GUIDELINE

ASHRAE

ASHRAE Guideline 42-2023

Enhanced Indoor Air Quality in Commercial and Institutional Buildings

Approved by ASHRAE on November 30, 2023.

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NOTE

Approved addenda, errata, or interpretations for this guideline can be downloaded free of charge from the ASHRAE website at www.ashrae.org/technology.

(This foreword is not part of this guideline. It is merely informative and does not contain requirements necessary for conformance to the guideline.)

FOREWORD

Since 1999, ASHRAE has maintained a minimum standard for ventilation, first through Standard 62 and then through its successor, Standard 62.1. As a minimum standard intended for international code adoption, ANSI/ASHRAE Standard 62.1 cannot mandate the abundance of evidence-based, improved indoor air quality (IAQ) practices. ASHRAE Guideline 42 was developed to fill this gap.

ASHRAE Guideline 42 is intended for a global audience of engineers, designers, hygienists, air quality practitioners, and building owners and provides a roadmap of varied best practices for improving ventilation and acceptable IAQ. The guideline steps users through concepts, research, and processes that have proven useful when effectively designed, installed, and operated. Guideline 42 also aims to supplement related publications from ASHRAE and other organizations. Future editions will incorporate relevant research and technologies as they are tested and validated to improve IAQ. Guideline 42 is not intended to be all inclusive, nor does its use guarantee enhanced ventilation.

The sections of Guideline 42 are purposefully organized to reflect the path of air, beginning outside the building and moving through the building envelope, systems, and equipment to the indoor space. Enhanced IAQ is a function of interacting building systems and occupant activity. Highlighting the air path, and arranging subsections accordingly, creates a logical framework for future revisions. Figure 1 shows how the sections of ANSI/ASHRAE Standard 62.1 relate to those of Guideline 42. Figures 2 and 3 show how the sections of Guideline 42 relate to areas of the building and ventilation system.

1. PURPOSE

1.1 The purpose of this guideline is to recommend measures that exceed minimum requirements for improving indoor air quality (IAQ) in commercial and institutional buildings. These measures are intended to provide enhanced IAQ that is acceptable to human occupants and that minimizes adverse health effects.

2. SCOPE

2.1 This guideline applies to spaces intended for human occupancy within commercial and institutional buildings except those within dwelling units in residential occupancies in which occupants are nontransient.

2.2 This guideline provides recommendations related to certain sources and for ventilation and air-cleaning system design, installation, commissioning, and operation and maintenance.

3. DEFINITIONS

Definitions for terms designated with an asterisk (*) are from ANSI/ASHRAE Standard 62.1, and terms designated with a dagger (†) are from the online ASHRAE Terminology Database (www.ashrae.org/terminology).

acceptable indoor air quality (IAQ)*: air in which there are no known contaminants at harmful concentrations as determined by cognizant authorities and with which a substantial majority (80% or more) of the people exposed do not express dissatisfaction.

air:

> ***ambient air*:*** the air surrounding a building; the source of outdoor air brought into a building.
>
> ***exhaust air*:*** air removed from a space and discharged to outside the building by means of mechanical or natural ventilation systems.
>
> ***indoor air*:*** the air in an enclosed, occupiable space.
>
> ***locally recirculated air:*** indoor air that is recirculated within a space by mechanically powered equipment such as ceiling fans or in-room air-cleaning device.
>
> ***makeup air*:*** any combination of outdoor and transfer air intended to replace exhaust air and exfiltration.
>
> ***outdoor air*:*** ambient air and ambient air that enters a building through a ventilation system, through intentional openings for natural ventilation, or by infiltration.
>
> ***primary air*:*** air supplied to the ventilation zone prior to mixing with any locally recirculated air.
>
> ***recirculated air*:*** air removed from a space and reused as supply air.
>
> ***return air*:*** air removed from a space to be recirculated or exhausted.
>
> ***supply air*:*** air delivered by mechanical or natural ventilation to a space and composed of any combination of outdoor air, recirculated air, or transfer air.
>
> ***transfer air*:*** air moved from one indoor space to another.
>
> ***ventilation air*:*** that portion of supply air that is outdoor air plus any recirculated air that has been treated for the purpose of maintaining acceptable indoor air quality.

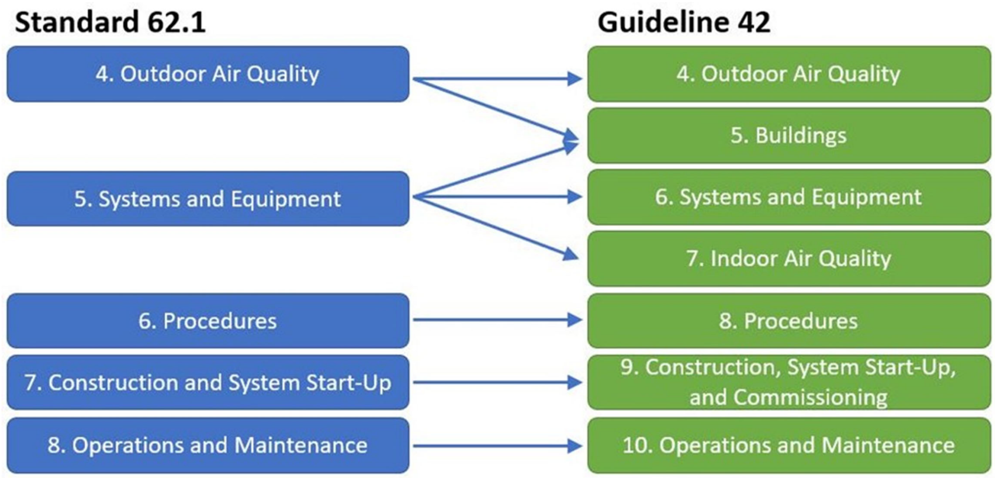

Figure 1 Sectional comparison of ANSI/ASHRAE Standard 62.1 and this guideline.

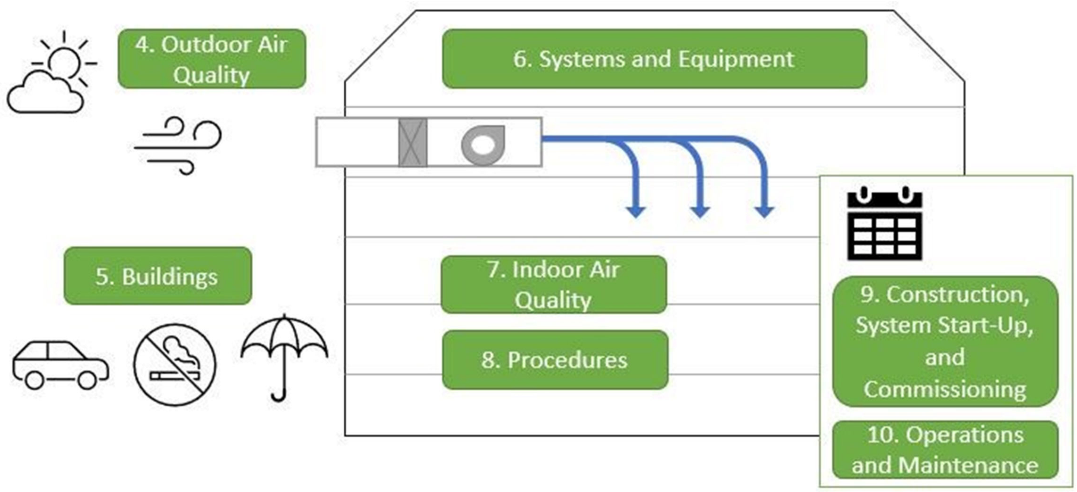

Figure 2 Sections of this guideline as related to a building.

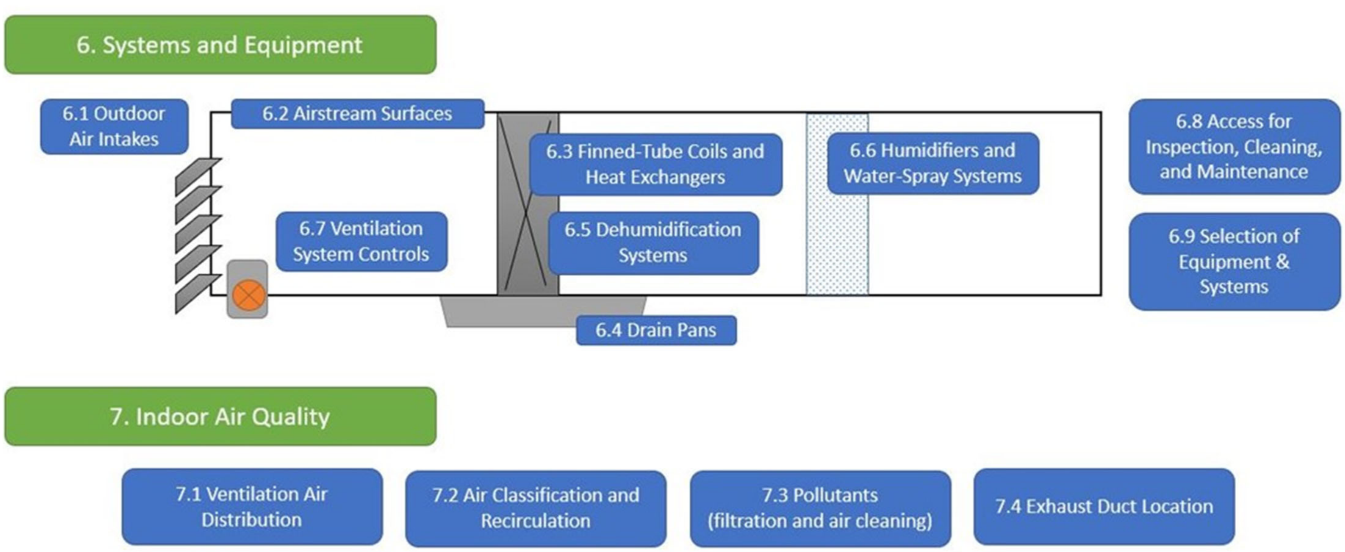

Figure 3 Sections 6 and 7 descriptive diagrams.

air-cleaning system*: a device or combination of devices applied to reduce the concentration of airborne contaminants such as microorganisms, dusts, fumes, respirable particles, other particulate matter, gases, vapors, or any combination thereof.

air conditioning*: the process of treating air to meet the requirements of a conditioned space by controlling its temperature, humidity, cleanliness, and distribution.

air change rate†: volume of air supplied to and removed from a space, via mechanical systems or through the building enclosure, per unit of time divided by the volume of the space, using the same units for volume such that the unit is inverse time.

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

cognizant authority*: an agency or organization that has the expertise and jurisdiction to establish and regulate concentration limits for airborne contaminants, or an agency or organization that is recognized as authoritative and has the scope and expertise to establish guidelines, limit values, or concentration levels for airborne contaminants.

concentration*: the quantity of one constituent dispersed in a defined amount of another.

conditioned space*: that part of a building that is heated or cooled, or both, for the comfort of occupants.

contaminant*: an unwanted airborne constituent with the potential to reduce acceptability of the air.

contaminant mixture*: two or more contaminants that target the same organ system.

demand-controlled ventilation (DCV)*: any means by which the breathing zone outdoor airflow (V_{bz}) can be varied to the occupied space or spaces based on the actual or estimated number of occupants, ventilation requirements of the occupied zone, or both.

dwelling unit*: a single unit providing complete, independent living facilities for one or more persons, including permanent provisions for living, sleeping, eating, cooking, and sanitation.

effective air change rate (eACH)†: the constant outdoor air change rate that would result in the same average pollutant concentration over the same period of time as actually occurs under varying conditions.

energy recovery device*: a device or combination of devices applied to provide the outdoor air for ventilation in which energy is transferred between the intake and exhaust airstreams.

enhanced indoor air quality: air quality that was or has been improved or has been prevented from becoming degraded to (or exceeds) minimum acceptable indoor air quality.

environmental tobacco smoke (ETS): the "aged" and diluted combination of both side-stream smoke (smoke from the lit end of a cigarette or other tobacco product) and exhaled mainstream smoke (smoke that is exhaled by a smoker). ETS is commonly referred to as *secondhand smoke*. This definition includes smoke produced from the combustion of cannabis and controlled substances and the emissions produced by electronic smoking devices. When ETS becomes embedded in materials (clothing, building finishes), it can remain concentrated long after the ETS source has been removed, re-emit into the space, and recombine to form other compounds, referred to as *third-hand smoke*.

exfiltration*: uncontrolled outward air leakage from conditioned spaces through unintentional openings in ceilings, floors, and walls to unconditioned spaces or the outdoors caused by pressure differences across these openings due to wind, inside-outside temperature differences (stack effect), and imbalances between outdoor and exhaust airflow rates.

industrial space*: an indoor environment where the primary activity is production or manufacturing processes.

infiltration*: uncontrolled inward air leakage to conditioned spaces through unintentional openings in ceilings, floors, and walls from unconditioned spaces or the outdoors caused by the same pressure differences that induce exfiltration.

integrated pest management (IPM): strategy to manage pest levels at an acceptably low level by combining multiple non-chemical interventions to prevent conditions favorable to pests. If active measures are needed, chemicals are used in a targeted and limited manner, starting with the least toxic products.

mechanical ventilation*: ventilation provided by mechanically powered equipment such as motor-driven fans and blowers but not by devices such as wind-driven turbine ventilators and mechanically operated windows.

microorganism: a microscopic organism, especially a bacterium, fungus, or protistan.

natural ventilation*: ventilation provided by thermal, wind, or diffusion effects through doors, windows, or other intentional openings in the building.

net occupiable area*: the floor area of an occupiable space defined by the inside surfaces of its walls but excluding shafts, column enclosures, and other permanently enclosed, inaccessible, and unoccupiable areas. Obstructions in the space, such as furnishings, display or storage racks, and other obstructions, whether temporary or permanent, are considered to be part of the net occupiable area.

nontransient*: occupancy of a dwelling unit or sleeping unit for more than 30 days.

occupant sensor*: a device such as a motion detector or a captive key system that detects the presence of one or more persons within a space.

occupiable space*: (1) any enclosed space inside the pressure boundary (including, but not limited to, all habitable spaces, toilets, closets, halls, storage and utility areas, and laundry areas) and intended for human activities; (2) that portion of the premises accessible to or occupied by people, excluding machinery rooms.

occupied mode*: when a zone is scheduled to be occupied.

occupied standby mode*: when a zone is scheduled to be occupied and an occupant sensor indicates zero population within the zone.

odor*: a quality of gases, liquids, or particles that stimulates the olfactory organ.

particulate matter (PM): a mixture of solid particles and liquid droplets found in the air. Some particles, such as dust, dirt, soot, or smoke, are large or dark enough to be seen with the naked eye, while others are so small they can only be detected using an electron microscope. Particle pollution includes PM10, particles with diameters 10 micrometers and smaller in aerodynamic diameter, and PM2.5, particles with diameters 2.5 micrometers and smaller in aerodynamic diameter. PM2.5 is referred to as the fine PM fraction and the portion from PM10 – PM2.5 as the coarse PM fraction. The general correlation between these designations and the terms inhalable, thoracic, and respirable are discussed in Informative Appendix A.

unoccupied mode*: when a zone is not scheduled to be occupied.

ventilation*: the process of supplying air to or removing air from a space for the purpose of controlling air contaminant levels, humidity, or temperature within the space.

ventilation zone*: any indoor area that requires ventilation and comprises one or more spaces with the same occupancy category, occupant density, zone air distribution effectiveness, and design zone primary airflow per unit area.

4. OUTDOOR AIR QUALITY

Indoor air quality (IAQ) can be strongly affected by outdoor air quality. Outdoor air enters a building by intentional ventilation (both natural and mechanical) and by unintentional infiltration driven by air pressure differences between indoors and outdoors.

When indoor contaminants of concern are less concentrated in outdoor air, untreated outdoor air can dilute indoor contaminants and improve IAQ. In many parts of North America[1,2] and Europe[3], particularly outside of urban centers, air pollution has decreased over the last decade, allowing for increased benefit from ventilation with outdoor air. Nevertheless, in some parts of North America, outdoor air is still not healthy. For example, the latest “State of the Air” report from the American Lung Association found that, “despite some nationwide progress on cleaning up air pollution, more than 40% of Americans—over 135 million people—are living in places with unhealthy levels of ozone or particle pollution. The burden of living with unhealthy air is not shared equally. People of color are over three times more likely to be breathing the most polluted air than white people.”[4] The EPA also reports, “Despite great progress in air quality improvement, approximately 97 million people nationwide lived in counties with pollution levels above the primary National Ambient Air Quality Standards (NAAQS) in 2020.”[1,5] Elsewhere in the world and in urban centers, frequent incidents of poor outdoor air quality can reduce, rather than enhance, the quality of indoor air. As of 2016, the World Health Organization (WHO) reports that 92% of the world population lives in areas that exceed guideline upper limits for air pollution; this exposure to ambient air pollution resulted in an estimated 4.2 million deaths.[6,7] Informative Appendix A discusses the health impacts of various air pollutants.

4.1 Regional Air Quality. ANSI/ASHRAE Standard 62.1[8] requires that the status of compliance with NAAQS[5] be determined for the building site. If the area is not in compliance (nonattainment) for PM10, PM2.5, or ozone, the standard includes requirements for air cleaning and says to consider using the IAQ Procedure (IAQP; Section 6.3) in lieu of the Ventilation Rate Procedure (VRP; Section 6.2) for the ventilation design. To design for enhanced IAQ, these air-cleaning strategies can beused to address the air pollutants with established national limits and any other air pollutants identified by the local air quality study. The use of air cleaning with the IAQP can also allow for a reduction in the amount of outdoor air required, thereby reducing the amount of pollution coming into a building by intentional ventilation.

Table 1 WHO Ambient Air Quality Mean Concentration Limits, 2006

Pollutant	10 minutes	1 hour	8 hours	24 hours	Annual
Particulate matter (PM2.5)	—	—	—	25 μg/m^3	10 μg/m^3
Particulate matter (PM10)	—	—	—	50 μg/m^3	20 μg/m^3
Ozone (O_3)	—	—	100 μg/m^3	—	—
Nitrogen dioxide (NO_2)	—	200 μg/m^3	—	—	40 μg/m^3
Sulfur dioxide (SO_2)	500 μg/m^3	—	—	20 μg/m^3	—

Table 2 WHO Ambient Air Quality Mean Concentration Limits, 2021

Pollutant	10 minutes	1 hour	8 hours	24 hours	Annual	Peak Season
Particulate matter (PM2.5)	—	—	—	15 μg/m^3	5 μg/m^3	—
Particulate matter (PM10)	—	—	—	45 μg/m^3	15 μg/m^3	—
Ozone (O_3)	—	—	100 μg/m^3	—	—	60 μg/m^3
Nitrogen dioxide (NO_2)	—	200 μg/m^3	—	25 μg/m^3	10 μg/m^3	—
Sulfur dioxide (SO_2)	500 μg/m^3	—	—	4 μg/m^3	—	—
Carbon monoxide (CO)	100 μg/m^3 (15 minutes)	35 μg/m^3	10 μg/m^3	4 μg/m^3	—	—

The NAAQS are summarized in ANSI/ASHRAE Standard 62.1, Informative Appendix D, and apply to the United States and its territories. The WHO's "Air Quality Guidelines Global Update 2005"[9] identifies the State of California, the European Union, Japan, Brazil, Mexico, South Africa, India, and China as jurisdictions with established standards or limits for outdoor air pollution. The WHO[9,10] further provides global limits for outdoor air pollutants. Table 1 shows the 2006 Air Quality Guideline (AQG) limits, and Table 2 shows the revised 2021 AQG limits, some of which were updated to reflect the current understanding of health impacts of the listed pollutants. The 2021AQG limits for 24-hour and annual averaging times are significantly lower than the 2006 limits. In many cases, these WHO limits are lower than those set by regional air quality standards. Designs that meet the lower of the regional or WHO limits are likely to result in enhanced IAQ.

4.1.1 Outdoor Air Treatment. Specific strategies that address air pollution include filtration and air-cleaning technologies to target the outdoor pollutants that exceed regional air quality standards. A more detailed discussion of technologies to handle air pollution is provided in Section 7.3 of this document.

4.2 Local Air Quality. A local air quality analysis that includes all known sources and variations in pollutants can help the designer and owner develop appropriate strategies to manage and enhance IAQ. A local air quality survey is intended to identify both fixed and transient sources of outdoor air pollutants on or near the building site. Examples of fixed sources include sewage treatment facilities, landfills, power plants, and industrial sites. The building itself may have boiler stacks, generator stacks, or exhaust discharges. Examples of transient sources include transportation systems, such as locomotive tracks and switchyards, expressways, airports, and helipads.

4.2.1 Wind Analysis. As part of the local air quality survey, analysis of prevailing wind patterns can inform the design of the building form, outdoor air intakes, and exhaust air discharges to encourage high-quality air at the outdoor air intakes.

4.2.2 Outdoor Air Intakes. In addition to the minimum separation distances from contaminant sources required by the standard, outdoor air intake locations sheltered from wind-driven transport of pollutants and away from recirculation regions tend to enhance IAQ.

4.2.3 Exhaust Air Discharges. Exhaust air discharge to outdoor areas generally downwind of the building's outdoor air intakes and outside recirculation regions enhance IAQ. The HVAC system design can result in safe and effective removal of exhaust air without impacting the building itself or its neighbors. To avoid negatively impacting the IAQ of nearby buildings, the locations of their outdoor air intakes can inform the siting of the project building's exhaust air discharges.

4.2.4 Seasonal Changes. Some sites experience seasonal differences in outdoor air pollutants. For example, coastal sites may have different pollutant and moisture loading from human or natural activities related to the waterfront. Agricultural sites present similar challenges where pollutants differ in both quantity and type between planting seasons, growing seasons, harvest seasons, and fallow seasons. Wildfires can be a source of pollutants over thousands of square miles (or kilometers). Recent increases in wildfire frequency and intensity emphasize the need for building systems that can minimize the negative impacts of wildfire smoke on air quality and human health. ASHRAE Guideline 44, *Protecting Building Occupants from Smoke During Wildfire and Prescribed Burn Events,* is currently under development.[11]

4.2.5 Infectious Aerosol Entry. While infectious aerosol transmission is primarily associated with indoor exposure of building occupants to aerosols released by other occupants, there is also interest in infectious aerosols that enter from outdoors. Although considered very rare, this route of exposure was highlighted during the 2003 SARS pandemic in Hong Kong when a SARS patient in the Amoy Gardens apartments led to the exposure of multiple building occupants via outdoor entry of aerosols released from within the building.[12] This event was linked to plumbing fixtures without effective traps, which led to infectious aerosols becoming airborne, which would not have occurred if the fixtures were properly installed and maintained per current practice. More recently, there was a study of potential entry from outdoors of the SARS-CoV-2 virus that is suspected of leading to an outbreak of COVID-19 in a residential building.[13]A more common infectious aerosol in the built environment is aerosolized *Legionella* from water sources such as cooling towers, decorative fountains, and hot tubs.[14] These examples highlight potential risks posed by exhaust or discharge from nearby units or buildings.

4.3 Documentation. Designers need adequate documentation of the local and regional air quality to inform their design decisions. Where provided to the building owner, such documentation helps inform decisions related to building and ventilation system operations. In addition to the documentation required by ANSI/ASHRAE Standard 62.1[8], including the following items helps the designer and operator enhance IAQ:

a. Regional air quality compliance status
   1. Average concentration over the averaging time of each air pollutant in the standard
   2. Air pollutant concentration limit for each air pollutant in the standard
b. Local survey information
   1. If a local weather station is available, wind rose based on the most recently available full-year weather data
   2. All historic air pollutant concentrations and the associated averaging times
   3. A site map indicating preferred locations for outdoor air intakes and exhaust air discharges

5. BUILDINGS

5.1 Building Envelope and Interior Surfaces. The requirements for the building envelope in ANSI/ASHRAE Standard 62.1[8] are intended to reduce the likelihood of moisture and air from damaging building materials. These requirements are also important for infiltration, which may have an immediate impact on indoor air quality (IAQ) and a long-term impact on building materials, where moisture penetration can contribute to mold growth, corrosion, and decay. Even when a designer properly details the required vapor retarders, air barriers, and weather-resistive layer, there is no guarantee that the building envelope will effectively control the penetration of moisture and air due to a faulty installation. Building envelope testing (blower door, water spray testing, etc.) can be used to identify and reduce the occurrence of flaws in the envelope design and construction. Publications to assist the designer with specifying building envelope testing include the National Institute of Building Sciences (NIBS) Guideline 3, *Building Enclosure Commissioning Process*[15], and the National Environmental Balancing Bureau (NEBB) *Procedural Standard for Building Enclosure Testing.*[16] For additional information about the occupant health risk related to dampness in buildings, see the 2020 report from the ASHRAE Multidisciplinary Task Group: Damp Buildings titled "Damp Buildings, Human Health, and HVAC Design."[17]

5.1.1 Intended Moisture Exchange in Existing Buildings. The design requirements in ANSI/ASHRAE Standard 62.1[8] are intended for new buildings and alterations to existing buildings. These requirements may not adequately address older forms of construction that relied on moisture exchange between layers of the building envelope to manage moisture penetration and accumulation. An example familiar to many designers on the east coast of the United States is brick face wall construction: moisture is anticipated to collect and condense in the air gap between the wetted exterior brick and lathe, and planned openings at the base of the wall, called "weep holes," allow water to drain out of the wall assembly. This same air gap also serves to maintain the moisture content in the interior wall structure, typically a plaster. The appropriate placement of air and vapor barriers in this assembly is necessary to prevent moisture accumulation at a damaging level. ANSI/ASHRAE Standard 160[18] provides guidance on how to use hygrothermal analysis of building envelope designs to reduce the likelihood of moisture problems.

5.1.2 Moisture Absorption and Condensation on Interior Surfaces. To avoid microbial growth, the building and its contents must remain dry.[19] To accomplish that goal, ANSI/ASHRAE Standard 62.1[8] requires that the indoor dew-point temperature remain at or below 60°F (15°C) in any space served by mechanical cooling whenever the outdoor air dew point is above that level for both occupied and unoccupied hours.

The 60°F (15°C) dew-point limit was selected because the HVAC system is able to keep the indoor air dry enough to reduce the potential for surface moisture absorption that leads to persistent dampness. Damp materials allow microbial growth that can increase the probability of negative health effects.[17] Although bacteria and fungi are present in all buildings and on all surfaces, their presence is generally without negative consequences for air quality or health until surfaces absorb enough moisture for a long enough period to allow growth and reproduction.

Using a lower dew-point limit as the basis of design exceeds the minimum requirements, further enhances comfort, and provides a more robust defense against persistent dampness. For example, the commonly used cooling system design target of 75°F (24°C), 50% rh represents a 55°F (13°C) dew point. That dew-point target has long been suggested by ASHRAE publications that provide detailed guidance for humidity control.[20, 21]

Although most cooling systems can intermittently achieve lower dew points, they often operate in response to a thermostat rather than a humidity sensor. Unless sensors and controls measure the indoor air dew point and activate the equipment accordingly, cooling systems may not keep the building dry at all times, even though they might have the dehumidification capacity to do so. Informative Appendix B provides further discussion of relative humidity, dew-point sensors, and controls.

