How I do it

Build a simple and inexpensive air purifier

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Abstract

To prevent airborne transmission of SARS-CoV-2 indoor spaces, it is important to use appropriate ventilation systems in buildings. Growing evidences about other technologies that remove infectious particles from the air showed that effectiveness of air purifiers fitted with high-efficiency filters. In the present study, we built a simple air purifier combining a box fan and a MERV13 filter, and investigated the performance of the device. The airflow rate achieved 0.41-0.71 m^3/s depending on fan speed. The device generated more than 50dB noise even at the lowest airflow. The amount of PM0.3 was reduced by 40-50% depending on fan speed, thus the estimated clean air delivery rate ranged from 343 to 751 cfm. The cost of the device was U.S.$128. The performance of this simple and inexpensive air purifier is comparable to another do-it-yourself air purifier such as the Corsi-Rosenthal Box.

Key Words: *SARS-CoV-2, airborne transmission, ventilation, quality of indoor air, clean air delivery rate (CADR), air change per hour (ACH), do-it- yourself air purifier, the Corsi-Rosenthal Box*

Introduction

When COVID-19 became pandemic status in early 2020, the WHO dismissed the role of airborne transmission, and health officials didn't pay much attention to the risks of indoor air, therefore rarely considered importance of ventilation. In the 316 classrooms in the Marche region of Italy, that had mechanical ventilation with rates of 1.4 to 14 litres/sec/person, the students' risk of infection was reduced by at least 74% compared with that for students in classrooms that relied on natural ventilation[1)]. One of the growing evidences about other technologies that removes

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infectious particles from the air showed that ventilation combined with air cleaning, equivalent to six air change per hour (ACH) in total, reduced exhaled aerosol concentrations in a gym to 5 to 10% of what they would have been whithout these measures[2)]. Recently, Raymenants J, et al.[3)] in Belgium found factors associated with respiratory pathogen detection by indoor air surveillance in community settings. According to their results, high CO_2 and low natural ventilation were independent risk factors for detection of targeted pathogens including SARS-CoV-2. Furthermore, CO_2 concentration and portable air filtration were independently associated with pathogen concentration. The effects of such as mask wearing, vocalization and mechanical ventilation were not significant. Their results support the importance of ventilation and air filtration to reduce transmission.

The primary transmission route of SARS-CoV-2 is airborne[4),5)], countermeasures for infection route should be focused on airborne transmission occurring especially indoors. Because droplets and small particles that people breathe out can contain viral particles, it is important to use appropriate ventilation systems which bring fresh, outdoor air into rooms, filter or disinfect the air there, thus improve quality of indoor air (QIA)[6)]. Center for Disease Control and Prevention (CDC) recommends to aim to deliver 5 or more ACH of clean air to rooms, and to use filters rated minimum efficacy reporting value (MERV)[7)]13 or higher grade[6)]. Using higher-rated filters in the HVAC system can remove more germs in the air, although incur costs and burden on the systems. Similar airborne mitigation standards are 6 ACH (The Lancet COVID-19 Commission)[8)] or 10 litres/sec/person (WHO) outside health-care settings[9)]. There should be ongoing verification that the systems are operating properly. The best and easy way to do this is by real time monitoring ventilation with CO_2 that should be less than 800ppm[3)]. Recently, American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) introduced a more detailed new standard (ASHRAE 241-2023) focusing on the control of infectious aerosol in buildings[10)].

In-room portable air purifiers fitted with high-efficiency particulate absorbing (HEPA) filters have potential to augment primary decontamination strategies such as ventilation systems and eliminate airborne SARS-CoV-2[11)]. The Association of Home Appliance Manufacturers (AHAM) provides assurance to the public that manufacturer's claimed ratings of Clean Air Delivery Rate (CADR) have been independently verified in accordance with Standard AC-1, which applies to portable electric room cleaners that remove particulate matter (PM) from the air that have CADR ratings with the range from 10 to 600 cubic feet per minutes (cfm) for tobacco smoke with particle size between 0.10μm and 1.0μm [12].

Due to the cost to introduce high grade air cleaners fitted with HEPA filters, different types of do-it-yourself (DIY) air purifiers using box fans and filters have been devised, however it is not enough to consider whether these device are effective in the real world[13, 14]. In this paper, we build a simple air purifier at low cost and evaluate efficacy of the device in terms of cost, sufficient air flow, noise, and removal of particles.

Materials and Methods

1) Preparation of the electric fan and high quality air filter

Portable electric fan (LASKO BOX FAN 3733, LASKO Products, LLC, PA, USA) was purchased from the company through an agent. It has five blades and the air volume increases from dial 1 to 3 (Fig.1). Sizes of the fan were 20.75"D×22.2"W×4.5"H. The rotation diameter of the blade was 20". High quality air filters of MERV13 were purchased from BNX Converting LLC (TX, USA) (Fig. 2). These filters are electrostatic pleated air conditioner heating, ventilation, and air conditioning (HVAC) AC furnace filters, which remove mainly pollen, mold, bacteria and smoke. Sizes of the filter were 20"D×20"W×1"H.

