



Application Manual

Air Cleaning Systems





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Preface

As a leading HVAC manufacturer, we deem it our responsibility to serve the building industry by regularly disseminating information that promotes the effective application of building comfort systems. For that reason, we regularly publish educational materials, such as this one, to share information gathered from laboratory research, testing programs, and practical experience.

This publication focuses on systems used to maintain indoor air quality, including filtration systems and other air cleaning devices. To understand the options available to system designers, this guide discusses the systems, their advantages and drawbacks, common implementation practices, and monitoring air quality.

We encourage engineering professionals who design building comfort systems to become familiar with the contents of this manual and to use it as a reference. Architects, building owners, equipment operators, and technicians may also find this publication of interest because it addresses system layout and control.

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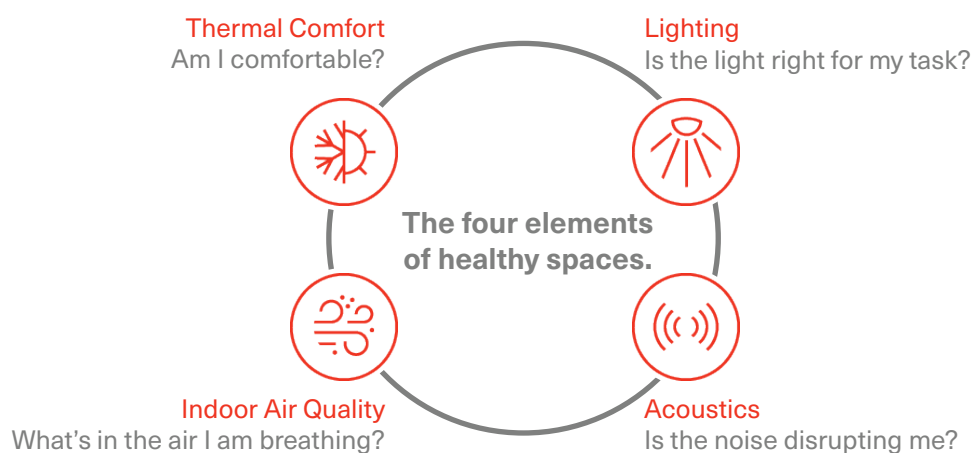
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Overview of Indoor Air Quality

Indoor air quality is one component of overall building indoor environmental quality. Trane has divided environmental quality into four components (Figure 1): thermal comfort, lighting, indoor air quality, and acoustics. Each of these contributes to occupant's overall feeling of satisfaction within the building. While all four components are important, this manual primarily focuses on indoor air quality.

Figure 1. Core elements of indoor environmental quality



Indoor air quality (IAQ) refers to the air quality within the interior spaces of the building, as it relates to the wellbeing and comfort of building occupants. In the past, the industry has generally focused on preventing contaminants from entering the building from outdoors and limiting the concentration of contaminants generated indoors. The United States of America's Environmental Protection Agency (EPA) monitors six common air pollutants in the outdoor air (known as criteria air pollutants).

Additionally, volatile organic compounds (VOCs) such as those produced by paints, fabric, foam, hairspray, air fresheners, perfumes, deodorants, cosmetics, photocopiers, fuels, cooking, and more are of concern.

Because the source of building contaminants varies, it is important to understand and treat the incoming outdoor air used for ventilation, along with the recirculated air inside the building.

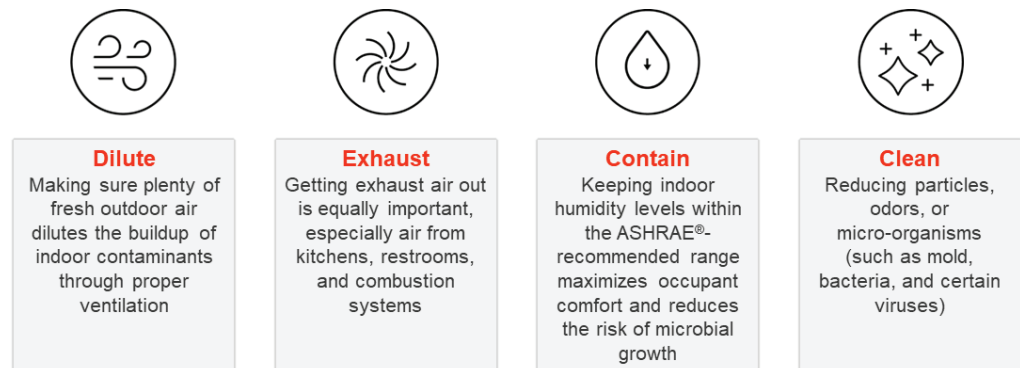
Reducing the Spread of Pathogens

Recently, IAQ quality has expanded to include the spread and propagation of pathogens throughout the occupied space, along with the role of pollutants in the spread of airborne pathogens. These pathogens spread when bacteria or viruses travel on dust particles or aerosolized droplets. For example, the size of a typical coronavirus is about 0.1 micron, these pathogens have been shown to travel on other particles to spread, such as: aerosols (up to 5 microns), droplets (>5 microns) and particulate matter.

HVAC systems can be designed to reduce the spread of pollutants and certain pathogens.

Trane recommends an approach that targets four critical areas that affect indoor air quality (Figure 2). This manual is primarily focused on the fourth critical area: *cleaning the air*.

Figure 2. Areas that influence the quality of indoor air
Image



Communicating Air Quality

Public health officials have created systems to communicate general air quality to the public. The Air Quality Index (AQI) is a tool developed by the United States Environmental Protection Agency (EPA) to communicate air quality. This is done with a numerical score, color-coded categorization, and written statements regarding air quality. Air quality monitoring stations are installed throughout the United States and are required in metropolitan areas exceeding 350,000 people. The AQI is calculated based upon 24 hours of data. Five major pollutants are factored into the AQI calculation.

- **Particulate Matter (PM)** which can be inhaled through the respiratory system. Smaller particles can become lodged within the lungs and produce respiratory and circulatory system problems such as heart attack, irregular heartbeat, and impact lung function.
- **Ozone** which has short- and long-term respiratory health effects.
- **Carbon Monoxide (CO)** inhalation can cause dizziness, confusion, unconsciousness, and death.

- **Nitrogen Dioxide (NO₂)** can irritate respiratory diseases. Long-term exposure may contribute to the development of asthma and other respiratory infections.
- **Sulfur Dioxide (SO₂)** exposure in the short-term is linked to difficulty breathing and increased asthma symptoms.

The AQI, descriptor, and color are illustrated below.

For information on how the AQI numerical value is calculated, see "Technical Assistance Document for the Reporting of Daily Air Quality" at the Airnow.gov website.

The NowCast uses an average of the previous 12 hours with weighting factors. It is designed by more responsive to current conditions, like those found in wildfire events.

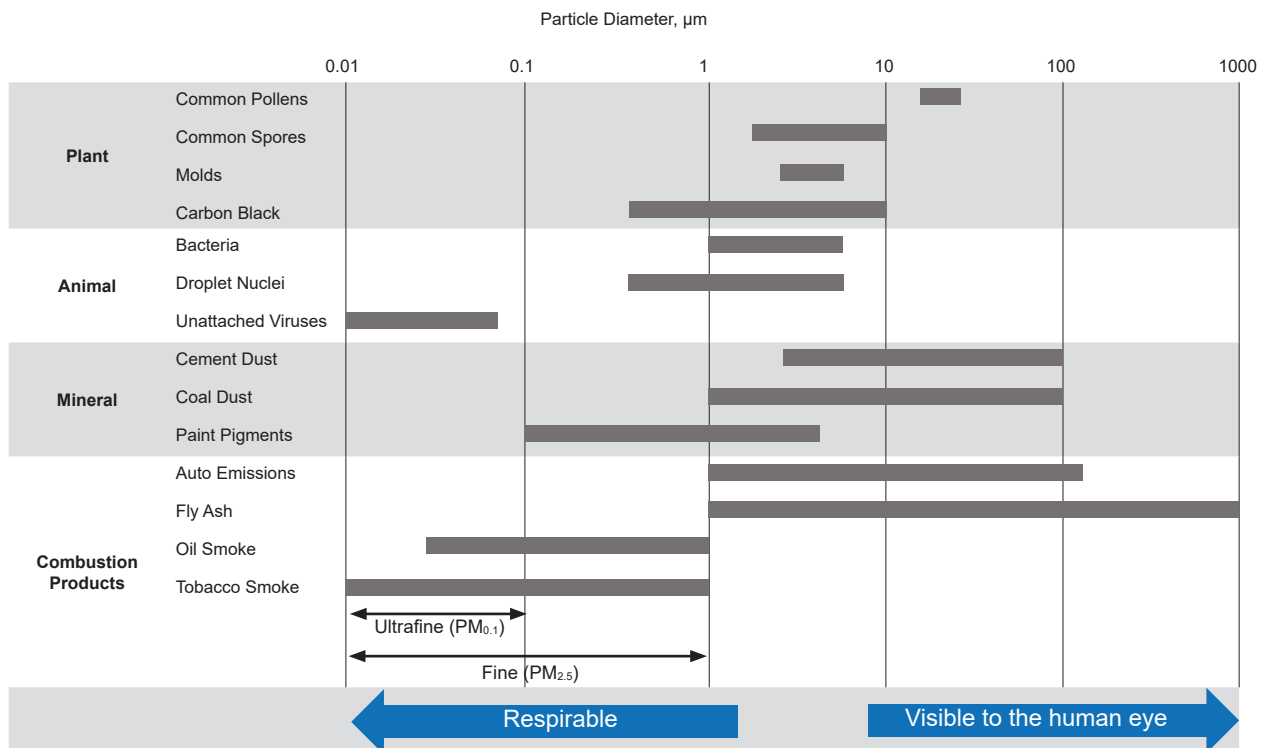
The AQI and NowCast can be accessed from www.airnow.gov. The interactive map can illustrate regional trends.

AQI	Descriptor	Color
0 to 50	Good	Green
51 to 100	Moderate	Yellow
101 to 150	Unhealthy for Sensitive Groups	Orange
151 to 200	Unhealthy	Red
201 to 300	Very Unhealthy	Purple
301+	Hazardous	Maroon

There are additional pollutant-specific cautionary statements for sensitive groups for different AQI values. Messages may include specific details for people who are sensitive or have existing health conditions, such as asthma, and heart disease.

Particulate Matter Sizing

Figure 3. Common particulate matter sizes



Microbiological Organisms

Biological, or microbial, contaminants describe a subset of airborne particles that originate from living or once-living organisms (e.g., bacteria, fungi, viruses). Inhaling these agents may cause occupants to experience hypersensitivity and allergic reactions, respiratory disorders, or infectious diseases.

Many of the larger biological particles, such as fungal and bacterial spores, are 3 microns to larger than 10 microns in size, which makes them easily captured with medium-efficiency particle filters. [Figure 3](#) shows the relative size of some common particles, including microbiological organisms. Other biological particles, such as viruses, are sub-micron in size and cannot be practically removed by particle filtration.

Particulate matter, also known as particle pollution or PM, is a complex mixture of extremely small particles and liquid droplets. Particle pollution is made up of several components, including acids (such as nitrates and sulfates), organic chemicals, metals, and soil or dust particles. Particulate matter (PM) is often measured using its diameter. [Figure 3](#) illustrates particle diameters for common pollutants. Particulate matter larger than 10 microns in diameter can be visible to the human eye.

Particulate matter is generally measured in microns or micrometers which is one millionth of a meter. The size of particles is directly linked to their potential for causing health problems. The industry is generally concerned about particles that are 10 microns in diameter and smaller because those particles can generally pass through the throat and nose to enter the lungs. Once inhaled, some of these particles can affect the heart and lungs and cause serious health effects.

Particle sizing is generally divided into three categories:

- Coarse—those particles at 10 microns and smaller (PM_{10}), such as human hair, skin flakes, dust, and pollens.
- Fine—particles 2.5 microns and smaller ($PM_{2.5}$), such as combustion products, bacteria, and fungi.
- Ultrafine—particles 0.1 microns and smaller ($PM_{0.1}$), such as vehicle emissions and viruses.

The dense concentration of this fine particulate matter is what makes air appear hazy and due to their size, they can travel deep into the lungs and cause health concerns. Airborne particulate matter varies by size, ranging from hundreds of microns to submicron.

ASHRAE® Standard 62.1: Ventilation and System Requirements

For more information on Indoor Air Quality, please refer to the Trane® white paper entitled, "Compliance with the Indoor Air Quality Procedure of ASHRAE® Standard 62.1" (IAQ-WPR001*-EN).

Note: This white paper was previously published as EDU-SLB038-EN.*

Ventilation refers to the introduction of outdoor air to dilute contaminants that are generated inside the building (by people, equipment, processes, or furnishings). Of course, the introduction of outdoor air requires the removal of an equal quantity of air from the building.

The "Ventilation Rate Procedure" (section 6.2) of ASHRAE® Standard 62.1, *Ventilation for Acceptable Indoor Air Quality*, prescribes the quantity of outdoor air that must be delivered to each zone, based on the expected use of that zone, and then prescribes how to calculate the outdoor airflow needed at the system level intake for many building types. Additionally, ASHRAE® publishes standards to cover the unique requirements of healthcare facilities (ASHRAE® Standard 170) and residential dwellings (ASHRAE® Standard 62.2).

Alternatively, the "Indoor Air Quality Procedure" (Section 6.3) of ASHRAE® Standard 62.1 can be used to determine ventilation airflows based on specified limits for design compounds and particulate matter. This procedure was revised and simplified in Addendum AA to Standard 62.1-2019. The revision allows designers to design the system so that it "shall be based on the design compounds and PM_{2.5}" listed in Table 6-5 of the standard along with other design compounds originating inside or outside of the building. The designer must perform a mass balance analysis to determine proper ventilation airflow and conduct a subjective evaluation to demonstrate at least 80 percent of the occupants are satisfied. This means the designer must identify design compounds and mixtures of compounds, and then establish a ventilation rate to ensure these contaminants are maintained below a prescribed design limit. If the analysis and subjective evaluation result in two different ventilation quantities, the designer is directed to utilize the larger value. This process does allow air cleaning devices to be utilized: "The IAQ Procedure (IAQP) is an alternative to the Ventilation Rate Procedure used to determine the design rate of outdoor airflow to maintain concentrations of design compounds (DCs) and PM_{2.5} in the indoor environment to be less than design limits, based on indoor and outdoor sources, air cleaning, and other variables." Compliance with the Indoor Air Quality Procedure of ASHRAE® Standard 62.1 IAQP: Updates and Examples" whitepaper (IAQ-WPR001*-EN) for additional information.

Identify Contaminants of Concern

The NAAQS can be found online and is republished in informative appendix D of Standard 62.1. Non-attainment areas are available in the EPA's Green Book. Real-time, daily, and historical air quality data collected by the EPA is available online. For more information, visit www.epa.gov or www.epa.gov/criteria-air-pollutants/naaqs-table.

It is important to understand which contaminants of concern are present in the outdoor air. This information can be used to make informed air cleaning device decisions helping ensure proper technologies are specified.

Section 4 of Standard 62.1 requires a survey of the local outdoor air be performed. If the building is within the United States of America, the standard requires the designer to determine compliance with the National Ambient Air Quality Standards (NAAQS) to identify whether the location is designated as "attainment" or "nonattainment". Attainment means the air quality is acceptable with respect to a specific contaminant.

Other jurisdictions may have additional authoritative resources which document local ambient air quality and contaminants of concern.

Next, the standard requires a local air quality observational survey of the building site and its surroundings be conducted. Air samples could be taken at the same times as the building is expected to be occupied to identify local contaminants that could be allowed to enter the building.

The results of the outdoor air quality surveys should be documented and reviewed with the building owner or owner's representative. A conclusion stating the acceptability of outdoor air quality and supporting information should be provided and utilized to make informed air cleaning decisions.

Additionally, Section 5 includes several requirements related to the design of the ventilation equipment and air distribution system.

