

Agreement between the duplicate Tests 4 and 4D was moderate – the duplicate unit produced a room ozone concentration 49 ppb greater than that produced by Unit 4 at steady state, a 40% increase. Their room ozone concentrations were sufficiently different as to eliminate the ozone analyzer precision (2% RSD) as a significant source of variability between the two units. A portion of this variability can be attributed to differences in the background ozone concentrations for the different testing periods: Test 4 was conducted in the morning when background ozone levels averaged 3 ppb, and Test 4D was conducted that afternoon when background ozone levels averaged 12 ppb, an 8 ppb increase. The room conditions such as temperature and humidity varied only slightly throughout the day. The room set-up was not changed, but it is possible the air exchange rate of the room or other conditions varied a bit. The majority of the between-unit difference is most likely due to the difference in the background ozone, some unknown factors such as small differences in AER, and inherent variability between the two units examined,.

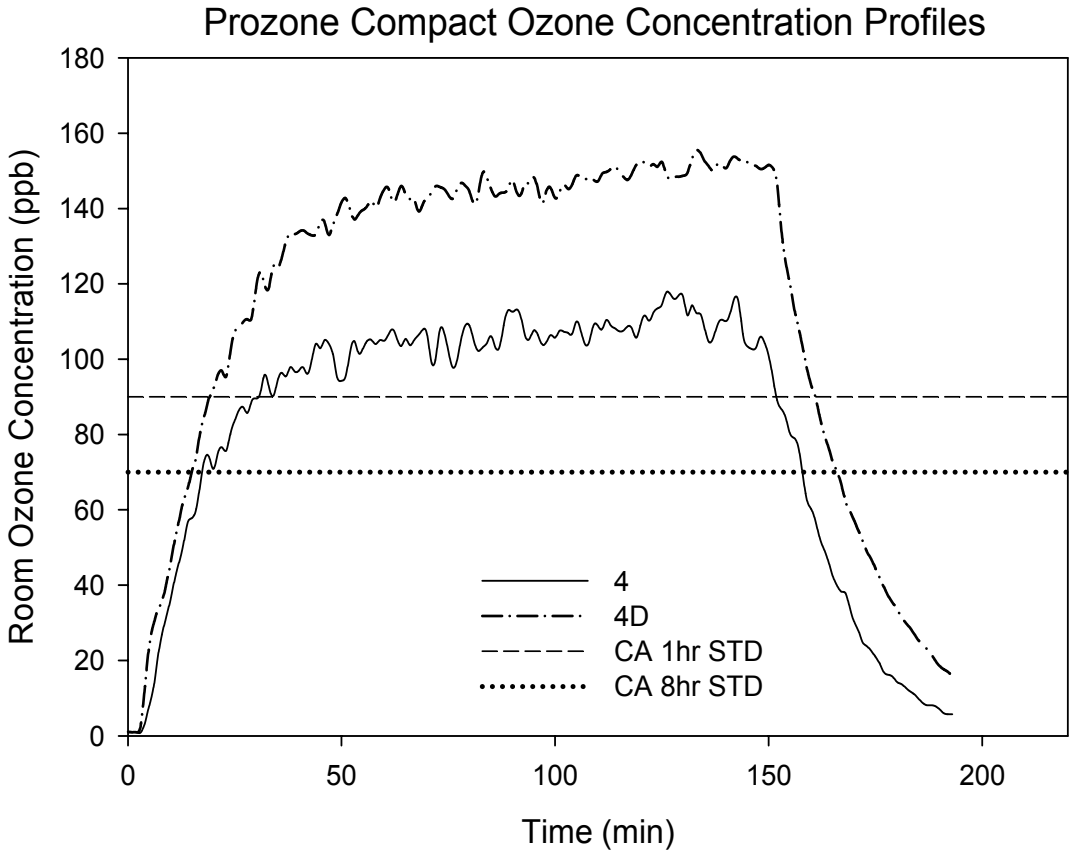


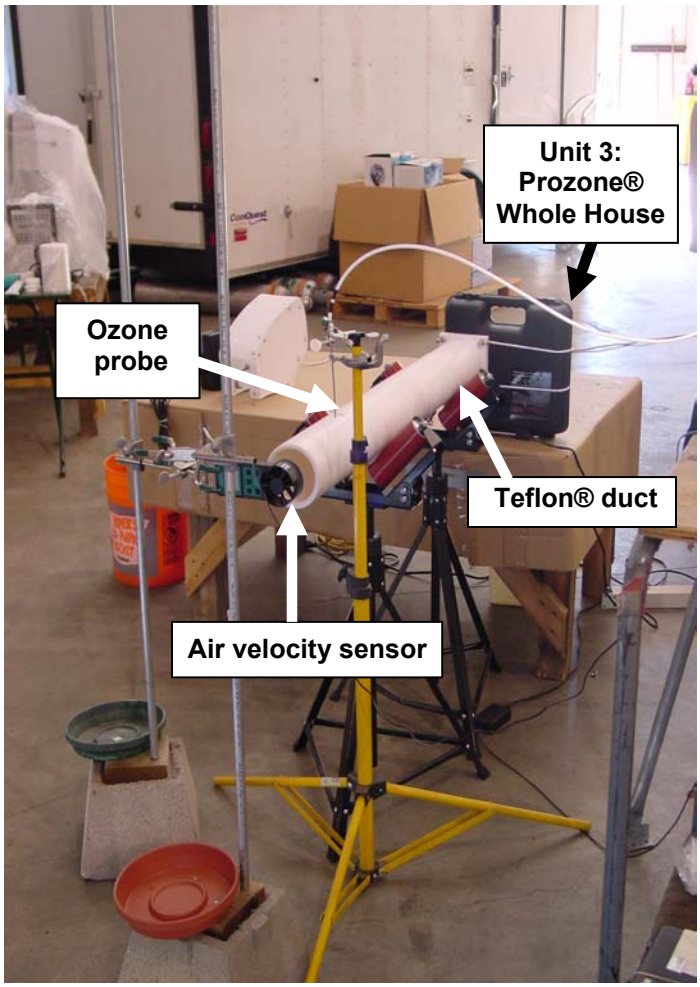
Figure 8. Ozone Concentration Profiles for Unit 4 Room Tests

6. EMISSIONS TESTS

A. Emission Test Methods

The emissions tests for each appliance were conducted in March, 2006, after completion of the room tests and after each appliance could be outfitted with custom ductwork for the emissions tests (discussed below). The emissions tests were conducted in the open, unoccupied area of the same warehouse building described previously. To avoid re-circulation of ozone to the appliance's air intake, a cross-draft was provided to the area by opening two opposing doors to the outside.

To allow measurements of ozone in a contained air volume, each appliance's exhaust air was directed into Teflon® ductwork that was custom designed to fit tightly over each unit's vent face. The duct was designed to direct the unconfined flow of air to the sampling port where ozone emissions could be monitored. The ductwork was circular, four inches in diameter, and 40 inches long. The ductwork was connected to the ozone generator using a custom Teflon® adapter, and all connections were made using stainless steel hardware to avoid reactivity losses of ozone.



Emissions Test Set-up with Prozone® Whole House

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. In order to ensure a well-mixed sample, the probe location was set at 8 duct-diameters length (32 inches) from the appliance face.

In addition, a K-type thermocouple measured the temperature of the ducted air. The ducted air was

assumed to be at atmospheric pressure. Moisture content of the ducted flow was determined from psychrometric charts. The velocity of the air from the duct was measured with a hot-wire anemometer.

