Guidelines for Selecting an Effective Portable Air Cleaner

Ontario Society of Professional Engineers Special Topics in Indoor Air Quality Report: Guidelines for Selecting an Effective Portable Air Cleaner

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Table of Contents

Introduction

Portable air cleaners have become an essential tool for improving indoor air quality, particularly in environments with high levels of airborne pollutants. These devices are widely used in both residential and commercial spaces to filter out particles, allergens, and microbes from the air. When selecting a portable air cleaner, several key factors should be considered to ensure optimal performance and efficiency. One of the most critical factors is the **Clean Air Delivery Rate (CADR)**, which measures the device's ability to clean the air, particularly for specific particle sizes like tobacco smoke, road dust, and pollen. CADR values are influenced by various factors such as air velocity, filter type, and the presence of bypass air. It is important to understand that CADR performance can vary based on air cleaner settings, particularly at lower speeds.

In addition to CADR, sound power and noise levels play a significant role in choosing the right air cleaner. Noise can impact the comfort of the space, especially in environments like offices and classrooms. Standards for sound power levels help users compare different models and determine the most suitable option for their needs. Another crucial consideration is the power efficiency of the air cleaner, which is especially important for energy-conscious consumers. Devices certified by **ENERGY STAR** offer a benchmark for energy efficiency by measuring CADR per watt of energy consumed.

Other factors such as filtration technology, air flow characteristics, and features like Wi-Fi connectivity and scheduling capabilities also influence the selection of air cleaners. This report delves into these essential selection criteria, helping consumers make informed decisions to improve indoor air quality effectively.

Clean Air Delivery Rate

The Clean Air Delivery Rate is the effective airflow rate measured as volume of air per unit of time, of particle-free air for a particular target particle size. It is an experimentally determined value. CADR is the overall performance of a device to remove a contaminant, airborne particle, or airborne microbe that falls within a certain size range.

Both the **ANSI/AHAM AC-1-2020 Standard**[1] and the **Standardization Administration of China's GB/T-18801**[2] obtain CADR values using three different types of particles:

- Tobacco smoke from test cigarettes, 0.1 - 1.0 µm;
- Arizona road dust, 0.5 - 3.0 µm;
- Paper mulberry pollen, 5 - 11 µm.

Other standards use aerosolized salt solution (sodium chloride or potassium chloride) or ultrafine test dust.

CADR from cigarette smoke, designated "Smoke CADR", is the most relevant to compare performance as it covers particles in the range of 0.1 to 1.0 µm in diameter, the most difficult size to filter.

[1] American National Standard Institute, "Method for Measuring Performance of Portable Household Electric Room Air Cleaners." Accessed: Mar. 13, 2024. [Online]. Available: https://webstore.ansi.org/standards/aham/ansiahamac2020?gad_source=1&gclid=Cj0KCQjwwMqvBhCtARIsAIXsZpaLr6W-1kA_npfwayZBX0tYA8DHmPHZXgXcQJqcsB4hpWoMDYw_XR-gaArI8EALw_wcB

[2] Robe Medical, "National Standard of The People's Republic of China - Air Cleaner," 2008.

CADR can be estimated by the volume airflow rate through the device multiplied by the single-pass removal fraction of the target particle size for the filtration media. At very low air velocity, the removal efficiency of **Minimum Efficiency Reporting Value (MERV)** rated filter media can be higher than stated at the standard test velocity, while at very high air velocity, the removal efficiency of a HEPA filter can be lower than the reported value for the filtration media. To optimize the effectiveness of portable air cleaners, users are advised to consider the specific air velocity settings that align with the type of filter media being used and the activity conducted within a room.

Gaps in the filter housing can cause a bypass, allowing unfiltered air to enter. A visual inspection can be conducted to check for gaps within the installation. By testing in a chamber, the entire air cleaner device as a system is tested using a drawdown method in a well-mixed air environment, not a single-pass efficiency test. In a drawdown experiment, the entire air cleaner device is tested as a system. In contrast, the single-pass method only assesses the efficiency of a single pass through the filter. The advantages of a drawdown experiment include realistic simulation, comprehensive evaluation, real usage conditions, and identification of bypass issues.