Note: Because ASHRAE® 62.1 is under continuous maintenance, it can change frequently. This manual is based on the 2025 published version of the standard. Refer to the most current version of the standard for specific requirements.

LEED "Enhanced Indoor Air Quality Strategies"

One of the available strategies for earning the "Enhanced Indoor Air Quality Strategies" credit of LEED v4.1 is to install a MERV 13 (or higher) filter to clean the outdoor air prior to its introduction to the occupied spaces. Another one of the available strategies is to install a MERV 13 (or higher) filter to clean any recirculation air.

MERV 13 or Better Filter Recommendations during the COVID-19 Pandemic

ASHRAE®, REHVA, CDC, and similar organizations recommended the use of MERV 13 or better filtration at the onset of the COVID-19 pandemic to capture and remove particles that contain the SARS-CoV-2 virus to reduce disease spread and infection.

Filtration Requirements

Section 5.5 of Standard 62.1-2025 requires MERV 8 filtration upstream of any cooling and dehumidifying coil or other device with a wetted surface. This helps ensure that devices producing condensate is kept clean. The standard does exempt cooling coils that are designed and controlled to provide sensible cooling only (i.e., sensible cooling terminal units, chilled beams).

The results of the ambient air analyses are used to determine if better filtration is required. Section 6.1.4 of Standard 62.1-2025 requires a MERV 8 filter located in an area of the country that exceeds the U.S. EPA limit for airborne particles with a diameter of 10 microns or less (PM₁₀), or a MERV 11 filter if the limit for airborne particles with a diameter of 2.5 microns or less (PM_{2.5}) is exceeded.

ASHRAE® Standard 241

ASHRAE® published Standard 241-2023 "Control of Infectious Aerosols" in July 2023. The authors described the purpose:

"... to establish minimum requirements for control of infectious aerosols to reduce risk of disease transmission in the occupiable space in new buildings, existing buildings, and major renovations to existing buildings, including requirements for both outdoor air system and air cleaning system design, installation, commissioning, operation, and maintenance."

The Standard indicates that it is not designed to address the requirements of maintaining acceptable indoor air quality. This means that Standard 241 is not designed to replace Standards 62.1, 62.2, or 170. Instead, Standard 241 provides guidance on what to do in an epidemic situation, which is designated **infection risk management mode (IRMM)**. When a public health emergency has been declared, the HVAC system operation may be altered

to accommodate additional air cleaning, more ventilation, or a combination to achieve an equivalent clean airflow rate per person and reduce the risk of disease transmission.

To accomplish this, the standard provides a zone-based procedure to determine equivalent clean airflow (ECA) for a variety of mechanisms, including but not limited to: outdoor air for ventilation, filtered recirculated air, ultraviolet germicidal irradiation (UVGI) systems, in-room air cleaning systems, and other air cleaning technologies. The standard does not advocate specific air cleaning technology, or combination of technologies. Additionally, multiple mechanisms may be used to achieve the equivalent clean airflow rate required per person (ECAi) during IRMM. To do this, individual systems are independently evaluated, and the resulting values are then summed for comparison against the predetermined required equivalent clean airflow per person for infection risk mitigation.

The standard includes requirements for a building readiness plan (BRP) that describes how the system will achieve the target equivalent clean airflow for infection control. This plan is required to be accessible to operating personnel and occupants. Additionally, it is to be reviewed annually. Appendix E of the standard includes a template.

ASHRAE® Guideline 44

ASHRAE® Guideline 44 “Protecting Building Occupants from Smoke During Wildfire and Prescribed Burn Events” is intended to provide guidance on how to design and operate HVAC systems before, during, and after wildland fire events. The guideline explains that wildland fires are complex because they're often characterized by a dynamic combustion mixture featuring both natural and manmade materials under varying weather conditions. This yields a complex and dynamic mixture of gases and particulates that can be hazardous to human health. The guideline scope includes commercial, institutional, healthcare, and multi-unit residential buildings. There are specific suggestions for at-risk populations (e.g., children, elderly).

The guideline acknowledges that wildland fires produce smoke with varying composition of gases and particles. The guideline explains that while Standard 62.1 is concerned about criteria air pollutants, the largest health impact is on particulate matter with an aerodynamic diameter of 2.5 microns and smaller (PM_{2.5}). So much of the guideline focuses on mitigating the risk of particulates. The guideline uses the concept of keeping indoor PM_{2.5} levels **as low as reasonably achievable (ALARA)**. To accomplish this, the guideline focuses on two key principles: reduction of PM_{2.5} infiltration and removal of PM_{2.5} in the indoor air.

There are no U.S. federal government standards for indoor PM_{2.5} levels. Outdoors, the U.S. EPA National Ambient Air Quality Standard (NAAQS) sets the maximum annual mean level over three years to 9.0 micrograms per cubic meter (µg/m³) and the 24-hour is currently set at 35 µg/m³. (Note: in 2024, the NAAQS PM_{2.5} limit was reduced from 12.0 µg/m³ to 9.0 µg/m³.) The guideline discusses several different wildland fire events and measured PM_{2.5}

concentration values easily exceeding 300 $\mu\text{g}/\text{m}^3$. The guideline states, "such outdoor concentrations translate to indoor concentrations of 60 $\mu\text{g}/\text{m}^3$ or higher under the assumption of a 20% infiltration coefficient with no indoor $\text{PM}_{2.5}$ sources."

The guideline also recognizes the balance required when reducing outdoor air for ventilation and the need for fresh air to dilute and remove indoor contaminants: "It should be noted that the ALARA approach to indoor $\text{PM}_{2.5}$ may need to be balanced against other potential health hazards. For example, wildfires often occur during hot weather when indoor overheating can pose a significant health risk, especially for susceptible populations. In such cases, building operators may need to balance indoor $\text{PM}_{2.5}$ concentrations with occupant thermal safety. Similarly, wildfires may occur during periods of heightened risk for diseases caused by infectious aerosols, which may pose a significant health risk to some building occupants. In such cases, building operators may need to adjust the balance between outdoor air intake and recirculated indoor air." It is not recommended to completely shut off outdoor air systems or ventilation delivery.

Strategies for Smoke Readiness

The guideline discusses different strategies in section 5 for smoke readiness:

- Building envelope sealing and tightening (e.g., seal doors, windows, skylights, other envelope penetrations)
- Use high efficiency filters
 - Follow the Guideline 44 performance, calculation-based procedure or prescriptive procedure (MERV 13 or better)
 - Replace lower efficiency filters where possible
 - Replace filters as needed (frequency will increase during wildland fires)
 - Increase supply fan run times
 - Add portable air cleaning devices with high efficiency filters
 - Use high efficiency filtration, such as HEPA
 - As a starting rule of thumb, select a unit with a smoke clean air delivery rate (smoke CADR) equal to the room's square footage (e.g., a 100 square foot room can use a device with a CADR of 100 cfm)
 - Consider space sound requirements, as these devices tend to produce the highest sound pressure when operating at full airflow
 - Avoid air cleaning devices that produce ozone (Standard 62.1 requires any device that produces ozone to be certified with UL 2998, which has an ozone production limit of 5 parts per billion)
 - Add temporary supplemental filtration to outdoor air intakes by duct taping filters to unit inlets
- Maintaining positive building pressure compared to outdoors
 - Reducing outdoor airflow
 - Adjusting or limit exhaust fan operation to maintain positive pressure (e.g., bathroom exhaust, system relief)

- Temporarily disable airside economizer operation
- Temporarily disable demand-controlled ventilation
- Manual or automatic control

Recognize that filters will be loaded up more quickly during a wildland fire event with ash and will require frequent replacement. The guideline suggests that filters may need to be replaced every 2-3 days during an event and will need to be replaced with fresh filters upon wildland fire conclusion. This means that filters should be stockpiled onsite.

Smoke Readiness Plan

The guideline suggests that a Smoke Readiness Plan be developed to address building operation. The plan documents the steps and mitigation strategies before, during, and after a wildland smoke event to maintain IAQ. It includes a decision matrix on when to place the building in smoke-ready mode and what tasks must be accomplished for this. The guideline leaves activation of smoke readiness to the building management team understanding that needs vary from building to building. For example, the building may be placed into a smoke ready mode when there's current smoke or smoke forecast in the coming days. Or it may be implemented when there is current smoke and smoke forecast for the coming days. Alternatively, automated controls may monitor outdoor PM_{2.5} levels or connect to an internet-based service and activate smoke ready mode when a prescribed threshold is exceeded.

Increase Supply Airflow

One method to improve space indoor air quality is to provide more airflow. Providing clean air into the space will displace contaminated air and result in improved overall air quality. “Flushing” the airborne contaminants out is directly related to the air change rate. This metric, air change rate, is measured in air changes per hour (ACH).

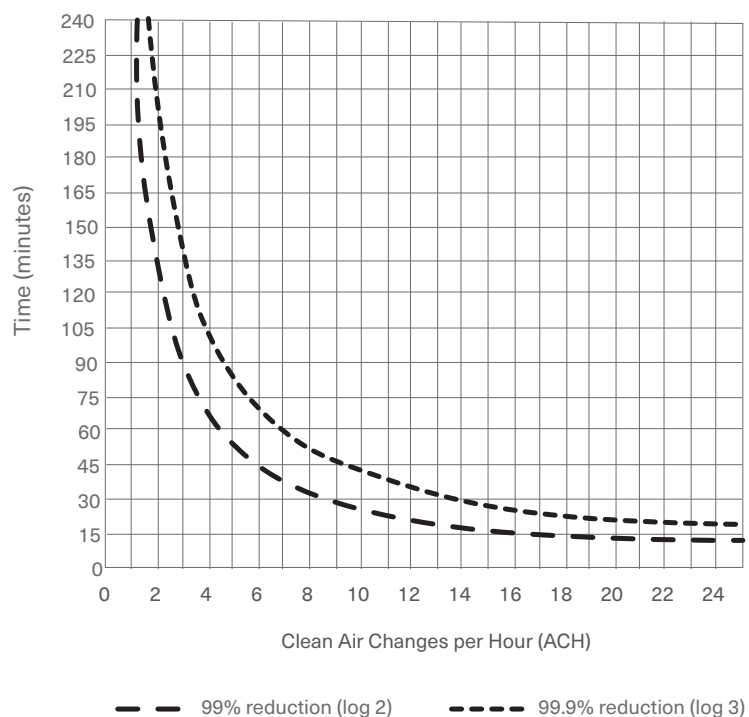
$$\text{Air changes per hour (ACH)} = \frac{\text{Clean airflow (cfm)} \times 60}{\text{Space volume (ft}^3\text{)}}$$

To calculate ACH, multiply take the supply air volume in cubic feet per minute (cfm), by 60 to convert to cubic feet per hour, then divided by the space volume in cubic feet. This air changes per hour value is used to quantify the rate air is replaced.

Impact of Air Change Rate

Figure 4 was developed from Chapter 9, Table 2 “Effect of Air Change Rates on Particle Removal” in the 2019 ASHRAE® Applications Handbook. This figure shows theoretical time it will take to remove 99 percent or 99.9 percent of airborne contaminants that are in a space by flushing it with clean air. How long it takes to reach each level of removal is a function of how often there is a clean air change in the space. For example, a system that provides ten air changes per hour will remove up to 99 percent of the airborne contaminants in 30 minutes and up to 99.9 percent in about 45 minutes.

Figure 4. Theoretical time to clean space with air



Consider Air-to-Air Energy Recovery

In many applications, air change rate requirements may exceed the supply airflow needed to offset the thermal loads. Many times, the supply air must be dehumidified to a specific dew point temperature then reheated to prevent over-cooling the space. The supply air volume will increase as air change rate requirements increase. As a result of this, air may not need to be delivered at a cold temperature and reheat needed to temper the air. Consider the use of air-to-air energy recovery as a method to reheat the air without the initial need for fossil fuel reheat.

There are many considerations when applying air-to-air energy recovery. See the *Air-to-Air Energy Recovery in HVAC Systems* applications engineering manual (SYS-APM003-EN) for more information.

How Many Air Changes are Required?

Certain buildings and spaces may have prescribed air change rate requirements based upon the application. For example, healthcare applications and laboratories may have specific minimum air change requirements in addition to minimum ventilation rate requirements. Verify air change rate requirements with cognizant authorities, standards, and codes.

Air Cleaning Technologies

There are a variety of air cleaning technologies available in the marketplace to serve different needs. These range from particulate filters to electronic air cleaning systems. Commonly applied technologies are discussed, but it is important to understand that this is not a comprehensive list.

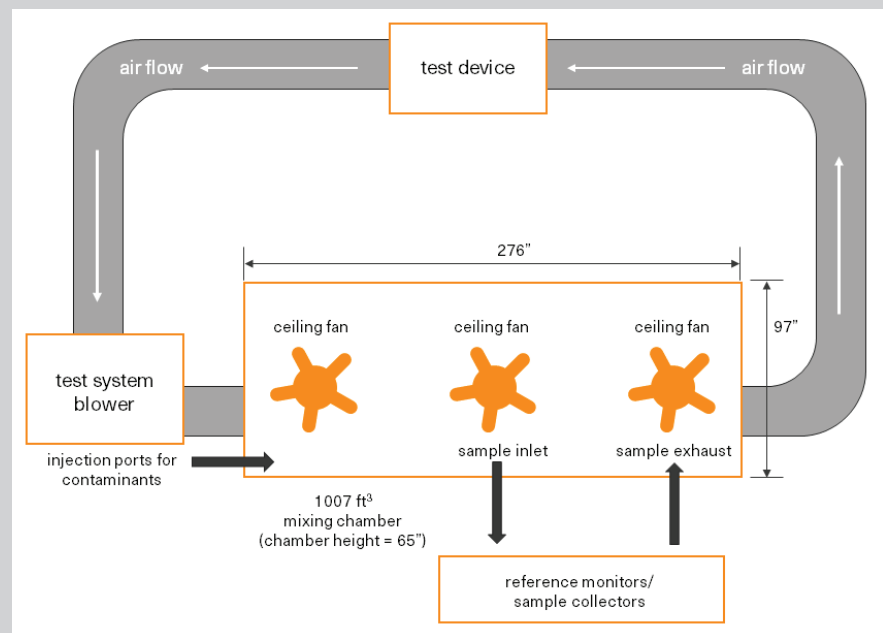
Trane® Air Cleaning Device Testing

Beginning autumn 2020, Trane Technologies started independent testing on air cleaning devices. Testing was conducted by LMS Technologies, Inc, an independent, third party air media and filter testing company serving multiple industries including aerospace, medical, automotive—and HVAC.

Technologies tested include particulate filtration, bipolar ionization devices, dry hydrogen peroxide devices, photocatalytic oxidation, and ultraviolet germicidal irradiation.

Comparative evaluation of IAQ technologies was performed for two applications: in-duct (within the HVAC system) and in-room (standalone solution within the space).

Testing was conducted on multiple technologies to determine their efficacy for removal of certain viruses, bacteria, VOCs, and particles [small (15-650 nanometers) and very small (< 100 nanometers)]. Byproduct generation was also monitored (ozone, ions, etc.). In all cases, testing was conducted in a 1,007 ft³ mixing chamber, as depicted below. Specific whitepapers detailing the results of the testing are listed in the references section of this manual.



What is MERV and MERV-A?

Particulate filter efficiency was historically expressed in terms of “dust-spot efficiency”. Dust-spot efficiency was defined by ASHRAE® Standard 52.1 and related to the amount of atmospheric dust that a filter could capture. ASHRAE® 52.1 is now obsolete and has been replaced by ASHRAE® Standard 52.2. The minimum efficiency reporting value (MERV) is defined by ASHRAE® 52.2 and expresses how efficiently a filter removes particles of various sizes, from 0.3 to 1 micron.

The scale ranges from MERV 4 to MERV 16 with larger numbers indicating a better ability to capture particles.

