CHAPTER 66. IN-ROOM AIR CLEANERS

An in-room air cleaner (IRAC) is one that is installed within a space rather than being installed within an HVAC system. Thus, it can be added to a room or other indoor space without adding resistance to airflow (i.e., pressure drop) to the HVAC system. Many are portable, allowing them to serve more than one location depending on need. Some are installed on walls or ceilings and cannot be easily moved.

IRACs have become widely used globally, particularly since the start of the COVID-19 pandemic. In prior years, they were often used for targeted applications to mitigate specific pollutant sources such as those associated with allergies and asthma. They are known by a variety of names, including room air cleaner or purifier, in-room purifier, add-on air cleaner, stand-alone air cleaner, or room HEPA (if containing a HEPA filter).

These units typically contain one or more technologies aimed at removing contaminants from the air. Media filters, including HEPA filters, remove particles (including viruses and other microorganisms). With sufficient dose, UV-C kills or inactivates viruses and other microorganisms to make them less likely to cause disease. Sorbents (e.g., carbon) remove gases, with some claiming bioaerosol inactivation. Technologies such as ionizers and UV-PCO, among others, commonly claim to remove multiple types of contaminants but may convert some of them to other compounds. Air contaminants of concern, and the technologies involved in removing them, are discussed in more detail below.

In-room air cleaners come in several types, ranging from small desktop units to floor or full-room models to large units that can be attached to room HVAC units. An in-room air cleaner can be useful in a variety of situations, such as when

- A building's HVAC system cannot be upgraded to high enough efficiency filters to deal with a particular contaminant problem
- The HVAC system does not provide enough clean air (this includes buildings without HVAC systems and buildings with too little HVAC run-time)
- Removal of contaminants near their source is needed

This chapter includes guidance on the types of IRACs available in the marketplace, determining the appropriate size of unit to deal with a given problem, locating the IRAC to obtain the best performance, and performing maintenance necessary to ensure continued good performance. Published or planned methods for assessing IRAC performance will also be discussed. This chapter can be considered complementary to Chapter 29 in the 2020 *ASHRAE Handbook—HVAC Systems and Equipment* and Chapter 47 in this volume, both of which cover duct-mounted air cleaners. Chapter 62 in this volume includes UV treatments for bioaerosols in ducts. Chapter 11 in the 2021 *ASHRAE Handbook—Fundamentals* addresses particulate, gaseous and biological contaminants.

1. TERMINOLOGY

Air cleaner: device or system for removing contaminants from air in a ventilation system, building or other enclosed space.

Aerosol: solid and/or liquid particles suspended in air.

Air contaminant: an unwanted airborne constituent that may reduce acceptability of the air.

Bioaerosol: particles of biological origin suspended in air.

Bypass: proportion of the incoming air that passes around or through an air cleaner without interacting with the air cleaner.

Byproduct: an airborne substance formed in or downstream of an air cleaner as a result of the air-cleaning process.

Chemical adsorption (chemisorption): binding of a gas or vapor to the surface of a solid by forces with energy levels approximately those of a chemical bond. Chemisorption is an irreversible process.

Electronic air cleaner: device or system for removing contaminants from air that uses electrical power supplied to the air-cleaning technology.

Microorganism: (1) viable particle of biological origin. (2) A microscopic organism, including bacteria, viruses, protozoa, algae, and fungi.

Physical adsorption: process in which the molecules of a gas or vapor adhere by physical forces (Van der Waals forces) to the surface, both the outer surface and the inner pore surfaces, of a solid substance. Physical adsorption is a reversible process.

Reactive air cleaner: device that emits species intended to react with contaminants to remove them from the air or to increase their removal by another technology.

Removal capacity: total amount of an air contaminant that can be removed by an air cleaner during its service life.

Removal efficiency: fraction or percentage of an air contaminant that is removed from the air by an air cleaner.

Abbreviations and Acronyms

ACH	air changes per hour
AHAM	Association of Home Appliance Manufacturers
ANSI	American National Standards Institute
CADR	clean air delivery rate
c-CADR	chemical clean air delivery rate
EAC	electronic air cleaner
EPA	Environmental Protection Agency (US)
ESP	electrostatic precipitator
HEPA	high-efficiency particulate air
HVAC	heating, ventilation and air-conditioning
IRAC	in-room air cleaner
IEC	International Electrotechnical Commission
ISO	International Organization for Standardization
MERV	minimum efficiency reporting value
NC/RC	Noise/Room Criteria
m-CADR	microbial clean air delivery rate
p-CADR	particulate clean air delivery rate
PCO	photo-catalytic oxidation
PPIA	potassium permanganate impregnated alumina
RAC	reactive air cleaner
REHVA	Federation of European Heating, Ventilation and Air Conditioning Associations
ULPA	ultra low particulate air
UVGI	ultra-violet germicidal irradiation
VOC	volatile organic compound

2. CONTAMINANTS TO ADDRESS

Air contaminants fall into three classes (particulate, biological, and gaseous), which dictate the technologies that can be used to remove them from air.

Particulate matter covers a vast range of particle sizes, from dust large enough to be visible to the eye to nanoparticles not much bigger than individual chemical molecules. Particles may be liquid, solid, or have a solid core surrounded by liquid.

Particulate contaminants are generally defined by their size. One designation divides the range into ultrafine particles (nanoparticles) with size 3 nm to 100 nm (0.1 µm), fine particles approximately 0.1-3 µm, and coarse particles approximately 3-100 µm. Sources for fine and ultrafine include combustion (vehicle exhaust, cigarette or wildfire smoke, gas cooking, etc.), and office machine emissions. Sources for coarse include road, cement, and house dust. Particles larger than 100 µm do not remain airborne for long unless their density is low, as with hair or some textile fibers. Figure 1 depicts relative particle sizes of some common air contaminants.

Another particle designation is particulate matter (PM), used by the EPA for regulating outdoor air, but also applicable indoors. $\mathbf{PM}_{\boldsymbol{x}}$ indicates the total mass concentration of all particles up to x µm in size. The ranges regulated outdoors are PM_{10} and $PM_{2.5}$, with PM_1 also in wide use.