5.1.3 Unintended Airflow Across the Envelope. Air that enters into or exhausts from the building through an opening designed for air transfer is ventilation. Unintended or uncontrolled airflow is exfiltration and infiltration driven by stack effects, wind pressure, and mechanical imbalances through building envelope components. Uncontrolled airflow through the building envelope can allow moisture to accumulate within the envelope assembly and/or facilitate passage of other pollutants. Season, geography, climate zone, envelope design, material selection, and installation all influence the potential for damage from unintended airflow. Buildings and zones within buildings may be designed to have positive, negative, or neutral pressure relative to the surrounding space based on their use, geographical location, or construction type. For example, seasonal pressure relationships between the building interior and the outside reduce the potential for condensation to occur within the building envelope. In the summer, a negative pressure relative to the outside can pull moist outdoor air into the envelope assembly, leading to condensation on the cool (air-conditioned) inner layers. In the winter, a positive pressure can drive moisture from the interior into the envelope assembly, leading to condensation on the cold (weather-cooled) outer layers. However, net building air intake (greater mechanical intake airflow than mechanical exhaust or relief airflow, as required by ANSI/ASHRAE Standard 62.1) by itself cannot guarantee a building interior with positive pressure relative to the outside. Buoyancy-driven (stack-effect) flows can be the dominant pressure differential, resulting in upper-floor infiltration of warm, moist air in summer, and upper-floor exfiltration of warm, moist air in winter. For example, the considerable in-flow draft experienced at entry doors to high bay spaces in the winter (where high differential indoor-to-outdoor temperatures result in very high stack-effect pressures) can seldom be significantly reduced by increasing net outdoor air intake flow. Design strategies to reduce warm weather infiltration and cold weather exfiltration include using entry air curtains, rotating doors, vestibules, and long-entry corridors.

5.1.4 Radon and Other Soil-Gas Contaminants. Local jurisdictions may have additional pressurization requirements to prevent the intrusion of radon or other soil-gas contaminants. The U.S. EPA has established an action level for radon of ≥4 pCi/L and recommends action in homes for lower levels (between 2 pCi/L and 4 pCi/L), as there is no known safe level of radon exposure. Resources for designers include the following ANSI/AARST standards: CC-1000, *Soil Gas Control Systems in New Construction of Buildings*[22]; RMS-LB, *Radon Mitigation Standards for Schools and Large Buildings*[23]; and RMS-MF, *Radon Mitigation Standards for Multifamily Buildings*[24].

5.2 Buildings with Attached Parking Garages. Attached parking garages contain operational internal combustion engines—a well-established source for pollutants. It is preferred that parking garages be detached structures. If they are attached to the building, these parking garages cannot be considered in the same manner as any other contributor to local air quality as discussed in Section 4.2. Measures that can reduce airflow from the garage into the building include pressurized vestibules, rotating doors, garage exhaust fans on lower levels, positively pressurized zones that abut the garage, and attention to air sealing at the garage-building interface during design and construction.

5.3 Requirements for Buildings Containing Environmental Tobacco Smoke (ETS) Areas and ETS-Free Areas. ASHRAE's position is that all smoking activity inside and near buildings should be eliminated, as the medical community and its cognizant authorities agree that ETS exposure at any level is a serious health risk.[25] Although ANSI/ASHRAE Standard 62.1 allows smoking in specified areas with prescribed separation requirements, prohibiting smoking is the only way to avoid ETS exposure and its harmful health effects and aligns with the goal of enhanced IAQ. In its position document on ETS, ASHRAE recommends that designers educate and inform their clients of the limits of engineering controls and their role to reduce, but not eliminate, exposure risk.

Design and operation considerations to reduce the risk of ETS intrusion, or intrusion of any occupant-generated combustion products (incense, smudging, candles, etc.), include the following:

- Constructing boundaries of ETS areas as smoke barriers
- Maintaining an air balance through active controls and interlocked doors
- Using sliding doors to reduce contaminant transfer due to "door pumping"
- Avoiding local recirculation systems
- Using a dedicated, reliable, and independently controlled exhaust system that is fully ducted from the ETS area to the building exterior
- Analyzing the exhaust discharge plume to limit exposure and re-entrainment
- Labeling ductwork, equipment, and components to prevent ETS intrusion during maintenance and construction activities
- Removing or sealing all materials exposed to ETS to minimize exposure to third-hand smoke prior to reclassifying an ETS area as an ETS-free area

6. SYSTEMS AND EQUIPMENT

6.1 Outdoor Air Intakes. The location and design of outdoor air intakes is critical for ensuring high-quality ventilation air. Careful selection of intake locations can reduce the entrainment of exhaust and other contaminants into the building. Louver design can also reduce the entrainment or intrusion of water into the building. Wet airstream surfaces can promote mold growth and poor indoor air quality (IAQ). The intrusion of debris, such as tree seeds, leaves, and litter, can obstruct the distribution system and degrade IAQ. Additional references include *Indoor Air Quality Guide: Best Practices for Design, Construction, and Commissioning*[26]; *ASHRAE Handbook—HVAC Systems and Equipment*[27], Chapter 4; *ASHRAE Handbook—HVAC Applications*[28], Chapter 45; ANSI/ASHRAE Standard 62.1; ANSI/ASHRAE/IES Standard 90.1[29]; ANSI/ASHRAE/ASHE Standard 170[30], Section 6.3; and ASHRAE Research Project (RP) 1635, *Simplified Procedure for Calculating Exhaust/Intake Separation Distances*.[31]

6.1.1 Location. Outdoor air intakes located a minimum of 10 ft (3.0 m) above grade reduce the likelihood of lawn care products, pesticides, leaves, and foliage trimmings entering the building. The likelihood of a malicious event[32] can also be reduced when intakes are elevated above ground level. An outdoor air intake located in the same architectural screen as an exhaust discharge increases the likelihood of exhaust air entrainment and reduction of IAQ. Packaged units with adjacent exhaust discharge and outdoor air intake have a similar risk, which can be reduced by adding a baffle or shroud or locating the unit's discharge/intake face sufficiently far from a wall or other large obstruction that could create recirculation. Examples can be found in *Indoor Air Quality Guide*[26], Strategy 3.2, "Locate Outdoor Air Intakes to Minimize Introduction of Contaminants." Intakes located near vehicle loading zones or other outdoor contamination sources, such as dumpsters, can lead to reduced IAQ, as discussed in *ASHRAE Handbook—HVAC Applications*[28], Chapter 45. Chapter 45 also discusses the effects of building geometry on airflow patterns near the building and important factors for separation distances from contamination sources.

Mechanical codes dictate minimum separation distances. The minimum required separation distance from all heat rejection equipment (particularly evaporative equipment such as cooling towers) and the associated discharged air is intended to minimize the risk of *Legionella* to building occupants.[33] Entrainment of contaminants can be further discouraged by modifying equipment, such as adding extension cowls or separating baffles to cooling towers or exhaust stacks on packaged units. The impact of contaminant sources, such as laboratory fume hood exhaust, on outdoor air intakes can be analyzed using a wind tunnel or a computational fluid dynamics (CFD) study. NFPA 45[34], ANSI/AIHA/ASSP Z9.5[35], and local codes include requirements for minimum separation distance between outdoor air intakes and laboratory exhaust airstreams. ANSI/ASHRAE/ASHE Standard 170[30], Section 6.3, includes minimum requirements for intake locations for health care facilities. The shortest distance between outdoor air intakes (including openings of a natural ventilation system) and any specific potential contaminant source is listed in ANSI/ASHRAE Standard 62.1, Table 5-1, or can be determined using the calculation method in Normative Appendix B.

Separation distances longer than these minimum requirements usually result in enhanced IAQ. The *Indoor Air Quality Guide*[26], Table 3.2-B, offers a helpful comparison of the ANSI/ASHRAE Standard 62.1 separation distances versus model codes. A simpler, more accurate equation for calculating the minimum separation distance from various types of contamination sources was developed in ASHRAE RP-1635.[31] This method includes dilution factors for Class 1 through 4 air, wood-burning kitchen, boiler, vehicle, emergency generator, and cooling-tower-type exhaust. Lastly, an intake location that is accessible facilitates cleaning and maintenance of the wildlife mesh, which may become loaded with pollen or other natural debris or may be damaged by wildlife.

6.1.2 Airstream Mixing. The location of the outdoor air damper with respect to the return air damper affects the mixing of the combined airstream. Poor mixing could result in improper distribution of the outdoor air and uneven conditions across the duct section. In some cases, the location and orientation of the outdoor air intake promotes appropriate mixing of outdoor air and return air. In freezing weather, operational staff may close outdoor air intake dampers to prevent freeze-stat lockout due to improper mixing and stratification. Outdoor air damper size and location along with mixing devices can help reduce stratification. *ASHRAE Handbook—HVAC Systems and Equipment*[27], Chapter 4, offers suggestions on the design of mixing plenums. ASHRAE RP-1045[36] reports the results of testing various configurations of mixing plenums. A mixing-box air blender may be added if there is stratification, but the benefits of improved mixing must be weighed against the energy penalty for increased pressure drop.

6.1.3 Water Entrainment. Properly designed intake louvers and air-handling equipment intakes reduce the volume of water entering the building. Reducing the maximum velocity of intake airflow discourages water entrainment. ANSI/ASHRAE Standard 62.1, Section 5.5.2, limits water and rain entrainment rates, and Section 5.5.4 includes requirements intended to reduce or otherwise deal with snow entrainment. Section 5.5.3 includes requirements that help air-handling and distribution equipment mounted outdoors reduce rain intrusion into the airstream. Backdraft dampers prevent exfiltration of conditioned air through the outdoor intake when the system is not in use, reducing condensation potential within the duct.

6.1.4 Bird Screens and Insect Control Devices. Provisions in the standard reduce the likelihood of wildlife intrusion at the outdoor air intake. Intake screening prevents penetration by a 0.5 in. (13 mm) diameter probe per ANSI/ASHRAE Standard 62.1, Section 5.5.5. Insect remediation or screening devices with smaller openings can prevent insect intrusion into the building spaces; this may increase the pressure drop across the outdoor air intake. Maintenance of these devices prevent buildup of dead insects.

6.2 Airstream Surfaces. According to ANSI/ASHRAE Standard 62.1, surfaces that are used to convey air must be resistant to microbial growth in accordance with a standardized test method, such as UL Standard 181[37] or ASTM Standard C1338.[38] A general exception for this testing is made for sheet metal surfaces and metal fasteners; however, this testing requirement applies to all other types of airstream surface materials, including plastic sheeting, fiberglass, mineral wool, closed cell, open cell, foils, Mylar, and other surfaces or liners.

This resistance to microbial growth is important because conditions that may result in the growth can occur in the HVAC system. Growth of microorganisms is dependent on a source of food, which can include paper or other organic materials. For growth to occur, there must also be a source of moisture or water. Microbial growth is faster when temperature and humidity conditions are within a suitable range. Metal, fiberglass, and other surface materials commonly used in duct construction are not organic matter and do not provide a direct source of food; however, organic matter can collect on them and serve as food for the microbes. For this reason, it is recognized that microbial growth (mold and bacteria, for instance) can occur on nonorganic surfaces when they are part of or located in the airstream surface and continuously or intermittently wetted or moistened.

6.2.1 Procedures to Minimize Dirt Accumulation and Wetting of Airstream Surfaces. Multiple studies have concluded that controlling moisture and reducing dirt and debris accumulation is important in reducing microbial contamination and improving IAQ.[39,40] These issues are addressed on a limited basis in ANSI/ASHRAE Standard 62.1. Specifically, Section 5.12, "Drain Pans," addresses requirements to minimize water carryover or wetting. Section 5.9, "Particulate Matter Removal," Section 6.1.4.1, "Particulate Matter Smaller than 10 Micrometers (PM 10)," and Section 6.1.4.2, "Particulate Matter Smaller than 2.5 Micrometers (PM 2.5)" address dirt introduction and accumulation.[8]

6.2.1.1 Additional Guideline Information for Minimizing Water Carryover. The minimization of water carryover or wetting is essential for the proper operation of humidifiers and drain pans and is discussed in Sections 6.3.3, "Moisture Carryover," and 6.6, "Humidifiers and Water-Spray Systems."

6.2.1.2 Additional Guideline Information for Preventing Accumulation of Dirt and Debris. The accumulation of dust and debris in HVAC systems can result in microbial growth on these materials. Prevention of dust and debris accumulation in HVAC systems is discussed in Sections 6.3.2, “Options for Improved Cleanliness and Access”; 7.3.1,” Particles”; 9.1.3, “Protective Measures”; 9.2, “System Start-up and Commissioning”; and 10.6.2.2, “Air-Cleaning Devices.”

6.2.2 Additional Performance Characteristics for Airstream Equipment and Surfaces. The airstream surface materials must demonstrate proven resistance to erosion and must not break away, crack, peel, flake off, or show evidence of delamination or continued erosion. The potential for erosion must be evaluated in accordance with the UL Standard 181[37] erosion test. Again, a general exception to this testing is made for sheet metal surfaces and metal fasteners.

Materials that break away can end up clogging filters, fans, turning vanes, diffusers, and dampers, thereby reducing airflow. Debris can travel through the distribution system and enter the occupied space and deposit onto surfaces. Furthermore, the rough surfaces left on the original substrate and at the collection points of the breakaway materials can more easily collect organic matter, which, in turn, can result in microbial growth.

Therefore, it is essential that the designer specify that HVAC system builders and installers comply with one of the following industry standards:

- Sheet Metal and Air Conditioning Contractor’s National Association (SMACNA) *HVAC Duct Construction Standards—Metal and Flexible*[41]
- North American Insulation Manufacturer’s Association (NAIMA) *Fibrous Glass Duct Liner Standard: Design, Fabrication and Installation Guide*[42]

Appropriate fabrication and installation of the airstream surfaces in a duct system are essential to the long-term performance of the surface products.

Additionally, flexible duct can provide another means for accumulation of dirt and debris, and these ducts can be difficult to properly clean. Therefore, the minimum length of flexible duct should be used as noted in the Model Building Codes, and the installation shall conform to SMACNA’s *HVAC Duct Construction Standards—Metal and Flexible*[41] and Air Duct Council’s (ADC) *Flexible Duct Performance & Installation Standards*.[43]

Airstream surfaces that must meet the requirements in ANSI/ASHRAE Standard 62.1 are designated by arrows on the schematic shown in Figure 4.

6.3 Finned-Tube Coils and Heat Exchangers. Depending upon coil geometry and depth, some coils are easier to clean and maintain. Stainless steel coil casings in wet environments can help to enhance IAQ and longevity of equipment.

6.3.1 Minimum Requirements for Cleaning. Thorough coil cleaning may be difficult for coils with many rows of tubes, with tight fin spacing, or with complex fin geometry. Using wider fin spacing and fewer rows in the coil will likely improve cleanability. In hot, humid climates the impact of fin spacing and number of rows on the latent ratio of the coil should be considered as well. ANSI/ASHRAE Standard 62.1 recognizes that all these issues impact coil air pressure drop at a fixed velocity, so the standard limits coil pressure

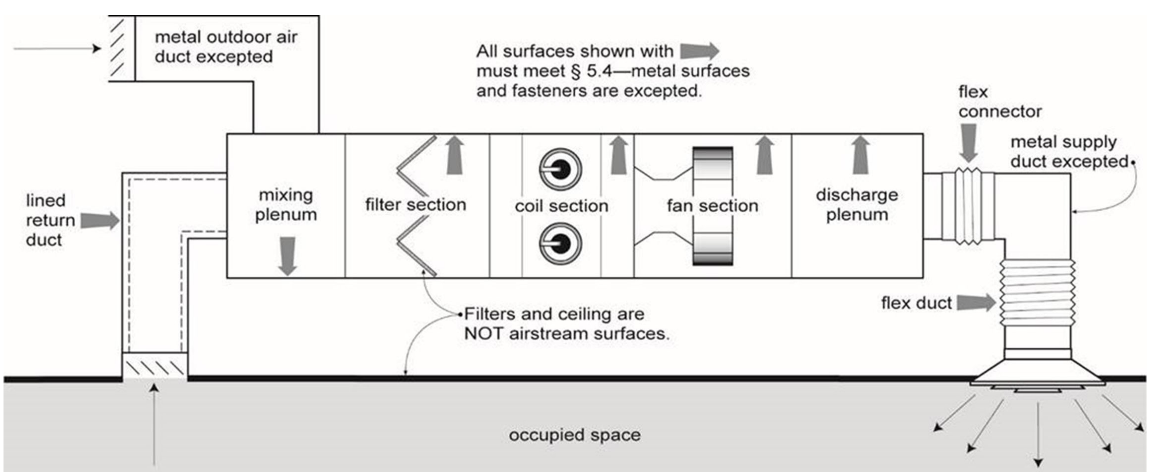

Figure 4 Airstream surface diagram. (Source: *Standard 62.1 User’s Manual*[44], Figure 5-J)

drop to 0.75 in. of water (187 Pa) maximum air pressure drop at 500 fpm (2.54 m/s) average face velocity through any coil or series of coils not separated by more than 18 in. (457 mm) of cleaning access. Minimum access for cleaning is covered in Section 6.8 of this document.

6.3.2 Options for Improved Cleanliness and Access. Access that encourages service is extremely important, and hinged access doors are offered on most air handlers that are large enough to serve more than one space. True walk-in access is offered on most large air handlers.

Designing for MERV 13 or higher enhances IAQ by reducing indoor particle concentrations and helping with cleanliness, as discussed in Sections 7.3.1, 9.1.2 and 10.6.2.2 of this document.

ASHRAE RP-1738[45] showed ultraviolet C (UV-C) irradiation can be effective at reducing air pressure drop and restoring the heat transfer coefficient of cooling coils that had been previously fouled by biofilm. New equipment coils and drain pans can potentially be kept clean with similar application of UV-C. If condensate drain pans contain standing water and cannot be modified to drain completely, UV lights can be installed to control biological waterborne pathogens as an option. Where the drain pans are also the floor of the air-handling unit and are required for service access, they are designed to be walked on and not create depressions, dents, or low spots where condensate can pool and will not drain completely.

6.3.3 Moisture Carryover. Properly designed drain pans and condensate drains reduce moisture carryover (the entrainment of condensate into the airflow) from evaporator coils that can cause downstream moisture problems and microbial growth. Coils operating at a face velocity below 500 fpm (2.5 m/s) typically do not cause a water droplet carryover problem. However, limiting velocity alone is too simplistic, and the issues in the following subsections impact moisture carryover. Therefore, the manufacturer's recommendations, as well as accurate airflow projections and clean coils, are critical.

6.3.3.1 Fin Surface Wettability. Fin surface wettability describes whether condensate will form droplets (low wettability) or a film (high wettability). The ASTM F21[46] test method determines if a surface is hydrophobic (nonwetting) and would be more likely to form droplets and result in moisture carryover. Aluminum fin surfaces are less likely to result in moisture carryover than copper fin surfaces. Anticorrosion coatings, factory applied or field applied, often reduce the fin surface wettability, allowing the formation of large moisture beads. Fin surfaces soiled with manufacturing process fluids, dirt, oil, and other field-acquired contaminants can negatively impact the wettability by lowering it as well. Ensuring the fin surfaces are free and clear of any substance is paramount.

6.3.3.2 Airflow Velocity. The air conditioning industry is aware that a higher face velocity is more likely to create moisture carryover, but this guidance often does not consider the air velocity uniformity. A coil designed with an average face velocity sufficiently low enough to discourage moisture carryover may still contain high-velocity spots where carryover is a risk. Leveling the air velocity profile entering the coil by using diffusers, perforated plates, and flow straighteners helps alleviate high-velocity spots on the coil. This method can be employed successfully in the field where the root cause of the problem is properly identified as uneven air velocity.

6.3.3.3 Fin Design. The most common fin type is a plate-fin design, but not all fin surfaces result in the same moisture management characteristics. As the fin surface becomes taller, it will have more condensate on the fin surface that it will need to move to the drain pan.

6.3.3.4 Fin Density (Fins per Unit Length). As the fin density of a coil increases, the gap between the fins becomes smaller to a point at which moisture can bridge between adjacent fins. The bridged condensate is more likely to be entrained into the airstream, resulting in moisture carryover. Manufacturers often vary the fin density of a coil to optimize heat transfer. Designers can reduce the risk of contamination and moisture carryover by reducing fin density.

6.3.3.5 Moisture Eliminator. Moisture eliminators are another method to combat moisture carryover. These devices are often sold as aftermarket solutions to improve the system's condensate collection. They are sometimes mounted directly to the leaving air side of a coil or at some distance downstream. If any moisture sheds from the coil to the airstream, it is physically captured by the moisture eliminators and carried into a drain pan. While these are usually not permanently attached to the coil, they can reduce the coil's ability to be cleaned.[33]

6.4 Drain Pans. Insulation beneath the bottom of the drain pan reduces condensation underneath the drain pan. Condensate traps must be designed to allow drainage while maintaining a seal between air above the drain pan and the air at the drain outlet. Proper piping and sizing of the P-trap is essential. Stagnant water, as in a drain pan, can promote the proliferation of microorganisms, such as *Legionella*, and create unwanted biofilm growth; drain pan design can effectively remove water before it can be contaminated and entrained in the airstream.[33]

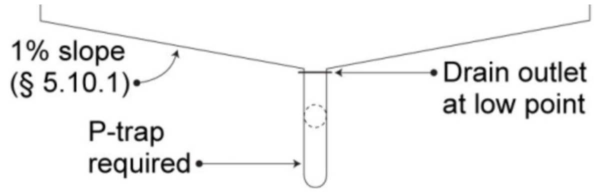

Figure 5 Compliant drain pan, end view. (Source: *Standard 62.1 User's Manual*[44], Figure 5-P)

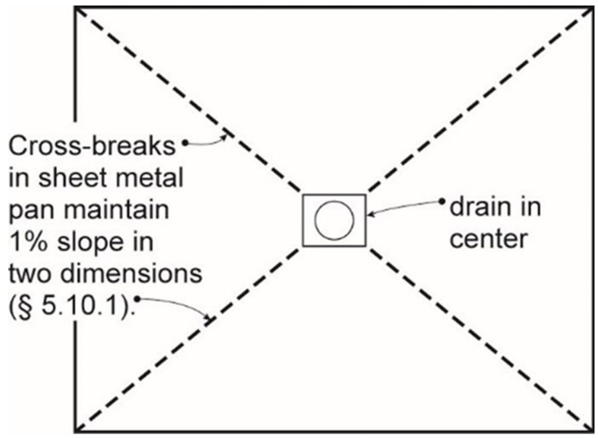

Figure 6 Compliant drain pan, plan view. (Source: *Standard 62.1 User's Manual*[44], Figure 5-Q)

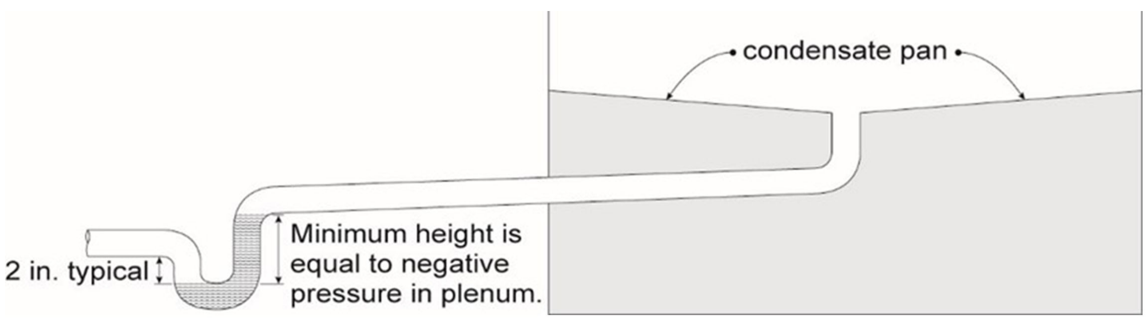

Figure 7 Condensate drain pan seal. (Source: *Standard 62.1 User's Manual*[44], Figure 5-R)

6.4.1 Geometry. Both longer drain pans and shorter coils help prevent carryover. Intermediate drain pans that drain to the primary pan are normally provided on coils taller than 42 to 54 in. (1.1 to 1.4 m) However, it is better to prevent water droplet carryover and not rely on longer drain pans, if possible.

6.4.2 Drain Pan Slope and Outlet. Where properly designed, drain pans extend under all condensing surfaces including return bends. Insulation on cold piping prevents sweating. ANSI/ASHRAE Standard 62.1, Section 5.12.1, prescribes a minimum slope of 0.125 in./ft (10 mm/m) toward the drain connection, as well as an adequately sized and properly placed drain connection, to prevent puddling and microbial growth (see Figures 5 and 6). A two-dimensional slope is usually required. This is only a 1% slope (0.125 in./ft [10 mm/m]), so leveling the unit is critical. Instruct service people to use caution when standing or walking in the drain pan of larger units to reduce the chances of distorting the slope. Manufacturers analyze the water removal capacity of the cooling coil and offer appropriate drain connection sizes.

6.4.3 Drain Seal. Drain pans on the draw-through side of the supply fan are at negative pressure compared to the pressure outside the cabinet. Therefore, ANSI/ASHRAE Standard 62.1, Section 5.12.3, requires a P-trap seal of sufficient height (see Figure 7) or other means to assure that the pan drains properly. Frequent inspection of traps by the owner can help assure that traps do not fail due to freeze up, lack of condensate (no condensate means no seal) in dry weather, and blockage with debris.

6.5 Dehumidification Systems

6.5.1 Indoor Humidity. Indoor humidity impacts occupant comfort, and ANSI/ASHRAE Standard 55[47] is the best guide for comfort. The Berkeley Center for the Built Environment (CBE) provides a useful Thermal Comfort Tool[48] for following ASHRAE Standard 55. Indoor humidity also impacts health, IAQ, and building durability as shown in ASHRAE RP-1630[49] and *ASHRAE Handbook—Fundamentals*[50], Chapter 22, both of which discuss the benefits of humidity control. Many sources such as these suggest keeping indoor humidity in a range between 30 and 60% rh when the air temperature is held at or below 75°F (25°C) during the cooling season and at or above 68°F (20°C) during the heating season. However, although humidity is usually defined in terms of relative humidity, caution is important with respect to the indoor dew point to avoid air quality problems and health risks associated with building dampness. During humid weather, when the outdoor dew point is above 60°F (15°C), ANSI/ASHRAE Standard 62.1 requires that the dew-point temperature of the indoor air (the absolute amount of humidity) must be limited to 60°F (15°C) or below, including unoccupied hours. Relative humidity is an imperfect control variable for dampness, as the relative humidity measured in the air is rarely the same as relative humidity at the surface of materials. Surfaces are nearly always either warmer or cooler than the air. When surfaces are cooler, the relative humidity at the surface is higher than the relative humidity as measured in the air, which results in moisture absorption even though the air relative humidity appears to be low enough to prevent such problems. Measuring the surface relative humidity of all indoor materials, contents, and HVAC components is not practical. Instead, a 60°F (15°C) dew-point limit helps reduce the absolute amount of indoor moisture that could lead to dampness and microbial growth. Note that ANSI/ASHRAE Standard 62.1 specifies minimum requirements, and a lesser dew point may be desirable. For humid climates, it is widely recognized that turning off air conditioning (dehumidification) for extended periods of time to save energy, such as in K–12 schools, can lead to moisture accumulation and mold growth.