Measurements in the duct were taken at different appliance settings once the ozone concentrations and air velocity had reached a maximum level and were fairly stable. 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/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 ambient (warehouse) ozone concentration. Assuming standard temperature and pressure, the conversions were accomplished using the following equations:

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

Air Flow Rate (m^3/s) = (X m/s duct air velocity) x (0.0081 m^2 duct area)

O_3 Emission Rate = (X $\mu g/m^3$ O_3) x (Y m^3/s flow rate) = µg/s

O_3 Emission Rate in mg/hr = µg/s x (0.001 mg/µg) x (3600 s/hr) = Mass/time in mg/hr

B. Emission Test Results and Discussion

Each of the units was examined to ascertain the ozone emission rate under operational settings generally analogous to the room test conditions. A summary of the results obtained in the emission rate tests is presented in Table 5. Figure 9 provides a graphical display of the ozone emission concentrations measured in the ducts, and Figure 10 shows the calculated ozone emission rate for each appliance and test condition in mg/hr.

Substantial variation was observed in the nine emission tests. The calculated ozone emission rates ranged over four orders of magnitude, from 0.079 – 94 mg/hr. In-duct ozone concentrations for all but two tests, when corrected for background, ranged from 153 – 1867 ppb. The other two tests, for the Alpine Air on low, and the Prozone Whole House on UV only, were 2 and 4 ppb, respectively. The measured air flow rates ranged from 0.0015 – 0.0167 m^3/s.

Table 5. Ozone Emission Rate Data

Test ID	Manufacturer and Model	Operational Setting	Measured Velocity (m/sec)	Volumetric Flow Rate (m^3/sec)	Corrected Ozone Emission Concentration (ppb) [a]	Ozone Emission Rate (mg/hr)
1L	Alpine XL-15	Ozonator at 100 ft^2; Fan at Low speed	1.26	0.0102	4	0.29
1H		Ozonator at 1,000 ft^2; Fan at Medium speed	1.60	0.0130	153	14
1LH		Ozonator at 2,500 ft^2; Fan at Low speed[b]	1.24	0.0100	1308	93
1HH		Ozonator at 2,500 ft^2; Fan at High speed[b]	2.06	0.0167	799	94
2L	Biozone® 500	Fan at Low	0.36	0.0029	502	10
2H		Fan at High	0.50	0.0041	327	9.4
3L	Prozone® Whole House	Timed output mode (System on; Timer mode at 15 min/hr) [c]	1.08	0.0087	520	32
3LA		UV mode only (Germicidal UV on; Timer inactive)	0.69	0.0056	2	0.079
3H		Continuous mode (Timer inactive)	1.13	0.0092	1359	88
4	Prozone® Compact, Unit A	On (no user-defined controls)	0.19	0.0015	1867	20
4D	Prozone® Compact, Unit B	On (no user defined controls)	0.19	0.0015	1727	19

a. Concentrations are the measured value minus the average background concentration on the day of testing.
b. No room tests were performed at these operational settings, but face test results are available,
c. Unit timer was set for 15 minutes of operation per hour, the maximum recommended by the manufacturer for occupied buildings.

