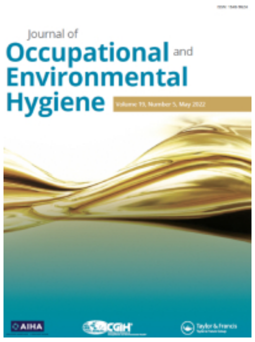

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# Use of portable air purifiers as local exhaust ventilation during COVID-19

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3M Company, St Paul, Minnesota

**ABSTRACT**
The purpose of this study was to determine if strategic placement of portable air purifiers would improve effectiveness of aerosol reduction in a space as compared to use as a general room air purifier. Two sizes of portable air purifiers were placed in two different positions intended to function similar to either a local exhaust ventilation hood or an air curtain to determine if strategic placement would lead to a reduction of particles in a worker's position at a desk in an office environment. Particle generators were used to introduce particulate into the air and personal aerosol monitors measured particles during each test condition. Results showed that when the medium room portable air purifiers used in this study were set to high, corresponding to 98 CFM, and placed near the breathing zone of each office worker with the unit's filter cover removed, the particle concentration was reduced 35% beyond the reduction that would be expected if the same units were placed on the floor behind the occupant's workstation. Results also indicated that the larger portable air purifier tested, positioned as close as reasonable to each occupant's breathing zone with the largest capture area possible (i.e., removing the unit's filter cover), delivers the best aerosol reduction performance. The authors concluded that as a layer of protection against transmission of airborne infectious organisms for office occupants, installing a portable air purifier, sized and operated similar to the units tested in this study on the desk 12 inches from the breathing zone of the worker, has the potential to reduce airborne particulate to a greater degree than if the same units were placed outside of the breathing zone, in the general cubicle area.

**KEYWORDS**
Aerosol; HEPA filter; supplemental filtration

## Introduction

During the COVID-19 pandemic, it has become clear that one of the principal transmission pathways of SARS-CoV-2 is via the airborne route as indicated by the Centers for Disease Control and Prevention (CDC, NCIRD 2020) and World Health Organization (WHO 2020). That is, smaller droplets and particles can remain suspended in air at distances beyond close contact (2 m). Ventilation and air cleaning have been recognized as effective controls in indoor spaces to help reduce suspended aerosol levels and, thus, risk of transmission. However, in many circumstances, general ventilation and air cleaning systems are not designed to provide the levels of air dilution or particle filtration efficiency needed to remove an infectious airborne contaminant.

Portable air purifiers have long been recognized as devices that can improve air quality in spaces by using a fan to move air across an air cleaning media and discharge purified air back into the space. They use different types of technologies (e.g., filtration, UVC light, ionization). Of these available technologies, high-efficiency particulate air (HEPA) filtration removes at least 99.97% of submicron particles from the air passing through the filter and is the method recommended by the National Institute of Environmental Health Sciences (NIH, NIEHS Worker Training Program 2021) for use in portable air purifiers. Portable air purifiers with HEPA filtration are also the most effective at removing airborne SARS-CoV-2 surrogate particles according to a review performed by Liu et al. (2021).

Previous studies such as Buising et al. (2021), Burgmann and Janoske (2021), Castellini et al. (2022), Coyle et al. (2021), and Curtius et al. (2021) found that when properly sized and positioned, these units increase the "effective air changes" (sum of air changes provided per hour by the heating, ventilation,

**CONTACT** Jodi D. Quam jquam@mmm.com Corporate Safety & Health, 3M Company, 3M Center, 224-6W-28, St Paul, MN 55144, USA.
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and air conditioning (HVAC) systems and the volume of air processed through portable air purifiers with HEPA filtration) and can provide another layer of protection in a space. For instance, Curtius et al. (2021) estimated a sixfold reduction in the inhaled dose of virus-containing aerosol for noninfectious individuals when four air purifiers totaling 5.7 air changes per hour (ACH) were placed in a classroom for 2 hrs with a surrogate for an infectious person.

When designing ventilation for contaminant control, capturing contaminants at the source with local exhaust ventilation typically is more effective and requires less airflow and energy than general exhaust ventilation systems. Research by Lindsley et al. (2021) and Narayanan and Yang (2021) demonstrated that placing portable air purifiers near the source of emission is most effective at reducing airborne aerosols. However, none of the studies reviewed considered each occupant as a possible source nor was the air intake of the portable air purifier placed in the breathing zone. During an infectious disease outbreak or pandemic, where infectious emissions precede symptoms, identifying the source(s) of contamination will be difficult.

