Camfil Farr

Technical Services Bulletin

Air Filtration for Improved Indoor Air Quality Using Air Filters as a Substitute for Ventilation Air

This bulletin supplies information for mechanical system designers to apply a method of air cleaning consistent with using filtration to achieve air quality equivalent to "100% outdoor air". The concept was first introduced in *ASHRAE Standard 62-1981*, carried forth in *ASHRAE Standard 62-1989*, and continues in *ASHRAE Standard 62-1999, Ventilation Standard for Acceptable Indoor Air Quality*[1].

Indoor Air Quality

In our society it has been estimated that we spend up to 90% of our time indoors. EPA[2] studies of human exposure to air pollutants indicate that indoor air levels of many pollutants may be 2-5 times, and occasionally, more than 100 times higher than outdoor levels. Over the past several decades, our exposure to indoor air pollutants is believed to have increased due to a variety of factors, including the construction of more tightly sealed buildings, reduced ventilation rates to save energy, the use of synthetic building materials and furnishings, and the use of chemically formulated personal care products, pesticides, and cleaners.

At the same time the composition of outside air has changed. Society has done a wonderful job of cleaning the outside air of industrial level pollutants (larger contaminants). However, our affinity to improve technologies, move more people faster, and create new composites, has exploded the levels of sub-micron and gaseous additives to atmospheric air.

The EPA publishes limits for outdoor air pollutants. Defined as the *National Primary Ambient-Air Quality Standards* (NAAQS) (PM 10), these values should be examined when a design engineer plans on using ventilation air as the primary method of providing proper indoor air quality or designing for outside air as part of the overall air quality equation..

National Primary Ambient-Air Quality Standards

Contaminant	Long Term Concentration Averaging			Short-term Concentration Averaging		
	μg/m³	ppm	Time period	μg/m³	ppm	Time period
Sulfur dioxide	80	0.03	1 year	365[a]	0.14[a]	24 hours
Total particulate	50[b]		1 year	150[a]	------	24 hours
Carbon monoxide				40,000[a]	35[a]	1 hour
Carbon monoxide				10,000[a]	9[a]	8 hours
Oxidants (ozone)				235[c]	0.12[c]	1 hour
Nitrogen dioxide	100	0.055	1 year			
Lead	1.5		3 months[d]			

Ventilation air, introduced through a mechanical system to provide an acceptable indoor air environment, should meet the criteria in the NAAQS in that of the listed values none of the contaminants should exceed published levels. The parameters as published are also the minimum levels to clean the return air before it may be recirculated through the building

Unfortunately many areas of the country cannot meet this criterion. To determine whether the locale wherein your systems will operate meets the criteria please consult the annual report, *National Air Quality and Emissions Trends* as published by *United States Environmental Protection Agency*.

[a] Not to be exceeded more than once per year.
[b] Arithmetic Mean (average)
[c] Standard is attained when expected number of days per calendar year with maximum hourly average concentrations above 0.12 ppm (235 μg/m³) is equal or less than 1, as determined by Appendix H to subchapter C, 40 CFR 50
[d] Three-month period is a calendar quarter

Of the NAAQS pollutants, ozone continues to be the most pervasive air pollutant in the United States. Ambient ozone is formed through complex chemical reactions that are stimulated by sunlight and temperature. Peak levels occur primarily in metropolitan areas and during the warmer seasons. Ozone concentrations at outdoor air intakes can be determined from the outdoor air, since there are no other local sources. Ozone is a gaseous contaminant and may be addressed through the use of carbon filtration.

Both nitrogen dioxide and sulfur dioxide occur primarily on a localized basis. Elevated nitrogen dioxide can be found in indoor air because of poorly located outdoor air intakes which draw air from parking garages, loading docks and vehicular traffic. The primary local sources for sulfur dioxide are power plants and waste treatment facilities. Therefore, sulfur dioxide is not a common air pollutant for most commercial building applications. Different forms of filtration may address these pollutants.

Particulate, under the NAAQS, is measured in micrograms per cubic meter ($\mu g/m^3$). Using this parameter, particulate may reach elevated levels in industrial areas, during periods of localized construction, during plant germination seasons, and during other periods wherein larger particles may become airborne. Additionally, there are geographic areas that because of population, industrially generated contaminant, or other factors, may elevate levels of airborne particulate. In most cases this contaminant is easily controlled by the proper selection of ASHRAE grade particulate filters. During the design process these intermittent periods of contaminate generation should be considered. Even intermittent periods factor into the overall indoor air quality equation.

Particulate may also be the most difficult contaminant to classify. An office environment may have anywhere from 300,000 to 1,000,000 particles per cubic foot. Normally our body's natural protection mechanisms filter these particles before they can do any damage. There is consistent evidence that increased levels of fine particulate matter increases the risk of death from all causes and from cardiovascular and respiratory illnesses[3].

