Ventilation or Filtration? The Use of Gas-Phase Air Filtration for Compliance with ASHRAE Standard 62

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ABSTRACT

ASHRAE Standard 62, in its current form, employs two procedures to provide acceptable indoor air quality (IAQ) in buildings. These are the *Ventilation Rate* and *Indoor Air Quality (IAQ) Procedures*. This standard further endeavors to achieve the necessary balance between IAQ and energy consumption by specifying minimum ventilation rates *and* IAQ that will be acceptable to human occupants.

The *Ventilation Rate Procedure* provides only an indirect solution for the control of indoor contaminants. While it does allow for the use of cleaned, recirculated air, it does not allow the use of this air to reduce the amount of outdoor air specified in the standard. If this air is to be used to reduce the amount of outdoor air required, or for the implementation of energy conservation measures, the *IAQ Procedure* must be used.

The *IAQ Procedure* provides a direct solution by reducing and controlling the concentrations of air contaminants, through air cleaning, to specified levels. This procedure allows for both quantitative and subjective evaluation of the effectiveness of the air cleaning method(s) employed. The standard acknowledges that air cleaning, along with recirculation, is an effective means for controlling contaminants when using the *IAQ Procedure*. Employing this procedure allows the amount of outside ventilation air to be reduced below standard levels if it can be demonstrated that the resulting air quality meets the required criteria.

More buildings are using, or will be using, gas-phase air filtration as part of their overall design for providing and maintaining acceptable IAQ. This trend is being seen in retrofit applications as well as new construction. Among the driving forces behind this are the increased awareness of people to their environment and how it may affect their well-being, legislative actions that are in effect or have been proposed, and, of course, members of the legal community litigating complaints of sick building syndrome (SBS) and building-related illness (BRI).

This paper will focus on the use of gas-phase air filtration for compliance with ASHRAE Standard 62 by using the *IAQ Procedure*. It will cover the requirements of using this procedure, the information required, and will describe several projects where this procedure was successfully used to realize both acceptable IAQ and energy savings.

FOREWORD

The American Society of Heating, Refrigeration and Air-Conditioning Engineers (ASHRAE) first ventilation standard was ASHRAE Standard 62-73. Under the normal five-year review cycle the standard was revised to ASHRAE 62-1981. In the light of rapidly changing technology, ASHRAE 62-1989, "Ventilation for Acceptable Indoor Air Quality" was approved by the ASHRAE Standards Committee on March 1, 1989 and approved by the Board of Directors on June 29, 1989. The purpose of the standard is to specify minimum ventilation rates and IAQ that will be acceptable to human occupants and are intended to override adverse health effects.

INTRODUCTION

It is assumed that the "best" air is that which is of naturally occurring composition in the absence of any effects of man or man-made processes and in the absence of any natural pollutants. Thus, an idealized air pollution control strategy would attempt to achieve the naturally occurring composition of the air and to remove all pollutants. This is not saying that this level of pollution control is necessary, feasible, or even desirable; rather, that if one could achieve this objective, there would be no further way to improve the air quality.[1]

Indoor air quality (IAQ) is a function of many parameters—including outdoor air quality and the presence of internal sources of contaminants. Indoor air should not contain contaminants in concentrations known to cause discomfort or adverse health effects to occupants. Such contaminants include various gases, vapors, and smoke. These may be present in the makeup air or be introduced through indoor activities, by building materials and furnishings, surface coatings, and even the human occupants themselves.

An important challenge facing today's engineers is how to improve IAQ while at the same time reducing their buildings' energy consumption.[2] Historically, as energy conservation measures have been implemented and energy consumption has decreased, IAQ has suffered. And with the ever-increasing public awareness to IAQ issues, pending IAQ legislation, and the ever-present threat of litigation[3,4], this one-sided trade-off is no longer acceptable.

Fortunately, ventilation standards and mechanical codes have evolved to the point that those currently in place allow building designers/engineers the opportunity to address both IAQ and energy conservation. Paralleling this evolution, air-cleaning technologies have similarly developed to the point that they may be used in conjunction with these standards to provide healthy, comfortable indoor environments while continuing to conserve energy.

ASHRAE STANDARD 62-1989

Prior to the 1960s, the primary concern with regards to IAQ was human comfort. Indoor contaminants were mostly occupant-generated (i.e., body odors, tobacco smoke). Since then, building interiors have been equipped with synthetic furnishings and materials which generate various pollutants, especially significant levels of volatile organic compounds (VOCs). This, coupled with the energy conservation measures implemented in the 1970s, created indoor environments that were, at times, hazardous to human health.[5]

One of the first attempts to establish methods of providing acceptable IAQ was ASHRAE's Standard 62-73, "Standard for Natural and Mechanical Ventilation."[6] This standard provided a prescriptive approach to ventilation by specifying both minimum and recommended outdoor air flow rates to obtain acceptable IAQ for a variety of indoor applications.

The revised Standard 62-1981, "Ventilation for Acceptable Indoor Air Quality,"[7] recommended outdoor air flow rates for smoking and nonsmoking conditions in most occupied spaces. This standard also offered an alternative air quality procedure to allow for the use of innovative energy conservation practices. This procedure allowed for the use of whatever amount of outside air was deemed necessary if it could be shown that the levels of indoor air contaminants could be maintained below recommended limits.