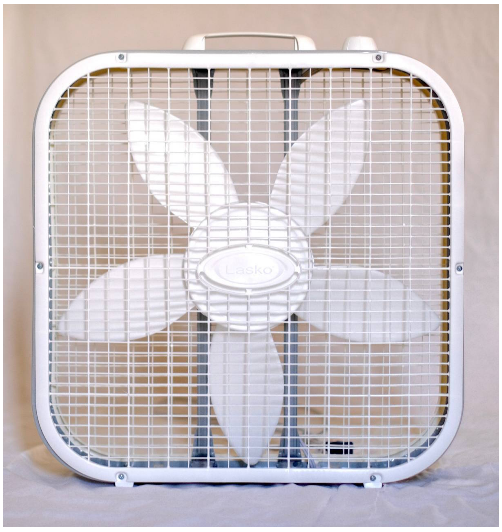


Fig.1 Portable electric box fan

Fig.2 The MERV13 filter

2) How to build a simple air purifier

The HVAC filter was sealed to the inlet side of the box fan with the plastic duct tape (3M Scotch® 3920-WH duct tape, 3M Japan). The tape was applied perpendicular to the fan to cover the four corners of the filter.

3) Evaluation of the air velocity and the airflow rate before and after filtration and calculation of the air change per hour (ACH) and the estimated clean air delivery rate (est.CADR)

To assess the airflow rate after installing of the filter, we measured the air velocity before and after installing the filter by Anemometer (OTraki GM816, ShenZhen QiYu Technology Co., Ltd., China). Data were measured at least twice and the average value was recorded. The air flow rate was calculated with the following formula[15]: $Q_{air}=u_{air}*\pi.D^2/4$

where *u_{air}: air velocity in conveying fan of diameter D (m/s), Q_{air}: air volumetric flow rate m^3/s on the surface of the fan, D: fan diameter (m)*

The ACH was calculated as follows[6]: ACH=F*60/A*H

where *F: the airflow through the system (cfm), A: the area of the room=length (ft) * width (ft), H: the height of the room (ft)*

The est.CADR (cfm) was calculated as follows[6, 14]: est.CADR $=Q_{air}*35.3*60*$particle removal rate (PRR)

where *PRR: 1-(Number of PM0.3 particles when filter is on)/(Number of PM0.3 particles when filter is off)*

4) Measurement of the noise generated by the fan

To evaluate the noise generated by the fan, National Institute for Occupational Safety & Health (NIOSH) sound level meter (v.1.2.6.42) was used. This is a smartphone-based sound level measurement application developed by NIOSH and EA Lab[16]. The measurement was done for 10 seconds at 1 ft from the device with the microphone pointed at 45° angle toward the device. The A-weighted Equivalent Sound Level (LAeq), Maximum Level measured during the current run time (Max.Level), and the C-weighted Peak Sound Pressure Level (LCpeak) were automatically displayed in decibels on the smartphone.

<u>5) Measurement of particulate matter (PM) in the air after filtration</u>

To examine the efficiency of the filtration, we measured three kinds of particulate matter (PM) with sizes 0.3, 2.5 and 10 μm by using the principle of laser scattering (Tc-8100, Hangzhou Shuiyue Technologies Co., Ltd., China). Counting or weighing mode was displayed as Piece/L or μg/m^3. Measurement was done in the room of 124 sqft (8-ft ceiling) under the central HVAC with temperature of 28.5℃ and humidity of 69%. At least two measurements were taken for 10 seconds at one ft from the fan and the average value was recorded.

Results

It took less than ten minutes to complete the build of an air purifier (Fig.3). The structure of the air purifier is very simple, which consists of a classical electric box fan and a MERV13 filter, and costs approximately U.S.$128 (as of August 28th, 2023, including cost of import).

Fig.3 Completed photo of the air purifier we prototyped

The air velocity (m/s) of each dial increased with increasing airflow (Dial 1-3). The slight decrease in air velocity was observed in filtered conditions at dial 2 (medium airflow) and 3 (high airflow) due to pressure drop (Fig.4).

