Portable Air Cleaner Test Report
February 2021

Yicheng Zeng, Mohammad Heidarinejad, PhD, and Brent Stephens, PhD
Built Environment Research Group
Department of Civil, Architectural, and Environmental Engineering
Illinois Institute of Technology
http://built-envi.com/portfolio/air-cleaner-testing

Built Environment Research @ IIT

Test Summary

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 and potential for chemical byproduct formation from a sample of convenience of several commercially available portable air cleaners.

Pollutant removal efficacy measurements included clean air delivery rate (CADR) characterizations for particulate matter, ozone (O_3), and total volatile organic compounds (TVOCs) following injection of incense and dust sources. Detection of potential byproduct formation involved measurements of ozone (O_3) and nitrogen oxides (NO_x). Measured CADR values for particulate matter are compared to those reported by the manufacturer for reference.

Measurement Description

Tests were conducted in a large aluminum environmental chamber on the main campus of Illinois Institute of Technology in Chicago, IL (interior volume of 1296 ft^3). Surrounding laboratory air was filtered through a charcoal fiber filter (Hydrofarm IGSCFF4, Petaluma, CA USA) and supplied into the chamber via a flexible aluminum duct to deliver between 1.2 and 1.6 air changes per hour (ACH). A mixing fan was operated in the chamber to achieve reasonably well mixed conditions.

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). Therefore, gas-phase CADR measurements herein also included TVOC and O_3 when possible (NO_x did not regularly achieve high enough peaks and decays to solve for loss rates).

Testing was first conducted with the air cleaner turned on 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, 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}), 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:

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

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)

Potential Byproduct Formation

Potential chemical byproduct formation was tested separately from pollutant injection and decay tests. The air cleaners were simply operated in the empty chamber for approximately 30 minutes to characterize if ozone (O_3) or nitrogen oxides (NO_x) were emitted during normal operation. Both O_3 and NO_x have been shown to be emitted from some (but not all) electronic air cleaning technologies, such as ionizers and electrostatic precipitators (Kim et al., 2017; US EPA, 2018; Zhang et al., 2011).

Equipment Used

1. Controlled test chamber
2. TSI NanoScan SMPS 3910 for ultrafine particle number concentrations
3. TSI OPS 3330 and MetOne GT-256S OPC for fine and coarse particle number concentrations
4. TSI DustTrak for PM_1, $PM_{2.5}$, PM_4, and PM_{10} estimated mass concentrations
5. Aeroqual Portable Handheld Air Quality Monitor for TVOC concentrations
6. 2B Technologies Model 211 for ozone concentrations
7. 2B Technologies Model 405 and Aeroqual NO_2 sensors for NO_x/NO_2 concentrations
8. Extech SD800 CO_2 monitors to assess air change rates
9. Low-cost consumer-grade air quality sensors (e.g., AirVisual Pro)

Photos of the Chamber and Instrumentation

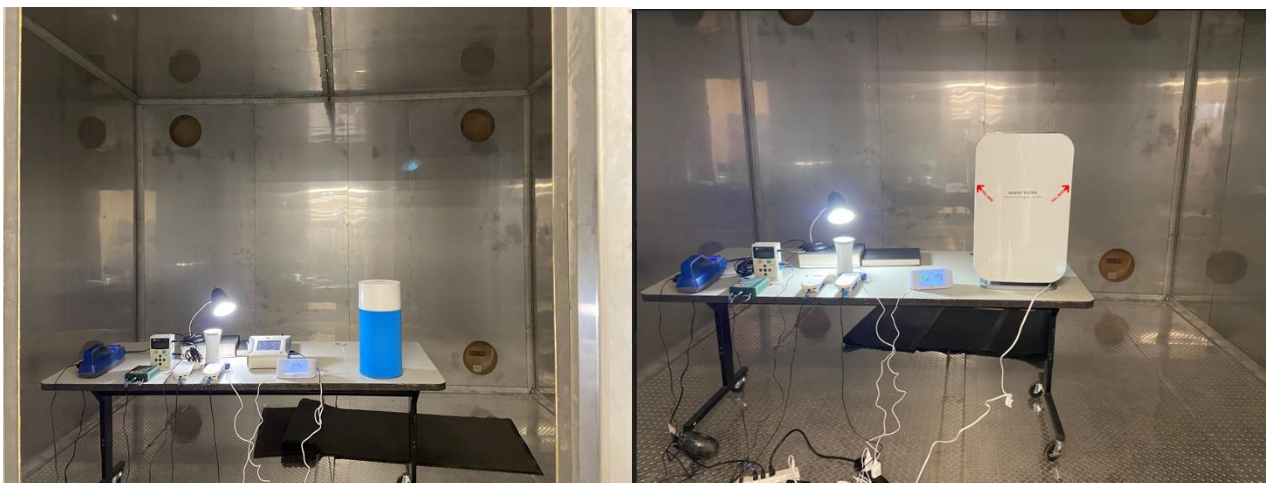

Figure 1. Inside chamber set up for the air cleaner CADR tests

Example Test Data

An example of resulting time-series test data is shown below for one example air cleaner for particles in the smoke size range:

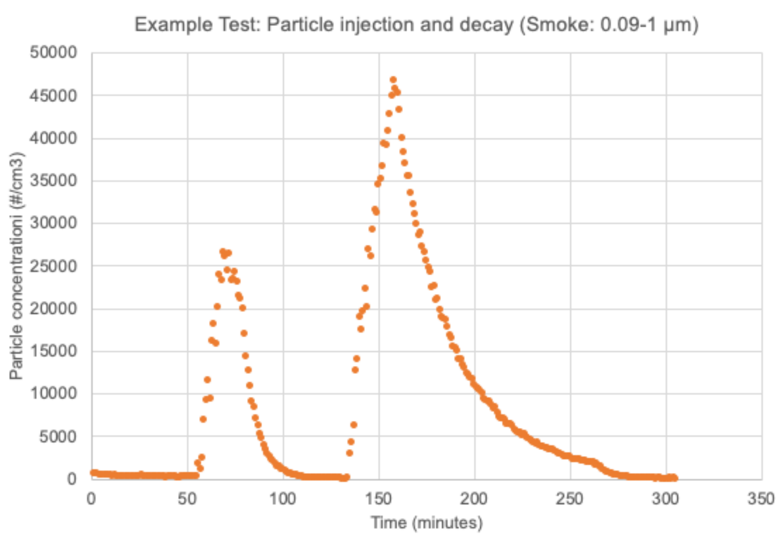

Figure 2. Example time-series test data from pollutant injection and decay

Example Pollutant Loss Rate Estimation

An example of pollutant loss rate estimates (during air cleaner on and off conditions) for particles in the smoke size range for one selected air cleaner is shown below:

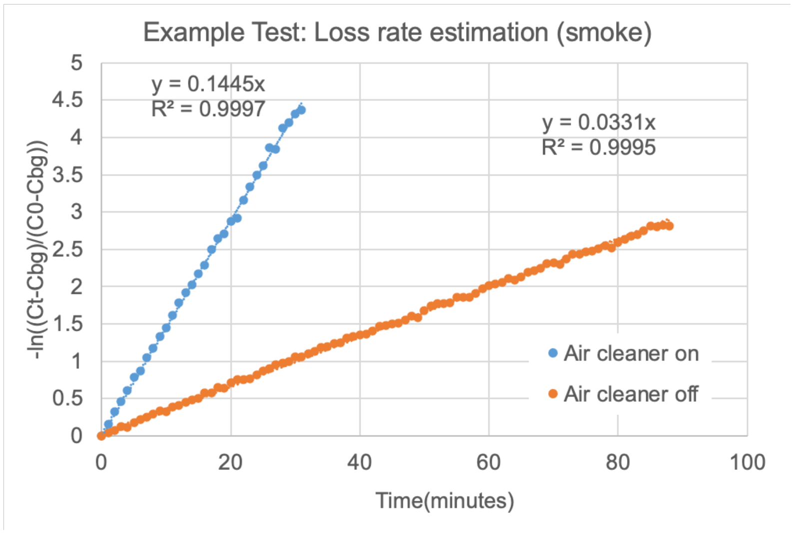

Figure 3. Example loss rate estimates for smoke-sized particles

Results

The following units were selected from a sample of convenience and tested in this work, with manufacturer reported CADR values for particles shown where possible:

- Alen BreathSmart Flex – CADR: 225 cfm, flow: 187 cfm (turbo)
- Blueair 121 – CADR: 400 cfm for smoke, dust, and pollen
- Blueair 211+ – CADR: 350 cfm for smoke, dust, and pollen
- Blueair Blue Pure 411 – CADR: 105 cfm (smoke), 120 cfm (dust), 120 cfm (pollen)
- Coway AP-1512HH – CADR: 233 cfm (smoke), 246 cfm (dust), 240 cfm (pollen)
- Hathaspace HSP001 – CADR: 160 CBM/hr (94 cfm)
- Hathaspace HSP002 – CADR: 450 CBM/hr (247 cfm)
- Levoit LV-H133 – CADR: 274 cfm
- Levoit LV-H134 – CADR: 312 cfm
- Medify MA-25 – CADR: 250 CBM/hr (147 cfm)
- Winix 5500-2 – CADR: 232 (smoke), 243 (dust)

Table 1 shows results from CADR tests for smoke, dust, and pollen size ranges. Three early tests failed to achieve CADR estimates in the pollen particle size range because of insufficient large particle generation, which has since been corrected.