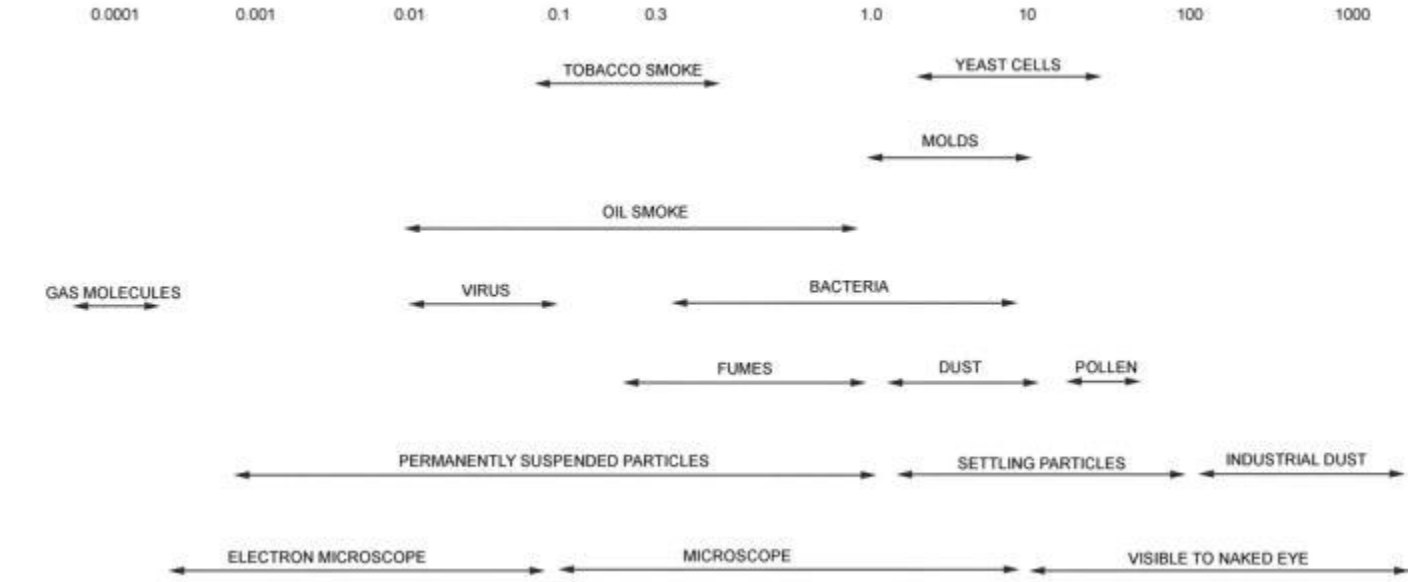

Figure 1. Relative Particle Size of Air Contaminants, µm

Bioaerosols are airborne particles of biological origin. Included are intact microorganisms (viruses, bacteria, algae, protozoa, fungi), as well as fragments, components, and products of some, and plant and animal allergens; their primary impact is related to their biological activity in the human body. Individual viruses (virions) typically range in size from 0.02 to 0.4 µm. Most individual bacteria range between 0.4 and 5 µm. Both viruses and bacteria may be found singly or as aggregates. Individual fungal and bacterial spores are usually 1 to 10 µm; whereas, pollen grains are 10 to 100 µm, with many common varieties in the 20 to 40 µm range. The size range of allergens varies widely: the allergenic molecule is quite small, but the source of the allergen (e.g., mite feces, animal dander, pollen) may be quite large. Bioaerosols may be removed from air by the same methods as work for non-biological particles. Some may be deactivated to render them harmless. Airborne particles containing viruses and bacteria, produced by the respiratory tract often through coughing or sneezing, but also talking, yelling, and singing, are generated in sputum or saliva. Therefore, in air when wet and after the water component evaporates, the particles are generally larger than the individual virion or bacterium.

The **gaseous** contaminant class covers chemicals that can exist in air as free molecules or atoms. This group covers both gases (which are naturally gaseous under ambient indoor or outdoor conditions) and vapors (which are normally solid or liquid under atmospheric conditions, but can exist as gas as a fraction of the surrounding air volume due to the law of partial pressures.) Gases include carbon dioxide, carbon monoxide, ozone, nitrogen oxides, ammonia, formaldehyde and some very volatile organic compounds (as defined by the World Health Organization). Vapors include all volatile organic compounds. VOCs are characterized by boiling point (which dictates how easily they evaporate, and how difficult they are to remove from the air by physical adsorbents) and by their chemical makeup which is responsible for toxicity and odor and which can point to the technology most suitable for removing them from air. Semi-volatile organic compounds are much less of a problem in indoor air than VOCs because their higher boiling points cause them to condense on dust and room surfaces. Information on chemical classes, and examples of VOCs and SVOCs can be found in Chapter 11 of the 2021 *ASHRAE Handbook—Fundamentals.*

3. PROBLEM ASSESSMENT

IRACs normally resolve air quality issues by removing contaminants. Scenarios where this is needed can vary widely, though, as shown by the following examples.

- The building of concern has no HVAC system. Often this is a residence or an older or heritage building.
- The existing HVAC system is designed for use of low-efficiency filters (e.g., MERV-8 or less) and cannot be upgraded to high-efficiency filters, or for use of other air cleaning equipment appropriate for dealing with the problem.
- The existing HVAC system does not provide enough clean(ed) air due to low airflow or seasonally low outdoor air (e.g.,due to summer heat, winter cold, or wildfires).
- The problem concerns a single, localized contaminant source, or a single, more-sensitive-than-average occupant. In both of these situations it is not economical to upgrade the central HVAC system.
- The problem requires removal of contaminant near the source. Such situations include the COVID pandemic, where it has been important reduce the risk of spreading infection in spaces where people must be present together.

Examples include classrooms, doctors' and dentists' offices and surgery rooms, and office conference rooms.

- The problem requires prevention of contaminant spread between spaces. For example, IRACs can be used to keep hospital isolation rooms at negative pressure while exhausting clean air to outdoors through installed ductwork.
- Airflow distribution is bad, such that one section of a room does not get sufficient air. Examples include return and inlet vents too close together, or plastic barriers or room dividers preventing airflow.

Finding an appropriate IRAC technology for a problem requires information on the type of contaminant(s) present in the space. Are they particles? If so, is there any information on the size range and likely concentration? The same questions are relevant for bioaerosols, but here it is also necessary to know the severity of the threat: is it allergy, mild infection, or severe illness; is it necessary to try to eliminate all, or just part, of the contaminant load? Gaseous contaminant problems require identification of the chemical(s) if possible, or, at minimum, the chemical class involved.

It is also important to size the IRAC appropriately, because the user does not want either to fail to remove enough contaminant to solve the problem, or to overspend on a unit that is too powerful and that may cause drafts or other issues. The design of the unit can also be important. Whether the flow of clean air is delivered from a single exhaust port, or a circular throw of air, or some other configuration, will impact the best place to locate the unit in the room. These issues are discussed in more detail in the section on Sizing, Selection, and Installation.