Many manufacturers only report CADR at the highest speed setting, as that is what is required for standards testing. The percentage of high-speed CADR at other settings can be inferred from the air velocity measured with an anemometer held in a fixed position. CADR scales linearly with the inlet or outlet velocity, apart from a possible filtration media efficiency increase at lower velocities. The independently tested CADR values, in units of **Cubic Feet per Minute (CFM)**, are available in two **Association of Home Appliance Manufacturers (AHAM)** verified directories: Certified Air Cleaners[3] and ENERGY STAR Certified Room Air Cleaners.[4]

AHAM verification requires listing fees based on units sold, while ENERGY STAR has minimum energy efficiency requirements, so a product may be listed in one directory but not in another. The CADR of any production unit tested during verification tests shall not be less than 90% of its claimed CADR for dust, 90% of its claimed CADR for tobacco smoke, and 80% of its claimed CADR for pollen. For details on the air cleaner certifications program, the procedural guide by AHAM provides specifications on exact requirements per AHAM.

Limitations of CADR Testing Standards

The **ANSI/AHAM AC-1** Test does not account for the mixing effectiveness of a unit. The standard requires a specific testing chamber size that includes a mixing blower operating continuously during the test to remove the chamber size dependency.

The **ANSI/AHAM AC-1** Standard does not evaluate the reduction in performance with filter loading over time, although China's **GB/T-18801 Standard**[5] includes a filter loading test with fifty cigarettes.

Technologies such as ionization or electrostatic charging are permitted in the test. It should be noted that ionization or electrostatic charging can improve the CADR by increasing particle deposition on the chamber surfaces rather than in the filter. However, these technologies should be avoided due to potential drawbacks. Ion generators, for example, charge particles in a room, causing them to

[3] Aham Verifide, "Certified Room Air Cleaners." Accessed: Mar. 13, 2024. [Online]. Available: https://www.ahamdir.com/room-air-cleaners/
[4] EPA ENERGY STAR, "ENERGY STAR Certified Room Air Cleaners." Accessed: Mar. 13, 2024. [Online]. Available: https://www.energystar.gov/productfinder/product/certified-room-air-cleaners/
[5] Robe Medical, "National Standard of The People's Republic of China - Air Cleaner," 2008

be attracted to surfaces, which can lead to the resuspension of particles into the air. Additionally, some ionization devices may produce ozone, a lung irritant, which can be harmful to human health. Therefore, it is advisable to avoid ionization or electrostatic charging technologies in air cleaners to ensure the safety and effectiveness of the air purification process.

Floor Area Sizing

The "floor area" rating under the ANSI/AHAM AC-1 standard[6] is based on the unit running at maximum speed in a room with 8-foot ceilings. It represents a reduction of continuously emitted cigarette smoke by 80% in a residential setting.

However, some manufacturers choose an arbitrary value, such as the floor area for an effective air change of once per hour, to make it appear to cover a much larger area. In this case, OSPE's position is to avoid selecting an air cleaner on a "floor area" rating and choosing a unit with double the "floor area" rating of the actual space, to reflect typical operation at a slower speed for a lower noise level.

Sound Power and Loudness

The standard for portable air cleaner noise measurement and reporting is **AHAM AC-2-2003, Method for Sound Testing of Portable Household Electric Room Air Cleaners**. It describes a test methodology to report two values for portable air cleaners:

(1) **A-weighted sound Power Level (LWA)** (re 1 pW), in picowatt. The LWA is a measure of the total sound power emitted by the air cleaner, considering the sensitivity of the human ear to different frequencies. The A-weighting is applied to mimic the way humans perceive the loudness of sounds.

(2) **Loudness, s_t** (unit: soneo - Stevens), determined from sound power at 1 m in a spherical free field.

Sound power cannot be directly measured, while **Sound Pressure L_p** (re 20 µPa) can be measured at any point in a room with an inexpensive handheld meter. Sound pressure at a point in a room from a device cannot be reliably predicted from the sound power specification alone. Confusingly, sound pressure is also denoted in units of decibels and can be numerically several dB lower than the sound power emitted by a device, depending on source placement, room acoustics, and location of the sound pressure meter.