This study was performed to evaluate the influence of portable air purifier placement on aerosol concentrations in likely room occupant positions in an office environment by investigating two hypotheses. The first hypothesis was that placing a portable air purifier as local exhaust near the simulated breathing zone of each seated cubical occupant would be more effective at removing airborne particles emitted by the TSI Particle Generator than the reduction expected by positioning the units throughout the area, not near occupants' breathing zones. A secondary hypothesis was that use of the portable air purifier's outlet as a clean air supply "air curtain" to the simulated breathing zone, by placing the units next to the occupant's chair, would further reduce exposure to airborne particles emitted by other occupants in the space.

Results of studies that did not show significant aerosol reduction beyond what was found in the control studies (i.e., portable air purifiers operating in general area supplementing the HVAC system), or contribute to this manuscript's conclusions, are included in the online supplemental materials accompanying this study.

## Methods

An unoccupied office area (910 $ft^2$) with six cubicles was used to conduct the pretests and studies. The pretests and studies were conducted in three of the cubicles (Cubes 1, 2 and 3, noted as Positions 1, 2 and 3 in Figure 1) that were immediately adjacent to one another and on top of the cube wall across the aisleway from Cube 2 (Position 4 in Figure 1). All pretests and studies were conducted in unoccupied workspaces to avoid introduction of additional air currents and aerosol sources. The hard-walled offices and entrance door to the area were kept closed, with minimal use throughout the pretests and studies. During all pretests and studies, the office HVAC system was maintained at a constant operational rate of three ACH to avoid introducing an additional variable to the room aerosol concentrations. The office area HVAC system had five supply diffusers evenly spaced throughout the area, with a single air return near the door to the hallway (Figure 1). All five supply air diffusers were measured with a calibrated Alnor Balometer Capture Hood EBT731 (TSI Inc., Shoreview, MN) and qualitative smoke tests were conducted to evaluate room airflow patterns.

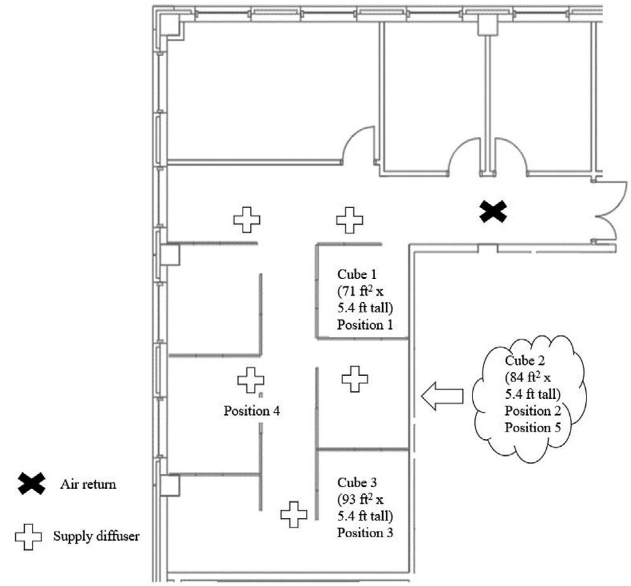


Figure 1. Study area office and cube layout.

Two sizes of Filtrete Room Air Purifiers from 3M Company (3M, St. Paul, MN) were used (Purifier 1: FAP-C02-A2, for medium room sizes up to 150 $ft^2$, smoke Clean Air Delivery Rate (CADR) of 98 cubic feet per minute (CFM) and Purifier 2: FAP-C03BA-G2, for large room sizes up to 250 $ft^2$, smoke CADR of 158 CFM). Both units have a removable cover that, when in place, provides a vertical slotted intake on each side and at the bottom. A HEPA filter (approximate area: 108 $in^2$ (697 $cm^2$)) is positioned vertically between the slots and the air is discharged through the top of the unit. For some studies, the covers of the units were removed, which provided a larger