The MERV-A rating is defined by Appendix J of ASHRAE® Standard 52.2. Many filters have an electrostatic charge applied during manufacture to increase filtration efficiency with a lower air pressure drop. As the filter loads with particles, the electrostatic charge dissipates and the resulting filtration efficiency generally decreases. The filter's MERV rating is based upon *initial* efficiency when the electrostatic charge has not yet dissipated. The MERV-A rating uses an optional preconditioning step that partially neutralizes the filter's static charge *prior* to testing. Filters which have been tested with this optional methodology should be designed as such. For example, “MERV-A 13-A.”

For more information on the various types of particulate filters, refer to Chapter 29 “Air Cleaners for Particulate Contaminants,” in the *2020 ASHRAE® Handbook – HVAC Systems and Equipment* (www.ashrae.org), the Trane® Engineers Newsletter Live program titled “Air Cleaning Technologies for Indoor Air Quality” (APP-CMC078-EN), and the *NAFA Guide to Air Filtration* (www.nafahq.org).

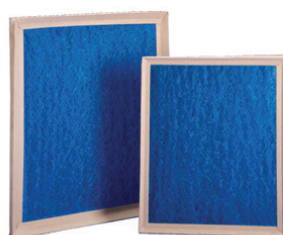
Filters

A requirement of the HVAC system is to ensure that the air delivered to the conditioned space is relatively clean. This improves system performance (by keeping the coils cleaner, for example) and keeps the air distribution system relatively clean.

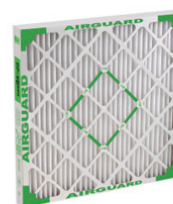
Airborne particulates vary in size, ranging from submicron to 100 microns (µm) and larger. Many types of particle filters are available. Some are designed to remove only large particles, while others—high-efficiency particulate air (HEPA) filters, for example—also remove particles with diameters less than one micron.

Figure 5. Filter types

Panel (up to MERV 13)



Pleated (up to MERV 13)



Bag/Pocket (up to MERV 16)



Cartridge (up to MERV 16, HEPA, ULPA)



Source: Images used with permission from Parker HVAC, a division of Parker Hannifin Corporation (<https://www.parker.com/>).

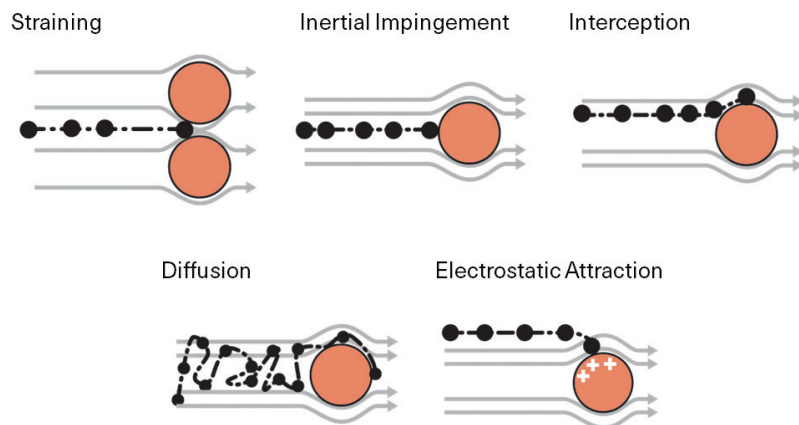
Filters can be obtained in a variety of sizes and configurations. The designer must select the filter type upon determining the required filter efficiency. There are several applications, including panel, pleated, bag, cartridge, and some hybrid models. Most are offered in different filter depths, multiple efficiencies, different air pressure drop levels, and other design features. As a result, it is possible to select a two-inch MERV 13 pleated media filter or a 30-inch MERV 13 bag filter. While they are both rated at MERV 13, these filters do not perform identically with respect to particle capture, life expectancy, or airflow resistance. Thinner filters often require more frequent changeouts and have a higher resistance to airflow, increasing their air pressure drop.

Panel and pleated filters are frequently chosen for their low first cost and limited space requirements. The designs are typically offered in 1-inch, 2-inch, and 4-inch depths. Their frames are often made of fiber board and are more susceptible to moisture and handling damage. Often, these filters are used as pre-filters in systems with both pre- and post-filtration. These filters are often available up to MERV 13 efficiency.

Bag or pocket filters offer very high particle capture efficiencies with large dirt holding capacities. To provide these attributes, these filters often require the largest amount of space in the HVAC system with common depths ranging from 12 to 30 inches. Some manufacturers offer supported bag filters which can work in VAV applications if space is available. Typical filter efficiencies range MERV 8 to 16.

Cartridge or box filters are offered with rigid frames that allow easier installation, compared to bag and pocket filters. Often, a cartridge or box filter weighs more than a comparable bag filter as a result. Typical filter depths range from 4 to 12 inches. They are more resistant to moisture and handling damage. Typical filter efficiencies range from MERV 8 to 16 units. Additionally, HEPA and ULPA filters are available in this configuration.

Figure 6. How filters work



Filters employ five methods to capture particles:

- **Straining.** The largest particles are strained when they are too large to pass through openings between filter media fibers.
- **Inertial impingement.** Large particles do not follow the air stream around filter fibers. Instead, they strike the fiber and remain there when the attraction between media and particle is strong enough to hold it there.
- **Interception.** Particles follow the airstream and pass closely to a filter fiber. The particle contacts the fiber and remains there due to Van der Waals forces—a weak attraction.
- **Diffusion, also called Brownian Motion.** Very small particles follow erratic paths as they collide and bump into gas molecules in the air. Throughout this erratic path, they end up being captured by a filter fiber.
- **Electrostatic attraction.** Particles and/or filter fibers are charged, and particles are attracted to a filter fiber as opposite charges attract.

Table 1 identifies common types of particulate filters and their typical applications.

Table 1. Application guidelines for various filter types

MERV ¹	Examples of contaminants controlled	Example applications	Example air filter/cleaner types
IEST Type F (99.999% on 0.1 to 0.2 µm particles) IEST Type D (99.999% on 0.3 µm particles) IEST Type C (99.99% on 0.3 µm particles) IEST Type A (99.97% on 0.3 µm particles)	n/a n/a n/a n/a	≤ 0.30 µm particles Virus (unattached) Carbon dust Sea salt All combustion smoke Radon progeny	- Cleanrooms - Radioactive materials - Pharmaceutical manufacturing - Carcinogenic materials - Orthopedic surgery
MERV 16 MERV 15 MERV 14 MERV 13	0.3 to 1.0 µm size range - Bacteria - Smoke (ETS) - Paint pigments - Face powder - Some virus - Droplet nuclei - Insecticide dusts - Soldering fumes	- Hospital general ventilation - Day surgery, general surgery - LEED commercial buildings - Smoking lounges - Turbo equipment, compressors - Welding, soldering - Prefiltration for HEPA filters	Box-style wet-laid or lofted fiberglass, box-style synthetic media, mini-pleated synthetic or fiberglass paper, depths from 2 to 12 in. Pocket filters of fiberglass or synthetic media, depths from 12 to 36 in.
MERV 12 MERV 11 MERV 10 MERV 9	1.0 to 3.0 µm size range - Milled flour - Lead dust - Combustion soot - Legionella - Coal dust - Some bacteria - Process grinding dust	- Commercial buildings - Schools - Gymnasiums - Better residential buildings - Industrial air cleaning - Food processing facilities - Air separation plants - Prefiltration for higher-efficiency filters	Box-style wet-laid or lofted fiberglass, box-style synthetic media, mini-pleated synthetic or fiberglass paper, depths from 2 to 12 in. Pocket filters either rigid or flexible in synthetic or fiberglass, depths from 12 to 36 in.
MERV 8 MERV 7 MERV 6 MERV 5	3.0 to 10.0 µm size range - Pollens - Earth-origin dust - Mold spores - Cement dust - Powdered milk - Snuff - Hair spray mist	- General HVAC filtration - Commercial property - Schools - Paint booth intakes - Industrial equipment filtration - Electrical, phone equipment protection - Prefiltration for high-efficiency filters	Wide range of pleated media, ring panels, cubes, pockets in synthetic or fiberglass, disposable panels, depths from 1 to 24 in.
MERV 4 MERV 3 MERV 2 MERV 1	> 10.0 µm size range	- Protection from blowing large particle dirt and debris - Industrial environment ventilation air	Inertial separators

1 Minimum Efficiency Reporting Value (MERV) is defined by ANSI/ASHRAE® Standard 52.2-2017, *Method of Testing General Ventilation Air-Cleaning Devices for Removal Efficiency by Particle Size*. Source: 2020 ASHRAE® Handbook—HVAC Systems and Equipment, Chapter 29, Table 3. American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., www.ashrae.org

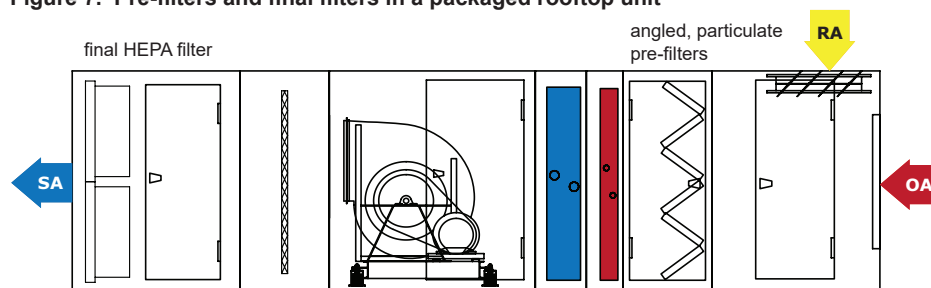
Key factors to consider when selecting filter types for a specific application include:

- **Target particle size and degree of cleanliness required (collection efficiency).** The “collection efficiency” of a particulate filter is a function of how well it removes particles of various sizes. Filters with higher efficiencies remove a higher percentage of particles, and smaller particles, than filters with lower efficiencies. Since particulate contaminants vary in size, it is important to define the contaminants of concern for a given facility when selecting the type of filter to be used.
- **Allowable airside pressure drop.** A direct correlation usually exists between collection efficiency and airside pressure drop. Generally, a filter with a higher efficiency will cause a higher pressure drop in the passing air stream, increasing fan energy use. The number of pleats in a media filter determines the surface area of the media. In general, the more surface area, the lower the airside pressure drop.
- **Dirt-holding capacity.** Dirt-holding capacity is an indication of how much dirt the filter will hold at the “dirty” (or final) pressure drop. This indicates how often the filter will need to be replaced. In general, a filter with more media surface area will hold more dirt and will need to be replaced less frequently. (This varies with the brand of filter.)
- **Available space.** In general, filters with higher efficiencies, lower airside pressure drop, and/or greater dirt-holding capacity, require more space than filters that perform more poorly in these categories. This can impact the physical size of the packaged rooftop unit or air-handling unit.
- **Available budget.** The cost of a filter is impacted by its media surface area, materials of construction, environmental operating conditions, and performance. This impacts both the installed cost and maintenance (replacement) cost of the filter system.

Pre-filters

In some system configurations, the mixture of outdoor air and recirculated return air passes through a pre-filter to remove many of the airborne particulate contaminants. Locating these filters upstream of the heating and cooling coils (Figure 7) helps keep the coils cleaner for a longer period and allows the system to operate more efficiently.

Figure 7. Pre-filters and final filters in a packaged rooftop unit



Source: Image adapted from Trane Select Assist program.

ASHRAE® Standard 62.1-2025 (Section 5.5) requires that a filter with a MERV rating of at least 8 be installed upstream of all wet surfaces, including cooling coils. In general, this requirement can be met with many standard “throwaway” or “pleated” filters (Table 1). However, when a higher level of filtration is desired, bag or cartridge filters are sometimes used. Bag or cartridge filters typically cost more than pleated filters, which may make them a good candidate for using a pre-filter to extend their useful life. To maintain the desired level of cleanliness and minimize system energy use, never operate the rooftop or air-handling unit without the filters in place, especially during construction of the building. Filters used during construction should be replaced prior to building occupancy.

It is important to maintain and replace filters as recommended by the manufacturer. Typically, filters are replaced based on the length of time in operation or on the measured air pressure drop across the filter. A differential pressure sensor (switch) can be used to indicate when the filters are dirty (the pressure drop exceeds a pre-determined limit) and can send an alarm to the building automation system to indicate that they need to be replaced. The replacement filters should have similar performance characteristics as the filters originally specified by the design engineer. Critical characteristics include efficiency (MERV rating, for example), airside pressure drop at the desired operating airflow, and physical size.

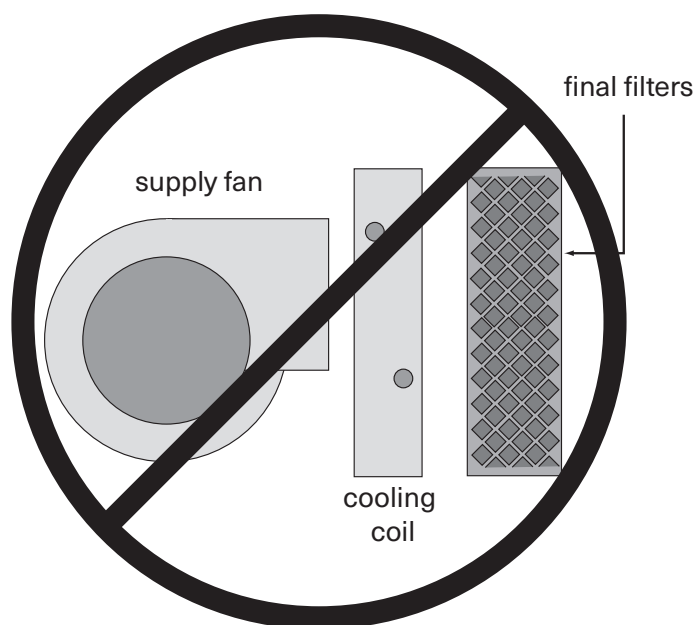
In addition, air bypass can reduce the effectiveness of the filtration system. During replacement, the filter assembly should be carefully inspected to identify any areas that can allow air to bypass around the filters. These areas should be sealed (with tape or gasketing, for example) to minimize airflow through the space between adjacent filters.

Final Filters

Some applications, such as certain areas of hospitals, clinics, laboratories, or manufacturing facilities require final filters located downstream of all other components in the rooftop unit ([Figure 7](#)).

When HEPA (high-efficiency particulate air) filters are used, locate them in the farthest downstream section of the unit. If these high-pressure-drop filters are located upstream of the supply fan, the pressure inside the unit casing—between the filters and fan inlet—will likely be at a *significantly negative* pressure with respect to the outdoors. Any air that leaks into the rooftop unit at this location will introduce particles from outdoors downstream of the high-efficiency filters, negating some of the benefit of using final filters.

Figure 8. Avoid combining a blow-thru supply fan with final filters



Finally, if possible, avoid combining final filters with a blow-thru supply fan—that is, where the cooling coil is located between the supply fan and final filters ([Figure 8](#)). Systems with this configuration often experience problems with final filters getting wet due to moisture carryover. Experience indicates that this problem can often be minimized by using a draw-thru supply fan—where the supply fan is located between the cooling coil and the final filters—or by adding a few degrees of heat to the air before it passes through the final filters.

Charged Filters

Some particulate filters use electrostatic attraction to enhance efficiency. These electronic air cleaners are either passively charged (electret) or actively charged (electrostatic precipitators). Passively charged filters are standard panel or pleated media filters that receive an electrostatic charge to the media during the manufacturing process. This charge increases the efficiency rating by one to two MERV levels and typically dissipates over time. The MERV-A rating system is used to describe the filter's performance without the electrical charge. For more information on MERV-A, see the sidebar on [page 19](#).

Actively charged air cleaners (electrostatic precipitators) include an active electrical field that charges the media and, in some cases, the particles, as they enter the filter system. This can greatly improve the fine-particle collection efficiency and, in some cases, the dirt-holding capacity of the filter system. Some types of electrostatic precipitators are cleanable, which significantly reduces the cost of system maintenance.