The purpose of Standard 62-1981 was "... to specify minimum ventilation rates and indoor air quality which will be acceptable to human occupants and are intended to minimize the potential for adverse health effects." Acceptable air quality was based upon the premise that "... 80 percent or more of the people exposed do not express dissatisfaction." In addition, acceptable air quality must not contain "known contaminants at harmful concentrations as determined by cognizant authorities." The key words in this definition are "people exposed." Who are the "people exposed" in a particular situation? Are the occupants of a space transient and what is the duration of the "exposure?"

The standard in current form, Standard 62-1989[8], retains these two procedures for ventilation design, i.e., the Ventilation Rate and the *IAQ Procedures*. This standard endeavors to achieve the necessary balance between energy consumption and IAQ by specifying minimum ventilation rates *and* indoor air quality that will be acceptable to human occupants. The classification section (section 4) describes these two alternative procedures specified for obtaining and maintaining acceptable IAQ.

These two procedures are the heart of the new standard. They approach the IAQ problem from different perspectives. The *Ventilation Rate Procedure* defines the rate at which ventilation air must be delivered to a space, as well as various approaches to conditioning that incoming air.

By contrast, the *IAQ Procedure* requires the calculation of the concentration of contaminants of concern in the indoor air, and limiting those contaminants to acceptable levels through dilution by ventilation or filtration.

The *Ventilation Rate Procedure* establishes:

- the minimum outdoor air quality acceptable for use in ventilation systems;

- outdoor air treatment when necessary;
- ventilation rates for residential, commercial, institutional, vehicular, and industrial space;
- criteria for reduction of outdoor air quantities when recirculated air is treated by contaminant removal equipment;
- criteria for variable ventilation when the air volume in the space can be used as a reservoir to dilute contaminants.

It goes on to state that if the outdoor air contaminant levels exceed those listed in the Ambient Air Quality Standards, this air must be treated to control the offending contaminants. For the removal of gases and vapors, appropriate air-cleaning systems should be used. Properly cleaned air may be used for recirculation

The above procedure provides only an indirect solution for the control of indoor contaminants. While it does allow for the use of cleaned, recirculated air, it does not allow using this air to reduce the amount of outdoor air specified in the standard. If this air is to be used to reduce the amount of outdoor air required, or for the implementation of energy conservation measures, the *IAQ Procedure* must be used.

The *IAQ Procedure* provides a direct solution by reducing and controlling the concentrations of contaminants, through air cleaning, to specified acceptable levels. This procedure allows for both quantitative and subjective evaluation of the effectiveness of the air cleaning method(s) employed. The standard acknowledges that air cleaning, along with recirculation, is an effective means for controlling contaminants when using the *IAQ Procedure*. Employing this procedure allows the amount of outside ventilation air to be reduced below standard levels if it can be demonstrated that the resulting air quality meets the required criteria.

It was stated earlier that this standard tries to achieve a balance between energy consumption and IAQ. Whereas the *Ventilation Rate Procedure* focuses primarily on assuring acceptable IAQ, the *IAQ Procedure* is intended to provide a way to reduce HVAC system operating costs while still providing a healthy environment.

The public's increased awareness of IAQ-related issues and their demand to be able to work in a healthy environment, along with building owners' and managers' desires to keep energy consumption to a

minimum, has fostered a growing need for economical and effective solutions. One of these solutions has been the use of air filtration systems. This mitigation measure can provide results similar to those expected through ventilation, i.e., the reduction of airborne contaminant levels. Air filtration can be applied for the reduction of particulate matter, gaseous contaminants, or both. It is the use of air filtration systems for the control of gaseous contaminants that will be the primary focus of the rest of this discussion.

AIR FILTRATION TECHNOLOGY

To understand and appreciate what air filtering systems can and cannot accomplish, one must look at the contaminants to be controlled. Airborne contaminants are divided into three basic types: liquids, solids (particulates), and gases. These contaminants come in a multitude of particle and molecular diameters. Liquid contamination can be most commonly found in the form of vapors and aerosols (i.e.; printing inks, paints, spray cleaners, air fresheners, fungicides, humidifiers), with typical size distribution in the range of 1 to 9 microns.[9] Common solid or particulate contaminants are tobacco smoke, paper and atmospheric dust, asbestos and fibrous particles, and viable particulate matter (e.g.; pollen, bacteria, fungal and plant spores, and viruses). Size distributions for particulate matter typically range from 0.003 to 100 microns. In contrast, gaseous contaminants, such as carbon monoxide and dioxide (CO and CO_2), nitrogen oxides (NO_x), formaldehyde (HCHO), ozone (O_3), ammonia (NH_3), tobacco smoke components, and volatile organic compounds, typically range in size from 0.003 to 0.006 microns.[8]

The most common technologies available to deal with the above sources of contamination are particle removal filtration, such as mechanical filters and electronic air cleaners, and gas-phase, or dry-scrubbing, air filtration.

Particulate Filtration

Filters made of cellulose, fabric, and glass fiber, are the most common types used for particle removal. However, since a majority of indoor air contaminants are submicron in size, it is not surprising that most particulate filter systems, while able to provide basic cleanliness, are mostly ineffective (with the exception of high-efficiency particulate air [HEPA] filtration).