Unfortunately, many manufacturers do not report whether the noise is sound power or sound pressure, or if the sound value is A-weighted for the sensitivity of the human ear or not. Many report a sound pressure value but omit the distance and other factors that would make a direct comparison possible between products.

Unless sound power L_{WA} (re 1 pW) is described, caution should be applied when interpreting the manufacturer's decibel noise specifications.

[6] American National Standard Institute, "Method for Measuring Performance of Portable Household Electric Room Air Cleaners." Accessed: Mar. 13, 2024. [Online]. Available: https://webstore.ansi.org/standards/aham/ansiahamac2020?gad_source=1&gclid=Cj0KCQjwwMqvBhCtARIsAIXsZpaLr6W-1kA_npfwayZBX0tYA8DHmPHZXgXcQJqcsB4hpWoMDYw_XR-gaArI8EALw_wcB

Loudness in units of sones is described in the AHAM AC-2 standard.[7] It is used in the ventilation industry for residential exhaust fans and home ventilation heat recovery units. Loudness in sones is useful because it more accurately represents the relative loudness of sounds on a linear scale for the human ear. However, few manufacturers of portable air cleaners report loudness in sones.

Target Maximum Noise from Portable Air Cleaners

Occupied office and school environments should be at or below $\mathbf{L_p}$ (re 20 µPa) 45 dB(A) in background sound pressure level including portable air cleaners, which allows for a +15 dB signal-to-noise ratio for a person's voice, with a sound power of 70 dB(A) and sound pressure of approximately 60 dB(A) at the listener's ears. **A portable air cleaner operating with sound power L_{WA} of 53 dB(A) should be acceptable in most rooms** to result in a background room sound pressure level of 45 dB(A) when occupied. This should be verified in *situ* using a handheld sound pressure meter. The noise of a DIY air cleaner made from a 50 cm (20") box fan is usually acceptable at the lowest speed setting.

Sizing and Operating for Noise

For box fans used in DIY air cleaners, the three speeds are typically 66%–83%–100% while commercial air cleaners are commonly split into larger steps with greater turndown, such as 30%–60%–100%, or 25%–50%–75%–100% (Table 1). If not provided by the manufacturer, speeds or airflow can be scaled using an inexpensive handheld anemometer on the outlet in a fixed position to measure the relative air velocity at each setting. The noise from a portable air cleaner at lower speed settings can be estimated from the sound pressure fan law: $SPL_2 = SPL_1 + 50 \log (N_2/N_1)$, where N is rotational speed, which is also directly proportional to air velocity and air volume flow. Total noise from multiple units can be approximated using decibel addition as noted in Table 2.

Table 1: Reduction in noise with lower speed setting.

Fan speed or airflow	**Approximate relative noise (dB) difference = 50 log (speed %)**
100%	0
80%	-4.8
75%	-6
66%	-9
50%	-15
33%	-24
25%	-30
20%	-35

Table 2: Noise from multiple portable air cleaners.

Multiples of air cleaners of equal sound power levels, n	**Approximate relative noise (dB) = 10 log (n)**
1	0
2	+3.0
3	+4.8
4	+6.0
5	+7.0
6	+7.8
7	+8.5
8	+9.0

[7] "AHAM AC-2-2006 (R2016) - Method for Sound Testing of Portable Household Electric Room Air Cleaners." Accessed: Mar. 13, 2024. [Online]. Available: https://webstore.ansi.org/standards/aham/ahamac2006r2016

Example of Selection and Operation for CADR and Noise

A classroom has been determined to require 190 L/s (400 CFM) CADR of in-room air cleaning to improve air quality beyond the existing ventilation. An air cleaner with AHAM-verified 410 CFM CADR is proposed.

However, when just one of these units is placed in the room, the resulting average sound pressure level in the room is 55 dB(A). If one unit is run at 50% speed, it will have a much lower noise level of 40 dB(A). If two units are added, each running at 50% speed, the average background sound pressure level is not expected to exceed 43 dB(A), and a total CADR of 410 CFM will be achieved.