The benefit of this technology is higher collection efficiency and increased dust-holding capacity at a lower airside pressure drop. The primary drawback is an increase in first cost, and it typically increases the cost and size of the air-handling unit. Many actively charged electrostatic precipitators are not MERV-rated but are rated by collection efficiency at a specific particle size (99.8 percent efficient at capturing 0.5-micron particles, for example).

Gaseous Phase Air Cleaning

The presence of undesirable gases and vapors (particularly carbon monoxide, radon, oxidants, and volatile organic compounds, or VOCs, such as formaldehyde) indoors can be detrimental to building occupants, materials, and contents. Controlling VOC concentrations is particularly challenging—hundreds of them are present (often at very low concentrations), few are unique to any one source, and there are many potential sources, some of which emit several VOCs and at various generation rates.

A common way to control the concentration of gaseous contaminants indoors is to dilute them with outdoor air. This approach is appealing because many VOCs defy individual treatment. However, it is only practical if the quality of the outdoor air is suitable, and if the resulting supply airflow is consistent and appropriate and if it mixes effectively with the air in the occupied space.

Removal of gaseous contaminants typically relies on the principles of adsorption, oxidation, or catalysis. Of these, adsorption is the most common.

The media used for adsorption depends on the contaminants to be removed ([Table 2](#)). Of these, granular, **activated carbon** is the most widely used. This typically involves installation of a pleated panel or packed-bed media in the air stream ([Figure 9](#)).

For more information on the various types of gaseous air cleaners, refer to Chapter 30, "Air Pollution Control and Industrial Process Cleaning," in the *2024 ASHRAE Handbook – HVAC Systems and Equipment* (www.ashrae.org), the Trane Engineers Newsletter Live program titled "Air Cleaning Technologies for Indoor Air Quality" (APP-CMC078-EN), and the *NAFA Guide to Air Filtration* (www.nafahq.org).

All types of gaseous air cleaners require medium- to high-efficiency particle filtration (typically MERV 13 or higher) upstream to keep the media or catalytic surfaces clean.

Figure 9. Activated carbon



pleated panel impregnated
with activated charcoal



packed-bed media filled with granular
activated charcoal (shown with pre-filters)

Source: Images used with permission from Parker HVAC, a division of Parker Hannifin Corporation (<https://www.parker.com/>).

Carbon filtration can reliably remove a variety of gases and odors from the air stream. Application considerations include:

- The activated carbon media adds a pressure drop to the airside system, which increases fan energy use.
- Lower air velocity is required through the bed (typically 250 to 300 fpm [1.3 to 1.5 m/s]) for effective operation, often increasing the size of the air-handling unit.
- Filtration efficiency is reduced by high humidity levels.
- Activated carbon does not remove some gases, such as carbon monoxide or carbon dioxide.
- The technology requires frequent maintenance to ensure expected performance and is messy.

No single media works for all gaseous contaminants ([Table 2](#)), so it is important to define the contaminants of concern for a given facility. In addition, the lack of standard performance ratings makes it difficult to effectively evaluate and apply gaseous air cleaners.

Table 2. Recommended removal media for gaseous contaminants

Contaminant	Activated Carbon	Potassium Permanganate Impregnated Media	Caustic Impregnated Carbon	Phosphoric Acid Impregnated Carbon
Acetic acid	•	•	•	
Acetone	•			
Acrolein	•	•		
Amines				•
Ammonia				•
Benzene	•			
Chlorine	•		•	
Ethyl alcohol	•			
Formaldehyde		•		
Gluteraldehyde	•	•		
Hydrogen cyanide			•	
Hydrogen sulfide		•	•	
Methyl alcohol	•	•		
Mercaptans	•	•		
Methylene chloride	•			
Methyl ethyl ketone	•			
Nitric oxide		•		
Nitrogen dioxide		•		
Ozone	•			
Sulfur dioxide		•	•	
Sulfur trioxide		•	•	
Toluene	•			

Source: NAFA Guide to Air Filtration, 6th Edition, Figure 11.4 © National Air Filtration Association, www.nafahq.org

Bipolar Ionization

Ozone Generation Requirements

Some standards and codes reference separate standards for maximum ozone limits. Two common standards in North America are UL 867 and UL 2998. The former limits ozone to 50 parts per billion (ppb) and the latter limits ozone to 5 parts per billion. ASHRAE® Standard 62.1-2025 references UL 2998 in its ozone requirements, effectively limiting air cleaning device ozone production to 5 ppb.

Bipolar ionization devices use electricity to create a local plasma field that extends three to five feet beyond the device and has strong electrostatic interactions. When the air passes through the device, atoms or molecules acquire an electrical charge, a process called ionization. Manufacturers claim oppositely charged dust particles attract to one another and form larger particles, a process called agglomeration. As a result, the larger particles are easier to capture in filters or fall out of the air.

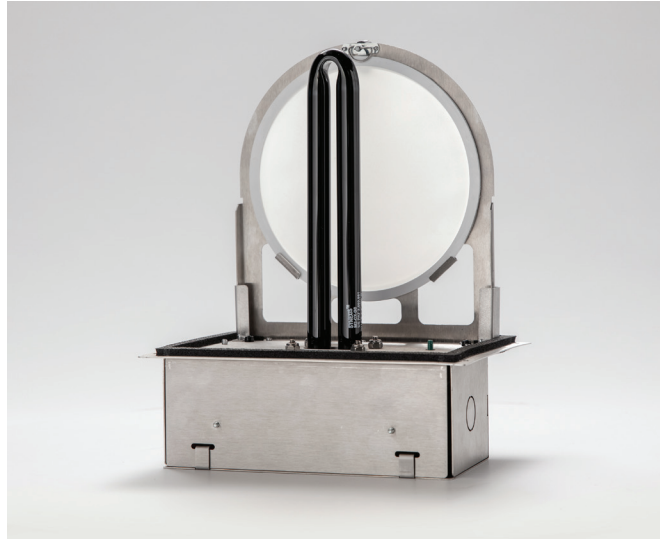
Some devices, particularly older models, have the potential to create ozone, which is widely accepted to be harmful to humans. ASHRAE® Standard 62.1-2025 now requires air cleaning devices comply with UL 2998, which limits ozone production to less than 5 parts per billion.

Bipolar ionization devices can be installed in a variety of units, including ventilation systems, terminal units, ductwork, and in the occupied space.

Unit manufacturers claim the technology increases the effectiveness of lower-MERV rated filters due to agglomeration. They also claim effective airborne pathogen mitigation for viruses and bacteria. The technology typically has a very low air pressure drop, meaning there is little impact to unit fan operation.

Dry Hydrogen Peroxide

Figure 10. Duct-mounted dry hydrogen peroxide air cleaning



Liquid hydrogen peroxide is commonly used as an antiseptic. Some technologies vaporize liquid hydrogen peroxide and disinfect an unoccupied room, while other technologies produce hydrogen peroxide at dosages less than Environmental Protection Agency (EPA) safety limits. These other technologies produce airborne “dry” hydrogen peroxide without vaporizing a concentrated solution. Often, a photocatalytic reaction created by a UV-A bulb is used to separate hydrogen and oxygen atoms from water molecules in the airstream passing through a device to create gaseous hydrogen peroxide. The hydrogen peroxide molecules oxidize a microbe’s cell membrane and disrupt its chemical structure to inactivate the pathogen. Devices may be installed with a filter to help ensure the catalyst stays clean. The technology itself has a low air pressure drop, however this increases when an upstream filter is used.

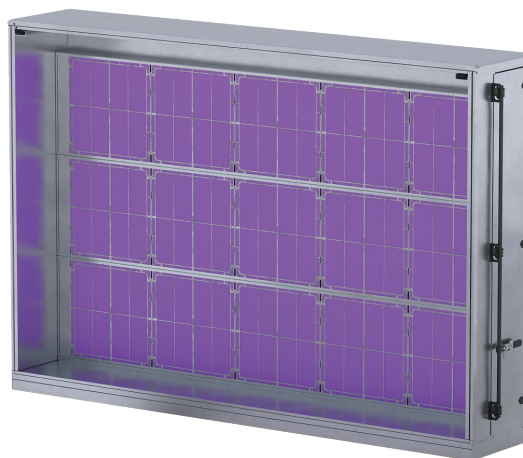
Manufacturers claim dry hydrogen peroxide is effective against air- and surface-borne microbiological organisms. They also claim the technology is effective at reducing VOCs and odors. Devices can be installed in a variety of locations, including inside equipment, inside ductwork, or standalone. Devices should be installed as close as possible to the occupied space to ensure the largest amount of dry hydrogen peroxide reaches the zone. Standalone units can operate continuously and independently of HVAC systems.

Dry hydrogen peroxide systems do not reduce particulate matter so they may be paired with filters. Systems do require periodic maintenance to replace the photocatalytic system and any unit filters.

For more information on photocatalytic oxidation (PCO), refer to the Trane engineering bulletin, "Trane Catalytic Air Cleaning System" (CLCH-PRB023-EN).

Photocatalytic Oxidation

Figure 11. Photocatalytic oxidation technology

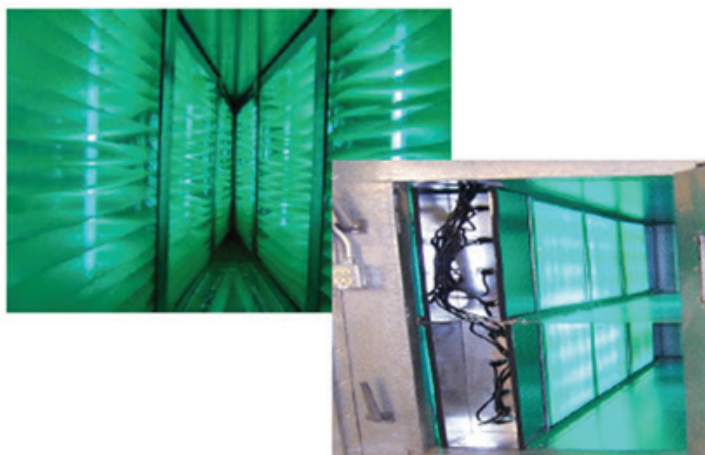


Photocatalytic oxidation (PCO) uses ultraviolet light shining on the surface of a catalyst, commonly a bed of titanium dioxide (TiO_2), to create highly reactive hydroxyl radicals. The cells of microbiological organisms that contact these hydroxyl radicals are destroyed through a process called lysis (destruction of the cell by rupturing its membrane or cell wall). Biological organisms also create low levels of VOCs, which typically cause odors.

Some PCO technologies can be used to remove VOCs from the air stream. VOCs are adsorbed onto the surface of the catalyst. Ideally, this process oxidizes all the organic compounds into carbon dioxide (CO_2) and water (H_2O).

PCO technology can be applied directly to the air stream since it has a very low airside pressure drop and the reaction takes place at ambient temperatures (Figure 12). The primary drawback is high installed cost and the operating costs associated with cleaning, replacing, and disposing of the UV lamps.

Figure 12. Photocatalytic oxidation (PCO)



UVGI Rating Value (URV)

The UVGI Rating Value (URV) metric has been proposed as a convenient method to correlate UVGI dosage with a numerical value, like the usage of MERV with air filters. This proposal was made in the early 2000s and while it has not been formally adopted by an organization, it is sometimes used. In addition to the numerical rating and dosage correlation, common pathogen inactivation rates have been added. Because this metric has not been adopted by an industry trade organization for development and maintenance, its usage should be exercised carefully.

Table 3. URV ratings to determine UV intensity for pathogen kill rates

URV	Dose $\mu\text{J}/\text{cm}^2$
1	1
2	10
3	20
4	30
5	50
6	75
7	100
8	150
9	250
10	500
11	1,000
12	1,500
13	2,000
14	3,000
15	4,000
16	5,000
17	6,000
18	8,000
19	10,000
20	20,000

For more information on the benefits and concerns related to using UV-C lights in HVAC systems, including recommendations and precautions when they are used, refer to the Trane engineering bulletin titled “Using Ultraviolet Light to Control Microbial Growth in Buildings” (CLCH-PRB014-EN) or Chapter 17, “Ultraviolet Lamp Systems,” in the 2020 ASHRAE® Handbook—HVAC Systems and Equipment (www.ashrae.org).

Ultraviolet Germicidal Irradiation

Ultraviolet germicidal irradiation, sometimes abbreviated as UV, GUV, or UVGI is used to produce a chemical reaction in several of the previous technologies, but it also has a germicidal effect. Given sufficient dose (time and intensity), C-band **ultraviolet energy (UV-C)** can inactivate (kill) microorganisms. UVGI devices emit energy which damages cell DNA and RNA preventing the organism from replicating.

In applications where sufficient residence times exist, such as on stationary surfaces, it is possible and often practical to deliver a “killing” dose of UV energy to the organism. In this application, the UV-C lamps are sized and positioned inside the air-handling unit to irradiate interior surfaces and components (typically the cooling coil and condensate drain pan) to limit fungal and bacterial growth on those stationary surfaces. Today, a combination of mercury-vapor and LED fixtures are used to produce the energy.

In addition to helping control microbial growth on surfaces, UV-C lights are sometimes applied to inactivate microbes in moving air streams (referred to as airborne, or “on-the-fly,” kill). The high air velocity through most air-handling units or air distribution systems requires the use of much higher intensity lamps to deliver the required dose of UV energy to the moving microbes (Figure 13). This approach has been effectively applied in some health care applications with specially designed low velocity air systems. However, it is typically impractical for most conventional HVAC systems.

The required dose of UV-C light varies widely depending on the type and form of the microorganism. Viruses require a much lower dose of UV energy than spore forms of fungi (such as mold) and bacteria.

UVGI dosage is equal to the average irradiance multiplied by time.

$$D_{uv} = I \times t$$

Where:

I = average irradiance in $\mu\text{J}/\text{cm}^2$

t = time, seconds

The required dosage to inactivate microbiological organisms vary by species and type. The average irradiance is often expressed as microwatts per square centimeter and the exposure time is expressed in seconds. In an application where the microbiological organism is in the airstream, passing by the UVGI lamp, the dosage is assumed to be single pass, therefore inactivating it by the end of the pass. As the distance between the fixture and the surface or airstream increases, the dosage decreases. As a result, single pass “fly-by” applications that are meant to treat airflow require a large amount of UVGI dosage compared to stationary applications.

UVGI works well for inactivating microbiological organisms, but it does not capture particulate matter. So, it is still often paired with a filtration system. UVGI fixtures do need to be replaced when their energy output degrades below manufacturer-specified levels. As a result, bulbs must be accessible for inspection and replacement.

If using UV-C lamps in air-handling units, be aware of the following safety and material considerations:

- **Include interlock switches and warning signs at each entry location.** UV-C energy poses a significant health hazard to unprotected human skin and eyes. To safeguard against inadvertent exposure by operators or maintenance personnel, electrical interlock switches should be provided at all entry locations to the air-handling unit to disconnect power to the lamps when a door is opened. Industry-recognized warning signs should also be placed at all entry locations.
- **Substitute or shield any susceptible materials.** UV energy can also prematurely age many polymeric (plastic) materials. Susceptible materials (such as electrical wiring insulation, gaskets, caulk and sealants, and insulation) near the lamps should be shielded from direct exposure to the UV energy or substituted with other materials. Failure to properly protect these materials can result in serious safety and equipment reliability issues.
- **Clean and replace lamps as specified by the manufacturer.** Proper maintenance, including periodic cleaning of the lamp surface (typically every three months), is important to keep the UV lamps operating effectively. The UV intensity degrades over time, so lamps need to be replaced at intervals specified by the manufacturer (typically every 9000 operating hours, or annually). Since UV lamps contain mercury, which is a regulated hazardous waste, disposal of lamps is subject to state and federal regulations.

Figure 13. UV-C installation in an air handler



Additional UV-C Technologies (Upper Air)

Inside HVAC equipment, UVGI fixtures might be installed downstream of the cooling coil for airstream cleaning. Or they could be installed in a duct system to treat the passing air. In addition, there are some applications where UVGI is applied in the occupied space. One variant irradiates surfaces and the air, only when the space is unoccupied. Another variant, called an upper-air system, irradiates the air above head-level in the space, during occupied and unoccupied periods.

