Portable Air Cleaner Test Report
Blueair 211+ Portable Air Purifier: Impact of Ionizer
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Test Description

As a result of recent global indoor air quality challenges, including the infiltration of smoke from historically large wildfires in the U.S. (Xu et al., 2020) and the increasing recognition of the potential for aerosol transmission of COVID-19 in poorly ventilated indoor environments (CDC, 2020), there has been an unprecedented level of interest and investment in indoor air cleaning technologies.

Here we report on controlled test chamber measurements conducted at the Illinois Institute of Technology to measure the pollutant removal efficacy of a Blueair 211+ portable air purifier. The product uses a combination of particle filtration and gas-phase (carbon) media,[1] as well as small ionizers integrated into the product.[2] The product has been tested by AHAM to have a clean air delivery rate (CADR) of 350 cfm for all three particle size ranges in the test and to meet AHAM ozone (O_3) emission limits of less than 50 ppb in a test chamber.[3]

Measurements included CADR characterizations for particulate matter ranging from 0.01 to 10+ µm in diameter following injection of incense and dust, both with and without the ionizer disabled, as well as measurements of negative ion concentrations during normal operation in the chamber (i.e., without pollutant injection) and with the ionizer disabled.

Measurement Description

Tests were conducted in a large aluminum environmental chamber (interior volume of 1296 ft^3). The unit was first tested in January 2021[4] and again in August 2021. The chamber is served by a recirculating air handling unit connected via a flexible aluminum duct, capable of recirculating between ~150 and ~200 cfm. Surrounding laboratory air enters unfiltered via infiltration through the chamber, air handler, and ductwork, typically around 1.9-2.0 air changes per hour (ACH) with the surrounding laboratory. A small mixing fan was operated in the chamber to encouraging mixing.

[1] https://www.blueair.com/ca/air-purifiers/blue-pure-211-plus/1695.html
[2] https://www.bestbuy.com/site/questions/blueair-blue-pure-211-540-sq-ft-air-purifier-white/5892131/question/03fa97d5-19ab-3cf7-bee4-1bd11a504b73
[3] https://www.ahamdir.com/room-air-cleaners/
[4] http://built-envi.com/wp-content/uploads/IIT-CADR-Testing-February-2021.pdf

Pollutant Removal Efficacy Testing

Pollutant removal efficacy testing involved measuring the CADR for each air cleaner using a pollutant injection and decay method (Offermann et al., 1985; MacIntosh et al., 2008; US EPA, 2018). The CADR is a measure of how much pollutant-free air an air cleaner provides, reported in units of airflow rate (e.g., cubic feet per minute, or cfm). The CADR is traditionally measured for particulate matter but can also be measured for other types of airborne pollutants (Howard-Reed et al., 2008). Three particle size ranges are commonly tested in the widely used ANSI/AHAM AC-1 Test Standard, *Method for Measuring the Performance of Portable Household Electric Room Air Cleaners*: tobacco smoke (0.09-1 µm), dust (0.5-3 µm), and pollen (5-10 µm).

Pollutant injection was achieved by burning incense to generate particles primarily in the 'smoke' and 'dust' size ranges and shaking a vacuum cleaner bag filled with vacuumed dust to generate particles primarily in the 'pollen' size range (Stephens and Siegel, 2012). Burning incense also generates numerous gaseous pollutants (e.g., carbonyls, carbon monoxide, nitrogen oxides, and VOCs (Lee and Wang, 2004)) that may be used to estimate CADR for the measured gas-phase pollutants. Ozone was also detected as a product of incense burning, likely due to reactions between NO_x and VOCs (Hsu et al., 2019). Only loss rate data for particulate matter are analyzed here.

Testing was first conducted with the air cleaner turned on either during or immediately after pollutant injection completed. This allowed for estimating the decay rate of pollutants with the air cleaner turned on, which includes losses due to the 'natural' (i.e., background) decay due to deposition to surfaces, ventilation/infiltration, etc., *plus* the effect of the air cleaner operating. After pollutant concentrations (C_t) mixed and then decayed from the initial mixed peak (C_0) towards background levels in the chamber (C_{bg}), the air cleaner was turned off to reach a new chamber background (C_{bg}), and then pollutant injection was repeated and pollutant concentrations were allowed to decay with the air cleaner turned off to characterize only the 'natural' (i.e., background) decay rate.