During the heating season, the indoor dew-point temperature must be much lower than 60°F (15°C) to avoid condensation on cold window frames and to limit moisture absorption into the cool surfaces of materials in interstitial spaces. These problems occur most often overnight, when indoor air temperature is sometimes reduced to save heating energy in unoccupied spaces. Risks of condensation increase with higher indoor humidity, colder outdoor air temperature, more cold hours, and higher wind speed during those cold hours. The appropriate winter humidity limit depends on the design and installation of the building's exterior air barrier and insulation.

For winter design, meeting the minimum building enclosure requirements of ANSI/ASHRAE/IES Standard 90.1[51] allows greater latitude in setting the humidity limit. Standard 90.1 requires that the building be designed and tested to be airtight. Airtightness minimizes cold air infiltration, which helps keep interstitial and indoor surfaces warmer and less likely to condense or absorb moisture. The standard further requires that exterior insulation be continuous, without thermal bridges that create cold spots that lead to condensation and moisture absorption. In most climates, building envelopes that are compliant with the minimum requirements of Standard 90.1[51] have little risk of moisture accumulation. *ASHRAE Handbook—HVAC Systems and Equipment*[52], Chapter 22, "Humidifiers," provides guidance on calculating moisture accumulation for a given application.

6.6 Humidifiers and Water-Spray Systems. A humidifier or other water-spray system (such as direct evaporative cooler) operates optimally with an unobstructed downstream absorption distance to prevent condensation. The area immediately downstream may be double wall or ductwork with external insulation and vapor retarding surface. The floor can collect inadvertent moisture, possibly with an integrated drain pan that extends beyond the absorption distance, allowing the collected water to drain out of the airstream. If space is constrained, installing drift eliminators with a drain pan can reduce moisture carryover. Stainless steel or aluminum generally provides better corrosion protection. Epoxy coatings may also be employed. Cost and galvanic corrosion are considerations. To minimize the risk of *Legionella*, consider equipment sitings that minimize contamination sources, provide maintenance access, and avoid external heat that could create conditions favorable to *Legionella* growth.[33,53] Humidifier controls that account for outdoor air temperature reduce the likelihood of condensation on cold surfaces.

6.7 Ventilation System Controls. While airflow measurement stations are fairly common factory-installed accessories for larger, multiple-zone variable-air-volume (VAV) units, they are less common for single-zone packaged units. However, there are options available for field-installed airflow measurement. Direct airflow measurement can provide better tracking of ventilation rates and assurance that minimum ventilation is achieved. Since air velocities vary across the traverse of an intake or duct, sensor location has a significant impact on measurement accuracy. The *Indoor Air Quality Guide*[26] discusses the placement of airflow sensors in Strategy 7.2, "Continuously Monitor and Control Outdoor Air." Commissioning and calibrating airflow sensors upon installation and regular calibration according to manufacturer recommendations can help ensure that airflow measurement remains accurate over time. The *Indoor Air Quality Guide* discusses airflow sensor accuracy and calibration and provides a table (Table 7.2-A) comparing the ranges and precision of various airflow measurement methods.

6.7.1 Intake Flow Control. Decoupled control of the outdoor air damper and return air damper allows a system to meet requirements for ventilation, energy efficiency, and building pressurization. The type and size of dampers (outdoor, return, relief) affects leakage, pressure drop, flow characteristics, air mixing, and airflow measurement accuracy.

6.7.2 Variable-Air-Volume Control. Air-handling units with economizers can present a challenge to accurate airflow measuring due to the large range of airflows. Consider using two dampers and actuators for outdoor air intake, one for minimum ventilation and a larger one for the economizer, as recommended in *ASHRAE Handbook—HVAC Systems and Equipment*[27], Chapter 4, and discussed in the *Indoor Air Quality Guide*[26], Strategy 7.2, "Continuously Monitor and Control Outdoor Air." This helps ensure minimum ventilation and may improve airflow measurement accuracy by limiting the measurement range. Outdoor air intakes serving conditioned spaces can have automatic dampers that shut when the systems or spaces served are not in use per ANSI/ASHRAE/IES Standard 90.1[51], Section 6.4.3.4.2. These dampers can be motorized or, in certain climates or with capacities less than 300 cfm (140 L/s), can be backdraft dampers. In an application with a variable speed fan, a motorized damper is preferred, because the opening force on a barometric damper may force the fan's minimum speed to be higher than it otherwise would be.

6.8 Access for Inspection, Cleaning, and Maintenance. This section discusses the provision of clearance and access to allow for inspection, cleaning, and maintenance of equipment. As ease of access can encourage regular maintenance, different access mechanisms and their benefits are presented. Consideration is also given to selecting components that require less frequent maintenance.

6.8.1 Equipment Clearance. Manufacturer's literature, *National Electrical Code*® (NFPA 70[54]), and local codes define critical clearances. Consideration for eventual replacement of the equipment or large components is important. Clearances for service access are discussed below.

6.8.2 Ventilation Equipment Access. ANSI/ASHRAE Standard 62.1, Section 5.15, (and the *Standard 62.1 User's Manual*[55]) prescribe minimum access requirements, including door swings and replacing components. Many levels of air-handler access are possible. Screwed-on panels may be the only option for smaller equipment. However, this level of access does not encourage maintenance, particularly regular filter changes, and lost screws often lead to air leakage. For units with airflows above 2400 cfm (1130 L/s), hinged and latched access doors are readily available for very little cost premium. SMACNA-recommended door sizes and other recommended door features are detailed in the *Indoor Air Quality Guide*[26], Strategy 4.3, "Facilitate Access to HVAC Systems for Inspection, Cleaning, and Maintenance". True walk-in access and quality doors are more feasible in larger equipment. The need for access can be reduced by selecting system components with less regular maintenance requirements. For example, direct drive fans have less need for regular, repeated access compared to belt driven fans. View ports and service lights can alert operators to service needs, particularly in areas with limited access.

6.9 Selection of Equipment and Systems. Conditioning and moving ventilation air comprises a large fraction of building energy use. Design strategies to reduce energy and promote better IAQ include dedicated outdoor air systems (DOAS), energy recovery ventilation (ERV), demand-controlled ventilation (DCV), natural ventilation, and the IAQ Procedure (IAQP).

6.9.1 Dedicated Outdoor Air Systems (DOASs). The *ASHRAE Design Guide for Dedicated Outdoor Air Systems*[56] and the *Indoor Air Quality Guide*[26] provide significant information on the application of DOASs, which directly treat outdoor-air latent loads. Decoupling the outdoor air system from the building heating- and air-conditioning system can provide design flexibility. DOAS units can optimize efficiency at design conditions, introducing conditioned air at or below 55°F (13°C) dew point to prevent unwanted moisture buildup inside the building envelope. When exhaust airstreams are located near DOAS units, ANSI/ASHRAE/IES Standard 90.1[29] requires that sensible and latent energy be captured for energy efficiency using either an integrated energy recovery component or a separate energy recovery ventilation (ERV) system. For some zones in many systems, Standard 90.1 also requires DCV (i.e., variable outdoor airflow based on zone population). Varying zone outdoor airflow by adjusting a damper in one zone results in varying static pressure in the outdoor air duct. To maintain minimum outdoor airflow in all zones, each zone requires an outdoor air damper and an airflow sensor. Consequently, most DOAS units that implement DCV deliver air to pressure-compensating VAV terminals.

6.9.1.1 Managing Latent Loads. The design goal for a DOAS is to manage 100% latent design load while managing a portion of the cooling sensible design load without overcooling or creating moisture issues. This involves dehumidifying the outdoor air to a dew point that is dry enough to offset both the ventilation latent load and the indoor latent load (due to people, infiltration, processes, etc.) Reheating this dehumidified air may reduce the overall energy efficiency. ANSI/ASHRAE/IES Standard 90.1 restricts reheating this dehumidified outdoor air to any warmer than 60°F (15.6°C) whenever the majority of zones require cooling. Design engineers can use the ventilation load index (VLI) to aid in comparing and selecting systems that manage the necessary latent and sensible loads.[57] Resources for DOAS design considerations and calculation methods include the *ASHRAE Design Guide for Dedicated Outdoor Air Systems*[56] and *ASHRAE Handbook—HVAC Systems and Equipment*[52], Chapter 51.

6.9.2 Air-to-Air Energy Recovery Ventilation (ERV). ERV reduces building energy consumption by transferring energy between the exhaust airstream and outdoor airstream to precondition ventilation air. There are two general types of air-to-air devices: (a) total, or enthalpy recovery ventilators, that transfer heat and moisture between incoming and exhaust air, and (b) heat recovery ventilators that transfer sensible but not latent energy. Types of energy recovery systems include energy recovery wheel (i.e., rotary heat exchange), fixed plate with latent transfer, fixed plate, heat pipe, runaround-loop systems, and fixed-bed regenerators. enthalpy recovery ventilators can be standalone systems serving zones or a component of an air-handling system. ERV is required for certain applications by ANSI/ASHRAE/IES Standard 90.1[51]. System design of ERV for commercial application is thoroughly discussed in *ASHRAE Handbook—HVAC Systems and Equipment*[27], Chapter 26, "Air-to-Air Energy Recovery Equipment."

6.9.2.1 Performance. Energy recovery devices can be independently certified for performance metrics through certification programs such as those provided by AHRI Standard 1060[58] or Eurovent. Independent certification validates energy recovery efficiency, air pressure drop, outdoor air correction factor (OACF), and exhaust air transfer ratio (EATR). "Exhaust air transfer" is the technical term used to define and quantify bulk air transfer from the exhaust to the supply airstream (discussed in Informative Appendix C). The ASHRAE Epidemic Task Force (ETF) adopted a document developed by ASHRAE Technical Committee (TC) 5.5, *Practical Guidance for Epidemic Operation of Energy Recovery Ventilation Systems*[59], which provides an in-depth exploration of recirculation concerns in energy recovery systems.

6.9.2.1.1 Cross Contamination and Exhaust Air Transfer Ratio (EATR). As part of the AHRI certification testing program, EATR is measured using an inert tracer gas. EATR, which is shown in Figure 8, quantifies the air that moves into Station 2 from Station 3 as defined in the related standards and *ASHRAE Handbook—HVAC Systems and Equipment*.[27] EATR is calculated as the tracer gas concentration difference between the leaving supply airflow (Station 2) and the entering supply airflow (Station 1) divided by the tracer gas concentration difference between the entering exhaust airflow (Station 3) and the entering supply airflow (Station 1) at the full rated airflows, expressed as a percentage. EATR is measured in both wheels and plate and frame energy recovery devices. Under AHRI 1060[58], participant manufacturers are required to subject their product to testing at balanced airflow and at two different static pressure differentials (a static pressure differential ratio of zero and a wildcard static pressure differential that is different each year). Static pressure differential is defined as the static pressure at Station 2 less the static pressure at Station 3. The best

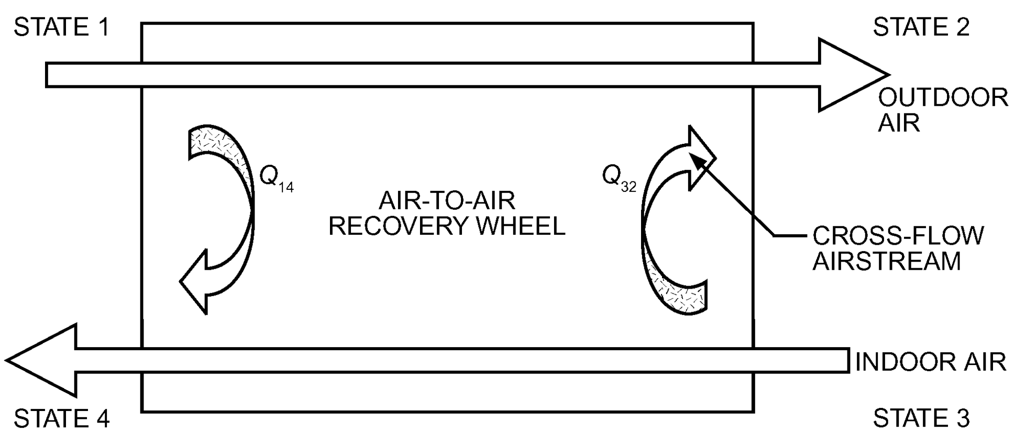

Figure 8 Exhaust air transfer ratio. (*ASHRAE Handbook—HVAC Systems and Equipment*[52], Figure 24, p. 26.18)

operating condition maintains a positive pressure in the supply airstream relative to the return or exhaust stream. Negative pressure ratios below –0.5 in. of water (–125 Pa) are not recommended.

As indicated in the *ASHRAE Journal* article, "IAQ & Energy Impact of Exhaust Air Transfer"[60], it is possible to achieve EATR of 1% to 3% with a small impact on fan operating cost. Achieving EATR levels lower than 1% generally results in higher fan energy usage that may not materially improve steady state dilution levels.

6.9.3 Demand-Controlled Ventilation (DCV). The intent of DCV is to vary ventilation airflow based on the number of occupants present to save ventilation load energy when spaces are below design occupancy levels. However, improper assumptions, improperly applied sensors, lack of calibration or maintenance, or incorrect control sequences or set points may result in more or less ventilation than intended by design or for current occupancy. More ventilation than intended can lead to wasted energy, excess moisture, overpressurization, or inability of equipment to adequately condition excess air. Less ventilation than intended can result in underpressurization, inadequate dilution, and other negative IAQ impacts. Changes in ventilation rates require a corresponding change in exhaust rates in order to maintain balance in the building. See Section 8.2.5.1 of this document for a full discussion of DCV.

6.9.4 Natural Ventilation. Natural ventilation can be a less energy-intensive strategy for mild climate conditions. Mixed-mode ventilation, where natural ventilation is supplemented by mechanical ventilation under certain conditions (extreme temperatures, high particulate matter levels in outdoor air), can provide similar benefits and extend applicability to additional climates through the limited use of mechanical equipment. Elevated air speed at the occupant level can be used to significantly extend the number of hours where natural ventilation can be used. The adaptive model, as defined in ANSI/ASHRAE Standard 55[47], can be used to determine conditions where natural ventilation with or without elevated air speed can provide acceptable levels of occupant thermal comfort.

6.9.5 Indoor Air Quality Procedure (IAQP). An alternative to the prescriptive Ventilation Rate Procedure (VRP), the IAQP in ANSI/ASHRAE Standard 62.1[8] is a performance-based approach where the amount of outdoor air (ventilation air) is calculated to maintain the levels of indoor air contaminants below specific limits. See Section 8.3 for further discussion of the IAQP.

7. INDOOR AIR QUALITY

Regardless of whether air is outdoor or indoor, all air quality is of concern to the designer. The target is enhanced indoor air quality (IAQ) regardless of the configuration of the ventilation system.

7.1 Ventilation Air Distribution. For enhanced IAQ, there are opportunities to improve upon the minimum requirements for how ventilation air is distributed to occupied zones and how it is mixed with room air. Systems with operating modes that have zone air distribution effectiveness that are less than 1.0 can benefit from increased locally recirculated air. In those cases, the use of a mixing fan, such as a ceiling fan, can increase the uniformity of ventilation air distribution and reduce the required outdoor air intake flow to achieve acceptable IAQ.

7.1.1 Plenum Systems. When the ceiling or floor plenum is used to both recirculate return air and distribute ventilation air to ceiling-mounted or floor-mounted terminal units, options for improving IAQ include one or more of the following:

a. Preconditioning outdoor air before introduction into the plenum to avoid condensation
b. Providing ductwork to bring outdoor air directly to terminal units
c. Using tracer gas to verify that unducted outdoor air reaches each space in fulfillment of the design requirements
d. Air sealing the plenum cavity from known contaminant sources

In cooling dominated climates, air sealing from outdoor air may be needed to reduce moisture potential within the envelope (see Section 5.1.3 of this document).

7.2 Air Classification and Recirculation. Air is classified according to the expected contaminants of a space, and ANSI/ASHRAE Standard 62.1[8] places limits on recirculating air between spaces with different air classifications.

7.2.1 Classification. The classification of air as Class 1, 2, or 3 is subjective based on the expected irritancy of the air's pollutants. Only Class 4 air has an objective metric, which is air with pollutants at concentrations that would be harmful to occupants. Some pollutant sources may be more noticeable to occupants in an environment with enhanced IAQ that would otherwise not be easily distinguished in typical environments.

7.2.2 Redesignation. Although redesignation of air class is a general requirement of Standard 62.1, its application is explicitly tied to the Ventilation Rate Procedure (VRP). The general principle behind air classes is that air from cleaner spaces (lower air class) may be transferred to dirtier spaces (higher air class) but not the reverse. Air is generally considered to have the air class of the dirtiest space through which it passes. There are two exceptions to this rule: air that has been cleaned and air that has been assigned a higher class (i.e., deemed dirtier) based on its relationship to other spaces.

7.2.2.1 Air Cleaning. ANSI/ASHRAE Standard 62.1[8] allows Class 3 and Class 4 air to be redesignated by following portions of the IAQ Procedure (IAQP) to demonstrate the reduction of contaminants. The reduction of contaminants below harmful levels allows Class 4 air to be redesignated as Class 3 air. The reduction of contaminants below significant levels allows Class 3 air to be redesignated as Class 2 air. The definition of significant levels is not provided by Standard 62.1; therefore, it is incumbent upon the designer to define and document this level with reference to a cognizant authority. The U.S. Occupational Safety and Health Administration (OSHA) permissible exposure limits (PELs)[61] and National Institute of Occupational Safety and Health (NIOSH) recommended exposure limits (RELs)[62] are common references for defining significant levels.

While odors are not included in the IAQP, they are part of the air class definition. Redesignation of Class 2 air does not require the identification of contaminants, as it is based on odor or sensory irritation. The designer could identify odorous contaminants and use odor threshold values to determine whether odors are likely to be present after air cleaning. Approval from the authority having jurisdiction (AHJ) is required to redesignate Class 2 air.

When choosing air cleaners for redesignation, important considerations include proven removal efficacies for the target contaminants, evaluation of the cleaning technology to avoid adding reactive compounds to the space, and ensuring that any chemical reaction within the air cleaner does not create harmful byproducts (consider the products of those reactions as contaminants).

7.2.2.2 Transfer. Requiring transfer air to be redesignated to the highest air class of a mixture is conservative, because all air designated Class 2 and above contains pollutants that are deemed irritating at the anticipated concentrations. If the irritating pollutants are independent of the pollutants present in the transfer air, the transfer air could provide a dilutionary effect. However, if the pollutants are similar, an even higher air class may be appropriate. For example, the mix of Class 2 air from a commercial kitchen transferred to the kitchen staff locker room, an ancillary space with Class 2 air, could result in an unusual mix of odorants that would be unfamiliar and therefore irritating to the occupants. This mixture may justify designation as Class 3 air and should not be recirculated, even within the context of the kitchen and its ancillary spaces.

7.2.2.3 Ancillary Spaces. The practice of intentionally designating a higher (dirtier) air class to ancillary spaces to permit recirculation is contrary to the concept of enhanced IAQ. However, it is generally not economical or feasible to serve ancillary spaces from different air-handling systems than the primary space. For example, in a restaurant, it would be expensive to provide a separate air-handling unit to serve the manager's office and staff break room, both Class 1 air, in the event that the kitchen or dining room, both Class 2 air, have air returned to the unit. Exhausting air from the higher air-class spaces, thus increasing system outdoor air, would increase operational costs but not capital expenditures and would improve the air quality. Another option is to consider the use of air cleaners to treat the recirculated air and redesignate it to a lower (cleaner) air class.

7.2.2.4 Recirculation Limitations. The limitations on recirculation apply only to those spaces designed under the VRP. When using the IAQP, it is the designer's responsibility to consider the impact of any transfer air and its pollutants on the air quality in the space being designed. When the Natural Ventilation Procedure (NVP) is used, there are no limits on how the air may transfer. However, common sense dictates that the pathways for natural ventilation should still follow the general rule that the lowest quality air be nearest the point of discharge. Regardless of the design procedure used or designation of the air class, air from any space that requires an exhaust airflow should not be recirculated. Recirculation of air with higher concentrations of pollutants only serves to increase the concentration of those pollutants within those spaces.

7.2.2.5 Class 1 Air. Although Class 1 air is permitted to be transferred to any other space, the designer should consider the frequency and pathways by which the air transfers as a contribution to the air quality in the other space. For example, air that transfers primarily through door undercuts in an office suite may accumulate higher particulate concentrations from resuspension of particulates from the flooring.

7.2.2.6 Class 2 Air. Class 2 air can be transferred and recirculated to other Class 2 spaces with similar contaminants. It is important to note that although this provision could be interpreted to allow an art classroom to share air with a science laboratory when the two are part of a school building, this would be inappropriate, because the pollutants in each space are unique from each other. The occupants of an art class are likely to be irritated by the smell of preservatives used in a biology lab, just as the occupants of the biology lab are likely to be irritated by the smell of adhesives. An extreme case to consider would be general classrooms redesignated as Class 2 air to allow the whole school to be served by a single recirculating air system. Rather than redesignation, the designer could still use a whole-building recirculating air system but have any Class 2 air spaces serve as the relief for the system. These spaces would be fully exhausted rather than contribute to the return air path.

7.3 Pollutants. Pollutants broadly include particles and gases and may include inert material, either organic or inorganic; reactive compounds; and living material such as viruses, bacteria, and fungi. This section focuses on the technical strategies for pollutant removal; pollutants and their impact on occupant health are discussed in Informative Appendix A. Designers consider the pollutants that will be present based on the outdoor air quality, building occupants, and processes occurring in the building and use that information to inform ventilation rates. The best way to manage pollutants is through source control, by not allowing entry into the space in the first place. This is not always possible, and there are methods to capture, contain, and convey pollutants out of the building. The *ASHRAE Position Document on Filtration and Air Cleaning*[63] provides an overview of available research on technologies and the health implications of air cleaning. The specific strategies that are effective depend on the type of pollutant.

7.3.1 Particles. Mechanical filtration is the most effective strategy for removing particles (of both inert and living materials) from the airstream. Filters with higher MERV ratings, as defined in ANSI/ASHRAE Standard 52.2[64] and illustrated in Table 3, capture more particles, including those particles that have adverse health effects. For example, MERV 8 filters, the minimum filtration level required in ANSI/ASHRAE Standard 62.1[8], remove at least 70% of particles 3.0 to 10 µm and 20% of particles 1.0 to 3.0 µm but have no efficiency requirement for particles 0.3 to 1.0 µm in size. MERV 13 filters remove at least 90% of particles 3.0 to 10 µm in size, 85% of particles 1.0 to 3.0 µm in size, and 50% of particles from 0.3 to 1.0 µm in size. The designer can evaluate the impacts of more effective filtration in the HVAC system and compensate for any impacts on system performance. An alternate or temporary option is the use of in-room air cleaners or filtration devices, often using high-efficiency particulate air (HEPA) filters, which exceed the performance of MERV 16. For information on selecting and using these alternate or temporary filtration options in existing buildings, see Section 10.6.2.2. When additional devices are used to remove pollutants, the reliability of the overall system cannot be adversely impacted by the failure of the filtration devices. Temporary systems are not a substitute for minimum design requirements. Proper cleaning and replacing any filters that are part of the electronic devices can provide a more reliable system.

7.3.2 Microorganisms including Viruses. Effective filtration can remove microorganisms from the airstream in the same manner as particulates. When airborne, they are usually attached to or part of larger solid or liquid particles. Microorganisms can also be rendered inert by ultraviolet C (UV-C) light; the required dose varies with target and desired reduction. UV sources that emit wavelengths at 185 nm can produce ozone, so the 254 nm frequency emitted from mercury-based sources are preferred for treatments directly exposed to the airstream. The Illuminating Engineering Society (IES) *Committee Report on Germicidal Ultraviolet (GUV)—Frequently Asked Questions*[65] provides clear guidance on UV applications, particularly for SARS-CoV-2. Additional UV-C resources include *ASHRAE Handbook—HVAC Applications*[66], Chapter 62, "Ultraviolet Air and Surface Treatment"; *ASHRAE Handbook—HVAC Systems and Equipment*[27], Chapter 17, "Ultraviolet Lamp Systems"; *ASHRAE Journal* article, "Ultraviolet Germicidal Irradiation: Current Best Practices"[69]; and NIOSH guidelines[70] for upper-room systems.

7.3.3 Gases and Gaseous Mixtures. Gas-phase air cleaners are used to remove ozone, volatile organic compounds (VOCs), and odors from the air.[71] ANSI/ASHRAE Standard 145.2[72] is a test method for measuring the performance of in-duct sorptive media gas-phase air-cleaning devices and is being updated to address other type of gas-phase air cleaners, including electronic air cleaners.The *ASHRAE Position Document on Filtration and Air Cleaning*[31] states the following:

> All filtration and air-cleaning technologies should be accompanied by data documenting their performance regarding removal of contaminants; these data should be based on established industry test standards. If not available, scientifically controlled third-party evaluation and documentation should be provided. [. . .] Commissioning, active maintenance, and monitoring of filtration and air-cleaning devices are needed to ensure design performance. Additionally, filtration and air cleaners should be tested for extended durations to examine the possible change of performance in time of operation and the minimum period at which regular performance checks should be made.

7.3.3.1 Ozone. Ground-level ozone is created by chemical reactions between nitrogen oxides (NOx) and VOCs. This happens when pollutants emitted by cars, power plants, industrial boilers, refineries, chemical plants, and other sources chemically react in the presence of sunlight. Ozone is chemically unstable and decomposes rapidly in air. A study of standard HVAC filters concluded that they may contribute between 22% and 95% of ozone removal, with higher efficiency associated with dirty filters.[73] Another study showed

Table 3 Comparison of Air Filter Efficiency Designations for Applicable Testing Standards

MERV[a]	Typical Application	52.2 Range 1: Efficiency at 0.3 to 1 Microns	52.2 Range 2: Efficiency at 1 to 3 Microns	52.2 Range 3: Efficiency at 3 to 10 Microns	ISO16890[b] Equivalent: ISO ePM_1	ISO $ePM_{2.5}$	ISO ePM_{10}	ISO ePM_{coarse}
1	Low-efficiency fiberglass panels, synthetic media panels, permanent media cleanable filters, and electrostatic media panels. Used primarily for the protection of HVAC equipment.	N/A	N/A	$E_3 < 20$				
2		N/A	N/A	$E_3 < 20$				
3		N/A	N/A	$E_3 < 20$				
4		N/A	N/A	$E_3 < 20$				
5	Pleated panels, cartridges or cube filters, multi-density synthetic media panels. Used primarily for the protection of HVAC equipment and extending the life of valuable downstream higher efficiency filters.	N/A	N/A	$20 \leq E_3$				≤ 45%
6		N/A	N/A	$35 \leq E_3$				
7		N/A	N/A	$50 \leq E_3$				≤60%
8		N/A	$20 \leq E_2$	$70 \leq E_3$				
9	Pleated panels, bag filters, rigid box or v-bank box filters, cartridge filters. Used to protect building occupants from contaminants ranging from nuisance dust to small particle agglomerations.	N/A	$35 \leq E_2$	$75 \leq E_3$			≤50%	
10		N/A	$50 \leq E_2$	$80 \leq E_3$				
11		$20 \leq E_1$	$65 \leq E_2$	$85 \leq E_3$		50% to 70%	≤60%	
12		$35 \leq E_1$	$80 \leq E_2$	$90 \leq E_3$				
13[d]	Bag filters, rigid box or v-bank box filters, cartridge filters. Used to protect building occupants from contaminants ranging from nuisance dust to sub-micron size particles of concern.	$50 \leq E_1$	$85 \leq E_2$	$90 \leq E_3$	50% to 70%	65% to 80%	≤60%	
14[e]		$75 \leq E_1$	$90 \leq E_2$	$95 \leq E_3$	70% to 80%	>80%	≤85%	
15		$85 \leq E_1$	$90 \leq E_2$	$95 \leq E_3$	≤80%	≤90%	≤90%	
16		$95 \leq E_1$	$95 \leq E_2$	$95 \leq E_3$	≤90%	≤95%	≤95%	

High-Efficiency Particulate Air Filters (HEPAs/ULPAs) Classified per ISO HEPA Filter Testing Standard 29463[c]

ASHRAE not applicable	Filter Group	Efficiency	Particle count testing at most penetrating particle size (MPPS) for each filter with appropriate labeling and serialization.
	ISO 35 H	≥99.95%	
	ISO 40 H	≥99.99%	
	ISO 45 H	≥99.995%	
	ISO 50 U	≥99.999%	
	ISO 55 U	≥99.9995%	
	ISO 60 U	≥99.9999%	
	ISO 65 U	≥99.99995%	
	ISO 70 U	≥99.99999%	
	ISO 75 U	≥99.999995%	

a. ANSI/ASHRAE Standard 52.2 [64]
b. ISO 16890 [67]
c. ISO 29463 [68]
d. MERV 13 is typically used in offices or commercial spaces for the protection of living beings within the facility.
e. MERV 14 is typically the final filter in the HVAC system in health care facilities.

that activated carbon filters provided a more durable removal effectiveness between 60% and 70%.[74] For design purposes, the use of activated carbon filters is the most reliable means to control ozone concentrations from outdoor sources.

