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Meeting IAQ Needs with Enhanced Filtration
(A Review of ASHRAE Standards Related to Building Air Quality)

Achieving balance among desired goals for indoor air quality (IAQ), energy consumption, and occupant comfort within the built environment is challenging. The American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) endeavors to achieve this through guidelines and standards focused on advancing building science as it relates to environmental quality. This article will review the commonly used design guides found in ANSI/ASHRAE Standard 62.1, "Ventilation for Acceptable Indoor Air Quality."[1] The current form of ANSI/ASHRAE Standard 62.1 employs two mechanical ventilation procedures to provide acceptable IAQ in buildings: the Ventilation Rate Procedure and the Indoor Air Quality Procedure. While the Ventilation Rate Procedure provides only a dilution solution for the control of typical offending contaminants for a specified occupancy, the Indoor Air Quality Procedure provides a directed approach by reducing and controlling the concentrations of selected air contaminants of concern through both dilution and enhanced air cleaning.

Rather than relying only on diluting the concentration of contaminants with outdoor air, designing with enhanced filtration of both recirculated and ventilation outdoor air can improve IAQ and result in the protection of the occupied space. This newsletter will focus on the application of enhanced particle, gas-phase and biological filtration for compliance with Standard 62.1. An outline of the design aspects to consider will be reviewed, with the focus on achieving acceptable levels of contaminants of concern within the occupied space while considering the desire to meet high-performance building standards.

Introduction

Indoor air quality is a key design consideration for commercial buildings, important for maintaining employee health, well-being, and productivity. The common design method for creating acceptable indoor air quality is to provide sufficient outdoor ventilation air to dilute indoor contaminants to a safe level. There are several reasons why this may not always be the best approach. In addition to increasing energy consumption, using outdoor air for dilution can be challenging, particularly when the outdoor air is suspected of containing contaminants that exceed prescribed threshold concentrations. Under these circumstances, introducing outdoor air quantities above those prescribed in ANSI/ASHRAE Standard 62.1 can have the opposite of the desired effect. Many earlier-version LEED[2] certified projects increased the outdoor air (OA) ventilation beyond the minimum requirement with the goal of achieving more effective dilution. Now, sections of the LEED v4[3] program and ASHRAE's high-performance green building standard 189.1-2014 outline enhanced indoor air quality strategies in which advanced filtration arrangements are encouraged as part of promoting occupants' comfort, well-being, and productivity through enhanced indoor environmental quality (IEQ). Recent cognitive function studies of occupants within green building office environments have shown that people perform better in work spaces that have non-detectable levels of common indoor air pollutants. Key indicators of acceptable IEQ are CO_2 levels, temperature, relative humidity, barometric pressure, sound levels, volatile organic compound (VOC) levels, SO_x, NO_x, O_3, PM_{10}, $PM_{2.5}$,[4] and lighting. This document will focus primarily on the constituents found in outdoor / indoor air, recognizing that other aspects may influence the quality of the occupied space.[5]

1 ANSI/ASHRAE Standard 62.1-2016, *Ventilation for Acceptable Indoor Air Quality.*

2 LEED (Leadership in Energy and Environmental Design) is a registered trademark of the U.S. Green Building Council.

3 U.S. Green Building Council's Green Building Program.

4 PM_{10} refers to particulate matter with aerodynamic diameter of 10 microns or less. $PM_{2.5}$ refers to particulate matter with aerodynamic diameter of 2.5 microns or less, which has particularly serious effects on human respiratory health.

5 Joseph G. Allen, Piers MacNaughton, Usha Satish, Suresh Santanam, Jose Vallarino, and John D. Spengler, "Associations of Cognitive Function Scores with Carbon Dioxide, Ventilation, and Volatile Organic Compound Exposures in Office Workers: A Controlled Exposure Study of Green and Conventional Office Environments," *Environmental Health Perspectives* 124 (6) (June 2016):DOI:10.1289/ehp.1510037. www.naturalleader.com/thecogfxstudy/

ANSI/ASHRAE STANDARD 189.1 HIGH-PERFORMANCE GREEN BUILDINGS

ASHRAE Standard 189.1 High-Performance Green Buildings specifies the following filtration requirements in addition to those found in Standard 62.1:

- *Outdoor airflow rate must be monitored*
- *MERV 8 (rather than MERV 6) filters must be used upstream of coils and in PM_{10} non-attainment areas*
- *MERV 13 (rather than MERV 11) filters must be used in $PM_{2.5}$ non-attainment areas*
- *Ozone air cleaners that are a minimum 40-percent efficient must be used in all ozone non-attainment areas (rather than in those few areas with extremely high levels of ozone, as required by Standard 62.1-2016).*

Increased use of dedicated outdoor air systems (DOAS) as a means of reducing energy consumed in cooling, heating and de-humidification of ventilation air has made it easier to achieve acceptable IAQ. If outdoor air contaminant levels are low, increased ventilation from a DOAS is a viable solution. In this design application, the ventilation OA requirement is achieved through a dedicated system that is uniquely designed to meet the code-based ventilation airflow based on occupancy and space type, while the building's requirements for heating or cooling are met by a separate system. A dedicated source for OA can provide an opportunity to ensure adequate filtration using the variety of technologies that are consistent with the IAQ Procedure as outlined in Standard 62.1.