We also produce bioeffluents that although non-threatening, can create an uncomfortable perception of indoor air quality. We introduce ventilation air to control these bioeffluents and foster the perception of 'fresh' air. The use of carbon dioxide measurements to evaluate indoor air relates specifically to these bioeffluents. In the appendix of *ASHRAE 62-1999* there is a formula that allows evaluation of indoor air through the use of CO_2. This formula produces a value that is only significant to determining the amount of ventilation air that is being introduced into a building. It is not meant to be a determinant as to whether the facility has proper indoor air quality. If all factors have been considered, and a check-and-balance is required to determine the actual amount of outside ventilation air that is being introduced this formula may be applied. CO_2 levels on their own, may not be indicative of an indoor air quality problem.

As the public recognizes the importance of healthy, comfortable, and productive indoor environments, their awareness and demand for good indoor air quality (IAQ) increases. This demand has resulted in IAQ emerging as a major concern in many working environments. Most of our working environments have significant indoor air pollution sources. These sources include furnishings, occupant activities, housekeeping practices, pesticide applications, and microbial contamination. A factor greatly influencing the effect of these sources and the overall quality of indoor air in offices is the ventilation system design, operation and maintenance. The design engineer must be part of the initial building design process. The engineer must be informed of any unusual contaminant sources that may be outside the realm of the planned environment.

People generally have less control over the indoor environment in their work environments than they do in their homes. This lack of control sometimes results in a psychosomatic view of their environment. As a result, there are large numbers of reported health problems associated with working environments. Indoor air quality, however, is a well-documented and significant problem. A number of illnesses, such as Legionnaire's disease, asthma, hypersensitivity pneumonitis, and humidifier fever, have been directly traced to specific building problems. These are called ***building-related illnesses***. Most of these diseases can be treated; nevertheless, some pose serious health risks and may require prolonged recovery times after leaving the building.

When most of the complainants report relief of these symptoms soon after leaving the building, the phenomenon has been labeled ***sick building syndrome.***

Sometimes, however, building occupants experience symptoms that do not fit the pattern of any particular illness and are difficult to trace to any specific source. People may complain of one or more of the following symptoms: dry or burning mucous membranes in the nose, eyes, and throat; sneezing;

stuffy or runny nose; fatigue or lethargy; headache; dizziness; nausea; irritability and forgetfulness. These symptoms may or may not be related to poor indoor air quality. Poor lighting, noise, vibration, thermal discomfort, and psychological stress may affect perception. The complaints may be localized in a particular room or zone, or may be widespread throughout the building. Diligence in initial design, an adherence to the proper technologies and standards, can eliminate the design engineer, and the HVAC system, from the problem process should difficulties arise.

In the opinion of some *World Health Organization* (WHO) experts, up to 30 percent of new or remodeled buildings worldwide may be the subjects of excessive complaints related to indoor air quality.

Three major reasons for poor indoor air quality in work environments are the presence of indoor air pollution sources; poorly designed, maintained, or operated ventilation systems; and uses of the building that were unanticipated or poorly planned for when the building was designed or renovated.

As with homes, the most important factor influencing indoor air quality is the presence of pollutant sources. Commonly found work environment pollutants and their sources may include environmental tobacco smoke; formaldehyde from pressed wood products; other organics from building materials, carpet, and other furnishings, cleaning materials and activities, restroom air fresheners, paints, adhesives, copying machines, and photography and print shops; biological contaminants from dirty ventilation systems or water-damaged walls, ceilings, and carpets; pesticides from pest management practices; and in older buildings, asbestos from insulating and fire-retardant building supplies.

Formaldehyde in particular, creates many indoor air quality problems. The EPA has classified formaldehyde as a probable human carcinogen. Formaldehyde-based resins are components of finishes, plywood, paneling, fiberboard, and particleboard, all widely employed in construction as building materials (sub-flooring, paneling, etc.) and as components of furniture, cabinets, permanent press fabric, draperies, and other common items.

Airborne formaldehyde acts as an irritant to the conjunctiva and upper and lower respiratory tract. Symptoms are temporary and, depend upon the level and length of exposure. Symptoms may range from burning or tingling sensations in the eyes, the nose, and the throat, to chest tightness and wheezing. Acute, severe reactions to formaldehyde vapor -- which has a distinctive, pungent odor -- may be associated with hypersensitivity. It is estimated that 10 to 20 percent of the U.S. population, including asthmatics, may have hyper reactive airways, which may make them more susceptible to formaldehyde's effects.

Mechanical ventilation systems in large buildings are designed and operated not only to heat and cool the air, but also to draw in and circulate outdoor air. If they are poorly designed, operated, or maintained, ventilation systems can contribute to indoor air problems in several ways. The design engineer must be diligent as to all facets of the HVAC system. There are factors beyond the designers control but care must be forethought to avoid any extraneous future expenses.

For example, problems may arise when, in an effort to save energy, ventilation systems are not used to bring in adequate amounts of outdoor air. Inadequate ventilation also occurs if the air supply and return vents within each room are blocked or placed in such a way that outdoor air does not actually reach the breathing zone of building occupants. Improperly located outdoor air intake vents can also bring in air contaminated with automobile and truck exhaust, boiler emissions, fumes from dumpsters, or air vented from restrooms. Finally, ventilation systems can be a source of indoor pollution themselves by spreading biological contaminants that have multiplied in cooling towers, improperly operating condensate drains, humidifiers, dehumidifiers, air conditioners, or the inside surfaces of ventilation duct work.