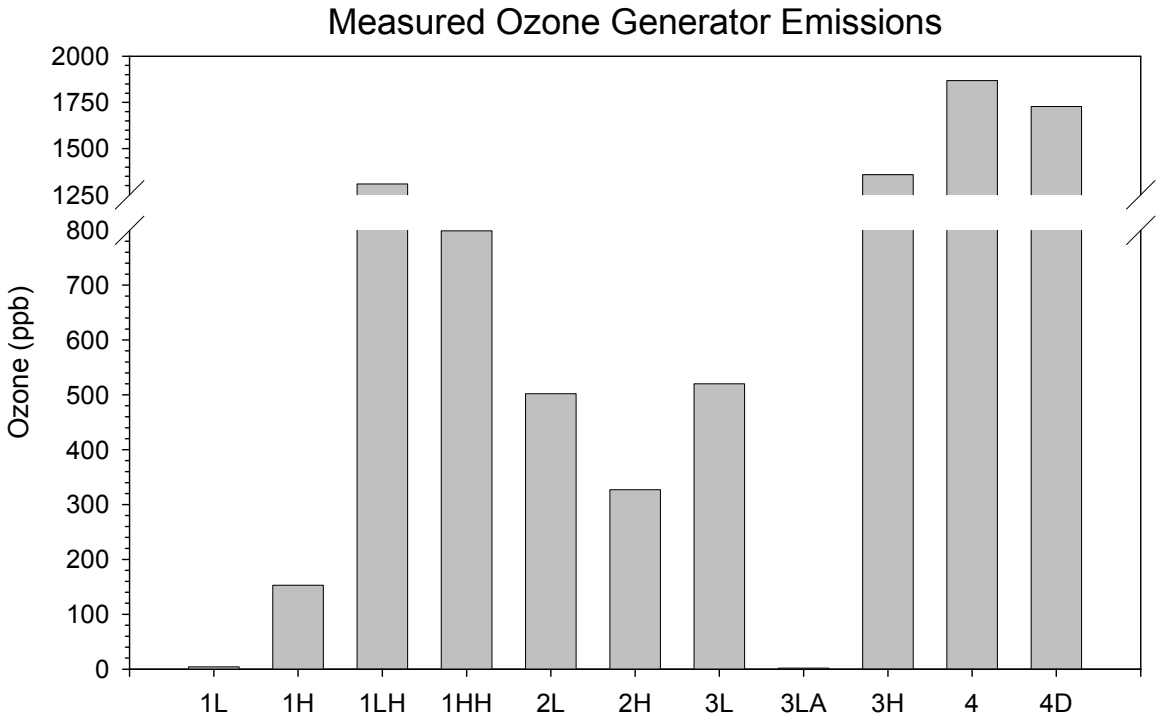


Figure 9. Measured Ozone Emission Concentrations (in Duct)