A balanced approach can provide adequate outdoor air quantity for acceptable IAQ while avoiding an excessive energy penalty to heat, cool, and de-humidify that air. This result can be achieved through enhanced filtration to reduce particle, gas and biological contaminants in both the OA and the recirculated indoor air. We will review the available technologies, identifying their strengths and weaknesses, and evaluate how they can be integrated into a DOAS or any system that introduces OA to the occupied space.

Outdoor Air Requirements

Typically, the design outdoor air requirements for a commercial building will be based on the prescriptive requirements of Section 6.1.1 Ventilation Rate Procedure of ANSI/ASHRAE Standard 62.1. Under this procedure, OA requirements are based on space type, application, occupancy level, and floor area.

As noted earlier, even when the outdoor air requirements of the Ventilation Rate Procedure have been met, IAQ issues may exist and must be addressed.

The Ventilation Rate Procedure, although the most commonly used method of controlling contaminants, is based on the premise that the contaminant sources and their respective source strengths are well within the acceptable level for that particular category of building. Unfortunately, this is not always true.

Current World Health Organization (WHO) reports indicate that air pollution levels are rising in all urban areas, worldwide. While over 80% of the people who live in urban areas that monitor air pollution are exposed to pollution levels that exceed the WHO air quality guidelines, the greatest effects are felt by populations in low-income cities.[6] High pollution levels have an impact on health of the population, including increased risk of stroke, heart disease, lung cancer, and respiratory disease. Outdoor air is not acceptable in many city centers. ANSI/ASHRAE 62.1 outlines the acceptable requirements from a local or regional perspective.

Specifically, Section 6.2.1 Outdoor Air Treatment states: "If outdoor air is judged to be unacceptable in accordance with Section 4.1 (Regional/Local Air Quality), each ventilation system that provides outdoor air through a supply fan shall comply with the following sub-sections."[7]

The sub-sections relate to particulate matter (PM_{10} and $PM_{2.5}$), ozone, and other outdoor contaminants that may have a synergistic effect on the air quality. The National Ambient Air Quality Standard (NAAQS) outlines acceptable levels of these contaminants (see Table 1).[8] When outdoor air is suspected of containing one or several contaminants in concentrations that are above the NAAQS, the designer should follow Section 6.1.2 IAQ Procedure, which is a performance-based design approach. Under this method, filtration plays a greater role, and the building outdoor air rates are based on the analysis of contaminant sources, concentration limits, and general levels of perceived acceptability.

[6] WHO, Geneva May 2016.
[7] ANSI/ASHRAE Standard 62.1-2016, *Ventilation for Acceptable Indoor Air Quality*
[8] www.epa.gov/criteria-air-pollutants/naaqs-table

Even when the contaminants found in the outdoor air are within the acceptable range for levels of concentration, indoor air pollutants may be at a higher than desired level. When this occurs, the IAQ Procedure with filtration can be followed as an alternative to bringing in a greater quantity of outdoor air.

In all cases, contaminant sources and their concentrations must be evaluated so as to ensure that the occupants are not subjected to concentrations beyond the recommended exposure period. If the IAQ Procedure is used, a mass balance of the occupied space can be undertaken to validate this approach, not only to determine the amount of outdoor air that is required to satisfy the space, but also to outline the appropriate air cleaning technology and the location of the cleaning system. (See Figure 1.) The efficiency of the air cleaner for the specific contaminant is referred to as E_f in the mass balance equation.