We must also be cognizant that indoor air pollutants may be recirculated from other portions of the building used for specialized purposes, such as restaurants, print shops, and dry-cleaning stores. Carbon monoxide and other components of automobile exhaust can be drawn from underground parking garages through stairwells and elevator shafts into office spaces.

In addition, buildings originally designed for one purpose may end up being converted to use as office space. If not properly modified during building renovations, the room partitions and ventilation system can contribute to indoor air quality problems by restricting air re-circulation or by providing an inadequate supply of outdoor air.

Key ASHRAE Definitions

ASHRAE 62-1999, Ventilation Standard for Acceptable Indoor Air Quality, contains many key passages that should be considered during the initial design process.

Key *ASHRAE 62* definitions include:

Acceptable Indoor Air Quality - 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.

Note: The acceptable ratio of dissatisfaction is 1 in 5. ASHRAE recognizes that perception of air quality may be subjective, as is thermal comfort, and publishes this caveat within their Standard. In other words, it may not be possible to please all of the people all of the time.

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, and/or vapors in air.

Note: The air cleaning system must be considered with all components as a whole, evaluating their effectiveness at removing items that may be defined as contaminants.

Occupied 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.

Note: In this publication, we often refer to this as the ***occupied breathing zone***. When considering the importance of indoor air quality, and the possible expense associated with providing such, supplying the proper air to the point where it will service the occupants becomes very important. As an example, air quality at the point of a 12-foot ceiling although important for staining size particles, is not as important as air that is at the breathing level of those occupying a conference room (3-5 feet from the floor).

Respirable Particles - respirable particles are those that penetrate into and are deposited in the nonciliated portion of the lung. Particles greater than 10 micrometers aerodynamic diameter are not respirable.

Note: Various medical authorities point out that the critical particle sizes are in the range of 0.2 to 5 micron in size. In the typical working environment considered in this publication, the mass mean diameter of this range is 0.35 micron.

ASHRAE methods of Obtaining IAQ

ASHRAE 62-1999 prescribes two methods of designing for acceptable indoor air quality.

Ventilation Rate Procedure

Using this method acceptable indoor air quality is achieved by providing ventilation air of the specified **quality and quantity** to the space.

To use this method the designer must first consider the **quality** of the outside air to be introduced. **If the air does not meet the quality levels defined by the NAAQS, than air filtration must be used to remove contaminants to move the air to an acceptable level.** The primary contaminants, based upon *the EPA Trends Report* are particulates and oxidants (ozone). If these concentration averages of these contaminants exceed 50 $\mu g/m^3$, and 0.12 ppm respectively, the air must be filtered before introduction into the HVAC system. These, and other contaminants may be removed at the air intake or through proper filter application at the mixing area of return and outside air.

To obtain the proper **quantity** of outside air please refer to Table 2 as published in *ASHRAE Standard 62-1999*. For quick reference we have included some key facility applications on page 5. The typical office environment requires 20 cfm per person of 'acceptable' outside air if the *Ventilation Rate Procedure* is used. Please note that all criteria published relates to what is considered the 'typical' office environment. In the design process we must ask the proper questions. As an example, if the number of people per 1000 ft^2 is increased, than considerations must be made to increase the outside air introduced accordingly. Please note the increased requirements for high human activity environments. If human metabolism increases, such as it may be in a spectator arena, the human process of skin shedding and releasing bioeffluents is increased. Ventilation air must be adjusted accordingly to address this situation.

The *Ventilation Rate Procedure* is simple, based upon evaluating the outside air and assuring clean air compliance. This procedure requires an increase in the heating/cooling capacity of the HVAC equipment to overcome the additional loads required for heating and cooling the introduction air to comfort temperatures. It requires a larger equipment footprint, resultant in additional plumbing, electrical, ductwork, and structural support. It requires additional energy expenditures to heat and cool the introduced air. It cannot assure proper indoor air quality as well as source capture or application of the *Indoor Air Quality Procedure* (ASHRAE 62-1999).

Partial Listing of Outside Air Requirements per ASHRAE Standard 62-1999

Application	Estimated maximum occupancy of space	Outside cfm/person
Office space	7 per 1000 ft^2	20
Reception Areas	60 per 1000 ft^2	15
Conference rooms	50 per 1000 ft^2	20
Dining rooms	70 per 1000 ft^2	20
Cafeteria	100 per 1000 ft^2	20
Auditoriums	150 per 1000 ft^2	15
Classroom	50 per 1000 ft^2	20
Libraries	70 per 1000 ft^2	15
Laboratories	30 per 1000 ft^2	20
Gymnasiums	30 per 1000 ft^2	20
Bars, cocktail lounges	100 per 1000 ft^2	30
Bars, cocktail lounges	100 per 1000 ft^2	30
Gambling Casinos	120 per 1000 ft^2	30
Spectator arenas	120 per 1000 ft^2	15
Hospital patient rooms	10 per 1000 ft^2	25
Operating suites	20 per 1000 ft^2	30
Medical procedure	20 per 1000 ft^2	15
Recovery & ICU	20 per 1000 ft^2	15
Prison cell	20 per 1000 ft^2	20
Prison guard station	40 per 1000 ft^2	15
Prison dining hall	100 per 1000 ft^2	15
Retail pharmacy	20 per 1000 ft^2	15
Dormitory or hotel sleeping areas	20 per 1000 ft^2	15

Indoor Air Quality Procedure

This procedure achieves acceptable indoor air quality through the control of known and specifiable contaminants.