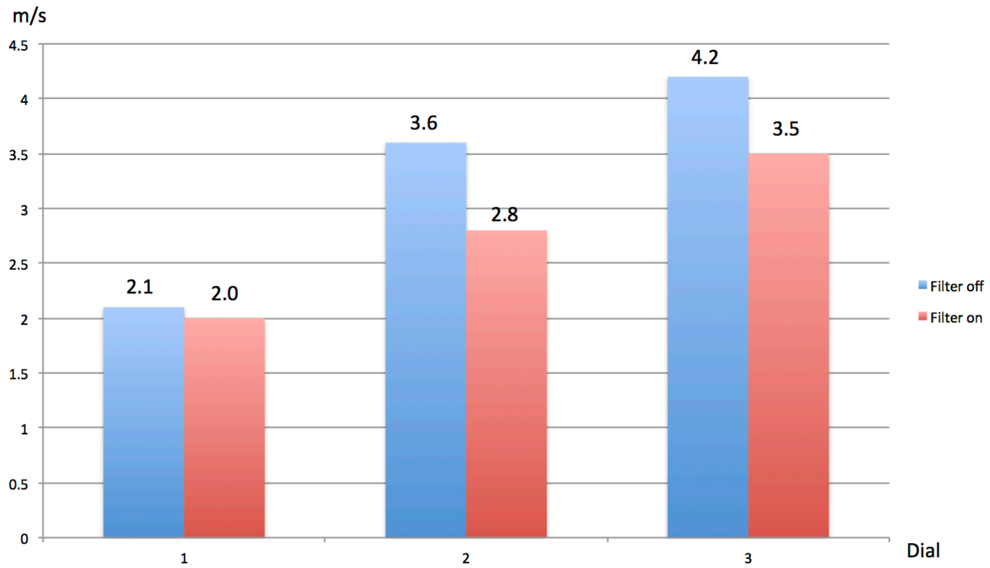


Fig.4 The air velocity at different air flow with or without the filter.

The airflow rate (Q_{air}) of filtered condition on the device was 0.41-0.71 m^3/s depending on fan speed (Table1). The number of ACH of the room was estimated as 51.9-90.8 /h, which corresponded to 6.4-11.3 /h of those typical floor size of a U.S. classroom of 1,000 ft^2 (Table 1).

Table 1 The airflow rate (Q_{air}), the air change per hour (ACH), and the est.CADR by fan speed

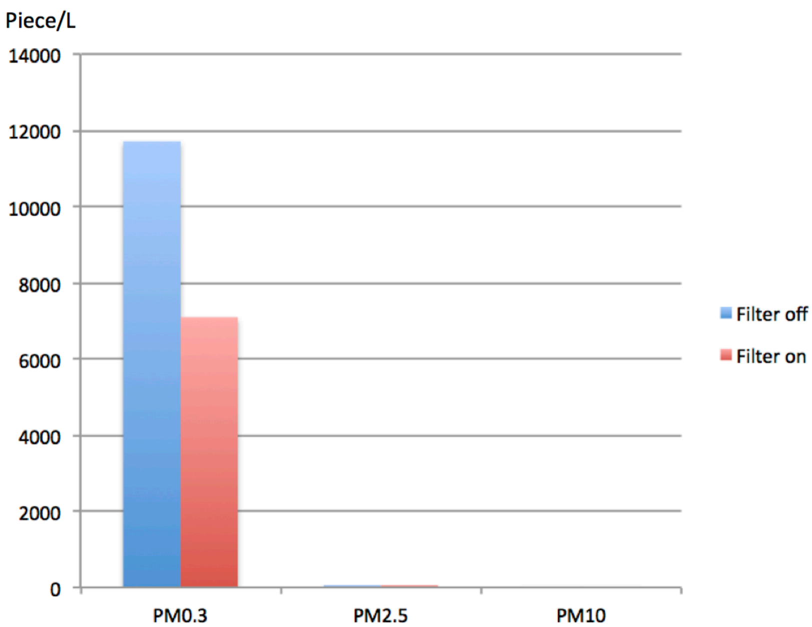
	Dial 1	Dial 2	Dial 3
Q_{air}(m^3/s)	0.41	0.57	0.71
ACH (/h)	51.9	73.0	90.8
est. CADR(cfm)	343	604	751

The noise generated by the device was evaluated using LAeq, Max.Level, and LCPeak. The data taken from the quiet room was considered as a control value. The LAeq increased with air volume, however the LCPeak was reached a plateau in the medium airflow (dial 2). Even the lowest airflow (dial 1) generated the LAeq value of 53.5 dB (Table2).