Most IRACs contain a fan for moving room air through the cleaning module. The noise that the fan makes can also be an issue (e.g., in a classroom or a sleeping room). This is also covered in the section on Sizing, Selection, and Installation.

4. BASIC FUNCTIONS OF IN-ROOM AIR CLEANERS

There are multiple contaminants removed with IRAC, and many technologies used to achieve this goal. However, all of the combinations of contaminants and technologies have some things in common. IRAC are placed in rooms, or more generally in indoor occupied spaces, to clean the air. Thus, IRAC are expected to reduce contaminant concentrations in the indoor air. Traditionally, most IRAC used filters or sorbent media that had essentially constant removal efficiency, at least over the short term. Thus, these devices in rooms have been considered to function according to certain expectations. Newer devices may not have constant efficiency: their efficacy is tied to the concentration of species in the air, which may change over time. Different approaches will probably come into the common discussions; specifics of these technologies are discussed in the section on Air Cleaning Technologies. This current section introduces some of the common terminology and approaches to assessing and using IRAC.

For a contained space starting with a given concentration of contaminant, no new source of contaminant, perfect mixing, and an air cleaner with constant removal efficiency, the following equation applies:

$$C_i/C_o = e^{-kt}$$

where

C_i = concentration of contaminant at any time i

C_o = concentration of contaminant at start (or time 0)

t = time

k = slope of ln-linear fit of concentration versus time; also called k-value. If time units are hours, k-value = ACH for room.

Using this relationship, test data can be fitted to this curve. Commonly used testing (see the section on Performance Testing) uses a chamber spiked with a contaminant. The concentration is monitored over time for both the device-off case (called **natural decay**, because it captures what happens without the device) and for the device-on case. k-values are calculated for both cases. Then a CADR or similar clean air production rate can be calculated using the difference of the k-values and the volume of the test chamber. For a constant-efficiency device, the CADR is essentially equal to the airflow through the device multiplied by the contaminant removal efficiency of the device.

The **CADR** is the most commonly used term for assessing IRAC at this point, so it is important to understand that it is a calculated value based on these assumptions. If the CADR and room volume are known, the room air exchange rate provided by the IRAC can be calculated:

$$\text{CADR} = \text{IRAC airflow rate} \times \text{Removal efficiency}$$

To reach a desired room air exchange rate in air changes per hour (ACH),

$$\text{ACH} = \text{CADR (cfm)} \times 60 \text{ (min/h)} / \text{Room volume (ft}^3\text{)}$$

An example of the how the concentration changes in a room due to an air cleaner based on the CADR is shown in Figure 2. Part A shows the concentration in linear scale, which is usually easier to read when finding the concentration at a given time. Part B of Figure 2 shows the same data in a ln-linear plot to illustrate how the k-value derives from the data fit.

5. AIR CLEANING TECHNOLOGIES

Particle Removal

The most widely used technology for particle removal is media filtration. Chapter 29 in the 2020 *ASHRAE Handbook—HVAC Systems and Equipment* explains the removal mechanisms and application in HVAC systems. The same principles apply for IRAC, though the filter size is usually much smaller. For media filters, the main variable influencing the efficiency is the media velocity. So, less air will be cleaned than for an HVAC filter, but the cleaning efficiency can be the same.

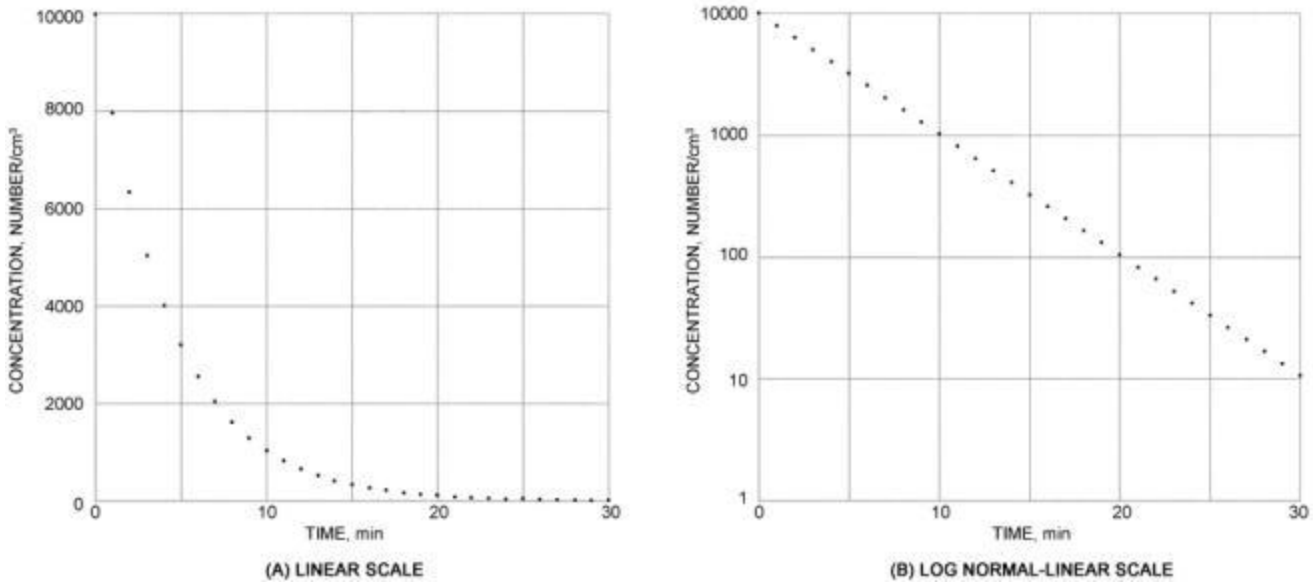

Figure 2. In-Room Air Cleaner Performance CADR = 200 cfm, Room size: 1000 ft^3; Air cleaner airflow: 240 cfm; Air cleaner efficiency: 85%; Assumes perfect mixing.

Filters are rated by their single-pass removal efficiency for particles in different size ranges and to a lesser extent by removal capacity which is a measure of filter service life. The most frequently used rating systems are MERV for low- and medium-efficiency filters, and HEPA for high-efficiency filters.