Based upon Farr Company's original publication and methodology, the *Two-Step design Solution* (developed in accordance with *ASHRAE 62-1989*, the precursor to the existing Standard), this procedure builds upon concepts and successes applied in the last decade.

The two-steps are:

The designer selects the amount of outdoor air required per person to dilute indoor contaminants. The designer decides what portion of the required outside air can be safely substituted with filtered recirculated air.

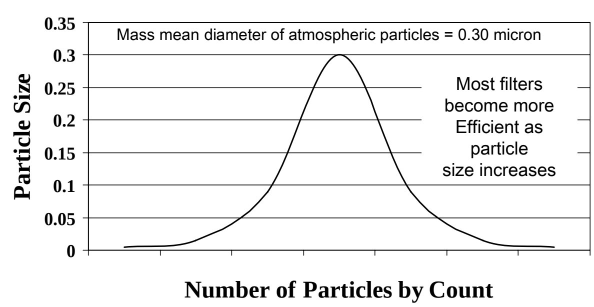
The benefits include:

- Reduced outside air resulting in a lower heating and cooling load, resultant in a reduced capacity requirement for the HVAC equipment
- Reduced energy costs based upon the reduced heating and cooling loads
- Reduced space requirements based upon the smaller footprint of the HVAC equipment
- Reduced initial expenditures for HVAC piping, electrical conduits, and possibly structural support requirements.

Particulate Filtration Considerations

When the typical atmospheric air sample is considered the average diameter of all of the particles by volume is about 0.3 microns[4]. This procedure selects particulate filtration based upon the premise that if a filter's efficiency is selected from the most offending particle size (0.3µ) it will exceed filtration efficiency requirements for other offending particles.

Particle by Count
of Typical Atmospheric Air Sample



The introduction of the new ASHRAE Standard for evaluating filters was a major step in this direction. *Standard 62.2-1999, Method of Testing General Ventilation Air-Cleaning Devices for Removal*

Efficiency by Particle Size, allows the evaluation of a filter for removing respirable size contaminant. The chart on page11of this publication notes some of the commonly referenced filter efficiencies, their new MERV (Minimum Efficiency Reporting Value), and the filter's efficiency at 0.3 micron. Camfil Farr will provide a filter's efficiency at 0.3µ when applying the *Indoor Air Quality Procedure*.

Gaseous Filtration Considerations

To complete the circle of air filtration, gaseous contaminants must be considered. Research has shown that when evaluating all gases of the typical working environment (office space, classrooms, etc.) toluene is representative of the boiling point average of these gaseous contaminants (particularly VOC's, or volatile organic compounds). Camfil Farr will provide gaseous filtration efficiencies based upon toluene when applying the *Indoor Air Quality Procedure*. It's selection follows the same thought pattern as the selection of a filter for the removal of particulate (toluene being representative of other VOCs found in these environments).

An additional caveat to the use of gaseous contaminant filtration is carbon's ability to remove ozone. Ozone is detriment to human health, propagates the oxidation of valuable artifacts, and contributes to the breakdown of building wares and components. Carbon actually incorporates a catalytic reaction with ozone turning the gas O^3 into O^2. Ozone does not use surface area upon the carbon, thus saving these valuable spaces for the adsorption of other contaminants. Camfil Farr carbon product efficiencies for applying the *Indoor Air Quality Method* are on the chart on page 11 of this publication.

Indoor Air Quality Procedure

The First Step: Determining Outdoor Air Requirement

Determine Required Ventilation Rate (page 5)

If polluted outdoor air is introduced for ventilation purposes, it may actually add to the contaminant levels within a building. Thus, an important first consideration is the quality of the outdoor air.

National Ambient Air Quality Standards (NAAQS) as published by the EPA have set both short-term and long-term limits for six pollutants: sulfur dioxide, total particulate, carbon monoxide, ozone, nitrogen dioxide and lead. These standards are equally applicable to indoor air and are found in *ASHRAE Std. 62-1999*.

For the geographic location of design, check the *EPA Trends Report* for data to assure that the area meets the defined requirements for acceptable outside air. The latest version of the document can be obtained at www.epa.gov or please contact your local Camfil Farr Representative or Distributor for the information in the design area. If the air quality meets requirements you may now reference *ASHRAE Standard 62-1999* Table 2 for the amount of outside air to be introduced per person. Apply the outside air load to the heating and air conditioning equipment and design accordingly. Select air filtration modules based upon the recommendations as noted in the *ASHRAE Handbook of Applications*.