7.3.3.1.1 Ozone Generating Devices. ANSI/ASHRAE Standard 62.1[8] includes requirements for devices that may generate ozone, and cautions that ozone generation is expected from ozone generators, corona discharge technology, some UV lights, electronic devices that create chemical reactions within the system, and some devices using a high voltage (>480 V). Therefore, Standard 62.1 includes the provision that air-cleaning devices shall be listed and labeled in accordance with UL 2998[75], which ensures that the device is certified to the Environmental Claim Validation Procedure (ECVP) for zero ozone emissions from air cleaners.

7.4 Exhaust Duct Location. Separate exhaust ducts combined into a central duct can both improve dilution and increase the momentum of the exhaust plume. This is discussed in *ASHRAE Handbook—HVAC Applications*[28], Chapter 45. This chapter also provides details on stack design, stack height, exhaust velocity, effects of building geometry on plume direction, and exhaust dilution calculations.

7.4.1 Negatively Pressurized Exhaust Ducts. ANSI/ASHRAE Standard 62.1[8] requires that exhaust ducts that convey Class 4 air be negatively pressurized relative to ducts, plenums, or occupiable spaces through which the ducts pass. To further reduce the leakage of unpleasant or irritating contaminants into breathing zones, exhaust ducts that convey Class 3 air can also be negatively pressurized or can be sealed in accordance with SMACNA Seal Class A and leak tested in accordance with the SMACNA *HVAC Air Duct Leakage Test Manual*[76] and ANSI/ASHRAE/IES Standard 90.1[51], Section 6.4.4.2. In most jurisdictions, health care facility exhaust is specified by ANSI/ASHRAE/ASHE Standard 170[30], Section 6.3.2, which requires the negative pressurization of ducts relative to the spaces through which they pass.

7.4.2 Positively Pressurized Exhaust Ducts. ANSI/ASHRAE Standard 62.1[8], Section 5.2.2, prohibits exhaust ducts under positive pressure that convey Class 2 or Class 3 air to extend through ducts, plenums, or occupiable spaces other than the space from which the exhaust air is drawn. However, it does provide exceptions for Class 2 and residential kitchen hood exhaust if the ducts are sealed in accordance with SMACNA Seal Class A. Minimizing the distance of positively pressurized Class 2 or Class 3 exhaust ducts reduces leakage into ducts, plenums, or occupiable spaces other than the space from which the exhaust air is drawn. This can be accomplished by strategically locating rooms requiring exhaust (in collaboration with the rest of the design team) and careful design of duct routing and exhaust fan locations.

8. PROCEDURES

8.1 General. ANSI/ASHRAE Standard 62.1[8] includes three procedures to design for indoor air quality (IAQ): Ventilation Rate Procedure (VRP), Indoor Air Quality Procedure (IAQP), and Natural Ventilation Procedure (NVP). These procedures offer three fundamental strategies for maintaining acceptable IAQ: dilution, extraction, and source control. These three strategies can be used with any procedure and implemented throughout the design process, but the IAQP must be used if the intent is to offset a portion of the minimum ventilation rate with extraction and source control strategies. These procedures determine quantity of air and size of openings but do not address an overall design philosophy for achieving acceptable IAQ. For consideration of IAQ impacts across disciplines (plumbing systems, building finishes, furniture and equipment, etc.) and the lifetime of the building (phases of construction, start up, and transition to occupancy), see Sections 9 and 10.

8.1.1 Determining the Optimal Procedure for Enhanced Indoor Air Quality. Improved IAQ entails assessing sources of pollutants in the outdoor and indoor air, defining design targets for contaminants, and selecting strategies to achieve those targets. A single building can use any and all of the procedures. This section identifies potential strategies to improve IAQ:

- Ventilation strategy
  - Consider the efficiency of heating and cooling components serving the ventilation system.
  - Recognize restrictions on the physical size of the ventilation system.
  - Identify nonmandatory energy recovery requirements—in some cases, energy recovery can be eliminated with the installation of an air-cleaning system and respective reduction in percentage of outdoor airflow on the supply air.
- Air-cleaning strategy (if needed)
  - Document the capture efficiency of air-cleaning system, as determined by third-party tests based on ANSI/ASHRAE Standard 145.2[72], ANSI/ASHRAE Standard 52.2[64], or ISO or other standards.
  - Optimize airflow of the air-cleaning system.
  - Recognize restrictions on the physical size of the air-cleaning system.

- Source control strategy
  - Assess outdoor concentrations of design compounds as determined by investigation of regional and local outdoor air quality in accordance with Section 4 of this document and ANSI/ASHRAE Standard 62.1[8], Section 4; using dilution to maintain IAQ can increase contaminant concentrations within the indoor space if there are high concentrations of contaminants in the outdoor air, such as particulate matter, ozone, carbon monoxide, and nitrogen dioxide, and addressing these contaminants before they can be introduced to the occupied space reduces occupant exposure.
  - Use the IAQP for design through construction, as described in Section 9 of this document, to address construction practices and material selection.
  - Limit the introduction of contaminants during occupancy; Section 10 of this document addresses operations and maintenance considerations, such as cleaning and pest management procedures.
- Establish IAQ design targets
  - Local standards and green certifications such as LEED®, WELL, and others may employ their own design targets for enhanced IAQ.
  - Refer to ANSI/ASHRAE Standard 62.1, including the testing requirements.

Figure 9 provides a holistic design process flow for how procedures can be applied to arrive at an enhanced IAQ solution.

For each ventilation procedure (VRP, IAQP, and NVP), the following sections outline strategies that can be used to enhance IAQ.

8.2 Ventilation Rate Procedure (VRP). The VRP is a prescriptive procedure in which outdoor air intake rates for various zone types (occupancy categories) are based on contaminant sources and source emission rates that are typical for the space type. The rates are intended to dilute and exhaust odorous bioeffluents from occupants and odors, sensory irritant contaminants, and particulate matter from the materials and activities common to that space type.

The VRP is intended to reduce concentrations with the goal of meeting the sensory satisfaction of a substantial majority (greater than about 80%) of adapted occupants within the space. Adapted occupants have occupied a space for a sufficient period of time that their sensory perceptions have become desensitized to some air contaminants, in particular bioeffluents (contaminants emitted by people, such as body odor), adaptation to which usually only takes a few seconds. Adaptation to other contaminants, such as volatile organic compounds (VOCs), can take much longer or not occur at all. People who have yet to adapt to air contaminants (unadapted occupants) are more commonly called "visitors" to the space. The cognizant designer determines whether occupants are considered adapted or unadapted. Occupancies with frequent transience, such as assembly and retail, mostly will have unadapted occupants and may require increased ventilation in consideration of their comfort.

ANSI/ASHRAE Standard 62.1[8] requires that when unusual sources are expected, additional ventilation or air cleaning shall be calculated using the IAQP or using criteria established by an environmental health and safety (EHS) professional designated by the owner. The *Standard 62.1 User's Manual*[55] further explains this requirement, noting that the designer, with the guidance of the EHS professional, also determines the different and/or unusual contaminant sources that are present in the ventilation zone. If a ventilation zone is determined by the designer to have these different and/or unusual contaminant sources, or sources where emission levels can be elevated, additional ventilation and/or air cleaning should be included in the design. As previously noted, the *Standard 62.1 User's Manual* states that the additional ventilation and/or air cleaning shall be determined by the designer using the IAQP. It also states that these changes and additions shall be reviewed by the designated EHS professional who has based their opinion on recognized and accepted EHS standards.

8.2.1 Considerations for Enhancing the Ventilation Rate Procedure (VRP). When using the VRP to determine the outdoor air intake flow rates, the most direct method for enhancing IAQ is to increase the corrected outdoor air intake. An equivalent method is to increase the zone requirements by some proportional value before correcting for the system. The following subsections provide guidance for the designer to be more precise about increasing the breathing zone requirements, which allows the designer to enhance IAQ without the same broad impact to building energy usage as typical universal strategies.

8.2.1.1 Zone Calculations. The *Standard 62.1 User's Manual*[55] contains a detailed discussion of the rationale for the VRP. ANSI/ASHRAE Standard 62.1[8], Informative Appendix I, provides specific rationale for each occupancy category listed in the standard's Table 6-1. The typical values of 5 cfm (2.5 L/s) per occupant and 0.06 cfm/ft^2 (0.3 L/s·m^2) for offices were chosen to correlate to the 20 cfm (10 L/s) per person that were the standard rate in editions of ANSI/ASHRAE Standard 62.1 between 1989 and 2004. Recent research[77,78] shows that the standard area ventilation rate may not control formaldehyde concentrations to

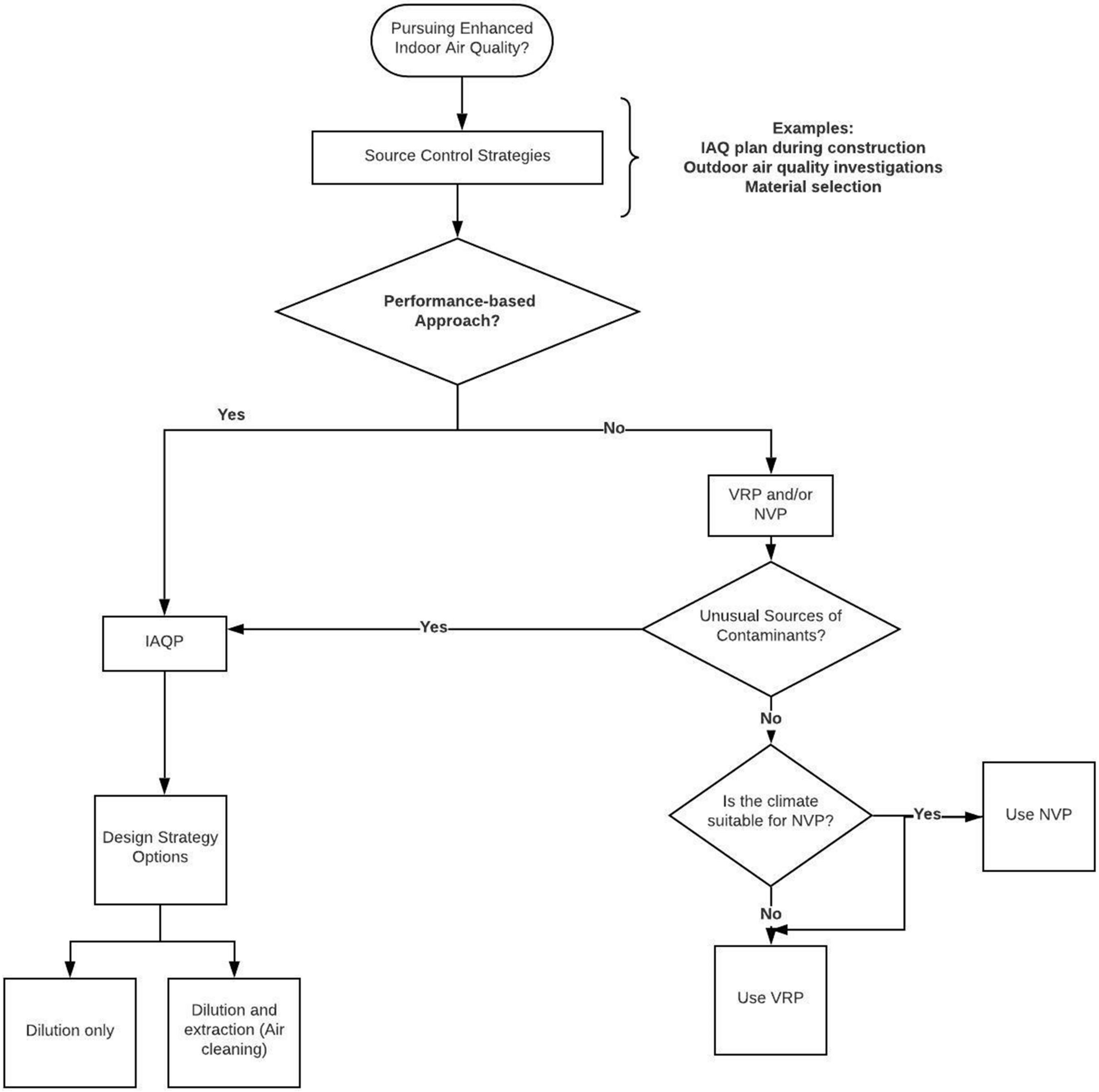

Figure 9 Process flow for applying ASHRAE Standard 62.1 procedures to meet IAQ design targets.

Informative Notes:

1. VRP: Consider enhanced parameters such as higher zone airflow rates (Section 8.2) and/or additional source control.
2. NVP: Consider enhanced parameters such as larger openings, stack effect chimneys, outdoor air entry tunnels (Section 8.4), and/or additional source control.

regulatory exposure limits. Another consideration is that the ventilation rates are based on assumed proportions and metabolic output of male and female occupants, which may not be appropriate for all settings.

8.2.1.2 Breathing Zone Outdoor Airflow. Within the *Standard 62.1 User's Manual*[55], it is noted that for an unadapted occupant, 15 cfm (7.5 L/s) is typically necessary to dilute occupant-generated odors. For adapted occupants, the familiar 5 cfm (2.5 L/s) per person for diluting occupant-generated odors and a mean value of 0.40 cfm/ft^2 (2.0 L/s/m^2) for diluting building-generated odors are suitable for office environments.[79] If a designer were to utilize the mean values for adapted occupants, the amount of ventilation would increase to five times the minimum ventilation rate, but such an increase would not quite double the rate of dilution because of the asymptotic nature of the ideal mixing equation. More modest increases in ventilation rates—for example, the 30% common among sustainable building standards, which results in a 25% increase in dilution rates—are better able to balance energy concerns with improved IAQ.

8.2.1.3 Zone Air Distribution Effectiveness. The goal of ventilation is to maintain acceptable air quality near to the occupants, which means airflow patterns that promote the efficient removal of pollutants from the breathing zone do not require dilution rates as high as those for airflow patterns that do not efficiently remove pollutants. Designers seeking to achieve enhanced IAQ should utilize the principle of capturing, containing, and conveying pollutants from known fixed sources and delivering outdoor air as directly as possible to the breathing zone in a manner that does not disrupt natural processes, such as buoyancy, that may aid in the removal of pollutants. See Section 7.1 of this document for additional discussion.

8.2.2 System Considerations

8.2.2.1 100% Outdoor Air Systems. Air cleaning installed in this system is intended to clean outdoor air in a single pass before it is delivered to the space.

8.2.2.2 Multiple-Zone Recirculating Systems. Consideration of the interactions of the air quality in the different zones, which are frequently at different operating conditions, is required.

8.2.2.3 Single-Zone Systems. Air cleaning installed in this system is intended to clean outdoor air in a single pass before it is delivered to the space.

Wide variations of zone outdoor air fractions can have the effect of increasing the overall outdoor air intake rate required compared to the minimum requirements in many zones. This problem can be mitigated by taking credit for population diversity—all zones are never at design peak population simultaneously, so outdoor air intake flow for the system can be lower than the sum of zone outdoor airflow requirements. The simultaneous heating and cooling limits in ANSI/ASHRAE/IES Standard 90.1[51] allow higher airflows to be reheated if necessary, even in the prescriptive path, provided these airflow increases result in energy use reductions due to lower outdoor air intake airflows. Increasing the primary airflow, particularly at zone minimum flow, will result in higher system ventilation efficiency and therefore lower outdoor air intake airflows.

8.2.3 System Ventilation Efficiency. The system ventilation efficiency depends on the average outdoor air fraction and the primary outdoor air fraction. As the following example demonstrates, analyses of an interim condition can result in specifying a system outdoor air requirement significantly higher than if the analyses were performed at a uniform peak or uniform minimum airflow condition. Ideally, the designer would determine the combination of average outdoor air fraction and primary outdoor air fraction that results in the smallest system ventilation efficiency to determine the outdoor air intake requirement. Conservatively, the designer could determine the average outdoor air fraction with only the critical zone at minimum primary airflow with all other zones being at maximum primary airflow.

Consider a 10,000 cfm (4720 L/s) system, without local recirculating systems, with a critical zone requiring 300 cfm (140 L/s) of outdoor airflow in the breathing zone and 1000 cfm (470 L/s) of primary airflow; the balance of the zones requires 1450 cfm (685 L/s) of outdoor air. The system ventilation efficiency for this system (using ANSI/ASHRAE Standard 62.1[8], Normative Appendix A) would be 0.875, meaning 2000 cfm (945 L/s) is required at the outdoor air intake. If the primary air in all zones were reduced by 50% while the breathing zone outdoor airflows stayed constant, the system ventilation efficiency would be 0.75, and the system outdoor air requirement would be 2334 cfm (1100 L/s). However, if the primary airflow in the critical zone were to only turn down to 500 cfm (235 L/s) without a reduction in the breathing zone outdoor air requirement, the new system ventilation efficiency would become 0.58, and the system outdoor air requirement would increase to 2996 cfm (1414 L/s). Even for small systems, it is exceedingly cumbersome to determine the outdoor air requirement for all possible combinations of zone airflows that are likely to occur.

8.2.4 Design for Varying Operating Conditions. Most buildings have varying thermal, pollutant source, and occupancy loads that can trigger changes to ventilation rates. Calculating all possible combinations during design may be burdensome, so judicious selection of critical cases or the application of advanced controls is necessary.

8.2.4.1 Variable Load Conditions. Under the standard, it is permissible to reduce the outdoor air intake airflow from the design airflow for part-load (not design) conditions. Doing so can save substantial amounts of energy but can be technically complicated for multiple-zone recirculating systems, even with direct-digital controls (DDC) and advanced programming. In order to have a system respond to variable conditions, it is necessary to actively measure the outdoor air intake, poll airflows at all zones, and have a means of determining the building zone population (e.g., by using CO_2 sensors and occupancy sensors).[80,81,82] With these inputs and the occupant and building components of the breathing zone outdoor airflow programmed for each zone controller, it is possible to have the system controller actively calculate the system outdoor air intake requirement. For simpler systems, it may be possible to tie the outdoor air intake requirement to the primary airflow in a known critical zone and reduce outdoor airflows at peak conditions if the designer is careful that the critical zone is the same at all points of operation.

8.2.4.2 Short-Term Conditions. The time constant for averaging is inversely related to the breathing zone outdoor air change rate of the zone. This means that areas with higher breathing zone outdoor airflow requirements are less tolerant to short-term conditions than areas with lower breathing zone outdoor airflow requirements.

8.2.5 Dynamic Reset. Both the system outdoor air intake and the zone outdoor airflow can be varied based on operating conditions. However, reducing the outdoor air intake flow may have unintended consequences if the designer does not have a full understanding of the impact on all zones served by the system.

8.2.5.1 Demand-Control Ventilation (DCV). DCV can be achieved with various technologies. It is important to understand that DDC has limitations and is not a one-size-fits-all strategy. It is also important to note that DCV may only be used to limit the people component of the VRP calculation and not the area component when the space is occupied.

The most prevalent technology is the use of CO_2 sensors. Humans respirate CO_2 at quantities that are interdependent with their mass, gender, age, and metabolic activity.[83] As CO_2 exists naturally in the atmosphere, this creates a codependent relationship between the ventilation rate, the rate of increase in concentration above ambient, and the steady state value in parts per million (ppm). Understanding this relationship is important when determining what ppm value to maintain. For example, if a classroom has a higher VRP outdoor air rate than a conference room, maintaining the same ppm value in the conference room would cause a much higher ventilation rate than the VRP and, if not designed that way, would lead to problems associated with too much ventilation. Another difference in this example is that the CO_2 generation rate of children is less for the same metabolic rate. Additional challenges with this methodology may be the time lag between an occupant entering a space and a detectable rise in CO_2, leading to an adjustment of the ventilation system. Avoid control sequences that wait until the room concentration is close to the desired ppm value before initiating increased ventilation. This may lead to providing too little ventilation during the rise and too much ventilation when trying not to overshoot the desired value. A strategy that couples CO_2 and airflow measurement can better reset rates and set minimum and maximum limits.

The use of occupancy sensors results in a faster response time but can only affect gross adjustments of ventilation based on the presence or absence of occupants. Occupancy sensors are a good choice when there is very little diversity in occupancy but great diversity in schedule. Occupancy sensors can also be used in combination with other methods and are an effective way to enable and disable occupancy standby mode.

Occupancy counters can effectively increment adjustments to zone outdoor airflow by providing a corresponding increase in the VRP per person rate with fast response times. Traditional counters can be more expensive and difficult to implement with multiple entries into a space. New technologies incorporating proximity sensing through various platforms, such as ID badges or mobile phones, not only make people counting easier to incorporate and less expensive but also have the potential to do a better job of reducing ventilation in one zone and correspondingly increasing in another when people are transient. Occupancy counters are most appropriate in spaces with fixed seating, such as classrooms and lecture rooms, and in larger spaces where CO_2 lag would be greatest, such as gymnasiums or libraries.

Point-of-sale systems could also be successfully integrated into the ventilation logic. They can provide the exact number of people coming in, and in most circumstances, they exit at a set time. There are multiple spaces where this could be the best option, such as movie theaters, concert halls, and spectator sports.

Whenever the outdoor air ventilation rates are modulated, use of airflow measurement should be considered, as dampers are not linear flow devices. Airflow measurement can also compensate for changes in pressure relationships, either system or weather induced, and can be used to set limits, such as the building component or the maximum capacity of the mechanical equipment. When designing for enhanced IAQ, the designer should generally avoid reducing ventilation below the building component, as off-gassing occurs even when a building is unoccupied. Consideration should be given to the maintainability and calibration of the sensors for this application.

8.2.6 Ventilation Efficiency. One way to improve the efficiency of a multiple-zone recirculating VAV system is to dynamically reset the system outdoor airflow set point as the zone primary airflow rates vary.[80] This requires the HVAC digital control system to dynamically calculate the system ventilation efficiency on a real-time basis. The *Standard 62.1 User's Manual*[55], Appendix A, describes one way to implement this dynamic reset sequence.

8.3 Indoor Air Quality Procedure (IAQP). The IAQP is a performance-based procedure. Rather than prescribing rates based on occupancy categories, rates are calculated based on contaminant source emission rates for a list of design compounds and indoor concentration limits provided in ANSI/ASHRAE Standard 62.1[8] using mass balance calculations. The IAQP allows designers to take credit for contaminant source control and removal measures, such as selection of low-emitting materials and operation of air-cleaning devices. It is often used with air-cleaning technology in an effort to adjust the total amount of ventilation to a space relative to the amount required by the VRP. Cautious designers understand that some air-cleaner manufacturers have not published removal efficiencies for air pollutants. Additional information is available in the *ASHRAE Position Document on Filtration and Air Cleaning*.[63] Furthermore, any reduction in the outdoor air intake flow will cause elevated concentrations for any pollutants that cannot be controlled by source control and removal measures. Consideration of all potential contaminants in the space often results in enhanced IAQ.

8.3.1 Establishing Enhanced Indoor Air Quality Design Targets. Cognizant authorities such as the U.S. EPA, California EPA, California Department of Public Health (CDPH), NIOSH, and the Committee for Health-Related Evaluation of Building Products (AgBB) publish concentration limits for compounds, many of which may be present in the indoor environment. Table 4 includes design compounds, respective design targets (or concentration limits), and cognizant authority, which have been incorporated into ANSI/ ASHRAE Standard 62.1[8]. This table does not include every possible compound that may be present in indoor air but rather includes a sufficient number and diversity of compounds such that control of the compounds is anticipated to result in air quality that meets the Standard 62.1 definition of "acceptable."

Table 4 lists the required design compounds and PM2.5. When designing for enhanced IAQ, the designer may choose additional design compounds, such as CO_2, and more stringent design targets (concentration limits), such as a more stringent formaldehyde limit. Considerations for the selection of design compounds include the following:

a. Is a compound expected to be present in indoor air with reasonable frequency at concentrations relevant to (but not necessarily above) the design target?
b. Has a design target been proposed by a cognizant authority for the proposed contaminants?
c. Does it seem reasonable to expect that product emissions rates may be available for the proposed contaminants?

In addition to the individual compounds, contaminant mixtures (two or more contaminants that target the same organ system) must also be considered such that the ratio of the concentration of each contaminant to its concentration limit shall be determined, and the sum of these ratios shall not be greater than one.

8.3.2 Enhancing the Indoor Air Quality Procedure (IAQP). The IAQP enables the designer to use dilution and/or extraction as strategies to achieve the established enhanced IAQ design targets. In this section, the results for two sample IAQP calculations are presented and discussed. Both sample calculations are for a single zone and assume the zone characteristics shown in Table 5.

Sample calculations assume the air-side system serving the zone provides a constant flow of supply air and outdoor air.

8.3.2.1 Baseline VRP and IAQP. For comparative purposes, the minimum outdoor air intake flow (V_{ot}) required under VRP and IAQP following Table 4 are as follows:

Minimum outdoor air intake flow (V_{ot}) required under VRP is 2125 cfm (1000 L/s).

$$V_{ot} = V_{oz} = V_{bz}/E_z$$

$$(5 \text{ cfm/person} \times 100 \text{ people} + 0.06 \text{ cfm/ft}^2 \times 20{,}000 \text{ ft}^2)/0.8 \quad \text{(IP)}$$

$$(2.5 \text{ L/s/person} \times 100 \text{ people} + 0.3 \text{ L/s/m}^2 \times 1858 \text{ m}^2)/0.8 \quad \text{(SI)}$$

Minimum outdoor air intake flow (V_{ot}) required under IAQP is calculated using the following mass-balance equation and the inputs in Table 6. For a full overview on how IAQP calculations are performed, refer to the *Standard 62.1 User's Manual*[44].

$$C_{bz} = \frac{N + E_z V_{oz}(1 - E_f)C_o}{E_z(V_{oz} + \mathrm{RV}_r E_f)}$$

8.3.2.2 Enhanced IAQP. Sample calculations of enhanced IAQ were performed to achieve the design target established by NIOSH of 20 μg/m^3 for formaldehyde, while keeping all other compounds in Table 4 under their established targets.