MERV is a product of an ASHRAE *Standard* 52.2-2017 test of removal efficiency for particles in the 0.3-10 mm size range. The scale goes from MERV 1 filters (<20% efficient for 3-10 µm particles) up to MERV 16 filters that are 95% or better across the 3 size bins of 0.3-1, 1-3, and 3-10 µm. HEPA filters are more efficient than MERV 16, and are usually rated at 99.97% efficiency for 0.3 µm particles. Table 1, which is reproduced from ASHRAE *Standard* 52.2-2017, shows the removal efficiency for each MERV against the three particle size ranges of the *Standard* 52.2 test.

Table 1 MERV Removal Efficiencies for Different Particle Size Ranges

	Composite Average Particle Size Efficiency, % in Size Range, mm			
Standard 52.2 Minimum Efficiency Reporting Value (MERV)	**Range E1 0.30 to 1.0**	**Range E2 1.0 to 3.0**	**Range E3 3.0 to 10.0**	**Average Arrestance, %**
1	N/A	N/A	$E_3 < 20$	$A_{avg} < 65$
2	N/A	N/A	$E_3 < 20$	$65 \le A_{avg}$
3	N/A	N/A	$E_3 < 20$	$70 \le A_{avg}$
4	N/A	N/A	$E_3 < 20$	$75 \le A_{avg}$
5	N/A	N/A	$20 \le E_3$	N/A
6	N/A	N/A	$35 \le E_3$	N/A
7	N/A	N/A	$50 \le E_3$	N/A
8	N/A	$20 \le E_2$	$70 \le E_3$	N/A
9	N/A	$35 \le E_2$	$75 \le E_3$	N/A
10	N/A	$50 \le E_2$	$80 \le E_3$	N/A
11	$20 \le E_1$	$65 \le E_2$	$85 \le E_3$	N/A

12	$35 \le E_1$	$80 \le E_2$	$90 \le E_3$	N/A
13	$50 \le E_1$	$85 \le E_2$	$90 \le E_3$	N/A
14	$75 \le E_1$	$90 \le E_2$	$95 \le E_3$	N/A
15	$85 \le E_1$	$90 \le E_2$	$95 \le E_3$	N/A
16	$95 \le E_1$	$95 \le E_2$	$95 \le E_3$	N/A

Source: ASHRAE *Standard* 52.1-2017.

Several technologies use electrostatic charge to remove particles from air. The simplest one enhances removal efficiency of media filters by creating an induced electrostatic field in the media during manufacture. Others require electrical power to function during operation. These include media filters where the electrostatic field is induced in situ by electrical energy and electrostatic precipitators (ESPs) that use high voltage to charge the particulate contaminants then remove them by attraction to an oppositely charged plate. As with fiber filters, the air cleaner's cleaning ability is determined by the airflow through the device and the removal efficiency within the device. These technologies are attractive because they enable particle removal efficiencies similar to simple media filters but with lower pressure drop. More details on these technologies can be found in Chapter 29 in the 2020 *ASHRAE Handbook—HVAC Systems and Equipment*.

Microorganism Removal or Inactivation

Microorganism removal from air can be achieved using a filter or any other particle removal device that works for the same size range of nonviable particles, in which case the preceding information for particle removal applies.

Alternatively, the bioaerosol may be treated with UV-C (ultraviolet light in the germ-killing wavelength range), which can render viruses and bacteria inactive, including noninfectious and noncontagious, but does not remove them from the air. This is beneficial for disease-causing organisms, but allergens are likely to still cause allergic responses. Since the inactive particles are still in the air, they will still interact as PM.

Gaseous Contaminant Removal

The most widely used technologies are physical adsorption and chemical adsorption (chemisorption). Physical adsorption is a reversible process (i.e., adsorbed contaminants can later be released when either clean air or a contaminant that is more strongly adsorbed than the earlier one passes through the cleaning module). Thus, the technology is good for leveling an intermittent contaminant load in a space. Physical adsorbents include various types of activated carbon used without impregnated chemicals. VOCs with higher boiling points are more effectively removed than those with lower boiling points because they condense more easily into the carbon pores.

Chemical adsorption binds air contaminants irreversibly and is followed by chemical reaction(s) that remove the contaminant from the airstream, but which may release reaction byproducts. Potassium permanganate impregnated alumina (PPIA), also known as purple pellets, is a common chemisorbent. Activated carbon impregnated with acid can be used as a chemisorbent to remove ammonia, and alkali-impregnated carbon can be used to remove acid gases such as sulfur dioxide and hydrogen sulfide. Note that these adsorbents do not reduce virus levels or render infectious or contagious microorganisms harmless.

Catalysts can clean air by stimulating chemical reactions of gaseous contaminants on the surface of media. Photocatalytic oxidation (PCO) is the technology of this type most widely used in the air-cleaning industry. Typically, it uses a UV lamp with titanium dioxide as the catalyst. Ideally, hydrocarbons and other VOCs can be fully oxidized to carbon dioxide and water by reaction with atmospheric oxygen. In practice, if the residence time of the contaminants in the cleaning module is too short, incomplete oxidation occurs, which can yield undesirable products such as aldehydes. However, UV-PCO can be an attractive option because of its promise of reduced maintenance (no filters and/or adsorption media to maintain and dispose of periodically) and ability to treat a wide variety of airborne chemicals. The term PCO is also used to describe units that produce reactive species that enter the air in the room, where these species can interact with whatever is in the air.

Multi-Contaminant-Type Removal

In addition to IRAC that include multiple technologies to remove multiple contaminants, some IRACs use one technology to address more than one contaminant type. Their efficiency at removing different contaminants is likely to vary.

Air ionizers (ion generators) may be effective under some circumstances for particulate, VOC, and/or odor removal. Most ionization technologies are based on the principle of corona discharge (or non-thermal plasma) and can be classified into three categories: bipolar ionization, needlepoint ionization, and ozone generation. Users should be aware that ionization systems are prone to generate some NO_x and ozone, which are harmful to humans. Although ozone had

in the past been touted as a panacea for removing gas-phase contaminants from indoor air, the U.S. EPA now strongly recommends against using ozone generating air cleaners. More detailed information on PCO and ionizers can be found in Chapter 47.

Other technologies may remove or change gaseous contaminants or both. Since devices using these technologies are variable in construction and may also contain other technologies, general statements are not currently possible. Refer to Chapter 11 in the 2021 *ASHRAE Handbook—Fundamentals* and to test results for the specific devices to understand their function.

