From Modeling to Implementation: Achieving IAQ and Energy Conservation Goals with ASHRAE 62-2001.

Christopher O. Muller, Technical Services Manager
W. Brad M. Stanley, Chemical Engineer

Purafil, Inc., Doraville, Georgia, USA

ABSTRACT

Being able to achieve IAQ goals while reducing energy consumption is one of the more valuable aspects of the application of ASHRAE Standard 62-2001. By meeting the requirements of the IAQ Procedure, one is allowed to take credit for the application of validated air cleaning technologies and reduce the amount of ventilation air that has to be heated and/or cooled.

Revisions to Standard 62 have caused some confusion in its use and the application of energy conservation measures. This paper will review the applicable provisions of the Standard, discuss indoor air quality models in use, and provide examples where the IAQ Procedure has been used as part of an energy conservation program.

INTRODUCTION

Indoor air quality (IAQ) is a function of many parameters - including outdoor air quality and the presence of internal sources of contaminants. 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 today is how to improve and maintain IAQ in buildings while, at the same time, reducing their overall energy consumption. The classic problem of balancing tenant satisfaction and profitable operation increases tremendously when air quality and tenant health concerns are added to the equation. Historically, as energy conservation measures have been implemented, and energy consumption has decreased, IAQ has suffered.

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

One of the first attempts to establish methods of providing acceptable IAQ was ASHRAE's Standard 62-1973, “Standard for Natural and Mechanical Ventilation” [1]. This standard provided a prescriptive approach to ventilation by specifying both minimum and recommended outdoor air flow rates to obtain acceptable IAQ Quality for a variety of indoor applications.

The revised Standard 62-1981, “Ventilation for Acceptable Indoor Air Quality” [2], recommended outdoor airflow 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 deemed necessary if it could be shown that the levels of indoor air contaminants could be maintained below recommended limits.

The third revision of the standard, Standard 62-1989 [3], retained 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 IAQ that will be acceptable to human occupants. These two procedures, however, approached IAQ and energy conservation from different perspectives.

The Ventilation Rate Procedure (VRP) defined the rate at which ventilation air must be delivered to a space, as well as various approaches to conditioning that incoming air. The IAQ Procedure provided a direct solution by reducing and controlling contaminant concentrations through air cleaning to specified acceptable levels. The IAQ Procedure allowed 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.

Standard 62-2001

Previous versions of Standard 62 strived to achieve a balance between energy consumption and IAQ. Whereas the VRP focused primarily on assuring acceptable IAQ, the IAQ Procedure was intended to provide a way to reduce HVAC system operating costs while still providing a healthy environment.

In its current form, ASHRAE Standard 62-2001 [4], limits the applicability of the VRP for energy conservation purposes to the use of recommended ventilation rates and measures other than reducing outside air. This includes efficient location of supply and return air devices, variable ventilation rates based on occupancy indicators, insulation of HVAC system components, subcooling of refrigerants, and other techniques [5,6,7].

The IAQ Procedure provides an alternate, performance-based design approach in which outdoor air intake rates and other system design parameters are based on an analysis of contaminant sources, contaminant concentration targets, and perceived acceptability targets. The IAQ Procedure allows credit to be taken - in the form of a reduction of the outside air intake rate(s) - for controls that remove contaminants or for other design techniques that can be reliably demonstrated to result in indoor contaminant concentrations equal to or lower than those achieved using the VRP. The IAQ Procedure may also be used where the design is intended to attain specific target contaminant concentrations or levels of acceptability of perceived indoor air quality.

The standard acknowledges that air cleaning, along with recirculation, is an effective means for controlling indoor levels of contaminants. Employing the IAQ procedure allows the amount of outside ventilation air to be reduced below levels prescribed by the VRP. And although the VRP 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 Today

A standing committee (SSPC 62.1) was formed in 1991 to revise the 1989 version of the standard. In 1997, the revision process was converted to continuous maintenance, wherein the standard is revised through stand-alone changes or addenda that are reviewed and approved separately.

Ventilation system designs based on the IAQ Procedure will have to comply with the requirements specified in *Addendum h* of Standard 62-2001*. This addendum modifies the IAQ Procedure in Section

[1] Addendum h has been approved for publication by SSPC 62.1 and is waiting final approval by ASHRAE.

6.2 of the standard, as well as some related material in Section 6.1. Specific requirements for compliance are shown here.