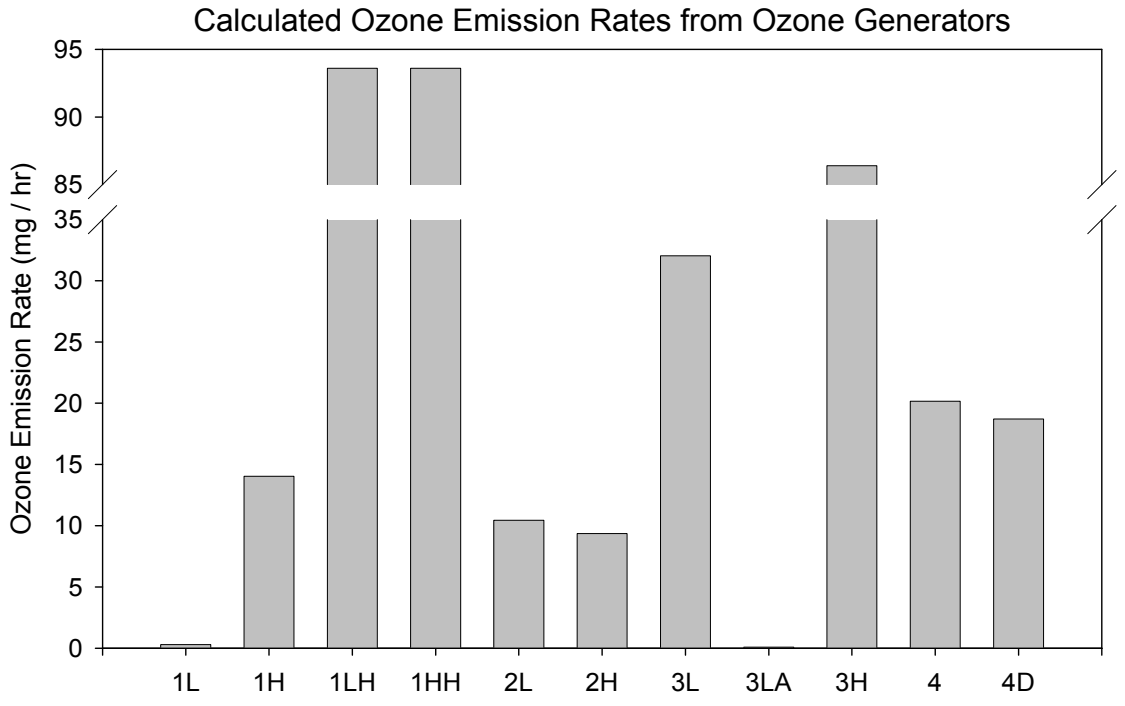


Figure 10. Calculated Ozone Emission Rates

The emission rate results can be used to model resultant concentrations in rooms and buildings under different ventilation and ozone removal conditions. The highest and mid-range emission rates for ozone are a public health concern because they can produce indoor ozone levels above the FDA standard and the 1-hour CAAQS. Using the test home results of Mason *et al.* (2000) as a basis, an ozone emission rate of 58 mg/hr in a 1200 ft^2 home can produce 158 ppb in the room with the ozone generator and 48 ppb in a distant room. The higher room concentration is three times the FDA standard of 50 ppb in room air. This suggests that an emission rate below about 15 mg/hr is needed to meet the FDA standard in this house, assuming outdoor ozone contributions are negligible. In the present study, this emission rate was exceeded in Tests 1LH and 1HH (maximum setting), Tests 3L and 3H, and Tests 4 and 4D, and was nearly exceeded in Tests 1H (14 mg/hr) and approached in Tests 2L and 2H (9-10 mg/hr).

The following sections examine each unit individually and compare the calculated emission rate to the results obtained in the room tests.

1. Unit 1: Alpine Air / Lightning Air

The emission results obtained from Tests 1L and 1H under the 100 ft^2 and 1,000 ft^2 settings, respectively, were very different, as expected. Test 1L yielded one of the lowest ozone emission rates observed, 0.29 mg/hr. Test 1H yielded an ozone emission rate of 14 mg/hr, in the low-medium range among all tests. The Test 1H emission rate is 48 times that of Test 1L, rather than the 10-fold factor in the square foot settings of the Ozonator. This indicates that the Ozonator control knob does not have an accurate, linear response in producing ozone.

Figures 9 and 10, and Table 5 also show results for the two emission tests that were conducted in addition to those using the appliance settings in the room tests: Test 1LH and Test 1HH. Both tests were conducted at the maximum Ozonator setting of 2,500 ft^2, and at low and high fan speeds, respectively. As expected, both tests yielded nearly identical ozone emission rates, 93 and 94 mg/hr, which were the highest values among all the tests. The emission test results for the Alpine/Lightning Air unit at the maximum setting of 2,500 ft^2 were similar to those of the Prozone® Whole House unit in continuous mode – 94 vs. 88 mg/hr, respectively.

In comparing the emission test results to the room test results, these two sets of results were consistent for Unit 1 under the same appliance settings. Test 1L produced very low ozone emission rates and very low ozone room concentrations (1-2 ppb). The higher emission rate for the 1H setting agrees with the elevated room concentrations measured (89 ppb maximum 1-minute average). Similar to the relationship between the emission rates, the 1H room concentration is approximately 45 times higher than for the 1L setting. The agreement between the room test results and the emission rate measurements strengthens the validity of both sets of measurements.

2. Unit 2: Biozone® 500

The emission rate measurements for Unit 2 were made under the same low and high operational setting as in the room tests, Tests 2L and 2H, respectively. The ozone emission rates for these two tests were quite similar: 10 mg/hr and 9.4 mg/hr, respectively. These emission rates agree with the measured room concentrations, 115 ppb and 110 ppb (maximum 1-minute average) for the 2L and 2H room tests, respectively. The low:high ratio for the emission rates and for the room concentrations for unit 2 reveals a similar result of 1.05 and 1.06, respectively. This close agreement between these ratios for emission rates and the room concentrations provides further confidence in both data sets.