Some air cleaners use the principles of electrostatic precipitation which basically charge particles and capture them on oppositely charged collecting plates. They are fairly efficient against submicron-sized particles but require regular cleaning. Also, these devices, if not installed and maintained properly, may produce ozone, an unwanted and unwelcome chemical irritant.[9] Other types of electronic air cleaners use ionization to positively or negatively charge fine airborne particulates, purportedly making them easier to filter by causing agglomeration into larger particles.

Gas-Phase Air Filtration

The indoor and outdoor environments differ significantly in both the types and levels of gaseous contaminants common to both.[10,11,12,13,14,15,16] Contaminants with sources predominantly outdoors include sulfur dioxide (SO_2), nitrogen dioxide (NO_2), ozone (O_3), and a number of VOCs. Contaminants generated primarily from indoor sources include CO, formaldehyde (HCHO), ammonia (NH_3), acrolein, and a variety of organic chemicals.

Gas-phase air filters based on adsorption and/or chemisorption are available in a variety of commercial designs—usually as packed-bed media filters where the dry, granular gas-phase media is filled in the space between perforated metal or plastic screens. As shown in Figure 1, these include units in which a variety of filter bed types and depths are employed.[13] Many of these type systems are used in tandem with particle removal filters for optimal filtration capabilities. These filters can be installed in side or front-access housings or other standardized equipment. They can also be installed in some self-contained air cleaner units. These filters are available as refillable or disposable units.

As described previously, dry-scrubbing media can be applied in a number of different configurations. These media, regardless of how installed, utilize two main processes used to remove airborne gaseous contaminants. One is a reversible physical process known as adsorption. The other, which involves adsorption and irreversible chemical reaction(s), is termed chemisorption. Each of these processes will be described briefly below.

The most common form of gas-phase filtration is adsorption, and, by definition, adsorption is the process by which one substance is attracted to and held on the surface of another. Adsorption can occur

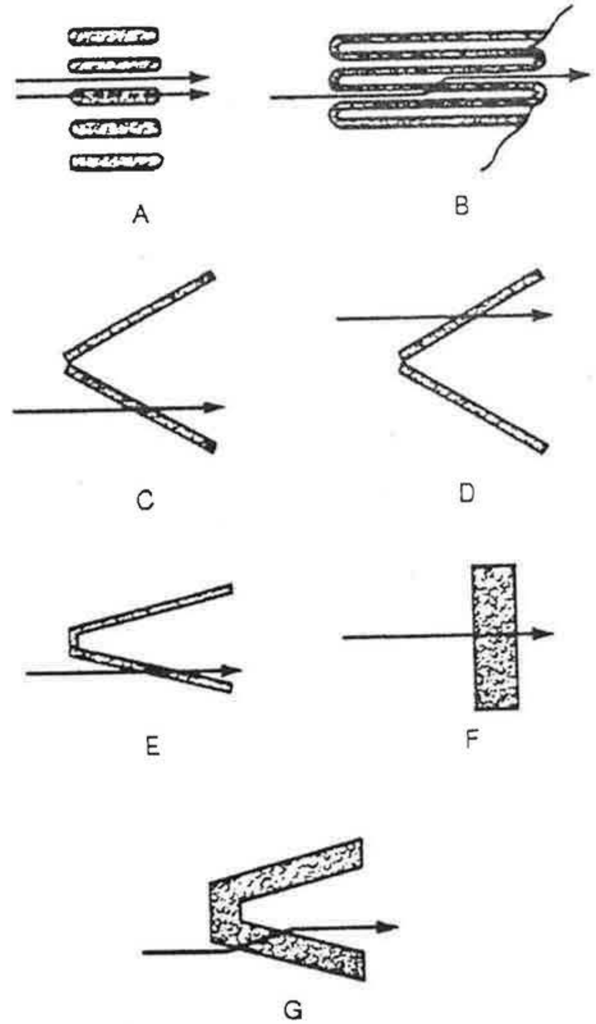

Figure 1. Gas-Phase Air Filtration Equipment Designs

wherever a material has sufficient attractive force to overcome the kinetic energy of a gas molecule. This is evident by the adsorption of cigarette smoke on the interior of an automobile or on a person's clothing.

Adsorption is viewed as a surface phenomenon, and it is well to understand the significance of this statement. The removal capacity of an adsorbent is directly related to its total surface area, and in a porous solid adsorbent, the surface extends well into the interior of the solid. Therefore, it is important to develop as large an accessible surface area per unit volume as possible. Granular activated carbons (GACs) are the most common materials which fulfill this requirement. Other commonly used sorbents include activated aluminas.

Because of the relatively weak forces involved, adsorption is (essentially) totally reversible.[17] Thus the net rate of adsorption depends on the rate at which gas molecules reach the surface of the adsorbent, the percent of those making contact which are adsorbed, and the rate of desorption. However, many other factors can affect removal of gaseous contaminants by physical adsorption. Among these are the type of adsorbent, the resistance to airflow (ΔP) the adsorbent bed depth, the gas velocity, the concentration and characteristics of the contaminant(s) in the space around the adsorbent, the removal efficiency required, and the temperature and relative humidity of the gas stream.

Adsorbent materials do not adsorb all contaminant gases equally.[18,19,20] One way to improve the effectiveness of sorbents for these materials is by the use of various chemical impregnants which react with these "less-adsorbable" gases. These impregnates react (essentially) spontaneously and irreversibly with these gases forming stable chemical compounds which are bound to the media or released into the air as CO_2, water vapor, or some material more readily adsorbed by other adsorbents. Therefore, it is not uncommon to have a gas-phase air filtration system which uses a combination of unimpregnated and chemically impregnated adsorbent media.