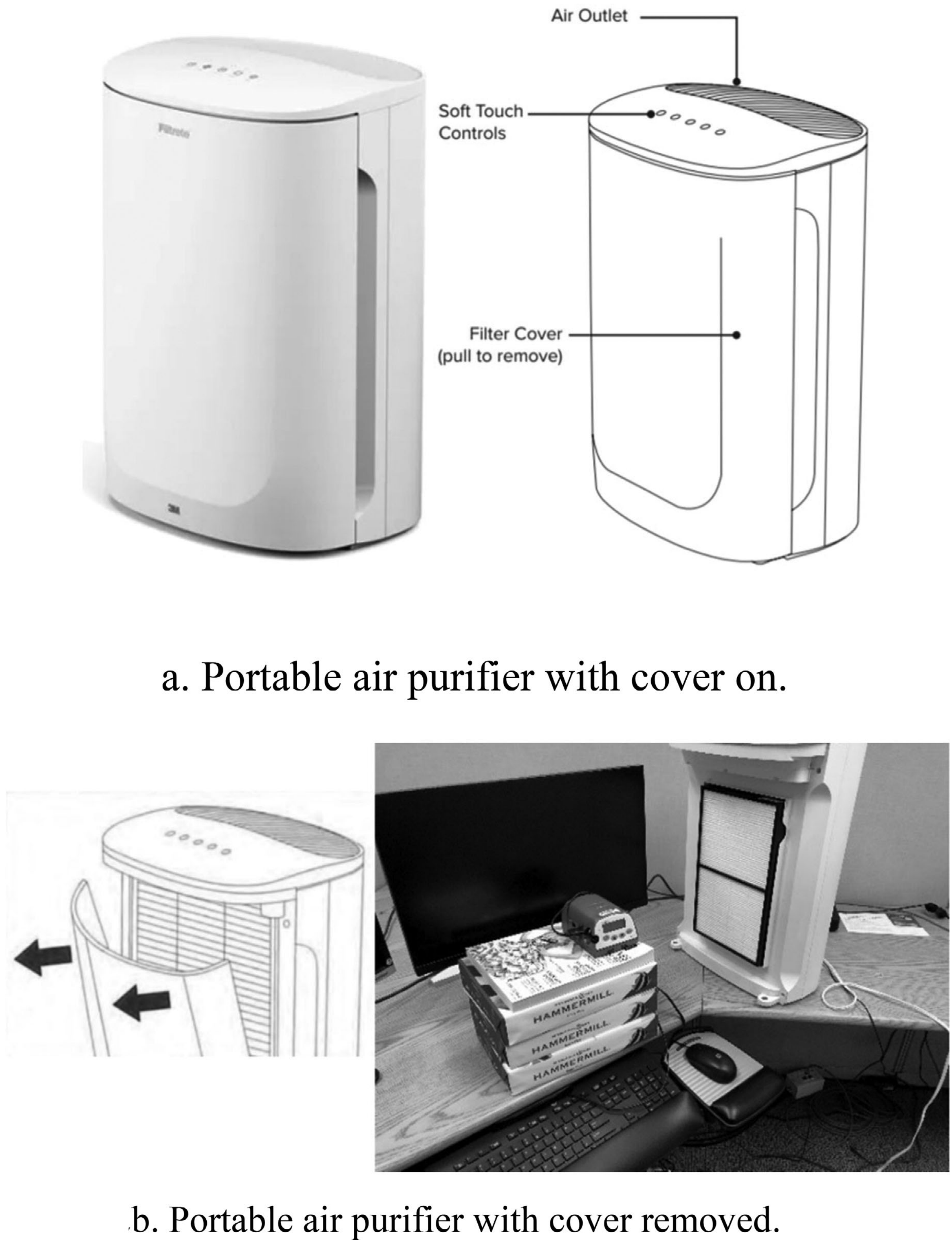


**Figure 2.** (a) Portable air purifier with cover on. (b) Portable air purifier with cover removed.

"capture zone" when placed on the desk (see Figure 2a and b). The purifiers were set to the highest fan setting for all studies.

The center cubicle (Cube 2) was set up to simulate a theoretical sick person emitting virions. The TSI Aerosol Generator Model 8026 (TSI Inc., Shoreview, MN), found by Wu et al. (2018) to produce sodium chloride aerosols with a typical count median diameter of 75–85 nm, was selected as a steady source of aerosols in a size range that would be expected to remain airborne for the duration of testing. Two TSI particle generators were placed in Cube 2 on the desk at breathing zone height to simulate aerosols generated from an infected worker. Two particle generators were utilized to obtain what was estimated to be a sufficient concentration of particles suspended in air to evaluate concentration reduction over the test periods.