- X **Contaminant Sources** - for each contaminant of concern, indoor and outdoor sources shall be identified, and the strength of each source shall be determined.
- X **Contaminant Concentration** - for each contaminant of concern, a target concentration limit and its corresponding exposure period, and an appropriate reference to a cognizant authority, shall be specified.
- X **Perceived Indoor Air Quality** - the criteria to achieve the design level of acceptability shall be specified in terms of the percentage of building occupants and/or visitors expressing satisfaction with perceived indoor air quality.
- X **Design Approaches** - one or a combination of the following design approaches should be selected to determine minimum space and system outdoor airflow rates and all other design parameters deemed relevant.

a. The steady-state equations in Appendix D, which describe the impact of air cleaning on outdoor air and recirculation rates, may be used as part of a mass balance analysis for ventilation systems serving a single space.
b. Design approaches that have proved successful in similar buildings.
c. Approaches validated by contaminant monitoring and subjective occupant evaluations in the completed building.
d. Application of one of the design approaches listed above to specific contaminants and the use of the VRP to address the general aspects of indoor air quality in the space being designed.

- X **Documentation** - when the IAQ Procedure is used, the following information shall be included in the design documentation: the contaminants of concern considered in the design process; the sources and source strengths of the contaminants of concern; the target concentration limits and exposure periods, and the references for these limits; the design approach used to control the contaminants of concern; and the background or justification for this design approach. If the design is based on an approach that has proved successful for similar buildings, the documentation shall include the basis for concluding that the design approach was successful in the other buildings and the basis for concluding that the previous buildings are relevant to the new design. If contaminant monitoring and occupant evaluation are to be used to demonstrate compliance, then the monitoring and evaluation plans shall also be included in the documentation.

APPLICATION OF THE IAQ PROCEDURE

Calculating the contamination concentrations in a space or the required ventilation for a space has been a difficult and confusing part in the application of the IAQ Procedure. Appendix D of the standard offers one method for performing these calculations, but it is limited to the steady-state analysis of a single zone. These equations have been used for many years to calculate contaminant concentrations in a zone and compare them to guideline levels.

The equations provided in Appendix D take into account (among other things) the amount of outdoor air, contaminant generation rate(s), outdoor contaminant concentrations, filter locations and efficiencies, ventilation effectiveness, supply air recirculation rate and the fraction of air that is recirculated.

The U.S. National Institute of Standards and Technology (NIST) has developed another calculation tool. The Indoor Air Quality Design Tool (IAQDT) was developed to aid in contaminant-based design of ventilation systems, such as when using the IAQ Procedure [8]. The IAQDT calculates transient concentrations of contaminants based on the HVAC system configuration and operation. It differs from Appendix D in that it does not assume steady state conditions to exist.

The mathematical model behind the IAQDT is also based on mass balances of a single zone system. It takes into account the amount of outside air, recirculation, total supply air, and infiltration to the space as well as the amount of exhaust, return air, and exfiltration from the space. Air cleaning technologies applied in the HVAC system or in the space can be modeled if efficiencies and flows are determined.

These two methods have been shown to give similar results for a given set of conditions [9]. Although the calculated contaminant concentrations shown in TABLE 1 are very similar, those obtained using the equations in Appendix D can be substantially higher due to the standard's assumption of steady-state conditions based on continuous occupancy and minimum airflows

Table 1. Comparison of Results from IAQDT and Standard 62 Formulas

Contaminant	Maximum Calculated Concentration (Φg/m^3)		Difference
	Standard 62	IAQDT	
Acetone	33.09	33.11	(0.06)%
Ammonia	161.42	152.13	5.76%
Carbon monoxide	3436.81	3291.15	4.24%
Formaldehyde	203.1	203.1	0.00%
Hydrogen sulfide	17.4	17.4	0.00%
Methyl alcohol	46.23	46.23	0.00%
Nitrogen dioxide	3.93	4.00	(1.78)%
Ozone	21.27	21.62	(1.65)%
Phenol	5.94	5.94	0.00%
Sulfur dioxide	0.75	0.76	(1.33)%
TVOC	167.69	167.72	(0.02)%

THE IAQ PROCEDURE AND ENERGY SAVINGS

On the mechanical side, there are several factors that must be known in order to perform IAQ and energy savings calculations. These include the amounts of outside and recirculation air, ventilation efficiency, and filter location. On the contaminant side, there are factors pertaining to geographic location, building use, and air cleaner efficiencies and removal capacities that must be considered.

