providing insights for today's hvac system designer

Engineers Newsletter

volume 40–3

Minimum Outdoor Airflow Using the IAQ Procedure

Past *Engineers Newsletters*[1] and *ASHRAE Journal* articles[2,3] have discussed compliance with the requirements of the Ventilation Rate Procedure (VRP) because most engineers use it, most building codes base minimum outdoor airflow requirements on it, and several energy labeling programs and building rating systems require compliance with it.

This newsletter, however, describes compliance with the Indoor Air Quality Procedure (IAQP) requirements. Although this procedure is not widely used because it requires significant judgment on the part of the designer, nevertheless it deserves a detailed discussion.

ANSI/ASHRAE Standard 62.1-2010[4] includes three alternative procedures for determining minimum outdoor airflow (OA) rates: **the ventilation rate procedure (VRP)**, the **indoor air quality procedure (IAQP)**, and the **natural ventilation procedure (NVP)**.

The VRP prescribes minimum zone-level OA rates and procedures to find system-level OA intake rates. The IAQP allows compliance based on contaminant concentrations and perceived air quality, i.e., based on performance criteria. The NVP prescribes minimum outdoor air openings (not OA rates) for natural (passive) ventilation; in most cases, the NVP must be used in conjunction with either the VRP or the IAQP, since mechanical ventilation must be available whenever passive ventilation is undesirable or ineffective.

Summary of the IAQP

To find the minimum required breathing zone OA rate for each zone using the IAQP, the following steps must be completed (see inset p.3):

1. Identify all contaminants-of-concern and mixtures-of-concern for the zone.* For simplicity we'll refer to all of these as "pollutants."
2. Identify both indoor and outdoor sources for each pollutant.
3. Determine the emission rate for each pollutant from each identified source.
4. Specify a concentration limit for each pollutant.
5. Specify the design limit for perceived IAQ in terms of the minimum percentage of occupants or visitors expressing satisfaction with the air quality in the completed building.
6. Using mass balance calculations, determine the minimum breathing zone OA rate necessary to meet the specified concentration limits for each pollutant.
7. Find the OA rate required to meet the perceived IAQ limit by conducting a subjective evaluation in the completed building or by establishing that the current zone design meets the criteria for a "substantially similar zone" wherein a successful subjective evaluation has been conducted.
8. For each zone, find the minimum breathing zone OA rate—the largest OA rate among those determined by mass balance for each pollutant or the OA rate determined by subjective evaluation—whichever is greater.
9. Finally, find system-level OA intake flow based on the breathing zone OA rate found for each zone.

Standard 62.1 allows designers to apply the IAQP in some zones within a system, and the VRP in other zones, and it requires designers to document design assumptions and calculations, but here we focus on the nine steps listed.

* Although Section 6.3.1 seems to require identification of either contaminants-of-concern OR mixtures-of-concern, most designers logically interpret this as a requirement to identify all contaminants- AND mixtures-of-concern.

Identify contaminants and mixtures of concern. For designers, identifying all pollutants to be considered for a given design represents the first and most important set of judgments. Since the *ASHRAE Handbook*[5] classifies indoor pollutants as either *particulate matter* or *gaseous contaminants*, designers must consider both when identifying contaminants of concern, and they must consider *mixtures* as well to comply with the standard. (See Table 1.)

Particulate matter includes inert particles, biological particles and liquid droplets. There are many sources of particles. Most inert particles and liquid particles originate outdoors. Biological particles originate both indoors and outdoors.

Gaseous contaminants are either organic or inorganic. Like particles, gases originate both indoors and outdoors.

Mixtures of concern are either source related or impact-related. *Source mixtures* (such as diesel exhaust or tobacco smoke) comprise a wide range of contaminants, often both particles and gases, which originate from known sources or processes. *Impact mixtures* comprise a set of particles or gases known to impact the same human organ or system, such as the eyes, the respiratory system or the nervous system. Standard 62.1 doesn't currently make this distinction between source and impact mixtures, although it probably should in the future.

Many contaminants must be considered both as individual contaminants of concern and as constituents of one or more mixtures. Formaldehyde, for example, should be considered as an individual contaminant (since it is a known carcinogen) and as a constituent of one or more impact mixtures (since it has a pungent odor and impacts the respiratory system).

Both indoor and outdoor pollutants must be considered. Although lists of some potential outdoor pollutants[6] and some potential indoor pollutants[7] exist, no complete and widely accepted list of pollutants exists—such a list would vary widely from one project to the next. Even if a comprehensive pollutant list existed, the designer would be required to judge which pollutants apply for each specific zone in each building project.