A linear regression is used to estimate pollutant loss rates (K) under air cleaner on (K_{ac}) and off (K_{nat}) conditions:

$$-\ln \frac{C_{in,t} - C_{bg}}{C_{in,t=0} - C_{bg}} = K \times t$$

The CADR is calculated as the difference between the two loss rates multiplied by the interior chamber volume:

$$CADR = V \times (K_{ac} - K_{nat})$$

Where:
- V = volume of the test chamber (ft^3)
- K_{ac} = total decay rate with air cleaner on (1/min)
- K_{nat} = natural decay rate with air cleaner off (1/min)
- t = time from the beginning of the decay period (min)

Measurement Equipment Used

1. TSI NanoScan SMPS 3910 for ultrafine particle number concentrations
2. TSI OPS 3330 and MetOne GT-256S OPC for 0.3-10+ µm particle number concentrations
3. Aeroqual Portable Handheld Air Quality Monitor for TVOC concentrations
4. 2B Technologies Models 211 and 405 for ozone and NO_x concentrations, respectively
5. Extech SD800 CO_2 monitors to assess air change rates
6. AlphaLab Air Ion Counter

Test Conditions

The air cleaner was placed on a table in the chamber and tested once on the highest fan speed setting. The first test was conducted with the unit new out of the box in January 2021. A second round of testing was conducted in August 2021 with another new unit out of the box, once to characterize ion concentrations during normal operation (i.e., without pollutant injection) in the chamber, and then again using injection and decay tests to characterize the CADR for particulate matter but with the ionizer function disabled (see Figure 1).

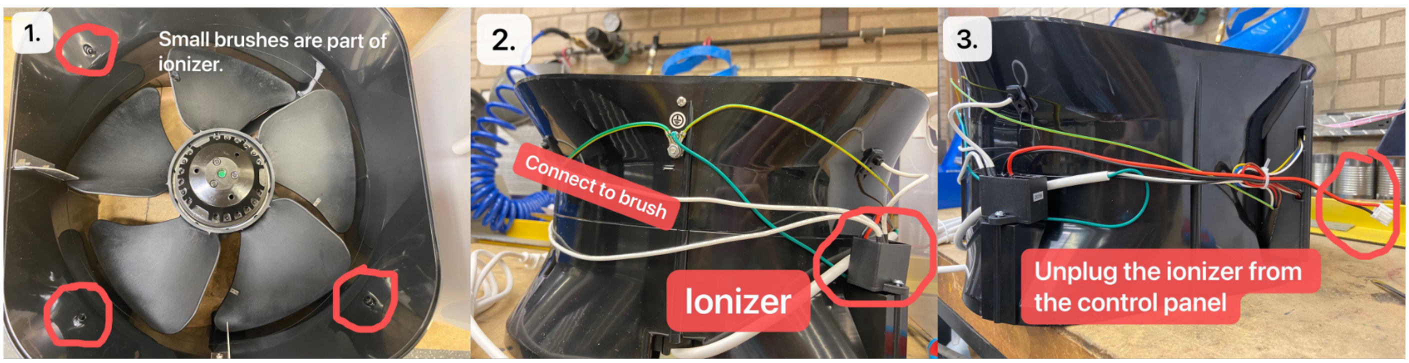

Figure 1. Steps taken to disable ionizer during the second round of testing

Example Test Data: Particle Injection and Decay

An example of resulting time-series test data is shown below for particles in the 'smoke' size range during injection and decay measurements (i) during normal operation (January 2021) and (ii) during operation with the ionizer disabled (August 2021).