In contrast to the reversible process of physical adsorption, chemical adsorption, or chemisorption, is the result of chemical reactions on the surface of the adsorbent. Chemisorption is specific and depends on the chemical nature of both the adsorption media and the contaminants. It is actually a two-stage process. First contaminants are physically adsorbed onto the media. Once adsorbed, they react chemically with the media. The chemical impregnant added to the media makes it more or less specific for a contaminant or group of contaminants. Many of the same factors which affect the removal of gases by physical adsorption also affect their removal by chemisorption.

One of the more broad-spectrum chemical impregnants in common use is potassium permanganate ($KMnO_4$) and is typically used as an impregnant on activated alumina. Potassium permanganate-impregnated alumina (PIA) is often used in conjunction with GAC to provide a very broad-spectrum gas-phase air filtration system.

Just as with other forms of air filtration, there are certain negative aspects of gas-phase air filtration. Particular gases, most importantly carbon monoxide and carbon dioxide, are not controlled. There is an increased cost in energy to overcome higher pressure drops. And when the media are spent, they must be replaced. Fortunately, the energy cost savings realized by using effective gas-phase filtration systems for air recirculation can far exceed the additional costs.

Control Strategies

The three methods of gaseous contaminant control most commonly employed in HVAC systems are source control, ventilation control, and removal control. Source control should always be the first strategy examined. Removing the sources of contaminants prevents them from becoming a problem in the first place. However, the source of gaseous contaminants cannot always be readily identified and, therefore, cannot be removed. Many times the buildings themselves are the greatest sources of gaseous contaminants.

When source control is not feasible or practical, ventilation control should be the next option. Ventilation control involves the introduction of clean dilution air into the affected space. Contaminant levels can thus be reduced below acceptable threshold levels. However, as in source control, this may not prove viable in all cases, either.

Most ventilation air used for dilution would come from outside the building. The degree to which internally generated contaminants are diluted depends on the quantity and quality of ventilation air used. The use of outdoor air alone is the simplest means for providing dilution. However, the use of large amounts of outdoor air to reduce contaminant levels is neither energy-efficient nor cost-effective.

The National Primary Ambient Air Quality Standards[21] (Table 1) represent national goals for permissible outdoor air exposure levels to sulfur dioxide (SO_2), total particulates (PM_{10}), carbon monoxide (CO), ozone (O_3), oxides of nitrogen (NO_x), and lead (Pb). However, in many of our urban environments today, the outside air does not meet this criteria with regards to gaseous contaminants. Therefore, if this air were to be used for ventilation, one would simply be substituting one (group of) contaminant(s) for another and even possibly increasing the total contaminant load in the space. In such cases, the outdoor air would require cleaning to be suitable for dilution of internally generated contaminants.

Table 1. National Primary Ambient-Air Quality Standards for Outdoor Air as set by the U.S. Environmental Protection Agency

Contaminant	Long/short term Concentration µg/m³	Averaging ppm	
Sulfur dioxide	80/365[a]	0.03/0.14[a]	1 yr/24 hr
Particles(PM_{10})	50[b]/-	150[a]/-	1 yr/24 hr
Carbon monoxide	-/40,000'	-/35[a]	-/1 hr
Carbon monoxide	-/10,000[a]	-/9'	-/8 hr
Oxidants (ozone)	-/235[c]	-/0.12[c]	-/1 hr
Nitrogen dioxide	100/235	0.055/0.12	1 yr/-
Lead	1.5/-	-/-	3 mos[d]/-

[a]Not to exceed more than once per year.
[b]Arithmetic mean.
[c]Standard is attained when expected number of days per calendar year with maximum hourly average concentration above 0.12 ppm (235 µg/m³ is equal to or less than one.
[d]Three-month period is a calendar quarter.

If it is clear that neither source nor ventilation control will adequately control the levels of gaseous contaminants in the affected space, removal control should be employed. Gas-phase air filtration systems employing dry-scrubbing filtration media as an integral part of an HVAC system can effectively reduce gaseous contaminants to well below standard levels. The use of gas-phase air filtration in either recirculation or mixed recirculation and outdoor air flows is effective both for controlling the levels of undesirable contaminants and for conserving energy.

MODELING PROCEDURE FOR CLEANED RECIRCULATED AIR

Section 6.2 and Appendix E of the ASHRAE standard describes the *IAQ Procedure* and presents the procedure for the use of cleaned recirculated air, respectively. Basically, the amount of outside air specified in

Table 2 of the standard—15 cfm per person in this application—may be reduced by recirculating air from which offending contaminants have been removed or converted to less objectionable forms. The amount of outside air required depends on the contaminant generation in the space, the contaminant concentrations in the indoor and outdoor air, the filter location, the filter efficiency for the contaminants in question, the ventilation effectiveness, the supply air recirculation rate, and the fraction recirculated.

Figure 2 shows a representative system employing recirculation and filtration. Filters may be located in the recirculated airstream (position A, most common placement for gas-phase air filters) or in the supply (mixed) airstream (position B, most common for particulate air filters). The ventilation effectiveness will depend on the location of the supply outlet, the return inlet, and the design and performance of the supply diffuser. Figure 2 is a schematic of a typical system with the supply outlet and the return inlet in the ceiling. It is possible for some supply air to flow directly from the supply to the return, bypassing the occupied zone of the room. This reduces the effectiveness of the ventilation supplied to the space.