Table 1. CADR test results for particles

Air Cleaner	Test date	Smoke CADR cfm (0.09-1 µm)	Dust CADR cfm (0.5-3 µm)	Pollen CADR cfm (5-11 µm)
Alen BreatheSmart Flex	01/29/2021	144	144	144
Blueair 121	01/24/2021	372	383	418
Blueair 211+	01/20/2021	285	309	389
Blueair Blue Pure 411	02/01/2021	103	101	95
Coway AP-1512HH	01/12/2021	241	247	*
Hathaspace HSP001	01/25/2021	84	115	105
Hathaspace HSP002	01/16/2021	207	207	*
Levoit LV-H133	01/27/2021	258	292	306
Levoit LV-H134	01/26/2021	258	310	302
Medify MA-25	02/03/2021	127	128	131
Winix 5500-2	01/13/2021	262	245	*

* Denotes a failed test due to instrumentation or methodological issues

Figure 4 shows a comparison of measured CADR values for (a) smoke and (b) dust particle size ranges compared to CADR values for (a) smoke (or unknown) and (b) dust (or unknown) reported by the manufacturers of each tested air cleaner.

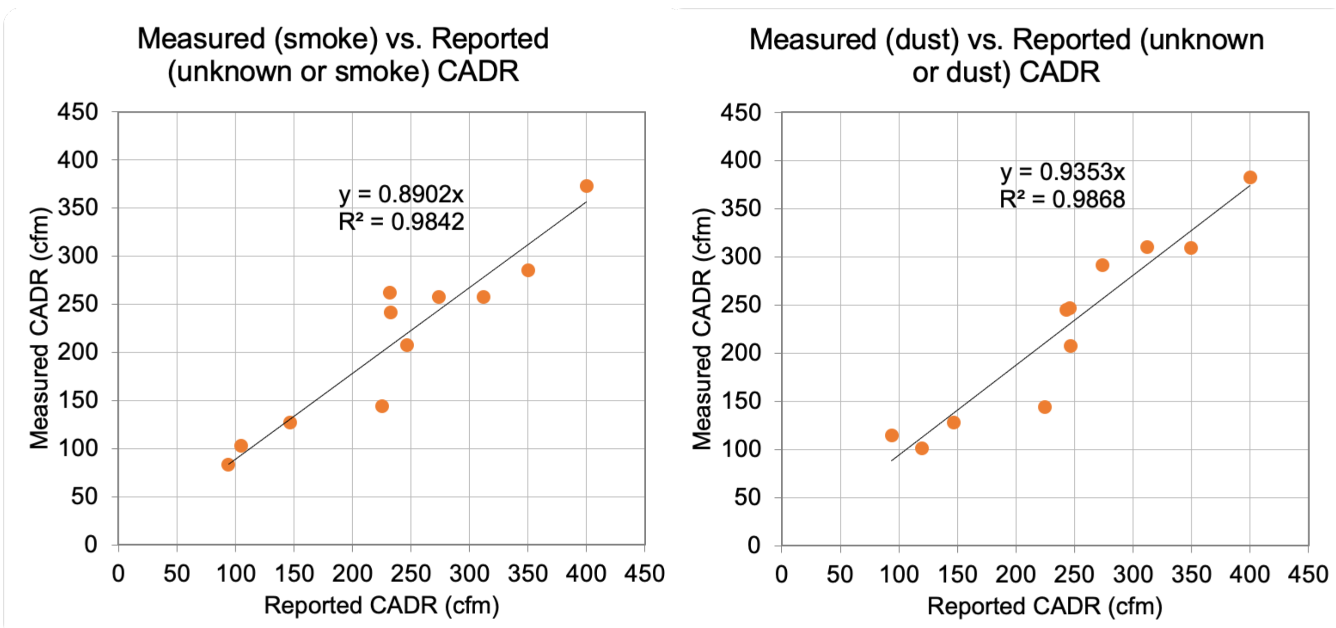

Figure 4. Measured vs. reported CADRs for particles (smoke and dust size ranges)

Table 2 shows results from CADR testing for ozone and TVOC, when estimates were achievable (i.e., when sufficient peaks and decay periods existed), as well as a qualitative measure of detection of the formation of ozone (O_3) or nitrogen oxides (NO_x) as potential byproducts from operation.