To reduce the amount of outside air, for purposes of decreasing equipment load, decreasing operating costs, and assuring proper indoor air quality continue..

Determine Reduced Outside Air Level

Decide upon the actual reduced amount of outside air you would like to use in the system based upon anticipated outside air quality conditions, and the applicable savings that you would like to apply to equipment sizing and equipment operational energy savings.

Camfil Farr does not recommend a reduction of outside air below 5 cfm per person as a failsafe for future building modifications or unanticipated future building use changes.

Based upon these selections we can derive a mass balance equation that uses the following assumption:

1. Temperature and humidity control will occur via equipment placed in a recirculating air mode whose quantity will be independent of the outdoor air required for IAQ purposes alone;
2. There will be no filtration of the recirculation air or the outdoor air;
3. Secondary contaminant removal mechanisms are ignored (infiltration, exfiltration, dust fallout);
4. Only the steady state contaminant level is considered;
5. Ventilation effectiveness is at or near 1 (perfect mixing at the occupied breathing zone)

The drawings on page 9, referencing 100% mixing, show these idealized systems. An outdoor air rate of

V_0, 100% ft^3/min is brought into an occupied space of volume V ft^3. This outdoor air has a concentration C_0 mg/ft^3 of contaminant. The contaminant is also being generated within the space in a net amount of N mg/min.

Because ventilation effectiveness equals 1, all of the incoming outdoor air (and its contaminant C_0V_0, 100%) fully mixes with the contaminant generated within the space. Assuming a steady state concentration C_S in the occupied space, the mass balance on the volume V dictates:
Amount removed = amount added, or;

C_SV_0, 100% = N + C_0V_0, 100% **(EQ 1.0)**

Thus, the breathing zone concentration C_S (and concentration everywhere else in the volume) is:

$$C_S = \frac{N}{V_0, 100\%} + C_0 \qquad \textbf{(EQ 1.1)}$$

And the required outside air to satisfy the breathing zone concentration is:

$$V_0 = \frac{N}{C_S - C_0} \qquad \textbf{(EQ 1.2)}$$

Key Values for Above	
C_0	Concentration of contaminant of the outdoor air intake
C_S	Steady state concentration of contaminant in the occupied space
E_V	Ventilation effectiveness defined as a fraction of supply air delivered to the occupied space
N	Net internal generation rate of contaminant within an occupied space
V_0, 100%	Quantity of 100% outside air required for diluting internally generated contaminants to acceptable levels by dilution alone (no recirculation)

Equation 1.2 is the cornerstone for estimating outdoor air requirements at the design phase by means other than the ventilation rate tables or subjective evaluations of previous similar designs. Its use depends on advance knowledge of contaminant generation rates and concentration levels (C_S) deemed appropriate for good long-term health.

The principal advantage to the Equation 1.2 simplified mass balance is that it permits direct calculation of contaminant concentration levels, independent of recirculation flow and its level of filtration.

This mass balance also forms the basis of the concept of filtration to achieve air quality equivalent to "100 percent outdoor air", which can be applied no matter what method is used to estimate outdoor air ventilation rates.

The Importance of VOC Control

In the modern working environment, VOCs emitted from synthetic building materials and furnishings, office equipment and other sources, are of major concern. There has been considerable debate over VOC levels acceptable for long-term exposure. L. Molhave[5] has suggested a total VOC concentration of 0.16 mg/m^3as having no long-term health effect. Heightened sensitivity because of other factors (such as particulates) may occur between 0.2 and 3 mg/m3. Above 5 mg/m^3 discomfort is expected; and above 25 mg/m3 toxic effects may appear. The Molhave VOC guideline may be the most stringent yet published; His total VOC concentration limit is at least three orders of magnitude lower that threshold limit values (TLVs) of individual compounds considered in an industrial workplace. These analyses have been considered in the Indoor Air Quality method application.

As stated in *ASHRAE 62-1999*, outdoor air requirements specified in the *Ventilation Rate Procedure* apply strictly to buildings with no unusual contaminant sources. If unusual sources are identified or anticipated, the *Indoor Air Quality Method* must be used. Can any of us adequately predict possible additional contaminant sources?

The following studies, by Knoppel & DeBortoli[6], by Morey & Jenkins[7], and by Grot, Persily, Hodgson & Daisey[8], portray the normal VOC concentrations in the typical office building. Based upon these studies, 80-90% of the buildings studied qualified as normal VOC building activity (using 1 mg/m^3 total concentration as the limit). The use of 20 cfm per person outdoor air as specified in the Ventilation Rate Procedure would then be adequate to achieve acceptable VOC concentrations. However, for the remaining 10-20 percent of these buildings (mostly new structure or high occupancy buildings), the Ventilation Rate Procedure would be inadequate to marginal for controlling VOCs.