Air Flow Characteristics

Airflow characteristics refer to the various factors that influence the distribution of air within various spaces. Some of the key flow characteristics are throw/directional, turbulent vs laminar outflow, personal cooling effect, vertical outlets, etc. “Throw” refers to the distance and the direction of air travelling from an outlet. Adjusting the throw/direction optimizes the distribution of the airflow to provide comfort.

Turbulent airflow refers to the irregular flow of air. On the other hand, laminar airflow refers to the smooth and orderly flow of air. To maintain the desired air quality within a space, an understanding of airflow is critical.[8]

Personal cooling effect is the subjective feelings of individuals within a space, depending on the velocity of airflow as well as airflow patterns within a particular space. Optimizing the velocity of airflow as well as the pattern of airflow increases personal comfort levels.[9]

Lastly, vertical outlets are often preferred for their ability to efficiently distribute air through different spaces. Vertical outlets ensure more stable comfort levels across different heights within a room.[10]

Power

For ENERGY STAR models, third-party certification is required for dust, CADR/Watt and Standby Power ratings, per ENERGY STAR procedures. As mentioned before, CADR/Watt increases at lower speeds. The criteria for ENERGY STAR are shown below, where CADR is at the maximum speed, reported in units of CFM:

Table 3: Minimum Smoke CADR/W Requirements.

Smoke CADR Bins	Minimum Smoke CADR/W
30 ≤ CADR ≤ 100	1.9
100 ≤ CADR ≤ 150	2.4
CADR ≥150	2.9

[8] M. Narasaki, D. Park, S. Yoshida, and K. Fujiiwa, “Characteristics of airflow in vertical laminar flow clean room,” *Technol. Rep. Osaka Univ.; (Japan)*, vol. 38:1909-1929, 1988.
[9] A. Bonell et al., “Impact of Personal Cooling on Performance, Comfort and Heat Strain of Healthcare Workers in PPE, a Study From West Africa,” *Front Public Health*, vol. 9, p. 712481, Sep. 2021, doi: 10.3389/FPUBH.2021.712481/BIBTEX.
[10] D. Jeong, H. Yi, J. H. Park, H. W. Park, and K. H. Park, “A vertical laminar airflow system to prevent aerosol transmission of SARS-CoV-2 in building space: Computational fluid dynamics (CFD) and experimental approach,” *Indoor and Built Environment*, vol. 31, no. 5, pp. 1319–1338, May 2022, doi: 10.1177/1420326X211063422/ASSET/IMAGES/LARGE/10.1177_1420326X211063422-FIG12.JPEG.

Devices with low CADR/W mean increased electricity consumption for a given clean air delivery rate, and therefore higher operational costs.

The most power-efficient air cleaners have full-speed CADR/W values above 10, and partial speed efficiencies even higher, while some air cleaners with more restrictive filters can be below ENERGY STAR minimum requirements.

The general selection criteria for portable air cleaners can vary based on specific scenarios and user preferences. For general use at home, it is important to note the **CADR Ratings** and **Room Size Coverage**. For low noise requirements, consider looking at the decibel levels. For **Volatile Organic Compounds (VOCs)**, models equipped with activated carbon filters are effective in capturing VOCs and odors. For energy efficacy, look for the CADR/W, as specified by ENERGY STAR, for an indication of energy efficiency in capturing airborne particles.

Features and Operational Characteristics

Other features and considerations when selecting a portable air cleaner are:

- Power cord length: Ensure the power cord length is sufficient for the intended placement of the air cleaner within the room, allowing flexibility in positioning.
- Power-on recovery: Check if the air cleaner has a power-on recovery feature. This feature ensures that the device resumes its previous settings after a power outage, eliminating the need for manual intervention.
- Integrated sensors: Air cleaners with integrated sensors, such as a PM2.5 meter, provide real-time air quality feedback. This allows users to monitor and adjust settings based on current pollution levels.
- Wi-Fi/Bluetooth access, app, networking capabilities, and digital security: Connectivity features like Wi-Fi or Bluetooth, along with dedicated apps, offer remote control and monitoring. Prioritize models with robust digital security to protect personal data.
- Scheduling capability: Scheduling features allow users to program when the air cleaner operates. This can optimize energy usage and align the cleaner's performance with specific times of higher pollutant concentration.
- Air cleaner run-hour meter, or filter loading estimation (such as a combination PM2.5 meter with run hours and speed): Un-hour meters or filter loading estimations provide insights into the device's usage and filter lifespan. This helps users plan timely filter replacements for sustained effectiveness.
- Fixed speed steps versus continuously variable: Fixed speed settings allow for setting predetermined CADR values for the space. Continuous variables can allow for greater control over noise, but can easily be turned down too low.
- Auto mode that can be disabled: Auto mode adjusts the air cleaner's settings based on real-time air quality. Having the option to disable this mode allows users to manually control the device when desired.