Figure 1 – Performing a Mass Balance of the Occupied Space

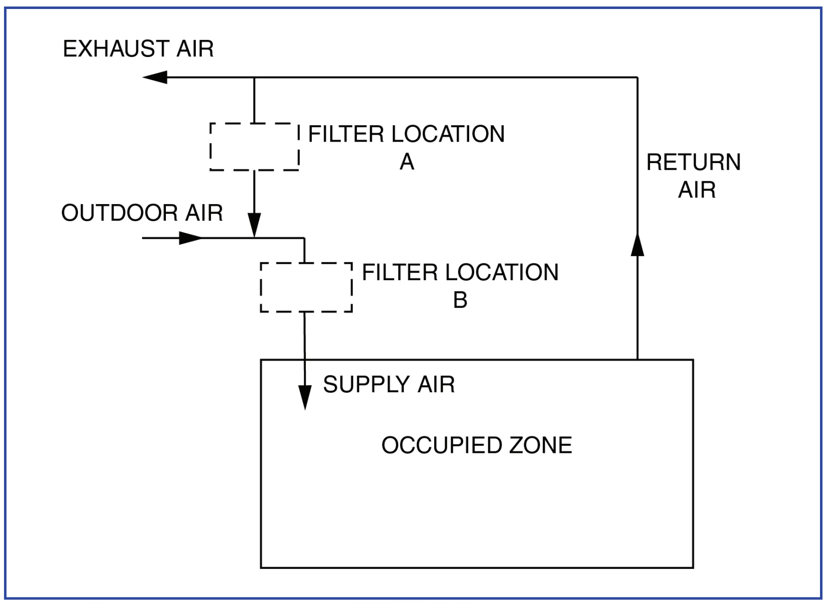


Table 1 - National Ambient Air Quality Standards

Pollutant	Primary/ Secondary	Averaging Time	Level	Form
Carbon Monoxide (CO)	Primary	8 hours	9 ppm	Not to be exceeded more than once per year
		1 hour	35 ppm	
Lead (Pb)	Primary and secondary	Rolling 3 month average	0.15 μg/m^3	Not to be exceeded
Nitrogen Dioxide (NO_2)	Primary	1 hour	100 ppb	98th percentile of 1-hour daily maximum concentrations, averaged over 3 years
	Primary and secondary	1 year	53 ppb*	Annual Mean
Ozone (O_3)	Primary and secondary	8 hours	0.070 ppm	Annual fourth-highest daily maximum 8-hour concentration, averaged over 3 years
Particle Pollution (PM) $PM_{2.5}$	Primary	1 year	12.0 μg/m^3	Annual mean, averaged over 3 years
	Secondary	1 year	15.0 μg/m^3	Annual mean, averaged over 3 years
	Primary and Secondary	24 hours	35 μg/m^3	98th percentile, averaged over 3 years
PM_{10}	Primary and Secondary	24 hours	150 μg/m^3	Not to be exceeded more than once per year on average over 3 years
Sulfur Dioxide (SO_2)	Primary	1 hour	75 ppb	99th percentile of 1-hour daily maximum concentrations, averaged over 3 years
	Secondary	3 hours	0.5 ppm	Not to be exceeded more than once per year

* The level of the annual NO_2 standard is 0.053 ppm. It is shown here in terms of ppb for the purposes of clearer comparison to the 1-hour standard level.

Air Filtration Technologies

Filtration technologies available for HVAC (heating, ventilating, and air conditioning) commercial systems can be categorized by filtration of three distinct groups of contaminants of concern: particles, gases, and airborne biological contaminants. It is important to note that some of the prevailing technologies claim to remove or destroy two or all three of these groups simultaneously as the contaminants pass through the system. However, recent articles in ASHRAE Journal[9] suggest that although many claims have been made, some of the technologies require further study to confirm their efficiencies (E_f) and ensure that, over the long term, filtration performance is maintained as originally designed.

When evaluating any technology, consideration must also be given to the potential generation of ozone as either the oxidant performing the chemical conversion or the by-product of the chosen filtration technology. The synergistic effect of gases, for instance, as they are broken down or subjected to ozone is still relatively unknown, particularly over long-term exposure of building occupants. Ozone itself is no longer permissible in many jurisdictions and can be a lung irritant at best, or a carcinogen at high concentrations.

Particulate filtration is well understood and standardized through the ASHRAE Minimum Efficiency Reported Value (MERV) rating system (Table 2). Most often, applications will require a staged filtration approach whereby a MERV 6 (minimum as required by Standard 62.1) will be combined with a MERV 11-12 and finally a MERV 16 or 17. This staged filtration approach provides the most efficient particle removal method since filters retain particulate in their most efficient range down to 0.3 micron as mean particle diameter.

Gas-phase filtration is often used along with particulate filtration, after initial particles have been removed. Gaseous contaminants tend to break through particle filters and can be more readily absorbed through Granular Activated Carbon (GAC) and Potassium Impregnated Alumina (PIA) filters. For outdoor air contaminants a blend of GAC/PIA is recommended in order to ensure adequate absorption of outdoor air pollutants such as hydrocarbons, total volatile organic compounds (TVOCs), sulphur oxides, nitric oxides and ozone. (See Figure 2.) Working with a qualified manufacturer is recommended to get the appropriate blend to remove the identified contaminants.

The technologies described above are most often applied to OA applications, particularly where the IAQ Procedure is implemented because the OA has been deemed unacceptable due to above normal concentration of the offending contaminants as identified by the NAAQS. Enhancing the filtration design may make it possible to reduce the normal OA requirements for dilution or provide assurance that the prescribed OA is acceptable.

[9] Paolo Tronville and Richard Rivers, "New Method for Testing Air Filter Performance," *ASHRAE Journal* (May 2016).