Table 4 Design Targets—Acceptable Indoor Air Quality

Compound or PM2.5	CAS Number	Cognizant Authority	Design Target
Acetaldehyde	75-70-0	CA EPA CREL (June 2016)	140 $\mu g/m^3$
Acetone	67-64-1	AgBB LCI	1200 $\mu g/m^3$
Benzene	71-43-2	CA EPA CREL (June 2016)	3 $\mu g/m^3$
Dichloromethane	75-09-2	CA EPA CREL (June 2016)	400 $\mu g/m^3$
Formaldehyde	50-00-0	CA EPA 8-hour REL (2004)	33 $\mu g/m^3$
Naphthalene	91-20-3	CA EPA CREL (June 2016)	9 $\mu g/m^3$
Phenol	108-95-2	AgBB LCI	10 $\mu g/m^3$
Tetrachloroethylene	127-18-4	CA EPA CREL (June 2016)	35 $\mu g/m^3$
Toluene	108-88-3	CA EPA CREL (June 2016)	300 $\mu g/m^3$
1,1,1-trichloroethane	71-55-6	CA EPA CREL (June 2016)	1000 $\mu g/m^3$
Xylene, total	108-83-3, 95-47-6, and 106-42-3	AgBB LCI	500 $\mu g/m^3$
Carbon monoxide	630-08-0	U.S. EPA NAAQS	9 ppm
PM2.5	—	U.S. EPA NAAQS (annual mean)	12 $\mu g/m^3$
Ozone	10028-15-6	U.S. EPA NAAQS	70 ppb

Table 5 Sample Zone Characteristics

Area	Occupancy	Space Type	Supply Location	Return Location	Zone Air Distribution Effectiveness	Minimum Space Pressurization Requirement
20,000 ft^2 (1858 m^2)	100	Office	Ceiling	Ceiling	0.8	500 cfm (236 L/s)

Table 6 Example Indoor Air Quality Procedure Calculation for Formaldehyde

Variable Name	Variable (Units)	Value	Notes
Formaldehyde indoor concentration limit at breathing level	C_{bz} ($\mu g/m^3$)	33	Table 4
Formaldehyde indoor emission rate	N (µg/h)	69,677	Conservative estimate: • Based on the maximum calculated value of the whole building emission rate reported by Wu et al.[84] for offices • Consistent with calculated indoor emission rate by measuring formaldehyde at a new office building
Formaldehyde outdoor concentration	C_o ($\mu g/m^3$)	3	• Median concentration reported for the state of California[85] • Median concentration reported for the state of Pennsylvania (ASHRAE RP-1596[77])
Local source contaminants	C_{o-l} ($\mu g/m^3$)	Source dependent	Unique local sources need specific levels defined. Examples of local sources include dust from quarries, bioaerosols from composting facilities, or odors from animal confinement or cannabis grow facilities.
Clean return air volume	RV_r (cfm)	1000	Minimum volumetric flow of recirculated air through the air-cleaning system for which IAQ of particular design compound will be maintained.
Air cleaning efficiency	E_f	0.55	• Sample air cleaner published efficiency • Based on third-party certified tests per ANSI/ASHRAE Standard 145.2[72] (Source: Research Triangle Institute, Research Triangle Park, North Carolina)
Outdoor air intake flow	V_{ot} (cfm)	1125	Minimum volumetric flow of outdoor air for which IAQ concentration of particular design compound will be maintained below selected enhanced limit.

Table 7 Example Indoor Air Quality Procedure Calculations using Formaldehyde

Variable Name	Variable (Units)	Value	Notes
Formaldehyde indoor concentration limit at breathing level	C_{bz} (μg/m^3)	20	NIOSH
Formaldehyde indoor emission rate	N (μg/h)	69,677	Conservative estimate: • Based on the maximum calculated value of the whole building emission rate reported by Wu et al.[84] for offices • Consistent with calculated indoor emission rate by measuring formaldehyde at a new office building
Formaldehyde outdoor concentration	C_o (μg/m^3)	3	• Median concentration reported for the state of California[85] • Median concentration reported for the state of Pennsylvania (ASHRAE RP-1596[77])
Local source contaminants	C_{o-l} (μg/m^3)	Source dependent	Unique local sources need specific levels defined. Examples of local sources include dust from quarries, bioaerosols from composting facilities, or odors from animal confinement or cannabis grow facilities.
Clean return air volume	RV_r (cfm)	0	Minimum volumetric flow of recirculated air through the air cleaning system for which IAQ of particular design compound will be maintained.
Air-cleaning efficiency	E_f	0.55	• Sample air cleaner published efficiency • Based on third-party certified tests per ANSI/ASHRAE Standard 145.2[72] (Source: Research Technology Institute (RTI), North Carolina)
Outdoor air intake flow	V_{ot} (cfm)	3015	Minimum volumetric flow of outdoor air for which IAQ concentration of particular design compound will be maintained below selected enhanced limit.

Table 8 Comparison of Ventilation Rate Procedure and Enhanced Indoor Air Quality Procedure

	VRP	IAQP	Enhanced IAQP or VRP +42%
Formaldehyde limit (μg/m^3) and all other compounds below their established limit under Table 4	33	33	20
V_{ot} (cfm [L/s])	2125 (1000)	1125 (530)	3015 (1420)

8.3.2.3 Enhanced Indoor Air Quality Procedure (IAQP) with Dilution Only. In this calculation, the following mass-balance equation in ANSI/ASHRAE Standard 62.1[8] Table E-1 was used to solve for zone outdoor air flow (V_{oz}). An example is provided in Table 7.

$$V_{oz} = \frac{N}{E_z \times (C_{bz} - C_o)}$$

Solving for V_{ot} for each compound in Table 4, the outdoor airflow was determined to be 3015 cfm. Achieving this level of enhanced IAQ using only dilution requires a ventilation airflow 42% higher than the minimum airflow required to achieve acceptable IAQ, as calculated using the VRP. See Table 8.

8.3.2.4 Enhanced Indoor Air Quality Procedure (IAQP) with Dilution and Maximum Air Cleaning. In this calculation, the mass-balance equation was rearranged as shown below to solve for RV_r, or volumetric flow of recirculated air through the air-cleaning system. Note that V_{oz} is now a function of minimum outdoor airflow required to maintain building pressure.

$$\mathrm{RV}_r = \frac{N - V_{oz} \times E_z \times (C_{bz} - C_o)}{E_z \times E_f \times C_{bz}}$$

Example IAQP calculations using formaldehyde are presented in Table 9. The calculations are repeated for every compound listed in Table 4.

Solving for RV_r for each compound in Table 4, the required airflow through the air-cleaning system is 3564 cfm (1680 L/s) while providing only 500 cfm (235 L/s) of minimum outdoor airflow.

Table 9 Enhanced Indoor Air Quality Procedure with Dilution and Maximum Air Cleaning

Variable Name	Variable (Units)	Value	Notes
Formaldehyde indoor concentration at breathing level	C_{bz} (μg/m³)	20	NIOSH
Formaldehyde indoor emission rate	N (μg/h)	69,677	Conservative estimate: • Based on the maximum calculated value of the whole building emission rate reported by Wu et al.[84] for offices • Consistent with calculated indoor emission rate by measuring formaldehyde at a new office building
Formaldehyde outdoor concentration	C_o (μg/m³)	3	• Median concentration reported for the state of California[85] • Median concentration reported for the state of Pennsylvania (ASHRAE RP-1596[77])
Local source contaminants	C_{o-1} (μg/m³)	Source dependent	Unique local sources need specific levels defined. Examples of local sources include dust from quarries, bioaerosols from composting facilities, or odors from animal confinement or cannabis grow facilities.
Clean return air volume	RV_r (cfm)	3564	Minimum volumetric flow of recirculated air through the air-cleaning system for which IAQ of particular design compound will be maintained.
Air-cleaning efficiency	E_f	0.55	• Sample air cleaner published efficiency • Based on third-party certified tests per ANSI/ASHRAE Standard 145.2[72] (Source: Research Technology Institute (RTI), North Carolina)
Outdoor air intake flow	V_{ot} (cfm)	500	Minimum volumetric flow of outdoor air for which IAQ of particular design compound will be maintained and is adequate for building pressure.

Table 10 Comparison of Ventilation Rate Procedure and Indoor Air Quality Procedure Options

	VRP	IAQP—Option 1	IAQP—Option 2	Enhanced IAQP with Air Cleaning
Formaldehyde limit (μg/m³) and all other compounds below their established limit under Table 4	33	33	33	20
Air-cleaning RV_r (cfm [L/s])	0 (0)	1000 (470)	1831 (865)	3564 (1680)
V_{ot} (cfm [L/s])	2125 (1000)	1125 (530)	500 (235)	500 (235)

Compared against the VRP for acceptable IAQ, the dilution and extraction IAQP solution for enhanced IAQ represents a 76% reduction in ventilation. Compared to the dilution-only IAQP solution for enhanced IAQ, the dilution and maximum extraction IAQP solution for enhanced IAQ represents an 86% reduction in outdoor air. A comparison is presented in Table 10. Case studies are presented in Informative Appendix D.

8.4 Natural Ventilation Procedure (NVP). Natural ventilation generally does not involve filtration or conditioning of air that enters the building, so the designer must consider whether the outdoor air quality is naturally suitable for indoor environments. Higher concentrations of particulate matter should be anticipated when compared to a mechanically ventilated space. ANSI/ASHRAE Standard 62.1[8] assumes that outdoor air is cleaner than the interior air and therefore suitable for the dilution and removal of indoor pollutants. The designer seeking to achieve enhanced IAQ must validate this assumption and should only use natural ventilation in a manner that enhances the quality of the indoor environment. Strategies to enhance the natural ventilation procedure include such enhancements as larger openings, stack effect chimneys and outdoor air entry tunnels, air quality monitoring, and local filtration.

9. CONSTRUCTION, SYSTEM START-UP, AND COMMISSIONING

9.1 Construction Phase

9.1.1 Indoor Air Quality Plan, Design Phase through Construction. Creating and communicating an indoor air quality (IAQ) plan with all parties prior to the construction phase helps ensure that all IAQ goals are understood, documented, and met. As noted in the *Indoor Air Quality Guide*[26] Objective 1, "Manage the Design and Construction Process to Achieve Good IAQ," the coordination of the design team, contractors, and owners in developing an IAQ plan can identify and control issues early in the design. A comprehensive IAQ plan includes means to evaluate and control contaminants from construction practices, materials, equipment, and the environment.

An IAQ plan is particularly critical for renovation or additions, especially if the building remains partially occupied during construction. Representatives of the current occupants can play an important role in the creation of the project IAQ management plan. This broad involvement is especially important when there is possible contaminant transfer from project spaces to adjacent occupied spaces and multiple risk mitigation measures are used. From the project outset, all parties (design and construction team as well as representatives from the current occupants) need a thorough understanding of intended goals, known or anticipated problems, existing building systems and their interaction with the construction space, anticipated mitigation strategies, testing procedures, and remedial actions needed to ensure the IAQ targets are achieved.

The integrated design process is an opportunity for the mechanical designer to emphasize the impact other designers' choices can have on the ventilation system requirements, such as the reduction of contaminants from low-emission building finishes. The mechanical designer can also use the IAQ plan to ensure trades are scheduled in an order that avoids IAQ problems. For example, completing drywall before installing carpet facilitates drywall cleanup. Other IAQ plan goals can relate to construction practices, such as the responsible use of water on construction sites to prevent moisture contamination.

Designers can ensure compliance with an IAQ plan by including the requirements in drawings and specifications. Reviewing and updating the IAQ plan regularly throughout and at the end of the construction phase can ensure a successful transition to a complete and occupied space. The IAQ plan documents, including records of progress through construction and project completion, can be part of the project close-out documentation submitted to the owner.

9.1.2 Filters. It is best practice to avoid the operation of HVAC equipment during construction. If equipment must be operated, using a filter of lower efficiency or MERV rating than was specified in design can result in the contamination of air system equipment in ways that are not easily remediated, as filters with lower MERV ratings allow more of the smallest particles to pass. Using higher-efficiency filters during construction requires more frequent filter changes due to the high level of dust and contaminants present during the construction process.

9.1.3 Protective Measures. ANSI/ASHRAE Standard 62.1[8] requires a baseline of moisture protection and either disposal of porous materials or cleaning of nonporous materials with visible microbial growth. In addition, there are other protective measures to consider, as construction procedures, materials, and processes can produce contaminants with adverse effects for IAQ. Many IAQ problems can be eliminated or reduced with proper planning and action prior to the construction phase (source control).

9.1.3.1 Construction Practices. ANSI/ASHRAE Standard 62.1.[8] requires minimizing the migration of construction-generated contaminants, such as dust, debris, particulate matter from sanding or grinding, and fumes from welding, to occupied spaces. Some examples of strategies to meet this requirement include

- Using portable or supplementary HVAC equipment for temperature or humidity control to avoid using and contaminating permanent systems during construction
- Using local capture or exhaust systems for welding, grinding, or sanding
- Placing entrance mats to control dirt tracked into and out of construction areas from footwear[26]
- Separating construction work areas with doors
- Sealing ends of open ductwork with plastic to prevent contaminants from entering air systems during construction
- Establishing smoke-free site policies that prohibit all smoking (combustion and electronic) and use of tobacco products within the building and construction area (Additional discussion of environmental tobacco smoke (ETS) impacts on IAQ can be found in Section 5.3 of this document.)
- Limiting the use of equipment powered by internal combustion engines[86]
- Limiting engine idling for heavy equipment, delivery trucks, and other vehicles near building openings
- Implementing a storm water and erosion control program[87] (This is typically required as part of permitting but must be actively managed by those on site.)
- Inspecting and cleaning the construction site daily, including removal of unnecessary trash; assigned break/rest areas can limit food and drink inside the building during construction
- Cleaning equipment (including rental equipment) before it is relocated from one site and after arrival at another to avoid transfer of potential contaminants from other projects and transit

9.1.3.1.1 Construction Materials. Building materials can be significant sources of contaminants that negatively impact IAQ. Careful selection, storage and installation, and postinstallation treatment of materials can minimize the introduction of contaminants. Source reduction reduces the burden on the mechanical ventilation system to ensure enhanced IAQ. Prioritizing materials with low volatile organic compounds (VOCs) emissions, ease of maintenance, and resistance to degradation and ensuring materials are stored and installed properly can reduce sources of contaminants.

Many standards and green building certification programs such as the U.S. EPA's Indoor airPLUS[88] program (for homes) and the U.S. Green Building Council's LEED[89] rating system specify criteria for zero- and low-emission materials. *LEED v4.1 Building Design and Construction*, "EQ Credit: Low-Emitting Materials,"[90] encourages the use of inherently nonemitting materials (e.g., stone, glass, and untreated wood), salvaged or reused materials, and materials that meet limits for volatile organic compound contents and emissions, with a specific focus on formaldehyde. The California Department of Public Health (CDPH) has its own concentration limits for indoor air in new construction (Section 01350 or *Standard Method for the Testing and Evaluation of Volatile Organic Chemical Emissions from Indoor Sources Using Environmental Chambers*, v 1.2').[91]

Materials resistant to moisture uptake, materials resistant to secondary chemical reactions with other materials in the space, materials resistant to degradation over time, and materials that can be cleaned and maintained without the use of strong chemicals prevent later introduction of contaminants into the space.

Once selected and delivered to the project site, proper storage and installation strategies such as the following can support material integrity:

- Storing materials in a cool, dry location reduces the likelihood of absorption of moisture or other on-site contaminants (e.g., drywall stored outside and exposed to the weather can absorb moisture and create an environment conducive to microbial growth).
- Storing materials in a ventilated location facilitates outgassing prior to installation, especially if materials are not already zero- or low-emitting materials or if materials were delivered in sealed packaging. The rate of outgassing varies with temperature and humidity; however, emissions generally decay exponentially over time, so any time spent in this initial conditioning phase is beneficial.
- Installing products that require in-place curing (such as caulks and sealants) with sufficient time, ventilation, and proper curing conditions can reduce emissions to a low level prior to enclosure of the space.
- Installing absorbent materials only after the building has been enclosed and moisture can be controlled, and after installing products that require in-place curing, protects absorbent material from contamination.

Measurement and documentation of exposure levels from preconstruction through postconstruction phases can assist in identifying contaminant sources. Different approaches that are used to measure or estimate exposure include ambient concentration measurements, exposure modeling, personal monitoring, and biomonitoring.

9.1.3.1.2 Mitigation. Once all efforts have been taken to minimize the introduction of contaminants, postinstallation actions can further reduce contaminant levels before occupancy (see the *Indoor Air Quality Guide*[26], Strategy 5.2, "Employ Strategies to Limit the Impact of Emissions").

Mitigation methods include building flush-out procedures, in which the space is fully ventilated and exhausted by a set volume of air. ANSI/ASHRAE/ICC/USBGC/IES Standard 189.1[92] identifies postconstruction/preoccupancy building flush out as an effective means of controlling contaminants introduced to the space. The design team must be aware of the local climate, as minimum temperatures and maximum humidity requirements for the indoor space can impact scheduling or overall feasibility of flush out. The volume of air required for building flush out can result in long operating times for the HVAC equipment or require greater heating or cooling capacities than would be typical of normal operation.

As an alternative to a prescribed flush-out air volume, Standard 189.1 provides requirements for IAQ testing that can be used to document the levels of contaminants in a space and address specific contaminant levels that exceed predefined limits. Provided that the contaminants brought into the space were well understood and controlled in the IAQ plan, IAQ testing can be a very straightforward process.

While some jurisdictions may permit the use of bake-out procedures (use of heating equipment to accelerate the outgassing process), high temperatures adversely impact material properties and may not have long-lasting effects on outgassing rates. Additionally, heavier compounds that are not volatile at normal temperatures can be driven to off-gas at higher temperatures and may participate in undesirable chemical reactions.

9.1.4 Protection of Occupied Areas During Construction. The information in Sections 9.1.1 through 9.1.3 apply to all construction projects, including those in occupied buildings. Additional measures and practices can protect occupants in or adjacent to the construction space for renovations during and after occupied hours. The *Standard 62.1 User's Manual*[44], Part 7.1.4, outlines recommended protective measures, including sealing the construction area, exhausting the construction area, and pressurizing the occupied areas. SMACNA's *IAQ Guidelines for Occupied Buildings under Construction*[93], Chapter 3, recommends control measures specific to HVAC protection, source control, pathway interruption, housekeeping, and scheduling.

The unique challenges of construction in an occupied school building are explored in the *ASHRAE Journal* article, "Maintaining IAQ While Updating Occupied Schools."[94] While not directed specifically at mechanical designers, the process overview and case examples highlight common problems that can impact the final operation of a ventilation system.

9.2 System Start-Up and Commissioning. It is important that the building and building systems be cleaned and operating properly *prior to occupancy* so these items do not contribute to poor IAQ. Consider the following:

- Use of the permanent HVAC systems during construction is typically avoided to prevent contamination of equipment. If those systems must be used, proper filtration (MERV rating not less than the final MERV rating required by the project) can mitigate contamination.
- Clean building systems equipment prior to start-up.
- As noted in Section 9.1.3.1.2, mitigate contaminants prior to occupancy.
- Commissioning prior to occupancy ensures proper operation of all systems.

9.2.1 Application. These start-up considerations apply to newly installed ventilation systems, existing systems undergoing alteration, and unaltered existing systems that serve spaces that have been under construction. Section 10, "Operations and Maintenance," of this guideline provides additional commissioning recommendations for use after the building is constructed and turned over to the owner.

9.2.2 Air Balancing and Verification of Outdoor Air Performance. Commissioning of building systems is important to ensure that the IAQ of the constructed space meets the intent as outlined in the IAQ plan. ASHRAE Guideline 0[95] reviews aspects of commissioning that, when implemented with the integrated design, can be instrumental in ensuring IAQ targets are achieved. This includes engaging a commissioning agent to be part of the team and reviews of the project from the outset, through the design and construction phases. At the end of the construction phase, the commissioning process is effective in documenting that the IAQ goals have been met. This can include confirming and documenting items such as the following:

- Appropriate volumes of outdoor air are delivered to the space(s)
- Appropriate balancing of systems
- Pressure relationships between building areas
- Pressure relationships across the building envelope
- Identification of remedies to problems
- Performance testing of equipment
- Performance testing of systems (including the building envelope and air tightness)
- Verification of applicable sequences of operation
- Verification that all systems are tested in alternate seasons (e.g., if certain equipment require particular ambient conditions for testing, it is important to ensure that this equipment is tested under the required conditions)
- Warranty and/or final commissioning walk-through after the building has been occupied more than six months
- Postoccupancy verification of all monitoring systems to determine the Basis of Design and Owner's Project Requirements intent (energy meters, occupancy sensors, dampers, and controls programming)
- Evaluation of occupant comfort surveys

10. OPERATIONS AND MAINTENANCE

10.1 Application. This section applies to buildings, their ventilation systems, and their components regardless of the version of ANSI/ASHRAE Standard 62.1 to which they were constructed or renovated. This section provides additional commissioning recommendations for use after the building is constructed and turned over to the owner.

10.2 Building Alterations or Change of Use. Building alterations or changes in space use without reevaluation and adjustment of the ventilation system can result in poor indoor air quality (IAQ). Common examples of changes include repurposing a private office into a conference room (or vice versa), relocating or removing interior partitions, or adding light-duty cooking equipment to a meeting space without altering the air distribution system. These minor adjustments may be initiated by occupants without the knowledge of facility operators, or they may be operator-initiated but are not significant enough to require permitting and review of code compliance.

Initial system design assumptions may not apply to the new space use, requiring adjustments to the air distribution system for compliance with the minimum ventilation standard. However, for enhanced IAQ, a discussion with building operators and current occupants about IAQ concerns can inform the redesign of the space. When the opportunity exists to improve air quality along with function of the space, occupant satisfaction and productivity will be increased.

10.3 Source Control during Operation. Environmental tobacco smoke (ETS), door mats, operational procedures, processes that occur in the building, occupant consumables, and durable goods are all contaminants that are brought in and can lead to poor IAQ. Methods and strategies for identification and potential removal or reduction are discussed in this section.

10.3.1 Contaminants Introduced by Occupants. Consideration should be given to chemicals and products used for the specific building occupancy or area use, such as laboratories, art studios, nail salons, food storage, and rubbish rooms. Chemical storage or use should be accompanied by access to safety data sheets (SDS), properly labeled storage containers, required ventilation, and controls to manage a spill or fume release. Some products that can create IAQ issues may not be obvious to occupants, such as houseplant fertilizer or ozone-producing printers and copiers, or are considered to improve IAQ, such as air fresheners or room deodorizers.

Occupants can inadvertently transport contaminants, such as dirt and debris, pollen, food waste, and spills, into the building. Walk-off mats, pressurized entrance/exit vestibules, and cleaning procedures can address many of these problems. Occupants might also open windows to increase ventilation air; however, in a mechanically ventilated building, this may do more harm than good, as it can change space pressure relationships; introduce hot, humid air that can condense on air-conditioning vents; allow pollen to bypass central filtration; or create a path for transportation fumes. Natural ventilation can be an efficient way to improve occupant satisfaction while also saving energy, and evaluation of mixed mode operation and potential air quality impacts are critical to its successful implementation.

Many air quality issues arise or become more noticeable after a change in equipment operation, occupancy, space use, or weather. Collaboration with a certified industrial hygienist or indoor environmental professional can provide insight to IAQ issues, especially those exacerbated by poor equipment performance or housekeeping techniques. The source of an air quality issue in an operating building is often the result of multiple factors, including outdoor air quality, equipment failure, occupant activities, design, and operation and maintenance procedures.

10.3.2 Environmental Services. Ongoing maintenance services, such as janitorial services and pest management, can be a significant source of regular contaminant. Sustainable cleaning practices and integrated pest management (IPM) can improve IAQ over standard practices. Green Seal's GS-42[96] and APPA[97] standards and codes provide guidance on commercial and institutional cleaning standards. A well-managed environmental services or cleaning program will include a space inventory, description of space (area, use, and flooring), and frequency of cleaning necessary, including trash removal. All aspects of the cleaning plan should be documented, including types of cleaning products, equipment use, and training program. While APPA standards target higher education, APPA Levels 1 through 5 are often cited in other industries. Further, CDC, NIH, and other health-care-associated organizations have more stringent and specific recommendations targeted at infection control.

Products and chemicals with limited human and environmental toxicity are helpful in minimizing IAQ issues. A documented housekeeping plan that includes proper chemical storage and product labeling can reduce problems associated with occupant sensitivities or unintended chemical mixtures and reactions. However, some situations may require stronger products, such as biocides, to eliminate reoccurring mildew, hazard cleanup, or increased sanitization due to biological or infectious contamination. Trained personnel only should perform cleaning duties in personal protective equipment (PPE) in a properly ventilated area. These considerations apply to most office, educational, and commercial settings; health care and industrial settings have additional regulations addressed by OSHA, CDC, or other appropriate agency. Generally, all cleaning products should be EPA-approved and have appropriate labeling for effectiveness and proper application.

10.3.3 Integrated Pest Management (IPM). IPM refers to a strategy to manage pest presence at an acceptably low level by combining multiple nonchemical interventions to prevent conditions favorable to pests. A guiding principle of IPM is to minimize the use of chemical pesticides by pursuing nonchemical means first, then using chemicals in a targeted and limited manner, starting with the least toxic products. Elimination of pest problems entirely may be impractical, but effective control is a reasonable goal. Combining structural, environmental, and policy elements can help manage pests at low levels with a minimal judicious use of pesticides.

Successful IPM focuses on prevention, such as addressing design and construction issues like wall and floor penetrations that could allow pests to enter a building. Environmental measures can discourage pests from settling in the building. Moisture management, from quickly addressing plumbing leaks to controlling humidity levels, can prevent pest problems. Policies that discourage occupants from eating at their desks can reduce available food, while minimizing clutter reduces cover for pests.

10.4 Operations and Maintenance (O&M) Manuals. O&M manuals are critical tools for owners and operators. This topic is discussed in detail in Section 9 of this document. This section covers the activities of the O&M postwarranty phase.

O&M manuals; testing, adjusting, and balancing (TAB); building as-builts; and relevant documents in hard copy should be stored in a secure, dry space. The intent is to make these valuable documents available for required maintenance and facility personnel, whether within the warranty period or at a time well into the life cycle of the building. Additionally, electronic copies of all these documents should be stored on a server that is backed up and protected. If possible, obtain a building information modeling file for the building as part of the close-out documents. Whether through a commissioning authority or through the owner's representative, there should be a documented process for turning over these documents. See ASHRAE Guideline 1.4, *Preparing Systems Manuals for Facilities*[98] for more information.

