Portable Air Cleaners:

Selection and Application Considerations for COVID-19 Risk Reduction

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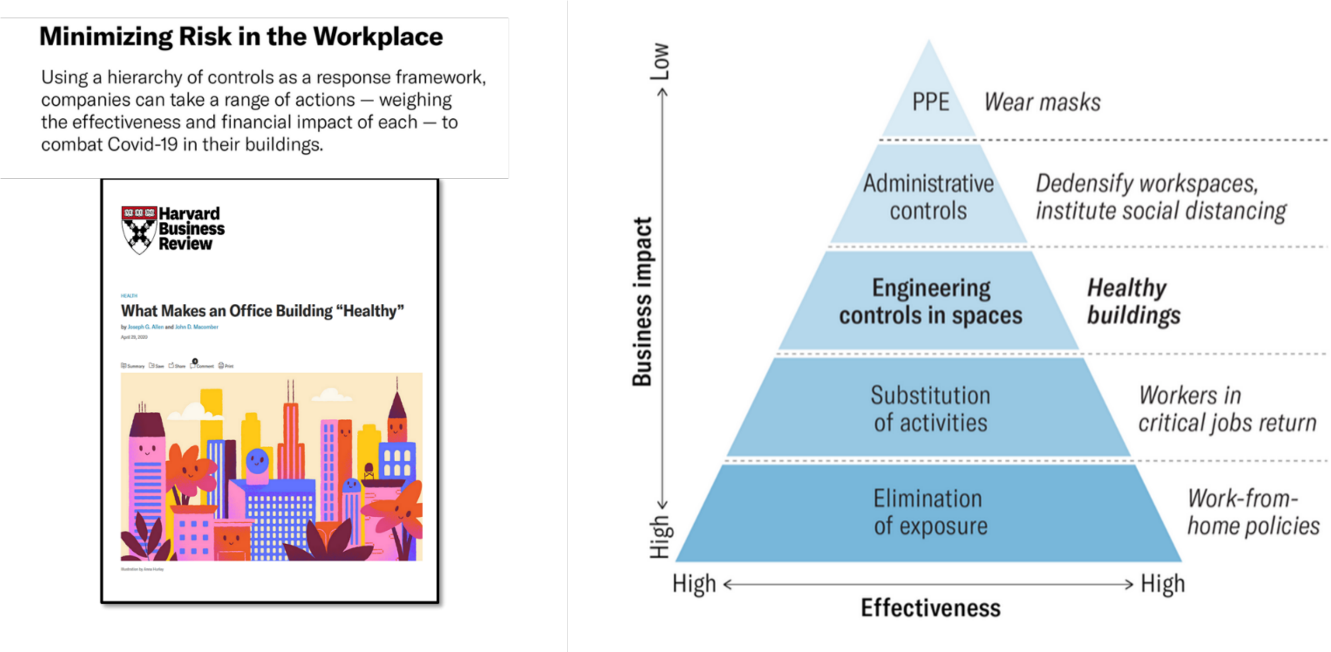
Healthy Buildings as part of a Layered Defense Strategy