Five TSI SidePak Personal Aerosol Monitors (Models AM510 & AM520) (TSI Inc., Shoreview, MN) were used to measure aerosol concentrations (mg/m$^3$) over time. The TSI SidePak is a laser photometer measuring aerosols over a size range from 0.1–10 $\mu$m providing a mass concentration estimate based upon a calibration to Arizona Road Dust A1. The unadjusted calibration was utilized to obtain information on relative concentration changes rather than specific mass concentrations. Three SidePaks were placed on each desk (one each, approximately 44 inches above the floor) simulating a seated worker's breathing zone in Cubes 1, 2, and 3 (Positions 1, 2, and 3, respectively) (Figure 2b), another was suspended from a pole in the center of Cube 2 at a height of approximately 5.4 ft. (Position 5), and the final SidePak was across the aisleway from the center cubicle (Cube 2) on top of the cubicle wall (5.4 ft above the floor) (Position 4).

### Pretests

An initial series of pretests was conducted to establish how long to operate the aerosol generators to achieve a stable airborne aerosol concentration. Initial pretests, conducted for 30–60 min, included background conditions with no portable air purifiers operating.

### Studies

Ten study conditions (six of which are detailed in the supplemental materials), including the use of Purifier 1 and Purifier 2 (see above for description), were conducted to determine the portable air purifier locations and size showing the greatest aerosol reduction.

For each study, a series of trials was run with one portable air purifier placed in each of Cubes 1, 2 and 3, which included both sizes of the portable air purifiers placed in different positions.

### Control trials

Three portable air purifiers were placed on the floor behind the desk chairs, at least 1 ft. from walls and furniture, to demonstrate the effect of air cleaners spaced throughout the room, supplemental to general ventilation. These trials treated each of the three cubicles the same to simulate the real world, where it is not known which worker might be infectious. See Figure 3 for a picture of the setup.

Figure 3. Picture of Control Trial setup.

Figure 4. Picture of Experimental LEV setup.

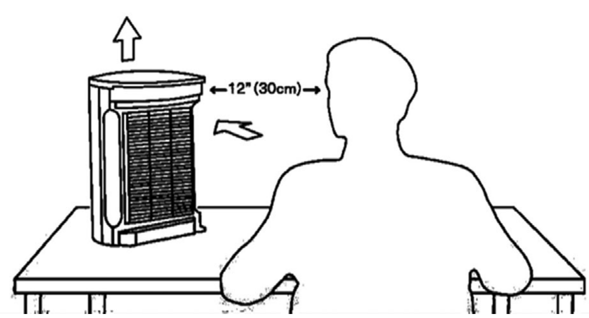


Figure 5. Theoretical schematic of Experimental LEV setup.

### Experimental air curtain trials

These tests assessed the potential advantage of blowing "clean" HEPA-filtered air toward the breathing zone of a worker seated at a desk, acting as an air curtain. In these trials, a portable air purifier was placed in each of the three cubicles on the floor next to the desk chair, with the discharge air blowing up toward the breathing zone. See supplemental material Figure S1 for a picture of the setup.

### *Experimental local exhaust ventilation (LEV) trials*

These tests investigated the “local exhaust ventilation” (LEV) effect by placing the portable air purifiers on the desks of each of the three cubicles with the air inlet of the portable air purifier positioned 12 inches and 18 inches (see individual test details) from the breathing zone to evaluate the additional benefit that could be achieved by capturing aerosols at the source. These studies were run both with the air purifier front cover installed (see supplemental material Table S1) and removed to understand impacts of the air intake orientation. See Figure 4 for a picture and Figure 5 for a theoretical schematic of the Experimental LEV setup.

## Results

### *General*

All five supply air ceiling diffusers in the office area were measured daily with a calibrated Alnor Balometer Capture Hood and were determined to supply an average of 432 CFM (standard deviation of 7) and 3.2 ACH to the office area. Qualitative smoke tests were conducted to evaluate room air flow patterns. The general air flow pattern observed from all areas was slow and steady movement toward the air return ceiling grille near the exit to the hallway. No eddies were observed, including within the cubicles.

The average exit velocity at 10 cm above Purifier 2’s discharge was 548 fpm (feet per minute). The measured capture velocity at 12 in. from the face with the filter cover removed is 30 fpm and at 18 in. it is 12 fpm. The average noise level measured with a calibrated Type 2 sound level meter 12 in. from the portable air purifier running on high was 55.5 dBA.