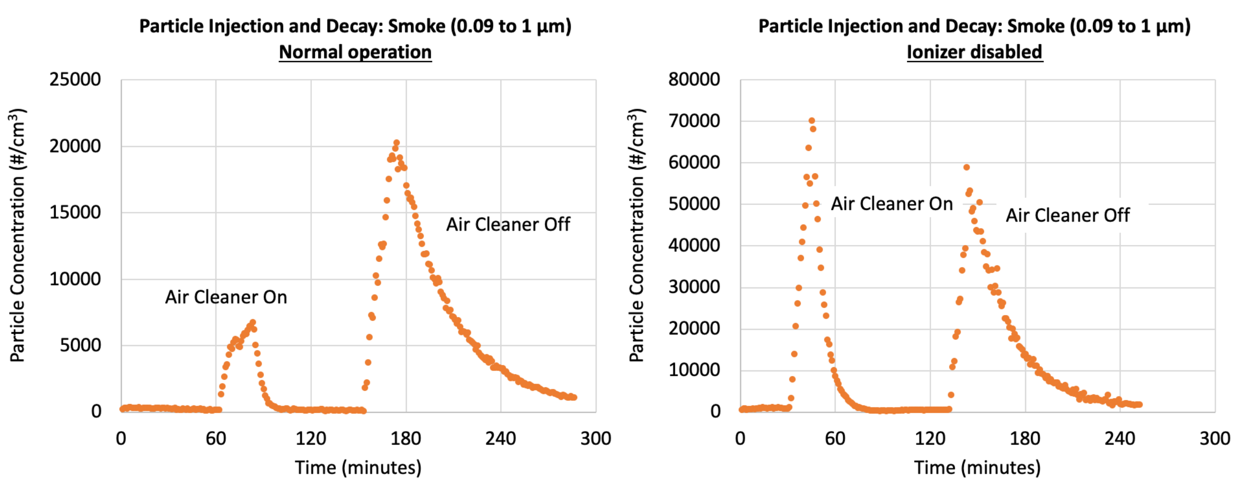

Figure 2. Example time-series test data from 'smoke' size particle injection and decay tests

Example Test Data: Ion Concentrations

Figure 3 shows a time-series profile of negative ion concentrations measured with the unit operating in the test chamber without any pollutant injection. At 17:45, the air cleaner, located on the table, was turned on and operated normally (i.e., with ionizers enabled). The ion counter was located on the table as well. A large burst of negative ions was observed, briefly reaching >250,000 ions/cm^3 and then decreasing to ~50,000 ions/cm^3. At 18:05, the air cleaner was moved to the floor to increase the distance between the air cleaner outlet and the ion measurement location. Ion concentrations then averaged approximately -21,700 ions/cm^3 (standard deviation of 8,440 ions/cm^3) during the next ~30 minutes of operation. The air cleaner was then switched off at 18:43. The product was switched on again at 19:12, but with the ionizer disconnected, and there was no subsequent increase in ion concentrations.

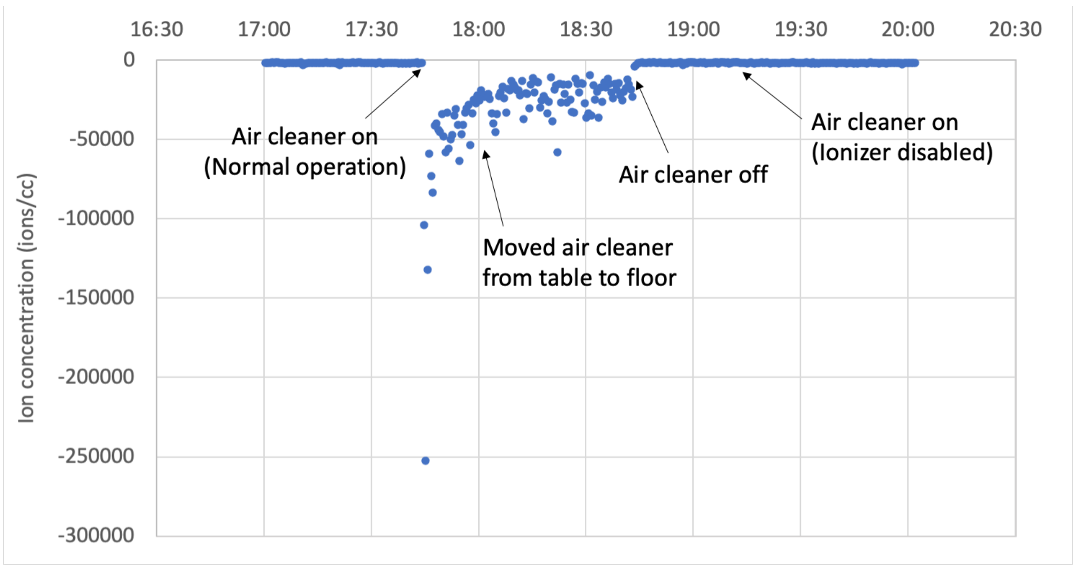

Figure 3. Time-series ion concentrations measured in the chamber during normal operation (i.e., no pollutant injection) first with the ionizer enabled (default condition) and then with the ionizer disabled

