Portable Air Cleaner Test Report – Box Fan Filter
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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 of a custom box fan and filter (MERV 12) combination, tested under three different operating conditions (ranging from high speed to low speed).

Pollutant removal efficacy measurements included clean air delivery rate (CADR) characterizations for particulate matter ranging from 0.01 to 10 μm in diameter following injection of incense and dust sources.

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). Only particulate matter data are shown here.

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)

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

The box fan filter combination included a Lasko box fan and a MERV 12/13 filter. The device was tested once at the highest fan speed (setting 3), once at the lowest fan speed setting (setting 1) while also connected to a voltage regulator to drop voltage to 80 V (to explore the trade-offs in likely increased filter removal efficiency but decreased flow), and an in-between setting of fan speed 3 and voltage reduced to 80 V.

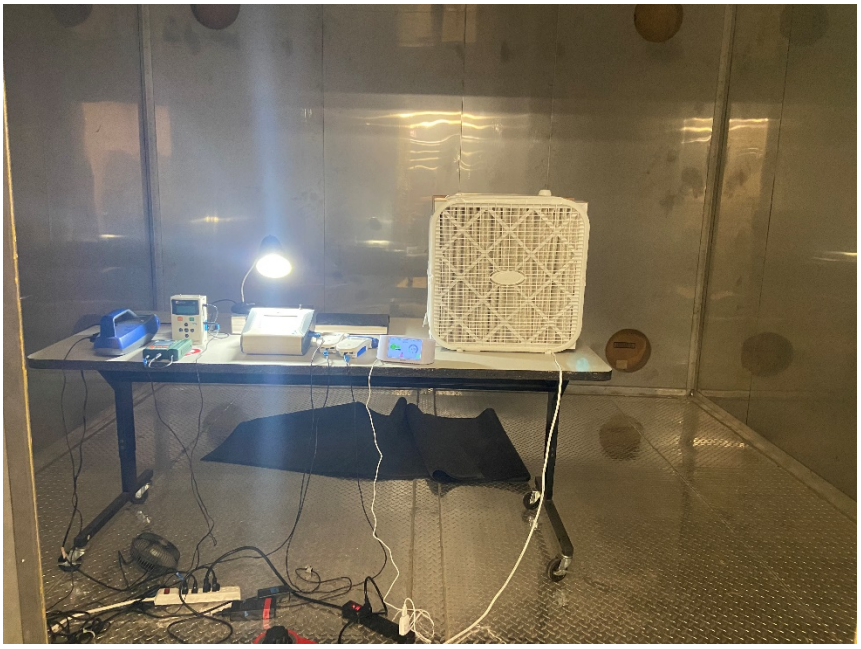

Figure 1. Inside chamber set up for the air cleaner CADR tests

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:

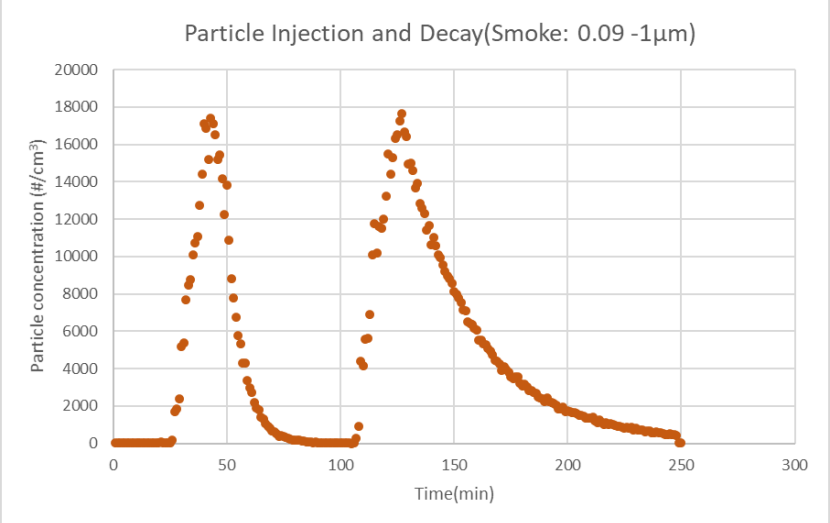

Figure 2. Example time-series test data from pollutant injection and decay

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:

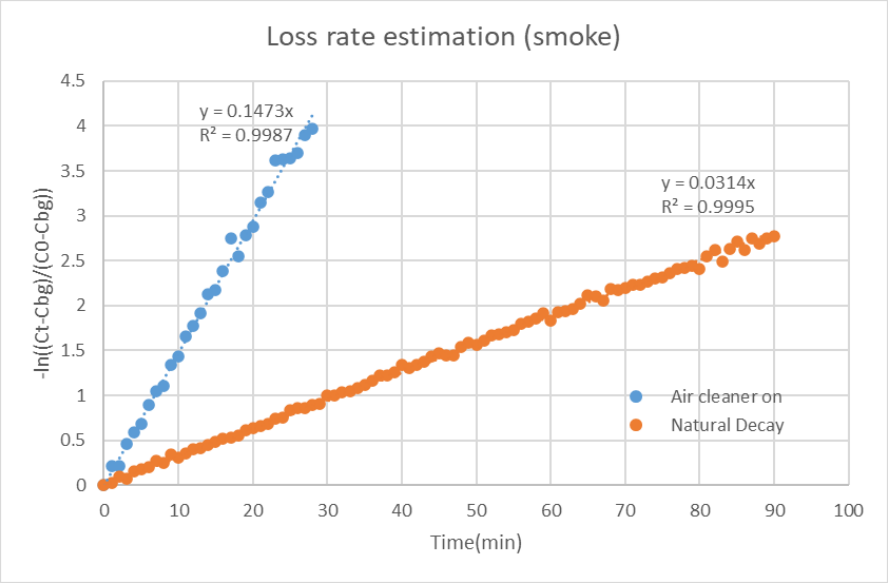

Figure 3. Example loss rate estimates for smoke-sized particles

Results

Table 1 shows results from CADR tests for smoke, dust, and pollen size ranges.

Table 1. CADR test results for particles

Fan with different speed	Test date	Smoke CADR cfm (0.09-1 µm)	Dust CADR cfm (0.5-3 µm)	Pollen CADR cfm (5-11 µm)
Fan Speed 3	2021/03/04	150.2	203.1	285.6
Fan Speed 3 with 80v	2021/03/10	87.2	108.1	110.8
Fan Speed 1 with 80v	2021/03/17	47.7	55.1	80.0

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