An upper air fixture does not treat surfaces, like tables, desks, and furniture in the occupied space. If a UVGI fixture does shine downward onto these surfaces, it can only be used when the space is unoccupied. And it is important to consider what materials comprise the surfaces and furniture that are being irradiated to ensure degradation does not occur.

Irradiance Levels Vary Based Upon Application

In a stationary application where UVGI is designed to shine upon a cooling coil and provide surface cleaning, the irradiance will not need to be as great, because the lamps are shining on the surface continuously. However, in an application where a stream of air must be disinfected, time is short. As a result, the irradiance must increase. And it is important to consider whether this “fly-by” application is at a cooling coil, where velocities might be around 500 feet per minute, or in a duct system where the velocity could be much higher! Surfaces inside the air handler, rooftop, or ductwork can reflect the UVGI energy, affecting dosage. As a result, it is a good idea to work with a manufacturer to design and size UVGI systems.

Air Cleaning Technology Testing and Safety

The industry has developed many safety and test standards covering various air cleaning technologies. There are different test standards to cover the wide range of air cleaning technologies and different installation methods. The test standards are designed to help users understand how well the technology performs using an industry-developed standard. Safety standards are generally designed to evaluate a specific technology and limit potentially harmful byproduct generation.

Table 4. Common North American Air Cleaning Technology Safety and Test Standards

Industry Standard	Title	Scope	Primary Claim Type	Application Considerations
AHAM AC-1	Method for Measuring Performance of Portable Household Electric Room Air Cleaners	Method for measuring the performance of portable household electric room air cleaners, commonly including Clean Air Delivery Rate (CADR) testing for smoke, dust, and pollen in a controlled environment.	Portable room air cleaner performance / CADR	Most applicable to portable room air cleaners rather than central HVAC or duct-mounted devices. Useful when discussing in-room consumer devices.
ASHRAE® 145.1	Laboratory Test Method for Assessing the Performance of Gas-Phase Air-Cleaning Systems: Loose Granular Media	Small-scale laboratory method for evaluating contaminant removal by loose granular sorptive media in gas-phase air-cleaning equipment under steady-state, elevated challenge gas conditions. Includes calculation and reporting methods. Excludes bonded carbon panels, beaded activated carbon, carbon cloths, absorbent-loaded nonwovens, dry-process carbon composites, and particulate removal equipment.	Gas-phase contaminant removal	Best used to compare sorptive media performance, not to directly predict field performance in a specific application. Most relevant when evaluating loose granular gas-phase media as a component of an air-cleaning system.
ASHRAE® 145.2	Laboratory Test Method for Assessing the Performance of Gas-Phase Air-Cleaning Systems: Air-Cleaning Devices	Full-scale laboratory method for evaluating in-duct gas-phase air-cleaning devices under steady-state, elevated challenge gas conditions. Covers removal of specified gaseous contaminants or mixtures and includes equipment, calculation, and reporting requirements. Excludes stand-alone room air cleaners.	Gas-phase contaminant removal	Appropriate for comparing in-duct gas-phase air-cleaning devices. Results are comparative and should not be used as a direct predictor of field performance.
ASHRAE® 145.4P ¹	Method of Test for Assessing the Gas-Phase Performance of Air Cleaning Devices and Systems in a Duct-Chamber Apparatus	Proposed duct-chamber method with continuous recirculation for evaluating gas-phase performance of in-duct devices and certain in-room commercial/industrial devices, including challenge gas reduction and likely byproducts over time. Includes equipment, calculation, and reporting requirements. Does not address health and safety effects in occupied rooms.	Gas-phase contaminant removal and byproducts	Proposed standard that may be useful for future comparison of gas-phase performance in recirculating chamber/duct configurations.
ASHRAE® 185.1	Method of Testing UV-C Lights for Use in Air-Handling Units or Air Ducts to Inactivate Airborne Microorganisms	Laboratory test method to measure the performance of UV-C lights used in general ventilating systems to inactivate selected airborne indicator microorganisms. Defines procedures for generating bioaerosols, counting upstream and downstream bioaerosols, and calculating inactivation efficiency. Also establishes equipment specifications and reporting methods.	Airborne microorganism inactivation	Relevant for UV-C systems intended to inactivate airborne microorganisms in ducts or air-handling units. Best used for comparing airborne microbial inactivation performance under controlled laboratory conditions.
ASHRAE® 185.2	Method of Testing Ultraviolet Lamps for Use in HVAC&R Units or Air Ducts to Inactivate Microorganisms on Irradiated Surfaces	Laboratory test method to measure UV-C irradiance of ultraviolet lamps used in HVAC&R systems on irradiated surfaces under typical operating conditions. Defines calculation and reporting methods and establishes a reporting system for covered ultraviolet lamps/sources.	Surface microbial inactivation / UV irradiance on surfaces	Relevant for applications such as coil, drain pan, and other irradiated-surface treatments. More applicable to surface irradiation performance than to airborne inactivation claims.
ASHRAE® 185.3	Method of Testing Commercial and Industrial In-Room Air-Cleaning Devices and Systems for Microorganism Bioaerosol Removal or Inactivation in a Test Chamber	Test method for evaluating commercial and industrial in-room air-cleaning devices and systems for microorganism bioaerosol removal or inactivation in a test chamber. Specifies selected indicator microorganisms, defines bioaerosol generation procedures, provides a method for counting viable microorganisms, and establishes equipment, calculation, and reporting requirements. Does not address health and safety effects in occupied rooms. Does not address health and safety effects in occupied rooms. Applies to commercial and industrial in-room air-cleaning devices and systems.	In-room bioaerosol removal or inactivation	Useful for in-room commercial/industrial air cleaners where bioaerosol removal or inactivation is the primary claim. Distinct from duct-mounted UV or filter test methods. Does not by itself address occupied-space safety.

Air Cleaning Technologies

Table 4. Common North American Air Cleaning Technology Safety and Test Standards Cont.

ASHRAE® 185.4	Method of Testing In-Room Ultraviolet Devices and Systems for Microbial Inactivation on Surfaces in a Test Room	Test method for evaluating ultraviolet disinfection systems for microbial inactivation on multiple surface locations in a test room. It applies to devices and systems using only germicidal ultraviolet energy for disinfection. Specifies selected indicator microorganisms, procedures for inoculating test carriers, carrier quantity and positions, viable count methods, and reporting requirements. Does not address health and safety effects in occupied rooms.	In-room surface microbial inactivation	Best suited to in-room UV devices making surface disinfection claims. It addresses microbial inactivation on surfaces, not particle filtration or gas-phase contaminant removal. Occupied-room safety must be evaluated separately.
ASHRAE® 234P ¹ (Formerly ASHRAE® 185.5P)	Method of Testing Air Cleaning Devices and Systems with Duct-Mounted Components for Particle and Microorganism Removal or Inactivation using a Chamber with a Recirculating Duct System	Proposed method for evaluating duct-mounted air-cleaning devices and systems for particle removal and/or microorganism removal or inactivation in a recirculating chamber-duct system. Defines challenge generation, sampling, quantification, equipment, and reporting requirements. Does not address health and safety effects in operation.	Particle removal and/or airborne microorganism removal or inactivation	Proposed standard that is intended to address systems requiring a duct-mounted component and a recirculating chamber/duct arrangement.
ASHRAE® 52.2	Method of Testing General Ventilation Air Cleaning Devices for Removal Efficiency by Particle Size	Laboratory test method for measuring performance of general ventilation air-cleaning devices as a function of particle size. Measures removal of particles of specific diameters as devices are loaded with standardized dust to simulate service life. Includes aerosol generation procedures, counting of airborne particles from 0.3 to 10 µm upstream and downstream, calculation/reporting methods, and a minimum efficiency reporting system. Defines MERV and MERV-A rating systems.	Particle removal efficiency by size	Foundational North American method for general ventilation particulate filters. Appropriate where particle-size efficiency and minimum efficiency reporting are needed. Particularly useful for comparing ducted particulate filters used in general ventilation.
CSA C22.2 No. 187	Electrostatic Air Cleaners	Canadian safety standard covering certain electrically powered electrostatic air cleaners and related air-cleaning devices. It addresses construction, electrical safety, and associated test requirements rather than comparative air-cleaning effectiveness.	Electrical safety for electrostatic air cleaners	Canadian safety and compliance reference for electronic air cleaners. It does not directly measure particulate, gas-phase, or microbial air cleaning performance.
IEST-RP-CC001	HEPA and ULPA Filters	Recommended practice addressing definitions, performance, testing, selection, and application of HEPA and ULPA filters.	High-efficiency particulate filtration	Most relevant for very high-efficiency particulate filtration applications, especially cleanrooms, healthcare, laboratory, and critical-process environments. It is not a replacement for ASHRAE® 52.2 in general ventilation filter rating but may be useful where HEPA/ULPA performance and leak testing are central concerns.
UL 2998	Environmental Claim Validation Procedure for Zero Ozone Emissions from Air Cleaners	Procedure for validating that an air cleaner produces zero or no measurable ozone emissions under the defined test conditions, supporting "zero ozone" claims.	Ozone emissions claim validation	Useful when evaluating ionization, electronic, or other air-cleaning technologies for ozone-related marketing claims. It addresses ozone emissions claims, not overall cleaning effectiveness for particles, gases, or microorganisms.
UL 867	Electrostatic Air Cleaners	Safety standard covering electrostatic air cleaners, including electrical construction and safety-related requirements for devices intended for residential or commercial use.	Electrical safety for electrostatic air cleaners	Primarily a safety standard rather than a performance rating standard. Useful when discussing code/listing/safety considerations for electronic air cleaners, but it should not be interpreted as a full measure of filtration, gas-phase removal, or bioaerosol control performance.

¹ : ASHRAE® adds 'P' to denote a proposed standard which has not been published as a consensus standard.

Implementing Air Cleaning Technologies in Common Airside Systems

While there are a variety of air cleaning technologies available to address different contaminants, proper implementation is critical to ensure proper operation. Some air cleaning technologies are less applicable to certain system types.

This portion of the manual seeks to provide typical air cleaning device availability and installation location for common air conditioning equipment.

Typical unit availability is expressed for the system in three different ways:

- **Widely available** – the air cleaning device is a common feature or option, likely available as a factory option.
- **Possibly available** – the air cleaning device may be available from the factory or field-installed as an option. In some cases, the air cleaning device may need to be installed independently of the system within the occupied space.
- **Rarely available** – the air cleaning device is likely not available from the factory or as a field-installed option.

Typical Installation is expressed in a variety of ways that pertain to the specific system. For example, it may be available as option within the system or terminal unit, in the ductwork system, or in the space.

Centralized Air Distribution Systems

These types of systems include everything needed to condition and ventilate multiple occupied zones. Often, the air conditioning components are located on the rooftop, beside the building, or in a mechanical room. Centralized systems include packaged DX rooftops, commercial self-contained units, and central station air handlers.

Centralized systems can typically accommodate many air cleaning device options. Additionally, systems often can provide airside economizing. Airside economizing allows the building HVAC system to offset some or all the cooling loads by introducing cool outdoor air into the building to reduce system energy consumption. While this is designed to primarily address energy usage, airside economizing also has the added benefit of increasing the amount and percentage of outdoor air being introduced into the building which helps with contaminant dilution.

Packaged Direct Expansion Rooftop Units

Figure 14. Packaged rooftop example



A typical packaged rooftop contains a mixing box, filters, a cooling coil, possibly a heating coil or gas-fired heat exchanger or electric heater, a supply fan, possibly a return or relief fan, controls, and all the components of a direct-expansion (DX) refrigeration system.

A supply air system consisting of ductwork and diffusers is used to convey conditioned air. If the system serves multiple thermal zones, variable air volume terminal units are installed in the supply air ductwork system and used to regulate the flow of conditioned air into the spaces. Return-air grilles, a ceiling plenum, and return ductwork are used to return air to the rooftop unit.

Manufacturers often distinguish between “light” and “large” unitary applications and may offer different rooftop unit platforms. The cutoff between light and large unitary is often around 25 tons of cooling capacity.

Implementing Air Cleaning Technologies in Common Airside Systems

Table 5. Typical air cleaning device options - light commercial unitary packaged rooftop units

Air Cleaning Technology	Typical Unit Availability	Typical Installation
MERV 8 Filters	Widely available	• Rooftop
MERV 13 Filters	Widely available	• Rooftop
MERV 14+ Filters	Possibly available	• Rooftop
HEPA/ULPA Filters	Rarely available	• Rooftop • In-space air cleaner
Gas-phase filtration	Rarely available	• Rooftop
Bipolar Ionization	Possibly available ¹	• Rooftop • Supply duct
Dry Hydrogen Peroxide	Possibly available ¹	• Supply duct • In-space
Photocatalytic Oxidation	Rarely available	• Rooftop
Ultraviolet Germicidal Irradiation	Possibly available ²	• Rooftop • Supply duct • Upper air system
Notes: ¹ May be field installed close to the occupied zone(s). ² Coil or drain pan treatment dosage is likely insufficient for "fly-by" applications.		

Table 6. Typical air cleaning device options - large commercial unitary packaged rooftop units

Air Cleaning Technology	Typical Unit Availability	Typical Installation
MERV 8 Filters	Widely available	• Rooftop
MERV 13 Filters	Widely available	• Rooftop
MERV 14+ Filters	Possibly available	• Rooftop
HEPA/ULPA Filters	Possibly available	• Rooftop • In-space air cleaner
Gas-phase filtration	Possibly available	• Rooftop
Bipolar Ionization	Possibly available ¹	• Rooftop • Supply duct
Dry Hydrogen Peroxide	Possibly available ¹	• Supply duct • In-space
Photocatalytic Oxidation	Rarely available	• Rooftop
Ultraviolet Germicidal Irradiation	Possibly available ²	• Rooftop • Supply duct • Upper air system
Notes: ¹ May be field installed close to the occupied zone(s). ² Coil or drain pan treatment dosage is likely insufficient for "fly-by" applications.		

Central Station Air Handling Units

Figure 15. Air handling system example



A central station air handling unit (AHU) typically consists of a mixing box, filters, a cooling coil, possibly a heating coil or gas fired heat exchanger or electric heater, a supply fan, possibly a return or relief fan, and controls.

A supply air system consisting of ductwork and diffusers is used to convey conditioned air. If the system serves multiple thermal zones, variable air volume terminal units are installed in the supply air ductwork system and used to regulate the flow of conditioned air into the spaces. Return-air grilles, a ceiling plenum, and return ductwork are used to return air to the air handling unit.

Table 7. Typical air cleaning device options - air handling units

Air Cleaning Technology	Typical Unit Availability	Typical Installation
MERV 8 Filters	Widely available	• Air handling unit
MERV 13 Filters	Widely available	• Air handling unit
MERV 14+ Filters	Widely available	• Air handling unit
HEPA/ULPA Filters	Widely available	• Air handling unit • In-space air cleaner
Gas-phase filtration	Widely available	• Air handling unit
Bipolar Ionization	Possibly available	• Air handling unit • Supply duct
Dry Hydrogen Peroxide	Possibly available ¹	• Supply duct • In-space
Photocatalytic Oxidation	Widely available	• Air handling unit
Ultraviolet Germicidal Irradiation	Widely available ²	• Air handling unit • Supply duct • Upper air system
Notes: ¹ May be field installed close to the occupied zone(s). ² Coil or drain pan treatment dosage is likely insufficient for "fly-by" applications.		

Self-Contained Units

Figure 16. Self-contained unit example



A commercial self-contained unit, often abbreviated as CSC, typically consists of a mixing box, filters, a direct expansion refrigeration system with a water-cooled condenser, possibly a heating coil or gas fired heat exchanger or electric heater, a supply fan and controls. One or more of these units are typically installed in a small equipment room on each floor of the building. Alternate configurations use a remote air-cooled condenser.