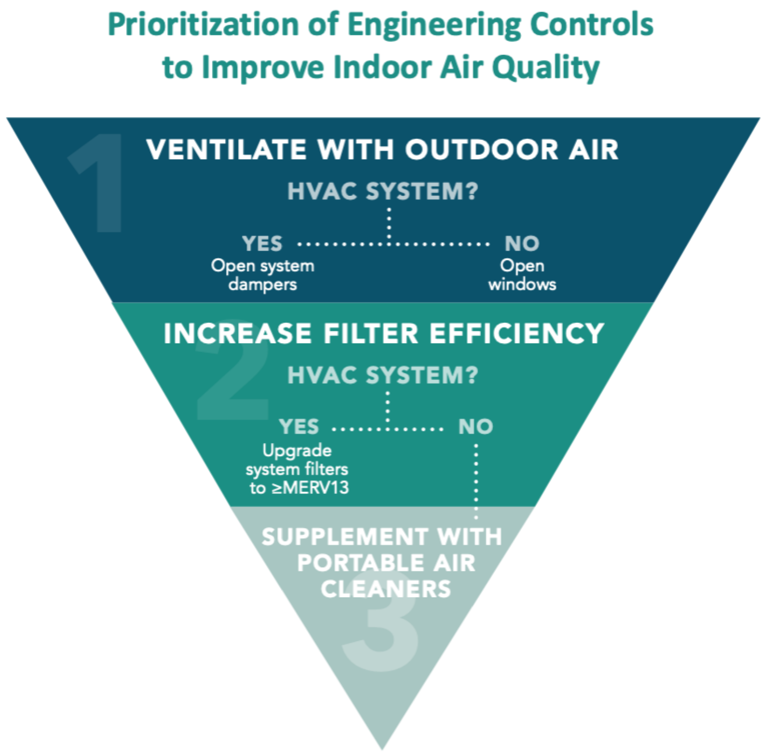
This document is intended to provide an overview of the principles and application of portable air cleaners to reduce the risk of transmission of COVID-19. Before continuing with this document, we present this reminder that this strategy should be considered within the larger context of holistic risk reduction strategies. We advocate a layered defense approach based on the 'hierarchy of controls', of which engineering controls and Healthy Buildings strategies are one critical component. We also caution that this document on portable air cleaners addresses one mode of COVID-19 transmission – airborne – but does not address transmission through close contact (large droplets and aerosols) or contaminated surfaces.



Source: Allen, J.G. and Macomber, J.D., 2020. What makes an office building 'healthy'? *Harvard Business Review*, *29*.

Portable Air Cleaners (PACs), along with other Engineering Controls, can be used to reduce airborne concentrations of SARS-COV-2.

Controlling airborne contaminants, including the virus that causes COVID-19, at their sources is a key strategy to protect indoor air quality. When source control is not feasible or sufficient, airborne pollutants can be diluted by providing clean, fresh outdoor air via ventilation, supplemented with in-duct filtration. In cases where ventilation and in-duct filtration do not provide sufficient clean air, PACs can be used.



Source: Jones et al., 2020. Schools for Health: Risk Reduction Strategies for Reopening Schools. Harvard Healthy Buildings Program. https://schools.forhealth.org.

PACs, also called air purifiers or air sanitizers, are stand-alone devices that can be operated to reduce the concentrations of pollutants indoors. PACs can target airborne particles, gases, or both. PACs employ various air-cleaning technologies that can be classified into two categories: 1) fibrous media air filters, and 2) electronic air cleaners. PACs with a specific type of fibrous media filter called a High Efficiency Particulate Air (HEPA) filter can be used to provide supplementary protection against airborne COVID-19 transmission.

Only PACs with *HEPA filters* should be used to reduce COVID-19 transmission risks. Air cleaning devices with additional air cleaning technologies, such as ozone, UVC, or ion-generators, should be avoided for two main reasons: 1) their ability to improve air quality is less well-studied compared to fibrous media filters; and 2) their use may produce byproducts that can cause adverse health effects.

PAC Performance

The **effectiveness of an air cleaner** depends on several factors including the efficiency of its filter, the airflow rate through its filter, its location in a room, and its operating hours. One of the commonly used metrics to characterize the effectiveness of air cleaners is **Clean Air Delivery Rate (CADR)**, expressed in cubic feet per minute (cfm). CADR is a function of 1) the single-pass efficiency of the filter and 2) the airflow rate passing through the filter.

$$CADR\ (cfm) = \eta_{single\ pass} \times airflow\ rate\ (cfm)$$

Efficiency of a filter (η) is defined as the fraction of airborne pollutant concentration (c) that the filter can capture from air, as air passes through the filter once.

$$\eta = \frac{c_{in} - c_{out}}{c_{in}}$$

A commonly used filter efficiency metric is **MERV (minimum efficiency reporting value)**, developed by the American Society of Heating, Refrigerating, and Air Conditioning Engineers (ASHRAE). MERV values range from 1 to 16, with higher MERV values representing higher filtration efficiency.

