# Portable Air Cleaner Test Report
## *'Corsi-Rosenthal' Box Fan Air Cleaner w/ MERV 13 Filters*
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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 version of a 'Corsi-Rosenthal' box fan with MERV 13 filters (we previously tested a C-R box with MERV 10/11 filters). This is a variation on the single-filter and box fan model in which five filters and a fan are used to form a box, providing a larger surface area of filtration through which air flows.[1] 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.

## 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$^3$) on August 18, 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 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

[1] https://www.texairfilters.com/a-variation-on-the-box-fan-with-merv-13-filter-air-cleaner/

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/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)

## 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 0.3-10 μm 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 Models 211 and 405 for ozone and $NO_x$ concentrations, respectively
7. Extech SD800 $CO_2$ monitors to assess air change rates

## Photos of the Chamber and Instrumentation

The box fan filter combination included a box fan (Lasko 20-inch Air Circulating Box Fan with 3 Speeds) and five air filters from Tex-Air Filters. Two of the filters (left and right sides) were 16-inch by 20-inch by 2-inch depth MERV 13 filters and three of the filters (top, bottom, and back) were 20-inch by 20-inch by 2-inch depth MERV 13 filters.[2] The filters were assembled to form five sides of a box and taped to the inlet/suction side of the box fan. A cardboard 'fan shroud' was cut to fit the fan outlet. The device was tested once at the highest fan speed.

**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:

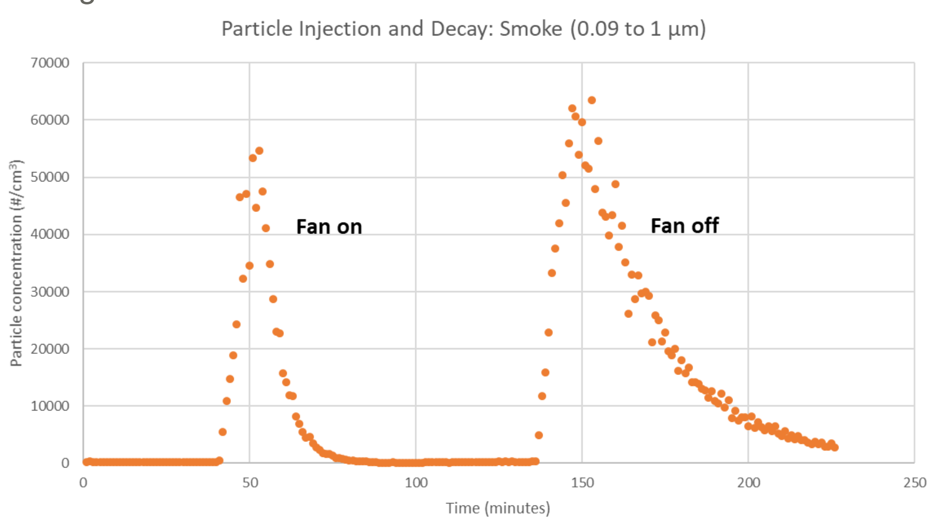


**Figure 2. Example time-series test data from particle injection and decay**

[2] https://www.texairfilters.com/commercial-pleated-air-filters/#5381

## Particle Loss Rate Estimates

Resulting estimates of particle loss rate estimates during air cleaner on and off conditions for five particle size ranges are shown below.

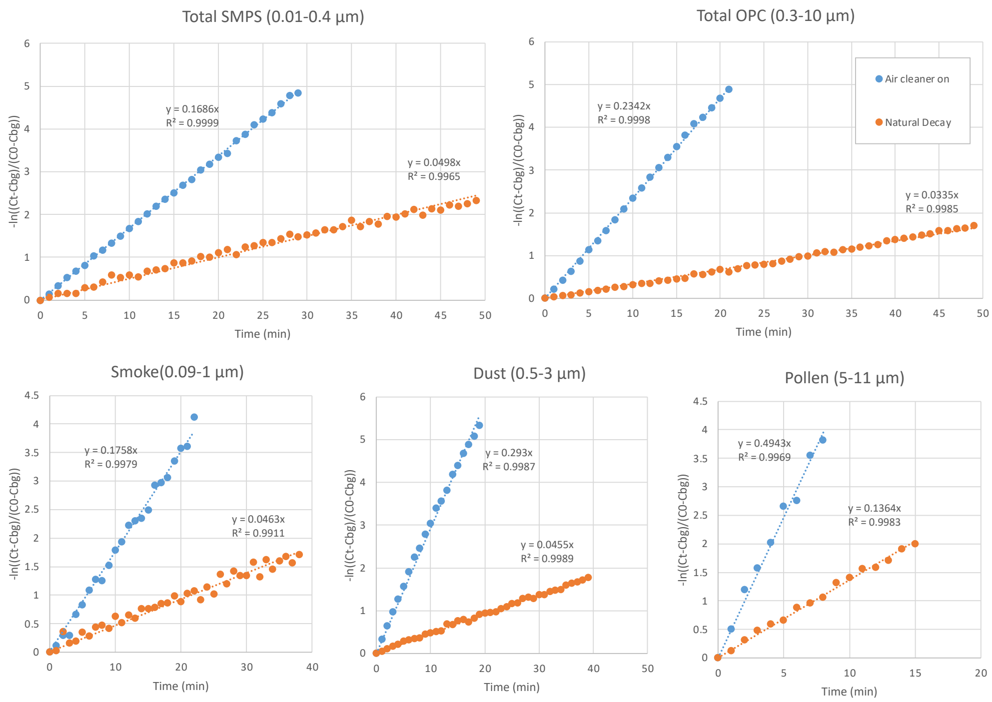


**Figure 3. Estimated loss rate constants for five particle size ranges**

# Summary of Results

Table 1 shows results from CADR tests with the tested Corsi-Rosenthal box fan with MERV 13 filters operating at its highest fan speed setting for the entire SMPS (0.01-0.4 µm), OPS (0.3-10 µm), smoke (0.09-1 µm), dust (0.5-3 µm), and pollen (5-11 µm) size ranges. The measured CADR increased with increasing particle size, from 166 cfm for the smoke size range, to 321 cfm for the dust size range, to 464 cfm for the pollen size range. This increase is intuitive, as the minimum single-pass removal efficiency of MERV 13 filters, as tested in an ASHRAE Standard 52.2 laboratory test duct under repeated loadings, also increases with particle size, from at least 50% for 0.3-1 µm particles, at least 85% for 1-3 µm particles, and at least 90% for 3-10 µm particles.[3]

**Table 1. CADR test results for five particle size ranges**

| Metric | $K_{ac}$ (1/min) | $K_{nat}$ (1/min) | CADR (cfm) |
|---|---|---|---|
| **Total SMPS (0.01-0.4 µm)** | 0.1686 | 0.0489 | 155 |
| **Total OPS (0.3-1 µm)** | 0.2342 | 0.0335 | 260 |
| **Smoke (0.09-1 µm)** | 0.1758 | 0.0463 | 168 |
| **Dust (0.5-3 µm)** | 0.2930 | 0.0455 | 321 |
| **Pollen (5-11 µm)** | 0.4943 | 0.1364 | 464 |

[3] https://www.nafahq.org/understanding-merv-nafa-users-guide-to-ansi-ashrae-52-2/

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