Added Species and Byproduct Formation

Reactive air cleaners (RAC) operate by adding different species to the air. Some of these species are ions (both charged atoms or molecules and charged particles), hydrogen peroxide, reactive oxygen species, and others. These species are intended to react with the contaminants either to enhance capture by filters, to inactivate microorganisms, or to react chemically with contaminants to change them into other compounds. For chemically reactive species reacting with contaminants, the reaction products may be safer or less safe than the initial contaminant. The goal is to react and re-react to form safe species (usually CO_2 and water). Note that these species may react with other compounds in the air in addition to, or instead of, the intended contaminant. This can result in different compounds in the air after IRAC treatment depending on the mixture of gases in the air before treatment.

6. EQUIPMENT

Most IRACs (except for the smallest desktop/tabletop units, and some ionizer-based technologies) contain a fan to take air in, move it through the air-cleaning module(s), and return it to the room. Almost all the ones containing a fan need a power source, which is typically an electrical outlet. Batteries can only be used for the smallest units.

IRAC equipment can be movable, including small desktop/tabletop units and larger floor-based units on wheels. Alternatively, they may be fixed, including UV-C units (which are often mounted on ceilings or near the top of walls to reduce the likelihood of human exposure to harmful UV radiation), and ceiling-mounted units containing various technologies. UV-C equipment is discussed in more detail in Chapter 62 of this volume.

An advantage that IRACs have over in-duct air cleaners is that recirculation through the air cleaning module is usually faster. This allows low-efficiency processes to become effectively higher efficiency. Thus, a filter at the upper end of the MERV specification can mimic the performance of a HEPA filter after several passes of room air through the unit. Photocatalytic oxidation and ionizer technologies can also show improved performance over single pass results.

The faster an IRAC can draw air through the air-cleaning module, the faster it can reduce contaminants in the air of a room. Alternatively, for a given ability to clean (as specified by the CADR), the faster an IRAC moves air, the larger the space it can clean. Airflow through the device also results in breezes within the space, so the total airflow can be important. Rough guidance on air-moving requirements for different size spaces is listed here, using airflow as an indicator of ideal use based on rational air movement. A similar list could be done using CADR to indicate air cleaning rate. For best choice, both should be considered. This list was based on assuming the airflow would be close to the CADR.

- **Personal level:** under 100 cfm, intended for office or small bedroom. Easy to set on desk or bedside table.
- **Residential/room level:** around 100 to 250 cfm. Except in times of high demand (such as the recent pandemic), these are easily obtained from local home improvement stores or online. Often intended to serve one bedroom, a standard office, or a small living room, these plug into standard wall outlets.
- **Light commercial/large residential/space level:** around 300 to 500 cfm to . These are more expensive units that usually are for sale online from air cleaner sales sites, or specialized sites such as those serving people with allergies.
- **Industrial level:** >500 cfm. These are more expensive units, usually requiring professionals such as design engineers, contractors, etc., to properly apply, size, select, and install. Some are designed to provide negative pressure in rooms by exhausting air to elsewhere through ductwork. Other large units are permanently installed on ceiling (or in plenums above ceiling) and using ductwork, supply air diffusers, and return air grille(s). Users need to be sure to specify that they need this when buying, and also to install it correctly (co-ordination with existing HVAC provision is necessary). Larger and permanently installed units typically need more specialized electrical wiring, power supply, and, when applicable, communication and connectivity to building automation systems.

Standalone, portable, add-on, wall-mounted, and ceiling-mounted devices and any others can fit into any of these categories.

The air-cleaning technologies used in IRACs have been discussed in the previous section. Some IRACs use only a single technology, but many use more than one. The most common use of multiple air-cleaning technologies occurs

with filtration. Usually, this involves two or three levels of filtration such as a prefilter and a good particulate filter or carbon filter, sometimes with a HEPA filter in the same device.

Some notes on multi-component units:

- If trying to remove COVID-19 (a virus, thus a particle), a HEPA or ULPA filter will remove essentially all of the particles that go through it. Additional technologies are unlikely to help with removal.
- HEPA filters have very high efficiency. Since many of these air cleaners have HEPA filters, these are likely the best choice.
- Prefilters are often included with HEPA or other high-efficiency filters to prevent large particles from clogging the expensive, higher-efficiency filters.
- Washable filters may be provided instead of a prefilter. These serve the same purpose but can be washed and reused.

Multicomponent IRACs may include more than one type of technology and often address more than one of the contaminant types. For example, an IRAC may include a media filter and UV lamps or a HEPA filter and an ionizer. Information on each technology still applies to how those parts of the device function. However, it is possible that there will be synergies or negative influences of the technologies on each other. For example, an ionizer that causes agglomeration of particles may cause greater collection efficiency of a media filter due to increased particle size. On the other hand, UV light may degrade fibers or other components of media filters lowering the efficiency of the filter. CADR test results used to choose air cleaners should be based on tests with all the technologies turned on, unless the owner plans to deactivate or remove one of the parts of the device.

Some IRACs include high-level filtration (such as HEPA) followed by UV-C. From the perspective of dealing with infectious particles, this is redundant: the HEPA filter will have already removed the particles before air enters the UV-C section. Some devices include other redundant technologies. This may increase the cost compared to similar non-redundant devices but is not otherwise a disadvantage.

Note that UV light degrades some filter media. Correct pairing of type of media and UV, or simply distance or lack of line-of-sight between filter and UV lamp, can solve this problem.

Other technologies may remove or inactivate microorganisms or both. Since these technologies are implemented in a variety of ways in IRACs, general statements are not currently possible. See Chapter 11 in the 2021 *ASHRAE Handbook—Fundamentals* and test results for the specific devices to understand their function and performance.

The **clean air delivery rate (CADR)** may be part of an IRAC specification or can be calculated from data obtained during air-cleaner testing. The CADR expresses incomplete removal of contaminant as delivery of a lesser amount of fully cleaned air. The CADR needs to be specified/determined separately for each air contaminant. Confusion sometimes happens when IRAC are described by their "cfm." Sometimes the cfm is the actual airflow rate; for others, it is the CADR. It is important to know the difference before selecting devices. Note that for a device with constant 50% removal efficiency, a 200 cfm airflow is equal to a 100 cfm CADR. Thus, these numbers are not directly interchangeable.

7. SIZING, SELECTION, AND INSTALLATION

This section describes what to look for in IRAC sizing, selection and installation. Additional information can be found in REHVA per the Nordic Ventilation Group (tinyurl.com/REHVA-NVG) and AHAM (ahamverifide.org/ahams-air-filtration-standards/).