Figure 2 - Combined Particle and Gas Filters

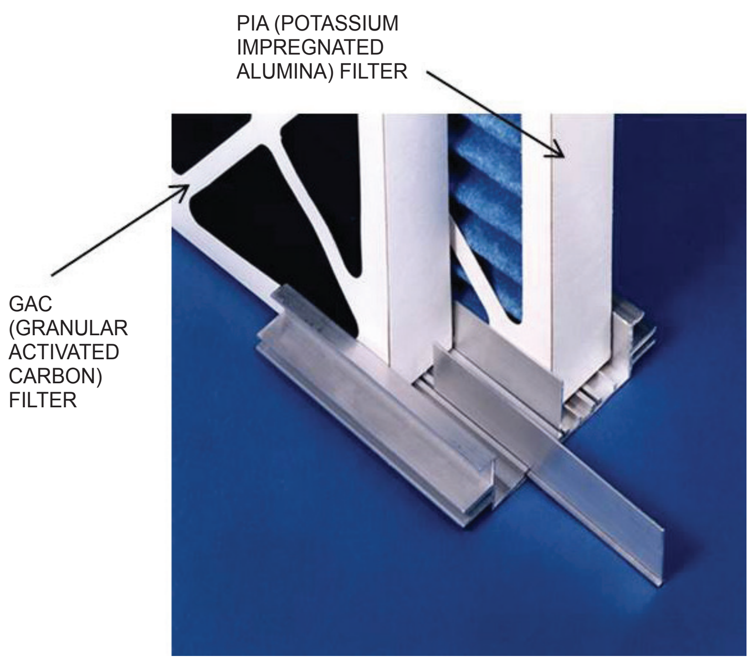
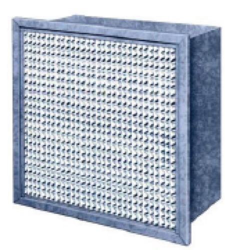


Table 2 – MERV Filter Ratings

MERV	Particle Size	Typical Pollutants	Applications	Filter Types
1	> 10 µm	Pollen, Dust Mites, Sanding Dust	Residential, Light Commercial	Construction, Throwaway
2				
3				
4				
5	3-10 µm	Dust, Molds, Spores	Commercial, Manufacturing	Pleated, Panel Filters
6				
7				
8				
9	1-3 µm	Legionella, Auto Fumes, Welding Dust	Commercial, Industrial	Bag, Cartridge, Mini-Pleat
10				
11				
12				
13	0.1-0.3 µm	Tobacco Smoke, Copier Toner, Bacteria	Commercial, Medical, Industrial	Bag, Cartridge
14				
15				
16				
17	< 0.3 µm	Sea Salt, Carbon Dust, Chemical-Biological, Viruses	Clean Rooms, Surgery, Isolation	HEPA
18				
19				
20				ULPA

HEPA - High-Efficiency Particulate Air
MERV - Minimum Efficiency Reported Value
ULPA - Ultra-Low Particulate Air

Pleated
MERV 7



Cartridge
MERV 13

Bag
MERV 16

When addressing internally generated contaminants, the designer must consider the source and the source strength, as well as the categorization (particulate, gas or biological). Biological contaminants are far more significantly present and generated in the indoor environment. The prevalence of colony forming units (CFU) can be measured and consequently addressed with ultra violet germicidal irradiance (UVGI) or other electronic based filters with enough intensity to disturb the DNA of the organism and prevent it from reproducing. It is important to mention that, unlike particles and gases that may challenge a building's IAQ with a fixed concentration, biological contaminants, if left unchecked, can easily multiply and render a facility unsafe for human occupancy within a short period. Moreover, there have been recent incidents of airborne legionella bacteria entering a building through the OA intake.

There are many variations of filtration technologies available to the design engineer (too many to fully describe in this paper). However, Table 3 categorizes the available filtration technologies in their generic forms and lists their limitations and merits. Figures 3 through 5 show examples of filtration assemblies. Since new technologies are emerging continually, ANSI/ASHRAE Standard 62.1 identifies them all generally as "air cleaning devices" and leaves the decision on type and combination to be made by the design engineer and the local authority having jurisdiction (AHJ) for the project.