UV technology in air cleaners can be beneficial, especially when paired with filtration media of lower single-pass effectiveness, such as MERV-rated filters. UV light can help neutralize or kill certain microorganisms, including bacteria and viruses, that may not be efficiently captured by the filter alone. In scenarios where respiratory viruses are a concern, the addition of UV technology can provide an extra layer of protection. However, in devices equipped with a HEPA filter, which is highly effective at capturing particles, the incremental benefits of UV may be limited, as HEPA filters are already proficient at trapping viruses and other particles.

Ionizing air purifiers release charged particles (ions) into the air, which can attach to airborne particles, causing them to settle. While this process can enhance particle removal from the air, there are potential drawbacks. Increased particle deposition may lead to a buildup of settled particles on surfaces in the room, potentially requiring more frequent cleaning. While ionizing air purifiers can be effective in reducing airborne particles, concerns about their potential harm exist. The increased particle deposition can create visible dust on surfaces, impacting the cleanliness of the environment. Moreover, the production of ozone as a byproduct is a point of contention, as elevated ozone levels can be harmful to respiratory health.

Air cleaning technologies not based on mechanical filtration alone require careful evaluation. The recommendations for portable air cleaners are presented through ENERGY STAR metrics. Air cleaning processes based on chemical reactions in the breathing zone may create unintentional byproducts that may be undesired contaminants. Moreover, the byproduct is a point of elevated contaminants that can be harmful to respiratory health. It is essential to carefully consider the balance between the benefits of particle removal and the potential drawbacks associated with ionizing air purifiers, especially in environments where air quality and human health are top priorities.

Optimization

There are various points of optimization when selecting portable air cleaners for a particular room. For example, **air movement optimization**, which is used for better mixing of air, distributes multiple units throughout the room rather than clustering them together.

Designs that have a vertical discharge and greater throw of air are generally preferred.[11] A lower-efficiency filter media (e.g., MERV-13) will have greater airflow to achieve the same CADR as a device with a higher-efficiency filter media (HEPA). Overall, the filters with higher MERV ratings will reduce the smaller particles, which are inhalable.

The trade-off between MERV rating and airflow involves finding the right balance between filtration efficiency and maintaining an acceptable level of airflow for the specific needs of the environment. In scenarios where high filtration efficiency is critical, such as in healthcare settings or environments with high levels of airborne contaminants, the trade-off in airflow might be acceptable. In contrast, in environments where maintaining higher airflow is prioritized, such as in HVAC systems for large commercial spaces, a lower MERV rating may be chosen to ensure optimal system performance.

Additionally, the following factors need to be considered for an optimal choice considering users' needs:

- Noise optimization – more units at a lower speed result in lower total noise.
- Power optimization – lower speeds have a higher CADR/W.
- Filtration optimization – a unit with slightly lower filtration capture efficiency can result in a higher overall clean air delivery rate because it can have less resistance, leading to greater airflow.

[11] Price Industries, “Engineering Guide Air Distribution,” 2011, Accessed: Mar. 15, 2024. [Online]. Available: https://www.priceindustries.com/content/uploads/assets/literature/engineering-guides/air-distribution-engineering-guide.pdf

- Cost optimization – this includes first cost, electricity cost, filter media replacement cost, and labour cost to maintain. Like noise, the total power draw of multiple units running at a lower speed can be less than the power draw of a single unit.
- Having multiple units spaced in the room improves the mixing of the air to maintain effectiveness and allows for a greater air cleaning capacity in situations where a higher noise level may be temporarily acceptable.
- A similar calculation could be repeated for a less expensive, lower-capacity model, with more total units in the room, to determine which model has the lowest total capital cost and operating cost to meet CADR requirements under the constraint of noise.