- Using MERV 13 or higher (which gives at least 50% removal efficiency for 0.3-1.0 μm particles) is recommended in ventilation ducts, to filter out virus-carrying aerosols from any recirculated air. HEPA filters have higher filtration efficiencies equivalent to MERV 17 to 20; they can remove 99.97% of particles as small as 0.3 μm in a single pass. Therefore, **air cleaners with HEPA filters can provide the highest single-pass airborne particle removal efficiency.**

- Filter efficiency depends on particle size. Consequently, the CADR of a PAC differs for particles of different sizes. When selecting a PAC to reduce the risk of airborne COVID-19 transmission, the CADR for 0.09-3.0 μm particles is most relevant.

Airflow Rate

Besides the efficiency of a PAC filter, the rate of airflow through the filter plays an important role in air cleaning effectiveness. If a filter is not operated, i.e. there is no airflow passing through the filter, it has zero effectiveness, regardless of its filter efficiency.

How to Select a PAC

Target at least 5 air changes per hour.

- Air change rates are used to describe outdoor air ventilation rates (i.e. how quickly outdoor air is delivered to indoor spaces). For example, an air change rate of 1 air change per hour (ACH) means that the volume of air in a room is replaced with fresh outdoor air on average once in an hour. Higher air change rates indicate more ventilation. The air change rate for a room can be calculated from the rate of airflow into the room and the room dimensions, as shown in the formula below.

$$ACH\left(\frac{1}{hr}\right) = \frac{Airflow\ Rate\ (cfm) \times (\frac{60\ \text{min}}{1\ hr})}{Room\ area\ (ft^2) \times ceiling\ height\ (ft)}$$

  To maintain good indoor air quality, providing **5 ACH** is recommended. In other words, the volume of air in the indoor space should be replaced with fresh outdoor air **5 times in an hour or one time every 12 minutes.**

- Although air change rates most commonly refer to outdoor air ventilation, they are also used to describe how much clean air a PAC can provide to a space. For example, a PAC with a CADR of 30 cfm can be interpreted as equivalent to an additional 30 cfm of fresh outdoor air ventilation on top of the actual airflow rate due to outdoor air ventilation.

- **The 5 ACH target can be achieved by a combination of outdoor air ventilation and supplementary air cleaning by PACs.** That said, if the ventilation system removes airborne contaminants very quickly relative to the PACs' CADR, the added benefit of the PACs may be negligible. A rule of thumb that helps ensure PACs are effective at supplemental air cleaning in ventilated spaces is to make sure that the ratio of ACH provided by supplementary air cleaning to ACH provided by outdoor air ventilation is at least 2:1 (i.e. there should be 2 or more ACH from PACs for every 1 ACH from outdoor air ventilation). When the ratio of ACH from PACs to ACH from outdoor air ventilation becomes much less than 2:1 (i.e. outdoor air ventilation moves a lot of air in and out of the room quickly compared to the speed of air movement through the PACs), PACs may not provide a significant additional benefit because the air they clean is removed from the room by ventilation so quickly.

- If the outdoor air ventilation rate is not reliably known, a **simpler rule of thumb for sizing a PAC for a room of 500 ft² area and 8 ft ceiling height is to select a PAC with CADR of 300 cfm**. This PAC can provide a supplemental ~5 ACH in the room.

Consider using multiple PACs.

- For larger spaces, multiple PACs can be used to achieve the target ACH for the room – i.e. the air cleaning benefit is additive. For example, if a large space requires a CADR of 600 cfm, two PACs with CADR of 300 cfm each can be used.

- Moreover, using multiple smaller PACs is more effective than one large PAC, to address the non-uniformity of air and contaminant distribution across a room. For example, if a room needs 300 cfm provided by air cleaning, placing two PACs with CADRs of 150 cfm or 3 PACs with CADRs of 100 cfm, in different locations of the room, may be more effective than using just one PAC with CADR of 300 cfm. This can help address the issue of the well-mixed assumption in the CADR measurement, discussed in the "Where to Place PACs" section below.