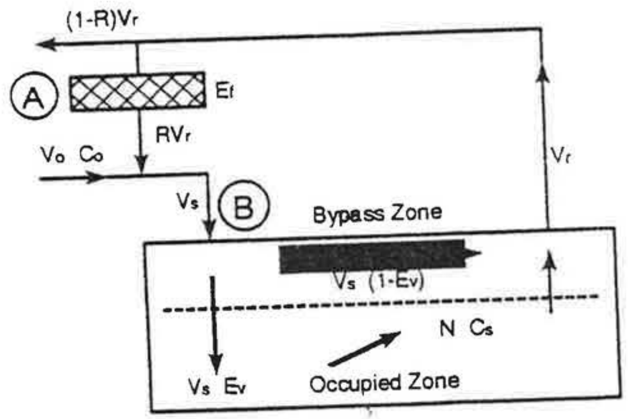

Figure 2. Recirculation and Filtration

V = Volumetric Flow
C = Contaminant Concentration
E = Filter Efficiency or Effectiveness
N = Contaminant Generation Rate
R = Recirculation Flow Factor

f = filter
o = outdoor
r = return
s = supply
v = ventilation

Variable-air-volume (VAV) systems reduce the circulation rate when the thermal load is satisfied. This is accounted for by an additional term, F_r, the flow reduction factor. VAV systems normally have a constant supply air temperature. Constant-volume systems require a variable supply air temperature. VAV systems may also have a constant or proportional outdoor air flow rate.

A mass-balance for the contaminants may be written to determine the space contaminant concentration for the constant-volume system configuration diagramed above.

$$[E_v V_o(1-E_f)C_o] + [E_v R V_r(1-E_f)C_s\} + N = E_v V_r C_s$$

The following equations were taken from Table E-1 of the standard (designated Class II) and are applicable for this system. Their use assumes the following:

- the gas-phase air filtration system will be in position "A" (Figure 2),
- a constant volume system,
- a variable supply air temperature,
- a constant outdoor air flow rate.

(1) $$V_o = \frac{N - (E_v R V_r E_f C_s)}{E_v(C_s - C_o)}$$

(2) $$C_s = \frac{N + (E_v V_o C_o)}{E_v(V_o + R V_r E_f)}$$

(3) $$R V_r = \frac{N + (E_v V_o(C_o - C_s))}{E_v E_f C_s}$$

Equation (1) is for calculating the required outdoor air given the allowable space contamination, Equation (2) for calculating the space contaminant concentration when the outdoor air flow rate is specified, and Equation (3) for determining the required recirculation rate. These three equations are shown above. (The standard lists the seven different system configurations accounting for the various permutations of the air-

handling and distribution systems. Mass balance equations for the six configurations not discussed here are presented in Table E-1.)

Typically, one would want to try and reduce the amount of outdoor air to an allowable minimum to maximize the potential for energy savings. Therefore, Equation 1 would be used with V, being a value less than that prescribed from the *Ventilation Rate Procedure*, but, not in any case, less than 5 cfm/person. Application of the *IAQ Procedure* using Equation (1) requires the following information.

V_o outdoor air ventilation rate, cfm/person—some value between 5 and 15 cfm/person

V_r return air, cfm/person—the total system air flow (cfm) minus the total outdoor air flow (cfm) divided by the total occupancy

C_o contaminant concentration in the outdoor air, mg/ft^3—for those contaminants of concern, i.e., SO_2, NO_2, and O_3

EPA monitoring data for specific locations can provide summaries for outdoor air concentrations of SO_2, NO_2, O_3 and, in some cases, total VOC. The air monitoring data shown below is that which was used for an actual application employing the *IAQ Procedure* (described more fully in the CASE STUDIES (Meyerland Plaza General Cinema section which follows).

Table 2. EPA Ambient Air Quality Monitoring Data for Houston, TX[22]

Gas	Concentration	Location
SO_2	0.00300 ppm (mean)	Croquet Monitoring Station
NO_2	0.01974 ppm (mean)	Avg. for Houston
O_3	0.02300 ppm (mean)	Croquet Monitoring Station
TOTAL	**0.04574 ppm (mean), used for design C_o**	

The total outdoor contaminant concentration, C_o, for these monitoring data would be:

$$C_o = 0.04574 \text{ ppm} = 0.04574 \text{ mg/l}$$
$$= 0.0474 \text{ mg/l} \div 0.03531 \text{ ft}^3\text{/l} = 1.30 \text{ mg/ft}^3$$

C_s total contaminant concentration in supply air, mg/ft^3—for those contaminants of concern; typically includes those from the outdoor air (C_o) along with various VOC. In retrofit applications, air monitoring may be required. For new construction applications, appropriate models may be used until actual air monitoring data becomes available. If contaminant generation rates are known, C, may be calculated directly using Equation (2). These calculated values may be added together and substituted into Equation (1).

N contaminant generation rate, mg/day/person—if actual data is not available, various mathematical models may be used to calculate emission rates from people, furnishings, building materials, etc. and may be used for design purposes.