- **Contaminant.** What needs to be removed? For particles, what type (e.g., general, PM2.5, dry, wet, biological, active/alive)? For gases, what type (ozone, VOCs, aldehydes, odorous chemicals)? Viruses like COVID-19 are biological particles, so can be removed by particle capture devices or inactivated by bioaerosol-treating devices.
- **Space size.** Length, width and ceiling height.
- **Space duty.** Office, lobby, classroom, etc.
- **Space layout.** How is the space arranged, where is the power access, are there safety issues?
- **Air distribution.** How is air distributed in the space? Can the air cleaner(s) be placed with air intakes unobstructed by furniture and with outlets able to move air as far as possible before being deflected or drawn into a return or exhaust grille? Optimally, in-room air cleaners should have fixed locations.
- **Existing HVAC system.** Total supply air and return air volumes.
- **Ventilation (outdoor air).** How much comes in through HVAC system or windows? If unknown, the designer should assume none.

- **Filtration.** Existing filters information and efficiency (MERV).
- **Amount of clean air needed (CADR).** What flow rate of clean air is needed? Is there a target for the clean-air equivalent (effective) number of air changes per hour (ACH) needed between ventilation and filtration combined (e.g., 3, 6, or 12 ACH equivalent)?
- **Room Noise Criteria.** Acceptable room noise level (e.g., 40 dBA, 35 NC/RC). Table 1 of Chapter 49 of this volume can be consulted. In cases where the IRAC is temporary (e.g., pandemic use), deviation from the required room noise criteria can be acceptable as long as it is carefully coordinated with the client.
- **Interference.** Is there anything in the space that makes a technology a bad idea? For example, a space where scented products or hand sanitizers are frequently used may not be a logical place to put a carbon-based air cleaner. A space that needs clean surfaces might make an ionizer unacceptable.

Sizing Example. Contaminant room needs to remove all sizes of particles, including COVID-19. The HVAC system has a MERV 8 and cannot be upgraded.

Space size: 25 × 10 ft room (250 ft^2) with 10 ft ceilings and volume of 2,500 ft^3
Space duty. Small office lobby, interior area.
Space layout. This room does not have any air-blocking walls to prevent good mixing.
Existing HVAC system.
Total supply airflow rate = 250 cfm
Return airflow = 175 cfm
Outdoor air = 75 cfm
Filter efficiency =MERV 8 (~35% efficient for 1 to 6 µm particles)
Required total clean-air equivalent ACH =6 (add 15% for safety margin), size for 6.9 ACH
Noise Criterion = 45 dBA

The ASHRAE Equivalent Outdoor Air Calculator (tinyurl.com/equivOAcalc; I-P units only) can be used to determine an IRAC's required CADR based on the information input. To achieve the desired outdoor air or clean-air equivalent for this example, the calculator indicates a 125 cfm CADR IRAC is required, as shown in Figure 3.

Name of Space / AHU / Building	Units	Small Lobby
Area	Sq Ft	250
Average Ceiling Height	Ft	10
Volume	Cu Ft	2500
Total Supply Air	CFM	250
Total Outdoor Air	CFM	75
Supply Air ACH	ACH	6.00
Outdoor Air ACH	ACH	1.80
Central AHU Filter MERV Rating	MERV	8
UVC Single Pass Inactivation	%	0.00%
In Room Fan HEPA Filter	CADR	125
Number of In Room Fan HEPA Filters	Qty	1
Effective Air Changes Based on Technology		
ACH_OA	ACH	1.80
ACH_MERV filter in AHU	ACH	2.08
ACH_e,c	ACH	0.00
ACH_air cleaner	ACH	3.00
Sub-Total Effective ACH	ACH	6.88
Total Effective ACH_e		6.88
Time Required to achieve Target Air Changes	Target Air Changes	6
Minutes	Min	52.34
Hours	Hours	0.87

Figure 3. In Room Air Cleaner Sizing Example

Selection

In the sizing example, the calculated CADR (125 cfm) is fairly low even with a push to allow a higher-than-requested ACH. When sizing an ACR, consider the following aspects.

- If **particles** must be removed, look for an air cleaner that removes the desired size of particles. A HEPA air cleaner or high MERV is good.
- Look at the unit's CADR (clean air delivery rate), which for a HEPA will be essentially the airflow rate at which the unit operates. For a MERV filter, ask for the CADR or estimate it using Table 1 and the unit's airflow. For example, a MERV-13 filter is >85% for 1-3 µm particles, so an airflow rate of 300 cfm would be close to a CADR of 255 cfm.
- Check for **unwanted or unneeded add-ons**. In the example, gases are not a target for removal, so add-ons such as carbon or UV are unnecessary (though they will not be harmful if they are used). Find units that are rated for the required level of clean air delivery and that remove the contaminant of concern. Be careful not to get an added technology that may cause problems (see the F&D section on COVID-19 ETF site at ashrae.org/COVID19).
- Check for **noise (decibel) levels**. The unit manufacturer should provide noise levels of the unit(s). The unit(s) should have the ability to vary fan speed, which results in several CADRs where each speed corresponds to different air flow and noise level. Information on fan/motor speed, CADR (cfm), and noise level (dBA) can help in meeting the required room noise criteria, but will likely need to be requested by the manufacturer. More detailed noise data such as noise level in each octave (125, 250, 500 Hz, etc.) might also be available.Consider selecting two or more units and running at a lower speed, where each unit supplies part of the total required CADR. Note that, in this case, operation of multiple units should be taken into account in the room noise level analysis. For cases where permanent, large IRACs are installed in or adjacent to the room and equipped with ductwork, air diffusers, and grilles, typical acoustic analysis and procedures for fan airborne supply duct path, breakout noise from ducts, return air path, radiated noise, etc., should be performed to ensure room noise criteria are met. Chapter 49 covers these procedures. Commercial acoustic analysis programs can be used as well.
- Make sure to locate the unit in the space without either **inlet or outlet** being blocked or causing gusts of air to re-entrain (put back in the air) dust from surfaces. This is also important when multiple units are applied, for example, to meet noise level criterion.
- Consider **cost**. Look around for prices and availability. Be sure to check prices and expected lifetimes for replacement filters.
- If high airflow is needed, consider buying two or more units. This gives both higher airflow and flexibility, as the units can later be used in separate rooms.