If an O&M manual or other relevant building documents are unavailable, a responsible party should take necessary steps to create or obtain them. Many equipment O&M manuals can be found online or requested from manufacturers.

Periodically, the O&M manuals should be checked for relevancy and updated should modifications to equipment occur and/or an improved industry standard is employed. O&M documents and TAB reports should be treated as living documents to assist operators in determining the root cause of problematic systems.

10.5 Strategies to Improve Indoor Air Quality and Ventilation

10.5.1 Building Operation Review. Periodic review of the existing building operation can produce opportunities to improve IAQ with new technologies, updated applicable standards, and changes to building use. There could be options to retrocommission or revise the ventilation rate utilizing the Indoor Air Quality Procedure (IAQP) to improve IAQ based on identification of compounds or change of occupancy or space use.

10.5.2 Occupant Feedback. Occupant perceptions of IAQ are an important, but imperfect, tool for identifying potential IAQ issues in a building. Many surveys focus on overall indoor environmental quality, which comprises a broader scope of space attributes, including acoustics, thermal comfort, lighting, air quality, and building cleanliness. Occupants may be more sensitive to some attributes than others—for example, where thermal conditions are acceptable, a perceived reduction or lack of ventilation.

Surveys should be evaluated for limitations and biases and should have a defined target audience, be relatively simple to complete, and have a defined time frame (e.g., seasonal, within so many months of occupancy). There should be a plan to take action based on survey results, including using the opportunity to have a discussion with occupants about building operation, the intended space design, or options that may improve IAQ. When occupants understand which zone is covered by what thermostat or gain control of reflective blinds, actual or perceived air quality and comfort issues can be resolved.

10.5.3 Reaction to Events. Even the best design cannot anticipate and prevent all negative events including water events (floods due to pipe breaks, storms), natural disasters (tornadoes, hurricanes, fires), and chemical attack. Planning, preparedness, and swift reaction can mitigate and protect the air quality within an occupied building and minimize overall capital damages. Managing these events should be documented in an emergency operations plan and should include representation of cognizant professionals. These professionals may be industrial hygienists, disaster recovery contractors, or even experienced technicians who have taken training and are aware of building systems that are integrated for these types of events. Resources are available through Indoor Air Quality Association (IAQA), American Industrial Hygiene Association (AIHA), Institute of Inspection Cleaning and Restoration Certification (IICRC), and Environmental Protection Agency (EPA).

10.5.3.1 Water Events. In the event of a pipe burst in a building, timely reaction can provide immediate relief from long-term detrimental issues. Situation-appropriate reactions are also key, such as determining when carpet and drywall should be replaced versus cleaning or minimal remediation. In the event of an extreme storm (e.g., hurricane, flooding), safety is the greatest factor. When evacuation is declared by a local authority, occupants must leave. When it is safe to return, measures to protect persons and buildings during cleanup should be employed. When damage is beyond repair, remove all materials and dispose of at an approved site.

10.5.3.2 Ambient (Outdoor Air Quality) Hazard Events. Wildfire, chemical attack, and high pollutant levels all contain hazardous particulates that can be irritating and hazardous to occupant health.

ASHRAE Guideline 44, *Protecting Building Occupants from Smoke During Wildfire and Prescribed Burn Events*, currently under development, will include a framework for building operations under these hazardous conditions. When sources are beyond safe levels, as established by the National Ambient Air Quality Standards[5] (NAAQS), shutting off outdoor air intakes may offer an acceptable means of protecting occupants. If a building is designed and operating with reduced ventilation air, systems and appropriate filtration for particles and gases should be in place. Evaluation of these systems should be part of the emergency operations plan. In other cases, where ventilation is provided and calculated based on prescriptive path or exhaust requirement, the overall mechanical systems and building balance should be considered. For example, shutting the outdoor air intakes at the units could cause the building to go into negative pressure if all the exhaust fans are left running, causing the outdoor air to infiltrate through building openings. Whether a building lockdown or emergency ventilation OFF procedure is fully automated through the building automation system or a series of detailed steps for operations staff to follow, it should be documented, periodically tested, and shared with appropriate personnel. If a regional area is more prone to elevated outdoor contaminants (i.e., is a nonattainment area), or the building is in a sensitive area prone to fires or other particulates, selection of filtration means is critical. In these cases, ventilation calculation and operation procedures should be evaluated frequently or as needed to ascertain the safest operation while maintaining enhanced air quality.[11]

10.5.3.3 Infectious Disease Events. Infection control is not a goal of ANSI/ASHRAE Standard 62.1[8], and typical commercial buildings do not have the design and operation features of a health care building designed to meet ANSI/ASHRAE/ASHE Standard 170.[30] Some infectious diseases spread particularly well in indoor environments (see the ASHRAE Environmental Health Committee's emerging issue report, *Biological Agents in Context of Globalization and Pandemic Influenza and Airborne Transmission*[99], and emerging issue brief, *Pandemic COVID-19 and Airborne Transmission*[100]). The *ASHRAE Position Document on Infectious Aerosols*[101] summarizes the challenges of an airborne infectious disease and a general building system's response. Specifically developed for COVID-19, the ASHRAE Epidemic Task Force's *Core Recommendations for Reducing Airborne Infectious Aerosol Exposure*[102] are based on the concept that ventilation, filtration, and air cleaners can be flexibly combined using an equivalent air change approach to achieve exposure reduction goals. These core recommendations are summarized as follows:

a. Follow all public health guidance.
b. Use a combination of ventilation, filtration, and air cleaning.
c. Promote air mixing to increase dilution.
d. Maintain basic HVAC system operating requirements.
e. Verify that all HVAC systems are functioning as designed.

10.6 Ventilation System Maintenance. Basic maintenance to meet minimum IAQ requirements is detailed in a variety of documents, such as ANSI/ASHRAE/ACCA Standard 180[103]; ANSI/ASHRAE Standard 62.1[8], Section 8; and ISO 55000.[104] A comprehensive preventive maintenance (PM) plan is part of any enhanced IAQ program. Failure to meet the minimum ventilation and maintenance standards greatly increases the risk of potential IAQ problems. Many of the recommended maintenance procedures are related to maintaining building IAQ and providing acceptable ventilation to the occupants. Ventilation air volume is required to be measured in many codes to confirm ANSI/ASHRAE Standard 62.1 requirements are met. In some cases, ventilation air volume can be increased if equipment and/or spaces are designed for increased ventilation, such as economizers, natural ventilation, or for flush out of contaminants and design compounds. An enhanced IAQ program looks at all systems involved to confirm that correct O&M procedures are being followed and periodically evaluated.

10.6.1 Types of Maintenance Activities. Maintenance activities can come in many forms: predictive (PdM), proactive (ProM), preventative, periodic, reactive (RM), and run to fail. There are a variety of ways to run maintenance programs: large buildings or campuses may use a computerized maintenance management system (CMMS), whereas a small building may only have hand-written logs. CMMS or other means of documented maintenance management assists in providing records of regulatory mandated maintenance and inspections, including management of an enhanced IAQ program. The CMMS also provides accountability for the facilities team and identifies staff assignments associated with workmanship.

10.6.1.1 Approach. PdM, when possible, can help resolve a potential IAQ problem before it happens. The cost of a PdM program is much less in the life cycle of a building when considering the costs of a major system failure. PdM uses sophisticated analytics and controls and automatic fault detection and diagnostics. This methodology may be employed voluntarily or required by code. PdM uses sensors to determine if equipment is operating as designed or intended. When key measurements are falling out of specification, an alarm is set. This alarm may be set so that a failure or uncalibrated component is monetized. The response and reaction to this alarm can be set to be much quicker than those alarms with no financial penalty. One example is an outdoor air damper stuck wide open at all times. Not only is the facility paying a penalty to heat/cool ambient air when occupied and unoccupied, but it is also taking a chance that the systems may not be designed and balanced to handle increased outdoor air. The result is not only higher energy costs but also a potential IAQ problem due to unconditioned air. The spaces may not be balanced, causing doors to slam, affecting room pressurization, and, finally, allowing contaminated air in spaces with positive pressurization to affect other areas of the building. When operating in a reactive or run-to-fail mode, the likelihood of IAQ issues is greater—often an IAQ problem is only symptomatic of a greater problem, such as an unattended air-conditioning unit allowing untreated air into a space. An owner or building operator should carefully document the reasons a building or equipment has been chosen to operate in this mode.

10.6.1.2 Utilization of a Computerized Maintenance Management System (CMMS). The type of maintenance (PM, PdM, RM, ProM, etc.) will be identified through a work order in a CMMS, which includes a job hazard analysis, description of PPE needed, and other safety measures such as lockout/tagout. Ensuring all pertinent steps are documented can remove guess work and unnecessary troubleshooting. Historical data, such as what work was completed, who completed it, costs associated with repairs (labor and material), and age of equipment, are helpful in extending the life cycle of the equipment, determining an appropriate time for replacement, and confirming that maintenance is occurring, as well as its frequency. Documentation of maintenance is just one part of an asset management framework. Asset input includes relevant equipment properties, such as make, model, value, age, and other significant components, but it also associates risk and criticality of an asset. If a dedicated outdoor air system (DOAS) is used to serve a large commercial office building, the criticality of the fan motor failing is much more significant than a small fan coil serving a portion of an open office. Associating these details that affect IAQ into the CMMS enhances the alarm and decision process of an immediate repair based on the financial and human resource risk of no ventilation air. If IAQ problems result in legal action or occupant dispute, preventative maintenance records may be used as evidence of IAQ efforts of an owner and/or of facilities maintenance.

10.6.2 Equipment and Systems. Maintenance on specific equipment and systems as it applies to IAQ is covered in this section but is not exhaustive. With all equipment, it is best to consult the O&M manual for detailed instructions. Even with properly maintained equipment, source control, system and equipment monitoring, space cleanliness, and walk-off mats can always lead to improved performance of mechanical systems.

10.6.2.1 Inspection of Systems. It is best practice to incorporate inspection of systems as preventative maintenance. If the CMMS or available preventative maintenance documents do not include specific inspection requirements and steps, refer to the O&M manual for inspection and observation details. Preventative maintenance may also include any necessary adjustments. Whether performing the inspection with in-house labor or outside contractors, personnel should be trained and familiar with the equipment they are looking at, wear the appropriate PPE, and understand the safety precautions necessary, such as de-energizing the unit. Typical inspections on an air-handling unit include confirming filters are properly installed in the rack, gaskets are intact with no bypass airflow, filters are clean, the condensate pan is draining with no biogrowth, the fan is operational, and doors close tight with gaskets in place. Gages should be checked to ensure they are reading within specified range. The inspection can go into more detail, but it is important to document any changes from previous inspections, which could include noises, housekeeping, and unit performance. These changes should be evaluated and discussed with appropriate personnel. Templates of common inspections can be found in Table 11, in facility maintenance standards such as ANSI/ASHRAE/ACCA Standard 180[103] and NFPA 25[105], and online. These standards and other guidance can be built into the CMMS. Knowledge of the individual components and the interactions of systems is useful in identifying the probable cause of a potential system failure or other problematic system issues, such as incorrect pressurization.

10.6.2.2 Air-Cleaning Devices. The *ASHRAE Position Document on Filtration and Air Cleaning*[63] discusses the health consequences of filtration and air cleaning and provides a detailed literature review of research and current technologies. This section discusses air-cleaning considerations in existing buildings.

Mechanical filters are the most common and effective air-cleaning device for commercial and institutional buildings. For enhanced IAQ, a filter rated at MERV 13 or higher should be used. However, existing HVAC units may only have a 1 in. (25 mm) or smaller filter rack. If this is the case, a headered filter that fits in the rack can offer lower pressure drop with sufficient room behind the filter rack. Many operators are concerned about insufficient static pressure to accommodate a higher level MERV filter, but there is wide variation in pressure drop among filters with the same rating. Some MERV 13 filters have the same, or lower, initial pressure drops than some MERV 8 filters. By monitoring filter pressure drop during use and changing filters when the final pressure drop of the original filter is reached, higher filtration can be achieved, with the trade-off of increased filter changes. This also mitigates any potential energy penalty of a filter upgrade by

Table 11 Example of Minimum Maintenance Activities and Frequency for Ventilation System Equipment and Associated Components

Inspection/Maintenance Task	Minimum Frequency[a]	Recommended IAQ Frequency
Investigate system for water intrusion or accumulation. Rectify as necessary.	As necessary	Monthly
Verify that the space provided for routine maintenance and inspection of open cooling tower water systems, closed cooling tower water systems and evaporative condensers is unobstructed.	Monthly	Monthly
Open cooling tower water systems, closed cooling tower water systems, and evaporative condensers shall be treated to limit the growth of microbiological contaminants including *Legionella sp.*	Monthly	Monthly, verified daily, or continuous via BAS/Web
Verify that the space provided for routine maintenance and inspection of equipment and components is unobstructed.	Quarterly	Monthly
Check pressure drop and scheduled replacement date of filters and air-cleaning devices. Clean or replace as necessary to ensure proper operation.	Quarterly	Monthly
Check ultraviolet lamp. Clean or replace as needed to ensure proper operation.	Quarterly	Monthly to quarterly
Visually inspect dehumidification and humidification devices. Clean and maintain to limit fouling and microbial growth. Measure relative humidity and adjust system controls as necessary.	Quarterly	Monthly
Maintain floor drains and trap primer located in air plenums or rooms that serve as air plenums to prevent transport of contaminants from the floor drain to the plenum.	Semiannually	Quarterly or part of monthly PM
Check ventilation and IAQ-related control systems and devices for proper operation. Clean, lubricate, repair, adjust, or replace as needed to ensure proper operation.	Semiannually	Quarterly or part of monthly PM
Check P-traps in floor drains located in plenums or rooms that serve as air plenums. Prime as needed to ensure proper operation.	Semiannually	Quarterly or part of monthly PM
Check fan belt tension. Check for belt wear and replace if necessary to ensure proper operation. Check sheaves for evidence of improper alignment or evidence of wear and correct as needed.	Semiannually	Quarterly or part of monthly PM
Check variable-frequency drive for proper operation. Correct as needed.	Semiannually	Quarterly or part of monthly PM
Check for proper operation of cooling or heating coil for damage or evidence of leaks. Clean, restore, or replace as required.	Semiannually	Quarterly or part of monthly PM
Visually inspect outdoor air intake louvers, bird screens, mist eliminators, and adjacent areas for cleanliness and integrity. Clean as needed. Remove all visible debris or visible biological material observed, repair physical damage to louvers, screens, or mist eliminators if such damage impairs the item from providing the required outdoor air entry.	Semiannually	Quarterly or part of monthly PM; could be weekly depending on location
Visually inspect natural ventilation openings and adjacent areas for cleanliness and integrity. Clean as needed. Remove all visible debris or visible biological material observed, repair physical damage to louvers and screens, if such damage impairs the item from providing the required outdoor air entry. Manual and/or automatic opening apparatus shall be physically tested for proper operation and repaired or replaced as necessary.	Semiannually	Quarterly or part of monthly PM; could be weekly depending on location
Verify operation of the outdoor air ventilation system and any dynamic minimum outdoor air controls.	Annually	Quarterly or part of monthly PM
Check air filter fit and housing seal integrity. Correct as needed.	Annually	Quarterly or part of monthly PM
Check control box for dirt, debris, and/or loose terminations. Clean and tighten as needed.	Annually	Quarterly or part of monthly PM
Check motor contactor for pitting or other signs of damage. Repair or replace as needed.	Annually	Quarterly or part of monthly PM
Check fan blades and fan housing. Clean, repair, or replace as needed to ensure proper operation.	Annually	Quarterly or part of monthly PM

a. Minimum frequencies may be increased or decreased if indicated in the O&M manual.

Table 11 Example of Minimum Maintenance Activities and Frequency for Ventilation System Equipment and Associated Components *(Continued)*

Inspection/Maintenance Task	Minimum Frequency[a]	Recommended IAQ Frequency
Check integrity of all panels on equipment. Replace fasteners as needed to ensure proper integrity and fit/finish of equipment.	Annually	Quarterly or part of monthly PM
Assess field serviceable bearings. Lubricate if necessary.	Annually	Quarterly or part of monthly PM
Check drain pans, drain lines, and coils for biological growth. Check adjacent areas for evidence of unintended wetting. Repair and clean as needed.	Annually	Monthly–quarterly, part of monthly PM
Check for evidence of buildup or fouling on heat exchange surfaces. Restore as needed to ensure proper operation.	Annually	Monthly–quarterly, part of monthly PM
Inspect unit for evidence of moisture carryover from cooling coils beyond the drain pan. Make corrections or repairs as necessary.	Annually	Monthly–quarterly, part of monthly PM
Check for proper damper operation. Clean, lubricate, repair, replace, or adjust as needed to ensure proper operation.	Annually	Quarterly
Visually inspect areas of moisture accumulation for biological growth. If present, clean or disinfect as needed	Annually	Quarterly
Check condensate pump. Clean or replace as needed.	Annually	Quarterly or part of monthly PM
Visually inspect exposed ductwork and external piping for insulation and vapor barrier for integrity. Correct as needed.	Annually	Quarterly or part of monthly PM
Verify the accuracy of permanently mounted sensors whose primary function is outdoor air delivery monitoring, outdoor air delivery verification, or dynamic minimum outdoor air control, such as flow stations at an air handler and those used for demand control ventilation. A sensor failing to meet the accuracy specified in the O&M manual shall be recalibrated or replaced. Performance verification shall include output comparison to a measurement reference standard consistent with those specified for similar devices in ANSI/ASHRAE Standard 41.2[111] or Standard 111.[112]	5 years	Annually
Verify the total quantity of outdoor air delivered by air handlers set to minimum outdoor air mode. If measured minimum airflow rates are less than the design minimum rate documented in the O&M manual, ± a 10% balancing tolerance, confirm the measured rate does not conform with the provisions of this standard and adjust or modify the air-handler components to correct the airflow deficiency. Ventilation systems shall be balanced in accordance with ANSI/ASHRAE Standard 111[112], or equivalent, at least to the extent necessary to verify conformance with the total outdoor airflow and space supply airflow requirements of this standard. ***Exception:*** Units under 2000 cfm (1000 L/s) of supply air are exempt from this requirement.	5 years	Two years, no exceptions on size of unit
Periodic inspection of building entrances to check building pressurization, walk-off mats, ETS, and patterns of travel. Intended to identify potential sources of air quality issues. Develop a list of deficiencies and report to owner/maintenance.	—	Daily
Implement housekeeping/janitorial quality control inspections based on space use, frequency, and criticality of function of space.	—	Quarterly

a. Minimum frequencies may be increased or decreased if indicated in the O&M manual.

operating within the same pressure parameters. Central HVAC units may also be retrofit with a prefilter at a unit intake or upstream in ductwork where more space is available. Prefilters can capture return air, ventilation air, or both.

If a higher level of filtration cannot be used in the central HVAC system, or if some areas require additional particle source control or removal, in-room HEPA filter devices in the occupied space or a return plenum can provide effective air cleaning. The Association of Home Appliance Manufacturers (AHAM) tests and verifies the clean air delivery rate (CADR) of air cleaners of all types at three different particle size ranges: cigarette smoke (0.10 µm to 1.0 µm), dust (0.5 µm to 3.0 µm), and pollen (0.5 µm to 11.0 µm).[102] Typical air-cleaning devices available on the market today have CADRs on the order of 50 to 500 cfm per device. As found in ANSI/AHAM AC-1[106], the rule of thumb for sizing is to select a device with a CADR at least two-thirds of the room's area; higher-CADR devices remove particles at a faster rate. CADR impacts are additive, and multiple smaller devices can be used together, which is a useful strategy for large areas or where noise levels are a concern. The ASHRAE Epidemic Task Force created a two-page guide[107] for adding an in-room air cleaner to reduce the concentration of infectious aerosols, including a sample calculation for sizing CADR. One study found that aerosol concentration was reduced by over 90% within 30 minutes in a classroom with four in-room HEPA filter devices—for 5.5 clean air changes per hour; drastic particle reductions occurred at all particle sizes and evenly throughout the room.[108]

Gas-phase devices may be used to remove gaseous contaminants such as ozone, formaldehyde, and other VOCs. They may also be used to achieve enhanced IAQ with the IAQP to replace a portion of the outdoor air requirement under the VRP with cleaned indoor air to achieve a more cost-effective and energy-efficient ventilation system design without compromising IAQ. When using gas-phase devices with the IAQP, it is important to use only devices with published removal efficiencies.

Supplemental air-cleaning technologies not based on mechanical filtration alone require close examination. Air-cleaning processes based on chemical reactions in the breathing zone require careful evaluation of potential byproducts and their levels, including those from incomplete reactions, as those byproducts may be contaminants. End users should be aware that UV-C may worsen the air quality by adding ultrafine particles, total volatile organic compounds, and ozone and accelerating the deposition of particles on surfaces.[109] For further information, see Informative Appendix E. ANSI/ASHRAE Standard 62.1[8] requires air-cleaning devices to be listed and labeled in accordance with UL 2998.[75] Owners of these devices should set up an O&M program to verify performance and proper operation based on the manufacturer's requirements and additional industry recommendations. The *ASHRAE Position Document on Filtration and Air Cleaning*[63] and the Epidemic Task Force's summary of filtration and disinfection technologies[110] provide information on devices that use reactive air-cleaner technology.

Supplemental air-cleaning devices do not eliminate the need for outdoor air unless they can be applied in full compliance with the IAQP, which allows that filtration and air cleaning, together with recirculation, can be used as a substitute for a portion of outdoor air ventilation.[113,114] Decreasing ventilation air at the expense of occupant health is not a viable trade-off. At the same time, outdoor air quality should be considered when increasing ventilation to avoid bringing outdoor-generated pollutants inside. The *ASHRAE Position Document on Filtration and Air Cleaning* states,

> One consideration that warrants discussion is that the overlap between contaminants with indoor sources versus those with external (outdoor) sources is relatively small and the use of increased ventilation air without filtration and air cleaning can result in substituting one set of contaminants (internally generated) with a different set (externally generated) with any associated health effects. This is especially important in regions that do not meet national or regional air quality standards for one or more criteria pollutants (i.e., ozone, PM10, PM2.5) or where there may be local sources of air pollution.[63]

10.6.2.3 Air Handlers, Fans. Using direct driven equipment eliminates fan belts, which can deteriorate and introduce belt pieces to the airstream when they fail. Retrofit evaluations can be completed by the original equipment manufacturer or experienced design professional.

10.6.2.4 Air Monitoring. Typical building automation systems monitor temperature, relative humidity, and, possibly, CO_2 concentration. Additional IAQ parameters can now be monitored with more accurate and lower-cost sensors, such as concentrations of particles in different size ranges, total and specific volatile organic compound concentrations, and other contaminants of concern. To provide useful information, a sensor's required range will depend on the expected measurement concentrations and limits established by a cognizant authority. For example, a sensor range of 0 to 10 ppm would be inappropriate for measuring concentrations expected in the 0 to 10 ppb (parts per billion) range. Consumer-grade sensors can provide substantially different readings than their lab-grade counterparts, but two recent studies of low-cost sensor performance by Lawrence Berkeley National Laboratory[115] and ASHRAE[116] can aid in sensor selection and measurement interpretation.

Interpretation of sampling results should be conducted by an experienced and qualified IAQ practitioner. Misinterpretation of sample data can lead to misapplication of additional engineering controls, including increased unnecessary ventilation, or missing potentially hazardous exposures to building occupants that can lead to occupational disease. The sampling data, as well as all other information about the workplace, should be carefully reviewed to determine what the results mean regarding the IAQ in the monitored areas.

10.6.2.5 Heating Systems. Heating systems (including domestic hot-water systems) can have a detrimental effect on air quality. For combustion systems, inspection tasks can include checking flues for deterioration, verifying that required combustion air is provided, verifying pressure relationships between the mechanical room and adjacent spaces, and detecting possible leaks with carbon monoxide monitors. Combustion fumes from heating plants can permeate walls when adjacent spaces are not pressurized properly or separated by vestibules. Dedicated buildings for heating plants can provide further separation from occupied spaces to improve IAQ. Even noncombustion heating can negatively impact air quality; electric strip heaters used for the first time in a season often burn off the coil dust and dander, creating noticeable odors. Checking and cleaning these coils before heating season can eliminate IAQ complaints and false fire alarms from the unit-mounted smoke detectors.

10.7 Commissioning as Part of Operations. In addition to identifying potential energy savings, commissioning and maintenance programs can be used to evaluate systems to ensure IAQ goals are being met.

As defined by ASHRAE Guideline 0[95], commissioning is a quality-oriented process for achieving, verifying, and documenting that the performance of facilities, systems, and assemblies meet defined objectives and criteria. Commissioning is often associated with construction; however, long-term commissioning after construction can be an important and effective part of operations and maintenance. Through the life of a building, equipment performance can change through wear and tear, equipment degradation, and adjustments made by O&M personnel.

Ensuring that sensors are properly calibrated, that system components are operating properly, and that the sequences of operation are effective is essential to meeting the long-term efficiency and performance goals of the system, including providing optimal IAQ to the occupants. Depending on the system and the needs of the owner or occupants, different levels of ongoing commissioning may be used, including continuous commissioning, periodic commissioning, and retrocommissioning.

10.7.1 Continuous Commissioning. Continuous commissioning refers to the ongoing process of assessing system performance to ensure that systems are meeting the intended goals. Continuous commissioning is typically used to resolve problems and to optimize energy performance and occupant comfort through building control systems and analytics.

10.7.2 Periodic Commissioning. Periodic commissioning is typically implemented as part of a comprehensive maintenance policy. Such policies often require a re-evaluation of system operation and performance at predefined intervals through the life of a system.

10.7.3 Retrocommissioning or Recommissioning. Retrocommissioning, or recommissioning, refers to the process of reevaluating system performance for the current occupant needs, sometimes many years after initial design. Obsolete equipment can become difficult to operate and maintain effectively, and changes to occupant needs and space use can limit the systems' ability to meet performance targets. Retro-commissioning is particularly useful when a space is used differently from its intended design use, such as a suite of private offices converted to a large meeting space.

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(This appendix is not part of this guideline. It is merely informative and does not contain requirements necessary for conformance to the guideline.)

INFORMATIVE APPENDIX A
HEALTH IMPACTS OF AIR POLLUTANTS

A1. PARTICLES

Particulate matter (PM) pollution is generally separated into coarse, fine, and ultrafine fractions. The coarse fraction consists of particles that are between 10 and 2.5 µm in aerodynamic diameter. The fine fraction is PM that is ≤2.5 µm (PM2.5) in aerodynamic diameter. Ultrafine particles (UFP) are those particles ≤0.1 µm. UFP overlap in size with nanoparticles, which is a term generally used for manufactured particles. UFP generally refers to naturally occurring (nonmanufactured) particles; these are predominantly the result of combustion.

Particles ≤10 µm in aerodynamic diameter are designated PM10 and include the coarse and fine fractions. PM10 and PM2.5 are regulated ambient pollutants in many parts of the world due to the well-established detrimental health effects of exposure to these pollutants.[6,117]

The size delimitations of PM10 and PM2.5 are in part derived from technological features of the equipment developed for monitoring ambient pollution. Starting in 1971, the U.S. EPA monitored and regulated total suspended particles (TSP) in ambient air based on PM mass captured by filter samplers. As the health effects of PM became better recognized, emphasis shifted away from the large PM (>10 µm in aerodynamic diameter), and by the late 1980s, monitoring equipment was in use that could segregate PM10 from TSP. From 1987, PM10 rather than TSP was regulated. Further progress in monitoring equipment technology and understanding health effects led to PM2.5 being regulated in 1997.