Placement

The use of portable air cleaners has become increasingly relevant in improving indoor air quality, particularly in spaces where the enhancement of air mixing and the strategic direction of airflow are critical. These devices can significantly contribute to a healthier environment by directing airflow toward the centre of the room, thus ensuring a more effective distribution of cleaned air relative to HVAC supply diffusers and return registers. This directional airflow can enhance the mixing of air within a room, making the air cleaner's operation more efficient and beneficial for occupants.

To mitigate the risk of accidents, such as tripping hazards posed by the power cord, implementing a cable cover is a practical and essential safety measure. Additionally, the placement of portable air cleaners plays a pivotal role in maximizing their efficacy. Positioning these units near people, yet in a manner that avoids direct airflow, ensures that the benefits of purified air are realized without causing discomfort.

An important aspect of using portable air cleaners effectively involves clear communication regarding their operation. A label placed prominently on the front panel, indicating the recommended location for the unit, its operation speed, and the recommendation not to use the automatic settings, ensures that the device is used in a manner that optimizes air quality improvements. This guidance helps in maintaining consistent and effective operation, contributing significantly to the creation of a safer and more comfortable indoor environment for all occupants.

Maintenance

The maintenance of portable air cleaners is a critical aspect of ensuring their effectiveness and longevity in improving indoor air quality. Key to this maintenance regime is the care of pre-filters, which are typically designed to capture large particles before they reach the main filter. These pre-filters are often washable or vacuumable, allowing for easy cleaning. Regular cleaning not only extends the life of the main filter but also maintains the efficiency of the air cleaner. Equally important is adhering to the recommended filter change frequency, which varies depending on the manufacturer's guidelines and the usage conditions. Changing filters on schedule prevents the accumulation of pollutants and maintains optimal air purification performance. The regularity of cleaning the filters should be based on the manufacturer's recommendations.

When performing maintenance tasks such as changing filters, safety precautions must be taken to protect against contaminants that might be released during the process. Wearing safety glasses and respiratory protection is advised to guard against airborne particles that may be dislodged. Gloves should be worn to protect hands from potential irritants or contaminants that have accumulated on the filters. To minimize exposure and ensure safe disposal, used filters should be carefully placed in a plastic bag and sealed before disposal. This approach to maintenance, emphasizing regular cleaning and adhering to change schedules and safety precautions, is essential for the effective operation of portable air cleaners and the health of their users.

Procurement Considerations

Procurement efforts for air cleaners should be focused on specifying quantitative performance requirements based on the selection criteria described above. For example, to enable direct comparisons between products, refer to sound power level, not sound pressure level. Additional decisions the consumer may want to make would be regarding clean air delivery rate, filtration technology, room size coverage, energy efficiency, features and controls, portability and design, capital and operational cost, and warranty and support. Note that the importance of user control will be based on the priorities of the user. For example, if the user is predominantly concerned about the filtration of particles below a certain size, then more importance should be placed on the filtration cycles. All information regarding the product can be found on the manufacturer's specifications. Before awarding a contract to purchase a large quantity of units, purchasers should acquire several units for evaluation.

Conclusion

In conclusion, selecting the right portable air cleaner involves carefully weighing factors such as CADR, noise output, energy efficiency, and ease of maintenance. Ensuring the unit delivers the appropriate CADR for the space, while balancing filtration effectiveness with airflow, is key to achieving optimal air quality. Quiet operation is particularly important in environments like offices and schools, so sound levels should be considered.

Energy efficiency, especially with ENERGY STAR ratings, can help guide decisions for cost-effective operation. Features like sensors, Wi-Fi control, and remote adjustments offer added convenience for those who prioritize advanced functionality. For maximum performance, using multiple air cleaners at lower speeds can strike a balance between efficiency and noise reduction. Regular maintenance, including filter care and proper placement, is essential to maintain long-term effectiveness. By considering these factors, consumers can choose the best portable air cleaner to improve indoor air quality and create a healthier living or working environment.

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