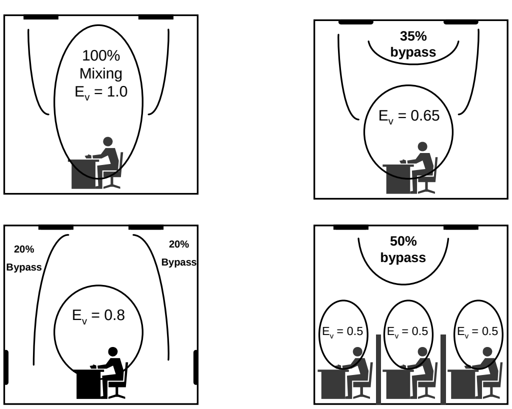
We must also pay special attention to new or renovated buildings where emissions may be high for the first year of occupancy. The design engineer should apply additional prudence to buildings with an inordinate number of contaminant generators, wet-process copiers, and printers, applying a higher ventilation rate than listed in *ASHRAE 62*. If VOC concentrations are known or can be estimated from existing data, the air quality equation (1.2) may be used to determine the required outdoor air.

The Second Step: Using Filtration With Reduced Outside Air

A key factor in determining whether a system will provide proper indoor air quality is the ventilation effectiveness of the air delivery system. A system with proper mixing to the occupied zone approaches a ventilation effectiveness of 1. The following chart provides some examples of ventilation effectiveness based upon supply air location, return air location, and whether there are any obstacles to proper mixing within the space.

There have been studies that most HVAC designs approach a ventilation effectiveness of 1 based upon thermal currents. There have also been studies of sick buildings that note poor ventilation effectiveness as a factor in a defined sick building. Although this is an arbitrary input by the HVAC design engineer there are guidelines to assist in the proper value selection.

There should be additional consideration when designing a variable air volume (VAV) system for supplying conditioned air to the space. Selection of a ventilation effectiveness value of less than 1 creates an allowance for reduced airflows and the possible contaminant build-up associated with the systems ability to remove contaminant. Camfil Farr recommends a minimum value of 0.8 for VAV ventilation effectiveness calculations.



Values will vary with supply rate and temperature.

As a rule of thumb Camfil Farr recommends the following ventilation effectiveness variables:

100% mixing to the occupied breathing zone, (IE: high supply - low returns, supply registered selected for proper throw with system velocities capable of supplying air to the occupied breathing zone)	**E_V = 1**
80% mixing to the occupied breathing zone, (IE: high supply – low returns, standard supply registers, standard system velocities) Minimum VAV system buffer	**E_V = 0.80**
65% mixing to the occupied breathing zone, (IE: high supply – high returns, standard supply registers, standard system velocities) VAV system buffer	**E_V = 0.65**
50% mixing to the occupied breathing zone, (IE: high supply – high returns, standard supply registers, standard system velocities, obstructions to airflows at the breathing zone) VAV system buffer) This level should be considered only if a building retrofit and there is no other method to correct the low level of circulation. It should not be considered for new systems.	**E_V = 0.50**

At this point we need to determine the supply air per person. The supply air per person is the amount of air supplied by the total HVAC system divided by the total number of people that will be supplied by the system.

Now we are ready to apply the parameters developed thus far. We have determined the required outside air to dilute internally generated contaminants, we have determined how much of the outside air we want to substitute with air filtration, we have determined our selection of a ventilation effectiveness value, and we have calculated the supply air per person within the serviced area.

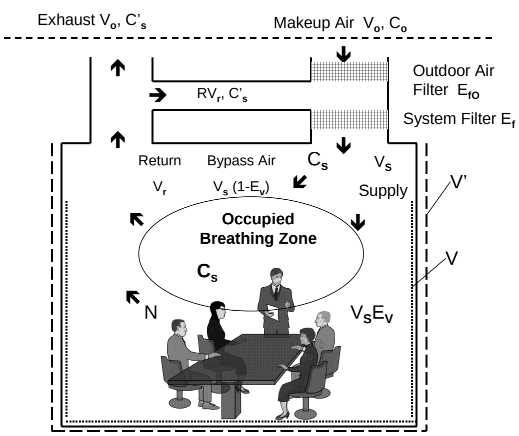
Calculations

The following section provides further theoretical background on using the *Indoor Air Quality Method*. This information may be used should you desire to perform your own calculations. Earlier we presented an equation that would allow calculation of outdoor air requirements at the design stage, based on anticipated contaminant generation rates and concentration levels. It is:

$$V_0 = \frac{N}{C_S - C_0} \qquad \textbf{(EQ 1.2)}$$

This equation applies only to the idealized ventilation system that has a ventilation effectiveness of 1. Since many systems will have parameters that will dictate the selection of a lower value for ventilation effectiveness the following mass balance equations for steady state concentrations apply[9]:

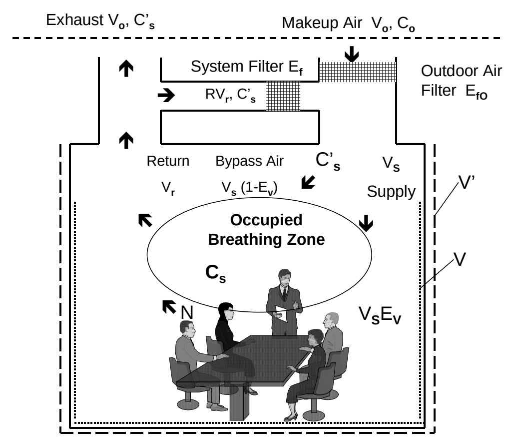
Given the following system (filtration after mixing):