3. Unit 3: Prozone® Whole House

Unit 3 was examined under the three operational settings used in the room tests: Tests 3L, 3LA and 3H room tests. Unit 3 had an emission rate of 88 mg/hr in Test 3H for the continuous mode, one of the highest emission rates in the study. For Test 3L, the intermittent setting, the emission rate was 32 mg/hr, mid-range among all the tests. For test 3LA, germicidal UV only, the emission rate was 0.079, the lowest among all tests. The volumetric flow rates of Unit 3 for the low and high setting were similar, 0.0087 and 0.0092 m^3/s, respectively, while that for the germicidal UV-only setting was significantly lower at 0.0056 m^3/s.

The emission rate for the high setting of 88 mg/hr is more than 4 times higher than for any other unit examined except for Unit 1 at the maximum setting. The low setting (32 mg/h) is 1.5 times higher than any other unit except for Unit 1 at the maximum setting. One major caveat is that the low setting produces ozone for 15 minutes each hour (25% of the hour), but maximum ozone levels were produced in 16 of the 40 minutes of sampling. This indicates that the emission rates reported above are overestimates for a 1-hour operating cycle, because the emission test was not conducted for a full hour. The fact that the room concentrations and determined emission rates for the high and low settings of unit 3 were the highest for both data sets adds confidence to the results obtained.

4. Unit 4: Prozone® Compact

The emission rate measurements made for Unit 4 were obtained from two identical units. The first unit tested, corresponding with room test 4, was determined to emit ozone at 20 mg/hr while the second unit, corresponding with room test 4D, had an emission rate of 19 mg/hr. These emission rates are mid-range among all the tests. The volumetric flow rate was 0.0015 m^3/s for both of the units.

Given the excellent agreement between the determined emission rates it is surprising that the room test concentrations differed by about 30%. However the differences in the room test concentrations are likely due to differences in room conditions at the time of

each test, such as the higher background in the 4D test when the data were collected in the afternoon versus the 4 test when the data were obtained in the morning, small differences in AER, and other factors. The close agreement in the emission rate tends to indicate that the variability between units is minimal.

7. SUMMARY AND CONCLUSIONS

This study confirmed that ozone generators sold as “air cleaners” and operated as recommended by the manufacturer can produce room ozone concentrations near or above the 1-hour CAAQS of 90 ppb, the 8-hour CAAQS of 70 ppb, and the FDA room air standard of 50 ppb. All four models tested in this study exceeded acceptable concentrations of ozone at their medium or high settings; only one model did not exceed the standards at its low setting, and one other model did not emit ozone when operated with only the UV feature turned on. In addition, some models operated at the whole-house or high settings produced very high ozone emission rates and consequently very high room concentrations – up to 5 times the 1-hour CAAQS of 90 ppb. Exposures to ozone concentrations at these elevated levels can cause acute and chronic health effects among building occupants, especially the persons with asthma or other respiratory diseases, and young children.

The face test worked well as a range-finding approach. It was able to locate the peak concentrations near the face of the units and characterize the decline in ozone concentrations with distance from the face. However, the ranking by ozone concentration was different between the measurements at 2 and 6 inches, as shown in Figure 1, indicating that such face testing is not appropriate for accurately and consistently estimating the impact of ozone generators on indoor air quality.

The emission test results are generally consistent with those of the room tests. The results of the emission tests indicate that all of the ozone generators could produce indoor air levels in a home that exceed the FDA standard of 50 ppb in room air and the 1-hour and 8-hr CAAQS.

We conclude that the use of ozone generators in enclosed spaces presents a serious public health risk from exposure to ozone and its toxic by-products. The use of such devices in close proximity to people cannot be justified based on any purported air cleaning or germicidal properties of ozone. Furthermore, even if operated according to manufacturer’s instructions, the safe operation of these devices by the general public cannot be ensured, especially those devices that have extremely high emission rates for ozone.

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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 (AAQS)	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.
Ozone Generator	An appliance that intentionally emits ozone but is advertised as an “air cleaner” or “air purifier”.
Quality Control (QC)	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.