Installation and Placement in Room

- The goal is to clean all of the room air and to provide clean air especially to the places where people will be breathing,
- Locating portable units can be challenging, since it depends on other constraints (space use, occupancy, electrical outlet location, and more) and the existing air distribution layout
- Consider air distribution. Although the CADR is the main variable in sizing and selection of the IRAC, performance can depend on its location in the room and whether the clean air reaches the occupants' breathing zone. Location of IRACs relative to room supply air diffusers and return air grilles can impact the airflow patterns in the breathing zone. Therefore, special attention is needed to set the optimum location of the IRAC.
- Special consideration, and more units, may be needed for large rooms such as classrooms.
- Unit location should be carefully coordinated to avoid high room noise near occupants.
- Keep safety in mind. Be sure people will not run into the IRAC or trip on cords. For schools, be careful about little fingers and openings.

8. OPERATION AND MAINTENANCE

Operation Issues

Bypass. To be treated, the air must flow through filters so sealing of the filters in the unit is very important. When first using the device or when replacing filters, be sure the filter is correctly in place to cover the airflow opening and that something (e.g., gasketing, pressure against the filter) holds the filter in place.

Safety. Issues include, but are not limited to, the following:

- Equipment with grounding type plug (with third, grounding pin) must only be plugged into a grounding type power outlet. Do not change the plug in any way. If you do not have an appropriate outlet, have one installed by a qualified person.
- Do not place units on beds, couches, or other soft surfaces as that could cause them to fall over.
- Do not place near heat sources such as radiators.
- Be sure cords are placed or secured to avoid creating tripping hazards.
- Do not place in or near water such as in a bathroom.
- Keep units indoors; these devices are not intended for outdoor use.
- Be aware of potential UV light exposure from a UV-based technology. UV light is harmful to eyes and skin. Be sure any UV lamps and their light are well contained within the unit or that the light is emitted in a location above people's heads. For more details on this issue, see Chapter 62.

Useful Standards. In the United States, UL *Standard* 507 is required for any device that has a fan. It is also used for any device with a contained UV-C source.

UL *Standards* 1598, 8802, and 8803 all deal with UV light safety, based on whether or not the device has a contained or uncontained source, is a portable or room-mounted device versus duct-mounted, if a device has other specific UV safety control features, or if a device is or is not in a medical setting.

UL *Standards* 867 and 2998 place limits on the production of ozone from electronic air cleaning technologies. This applies to photocatalytic oxidizers, ionizers, and other electronic equipment with the potential to create ozone.

UL *Standard* 61010 deals more broadly with electromagnetic safety in medical or laboratory settings (e.g., whether the electromagnetic field generated by the fan inside the device interferes with other life-maintaining equipment commonly found in a medical setting).

Maintenance Needs

- Units should come with **user's manuals**. Follow the instructions. Manuals are often available online, so the information can be viewed before purchase.
- **Filter change-out** schedules should adapt to circumstances. Do this on schedule, or more often if heavy dust is present (e.g., powder spills, wildfires). If the air smells when the unit is turned on, change the filter.
- When there is a scarcity of good filters, such as during the height of the rush to get filters into buildings due to COVID, order replacements early.
- Use appropriate PPE when changing the filter. Particles should not come off easily unless the filter is very dirty, but assume they might. Wear a good mask and gloves when changing the filter. Bag the used filter immediately to avoid dust falling off and exposure to whatever has been captured. A biological contaminant of concern will die or become inactive over time. A good time to replace filters is when the units have not been run recently (e.g., over a weekend or longer break: the day of return to school or work, before units are turned on again, would be a good day to change the filters).
- Be careful not to place filters backwards in the unit. Doing so will cause airflow to blow collected contaminants into the air.
- Consider adding a label to the outside of the air cleaner with a filter replacement date to avoid forgetting it.
- UV lamps need to be changed periodically. Follow the manufacturer's recommendations to keep the level of light emitted high enough to meet requirements. UV light can be unsafe for direct exposure, so the IRAC should be turned off before opening it to change the lamps (see Chapter 62).
- Other parts such as ionizer tips, sensors, water, etc., will need to be replaced periodically. Read the owner's manual carefully to determine timing. Do not assume the unit will work correctly or safely if instructions are not followed.
- Electric cords should be checked occasionally for fraying and general wear and tear.

9. ENVIRONMENTAL ISSUES

Using in-room air cleaners to clean your air does have some drawbacks that need to be balanced against the benefits. These are some of the items that need to be considered.

Filter Disposal

Devices containing a media filter will need replacement filters, and used filters will need to be disposed of. At this time, in most places, these filters may be discarded with regular trash. For individual in-room air cleaners, the filters are likely to be relatively small but the total bulk for many units could be large. Determine whether there are applicable regulations about special disposal for certain types of contaminants. The same advice applies to sorbent bed filters.

UV Lamp Disposal

UV lamps may need special disposal, and broken UV lamps must be handled carefully. UV-C lamps should be treated in the same manner as other mercury-containing devices, such as fluorescent lamps. Some lamps may need to be treated as hazardous waste and not discarded with regular waste, although low-mercury lamps may be an exception. Users should check state and local codes to determine the proper course of action. The most stringent of local, state, or federal regulations for disposal should be followed. For more details, see Chapter 62.

Other Component Disposal

Most devices will have some parts that need replacing and thus disposal. Read the device specifications before buying products and include both replacement cost and disposal of old parts in your life cycle analysis.

10. PERFORMANCE TESTING

Contaminant removal devices can be tested in sealed chambers by recirculating contaminated air through them and measuring the decay of the contaminant concentration over time. Most published test methods use room-sized chambers with volumes of 706 ft^3 or larger. Note that much of the peer-reviewed literature and advertising report results for much smaller chambers.

The chamber is first cleaned and sealed, then a contaminant is injected and mixed well. The concentration of the contaminant in the sealed chamber is monitored over time both with and without the air cleaner operating.

Chamber decay tests are generally used for devices that physically cannot be tested in a duct, that have single-pass efficiencies so low that they cannot be reliably measured using up- and downstream measurements, or that are designed specifically for in-room operation. Decay tests can provide valuable data, but the results are affected by factors extraneous to the air cleaner itself, such as errors introduced by adsorption on the chamber surfaces, leaks in the chamber, and the drawing of test samples. Robust test quality assurance and quality control are required to obtain meaningful data. Daisey and Hodgson (1989) compared the pollutant decay rate with and without the contaminant removal device to examine these uncertainties.

For a chamber test, the CADR is calculated as the product of the volume of the chamber and the contaminant decay rate constant due to action of the air cleaner, corrected for the natural decay rate (air cleaner off test). Units are those of airflow rate (i.e., cfm), allowing direct comparison between the impact of the air cleaner and use of ventilation air. Note that the CADR will be different for each of the contaminants that the air cleaner removes.