Various indoor air contaminants may give rise to odors that are of unacceptable intensity or character or that may irritate the eyes, nose, or throat. One factor which affects levels of organic contaminants in a building space are effluents from the human occupants. Such effluents are released from body openings and surfaces. Studies have been performed to correlate the types and concentrations of these contaminants with the presence of humans[22] (Table 3). Significant effects on organic compound concentrations associated with human occupancy have been reported. Both the number and concentration of organic compounds were observed to increase in the presence of humans. Significant increases were observed for acetone and ethanol, both of which are know to be exhaled in human breath. Outdoor air contributes only 5-20 percent of the total indoor VOC concentration. Therefore, it is more appropriate to concentrate on internal sources of VOCs.[5]

If the data from Table 3 are used to determine the generation rate, N, for this particular space, the following value would be obtained (using the "high" value):

$$N = 499.45 \text{ mg/day/person} \div (24 \text{ hr/day} \times 60 \text{ min/hr}) = 0.3468 \text{ mg/min/person}$$

E_r efficiency of the (gas-phase) air filter(s)—provided by the filter manufacturer or through independent testing. For typical packed-bed media configuration used most commonly in commercial applications (1" media bed depth, Fig. 1D & 1F), the default value should not be >85 percent unless specific test data is available. For partial-bypass or impregnated media filters default values should not be >20 percent unless specific test data is available.

Table 3. Average Generation Rates of Organic Bioeffluents in a Lecture Class (389 people at 9:30 a.m.)[23]

Organic Bioeffluent		Generation Rate mg/day/person Lecture Class
Acetone		50.7 ± 27.3
Acetaldehyde		6.2 ± 4.5
Acetic Acid		19.9 ± 2.3
Allyl alcohol		3.6 ± 3.6
Amyl alcohol		21.9 ± 20.8
Butyric acid		44.6 ± 21.5
Diethyl ketone		20.8 ± 11.4
Ethyl acetate		25.4 ± 4.8
Ethyl alcohol		44.7 ± 21.5
Methyl alcohol		74.4 ±5.0
Phenol		9.5 ± 1.5
Toluene		7.4 ± 4.9
Inorganic Bioeffluent		
Ammonia		32.3 ± 5.0
Hydrogen sulfide		2.73 ± 1.32
TOTAL	**228.61 (low)**	**499.45 (high)**

Due to the difference in the contaminant makeup of outdoor versus indoor air, one must be assured that the appropriate dry-scrubbing air filtration media are used. As a general rule, the use of two media granular activated carbon (GAC) and potassium permanganate-impregnated alumina (PIA)—is required to effectively control these contaminants.[19,20]

E_v ventilation effectiveness—the fraction of the outdoor air delivered to the space that reaches the occupied zone. A value of 1.0 indicates perfect mixing. A default value no higher than 0.65-0.75 should be used unless specific data is available.

Filters may be more or less effective against specific contaminants or groups of contaminants. Therefore, when designing a filtration system, consideration must be given to those contaminants for which the system has little or no effectiveness. The amount of outdoor air may only be reduced until some contaminant reaches its maximum acceptable limit.

R return air factor—percent of recirculation air in return air system. Most commonly expressed as RV, or recirculated air.

Example

Using the information data presented above, the following example illustrates how this data may be used to calculate whether a specified (or target) minimum outdoor air requirement can be used for design purposes when using recirculation with filtration.

Design: 8-screen, multiplex theater complex (auditorium # 1), seating capacity of 190 persons[24]
HVAC system: constant air volume
Total supply air: 2900 cfm
V_o = 5 cfm/person (desired outdoor air ventilation rate), 950 cfm total outdoor air volume
V_r = 10.26 cfm/person (2900 cfm - 950 cfm. 190 persons)
C_o = 1.30 mg/ft^3 (using data from Table 2)
C_s = To be calculated
N = 0.3468 mg/min/person (using data from Table 3)
E_f = 0.85 (default for 1" thick packed media filter)
E_v = 75 (using the high default value)

The one value yet to be determined is C_s, the total contaminant concentration in the supply air. Using Equation (2) and substituting the known values, C_s is as follows.

$$C_s = \frac{0.3468\ \text{mg/min/person} + (0.75 \times 5\ \text{cfm/person} \times 1.3\ \text{mg/ft}^2)}{0.75 \times (5\ \text{cfm/person} + (10.26\ \text{cfm/person} \times 0.85))}$$

$$= \frac{5.2218\ \text{mg/min/person}}{10.2844\ \text{cfm/person}}$$

$$= 0.5\ \text{mg/ft}^3 \text{ or } 0.0176\ \text{ppm } (17.6\ \text{ppb})$$

This total space contaminant value is well below any published IAQ action levels by either ASHRAE[8] or OSHA.[25] However, any analysis of the space contaminant concentration should be twofold: first, by the total contaminant concentration for all contaminants *of concern* (as above), and second, by each individual contaminant.

An analysis of C, by individual gas, provides the following:

Contaminant	Space Conc., C_s mg/ft^3	ppm	Standard Levels ppm	
Ozone	0.2246	0.00790	0. 120	EPA
Nitrogen dioxide	0.1928	0.00680	0.006	EPA
Sulfur dioxide	0.0293	0.00100	0.030	EPA
Acetone	0.0037	0.00013	2.950	ASHRAE
Ammonia	0.0020	0.00007	0.718	ASHRAE
Hydrogen sulfide	0.0002	0.00007	0.036	ASHRAE
Phenol	0.0005	0.00002	0.026	ASHRAE
Butyric acid	0.0032	0.00010	N.A.	
Methyl alcohol	0.0038	0.00010	N.A.	