Table 3 - Filtration Methods

Filtration Technology	Methodology	Advantages	System Limitations
Media filters (MERV 1-16)	Captures particulates	• Simplified installation	• Does not capture gases • Capture efficiency is lower than those of higher MERV rated filters • Pressure drop
HEPA filters (MERV 17-20)	Captures particulates	• Captures particulates with efficiency of 99.97% at 0.3 micron and above	• Does not capture gases • Substantial air resistance through filter media increases ventilation energy use • Typically requires HVAC system modifications • Cost
Anti-microbial filters	Captures particulates and controls the proliferation of microorganisms	• Minimal pressure drop increase • Can replace existing filters or augment HEPA filtration	• Does not capture gases • Destruction of microorganisms is not quantifiable • Unknown effectiveness
Electro-filtration (i.e. electrostatic filters, electrostatic precipitators)	Enhances particulate capture efficiency with electrostatic charge	• Relatively high capture efficiencies (>95%) of particulates • Low pressure drop • Can replace existing filters or augment HEPA filtration	• Does not capture gases • Ozone produced can cause adverse health effects • Require frequent cleaning to maintain efficiency • Electrostatic precipitators have minimal power requirement • Higher cost than media filters
UVGI and media filters	Captures particulates and irradiates microorganisms	• Alters DNA of microorganisms • Well suited for augmenting HEPA filtration systems	• Does not capture gases • May necessitate HVAC system modifications • Cost
Gas sorption and media filters	Captures gaseous and particulate contaminants	• Can capture gaseous contaminants, including VOCs and odors • Adsorbent coated media filters can replace existing filters • Well suited for additional stage in HEPA filtration systems	• Effectiveness depends on sorbent properties • Hybrid systems are costly
Bipolar ionization and media Filters	Captures gaseous and particulate contaminants	• Destroys microorganisms • Can reduce gaseous contaminants, including VOCs and odors • Lower pressure drop relative to gas adsorption/absorption • Well suited for additional stage in HEPA filtration systems	• Possible ozone emission • Effectiveness difficult to measure • Hybrid systems are costly
Photocatalytic oxidation and media filters	Captures particulate contaminants and oxidizes gaseous contaminants, microorganisms	• Destroys microorganisms • Can reduce gaseous contaminants, including VOCs and odors • Well suited for additional stage in HEPA filtration systems • Low pressure drop relative to gas absorption	• Possible ozone emission • Often used in conjunction with gas-phase absorption • Effectiveness relatively unknown • Hybrid systems are costly
Particle control technology (electrostatic and electrodynamic fields combined with particulate filters)	Captures particulates, and possibly other pollutants through coagulation / electromagnetic fields	• High capture efficiencies of particulates • Low pressure drop • Can destroy airborne microorganisms • Can replace existing filters or augment HEPA filtration	• Minimal effect on gases • Particulate capture efficiency can be as high as HEPA filters • May necessitate HVAC system modifications • More costly than media filters

HEPA – High-Efficiency Particulate Air
MERV – Minimum Efficiency Reported Value
UVGI – Ultra Violet Germicidal Irradiance
VOC – Volatile Organic Compounds

LEGIONELLOSIS

Outdoor air intakes can be subjected to numerous types and sources of air contaminants.

Concern typically has been focused on particulate and gas-phase sources, while biological risk often has not been considered. The reliance on the sun's UVC (Ultraviolet irradiance in the "C" bandwidth, often referred to as the "germicide range" which is approximately 240 nm wavelength) during daylight hours is typically considered enough to reduce the CFU's (Colony Forming Units) that are normally much higher in indoor environments.

Recent events in several city centers have highlighted the need for building design engineers to have a better understanding of bacteria that may infiltrate indoor air environments. Legionella bacteria are biological contaminants of concern.

ASHRAE 62.1 dedicates Section 5 – Moisture Management to help identify proper design practice when dealing with moisture-generating equipment in HVAC systems.

Legionella bacteria can cause Legionnaires' disease (LD) resulting in pneumonia and a less severe disease known as Pontiac Fever. As building design engineers, it is important to understand how the transport mechanisms of this contaminant work in order to reduce its negative impact on indoor air quality. Some of the mechanisms to be considered (especially as they relate to the protection of the air distribution system) include the following: how the potentially contaminated water-aerosols can be generated by a system, exposure of a susceptible person to the colonized water, and how the water-aerosol is inhaled or aspirated in the lungs. A better understanding of the complexities surrounding the Legionellosis topic can be found in ANSI/ASHRAE Standard 188-2015, Legionellosis: Risk Management for Building Water Systems.