The PM10 and PM2.5 designations derive from ambient pollution monitoring technology and programs. Pulmonologists and respiratory occupational physicians also developed a PM classification to address penetration of PM into the respiratory system (ISO 7708[118]). This segregates PM size classes that are inhalable (inspirable), thoracic, and respirable. These refer, respectively, to PM that is small enough to be inhaled, smaller and capable of penetrating into the large airways of the lungs, and even smaller and capable of penetrating to the gas exchange portion of the lung. The size of PM in these classes varies according to the person, air movement, and breathing rate, so the classes are distributions rather than clear-cut points. The delineations between the class medians fall at approximately 12 µm (inhalable/thoracic) and

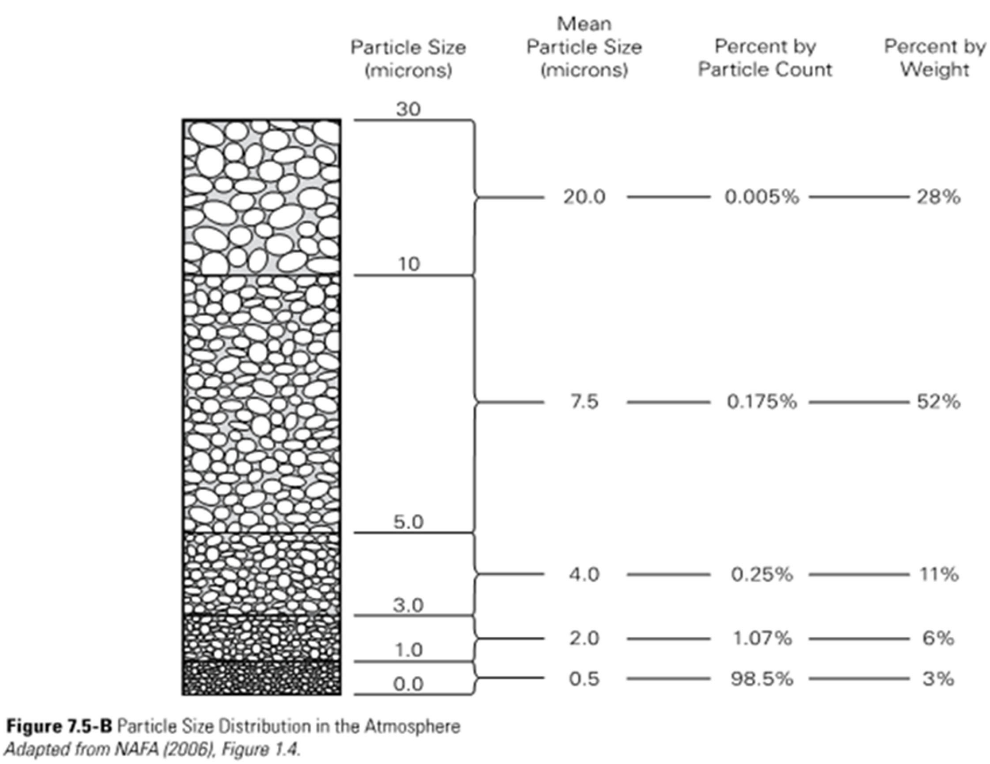

Figure A-1 Particle size distribution in the atmosphere. (Source: *Indoor Air Quality Guide*[26], Figure 7.5-B)

4.5 µm (thoracic/respirable) particle sizes. These classes overlap with the ambient PM designations but should be recognized as only generally equivalent. PM10 and PM2.5 are classes defined by physical features, whereas inhalable/thoracic/respirable are defined by functional features.

Short-term (up to one month) and long-term (longer than one month) exposure to PM are considered to be causal factors or likely to be causal factors for respiratory disease, cardiovascular disease, cancer, or mortality. The 2019 *Integrated Science Assessment* (ISA)[117] for PM concluded that short-term or long-term PM2.5 exposure is likely causal for respiratory effects and is causal for cardiovascular effects and mortality. Without delineation of duration, exposure to PM2.5 is also likely to be causal for cancer. The evidence is suggestive for several additional health effects due to exposure to coarse PM (PM10 to PM2.5) or PM2.5.

The major components of PM are sulfate, nitrates, ammonia, sodium chloride, black carbon, mineral dust, and water. It consists of a complex mixture of solid and liquid particles of organic and inorganic substances suspended in the air (see Figure A-1). The most health-damaging particles are those with a diameter of 10 µm or less (≤PM10), which can penetrate and lodge deep inside the lungs. Chronic exposure to particles contributes to the risk of developing cardiovascular and respiratory diseases as well lung cancer.

When concentrations of small and fine particulates are reduced, related mortality also decreases, presuming other factors remain the same. This allows policymakers to project the population health improvements that could be expected if particulate air pollution is reduced.

Small-particulate pollution has health impacts even at very low concentrations; indeed, no threshold has been identified below which no damage to health is observed.[9] The effects of PM on health occur at levels of exposure currently being experienced by many people in both urban and rural areas and in developed and developing countries, although exposures in many fast-developing cities today are often far higher than in developed cities of comparable size.

A1.1 Ultrafine Particles. Less is known about potential health effects due to exposure to particles smaller than 0.1 µm. One reason is that instruments that can reliably measure UFP concentration have not been available as long as instrumentation that measure coarse and fine PM. Detrimental health effects of UFP exposure have been shown, although the current epidemiologic evidence remains insufficient to support firm conclusions.[119]

A2. GASES AND GASEOUS MIXTURES

A2.1 Oxidizing (Ozone). Ozone at ground level—not to be confused with the ozone layer in the upper atmosphere—is one of the major constituents of photochemical smog. It is formed by the reaction of sunlight (photochemical reaction) and pollutants such as nitrogen oxides (NOx) from vehicle and industry emissions and volatile organic compounds (VOCs) emitted by vehicles, solvents, and industry. As a result, the highest levels of ozone pollution occur during periods of hot, sunny weather. Ozone is not created in cold weather conditions because of rate reaction, nor is it created at night without sunlight.

Excessive ozone in the air can have a marked effect on human health.[6,120] It can cause breathing problems, trigger asthma, reduce lung function, and cause lung diseases. In Europe, ozone is currently one of the air pollutants of most concern.

A2.2 Nitrogen Dioxide (NO_2). As an air pollutant, NO_2 has several correlated activities. At short-term concentrations exceeding 200 µg/m^3, it is a toxic gas that causes significant inflammation of the airways. NO_2 is the main source of nitrate aerosols, which form an important fraction of PM2.5 and, in the presence of ultraviolet light, of ozone. The major sources of anthropogenic emissions of NO_2 are combustion processes (heating, power generation, and engines in vehicles and ships).

Epidemiological studies have shown that symptoms of bronchitis in asthmatic children increase in association with long-term exposure to NO_2. Reduced lung function growth is also linked to NO_2 at concentrations currently measured (or observed) in cities of Europe and North America.[121]

A2.3 Sulfur Dioxide (SO_2). Studies indicate that a proportion of people with asthma experience changes in pulmonary function and respiratory symptoms after periods of exposure to SO_2.[122] Exposure to SO_2 concentrations of 500 µg/m^3 should not exceed ten minutes.

The 2006 revision of the 24-hour guideline for SO_2 concentrations from 125 to 20 µg/m^3 was based on multiple considerations.[9] Health effects are now known to be associated with much lower levels of SO_2 than previously believed. A greater degree of protection is needed.

Although the causality of the effects of low concentrations of SO_2 is still uncertain, reducing SO_2 concentrations is likely to decrease exposure to copollutants. SO_2 is a colorless gas with a sharp odor. It is produced from the burning of fossil fuels (coal and oil) and the smelting of mineral ores that contain sulfur. The main anthropogenic source of SO_2 is the burning of sulfur-containing fossil fuels for domestic heating, power generation, and motor vehicles.

SO_2 can affect the respiratory system and lung functions and cause irritation of the eyes. Inflammation of the respiratory tract causes coughing, mucus secretion, and aggravation of asthma and chronic bronchitis and makes people more prone to infections of the respiratory tract. Hospital admissions for cardiac disease and mortality increase on days with higher SO_2 levels. When SO_2 combines with water, it forms sulfuric acid; this is the main component of acid rain, which is a cause of deforestation.

A2.4 Carbon Monoxide (CO). Carbon monoxide (CO) is a colorless, odorless gas that can be harmful, even fatal, when inhaled in large amounts. CO is released when something is burned. The greatest sources of CO in outdoor air are cars, trucks, and other vehicles or machinery that burn fossil fuels. A variety of items in the home, such as unvented kerosene and gas space heaters, leaking chimneys and furnaces, and gas stoves, also release CO and can affect air quality indoors.

Breathing air with a high concentration of CO reduces the amount of oxygen that can be transported in the blood stream to critical organs such as the heart and brain. At very high levels, which are possible indoors or in other enclosed environments, CO can cause dizziness, confusion, unconsciousness, and death. Very high levels of CO are not likely to occur outdoors. However, when CO levels are elevated outdoors, they can be of particular concern for people with some types of heart disease. These people already have a reduced ability for getting oxygenated blood to their hearts in situations where the heart needs more oxygen than usual. They are especially vulnerable to the effects of CO when exercising or under increased stress. In these situations, short-term exposure to elevated CO may result in reduced oxygen to the heart accompanied by chest pain, also known as angina.

A2.5 Organics—Volatile Organic Compounds (VOCs). In the built environment, organic gaseous pollutants that are volatile in the temperature range of occupied spaces are referred to as VOCs. The chemical backbones of VOCs are in the range of 6 to 16 carbons long, although some programs consider 5 carbons the lower limit and some consider 17 carbons the upper limit. Other means of defining VOCs include a vapor pressure range or a boiling-point range. Since VOC concentrations in the built environment are most reliably measured with gas chromatography (GC) or mass spectrometry (MS), using the retention time in a GC of C6 and C16 compounds (or C5/C17) as the defining boundaries of what is a VOC has the greater practicality.

Compounds that are lighter (<6 carbons) than VOCs are referred to as "very volatile organic compounds" (VVOCs). Similarly, compounds that are heavier than VOCs (>16 carbons) are referred to as "semivolatile organic compounds" (SVOCs). VOCs are discussed more frequently than VVOCs and SVOCs, but many of the issues and concerns apply to all three categories. Exposure to VVOCs may be of shorter duration than that of VOCs, because VVOCs dissipate more quickly. Exposure to SVOCs is less well understood than to VOCs, because air sample collection for SVOCs is more challenging than for VOCs.

There are often dozens of VOCs present in indoor environments, especially if VVOCs and SVOCs are included. Many are present at levels in the low parts per billion concentration range. Some traditional industrial hygiene methods are not designed for measuring compounds at these low concentration ranges. VOCs indoors are emitted from construction materials, finishes, furniture, and equipment, as well from the occupants themselves (bioeffluents) and activities conducted indoors (e.g., cooking, burning candles, cleaning).

A3. VOLATILE ORGANIC COMPOUNDS, REACTIVE ORGANIC GASES, SMOG, CONTENT OR EMISSIONS

A3.1 Terminology and VOC Limits. Regulations on the VOC content of some materials creates confusion between indoor air quality (IAQ) concerns and ambient smog concerns. In the latter third of the 20th century, photochemical smog in some urban areas was recognized as a product of certain volatile hydrocarbons that reacted with NOx in the presence of sunlight in outdoor air. A specific list of reactive hydrocarbons or reactive organic gases (ROGs) that contributed to smog was regulated in order to control smog events. The regulatory limits were based on the percent content by weight of ROGs in products that contained the regulated compounds. Solvent-based coatings are one example of products that contain ROGs. Other volatile organic compounds prevalent in outdoor air that were negligibly reactive were exempted from the regulation. Thus, from an outdoor pollution perspective, ROGs were a well-defined and relatively small group of several dozen compounds that were regulated on the basis of mass content (g/L) in a product, and VOCs not on the list were exempt.

In the early 2000s, the U.S. EPA adopted the designation of "VOC" to refer to ROGs. Meanwhile, the VOC designation was already established in the IAQ community and referred to the mix of VOCs that accumulated indoors from emissions of indoor products and activities. VOC emissions indoors are far more diverse than ROGs, are largely not regulated, and are measured and assessed on the basis of emission rates (µg/h) or emission factors (µg/unit/hour) rather than percent mass. The use of the VOC designation to refer both to content-based regulated compounds that contribute to outdoor air pollution and to largely unregulated VOC emissions that are indoor pollutants continues to cause confusion. For IAQ, the emission and accumulation indoors of VOCs from products is relevant, whereas the VOC content of a product relates to outdoor air pollution and may provide little or no guidance on the IAQ impacts of a product.

A3.2 Control Measures. Managing levels of indoor air pollutants relies on three factors: source control, dilution ventilation, and air cleaning. Where possible, source control is preferred, because the pollutant that is avoided is the easiest to control. The design phase is the most effective time to select and specify low-emitting materials to implement source control. Reduce the source before it is brought into the building.

If emission rates are known, VOC levels can be managed using ventilation by applying the Indoor Air Quality Procedure (IAQP) in ANSI/ASHRAE Standard 62.1.[8] Multiple certification schemes for low emitting materials, furnishings, and equipment have been developed in recent decades. These include programs provided by industry trade groups, state regulatory agencies, multinational regulatory agencies, and independent third-party programs. These programs set maximum emission rate limits for numerous compounds. These emission rate limits are publicly available and can be used in the IAQP as a worst-case scenario for products that meet the criteria of the respective programs. Examples of these programs are included in Standard 62.1, Informative Appendix D.

Air cleaning is the third option for managing pollutant levels, including VOCs, for acceptable IAQ. Where source control of VOCs is not practical, dilution ventilation may be reduced if VOC emission rates are known or can be applied based on studies for similar space types and if the removal efficiency of gas-phase air cleaners is known. Emission rates for many VOCs can be inferred from maximum allowable emission rates in certification programs. Removal efficiency of some gas-phase cleaning devices is known. As removal efficiency of other devices become available, they can be used with the IAQP as well.

A3.3 Health Effects and Chemical Hygiene. The health effects of indoor VOCs remain incompletely characterized. For compounds with regulated or recommended occupational exposure limits, the indoor concentrations are generally below the occupational limit. However, occupational limits for these compounds were developed for healthy industrial workers, generally young males exposed during a 40-hour workweek. It is noteworthy that many of these limits were developed decades earlier when the industrial workforce was mostly male and when less was known about the health effects of many compounds. Generally, the health effects of compounds in industrial settings were also studied for single compounds rather than for mixtures of compounds, thus avoiding confounding factors that occur in nonindustrial settings.

In contrast, exposure to VOCs in many nonindustrial indoor environments is more than 40 hours per week and, in some cases, may be 24 hours per day all week. Additionally, the population of concern for IAQ is more diverse than industrial workers and includes children, the elderly, and those with underlying health effects, as well as the young healthy worker. These other groups may be more susceptible than industrial workers to exposure to VOCs. Thus, occupational limits are inappropriate for application to the general population without adjustment. Some certification programs use 10% or even 1% of the occupational limits to account for these factors. The European Chemicals Agency (ECHA) Derived No-Effect Level (DNEL) often have limit values for occupational exposures and general population exposures for compounds. These illustrate the differences without the practical, albeit simplistic, approach of taking a 10% or 1% value as an appropriate IAQ limit.

Health effects are more easily recognized for compounds that have long been in use; many new compounds are introduced into commerce each year. From 2013 to 2015, the U.S. EPA conducted review activity on over 1000 new compounds per year.[123] All of these were not VOCs, but this illustrates the rate of new compounds being introduced. Long-term effects are difficult to assess for new compounds. However, even full toxicological assessment for acute effects are not always provided before introduction into commerce. The uncertainty inherent in using materials without full knowledge of any health effects is often addressed by following the precautionary principle of seeking to diminish any harm by minimizing exposure.

Benzene and formaldehyde are compounds that have long been in use but for which exposure limits were recently reduced. Benzene has been widely used since the mid-19th century, but the carcinogenicity of benzene was only widely acknowledged in 1982[124], and benzene has only been included in the U.S. EPA Integrated Risk Information System (IRIS) database[125] since 1988. The chronic reference exposure level (CREL) exposure limit set by the California Office of Environmental Health Hazard Assessment (OEHHA) was 60 $\mu g/m^3$ in 2003 and was lowered to 3 $\mu g/m^3$ in 2014.[126]

Formaldehyde similarly has been used industrially since the early 20th century. In 1987, the U.S. EPA classified formaldehyde as a probable human carcinogen. That year, OSHA set an occupational limit of 3 ppm, which was lowered to 0.75 ppm (~920 $\mu g/m^3$) in 1992. The CREL exposure limit set by California

OEHHA was lowered from 27 μg/m^3 to 9 μg/m^3 in 2008. In 2011, the U.S. Department of Health and Human Services National Toxicology Program (NTP) included formaldehyde as a known human carcinogen.

The history of benzene and formaldehyde illustrates that health effects from some VOCs may not become evident until the compounds have been in wide use for years or even decades. This argues for the precautionary principle of managing VOC levels in the built environment.

This also argues for application of the total VOC (TVOC) concept as a guiding principle for IAQ management. TVOC is the aggregate concentration of VOCs expressed as the equivalent concentration of a surrogate compound, such as toluene or isobutylene. Thus, TVOC is a nonspecific read of the compounds in the air without the ability to distinguish between harmful or benign VOCs. Although assigning specific health effects to a TVOC level is unlikely, a TVOC level is a clear indication of the chemical hygiene of the air in a space, which informs pollutant management for improved IAQ.

(This appendix is not part of this guideline. It is merely informative and does not contain requirements necessary for conformance to the guideline.)

INFORMATIVE APPENDIX B
HUMIDITY AND INDOOR AIR QUALITY

Air quality is not directly affected by humidity; however, excessive humidity can indirectly degrade air quality by generating airborne contaminants through reactions with building contents, materials, and particles.[127] Excessive humidity also negatively affects perception of air quality when gaseous indoor air contaminants are present.[128] Further, as noted in the *ASHRAE Position Document on Limiting Indoor Dampness and Mold in Buildings*[19], when humidity remains high enough for long enough, microbial growth on surfaces can generate odors that degrade the quality of indoor air. The position document notes that these odors are a symptom of persistent dampness, which has been reliably correlated with increased risk of negative health effects for occupants.

B1. HUMIDITY LIMIT FOR MECHANICALLY COOLED SPACES

Because excessive humidity can indirectly affect air quality and health, ANSI/ASHRAE Standard 62.1[8] establishes the maximum indoor humidity at a dew-point temperature of 60°F (15°C) when designing a system that is equipped with components that provide mechanical cooling. Mechanical cooling systems may cool surfaces low enough to allow moisture absorption, accumulation, and persistent dampness unless indoor air is also kept dry.

Mechanical cooling equipment dehumidifies and cools the air that passes through its cooling coil. Often, however, cooling and dehumidification are intermittent, because systems either start and stop—or modulate—their cooling as sensible cooling loads in the space rise and fall. To keep the indoor dew point consistently less than a specified maximum, the system will generally use components and controls that remove humidity when there is little or no sensible cooling load to remove from the space. The issue arises principally during early morning hours and also during swing seasons when outdoor air temperatures are in the moderate range, reducing the need for sensible cooling.

Optimal equipment and control strategies for keeping indoor humidity below the 60°F (15°C) dew-point limit depends on the specifics of the system and application. ASHRAE publications provide a wide variety of system-specific suggestions to accomplish that goal in a reliable and economical manner.

B2. DEHUMIDIFICATION SENSORS AND CONTROLS

ANSI/ASHRAE Standard 62.1[8] defines the humidity limit for design in terms of dew-point temperature but does not mandate the use of sensors that only transmit dew point. Although dew-point sensor-transmitters are certainly available, many relative humidity sensors can also measure and transmit the concurrent dry-bulb temperature. From these two variables, building automation systems can calculate the dew point and use that value to control the dehumidification accomplished by the system.

Further, there are many good reasons to use relative humidity as a second control parameter. For example, absorption and release of moisture from materials is governed by the relative humidity at the surface of that material. The same is true of corrosion. Similarly, the reactions that result in generation of indoor air contaminants are often governed more by the relative humidity and dry-bulb temperature of the air rather than by its absolute moisture content (i.e., its dew-point temperature). An alternative strategy is to control the relative humidity. This can be an effective technique, provided the dry-bulb temperature in the space is also controlled within a predictable range so that the relative humidity set point selected will also prevent condensation on objects in the space that might be cooler than ambient, and also provided that the selected relative humidity will keep the space below the 60°F (15°C) dew-point limit specified by Standard 62.1.

B3. NATURALLY VENTILATED SPACES

Natural ventilation can provide adequate indoor air quality (IAQ) at very low cost when the incoming outdoor air does not contain excessive ozone or other objectionable airborne contaminants. ASHRAE standards do not currently limit humidity for systems that provide natural ventilation, perhaps because these systems are less likely to cool surfaces low enough that they will condense moisture.

Still, problems with microbial growth and IAQ often occur in buildings that mix naturally ventilated or unconditioned spaces with adjacent spaces that are mechanically cooled. Examples include hospitals and clinics in developing countries and multifamily dwellings where temperatures in adjacent apartments are controlled by occupants who have different thermal preferences and comfort expectations. To avoid IAQ problems, ANSI/ASHRAE Standard 62.1[8] cautions that naturally ventilated spaces adjoining mechanically cooled spaces inside the building enclosure must be separated by well-insulated walls and effective air barriers. In essence, such adjoining spaces in the interior of the building need architectural features similar to those of exterior walls.

B4. HUMIDIFICATION

ASHRAE standards do not currently specify a minimum humidity requirement, but avoiding excessive indoor dryness can improve comfort and reduce eye irritation and may also have additional health benefits. When adding humidification systems, it is important to avoid moisture absorption or condensation that could potentially degrade IAQ. Three aspects of humidified buildings in cold climates merit attention from owners and designers: insulation and air barrier design and installation of exterior walls and glazing, selection of humidification components and controls, and the target maximum indoor dew-point temperature to limit the risk of condensation. ASHRAE standards provide application-specific guidance for design of enclosures and humidification systems. Specifically, ANSI/ASHRAE Standard 160[18] provides guidance for hourly hygrothermal analyses of building assemblies that can help guide the selection of an appropriate indoor dew-point limit based on the enclosure design and climate zone.

B5. MICROBIALS AND DAMPNESS

Dampness in buildings has long been associated with the potential for microbial growth and with the possibility of adverse health effects for the occupants in the building. Recent documents from cognizant authorities, such as governmental departments and divisions, have reiterated this association, and recent research (see list below) has strengthened this connection between damp buildings and illness. However, the mechanism by which microbial contamination may play a role in the adverse health effects on occupants in damp buildings remains unknown.

- The *ASHRAE Position Document on Limiting Indoor Mold and Dampness in Buildings*[19] states,

  > Credible research and cognizant health authorities have established an association between health problems and indoor dampness...Further, in both North America and Europe, building dampness and mold growth have been documented to be associated with adverse health outcomes related to asthma and upper respiratory problems.

- The Institute of Medicine (IOM) *Damp Indoor Spaces and Health* report[129] states,

  > Currently, no quantitative, health-based exposure guideline or thresholds can be recommended for acceptable levels of contamination by microorganisms.

- The World Health Organization (WHO) guideline regarding dampness and mold in buildings[130] states,

  > The authors conclude that occupants of damp or moldy buildings, both private and public, have up to a 75% greater risk of respiratory symptoms and asthma. The guidelines recommend the prevention or remediation of dampness- and mold-related problems to significantly reduce harm to health...The review concludes that the most important effects are increased prevalence of respiratory symptoms, allergies and asthma as well as perturbation of the immunological system.

- The U.S. National Institute for Occupational Safety and Health (NIOSH) alert entitled *Preventing Occupational Respiratory Disease from Exposures Caused by Dampness in Office Buildings, Schools, and Other Nonindustrial Buildings*[131] states,

  > Research studies have shown that exposures to building dampness and mold have been associated with respiratory symptoms, asthma, hypersensitivity pneumonitis, rhinosinusitis, bronchitis, and respiratory infections. Individuals with asthma or hypersensitivity pneumonitis may be at risk for progression to more severe disease if the relationship between illness and exposure to the damp building is not recognized and exposures continue.

- In their 2011 study, "Respiratory and Allergic Health Effects of Dampness, Mold, and Dampness-Related Agents: A Review of the Epidemiologic Evidence"[132], Mendell et al. reviewed eligible peer-reviewed epidemiologic studies or quantitative meta-analyses, up to late 2009, on dampness, mold, or other microbiologic agents and respiratory or allergic effects. The study concludes,

  > Evident dampness or mold had consistent positive associations with multiple allergic and respiratory effects. Measured microbiologic agents in dust had limited suggestive associations, including both positive and negative associations for some agents. Thus, prevention and remediation of indoor dampness and mold are likely to reduce health risks, but current evidence does not support measuring specific indoor microbiologic factors to guide health-protective actions.

- In their 2015 study, "Indoor Fungal Diversity and Asthma: A Meta-Analysis and Systematic Review of Risk Factors"[133], Sharpe et al. conclude there is some evidence that in indoor environments *Penicillium*, *Aspergillus*, *Cladosporium*, and *Alternaria* species are associated with asthma outcomes, but more work is needed on the role of fungal diversity.

- In their 2015 paper, “Indoor Dampness and Mould Health Effects—Ongoing Questions on Microbial Exposures and Allergic Versus Nonallergic Mechanisms”[134], Cox-Ganser states,

  > It is currently not understood which specific contaminants or combinations thereof in damp indoor environments cause the various health effects, and results are inconsistent from study to study...There is much to learn about the role of exposure to microbial agents from diverse microbiomes in both the natural and built environment in relation to development and adaptation of our immune systems and how we cope with changes in such exposures at all stages of our lives. While research in these areas continues, it is prudent from a public health standpoint to recognize that damp and mouldy indoor environments are unhealthy and should be remediated or prevented in the first place with appropriate building design and maintenance.

- In their 2016 study, “Exposure and Health Effects of Fungi on Humans”[135], a meta-analysis of previously published studies on adverse health effects experienced by individuals who report they have been in damp and mold-contaminated buildings, Baxi et al. state,

  > The conclusion to take from these studies is that early exposure to environments with dampness, visible mold and moldy odor are associated with subsequent development of asthma. What is still not known is how much exposure is required (amount and duration), whether there is a dose-response, whether specific genera of fungi are responsible for the effect, and whether interventions to reduce exposure would prevent development of asthma. We also do not know if certain populations are more sensitive to exposure...Indoor exposure and dampness appears to be associated with an increased risk of developing asthma in young children, and with asthma morbidity in individuals who have asthma. Reduced indoor exposure using a variety of interventions primarily aimed at reducing moisture, killing fungi, and removing contaminated materials has been shown to decrease this risk of morbidity. What is not known is how much exposure is necessary to cause a particular health effect and whether certain species are more likely to cause such effects.