From the above, it has therefore been shown that using 5 cfm/person of outdoor air can reduce the total space contaminant concentration to levels low enough to be well below the published guidelines for these contaminants and provide acceptable IAQ. (It is not necessary to solve for V_o and RV_r in Equations (1) and (3). These are established values used to calculate C, in Equation (2).)

Although organic contaminants are the main sources of odors from humans, carbon dioxide has been widely used as a surrogate indicator of IAQ, due primarily to the fact that it is the contaminant produced by humans in the greatest quantities and it is easily monitored. When using the *Ventilation Rate Procedure,* keeping the level of indoor carbon dioxide below 1,000 ppm has been recommended to satisfy comfort criteria with respect to odors. However, simply controlling the carbon dioxide levels in the space does not guarantee the elimination of IAQ complaints due to odors coming from other contaminants whose sources may be inside or outside the space.

By implementing the *IAQ Procedure* and using n circulation along with gas-phase air filtration, one can directly control those contaminants that are known to be contributing factors to poor IAQ. In this instance, the levels of carbon dioxide do not have to be monitored. This is because carbon dioxide is used as an IAQ indicator only when the types and concentrations of other offending contaminants are not known. Air monitoring, however, must be performed in order to validate the performance of the gas-phase air filtration system. The Design Documentation Procedures (Section 6.3) of the ASHRAE standard state: "*Design criteria and assumptions shall be documented and should be made available for operation of the system within a reasonable time after installation.*" This means that one may use design data obtained from various modeling techniques or other sources as opposed to having to produce data specific to that application prior to system installation and start-up.

CASE STUDIES

Three case studies illustrating the use of gas-phase air filtration to clean and recirculate air within a building will be discussed briefly below. The first two are retrofit applications that involve ASHRAE award-winning buildings. Both have yielded substantial savings through the installation of gas-phase air filtration equipment to recirculate cleaned conditioned air within their environments. The third involves a new construction application in which ASHRAE's *IAQ Procedure* was used on the design phase to reduce the amount of outside air required which, in turn, reduced the size of the HVAC systems.

VA Medical Center[26]

Concerned about rising HVAC operating costs, the Veterans Administration Medical Center in Cincinnati, Ohio embarked on an aggressive energy conservation program. Built in the 1950s, this 10-story facility is divided into three major zones—North, South, and East Wings—each served by dedicated air-handling system. Under the existing system, 100 percent outside air was used to condition these areas. Having previously proved the effectiveness of gas-phase filtration in an animal laboratory located within the center, the VA pursued this technology further.

For this application, the South Wing was chosen to have its exhaust air filtered and recirculated on the basis of several factors: the general system layout (proximity of exhaust air ducts to supply air intakes), energy usage, and zone use characteristics. The 26,000 cfm delivered to this zone is split between patient rooms (~70 percent), general support areas (~20 percent), and restrooms (~10 percent). This air was conditioned, circulated, and exhausted at the roof. By cleaning and recirculating 22,000 cfm, or 85 percent of the air previously exhausted, the hospital realized substantial energy savings (Table 4).

Table 4. Exhaust Air Recirculation Cost/Benefit Analysis, VA Medical Center, Cincinnati, OH

Exhaust Air Cleaned & Recirculated	22,000 cfm
Refrigeration Ton Hours Saved	91,216 ton-hr/yr
Heating Fuel Saved	59,923 therms/yr
Humidification Fuel Saved	10,973 therms/yr
Annual Operating Cost and Savings	
Cooling Cost Saved	$4,925.68
Water and Chemical Cost Saved	$0.00
Heating Cost Saved	$47,938.18
Humidification Cost Saved	$8,778.11
Extra Fan Energy Cost	-$431.31
Purafil Media & Labor Cost	-$3,900.00
Net Operating Cost Savings	$57,311.00
Capital Investment Cost and Savings	
Chiller Capacity Reduction	72 tons
Boiler Capacity Reduction	2,163 MBtuh
Chiller Cost Savings	$0.00
Boiler Cost Savings	$0.00
Other Capital Savings	$0.00
Purafil Equipment (less media) Cost	-$13,000.00
Extra Ductwork Cost	-$1,400.00
Extra Controls Cost	-$2,600.00
Net Capital Savings (Cost if Negative)	-$16,900.00
Simple Payback	**0.29 years**

Today, the conditioned air from this zone is no longer exhausted but is mixed with 4,000 cfm of outside supply air and then routed through the gas-phase filtration system. The gas filter system consists of a particulate prefilter stage, a single stage of gas-phase air filtration medium, and a final particulate filter stage. The net effect is improved particulate filtration with the added benefit of gaseous contaminant control.

Annual energy operating savings are impressive. Due to the geographic location, the primary benefit is from heating cost saved: almost $48,000 annually. Even adding in the costs of the gas-filter medium and replacement labor, the extra fan energy cost required to overcome the additional pressure drop of the system (particulate and gas filters), net annual operating savings were projected to be over $57,000 (Table 4).

Since this was a retrofit application, there were no capital equipment savings to realize from downsizing the cooling and heating plant. Upfront capital costs of $16,900 were incurred for the gas-phase filtration system, extra ductwork, and controls. Even with these costs, the projected energy savings indicated the gas-phase filtration system would have a simple payback of 0.29 years.