A supply air system consisting of ductwork and diffusers is used to convey conditioned air. If the system serves multiple thermal zones, variable air volume terminal units are installed in the supply air ductwork system and used to regulate the flow of conditioned air into the spaces. Return-air grilles, a ceiling plenum, and return ductwork are used to return air to the self-contained unit.

Table 8. Typical air cleaning device options - commercial self-contained units

Air Cleaning Technology	Typical Unit Availability	Typical Installation
MERV 8 Filters	Widely available	• Commercial self-contained
MERV 13 Filters	Widely available	• Commercial self-contained
MERV 14+ Filters	Possibly available	• Commercial self-contained
HEPA/ULPA Filters	Rarely available	• Commercial self-contained • In-space air cleaner
Gas-phase filtration	Possibly available	• Commercial self-contained
Bipolar Ionization	Possibly available ¹	• Commercial self-contained • Supply duct
Dry Hydrogen Peroxide	Possibly available ¹	• Supply duct • In-space
Photocatalytic Oxidation	Rarely available	• Commercial self-contained
Ultraviolet Germicidal Irradiation	Possibly available ²	• Commercial self-contained • Supply duct • Upper air system
Notes: ¹ May be field installed close to the occupied zone(s). ² Coil or drain pan treatment dosage is likely insufficient for "fly-by" applications.		

Dedicated Outdoor Air Systems

Figure 17. Dedicated outdoor air system example



A typical dedicated outdoor air system (DOAS) includes filters, a cooling coil, possibly a heating coil or gas fired heat exchanger or electric heater, a supply fan, possibly a relief fan, controls, and possibly all the components of a direct-expansion (DX) refrigeration system (unless it uses a chilled water coil). The system is designed to condition ventilation air only, therefore the quantity of supply air passing through this system is less than other systems, such as a packaged DX rooftop.

A supply air system consisting of ductwork and diffusers is used to convey conditioned ventilation air. If the system serves multiple thermal zones, variable air volume terminal units may be installed in the supply air ductwork system and used to regulate the flow of conditioned ventilation air into the spaces. Some systems duct conditioned ventilation air to other equipment, such as terminal units.

Some dedicated outdoor air systems employ air-to-air energy recovery which necessitates the need to send building exhaust air back to the unit to transfer heat. Alternatively, a separate building exhaust system is employed to maintain space pressure.

The supply air ductwork for a dedicated outdoor air system is typically only sized for the ventilation air volume, which makes the usage of an airside economizer unlikely—the supply air ductwork is not large enough to accommodate the entire volume of supply air needed to offset all zone thermal loads. So, a ventilation system is unlikely to have an airside economizer meeting the full requirements of energy codes and standards.

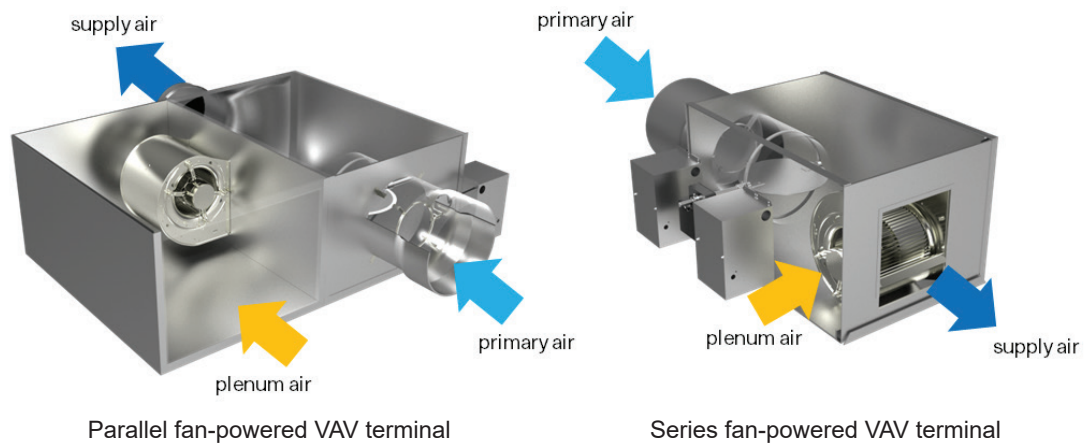
Implementing Air Cleaning Technologies in Common Airside Systems

Table 9. Typical air cleaning device options - dedicated outdoor air systems

Air Cleaning Technology	Typical Unit Availability	Typical Installation
MERV 8 Filters	Widely available	• Dedicated outdoor air unit
MERV 13 Filters	Widely available	• Dedicated outdoor air unit
MERV 14+ Filters	Widely available	• Dedicated outdoor air unit
HEPA/ULPA Filters	Possibly available	• Dedicated outdoor air unit • In-space air cleaner
Gas-phase filtration	Possibly available	• Dedicated outdoor air unit
Bipolar Ionization	Possibly available ¹	• Dedicated outdoor air unit • Supply duct
Dry Hydrogen Peroxide	Possibly available ¹	• Supply duct • In-space
Photocatalytic Oxidation	Possibly available	• Dedicated outdoor air unit
Ultraviolet Germicidal Irradiation	Possibly available ²	• Dedicated outdoor air unit • Supply duct • Upper air system

Notes:
¹ May be field installed close to the occupied zone(s).
² Coil or drain pan treatment dosage is likely insufficient for "fly-by" applications.

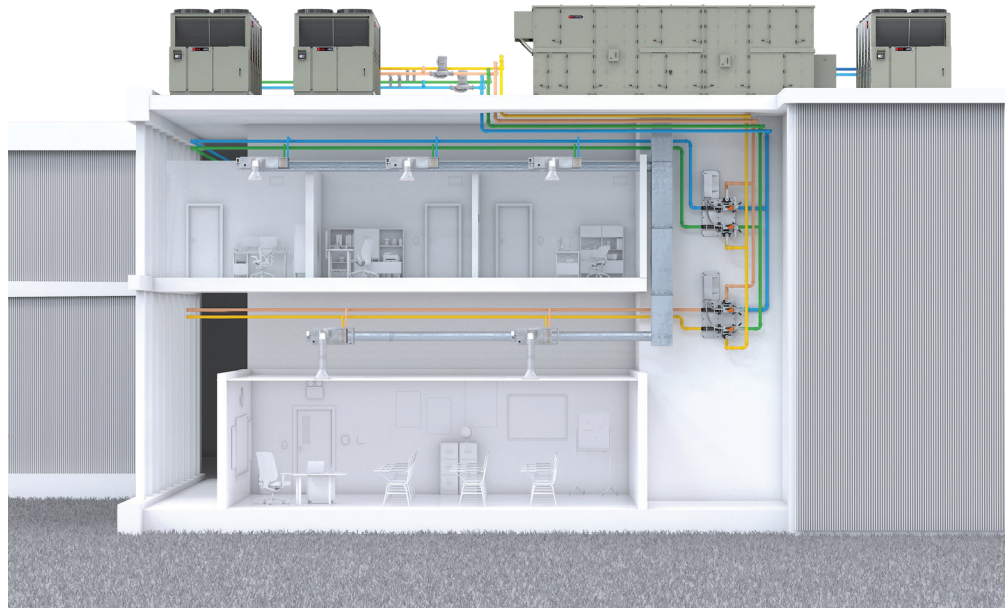
Figure 18. Fan-powered VAV boxes: limited filtration options



Often, rooftops, air handlers, self-contained units, or dedicated outdoor air systems utilize variable air volume (VAV) boxes to restrict the flow of conditioned air. Some systems may employ fan-powered VAV boxes that use small terminal fans inside the box to circulate air from the return air plenum into the box. Parallel fan-powered VAV boxes use a fan intermittently to temper the supply air, primarily during the heating mode whereas series fan-powered VAV terminals use the fan continuously. It may be difficult to obtain a MERV 13 or higher-rated filter on a fan-powered terminal.

Terminal Air Systems

Figure 19. Sensible cooling terminal unit system example



A terminal system uses a dedicated terminal unit to provide cooling or heating to maintain the desired temperature in each zone. Depending on the style of equipment used, this terminal unit may be installed along the wall or ceiling within the occupied space, in the ceiling plenum above the space, or in a closet near the space. In most cases, this necessitates a separate system to handle the building ventilation needs. The two systems work together to offset the thermal loads and maintain space comfort.

Special consideration may be needed when determining the air cleaning needs of a building served by a terminal air system and ventilation system. For example, the dedicated outdoor air system likely handles ventilation air so only outdoor contaminants should be considered. Likewise, the terminal system likely recirculates zone air so only indoor contaminants are important (see ["Dedicated Outdoor Air Systems" on page 40](#)).

Terminal systems often have fewer air cleaning options compared to centralized systems due to a lack of space in the cabinet and lack of supply fan static pressure capability.

Active Chilled Beam and Radiant Cooling Systems

Figure 20. Installed chilled beam example



Chilled beam and radiant cooling systems use chilled water and a network of radiant cooling devices above the space to cool the zone.

Chilled beams do not contain local fans. A **passive chilled beam** consists of a fin-and-tube heat exchanger, usually contained in a housing, and suspended from the ceiling. Chilled water passes through the tubes of the heat exchanger which cools warm air from the space that naturally rises toward the ceiling. The cooled air descends toward the occupied space.

Outdoor air for ventilation is provided by a separate system, often a dedicated outdoor air system. All dehumidification must be provided by this separate system because passive chilled beams cannot provide any humidity control.

An **active chilled beam** system also uses a fin-and-tube heat exchanger within a housing that is suspended from or recessed in a ceiling. Unlike a passive system, the active chilled beam contains an integral air supply from a centralized, or primary, air handling unit. The primary air may be 100 percent outdoor or contain recirculated zone air. The primary air passes through a series of nozzles which induce airflow from the space upward through the active chilled beam heat exchanger. Like the passive chilled beam system, an active chilled beam does not contain an integral supply air fan. However, it does require fan power to cool the space, as it relies on the centralized fan to pressurize the chamber upstream of the nozzles, allowing them to induce sufficient airflow across the local cooling coil.

A variation of the chilled beam is a **radiant panel** which uses the radiation method of heat transfer. Panels are typically mounted to the ceiling or walls of the occupied zone. Small tubes are attached to the back of the panel or embedded within it. These tubes convey chilled- or hot water to cool or heat the panel. Panels contain no fans and require separate dedicated outdoor air systems to provide conditioned ventilation air.

Implementing Air Cleaning Technologies in Common Airside Systems

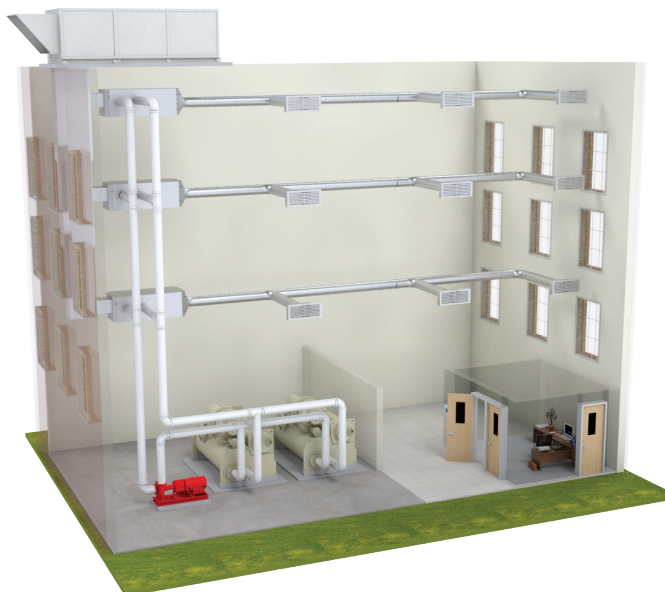
Due to their design, chilled beam systems often do not typically include terminal air filtration. Similarly, radiant cooling systems do not utilize air movement for heat transfer, so filters are not used. And because they are sensible-cooling devices that are not designed to dehumidify, so ASHRAE® Standard 62.1 does not require a filter upstream of the cooling coil in the chilled beam.

Table 10. Typical air cleaning device options - active chilled beams and radiant cooling systems

Air Cleaning Technology	Typical Unit Availability	Typical Installation
MERV 8 Filters	Rarely available	- Active chilled beam - Dedicated outdoor air system
MERV 13 Filters	Rarely available	Dedicated outdoor air system
MERV 14+ Filters	Rarely available	Dedicated outdoor air system
HEPA/ULPA Filters	Rarely available	- Dedicated outdoor air system - In-space air cleaner
Gas-phase filtration	Rarely available	Dedicated outdoor air system
Bipolar Ionization	Possibly available ¹	Ventilation supply duct
Dry Hydrogen Peroxide	Possibly available ¹	- Ventilation supply duct - In-space
Photocatalytic Oxidation	Rarely available	Dedicated outdoor air system
Ultraviolet Germicidal Irradiation	Rarely available	- Dedicated outdoor air system - Ventilation supply duct - Upper air system
Notes: ¹ May be field installed close to the occupied zone(s).		

Fan Coils

Figure 21. Fan coil example



A fan coil is an assembly containing a chilled-water or DX cooling coil, terminal fan, filter, and possibly a heating device. Return air is drawn into the casing directly from the zone or through a return air system. The air is then conditioned and discharged directly into the zone or through a supply air duct system. Some styles of fan coil include an outdoor air damper that allows outdoor air to be introduced into the fan coil and conditioned. It is more common, however, to use a separate ventilation system to provide outdoor air.

Fan coils are available in many different configurations to serve different building types and system layouts. Regardless of configuration, fan coils generally have the same components to provide conditioning.

Higher-static fan coils—sometimes called blower coils—often have a mixing box option which could enable full airside economizing. The additional fan static energy also enables the use of filters with higher air pressure drops.

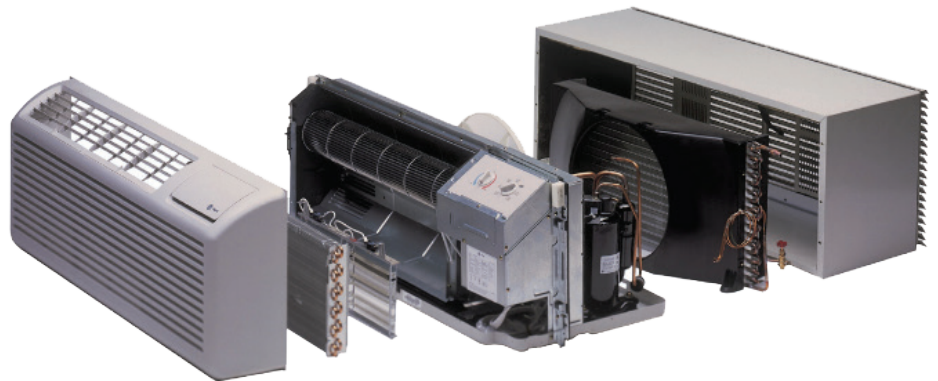
Implementing Air Cleaning Technologies in Common Airside Systems

Table 11. Typical air cleaning device options - fan coils

Air Cleaning Technology	Typical Unit Availability	Typical Installation
MERV 8 Filters	Widely available	- Fan coil - Dedicated outdoor air system
MERV 13 Filters	Widely available	- Fan coil - Dedicated outdoor air system
MERV 14+ Filters	Rarely available	Dedicated outdoor air system
HEPA/ULPA Filters	Rarely available	- Dedicated outdoor air system - In-space air cleaner
Gas-phase filtration	Rarely available	Supply duct
Bipolar Ionization	Possibly available ¹	Ventilation supply duct
Dry Hydrogen Peroxide	Possibly available ¹	- Supply duct - In-space
Photocatalytic Oxidation	Rarely available	Dedicated outdoor air system
Ultraviolet Germicidal Irradiation	Rarely available ²	- Dedicated outdoor air system - Supply duct - Upper air system
Notes: ¹ May be field installed close to the occupied zone(s). ² Coil or drain pan treatment dosage is likely insufficient for "fly-by" applications.		