The following formula applies **(Equation 2.0)**:

$$C_S = \frac{KN + C_0V_0\,(1-E_{f,0})}{V_0 + E_f\,(V_S-V_0)}$$

Given the following system (filtration of return air and outside air before mixing:



The following formula applies **(Equation 2.1)**:

$$CS = \frac{KN + C_0V_0\,(1-E_f)\,(1-E_{f,0})}{V_0 + E_f\,(V_S-V_0)}$$

Where **(Equation 2.2)**:

$$K = \frac{(1-E_V)\,(1-E_f)\,(V_0/V_S) + [\,(1-E_V)\,E_f = E_V\}}{E_V}$$

Equation 2.0 is essentially the same as 1.2, but has additional terms to account for ventilation effectiveness, recirculation, and outdoor air filter efficiency. The factor 'K' provides a direct means to account for ventilation effectiveness. It is a function of ventilation effectiveness (E_V), filter efficiency (E_f), and outdoor-to-supply air ratio V_0/V_S. Remember, the ventilation effectiveness is dependent upon the airflow to the conditioned space.

The concentration equations apply separately to each type of contaminant, both particulate and gaseous. The concentration equations also reveal some important facts regarding the role of air cleaning in IAQ control. First, the numerators contain the terms that determine the amount of contaminant added to the occupied space; while the denominators contain the terms that represent what is available for dilution. It is the dilution over which the designer has the most control. Second, the available dilution is the sum of outdoor air plus the product of filter efficiency and recirculation flow rate. If recirculation rates are high (>100cfm per person), even low filtration efficiency (>20%) can produce dilution comparable to typical outside air. And, if recirculation rates are low (<20 cfm per person), very efficient filtration is required to take full advantage of air cleaning.

No matter what method is used to determine the ‘100 percent’ outdoor air requirement, the resulting contaminant concentrations should produce air quality acceptable to occupants. If these contaminant concentrations (Equation 1.1) are set equal to those obtained by using reduced outside air and filtered recirculation (Equation 2.0 with EV = 0), a simple equation can be found. This equation determines the filtration efficiency needed to produce air quality equivalent to ‘100 percent’ outdoor air.

The efficiency equation is (Equation 3.0):

$$E_f = \frac{KV_{0,100\%} - V_{0,\ reduced}}{V_S - V_{0,\ reduced}}$$

Where V_0, reduced is the reduced amount of outside air to be used with filtered recirculation air.

This air quality equivalence concept was introduced in *ASHRAE Standard 62-1981*. Equation 3.0 is identical to that Standard, except for the factor ‘K’.

The equation is exact if outdoor air concentrations are negligible, and calculates higher efficiencies than required if they are not, as $C_0V_{0,100\%}$ is always greater than C_0V_0, reduced. If outdoor air concentrations are ignored (the conservative approach), the equation applies whether filtration is in the recirculated air stream or in the mixed air plenum. As previously noted, it applies equally to particulate and gaseous contaminants.

The equation for K (2.2) may be combined with the above equation for efficiency (Equation 3.1):

$$E_f = \frac{V_{0,100\%}\ [V_{0,reduced}(1-E_V)+E_VV_S\}- E_VV_{0,reduced}\ V_S}{(V_S-V_{0,\ reduced})\{E_VV_S-V_{0,100\%}(1-E_V)\}}$$

Equation 3.1 can be used by selecting:

Ventilation effectiveness (for the type of air delivery system planned) see chart on page 8

The desired level of reduced outside air.

The filter efficiency required to produce air quality equivalent to ‘100 percent’ outdoor air may then be found as a function of supply airflow.

Master Key	
C_0	Concentration of contaminant in outdoor air intake
C_S	Steady state concentration of contaminant in an occupied space
E_f	Efficiency of return or mixed air filter
$E_{f,0}$	Efficiency of outdoor air filter
E_V	Ventilation effectiveness defined as a fraction of supply air delivered to an occupied space
N	Internal generation rate of contaminant within an occupied space
R	Fraction of supply air which is recirculated
V	Occupied breathing zone control volume
V’	Total system control volume
V_0	Outdoor air ventilation rate
$V_{0,\ 100\%}$	Quantity of 100% outsdide air requied for diluting internally generated contaminants to acceptable levelsby dilution alone (no recirculation)
$V_{0,\ reduced}$	Reduced outside air in conjunction with the use of filtered recirculation air (to achieve air quality equivalent to V0,100%
V_r	Return air
V_S	Supply air ventilation rate (the sum of recirculation and outdoor air), equals return air
RV_r	Equal to recirculation flow

It is important to note, if an engineer is applying filtration per the *ASHRAE Applications Handbook,* they most likely are cleaning the air of particulate sufficiently to apply the Indoor Air Quality Method. The only additional consideration is the control of VOCs and ozone.