Energy analysis calculations for a specific building can be performed independently or with a number of commercially available software packages. In either case, basic assumptions must be made pertaining to the building. As above, different geographic locations require the use of several different sets of data (weather data, utility costs, etc.) that can affect the operation and performance of the HVAC system.

Many different applications can be designed using the IAQ Procedure. The most common applications, and those with the greatest potential for capital cost savings and operational cost reductions, involve new construction and renovation. Two such examples will be presented.

Example 1 - New Construction

An engineer applied the IAQ Procedure in a new construction application where air cleaning (filtration) and recirculation would be used in an effort to reduce the outdoor air below the 10 L/s (20 cfm) per person prescribed by the VRP. Input of the appropriate design criteria showed that a reduction to 2.4

L/s (5 cfm) per person would be possible. *This resulted in a much smaller HVAC system being specified for the theater that resulted in an immediate capital savings of US $68,000 for the owner.* The reduction in the amount of outside air also meant that less air would have to be tempered by the HVAC system. *This resulted in an additional operational savings (energy savings – air cleaner media replacement, etc.) of approximately US$15,000/year.* This takes into account an energy cost savings of US $23,000/year (as compared to the VRP) and maintenance and energy costs for the air cleaning system of US$8,000/year.

A mass balance for the contaminants can be written for a number of different HVAC system arrangements. The various permutations of the HVAC system are described in Table D-1 of the standard. These mass balance equation allow one to calculate space contaminant concentration(s), the required amount of outdoor air, or the required recirculation rate.

The HVAC system used in this case supplied a constant volume of supply and outdoor air while varying the temperature to meet comfort criteria. The air cleaning system was located in the recirculation airstream. The data used for the mass balance calculations are shown in TABLE 2. The outdoor air contaminants were obtained from the U.S. Environmental Protection Agency (EPA) Air Quality System (AQS) database [10]. The indoor contaminant generation rates were taken from a study of a college lecture hall [11].

The mass balance equations were used to calculate the space contaminant concentrations and to determine if the resulting space contaminant concentrations would be acceptable using the lower outdoor air quantities. These resulting concentrations were be compared against the EPA's ambient air quality standards [12] for the outdoor air contaminants and against Standard 62's recommendations for acceptable indoor levels of indoor levels of acetone, ammonia, hydrogen sulfide, and phenol. According to the mass balance model used, all contaminants would be below their listed limit values.

Table 2. Calculated space contaminant concentrations for new theater project

Contaminants	Molecular weight	Contaminant generation rate, N mg/(min*person)	Outdoor air contaminant concentration C_o, ppm	Space contaminant concentration C_s, ppm	Limit concentration, ppm
OUTSIDE AIR					
Nitrogen dioxide	46.01	0.0	0.01974	0.00681	0.053[a]
Ozone	48.00	0.0	0.02300	0.00793	0.120[a]
Sulfur dioxide	64.07	0.0	0.00300	0.00103	0.030[a]
BIOEFFLUENTS					
Acetone	58.08	0.0352	0.0	0.00102	2.950[b]
Ammonia	17.03	0.0224	0.0	0.00221	0.718b
Butyric acid	88.10	0.0310	0.0	0.00059	n.a.[c]
Hydrogen sulfide	34.08	0.0019	0.0	0.00009	0.036[b]
Methyl alcohol	32.01	0.0517	0.0	0.00272	n.a.[c]
Phenol	94.11	0.0066	0.0	0.00012	0.026[c]

[a] EPA National Primary Ambient Air Quality Standards [b] ASHRAE Standard 62 [c] Not Available

Example 2 - Renovation Application

An office building built in the mid 1970s was being renovated for a new owner. Applying the current version of Standard 62, the VRP would have meant bringing larger quantities of outdoor air to bring this building up to code. This would have required additional makeup air handlers along with the associated ductwork and controls. *The estimated cost of this upgrade was US $300,000.*

The IAQ Procedure was recommended and a cost/benefit analysis was performed. This would allow the owners maintain their current outdoor air intake rates and avoid the entire upgrade cost. There would be no retrofit or extra hardware requirements to add the additional filtration required.