In conclusion, research continues on the causal relationship between dampness and microbial growth in buildings and the potential for adverse health effects experienced by the building’s occupants. At this time, it is not known whether or not the presence of mold in a building, along with damp conditions, can be associated with these health effects, such as asthma. It is also unknown whether certain mold species can be associated with specific illnesses and adverse health effects.

However, based on the knowledge acquired to date regarding damp buildings, it remains good practice to complete effective and thorough remediation when dampness and mold are encountered. Also, in order to help prevent future moisture-related issues within the building, it is good practice to determine the source (or sources) of the dampness in the building. Once the dampness source is found, effective measures should be taken to reduce or eliminate the source to prevent future dampness and mold problems in the building.

(This appendix is not part of this guideline. It is merely informative and does not contain requirements necessary for conformance to the guideline.)

INFORMATIVE APPENDIX C
CARRYOVER IN ENERGY RECOVERY UNITS

C1. ENERGY RECOVERY SYSTEMS

Whether code mandated or not, energy recovery systems can reduce the energy required to condition ventilation air. *ASHRAE Handbook—HVAC Systems and Equipment*[52], Chapter 26, details a variety of system types.

ANSI/ASHRAE Standard 62.1[8], Section 5.18.3, allows an exception for recirculation in systems using energy recovery. It allows a maximum recirculation of Class 1 and Class 2 air to be 10% of the outdoor air intake flow, and 5% of the outdoor air intake flow can be recirculated Class 3 air. Keeping these limits in mind, it is possible to design systems that can reduce recirculation to achieve 2% to 4%, or about 20% to 70% lower than the maximum rates, depending on the classification of air. The purpose of this appendix is to present an understanding of performance characteristics of energy recovery that will allow engineers to reduce leakage well below the maximum allowable limits through design choices.

C2. TESTING ENERGY RECOVERY VENTILATION AHRI STANDARD 1060

Using ANSI/ASHRAE Standard 84[136], *Method of Testing Air-to-Air Heat/Energy Exchangers*, AHRI developed Standard 1060,[58] whose purpose is

> to establish definitions, test requirements, rating requirements, minimum data requirements for published ratings, marking and nameplate data, and conformance conditions for air-to-air exchangers intended for use in air-to-air energy recovery ventilation equipment (AAERVE).

One set of Standard 1060's performance ratings is exhaust air transfer ratio (EATR) and outdoor air correction factor (OACF). Most designers would interpret EATR to refer to recirculation or leakage. However, for an energy recovery device to have a flow balance, a corresponding OACF is needed —as one is reduced, the other must increase. EATR and OACF are inversely proportional characteristics.

EATR is the tracer gas concentration difference between the leaving supply airflow and the entering supply airflow divided by the tracer gas concentration difference between the entering exhaust airflow and the entering supply airflow at the 100% rated airflows, expressed as a percentage.

OACF is the entering supply airflow divided by the measured leaving supply airflow.

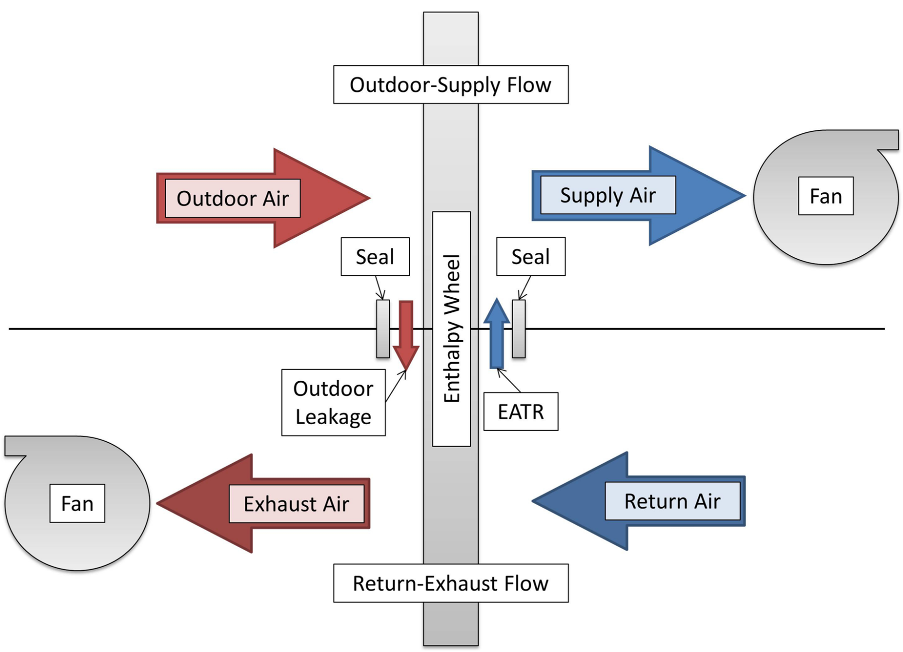

Figure C-1 Air-to-air heat exchanger diagram. (Source: "IAQ & Energy Impact of Exhaust Air Transfer Ratio"[60], Figure 1)

- If OACF greater than 1.0, there is leakage from supply to exhaust (i.e., X_1/X_2 = 5000/4800 = 1.04).
- If OACF less than 1.0, there is leakage from exhaust to supply (i.e., X_1/X_2 = 4800/5000 = 0.96, which is a negative OACF).

Enhancing system design to reduce recirculation rates can be accomplished by designing for higher static pressures in the supply airstream than in the return-exhaust airstream. When reviewing certified performance data, a static pressure differential greater than 1.0 indicates that all points in the outdoor/supply airstream are at higher station pressure than all points in the return/exhaust airstream. This is beneficial when designing for lower EATR. Fan placement is one tool to create positive static pressure in the supply airstream.

In conjunction with positive pressure differential, purge sections can be added to improve the transfer of air from outdoor air to exhaust air. Purge sections are sheet-metal housings that force a bypass of air from the outdoor airstream through the wheel matrix and back into the exhaust airstream, reducing recirculation of the incoming supply air. A purge sector uses a portion of the outdoor air to clean out return air cross transfer before it reaches the supply airstream. Achieving low leakage rates (4% leakage or less) on enthalpy wheels may use, but not necessarily require, a wheel with a purge section.

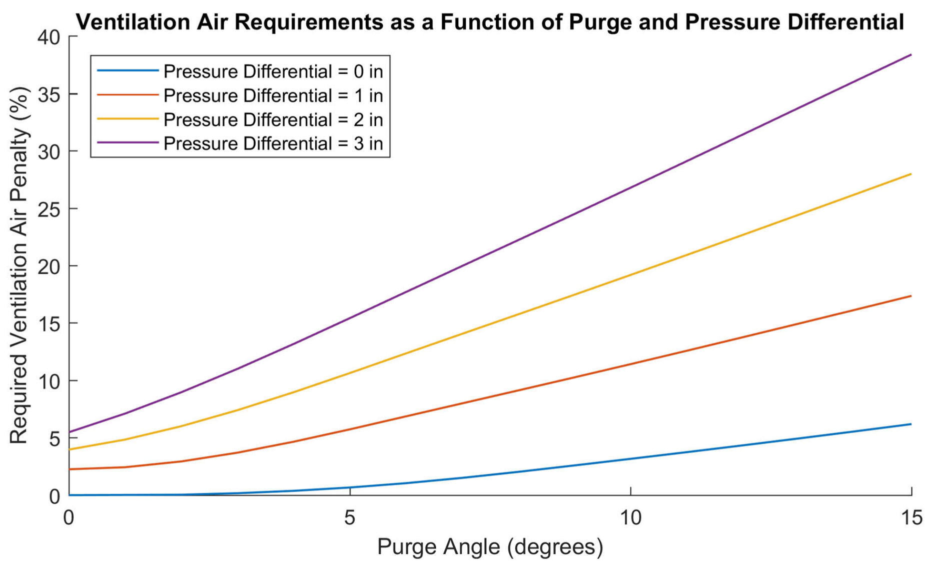

Figure C-2 Estimated increase in ventilation air required. (Source: "IAQ & Energy Impact of Exhaust Air Transfer Ratio"[60], Figure 2**)**

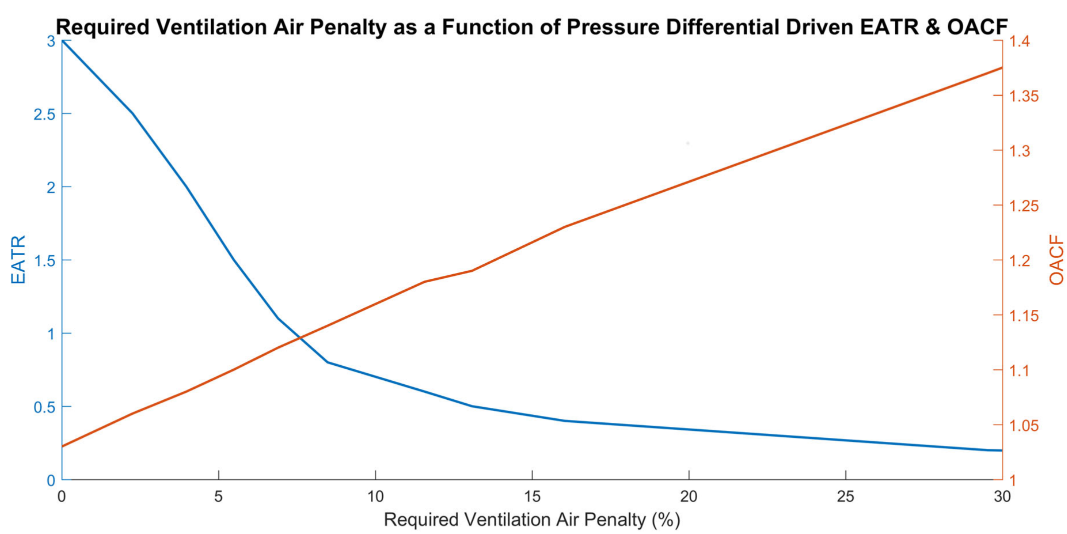

Figure C-3 How pressure differential increases gross ventilation airflow. (Source: "IAQ & Energy Impact of Exhaust Air Transfer Ratio"[60], Figure 3**)**

The ratio of OACF to EATR is a nonlinear function; OACF will increase rapidly with a decrease in EATR. This is especially true in applications with higher air pressure differentials between the supply and return airstreams. This relationship is represented in Figure C-2, which shows an increase in ventilation air required for an increase in purge used (especially for higher pressure differential cases, shown in red, yellow, and purple).

Figure C-3 demonstrates the increase in fan operation costs as EATR is decreased and how these increased costs are due to the increase in OACF because of the difference in pressure across the supply/exhaust interface. To avoid unnecessary expenses, designers and manufacturers can influence system design to optimize EATR/OACF to a point that optimizes fan energy. EATR can be minimized by

a. Using plate frame or other almost 0 EATR device
b. Optimizing the outdoor air/exhaust air pressure difference (exhaust air fan preferred to return air fan, minimize outdoor air path air pressure drop)
c. Specifying independently certified low EATR components at the application pressure
d. Designing runaround loops to eliminate cross-contamination

(This appendix is not part of this guideline. It is merely informative and does not contain requirements necessary for conformance to the guideline.)

INFORMATIVE APPENDIX D
CASE STUDIES

D1. SOURCE CONTROL

This case study demonstrates an example of source control combined with inadequate exhaust systems, which created an indoor air quality (IAQ) issue in a university residence hall. A four-person, two-bedroom suite shared a common living space and restroom (525 ft^2 [49 m^2] for entire suite). The suite ventilation was calculated per ANSI/ASHRAE Standard 62.1 of the relevant code year for that jurisdiction. Dedicated outdoor air units on the roof supplied a continuous 55 cfm (26 L/s) to each suite, while exhausting a continuous 25 cfm (12 L/s) from each suite's restroom, which contained one water closet and one shower stall. Facilities staff cleaned the restrooms weekly, and residents often cleaned as well. In the spring, residents complained of stuffiness and respiratory issues, which were exacerbated in the shower. The shower stall's original tile (which was ten years old) showed signs of biogrowth. Upon request of the occupants, air testing for microbials or active mold growth (AMG) was completed. Even though the regional pollen counts were high and noted in public advisories, the counts in the shower stall exceeded those levels. *Cladosporium* was found to be at 770 CFU/m^3, which was greater than 300 CFU/m^3 above the background. The common area and bedroom suites, with the thermostat set at 68°F (20°C) and 65% rh, did not have any significant biologicals or AMG. Upon further evaluation of exhaust systems and discussions with the occupants, the following information was found:

- Two of the four occupants had known allergies, with one specifically citing a struggle to control symptoms in the local climate with medication.
- The exhaust vent in the restroom near the shower was found to be almost closed. Other supply air vents (both recirculated and ventilation) were able to be manually adjusted by the occupants.
- The exhaust fan serving the restroom exhaust stack was running but at an airflow 20% lower than what was required.
- The occupants often showered within similar two-hour time periods and noted the water on the tile rarely dried.

In this case, the minimum required exhaust of 25 cfm (12 L/s) continuous was not adequate to draw out the latent load, inconsistent cleaning products and procedures did not eliminate biological growth, and the particularly high local concentrations of pollen, possibly carried into the suite on occupant clothing, increased the respiratory irritants and allergic reactions. Further, maintaining a balance of 25 cfm (12 L/s) of exhaust air, even in a new building, is hard to measure and maintain. When occupants are allowed to manually adjust air vents, the overall balance of the suite is altered. To solve the problem, the exhaust and ventilation systems were revised to increase airflow within equipment limits, and airflow was verified through a testing, adjusting, and balancing (TAB) agent. Showers throughout the building were deep cleaned with a stronger biocide and recaulked and retiled where necessary. Residents were instructed to squeegee showers after use to assist tile drying. Internal duct mounted balancing dampers were installed with fixed blade air devices to prevent occupant adjustments.

D2. INDOOR AIR QUALITY PROCEDURE (IAQP)

D2.1 Existing High-Rise Office Building in New York City

D2.1.1 Building Overview. Constructed in the 1980s, the global corporate headquarters building is located in the heart of Manhattan, New York, NY. The 1.35-million-square-foot building has 44 floors of office space and a maximum occupancy of 6863.

D2.1.2 Project Goals

D2.1.2.1 Reducing Flow of Outdoor Air Pollution to the Indoor Environment. New York City is considered a nonattainment zone by the EPA, which means it often has a high concentration of unhealthy ozone. New York City is also graded "F" by the American Lung Association for ozone. Ozone has been shown to increase mortality, and statistical approaches suggest that "safe O3 levels would be lower than 10 ppb"[137] In addition, this area of New York has a lot of automotive traffic, which generates ultrafine particles and combustion gases. Reducing the influx of outdoor-generated pollutants such as ozone, carbon monoxide, and particulate matter (PM) was highly desirable.

D2.1.2.2 Improving Employee Productivity. Numerous studies show poor IAQ directly impacts people's productivity, and recent studies from Harvard[138] and Lawrence Berkeley Labs[139] have shown high carbon dioxide levels alone can cause a 50% decline in cognitive performance. Given the important financial decisions being made in the building, as well as the benefits to health, maintaining low concentrations of carbon dioxide was a high priority.

D2.1.2.3 Reducing Energy/Water Consumption, Greenhouse Gas Emissions, and Energy/Water Costs. Heating and cooling associated with conditioning outdoor air for ventilation was a major energy end use. A 15% reduction in energy consumption and greenhouse gas emissions was targeted for this project. Cooling at the ventilation systems was supported by a chilled-water plant with heat rejection. Reduction in makeup water consumed for the cooling towers was also targeted.

D2.1.3 Existing Ventilation Design. Ventilation for the building is provided by 16 air-handling units located on the 7th and 28th floors, which are connected to the rest of the floors via vertical risers through the building. The air-handling units are inline-supply mixed-air type served by steam heating coils and chilled-water cooling coils. Inline return fans direct air into a plenum return to the air-handling units, while outdoor air is introduced through a louvered façade next to each air-handling unit. Outdoor air and return air dampers regulate the mixed air.

The air-handling units supply 190,000 cfm (89,670 L/s) of outdoor air (approximately 20% of total supply airflow provided by the 16 air-handling units).

D2.1.4 Enhanced Indoor Air Quality Solution. ANSI/ASHRAE Standard 62.1[8] IAQP calculations were performed using the path discussed in Section 8.3.2 of this guideline to determine how much return airflow would need to be cleaned in an effort to reduce outdoor airflow to pressurization and meet the established IAQ design targets in Table 4 and the enhanced design targets developed for ozone and carbon dioxide (see Table D-1).

Per the calculations, approximately 40,000 cfm (18,878 L/s) of clean return air was required. Forty (40) air-cleaning modules (each cleaning 1000 cfm (472 L/s) of return air) were installed across the 7th and 28th floors. The 7th floor mechanical room had space for an array of ten air-cleaning modules on both the north and south sides of the floor, next to the return air fans of the air-handling units. This placement allowed for the air-cleaning modules to clean the return air before entering the air-handling units. The 28th floor mechanical room had space for an array of two air-cleaning modules.

Table D-1 Enhanced Design Targets—Existing High-Rise Office Building in New York City

Compound or PM2.5	Design Target
Ozone (enhanced)	10 ppb
Carbon dioxide (enhanced)	1150 ppm

Table D-2 Measured Contaminant Concentrations vs. Design Targets—Existing High-Rise Office Building in New York City

Compound or PM2.5	Design Target	Measured Results
Acetaldehyde	140 μg/m^3	8.73 μg/m^3
Acetone	1200 μg/m^3	123 μg/m^3
Benzene	3 μg/m^3	0.3 μg/m^3
Dichloromethane	400 μg/m^3	
Formaldehyde	33 μg/m^3	15 μg/m^3
Naphthalene	9 μg/m^3	0.22 μg/m^3
Phenol	10 μg/m^3	0.67 μg/m^3
Tetrachloroethylene	35 μg/m^3	0.38 μg/m^3
Toluene	300 μg/m^3	5.98 μg/m^3
1,1,1-trichloroethane	1000 μg/m^3	
Xylene, total	500 μg/m^3	1.93 μg/m^3
Carbon monoxide	9 ppm	0 ppm
PM2.5	12 μg/m^3	0.5 μg/m^3
Ozone (enhanced)	10 ppb	0 ppb
Carbon dioxide (enhanced)	1150 ppm	848 ppm

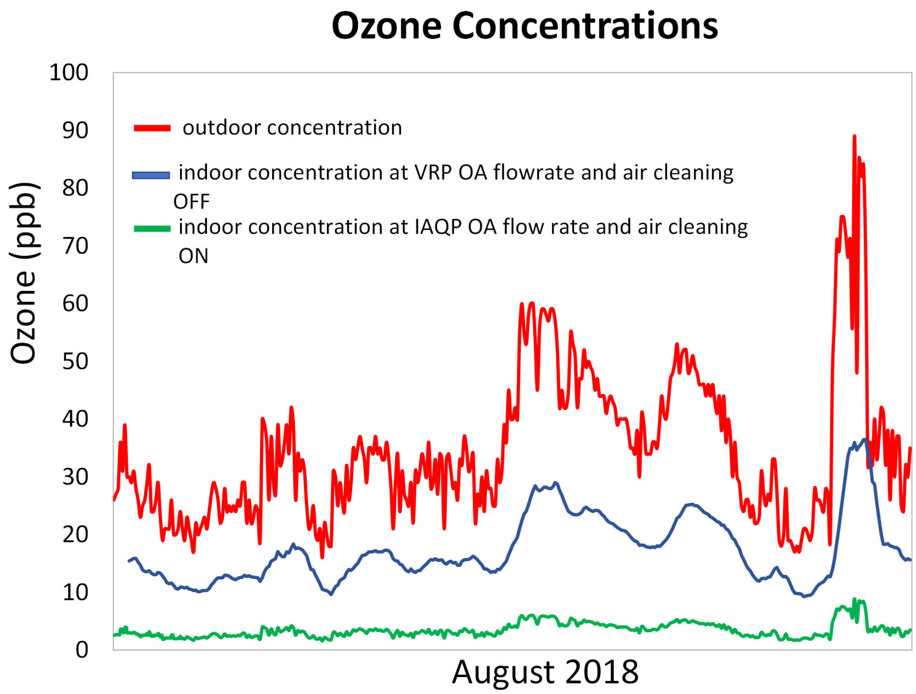

Figure D-1 Outdoor and indoor ozone concentrations. Y axis is ozone concentration in ppb; X axis is time. Indoor ozone measured when outdoor air was reduced to IAQP and air-cleaning modules were operating (green [bottom] line) show a significant improvement in indoor ozone concentration levels.

The air-handling units were rebalanced to supply 70,000 cfm (33,036 L/s) of outdoor air (approximately 3% of total supply airflow provided by the 16 air-handling units). Note that, like most office buildings, this building had low prescriptive exhaust requirements (i.e., toilet exhaust) relative to the minimum outdoor airflow required by the Ventilation Rate Procedure (VRP). As such, 3% outdoor airflow was sufficient to maintain positive pressure in the building.

D2.1.5 Measurement and Verification. Measurement and verification of IAQ included indoor and outdoor environmental air sampling of temperature, humidity, carbon dioxide, carbon monoxide, ozone, PM2.5, and detectable volatile organic compounds (VOCs).

Measurements were conducted at six indoor locations during the summer during normal business hours. All contaminants were measured to be below their allowable concentration limits (design targets). Table D-2 summarizes the results of the IAQ measurements.

D2.1.6 Outdoor Ozone Concentration Impact on Indoor Concentration. Ozone concentrations were measured outdoors and simultaneously indoors during August 2018, as shown in Figure D-1.

- Measured ozone concentrations outdoors reached 90 ppb (red [top] line, Figure D-1).
- Indoor ozone measured concentrations reached 35 ppb when the outdoor air dampers were set at VRP position (190,000 cfm [89,670 L/s]) and air-cleaning modules were off (blue [middle] line, Figure D-1).
- Indoor ozone measured concentrations were below 8 ppb when the outdoor air dampers were set at IAQP position (70,000 cfm [33,036 L/s]) and air-cleaning modules were on (green [bottom] line, Figure D-1).

D2.2 New Construction: Training Center in Boston, MA

D2.2.1 Building Overview. Designed in 2018 and constructed in 2019, the training facility provides teaching tools to demonstrate high-performance building technologies to students who will be learning to install them in future buildings. The four-story, 75,000 ft^2 (6968 m^2) building includes a workshop, classrooms, auditorium, and administrative spaces.

D2.2.2 Project Goals. The project team was targeting LEED v4 certification and exploring means to cost-effectively earn points in the Indoor Environmental Quality (IEQ) and Energy and Atmosphere (EA) credit categories.

The design team targeted LEED v4 Pilot Credit 124 (EQpc124)[140], Performance-Based Indoor Air Quality Design and Assessment, to earn a possible seven points under the IEQ credit category. To meet the

Table D-3 Enhanced Design Targets—Training Center in Boston, MA

Compound or PM2.5	CAS Number	Cognizant Authority	Design Target
Formaldehyde (enhanced)	50-00-0	NIOSH	20 μg/m^3

Table D-4 Measured Contaminant Concentrations vs. Design Targets—Training Center in Boston, MA

Compound or PM2.5	Design Target	Measured Results
Acetaldehyde	140 μg/m^3	3.3–9.0 μg/m^3
Acetone	1200 μg/m^3	1.8–26 μg/m^3
Benzene	3 μg/m^3	0.3–1.3 μg/m^3
Dichlorobenzene(1,4-)	800 μg/m^3	<0.3 μg/m^3
Dichloromethane	400 μg/m^3	—
Formaldehyde	20 μg/m^3	9.4–17 μg/m^3
Naphthalene	9 μg/m^3	<0.4 μg/m^3
Phenol	10 μg/m^3	<0.6 μg/m^3
Styrene	900 μg/m^3	<2.8 μg/m^3
Tetrachloroethylene	35 μg/m^3	<0.3 μg/m^3
Toluene	300 μg/m^3	1.3–2.7 μg/m^3
1,1,1-trichloroethane	1000 μg/m^3	<0.3 μg/m^3
Total volatile organic compounds	500 μg/m^3	<200 μg/m^3
Xylene, total	500 μg/m^3	<2.2 μg/m^3
Carbon dioxide	Equivalent to VRP	417–831 ppm
Carbon monoxide	9 ppm	<3.0 ppm
PM2.5	12 μg/m^3	2.2–9.2
Ozone	70 ppb	0 ppb

requirements of the credit, the building design had to be such that indoor air did not exceed the concentration for the specified contaminants in Table 4. An enhanced design target was developed for formaldehyde (see Table D-3). All other compounds listed in Table 4 were set at their established design target.

D2.2.3 Enhanced Indoor Air Quality Solution. ANSI/ASHRAE Standard 62.1[8] IAQP calculations were performed using the path discussed in Section 8.3.2 to determine how much return airflow would need to be cleaned in order to reduce outdoor airflow to pressurization (approximately 5000 cfm [2360 L/s]) and meet the LEED EQpc124 design targets.

Per the calculations, approximately 6000 cfm (2832 L/s) of clean return air was required. Six air-cleaning modules (each cleaning 1000 cfm [472 L/s] of return air) were installed on the return air side of three (3) rooftop units. The total outdoor airflow across the six rooftop units was reduced from 12,287 cfm (5799 L/s), per VRP calculations, to 5190 cfm (2450 L/s), per IAQP calculations.

D2.2.4 Air Quality Impact. Measurement and verification of IAQ included sampling of all design compounds included in Table 4 and D-2.

Measurements were conducted at eight (8) indoor locations during normal business hours. All contaminants were measured to be below their allowable concentration limits (design targets). Table D-4 summarizes the results of the IAQ measurements as a range from all eight locations.

In addition to IAQ testing, an IAQ survey was administered to the building occupants. One-hundred percent of the responses confirmed that the IAQ was acceptable.

(This appendix is not part of this guideline. It is merely informative and does not contain requirements necessary for conformance to the guideline.)

INFORMATIVE APPENDIX E
INFORMATIVE REFERENCES AND BIBLIOGRAPHY

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ASHRAE is concerned with the impact of its members' activities on both the indoor and outdoor environment. ASHRAE's members will strive to minimize any possible deleterious effect on the indoor and outdoor environment of the systems and components in their responsibility while maximizing the beneficial effects these systems provide, consistent with accepted Standards and the practical state of the art.

ASHRAE's short-range goal is to ensure that the systems and components within its scope do not impact the indoor and outdoor environment to a greater extent than specified by the Standards and Guidelines as established by itself and other responsible bodies.

As an ongoing goal, ASHRAE will, through its Standards Committee and extensive Technical Committee structure, continue to generate up-to-date Standards and Guidelines where appropriate and adopt, recommend, and promote those new and revised Standards developed by other responsible organizations.

Through its *Handbook*, appropriate chapters will contain up-to-date Standards and design considerations as the material is systematically revised.

ASHRAE will take the lead with respect to dissemination of environmental information of its primary interest and will seek out and disseminate information from other responsible organizations that is pertinent, as guides to updating Standards and Guidelines.

The effects of the design and selection of equipment and systems will be considered within the scope of the system's intended use and expected misuse. The disposal of hazardous materials, if any, will also be considered.

ASHRAE's primary concern for environmental impact will be at the site where equipment within ASHRAE's scope operates. However, energy source selection and the possible environmental impact due to the energy source and energy transportation will be considered where possible. Recommendations concerning energy source selection should be made by its members.

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