Several TVOC experiments failed because measurements were limited by instrument capabilities (i.e., low resolution) and test procedure limits (i.e., not generating enough TVOC signal at peak). No O_3 or NO_x emission were observed from any of the tested air cleaners.

Table 2. Gas-phase CADR test results and potential byproduct formation

Air Cleaner	Ozone CADR cfm	TVOC CADR cfm	Ozone emissions?	NOx emissions?
Alen BreatheSmart Flex	220	27	Not detected	Not detected
Blueair 121	314	*	Not detected	Not detected
Blueair 211+	269	20	Not detected	Not detected
Blueair Blue Pure 411	82	38	Not detected	Not detected
Coway AP-1512HH	162	0	Not detected	Not detected
Hathaspace HSP001	68	8	Not detected	Not detected
Hathaspace HSP002	257	9	Not detected	Not detected
Levoit LV-H133	239	42	Not detected	Not detected
Levoit LV-H134	296	31	Not detected	Not detected
Medify MA-25	123	10	Not detected	Not detected
Winix 5500-2	276	*	Not detected	Not detected

* Denotes a failed test due to instrument or methodological issues

References Cited

CDC, 2020. Scientific Brief: SARS-CoV-2 and Potential Airborne Transmission. Coronavirus Disease 2019 (COVID-19). URL https://www.cdc.gov/coronavirus/2019-ncov/more/scientific-brief-sars-cov-2.html

Howard-Reed, C., Nabinger, S.J., Emmerich, S.J., 2008. Characterizing gaseous air cleaner performance in the field. Building and Environment 43, 368–377. https://doi.org/10.1016/j.buildenv.2006.03.020

Hsu, C.-Y., Wu, J.-Y., Chen, Y.-C., Chen, N.-T., Chen, M.-J., Pan, W.-C., Lung, S.-C.C., Guo, Y.L., Wu, C.-D., 2019. Asian Culturally Specific Predictors in a Large-Scale Land Use Regression Model to Predict Spatial-Temporal Variability of Ozone Concentration. IJERPH 16, 1300. https://doi.org/10.3390/ijerph16071300

Kim, K.-H., Szulejko, J.E., Kumar, P., Kwon, E.E., Adelodun, A.A., Reddy, P.A.K., 2017. Air ionization as a control technology for off-gas emissions of volatile organic compounds. Environmental Pollution 225, 729–743. https://doi.org/10.1016/j.envpol.2017.03.026

Lee, S.-C., Wang, B., 2004. Characteristics of emissions of air pollutants from burning of incense in a large environmental chamber. Atmospheric Environment 38, 941–951. https://doi.org/10.1016/j.atmosenv.2003.11.002

MacIntosh, D.L., Myatt, T.A., Ludwig, J.F., Baker, B.J., Suh, H.H., Spengler, J.D., 2008. Whole house particle removal and clean air delivery rates for in-duct and portable ventilation systems. J Air Waste Manag Assoc 58, 1474–1482.

Offermann, F.J., Sextro, R.G., Fisk, W.J., Grimsrud, D.T., Nazaroff, W.W., Nero, A.V., Revzan, K.L., Yater, J., 1985. Control of respirable particles in indoor air with portable air cleaners. Atmospheric Environment 19, 1761–1771. https://doi.org/10.1016/0004-6981(85)90003-4
Stephens, B., Siegel, J.A., 2012. Comparison of test methods for determining the particle removal efficiency of filters in residential and light-commercial central HVAC systems. Aerosol Science and Technology 46, 504–513. https://doi.org/10.1080/02786826.2011.642825
US EPA, 2018. Residential Air Cleaners: A Technical Summary, 3rd edition.
Xu, R., Yu, P., Abramson, M.J., Johnston, F.H., Samet, J.M., Bell, M.L., Haines, A., Ebi, K.L., Li, S., Guo, Y., 2020. Wildfires, Global Climate Change, and Human Health. N Engl J Med NEJMsr2028985. https://doi.org/10.1056/NEJMsr2028985
Zhang, Y., Mo, J., Li, Y., Sundell, J., Wargocki, P., Zhang, J., Little, J.C., Corsi, R., Deng, Q., Leung, M.H.K., Fang, L., Chen, W., Li, J., Sun, Y., 2011. Can commonly-used fan-driven air cleaning technologies improve indoor air quality? A literature review. Atmospheric Environment 45, 4329–4343. https://doi.org/10.1016/j.atmosenv.2011.05.041