Packaged Terminal Air Conditioners

Figure 22. PTAC example



Packaged terminal air conditioners, or PTACs, are designed to condition single, small zones, and are often used in hotel rooms. Recirculated air enters the unit and passes through a filter, direct expansion evaporator coil, an electric heater (or heat pump heating coil), indoor fan, and is discharged from the top of the unit into the space. The entire unit, including the DX refrigeration system, is contained within a wall sleeve, and installed on the exterior wall. Some units are heat pumps and utilize a reversible DX refrigeration system to provide cooling and heating.

Implementing Air Cleaning Technologies in Common Airside Systems

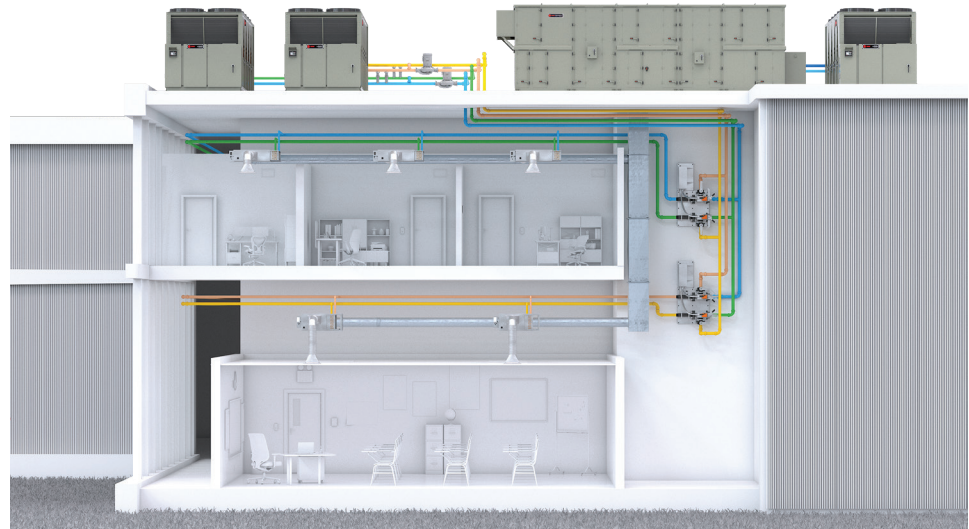
PTACs generally do not provide airside economizing. Units may include a non-motorized outdoor air opening to allow outdoor air to be mixed with the recirculated air for ventilation. Additionally, units may include a reusable mesh filter which typically has a low MERV rating.

Table 12. Typical air cleaning device options - packaged terminal air conditioning units

Air Cleaning Technology	Typical Unit Availability	Typical Installation
MERV 8 Filters	Possibly available	• Packaged terminal air conditioner • Dedicated outdoor air system
MERV 13 Filters	Possibly available	• Packaged terminal air conditioner • Dedicated outdoor air system
MERV 14+ Filters	Rarely available	• Dedicated outdoor air system
HEPA/ULPA Filters	Rarely available	• Dedicated outdoor air system • In-space air cleaner
Gas-phase filtration	Rarely available	• Dedicated outdoor air system
Bipolar Ionization	Rarely available	• Ventilation supply duct
Dry Hydrogen Peroxide	Rarely available	• In-space
Photocatalytic Oxidation	Rarely available	• Dedicated outdoor air system
Ultraviolet Germicidal Irradiation	Rarely available ²	• Dedicated outdoor air system • Supply duct • Upper air system
Notes: ¹ May be field installed close to the occupied zone(s). ² Coil or drain pan treatment dosage is likely insufficient for "fly-by" applications.		

Sensible-Cooling Terminal Units

Figure 23. Sensible-cooling terminal unit system example



For more information on sensible cooling terminal systems, see the CoolSense™ system catalog (APP-PRC004-EN).

A sensible-cooling terminal unit is typically installed in the ceiling plenum above the occupied zone. The unit typically includes a chilled-water cooling coil that conditions recirculated zone air. Inside the terminal, conditioned outdoor air from the dedicated outdoor air system passes through an airflow measuring damper and mixes with the conditioned recirculated air from the zone. A fan then pushes the air mixture through a heating coil and into the supply air ductwork to the zone.

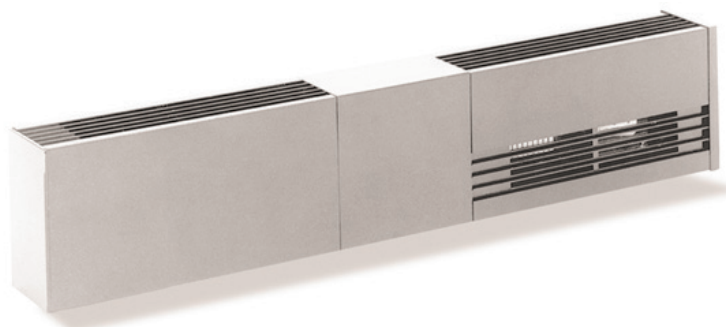
The sensible-only cooling coil is designed to cool, but not dehumidify the air. As a result, ASHRAE® Standard 62.1 does not require a filter upstream of the coil. Optionally, filters can be installed to clean the recirculated air.

Table 13. Typical air cleaning device options - sensible-cooling terminal units

Air Cleaning Technology	Typical Unit Availability	Typical Installation
MERV 8 Filters	Widely available	- Sensible-cooling terminal unit - Dedicated outdoor air system
MERV 13 Filters	Possibly available	- Sensible-cooling terminal unit - Dedicated outdoor air system
MERV 14+ Filters	Rarely available	Dedicated outdoor air system
HEPA/ULPA Filters	Rarely available	- Dedicated outdoor air system - In-space air cleaner
Gas-phase filtration	Rarely available	Dedicated outdoor air system
Bipolar Ionization	Possibly available ¹	Ventilation supply duct
Dry Hydrogen Peroxide	Possibly available ¹	- Supply duct - In-space
Photocatalytic Oxidation	Rarely available	Dedicated outdoor air system
Ultraviolet Germicidal Irradiation	Rarely available ²	- Dedicated outdoor air system - Supply duct - Upper air system
Notes: ¹ May be field installed close to the occupied zone(s). ² Coil or drain pan treatment dosage is likely insufficient for "fly-by" applications.		

Unit Ventilators

Figure 24. Unit ventilator



A unit ventilator is a special type of fan coil, designed specifically for school classrooms with a cabinet that is more durable than a typical fan coil and a coil sized to additionally handle ventilation. Units may include an integral outdoor-air intake designed to provide airside economizing. Accordingly, units are installed on an exterior wall of the classroom. Units are available in horizontal and vertical configurations. Heating is often provided by an electric heater or hydronic heating coil. Alternatively, unit ventilators can be connected to a VRF condensing unit.

Table 14. Typical air cleaning device options - unit ventilators

Air Cleaning Technology	Typical Unit Availability	Typical Installation
MERV 8 Filters	Widely available	• Unit ventilator
MERV 13 Filters	Widely available	• Unit ventilator
MERV 14+ Filters	Rarely available	• Unit ventilator
HEPA/ULPA Filters	Rarely available	• Unit ventilator • In-space air cleaner
Gas-phase filtration	Rarely available	• Unit ventilator
Bipolar Ionization	Possibly available ¹	• Unit ventilator
Dry Hydrogen Peroxide	Possibly available ¹	• In-space
Photocatalytic Oxidation	Rarely available	• Unit ventilator
Ultraviolet Germicidal Irradiation	Rarely available ²	• Unit ventilator • Upper air system
Notes: ¹ May be field installed close to the occupied zone(s). ² Coil or drain pan treatment dosage is likely insufficient for "fly-by" applications.		

Variable Refrigerant Flow Systems

Figure 25. VRF system example



For more information on VRF, see Variable Refrigerant Flow Systems (APP-PRC007-EN)

A variable refrigerant flow (VRF) system layout is typically a one-to-many split system that can provide both heating and cooling to multiple zones. Configurations include air- and water-cooled. Additionally, units may be heat pump or heat recovery, that latter to provide simultaneous heating and cooling to different zones. VRF systems can use many different terminal unit types, including ceiling cassettes, high-wall units, and fan coils.

In the common air-source configuration, the outdoor unit contains refrigerant compressors, an air-to-refrigerant heat exchanger (which serves as a condenser during cooling operation and an evaporator during heating operation), a fan to move air over the heat exchanger, and controls. Refrigerant piping links the outdoor unit to the indoor units. Heat pump units can provide cooling or heating to all the zones by reversing the refrigerant cycle. Heat recovery units add a branch controller between the outdoor and indoor units. The branch controller can route refrigerant from the outdoor unit to the respective terminal units to provide cooling or heating based upon zone needs.

Each indoor unit includes a refrigerant-to-air heat exchanger and supply fan. Some terminal units are installed in the space on the ceiling or wall and may include motorized dampers to direct the flow of conditioned air. Other units may be installed in the ceiling plenum or closet near the occupied space and use a small amount of supply ductwork and supply air diffusers.

Implementing Air Cleaning Technologies in Common Airside Systems

Applied VRF

Using applied air handling equipment with VRF equipment allows a variety of additional air cleaning options, detailed in the Central Station Air Handling Units (page 38) and Unit Ventilators (page 49) sections.

A separate ventilation system is typically used to provide conditioned outdoor air to the zones. As a result, airside economizing is very difficult to implement with a VRF system because the terminal units may not provide ventilation air.

Manufacturers can pair VRF compressor-bearing units with other types of air handling equipment using a linear expansion valve kit (LEV kit), known as “applied VRF”. This enables VRF to be paired with unit ventilators, blower coils, and air handlers. These pieces of air handling equipment are designed to provide ventilation, can provide airside economizing, and can often be equipped with a broader range of air cleaning options.

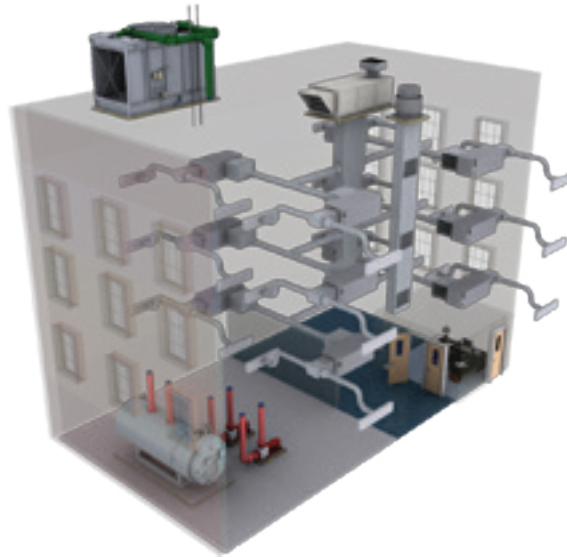
Air cleaning device options are generally limited with VRF terminal units. Terminal units with low static pressure capabilities often are limited to filters with lower MERV ratings. Some concealed, ducted terminal units can accommodate a filter with a higher MERV rating. Alternatively, some units utilize a field-installed filter box.

Table 15. Typical air cleaning device options - VRF terminals

Air Cleaning Technology	Typical Unit Availability	Typical Installation
MERV 8 Filters	Widely available	- VRF terminal unit - Dedicated outdoor air unit
MERV 13 Filters	Possibly available	- VRF terminal unit - Dedicated outdoor air unit
MERV 14+ Filters	Rarely available	- VRF terminal unit - Dedicated outdoor air unit
HEPA/ULPA Filters	Rarely available	In-space air cleaner
Gas-phase filtration	Rarely available	Dedicated outdoor air unit
Bipolar Ionization	Possibly available ¹	Ventilation supply duct
Dry Hydrogen Peroxide	Possibly available ¹	- Ventilation supply duct - In-space
Photocatalytic Oxidation	Rarely available	Dedicated outdoor air unit
Ultraviolet Germicidal Irradiation	Rarely available ²	- Dedicated outdoor air unit - Upper air system
Notes: ¹ May be field installed close to the occupied zone(s). ² Coil or drain pan treatment dosage is likely insufficient for "fly-by" applications.		

Water-Source Heat Pumps

Figure 26. Water-source heat pump example



Water-source heat pumps (WSHP) utilize a common water loop that circulates throughout the building to move heat between units. Each zone features its own WSHP that cools or heats the supply air to maintain space temperature. Each heat pump contains a DX refrigeration system, including one or more compressors, a refrigerant-to-air heat exchanger, a refrigerant-to-water heat exchanger, and an expansion device. A reversing valve allows the unit to reverse refrigerant flow and change operation to provide cooling or heating.

Depending on the style of equipment used, a WSHP may be installed along the wall within the occupied space, in the ceiling plenum above the space, in a closet or mechanical room near the space, or on the roof of the building.

Return air from the zone is drawn into the WSHP through the intake. This air passes through a filter, refrigerant-to-air heat exchanger, and fan before it is discharged either directly into the zone or through supply ductwork and supply-air diffusers.

All the heat pumps are connected to a common water loop. The water loop also includes a device to reject heat from the loop to the ambient environment, such as a cooling tower, fluid cooler, or ground heat exchanger. Additionally, a device to add heat is often included, such as a hot-water boiler, or ground heat exchanger. Alternatively, the heat rejecting and adding devices may be one or more air-to-water heat pump units. Finally, water circulating pumps are used to provide building loop fluid flow.

Typically, outdoor air required for ventilation is conditioned and delivered by a separate, dedicated outdoor-air system. Although waterside economizing is available, airside economizing is typically only available with the rooftop variation.

Implementing Air Cleaning Technologies in Common Airside Systems

Table 16. Typical air cleaning device options - water-source heat pumps

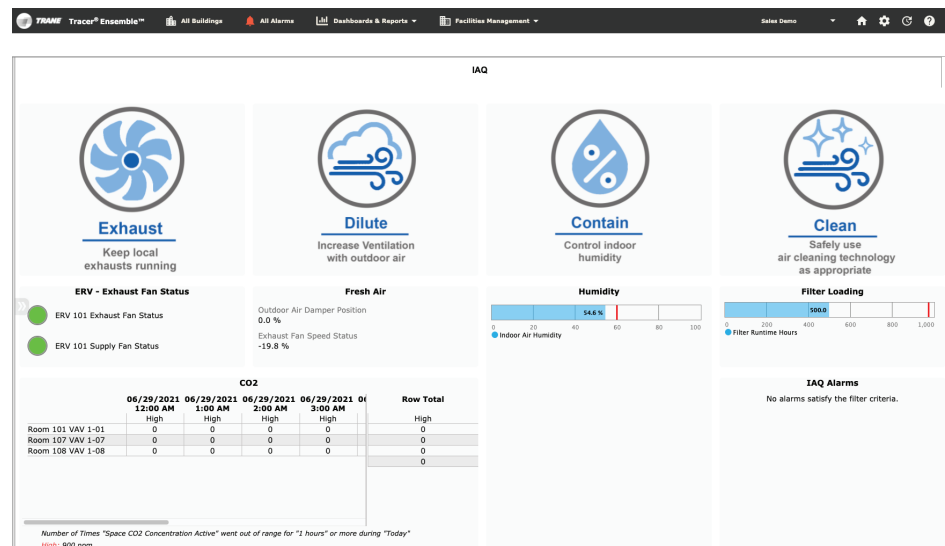
Air Cleaning Technology	Typical Unit Availability	Typical Installation
MERV 8 Filters	Widely available	- Water-source heat pump - Dedicated outdoor air system
MERV 13 Filters	Widely available	- Water-source heat pump - Dedicated outdoor air system
MERV 14+ Filters	Rarely available	Dedicated outdoor air system
HEPA/ULPA Filters	Rarely available	In-space air cleaner
Gas-phase filtration	Rarely available	Dedicated outdoor air system
Bipolar Ionization	Possibly available ¹	Ventilation supply duct
Dry Hydrogen Peroxide	Possibly available ¹	- Ventilation supply duct - In-space
Photocatalytic Oxidation	Rarely available	Dedicated outdoor air system
Ultraviolet Germicidal Irradiation	Rarely available ²	- Dedicated outdoor air system - Upper air system
Notes: ¹ May be field installed close to the occupied zone(s). ² Coil or drain pan treatment dosage is likely insufficient for "fly-by" applications.		