Review the CADRs for tobacco smoke or dust.

- CADRs of PACs are characterized under a controlled laboratory test – ANSI-AHAM AC-1-2015 – developed by Association of Home Appliance Manufacturers (AHAM) which is recognized by American National Standards Institute (ANSI). To compare the performance of different PACs, the AHAM website provides a list of certified PACs with CADR ranging 10-450 cfm: www.ahamdir.com/room-air-cleaners/

- AHAM reports the CADR values for three particle size ranges of 0.09-1.0 μm, 0.5-3.0 μm, and in 5.0-11.0 μm. AHAM uses tobacco smoke particles to determine the CADR for particles in the 0.09-1.0 μm size range, and reports the CADR values for particles in the 0.5-3.0 μm and 0.5-11.0 μm size ranges as dust and pollen, respectively. When choosing a PAC to reduce the risk of airborne COVID-19 transmission, consider the CADR value for **tobacco smoke** or **dust**.

Consider fan speeds that will be used.

- CADR is typically rated at highest fan speed of an air cleaner. If an air cleaner is operated at a lower speed, the aerosol removal effectiveness may drop significantly. Therefore, if occupant control over the PAC's fan speed is anticipated, the CADR at **part-load fan speed** should be considered, rather than the full-load CADR.

- One reported reason for operating PACs at lower fan speeds or for reducing runtime operation is **noise**. While noise level during PAC operation is not required to be reported, if such a rating is available, considering the noise level while selecting the PAC can help mitigate this issue.

Walk-through Example

Suppose we have a room with an area of 450 ft^2 and a ceiling height of 8 ft. To meet the 5 ACH target for this room, we calculate that 300 cfm of clean airflow rate is required, as shown below using the ACH equation.

$$Required\ Clean\ Airflow\ Rate\ (cfm) = \frac{ACH\left(\frac{1}{hr}\right) \times\ Room\ area\ (ft^2) \times ceiling\ height\ (ft)}{\left(\frac{60\ \text{min}}{1\ hr}\right)}$$

$$= \frac{5\left(\frac{1}{hr}\right) \times\ 450\ (ft^2) \times 8\ (ft)}{\left(\frac{60\ \text{min}}{1\ hr}\right)} = \mathbf{300\ cfm}$$

The required 300 cfm clean airflow rate can be provided by the **combination of outdoor air ventilation and PACs**. If the outdoor air ventilation is capable of providing 100 cfm, the remaining 200 cfm should be provided by a PAC (or by multiple PACs). Therefore, we should choose a PAC with a CADR of at least 200 cfm for tobacco smoke or dust (or multiple PACs with CADRs that sum to at least 200 cfm for tobacco smoke or dust) for the fan speed that we plan to use.

Where to Place PACs

CADR is tested under the assumption that the air in the space is well-mixed. However, in reality this well-mixed assumption may not be valid due to non-uniformity of air and contaminant properties. The mixing level of a space depends on the air distribution system. Therefore, the placement of PACs can play an important role in their effectiveness.

- Place PACs near the occupants such that clean airflow is at the breathing zone elevation rather than on the ground.
- Airflow should not be obstructed by other objects in the space. The PAC manufacturer may have specified a certain distance from surrounding objects that may obstruct the PAC's airflow.
- Avoid using PACs as fans such that air is blowing across people, since it may move the virus-laden air from the virus plume around an infector to the breathing zones of other people.

Operation & Maintenance of PACs

Over time, as a PAC is operated, dust particles get deposited on the filter and this dust loading can impact the performance of the PAC. Dust loading can impact the removal efficiency of filters with fiber media differently depending on the particle size range. Generally, the removal efficiency of fiber media filters increases as dust loading increases. However, if dust loading on the filter exceeds a certain level, the effectiveness of the air cleaner decreases due to reduced airflow rate and increased bypass of airflow around the filter. Therefore, PAC filters should be replaced periodically according to the manufacturer recommendations.

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