Table 1. Indoor pollutants

Pollutant category	Type	Examples	Example sources	Impact
particulate matter	solid	dust (less than 100 µm)	wind, volcanoes, grinding, demolition, burning fuels, unpaved roads and so on	asthma, nose and throat irritation, lung damage
		bioaerosols	living things, including viruses, bacteria, fungi, mites, plants and insects	allergies, asthma, various diseases, including tuberculosis, Legionnaire's disease, and influenza
	liquid	mist	cooling towers	evaporation may increase concentration of bioaerosols
		fog	condensation	evaporation may increase concentration of bioaerosols and very small particles
gaseous contaminants	inorganic	ammonia	cleaning products	respiratory irritant
		ozone	electrostatic appliances, printers, copiers, outdoor air	reduced lung function, asthma, eye irritation
		carbon monoxide	incomplete combustion, outdoor air	respiratory system damage
		radon	soil	lung cancer
	organic	formaldehyde	building materials, adhesives, insulation	eye, nose, and throat irritation, asthma, respiratory symptoms
		benzene	burning, automobile exhaust, some glues, paints, and detergents	cancer
		other volatile organic compounds (VOC)	people, processes, cleaning products	odor, wide range of physical symptoms
mixtures	source mixtures	smoke	burning organic material	see particulate matter
		tobacco smoke	burning tobacco	cancer; see particulate matter
		diesel exhaust	diesel fuel combustion	cancer; see particulate matter, inorganic and organic gases
		smog	products of combustion	see ozone and particulate matter
	impact mixtures**	example constituents: acetaldehyde, acrolein, ammonia, etc.	multiple sources	respiratory system impact
		example constituents: arsenic, benzene, carbon disulfide, etc.		nervous system impact
		example constituents: benzene, butadiene, carbon disulfide, etc.		reproductive system impact

**Example impact-mixture categories based on Office of Environmental Health Hazard Assessment (OEHHA) table (see www.oehha.org/air/allrels.html)

It's clear that the most important step in the IAQP—establishing the individual contaminants, source mixtures and impact mixtures of concern—is not easy and requires considerable designer judgment and therefore, risk.

Sources of contaminants. Having established a list of pollutants, the next step is to identify both indoor and outdoor sources of each. Possible indoor sources include people, furnishings, wall coverings, paints, adhesives, ceiling tiles, carpet and so on. Possible outdoor sources include the outdoor air in general (see inset p. 4), motor vehicles, dumpsters, cooling towers and so on.

Each identified source can contribute one or more contaminant, source mixture or impact mixture (or constituent). Although some pollutant emissions data have been established for some indoor products, laboratory measurements are often required to determine the pollutants emitted from specific products.

Since there are so many potential pollutants, identifying even the major sources for each requires a great deal of judgment and is inexact at best. So, like pollutant identification, source identification poses a risk for designers.

Source strength. With a list of all identified sources for each pollutant, source strengths must be determined. All sources for each pollutant must be evaluated so that the total emission rate can be determined to support mass balance calculations. For instance, if formaldehyde has been identified as a contaminant of concern as well as a constituent of an impact mixture, the formaldehyde emission rate from all potential sources must be determined to find the total emission rate in the zone. Emission rates for various contaminants from some products have been established, but for most contaminant sources, source strengths must be determined using appropriate materials-laboratory testing. This can be expensive and time-consuming.

And remember, contaminant sources include people and their activities, so emission rates for people-related pollutants must always be considered.

Establish target concentrations. For each contaminant and each mixture, an acceptable concentration and exposure-time limit must be established. Designers must cite a *cognizant authority* (see inset) as the source for these limits. Acceptable limits for individual contaminants vary among cognizant authorities, so each designer must judge which authority to rely upon.

ASHRAE Handbook[8] states that there are "no established exposure guidelines" for inert particles in nonindustrial indoor environments, so designers tend to rely on the outdoor air limits for particulate matter established by the Environmental Protection Agency (EPA) National Ambient Air Quality Standards (NAAQS). Some biological particles cause diseases such as tuberculosis, so specific exposure limits have been recommended by the National Institute for Occupational Safety and Health (NIOSH) and others.

Exposure limits have been established for many individual gases by various authorities, including NIOSH and the American Council of Industrial Hygienists (ACGIH).

Neither source-mixtures nor impact-mixtures of concern have been addressed directly. Cognizant authorities are not too concerned with concentration limits for most source mixtures—it's much easier to simply keep such mixtures out of the building. However, ACGIH has established a method to limit impact-mixture concentrations based on the threshold limit value (TLV) of the mixture constituents. TLVs have been established for many gaseous constituents of impact-mixtures, so it is often possible for designers to determine valid mixture-related limits.