Westin Peachtree Plaza[27]

The Westin Peachtree Plaza in Atlanta, Georgia, stands 73 stories tall and contains 1,100 guest rooms, nine restaurants and lounges, and two ballrooms. In all, roughly 1,150,000 ft^2 of floor space has to be heated and cooled. Heating and cooling costs for a building of this size, as one might suspect, were tremendous.

In another retrofit application, hotel management, with the help of several consulting/engineering firms, cut HVAC energy costs by $25,000 per year after installing an energy retrofit system that substitutes a mixture of minimum outside air and heated recirculated air for 100 percent outside air. In the retrofit, the conditioned air from each individual room is no longer exhausted through the roof, but is now routed through a gas-phase air filtration air system that removes odors and gaseous contaminants. The system saves more than 14 billion Btus of energy a year, the equivalent of 100,000 gallons of oil, cutting the energy requirements of the original HVAC system by 10 percent.

Yearly energy savings due to the operation of this system were calculated to be as follows:

- Natural gas cost savings $ 3,430.00
- Fuel oil cost savings $13,070 00
- Cooling costs saved $14,020.00
- Water and chemical cost savings $ 970.00
- Total annual savings $31,490.00

- Dry-scrubbing air filtration medium and labor costs -($ 6,000.00)

- Net operating cost savings $25,490.00
- Simple payback 2.74 years

Additionally, the installation of this energy-managed system qualified for the investment tax credit and earned the hotel some tax relief under the government's energy conservation tax clause.

Meyerland Plaza General Cinema[24]

The HVAC equipment for the Meyerland Plaza General Cinema in Houston, TX, an eight-screen, multiplex theater complex, consists of 14 self-contained rooftop electric cooling units with gas heat and dedicated exhaust fans. Each theater, ticket booth, concession stand, projection area, and lobby has its own dedicated unit. Each projector, restroom, and popcorn hood has dedicated exhaust fans. Air from each theater and lobby unit is returned through gas-phase air filtration systems. The outside air was filtered for particulates only. These systems are designed to induce outside air through dampers located in the HVAC units.

Because this was a new construction application, reducing the amount of outside air by using cleaned, recirculated air could offer a significant savings in the purchase of the HVAC equipment. The consulting engineer for this project decided to apply ASHRAE's *IAQ Procedure* to determine if the amount of outside air could be reduced to 5 cfm per person from the 15 cfm per person for this application if he were to use the *Ventilation Rate Procedure*. If possible, this alone would effectively reduce the cooling requirements from 370+ tons to a little more than 200 tons.

Values for all of the parameters listed above were obtained either by measurement, calculation, or from various references, and the final proposal submitted to the City of Houston for review. The proposal was approved as submitted. Because of this, the Meyerland Plaza General

Cinema was able to realize a significant front-end cost avoidance of more than $85,000.00 by downsizing the HVAC equipment. Operating at 5 cfm per person, it was shown that the HVAC systems would cost less initially, and cost less to operate than if the *Ventilation Rate Procedure* was followed. All this while providing acceptable IAQ to the customers.

SUMMARY AND CONCLUSIONS

Improving IAQ is particularly appropriate today. Increased concerns about the quality of indoor air and its economic ramifications are forcing the IAQ issue to be confronted head-on. The possible liabilities of loss of productivity, increased health-related costs, and litigation brought on by poor IAQ have become too great to ignore. Concurrently, engineers are being pressured to conserve energy in light of concerns about rising energy costs and questionable supply reliability, stricter regulations, and the economic environment that demands ever-increasing attention to the bottom line.

As described, a hospital, a hotel, and a multiplex theater complex, each with their own unique HVAC requirements, illustrate how the use of air filtration, and in particular gas-phase air filtration, can be successfully applied to improve and maintain IAQ while reducing the operating costs associated with a building's HVAC system.

The tools are in place. Industry standards, government regulations, technology, utility companies, and consumer awareness have all come together to provide innovative tools and incentives to those who make acceptable IAQ and energy conservation a joint benefit rather than conflicting goals. ASHRAE Standard 62-1989 and gas-phase air filtration technology now enable the engineer to improve IAQ while, at the same time, reducing energy consumption. This is due to a number of factors:

- ASHRAE has exercised jurisdiction over IAQ with Standard 62-1989;
- the prescriptive ventilation rates employed with the *Ventilation Rate Procedure* have apparently worked well, but with obvious limitations;
- the *IAQ Procedure* has theoretical superiority due to its being a contaminant-based procedure;

- selective use of the *IAQ Procedure* might provide practical superiority.

Additionally, many major utility companies, including Consolidated Edison of New York, Boston Edison, Ontario Hydro, and Kansas City Power & Light, have established aggressive programs to help large energy users develop conservation programs and, in most cases, will provide substantial funding to implement these system improvements in existing buildings and new designs. Similar funding is available from building control system suppliers like Honeywell, Johnson Controls, and others.

The need, the guidelines, the technology, and the economic justification are present to merge once disparate goals: IAQ and energy conservation. The means now exist to improve our existing building stock and make tomorrow's buildings even more heathy and energy efficient. The benefits of healthy, efficient buildings are reduced operating costs for the building owner/operator and satisfied tenants.

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