For particle removal, many IRAC designed for both commercial and residential use are tested using the ANSI/AHAM method AC-1, which is a chamber decay test as described above specifically intended for residential units. This test currently gives the CADR. In 2022, AHAM published a new test standard, AHAM AC-5, which uses a similar chamber decay test with microorganisms as the challenge. This test yields the microbial clean air delivery rate (**m-CADR)**. Also in 2022, AHAM published a gas-phase version of this test, AHAM AC-4, which gives a chemical clean air deliver rate (**c-CADR)**. To make the contaminant tested clear, the term CADR in AHAM AC-1 is expected to be changed to p-CADR for particle CADR in the next published edition. The user needs to be careful to verify which pollutant a quoted CADR applies to when using the equations shown earlier. Note that AHAM refers to gas-phase contaminants simply as chemical contaminants. For devices that make claims to remove multiple contaminants, tests are needed to support each claim.

There are several other published test methods that use room-sized chambers, including a national standard (GB/T 18801) from China (People's Republic of China 2015) and procedures from organizations in Japan (JACA 2016) and Canada (Sultan et al. 2011). In addition, an international standard method is being developed jointly by ISO and IEC. The first part, which defines the test chamber, is already published (IEC 2020), and separate parts covering methodology for particulate, gaseous and microorganism challenge contaminants are in progress. To meet the urgent need for a commercial IRAC standard for bioaerosol control, ASHRAE SSPC 185 had begun work on *Standard* 185.3P.

The AHAM tests do not determine levels of intentional species added to the air or by-products resulting from interaction of the air cleaning technology and the contaminant being removed. There is no current standard that requires measurements of these important species except for ozone, which is included in the Canadian procedure and UL standards described here, and will be present in the IEC/ISO standard.

UL *Standard* 867 is chamber test aimed at determining if an air cleaner produces ozone leading to concentrations exceeding 0.05 ppm (50 ppb) in this specific test. The test is performed in a 950-1100 ft3 (26.9-31.1 m3) chamber with temperature and relative humidity (RH) requirements. With the device running, the ozone concentration is monitored for 24 h.

UL *Standard* 2998 is an environmental claim validation that signifies that devices emit ozone low enough to meet its specifications. UL 2998 uses UL 867 as the test standard for most devices. However, Chinese *Standard* GB/T 18801 may be used to get this certification for single-pass devices, so a straight comparison to in-room devices may not be useful.

Some IRAC may include components that have been approved by other tests. For example, a filtration device may include a filter that has been tested to ASHRAE *Standard* 52.2 to obtain a MERV. The removal efficiency predicted by the MERV for a given size of particle and the airflow through the device can predict the CADR for devices that only contain the filter. For details of tests on single-pass duct-mounted devices applicable to components in IRAC, refer to Chapter 62 in this volume for UV, Chapter 47 for gas-phase testing, and Chapter 29 in the 2020 *ASHRAE Handbook—HVAC Systems and Equipment* volume for particle tests.

Particulate removal devices may also be tested using methodologies similar to the AC-1 test. For example, a device might be tested in a smaller chamber or with different particles. It is important to be sure what test results are presented to understand what they mean. A device that works well in a tiny chamber may not work well in a huge room.

Procedures used for gaseous air cleaners may be AHAM AC-4 or other gaseous contaminant analogs to the AHAM test. Given that AC-4 is very new and does not include non-challenge contaminant species measurements, and that the other tests are not widely used (at least in the United States), no consensus test standard exists. Thus, test methods vary between laboratories.

Several new test methods are in development at the time of this chapter's submission, so checking AHAM, ISO, and ASHRAEwebsites may yield additional information to that cited here.

REFERENCES

AHAM. 2022. Method of assessing the reduction rate of chemical gases by a room air cleaner. *Standard* AC-4-2022. Association of Home Appliance Manufacturers, Washington, DC.

AHAM. 2022. Method for assessing the reduction rate of key bioaerosols by portable air cleaners using an aerobiology test chamber. *Standard* AC-5-2022. Association of Home Appliance Manufacturers, Washington, DC.

ANSI/AHAM. Method for measuring performance of portable household electric room air cleaners. *Standard* AC-1-2020. Association of Home Appliance Manufacturers, Washington, DC.

ANSI/UL. 2021. Electrostatic air cleaners, 5th ed. ANSI/UL *Standard* 867.

ASHRAE. 2017. Method of testing general ventilation air-cleaning devices for removal efficiency by particle size. ANSI/ASHRAE *Standard* 52.2-2017.

ASHRAE. 2016. Method of testing gaseous contaminant air cleaning devices for removal efficiency. ASHRAE *Standard* 145.2-2016.

Daisey, J.M., and A.T. Hodgson. 1989. Initial efficiencies of air cleaners for the removal of nitrogen dioxide and volatile organic compounds. *Atmospheric Environment* 23(9):1885-1892.

IEC. 2020. Household and similar air cleaning appliances—Measurement of performance—Part 1: General requirements. *Standard* 63086-1. International Electrotechnical Commission.

JACA. 2016. *Guideline for performance evaluation of air cleaners.* Japan Air Cleaning Association.

Peoples Republic of China. 2015. Air cleaner. *Standard* GB/T 18801-2015. National Standard of the People's Republic of China.

Sultan, Z.M., G. Nilsson, R.J. Magee, and J.S. Bradley. 2011. Method for testing portable air cleaners. *Standard* NRCC-54013. National Research Council Canada.

UL. 2017. Standard for electric fans, 10th ed. *Standard* 507. Underwriters Laboratories.

UL. 2018. Electrostatic air cleaners. *Standard* 867. Underwriters Laboratories.

UL. 2020. Environmental claim validation procedure (ECVP) for zero ozone emissions from air cleaners, 3rd ed. *Standard* 2998. Underwriters Laboratories.

UL. 2021. Luminaires. *Standard* 1598. Underwriters Laboratories.

UL. 2021. Outline of investigation for UV germicidal equipment and systems. *Standard* 8802. Underwriters Laboratories.

UL. 2021. Outline of investigation for portable UV germicidal equipment with uncontained UV sources. *Standard* 8803. Underwriters Laboratories.

UL. 2016. Safety requirements for electrical equipment for measurement, control, and laboratory use. *Standard* 61010. Underwriters Laboratories.

World Health Organization. 2010. *WHO guidelines for indoor air quality: selected pollutants*. World Health Organization, Regional Office for Europe.