Example Test Data: Pollutant Loss Rate Estimates

Examples of resulting estimates of particle loss rates during air cleaner on and off conditions, with and without the ionizer enabled, for particles in the 'smoke' size range are shown in Figure 4.

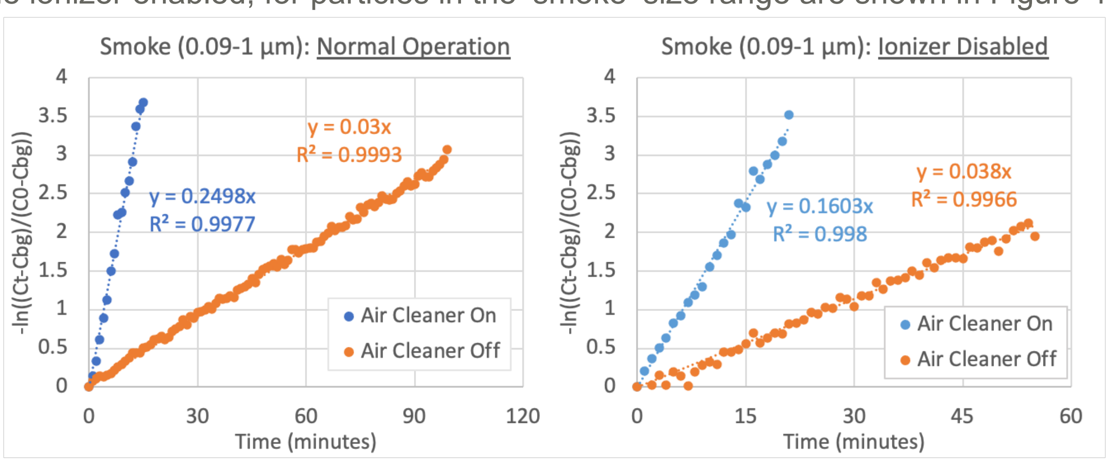

Figure 4. Example of estimated loss rate constants

Summary of Results

Table 1 shows results from CADR tests for the smoke (0.09-1 µm), dust (0.5-3 µm), and pollen (5-10+ µm) size ranges, both during normal operation (ionizer enabled) and with the ionizer disabled.

Table 1. CADR test results for three particle size ranges

Particle Metric	Normal Operation			Ionizer Disabled			% Difference in CADR
	K_{ac} (1/min)	K_{nat} (1/min)	CADR (cfm)	K_{ac} (1/min)	K_{nat} (1/min)	CADR (cfm)	
Smoke (0.09-1 µm)	0.2498	0.0300	285	0.1603	0.0380	159	**-44%**
Dust (0.5-3 µm)	0.2670	0.0285	309	0.2340	0.0414	250	**-19%**
Pollen (5-10+ µm)	0.3473	0.0475	389	0.2455	0.1055	181	**-53%**

The CADR for smoke, dust, and pollen particle size ranges during normal operation (with the ionizer enabled) were estimated to be 285, 309, and 389 CFM, respectively.

The CADR for smoke, dust, and pollen particle size ranges during operation with the ionizer disabled were estimated to be 159, 250, and 181 CFM, respectively, representing 44%, 19%, and 53% reductions in CADR compared to normal operation.

Based on these results, we estimate that between ~20% to ~50% of the measured CADR during normal operation may be attributable to the ionizer function, which was observed to increase negative ion concentrations from an average of less than 2000 ions/cm^3 to over 20,000 ions/cm^3 in the test chamber.

Given the potential for ionization technologies to initiate indoor chemical reactions (Kim et al., 2017; Zeng et al., 2021), further testing should characterize the impact of this device on gas-phase organic compounds (e.g., VOCs, aldehydes, etc.).

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