Camfil Farr provides the software to assist engineers in applying the *Indoor Air Quality Method*. It may be obtained from your local Camfil Farr Representative or downloaded from the Camfil Farr web page at www.camfilfarr.com. With four easy inputs you will be able to design a system that meets current IAQ standards, saves energy, and reduces the footprint of the HVAC equipment.

Camfil Farr ASHRAE Filter Selection Chart

Particulate Filtration

Camfil Farr Product	ASHRAE 52.1-1992 Efficiency	Filter Efficiency @ 0.3 Micron	ASHRAE 52.2-1999 Minimum MERV
20-20	20-25%	<5%	MERV 6
30/30®	25-30%	<5%	MERV 7
Aeropleat®	25-30%	<5%	MERV 6
Riga-Flo® XL	40-45%	5%	MERV 9
Riga-Flo® 15	60-65%	19%	MERV 11
Riga-Flo® 100	80-85%	48%	MERV 13
Riga-Flo® 200	90-95%	75%	MERV 15
Riga-Flo® E65	60-65%	19%	MERV 11
Riga-Flo® E85	80-85%	48%	MERV 13
Riga-Flo® E95	90-95%	75%	MERV 15
Riga-Flo® P65	60-65%	19%	MERV 11
Riga-Flo® P85	80-85%	48%	MERV 13
Riga-Flo® P95	90-95%	75%	MERV 14
Durafil® 60-65%	60-65%	19%	MERV 11
Durafil® 80-85%	80-85%	48%	MERV 13
Durafil® 90-95%	90-95%	75%	MERV 14
Opti-Pac® 65	60-65%	19%	MERV 11
Opti-Pac ® 85	80-85%	48%	MERV 13
Opti-Pac ® 95	90-95%	75%	MERV 14
Aeropac® 65	60-65%	19%	MERV 11
Aeropac® 85	80-85%	48%	MERV 13
Aeropac® 95	90-95%	75%	MERV 14
Hi-Flo® 35-40%	35-40%	<5%	MERV 9
Hi-Flo® 45-50%	45-50%	5%	MERV 10
Hi-Flo® 60-65%	60-65%	19%	MERV 11
Hi-Flo® 80-85%	80-85%	48%	MERV 13
Hi-Flo® 90-95%	90-95%	75%	MERV 14
HP® 2A	25-30%	<5%	MERV 7
HP® 15	60-65%	19%	MERV 11
HP® P85	80-85%	48%	MERV 13
HP® P95	90-95%	75%	MERV 14
Micretain®	99%	95%	MERV 15
Ultra-Pac	99%	95%	MERV 15
Filtra 2000 95 DOP	99%	95%	MERV 15

Carbon Products for Application of the Indoor Air Quality Method

	Initial Ozone Efficiency	Initial Toluene Efficiency
3CF Glide/Pack® for Side-Access Applications	>95%	95%
Riga-Sorb® Glide/Pack® for Side-Access Applications	80%	71%
CF4A Built-up System Modules	>95%	95%
Riga-Sorb® Retainer/Pack Built-up System Modules	80%	71%
Riga-Carb	85%	65%

References

[1] Available from ASHRAE, 1791 Tullie Circle, Atlanta, GA 30329 or at WWW.ASHRAE.ORG.
[2] United States Department of Environmental Protection (www.epa.gov).
[3] Fine Particulate and Air Pollution Mortality in 20 US Cities, 1987-1994, New England Journal of Medicine, Volume 343, Number 24, 24-Dec-2000, additional; The National Morbidity, Mortality, and Air Pollution Study Part I: Methods and Methodologic Issues, Health Effects Institute, Number 94, Part 1, June 2000.
[4] M. K. Owen, D.S. Ensor, L.S. Hovis, W.G. Tucker, & L.E. Sparks, Particles Size Distribution for an Office Aerosol, Aerosol Science & Technology 13; 486-492, 1990.
[5] L. Molhave, Volatile Organic Compounds, Indoor Air Quality and Health, presented at the Fifth International Conference on Indoor Air Quality and Climate, Toronto, Canada, July-August 1990.
[6] Knoppel & DeBortoli, 80 offices in 10 buildings, Total VOC concentrations; 50 percentile at 0.22 mg/m^3, 90 percentile at 0.87 mg/m^3, maximum 3.93 mg/m^3.
[7] Morey & Jenkins, 109 samples in 15 office buildings, 20% exceeded 1.0 mg/m^3, and 6% exceeded 2 mg/m^3.
[8] Grot, Persily, Hodgson, & Daisey, New office building with wet-process copy machines and plotters, At opening, TVOC 5.2 mg/m^3, after 10 weeks, TVOC 1.9 mg/m^3, after 23 weeks, TVOC 11 mg/m^3, after one year TVOC 2.3 mg/m^3, all average concentration in return air.
[9] H.H.Yu & R.R. Raber, Implications of *ASHRAE Standard 62-1989* on Filtration Strategies, Indoor Air Quality, and Energy Conservation, in the Fifth International Conference on Indoor Air Quality and Climate, Vol. 3, pages 121-126, Toronto, Canada, July-August 1990.