Figure 3 - Gas Filter and Particle Filtration Assembly

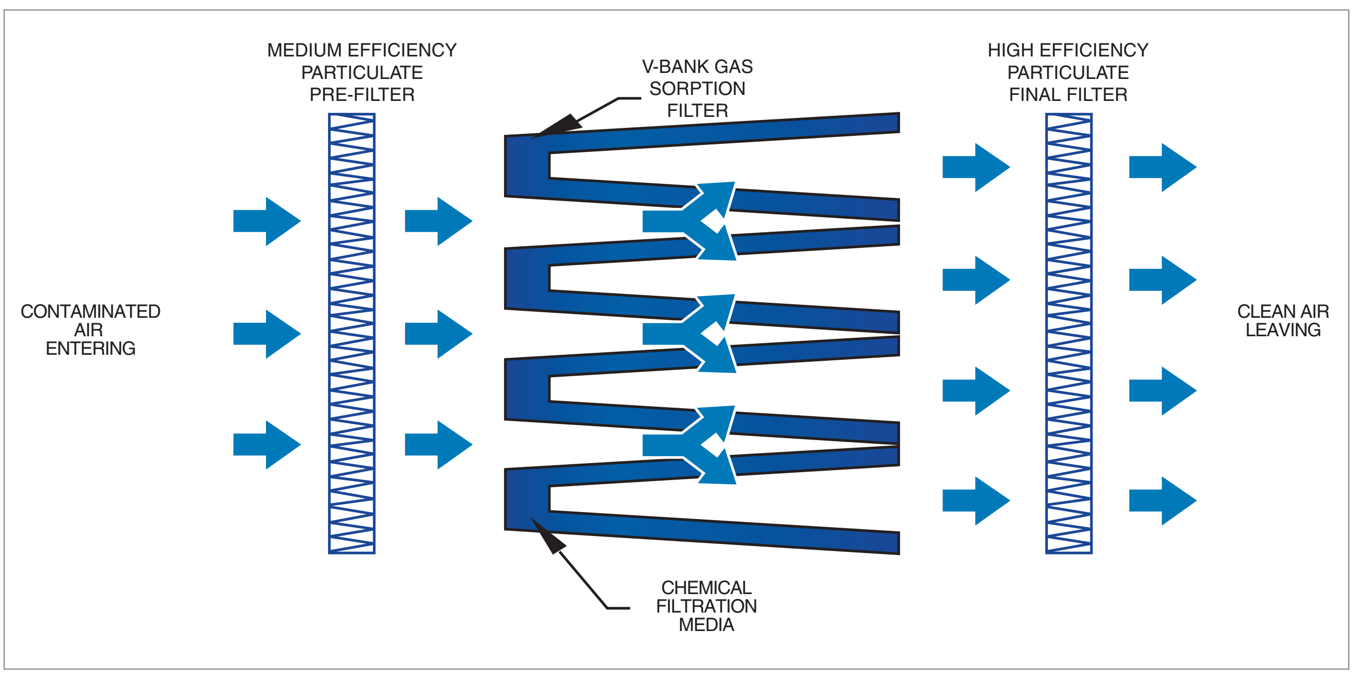


Figure 4 - Typical Particle Filter Assembly in Air-Handling Unit (MERV 16 with Low Leakage Filter Frame)

MERV – Minimum Efficiency Reported Value

HVAC SECURITY

With the many recent occurrences worldwide identified as chemical, biological, radiological, and explosive (CBRE) events, the concept of HVAC security has become a concern of increasing importance to design engineers. Whether such incidents are the result of accidental spill, explosion, or intentional release of airborne agents into a building's outdoor air intake, the effect on building occupants can be detrimental.

The protection of air intake using appropriate filtration can mitigate the effects of an extraordinary event and allow occupants time to evacuate a facility and/or minimize the concentration exposure to the contaminants of concern. In today's design climate, in addition to providing the appropriate filtration technology to reduce the effects of outdoor air contaminants, engineers must also consider the positioning of the OA intake to ensure that it is protected from pollutant sources or tampering. The OA intake should be positioned in a secure location on a building rooftop or mid-point several stories above street level in order to reduce the risk of introducing contaminants into the occupied space.

Initial CBRE considerations have been addressed by a multidisciplinary group outlining ASHRAE's "Report of Presidential Ad Hoc Committee for Building Health and Safety under Extraordinary Incidents." Outdoor air systems that are designed for shelter-in-place protection protocol, as opposed to evacuation, require more advanced filtration strategies that are not addressed in this newsletter but can be found in ASHRAE's 2015 HVAC APPLICATIONS Handbook, Chapter 59 "HVAC Security."

ASHRAE Standard 62.1 Indoor Air Quality Procedure

The Indoor Air Quality Procedure provides a direct control solution for indoor pollutants by enabling the designer to adjust the amount of OA and complement the HVAC system with appropriate air cleaning technologies as previously discussed. The goal of the IAQ procedure is to provide the designer with a mass balance formulation to achieve contaminant concentrations within the occupied space that are below acceptable prescribed thresholds. As noted above, the ultimate goal is the selection of a combined filtration approach, whereby particles, gases and biological contaminants are reduced and controlled. If the OA is deemed unacceptable based on the prevailing guidelines such as NAAQS, then introducing OA without filtration assistance would potentially aggravate the indoor air environment and defeat the purpose of the OA requirement.