### *Pretests*

Pretests were conducted to estimate the time needed to achieve a stable background aerosol concentration with the two TSI particle generators operating by measuring aerosol concentrations over time without the portable air purifiers running (Figures 6–8). Stability requirements appeared to be met after approximately 30–45 min using a ratio of the current aerosol concentration (mg/m$^3$) (5-min running average) divided by the maximum concentration (mg/m$^3$) (5-min running average) for each unique test. The 5-min running average was used to smooth out the measurement variations across the instruments’ logging time. Minutes one to four were cumulative averages to that point from the start of the test.

### *Studies*

Studies E1–E3 were Experimental LEV Trials using both Purifier 1 and Purifier 2 with the filter covers removed in all cases. The particle generators were operated for 1.5 hr before each study to allow the particle concentration to equilibrate in the area and for 1.5 hr during each study to measure the impact of the portable air purifiers running. The data was analyzed using a ratio of the final aerosol concentration (mg/m$^3$) (5-min running average) divided by the initial concentration (mg/m$^3$) (5-min running average). The 5-min running average was used to smooth out the measurement variations across the instruments’ logging time to determine the residual fraction of aerosol achieved in each position under the test

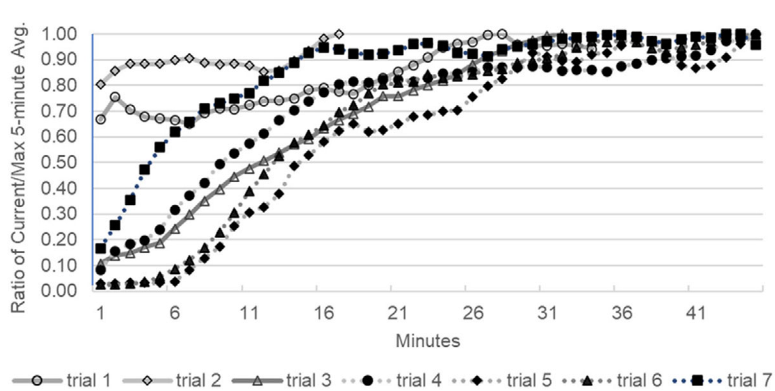


**Figure 6.** Pretest Study 1: Background conditions measured in Cube 1 with particle generators operational and no portable air purifiers.

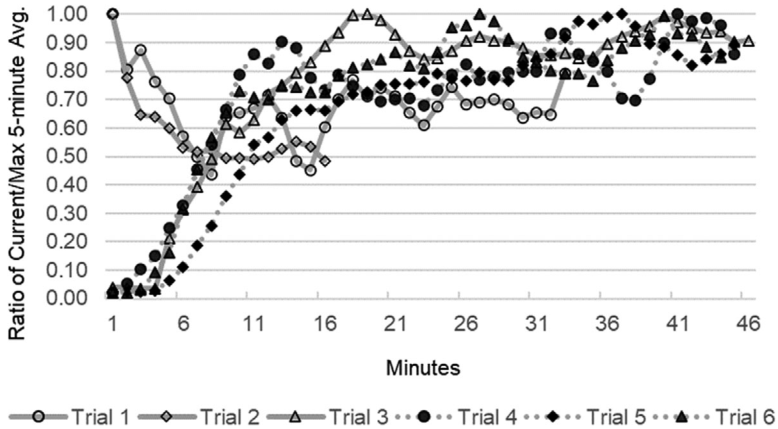


Figure 7. Pretest Study 1: Background conditions measured in Cube 2 with particle generators operational and no portable air purifiers.

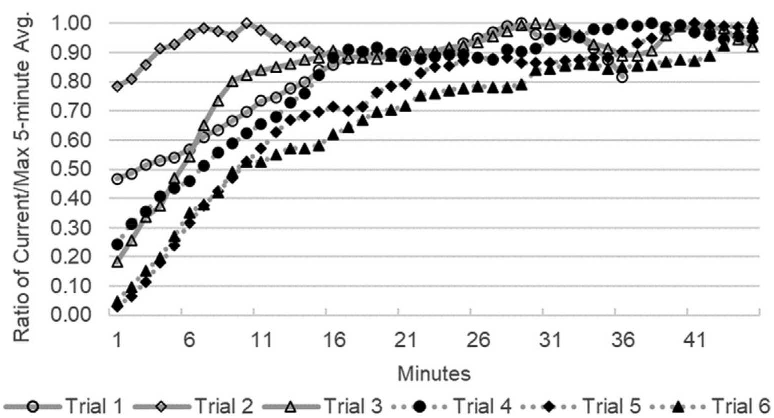


Figure 8. Pretest Study 1: Background conditions measured in Cube 3 with particle generators operational and no portable air purifiers.