The application of the IAQ Procedure would cost an additional US$11,000 per year over current operating costs (energy savings of US$11,000/year minus the annual replacement cost of the filters US$21,000). However, this still was more than enough justification for the increased operational costs over current levels. Avoiding the cost to fully upgrade the HVAC system would pay for 28 years of the additional operating cost.

For this renovated office building, the filters were located in the supply air stream contacting both recirculated air and make-up air. A different mass balance model from Appendix D was used for calculation of space contaminant concentrations, however, the results were the same.

For this application, the outdoor air contaminants were taken, as before, from the EPA AQS database. The internally generated bioeffluents were taken from the same classroom study, considering this as a conservatively high generation rate for office spaces. A study that measured levels during installation of office equipment and furniture was used to estimate generation rates for the office building [13]. These levels would be expected to decrease over the life of the building, and were also considered to be conservatively high. All of these parameters as well as resulting contaminant concentrations are shown in TABLE 3. The air cleaners used here were pleated combination particulate / chemical filters. The minimum removal efficiency was expected to be 25% and this value was used in the mass balance calculations.

Table 3. Calculated space contaminant concentrations for office renovation project

Contaminants	Molecular weight	Contaminant generation rate, N mg/(min*person)	Outdoor air contaminant concentration C_o, ppm	Space contaminant concentration C_s, ppm	Limit concentration, ppm
OUTSIDE AIR					
Nitrogen dioxide	46.01	0.0	0.018	0.00187	0.053[a]
Ozone	48.00	0.0	0.150	0.01556	0.120[a]
Sulfur dioxide	64.07	0.0	0.004	0.00041	0.030[a]
BIOEFFLUENTS					
Acetone	58.08	0.054	0.0	0.01480	2.950[b]
Methyl alcohol	32.01	0.055	0.0	0.02735	n.a.[c]
MATERIALS					
TVOC	80	114.7[d]	0.0	0.211	0.3[e]
Formaldehyde	30.03	1.539[d]	0.0	0.00755	0.1[b]

[a] EPA National Primary Ambient Air Quality Standards [b] *ASHRAE Standard* [c] Not Available
[d] Generation rates in mg/min [e] Converted from 1 mg/m^3 target level recommended by EPA [14]

The resulting concentrations in the space were compared with published limit concentrations. Even using the high initial contaminant levels, all resulting levels were shown to be below the corresponding limit concentrations. The total volatile organic compounds (TVOC) and formaldehyde concentrations would be expected to decrease due to change in building materials emission rates over time. Thus these calculations support the assumption of acceptable indoor air quality in this space by directly controlling those contaminants most often implicated as being causes or major contributors to poor IAQ and IAQ complaints.

SUMMARY AND CONCLUSIONS

Whereas the Ventilation Rate Procedure of ASHRAE Standard 62-2001 focuses primarily on assuring acceptable indoor air quality, the IAQ Procedure provides a way to reduce HVAC system operating costs while still providing a healthy environment.

The IAQ Procedure provides an alternate, performance-based design approach in which the building and its ventilation system are designed to maintain the concentrations of specific contaminants at or below certain limits identified during the building design and to achieve the design target level of perceived indoor air quality acceptability by building occupants and/or visitors. It provides a direct solution for reducing and controlling contaminants to specified acceptable levels through air cleaning.

This procedure uses one or more guidelines for the specification of acceptable concentration of certain contaminants in indoor air and allows for both quantitative and subjective evaluation of the effectiveness of air cleaning method(s), but does not prescribe ventilation rates or air cleaning methods.

Both the IAQ Procedure and NIST's IAQDT can be applicable for contaminant based design and provide results that are very similar for a single zone model, with exceptions occurring when transient effects are investigated.

If designing for the worst-case scenario, in terms of calculating the highest indoor contaminant concentrations, either method can be used with constant (always on) generation rates and minimum airflows to derive the steady state concentrations. If one wanted to examine the transient effects of HVAC operation on contaminant concentrations, the IAQDT serves as a good tool to view how contaminant concentrations change with time. ASHRAE's IAQ Procedure is more user friendly, but the IAQDT provides greater design flexibility.

The apparent complexity of the application of the IAQ Procedure is the most common reason given for this method being applied less often. Granted, there are more requirements for assuring compliance with the standard when using the IAQ Procedure, however, one should not ignore the significant capital and operational cost savings possible.

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