The baseline formulation is outlined as:

$$C_S = \frac{N + E_V V_O C_O}{E_V(V_O + R V_r E_f)}$$

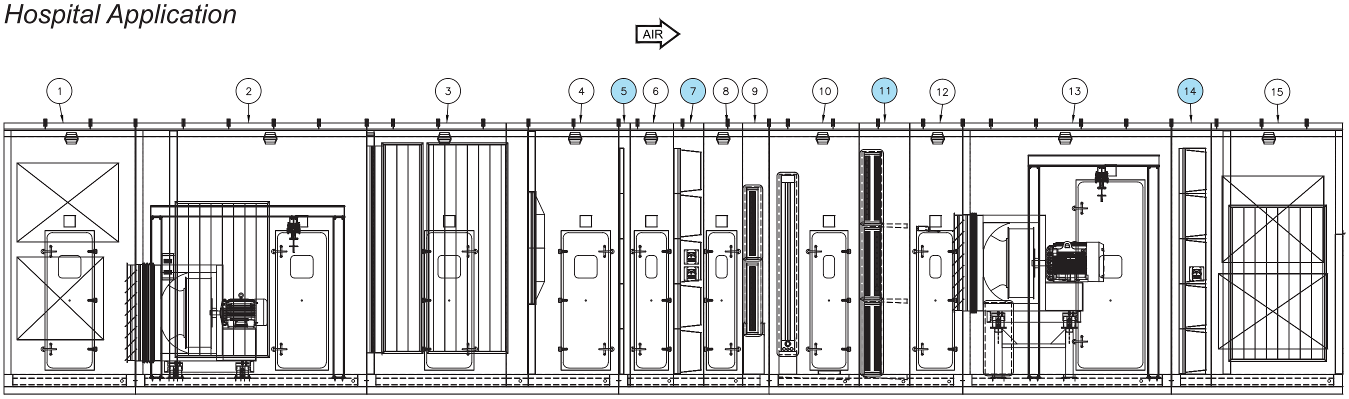
The variables used in this equation are defined as follows:

- C_S: Space contaminant sum concentration*
- C_O: Contaminant concentration in outdoor air
- E_V: Ventilation effectiveness
- E_f: Efficiency of filter for contaminant
- N: Contaminant generation rate in the space
- R: Recirculation flow factor
- V_r: Volumetric flow of return air
- V_O: Volumetric flow of outdoor air

*See ACGIH (American Conference of Governmental Industrial Hygienists) formula on the next page.

Depending on the application, the type of ventilation system design, and whether the system is Variable Air Volume or Constant Volume, the prescribed formula will vary slightly as it pertains to evaluating C_S, "Space Contaminant Concentration." Standard 62.1 provides an equation for each type of airflow application, e.g. variable air volume system with constant outdoor airflow. The formulation above uses the appropriate equation for a constant volume system with constant outdoor airflow, which is the baseline formulation.

Figure 5 - Staged Filtration in Custom Air-Handling Unit for Hospital Application



LEGEND

1 – Return Air Intake Plenum
2 – Return Fans
3 – Mixing Box
4 – Air Mixer
5 – Pre-Filters (2-in. MERV 7)
6 – Access Section
7 – Final Filters (12-in. MERV 14)
8 – Access Section
9 – Heating Coil
10 – Humidifier
11 – Cooling Coils with UVGI
12 – Access Section
13 – Supply Fans
14 – Carbon Filters (12-in.)
15 – Supply Air Discharge Plenum

MERV – Minimum Efficiency Reported Value
UVGI – Ultra Violet Germicidal Irradiance

Note that the use of the IAQ Procedure has been difficult to implement since it requires much more information upfront to successfully model the occupied space than the Ventilation Rate Procedure in Standard 62.1. In particular, it is often difficult to identify the Contaminant Generation Rate "N," as it must include all sources as a sum concentration. The American Conference of Governmental Industrial Hygienists (ACGIH) identifies the sum and the corresponding Threshold Limit Values of such pollutants in the formula below:[10]

$$\frac{C_1}{T_1} + \frac{C_2}{T_2} + \cdots + \frac{C_n}{T_n} \leq 1$$

where

C_i = the airborne concentration of the substance

T_i = the threshold limit value of that substance

Once the appropriate volume of OA is determined and the appropriate air-cleaning technology chosen with its respective efficiency as identified by E_f, locating the filtration modules is critical. Too often, the air cleaning technology is located in an area where maintenance and performance testing is impractical. The designer should consider accessibility for monitoring, maintenance, and testing feasibility. Since the building's mechanical room provides these features, the best location for the entire filtration assembly is often in the air-handling unit (AHU).

Contaminant control design considerations

Similar to a building thermal load analysis, contaminant concentration analysis is usually accomplished as a block load assessment for the entire building and/or by zone. Standard 62.1 refers to the "breathing zone" within the occupied space or C_{bz} (concentration of contaminants residing in the breathing zone region of the occupied space).