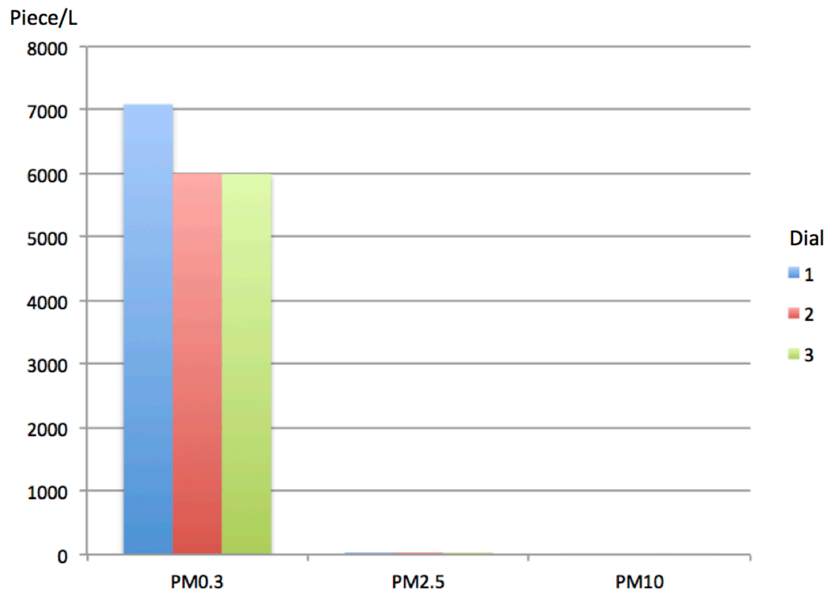
Table 2 The noise generated by the device at different fan speeds

	Control	Dial 1	Dial 2	Dial 3
LAeq (dB)	28.5	53.5	59.0	63.1
Max.Level (dB)	29.8	56.6	60.4	64.2
LCPeak (dB)	54.9	75.6	84.9	84.7

PM in the air was measured at one ft from the device at low airflow (Fig. 5a). The amount of PM0.3 was dramatically reduced after filtration from 11,710 to 7,090 Piece/L, which corresponded to a 40% reduction. The amount of PM2.5 was very low before (7 Piece/L) and after (4 Piece/L) filtration and the amount of PM10 was negligible. The value of PM0.3 reduced with increasing level of airflow, however no difference was observed between the medium (6,000 Piece/L) and the high (5,995 Piece/L) airflow levels (Fig. 5b). Therefore, a 50% reduction of PM0.3 was observed in the medium and the high airflow levels. Assuming that the PRR was 0.4 at Dial1, and 0.5 at Dials 2 and 3, estimated CADR ranged from 343 to 751 cfm depending on fan speed (Table1).



a



b

Fig. 5 The amount of PM in the air before and after filtration (a) and after filtration at different fan speeds (b)

Discussion

DIY air purifiers are generally assembled from box fans and square HVAC filters and different configurations can be found on line that use from 1 to 5 filters[6]. In general, all assembly methods are easy, however it is important to avoid air leaks resulting in filter bypass. In our case, a square-shaped MERV13 filter protrudes from the curved corners of a box fan, therefore it is important to seal corners as well as each side by the duct tape. The cost of this device is $128, which is cheaper than those of high end portable ones with HEPA filters usually cost $500-$1,800[17].

To achieve ACH of 5/h, minimum CADR required in the present room setting (124 sqft, 8-ft ceiling) would be 83 cfm. Therefore, our data (751 cfm) at high airflow, which is less than the value of manufacturer's test report (819 cfm), is sufficient numerical value for air exchange in U.S. standard classrooms with ACH of 11.3/h. The second important factor of the device is noise. Even the lowest wind force produces more than 50dB noise, which is comparable to the sound of a loud office or refrigerator. Therefore, some people may find it noisy and turn off or operate at a lower fan setting, resulting in an inappropriate function. Decreasing the noise level of the device without compromising filtration performance is necessary to improve box fan type air purifier.

Most of the respiratory droplets and particles exhaled during breathing, talking, singing, and coughing is less than 5 μm in size[6)]. Therefore CDC recommends using MERV13 filters which is at least 50% efficient at capturing particles in the 0.3 μm to 1.0 μm size range[6)]. In the present study, we showed that 40- 50% efficient at capturing PM0.3 with the MERV13 filter.

Original DIY air purifier, known as the Corsi-Rosenthal Box, consists of four or five HVAC particulate air filters so as to form a cube and a box fan to draw air upward through filters[6), 13), 14), 18), 19)]. A recent report indicated that the CADR of the five two-inch MERV13 filters was between 600 and 850 cfm depending on fan speed, demonstrating exceptional performance compared to most commercially available air purifiers fitted with HEPA filters[13)]. Srikrishna D. reported using simplified, low-cost measurement tools that the CADR (PM0.3) of single-filter (one-inch MERV14 filter) configurations with a box fan raged from 244 to 460 cfm[14)]. These data are comparable to our present CADR ranging from 343 to 751 cfm. Derk RC, et al. reported that increasing number of filters, filter thickness, and fan airflow signify enhanced the ACH, which resulted in exposure reductions of simulated respiratory aerosols up to 73%[19)]. Although the DIY air filter units can be an effective means of reducing aerosol exposure, the performance can vary considerably depending on their constructions[19)]. If future clinical trials prove they reduce viral infections in school classrooms, for example, installing these DIY air purifiers will gain acceptance.

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