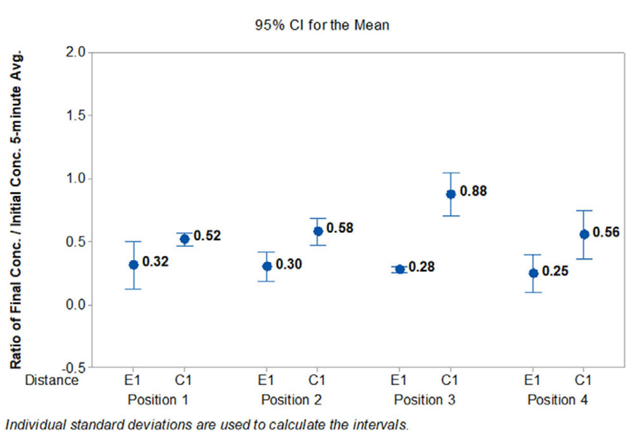


Figure 9. Study E1: Purifier 1 positioned on the desk approximately 12 in. from occupant's breathing zone in each cubicle with the units' filter covers off. Control Study C1: Purifier 1 s located on the floor several feet away from the desk chairs in each cubicle.

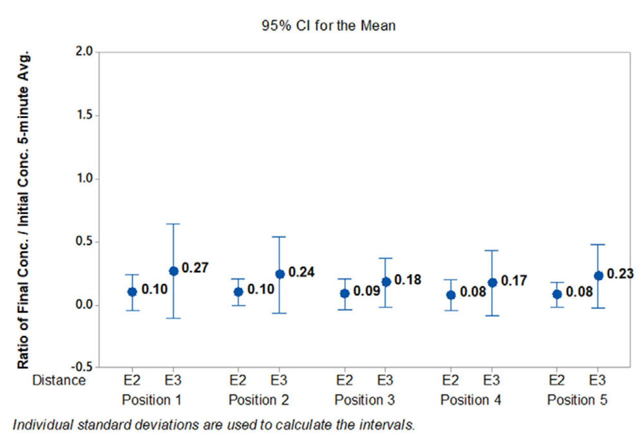


Figure 10. Study E2: Purifier 2 positioned on the desk approximately 12 in. from the occupant's breathing zone in each cubicle with the units' filter covers off. Study E3: Purifier 2 positioned on the desk approximately 18 in. from occupant's breathing zone (not 12 in.) in each cubicle with the units' filter covers off.

configurations. The plot (Minitab 18, Minitab, LLC, State College, PA) displays the mean of the fractions of measured concentration to the initial concentration at each position with their 95% confidence intervals. See Figures 9 and 10 for the results of Control Study C1 and Experimental LEV Studies E1–E3.

Since these values represent the residual fraction of aerosols measured, the inverse, or one minus the mean

Table 1. Summary of study results.

| Study | Description | Range of % reduction at all positions[a] |
|---|---|---|
| C1 | Control Study: All 3 Purifier 1s and were located on the floor several feet away from the desk chairs in each cubicle. | 13–48 |
| E1 | Purifier 1 positioned on the desk approximately 12 in. from occupant's breathing zone in each cubicle with the units' filter covers off. | 68–75 |
| E2 | Purifier 2 positioned on the desk approximately 12 in. from occupant's breathing zone in each cubicle with the units' filter covers off. | 90–92 |
| E3 | Purifier 2 positioned on the desk approximately 18 in. from occupant's breathing zone (not 12 in.) in each cubicle with the units' filter covers off. | 73–83 |

[a]Percent reduction is calculated using the inverse of the mean of the fractions of measured concentration to the initial concentration at each position.

of the ratios at each position, was calculated to represent the percent of aerosol reduction at each position. Table 1 summarizes the range of percent reduction at all measurement positions for Studies C1, E1, E2, and E3. Studies SC1 and S-E1 through S-E5 included Control, Experimental Air Curtain, and Experimental LEV type studies (see supplemental material Figures S2–S7). A summary of the studies' range of percent reduction at all measurement positions and study conclusions are described in Table S1 in the supplemental material.