In order to properly control offending contaminants, the designer should assess the air quality for all potential or existing contaminants. Consideration should be in the following order:[11]

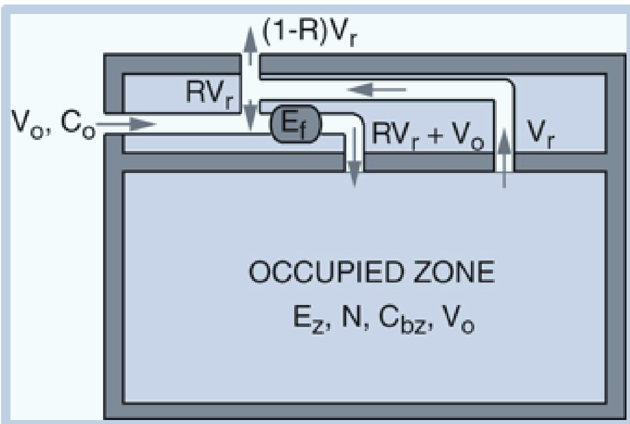
1. Identify all contaminants of concern, keeping in mind that individual contaminants may have a synergistic effect on one another within a mixture, once introduced into the occupied space.
2. Identify the nature/source of each pollutant (particle, gas, or biological) and establish each contaminant's relative maximum concentration during the occupied hours of the building. Some OA pollutants are only problematic during peak traffic times within a building's daily cycle, while indoor pollutants may increase in generation rate throughout the day.
3. Assess each contaminant's maximum permissible concentration (using NAAQS and ACGIH formula) as compared to either measureable or estimated maximum concentrations within the zone(s) daily life cycle.
4. Apply the mass balance formulation considering all previously identified indoor and outdoor pollutant sources.
5. An IAQ design can often result in problematic zones being treated with appropriate air cleaners, as noted as $\mathbf{E_f}$ in the below diagram. In order to effectively reduce the breathing zone contaminant concentration, problematic zones may have multiple staged filtration systems applied in either the OA, return air (RA) or supply air (SA) ductwork. It is common to see the air cleaning technology installed in areas where accessibility for maintenance purposes is easiest, usually the AHU.
6. Not all zones may require applied filtration under the IAQ Procedure, and, in some cases, non-problematic zones can be designed under the Ventilation Rate Procedure, provided the breathing zone is acceptable.

[10] ACGIH, "Mixtures-Dilution Ventilation for Health," in *Industrial Ventilation: A Manual of Recommended Practice,* ACGIH. (21st Edition).

[11] Dennis Stanke, "Minimum Outdoor Airflow Using the IAQ Procedure," *ASHRAE Journal* (June 2012).

Custom Air-Handling Unit with High-Efficiency Filters

In the below equation, the IAQ Procedure considers concentrations in the breathing zone (C_{bz}) with appropriate filtration (E_f). The breathing zone is the area in which we need to focus our IAQ efforts, similar to the way in which temperature stratification in high ceiling areas might be ignored when planning thermal conditioning. The same approach is taken with respect to contaminants. The designer might choose to effectively limit the targeted cleaner air to the occupied space while allowing mild pollutant escalation in the upper ceiling levels that are beyond 7 ft.



$$C_{bz} = \frac{N + E_v V_o (1 - E_f) \cdot C_o}{E_v (V_o + R V_r E_f)}$$

The variables used in this equation are defined as follows:

- C_{bz}: Breathing zone contaminant concentration
- C_o: Contaminant concentration in outdoor air
- E_z: Ventilation effectiveness in zone
- E_f: Efficiency of filter for contaminant
- N: Contaminant generation rate
- R: Recirculation flow factor
- V_r: Volumetric flow of return air
- V_o: Volumetric flow of outdoor air

Conclusion

The improvement of indoor air quality for a building's zone(s) can be effectively achieved at the initial design stage or at any time during a building's life cycle when the potential introduction of harmful pollutants exists. ASHRAE Standard 62.1 provides an effective guideline for the designer to navigate through a building's airborne pollution control requirements. Outdoor air normally established for dilution, in combination with filtration, can effectively control offending contaminants that are deemed to exist in the OA or occupied space. When air purification technologies are appropriately selected and located within air-handling systems, these technologies can provide a significant improvement to the building's overall IAQ and their cost can be justified with the promotion of high-performance building concepts.

Maintaining acceptable IAQ for a building is a continuous effort. Similar to a building's heating/cooling load fluctuations during the day or season, the contaminant profile will vary as outdoor air pollutants and building occupancy fluctuates during the course of the day. In the above, we have considered how to assess a building's IAQ under maximum permissible guidelines during an assumed peak occupancy within the breathing zone – occupied space. It is understood that a building will be under part load conditions thermally for most of its life cycle. Similarly, a building contaminant profile will not always require maximum established OA or filtration and filter life expectancy can be extended depending on contaminant concentrations and duration.

Building commissioning, performance testing, and maintenance play important roles in ensuring that the selected filtration technologies perform at intended levels throughout their life cycles. Additionally, air cleaning technologies should be tested regularly to ensure that long-term performance has not been compromised and that other unexpected contaminants are not present or are filtered or diluted appropriately. It is strongly recommended that long-term performance be measured and documented. Implementation of a high-performance building monitoring program will help achieve the IAQ goals for the building as part of a total IEQ strategy.

Carrier's line of custom and semi-custom air-handling units offer highly efficient filtration options, are equipped with the technology to control air quality, and can be designed to meet specific requirements for healthcare, pharmaceutical, and data center applications.

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