Monitoring Indoor Air Quality

There are a variety of sensors available to monitor temperature, humidity, carbon dioxide, light levels, and occupancy. To provide building air cleanliness information to occupants, owners may wish to install sensors which monitor indoor air quality. These devices periodically sample the air to measure the concentration of common pollutants. These sensors might measure temperature, relative humidity, carbon monoxide, carbon dioxide, particulate matter, and total volatile organic compounds (TVOCs). Additionally, some sensors may also measure lighting levels and sound pressure. This data is not only beneficial to make the end user aware of the environment that they are spending time in but more importantly it allows the controls system the opportunity to optimize the air quality of that environment.

Measured data is gathered and displayed on a dashboard for user awareness. Additionally, the building automation system may also use the information to automatically make decisions about ventilation rates, and demand-controlled ventilation.

Figure 27. Ensemble indoor air quality dashboard



Currently, there are two types of air quality sensors available, local and centralized. The local air quality sensor appears like a standard zone sensor—it is mounted to the wall. The sensor itself contains all the components needed to make measurements and display them. This type of device distributes the sensing duties throughout the occupied spaces. So, sensors are required in all areas that require IAQ measurements. Additionally, the sensor can relay the information to a networked device to store and report results.

The second type of sensor centralizes the measurements. Pneumatic tubing is used to transport air from various zones back to a single set of centralized sensors. This allows for fewer calibrated sensors, and it also provides additional flexibility to add sensors. Instead of adding a new sensor to each zone, a sensor is just added to the centralized measuring device.

Sensor density and layout will be dictated by a rating authority, standard or code, or sensor manufacturer. Typical density requires one sensor per floor and/or every 3,500-5,000 ft² based on which is more stringent. This may lead to there being more than one sensor associated to a single piece of HVAC equipment. In any case, the data will typically be integrated at the system controller.

The most common form of mitigation is to increase the outside air to aid in flushing the offending contaminant or contaminants out of the building. This action has the potential to negatively affect occupant comfort and/or to drive up energy cost since additional outdoor air must be conditioned. Fortunately, for TVOCs and particulate matter, there are other mitigation options available. Sites with controllable air cleaning devices can be enabled as needed, or when outdoor air conditions are not ideal for increasing ventilation beyond design rates.

Glossary

ACH. Air changes per hour.

AHRI. Air-Conditioning, Heating, and Refrigeration Institute (www.ahrinet.org).

air-cooled condenser. A type of condenser in which refrigerant flows through the tubes and rejects heat to outdoor air that is drawn across the tubes.

air-handling unit (AHU). A piece of equipment used to move, clean, and condition (heat, cool, humidify, dehumidify) air.

airside economizer. A method of free cooling that involves using cooler outdoor air for cooling instead of recirculating warmer indoor air.

air-to-air energy recovery. The transfer of sensible heat, or sensible plus water vapor (latent heat), between two or more air streams, or between two locations within the same air stream.

ANSI. American National Standards Institute (www.ansi.org)

ASHRAE. American Society of Heating, Refrigerating and Air Conditioning Engineers (www.ashrae.org)

blow-thru. A configuration where the fan is located upstream and blows air through the cooling coil.

boiler. A pressure vessel that typically consists of a water tank (or tubes with water flowing through them), a heat exchanger, fuel burners, exhaust vents, and controls. Its purpose is to transfer the heat generated by burning fuel to either water or steam.

breathing zone. The region within an occupied space between planes 3 in. and 72 in. (75 mm and 1800 mm) above the floor and more than 2 ft. (600 mm) from the walls or fixed air-conditioning equipment.

building automation system (BAS). A centralized control and monitoring system for a building.

collection efficiency. Describes how well a particulate filter removes particles of various sizes from the air stream.

compressor. A mechanical device used in the vapor-compression refrigeration cycle to increase the pressure and temperature of the refrigerant vapor.

condenser. The component of the refrigeration system where refrigerant vapor is converted to liquid as it rejects heat to water or air.

constant-volume system. A type of air-conditioning system that varies the temperature of a constant volume of air supplied to meet the changing load conditions of the zone.

controller. The component of a control loop that compares the measured condition of the controlled variable to the desired condition (setpoint), and transmits a corrective output signal to the controlled device.

cooling-only terminal unit. The simplest type of single-duct VAV terminal unit. It has the capability of varying the airflow, but has no method to provide heating for the zone.

COP. A dimensionless ratio of the rate of heat removal to the rate of energy input (in consistent units) for a complete refrigerating system or some specific portion of that system under designated operating conditions. A higher COP designates a higher efficiency.

critical zone reset. See fan-pressure optimization.

damper. A device used to vary the volume of air passing through a confined cross section by varying the cross-sectional area.

dedicated outdoor-air system (DOAS). A system that uses a dedicated air-handling unit to cool, heat, dehumidify, or humidify all of the outdoor air brought into the building for ventilation. This system then delivers this conditioned outdoor air directly to the conditioned spaces or to HVAC equipment.

direct digital control (DDC). A method of terminal unit control using an electric motor to operate the air-modulation damper actuator. It uses a microprocessor that enables digital communication between the unit controller and a central building automation system.

direct-drive plenum fan. A type of plenum fan in which the motor is mounted directly to the end of the fan wheel shaft, eliminating the need for sheaves or belts.

direct expansion (DX) system. A system that uses the refrigerant directly as the cooling media. The refrigerant inside the finned-tube evaporator absorbs heat directly from the air used for space conditioning.

discharge air. Air leaving a piece of ventilation, heating, cooling, humidification, or dehumidification equipment (sometimes used interchangeably with supply air).

displacement ventilation. See thermal displacement ventilation.

draft. Undesired local cooling of a body caused by low temperature and air movement.

drain pan. A device positioned under a cooling coil to collect condensate and direct it to a drainage system.

draw-thru. A configuration where the fan is located downstream and draws air through the cooling coil.

dual-duct terminal unit. A type of VAV terminal unit consisting of two airflow modulation devices, one for cool primary air and one for warm primary air. These units can be controlled to provide either a constant volume or variable volume of supply air to the zone.

dual-fan, dual-duct VAV system. A VAV system that consists of two air handlers, one that delivers cool primary air and one that delivers warm primary air. These two duct systems provide air to a dual-duct VAV terminal unit for each zone.

dust spot efficiency. A rating value, defined by ASHRAE Standard 52.1, that depicts the amount of atmospheric dust a filter captures.

ECM. Electronically commutated motor. A brushless DC motor that combines a permanent-magnet rotor, wound-field stator, and an electronic commutation assembly to eliminate the brushes.

Economizing, airside. Airside economizing allows the building HVAC system to offset some or all the cooling loads by introducing cool outdoor air into the building to reduce system energy consumption. While this is designed to primarily address energy usage, airside economizing also has the added benefit of increasing the amount and percentage of outdoor air being introduced into the building.

electronic air cleaner. Particulate filter that uses electrostatic attraction, either passively charged (electret) or actively charged (electrostatic precipitators), to enhance collection efficiency.

Energy Star®. A program, administered by the U.S. Environmental Protection Agency and Department of Energy, that helps reduce energy costs and protect the environment through energy-efficient products and practices (www.energystar.gov).

enthalpy. Describes the total amount of heat energy, both sensible and latent, in one pound of air at a given condition.

enthalpy wheel. See total-energy wheel.

evaporator. The component of the refrigeration system where cool, liquid refrigerant absorbs heat from air, causing the refrigerant to boil.

exhaust air. Air that is removed from the conditioned space(s) and then discharged to the outdoors.

face velocity. Velocity of the air as it passes through a device (airflow rate divided by the face area of the device).

fan array. A configuration that uses multiple fans, stacked to allow for parallel air paths.

fan-powered terminal unit. A type of single-duct VAV terminal unit that can provide heating to a zone by mixing warm plenum air with the cool primary air, using a small terminal fan.

fan-pressure optimization. An optimized method of VAV system static-pressure control, which uses the benefits of DDC control to continuously reset the static-pressure setpoint of the system so the VAV terminal requiring the highest inlet pressure is nearly fully open.

fan speed control. A method of supply fan modulation that affects a fan's capacity by varying its speed of rotation, commonly accomplished using a variable-speed drive on the fan motor.

flue gases. Exhaust gases from a boiler or gas-fired burner.

grille. A device used to direct air out of the conditioned space into the ceiling plenum or return duct system.

HEPA. High-efficiency particulate air filter.

IECC. International Energy Conservation Code. Model energy code published by the International Code Council, www.iccsafe.org.

integrated economizer mode. An operating mode of an airside economizer when the outdoor air is warmer than the current supply-air temperature setpoint. The outdoor-air dampers remain wide open (return-air dampers are closed), but the unit controller activates compressors to provide the balance of the cooling capacity needed to provide supply air at the desired setpoint.

interior zone. A conditioned space that is surrounded by other conditioned spaces, with no perimeter walls/windows. Typically requires some degree of cooling all year long to overcome the heat generated by people, lighting, or equipment.

latent heat. Heat that causes a change in the moisture content of the air with no change in dry-bulb temperature.

LEED®. Leadership in Energy and Environmental Design. A building rating system created by the U.S. Green Building Council, a building industry coalition (www.usgbc.org).

linear slot diffuser. A type of supply-air diffuser in which jets are formed by slots or rectangular openings with a large aspect ratio. See Coanda effect.

makeup-air unit. See dedicated outdoor-air unit.

MERV. Minimum Efficiency Reporting Value. A rating value, defined by ASHRAE Standard 52.2, that depicts how efficiently a filter removes particles of various sizes.

mixed air. A mixture of outdoor air and recirculated return air.

modulated economizer mode. An operating mode of an airside economizer when the outdoor air is cool enough to handle the entire cooling load, and the compressors are off. The controller modulates the positions of the outdoor-air and return-air dampers so that the mixture of outdoor and return air provides supply air at the desired setpoint.

multiple-zone VAV system. A system in which a centralized air-handling unit uses a variable-speed fan to deliver cool air down the duct to several zone-level VAV terminal units, which are typically each equipped with either a hot-water coil or electric heater.

nighttime economizing. See unoccupied economizing.

occupied mode. The typical daytime operating mode of a system. The building must be ventilated, and the comfort cooling or heating temperature setpoints must be maintained in all occupied zones.

optimal start. An optimized morning warm-up routine that determines the length of time required to bring the zone from its current temperature to the occupied setpoint temperature, and then waits as long as possible before starting the system, so the zone reaches the occupied setpoint just in time for scheduled occupancy.

optimal stop. An optimized system shutdown routine that determines how early heating and cooling can be shut off for each zone, so that the indoor temperature drifts only a few degrees from occupied setpoint by the end of the scheduled occupied period.

outdoor air. Air brought into the building from outside, either by a ventilation system or through openings provided for natural ventilation.

parallel fan-powered terminal unit. A fan-powered VAV terminal unit consisting of a primary airflow modulation device and a small, integral constant-volume fan packaged to provide parallel airflow paths.

PCO. Photocatalytic oxidation. An air cleaning technology that uses ultraviolet light shining on the surface of a catalyst to adsorb gaseous contaminants (such as VOCs) and inactivate biological contaminants.

perimeter zone. A conditioned space with walls and windows that are exposed to the outdoors. In most climates these spaces would require seasonal cooling and heating.

plenum. The space between the ceiling and the roof or the floor above.

plenum fan. A fan assembly consisting of a single inlet impeller, mounted perpendicular to airflow, which pressurizes a plenum chamber in the air distribution system.

primary air. Conditioned air delivered by a central supply fan to a terminal unit.

psychrometric chart. A tool used to graphically display the properties of moist air.

recirculated return air. Air removed from the conditioned space and reused as supply air, usually after passing through an air-cleaning and -conditioning system, for delivery to the conditioned space.

relief air. The portion of the return air that is discharged from the central air-handling unit to control building pressure.

return air. Air that is removed from the conditioned space(s) and either recirculated or exhausted.

return-air grille. See grille.

sensible-energy recovery. The transfer of sensible heat between two or more air streams or between two locations within the same air stream.

sensible heat. Heat that causes a change in the dry-bulb temperature of the air with no change in moisture content.

sensor. The component of a control loop that measures the condition of the controlled variable and sends an input signal to the controller.

series fan-powered terminal unit. A fan-powered VAV terminal unit consisting of a primary airflow modulation device and a small, integral constant-volume fan packaged so that the airflow paths are in series. Provides a constant volume of supply air to the zone when operating.

setback. The practice of changing the temperature setpoint of the zone during unoccupied hours in an effort to save energy.

setpoint. The desired condition of the controlled variable in a control loop.

single-zone VAV system. A system in which the air-handling unit uses a variable-speed fan to deliver either cooled or heated air to a single zone.

SMACNA. Sheet Metal and Air Conditioning Contractors National Association (www.smacna.org)

supply air. Air that is delivered to the zone by mechanical means for ventilation, heating, cooling, humidification, or dehumidification (sometimes used interchangeably with discharge air).

supply-air diffuser. See diffuser.

supply-air-temperature reset. A control strategy that raises the temperature of the primary air leaving the rooftop unit at part load, in an effort to reduce overall system energy use.

system ventilation efficiency (Ev). A measure of how efficiently the system distributes air from the outdoor-air intake to the breathing zone.

TAB. Test, adjust, and balance.

tempering. The process of adding sensible heat to the supply air at the VAV terminal unit to avoid overcooling the zone.

throw. Horizontal or vertical axial distance an air stream travels after leaving an air outlet before the maximum stream velocity is reduced to a specified terminal velocity, defined by ASHRAE Standard 70.

total-energy recovery. The transfer of sensible and latent (moisture) heat between two or more air streams or between two locations within the same air stream.

total-energy wheel. A rotating, heat-recovery device that recovers sensible (temperature) and latent (humidity) heat from one air stream and releases it to another adjacent air stream. Also known as a rotary heat exchanger, passive desiccant wheel, heat wheel, or enthalpy wheel.

Traq™ damper. Trane's flow-measuring outdoor-air damper.

unoccupied economizing. An energy-saving control strategy that attempts to precool the building, using cool outdoor air, prior to the morning cool-down period.

unoccupied mode. The typical nighttime operating mode of a system. The building does not require ventilation because it is not occupied, and the zone temperatures are allowed to drift to unoccupied setpoints.

UV-C. Ultraviolet radiation in the "C" wavelength band.

variable-air-volume (VAV) system. A type of air-conditioning system that varies the volume of constant-temperature air supplied to meet the changing load conditions of the zone.

variable-frequency drive (VFD). See variable-speed drive.

variable-speed drive (VSD). A device used to vary the capacity of a fan, pump, or compressor by varying the speed of the motor that rotates the drive shaft.

VAV box. See VAV terminal unit.

VAV reheat terminal unit. A type of single-duct VAV terminal unit that can provide heating using a small heating coil.

VAV terminal unit. A sheet metal assembly used to vary the quantity of supply air delivered to the conditioned space.

ventilation. The intentional introduction of outdoor air into a zone through the use of the HVAC system in the building.

ventilation optimization. An optimized control strategy that combines various demand-controlled ventilation approaches (time-of-day schedules, occupancy sensors, and CO2 sensors) at the zone level, with ventilation reset at the system level.

ventilation reset. A control strategy that attempts to dynamically reset the system outdoor-air intake based on changing system ventilation efficiency.

VOC. Volatile organic compound.

waterside economizer. A method of free cooling that diverts cool condenser water through a separate heat exchanger to precool the water returning to the water chillers.

zone. One occupied space or several occupied spaces with similar characteristics (thermal, humidity, occupancy, ventilation, building pressure).

zone air-distribution effectiveness (E_z). A measure of how effectively the air delivered to the zone by the supply-air diffusers reaches the breathing zone.

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