## Discussion

Results showed that when Purifier 1 devices were placed in the general area (Control Trial) the reduction in particulate concentrations were 13–48% compared to background without portable air purifiers. Study results showed the largest reductions when the portable air purifiers were placed near the breathing zone of occupants with the filter covers removed. During Studies E1, E2, and E3, the air purifiers were operated with the front covers removed. When the units were placed 12 in. from the workstation breathing zone, Purifier 1 showed a 68–75% reduction in particle concentrations and Purifier 2 showed a 90–92% reduction in particle concentration. Purifier 2 was moved to 18 in. from the worker's breathing zone to provide additional workspace flexibility and yielded a particle concentration reduction of 73–83%.

Purifier 1 showed an additional average reduction of 35% over the average reduction achieved by placing the portable air purifiers on the floor several feet away from the desk chair of 37% (Control Study C1). Purifier 2 at 12 in. from the occupant's breathing zone resulted in a 25% increase over Purifier 1 performance at the same distance. Purifier 2 at 12 in. showed a 17% increase over Purifier 2 at 18 in. from the occupant's breathing zone.

Results from this study were utilized in aerosol transmission modeling completed to develop a company-wide HVAC Guideline where occupancy duration limits were set for a given room volume and ventilation rate to help reduce the potential for aerosol transmission as described in "COVID-19 Aerosol Transmission Modeling in Support of Company HVAC Guideline" (Oberlin et al., forthcoming). In addition to the increased ACH from use of the portable air purifiers accounted for in the air exchange rate of the space, source emission reductions were included in the modeling where portable air purifiers were positioned either 12 or 18 in. from each occupant's breathing zone. Source emissions used in the model were reduced by 30% for smaller units (98–158 CFM) placed within 12 in. of each office occupant's breathing zone and 18 in. for larger units (>158 CFM). Source emissions used in the model were reduced by 45% for larger units (>158 CFM) placed within 12 in. of each office occupant's breathing zone. Conservative values were used for source emission reductions to account for study limitations and absence of Purifier 2 Control Study data.

The noise generated by the units was subjectively found to minimally interfere with office work, phone calls, etc., however individual responses may vary. Evaluation of the workspace by re-positioning other equipment (monitors, etc.) and selecting the side (right or left) for air purifier placement may help minimize disruption to work.

By demonstrating the effectiveness of this concept, the results of this study could be used to develop a portable air cleaner design with a less obtrusive configuration (e.g., in front of the worker, rather than the side, and integrated with a computer monitor) and lower noise levels for office desktop application. Successful implementation of portable air purifiers has the potential to reduce reliance on face coverings in an office setting and allow return to work during a pandemic.

This study was completed in one office space and utilized commercially available units, small enough to fit on a desk. The smaller size limited the airflow of the unit, which was not designed to function as LEV, but rather as general dilution. The cubicles were unoccupied during the studies with no cross currents generated from movement, talking, and breathing.

Only one manufacturer of portable air purifiers was used, and the two models both had similar design of air intake with the ability to remove the front cover and exhaust on the top of the unit. The TSI aerosol generator does not simulate airflow associated with breathing and coughing, which could have an effect on the distribution of aerosols in the space. TSI SidePaks were utilized instead of an instrument with higher sensitivity and specificity. The HVAC system was designed with variable controls but was set to constant flow.

## Conclusions

In a pandemic with potential for asymptomatic transmission, precautions must be taken with all potential encounters. Positioning portable air purifiers close to the breathing zone of workers appears to capture some exhaled particles at the point of release, further reducing the number of particles available to accumulate in the space compared to positioning them in the general area. The removal of the filter cover of purifiers created a larger, more effective capture zone that aligned with the worker's breathing zone, which was not possible with the slotted configuration when the cover was on. Study E2, using larger portable air purifiers positioned within 12 in. of the worker's breathing zone with the filter cover off, performed better than Study E1, which used the smaller unit, suggesting a bigger unit as close as reasonable to workers with the largest capture area will deliver the best aerosol reduction performance. Results of this study indicate that portable air purifiers strategically placed near the breathing zone of all space occupants can be used as another layer of protection to help reduce the risk of COVID-19 transmission. Strategic placement of the portable air purifiers in each occupant's breathing zone provides supplemental exhaust ventilation, which increases the area's effective ventilation exchange rate, and an additional reduction in aerosol concentrations from infectious individuals in a space.

## Data availability statement

The data that support the findings of this study are available from the corresponding author, JDQ, upon reasonable request.

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