Cognizant authority

Standard 62.1 defines cognizant authority as "an agency or organization that has the expertise and jurisdiction to establish and regulate concentration limits for airborne contaminants; or an agency or organization that is recognized as authoritative and has the scope and expertise to establish guidelines, limit values, or concentration levels for airborne contaminants."

IAQP requirements

6.3 Indoor Air Quality (IAQ) Procedure. Breathing zone outdoor airflow (V_{bz}) and/or system outdoor air intake flow (V_{ot}) shall be determined in accordance with Sections 6.3.1 through 6.3.5.

6.3.1 Contaminant Sources. Contaminants or mixtures of concern for purposes of the design shall be identified. For each contaminant or mixture of concern, indoor sources (occupants and materials) and outdoor sources shall be identified, and the emission rate for each contaminant of concern from each source shall be determined.

6.3.2 Contaminant Concentration. For each contaminant of concern, a concentration limit and its corresponding exposure period and an appropriate reference to a cognizant authority shall be specified.

6.3.3 Perceived Indoor Air Quality. The design level of indoor air acceptability shall be specified in terms of the percentage of building occupants and/or visitors expressing satisfaction with perceived IAQ.

6.3.4 Design Approach. Zone and system outdoor airflow rates shall be the larger of those determined in accordance with Section 6.3.4.1 and either 6.3.4.2 or 6.3.4.3, based on emission rates, concentration limits, and other relevant design parameters (e.g., air cleaning efficiencies and supply airflow rates).

6.3.4.1 Mass Balance Analysis. Using a steady-state or dynamic mass-balance analysis, determine the minimum outdoor airflow rates required to achieve the concentration limits specified in Section 6.3.2 for each contaminant or mixture of concern within each zone served by the system.

6.3.4.2 Subjective Evaluation. Using a subjective occupant evaluation conducted in the completed building, determine the minimum outdoor airflow rates required to achieve the level of acceptability specified in Section 6.3.3 within each zone served by the system.

6.3.4.3 Similar Zone. The minimum outdoor airflow rates shall be no less than those found in accordance with Section 6.3.4.2 for a substantially similar zone (i.e., in a zone with identical contaminants of concern, concentration limits, air cleaning efficiency, and specified level of acceptability; and with similar contaminant sources and emission rates).

6.3.5 Combined IAQ Procedure and Ventilation Rate Procedure. The IAQ procedure in conjunction with the Ventilation Rate Procedure may be applied to a zone or system. In this case, the Ventilation Rate Procedure shall be used to determine the required zone minimum outdoor airflow, and the IAQ Procedure shall be used to determine the additional outdoor air or air cleaning necessary to achieve the concentration limits of the contaminants of concern.

Some designers use the IAQP while ignoring mixtures altogether. But remember, established limits (TLVs) for many constituents of impact mixtures do exist, so they can be used to satisfy the additivity analysis (see inset) for specific impact mixtures.

If established limits from a cognizant authority cannot be referenced for all building contaminants and impact mixture constituents, then compliance with the IAQP isn't possible. For instance, no acceptable limits for environmental tobacco smoke (ETS) have been or will be established, so designers must either prohibit smoking or establish OA rates for ETS zones using an alternate approach. (Neither the VRP nor the IAQP can be used to find minimum OA rates for ETS zones.)

Impact mixture "additivity."

According to Informative Appendix B, contaminants that act on (impact) the same organ systems should be analyzed, and outdoor air should be provided so that the sum of concentration ratios for the "impact mixture" does not exceed 1.0.

> When many chemicals are present in the air, as they almost always are in indoor air, then some way of addressing potential additive effects is warranted. The ACGIH guidance on the subject instructs that when two or more substances acting on the "...same organ system are present, their combined effect, rather than that of either individually, should be given primary consideration." B-1 Information on affected organs is readily available on the websites of the cited references for ACGIH, OEHHA and ATSDR. If no contradictory information is available, the effects of the different substances "should be considered as additive." A formula is given wherein the ratios of the concentrations of each substance with the same health-related endpoint to the threshold limit value for each substance are added. If the sum of all these ratios exceeds unity, then it is considered that the concentration value has been exceeded.

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

where

C_i = the airborne concentration of the substance.

T_i = the threshold limit value of that substance.

Perceived IAQ. A minimum target level for perceived IAQ must be specified. For example, the designer might specify that at least 70 percent of visitors to a zone must express satisfaction with the air quality, or that at least 90 percent of occupants must express satisfaction. Setting this target too high may require higher OA rates or more filtration for the zone. Setting it too low may lead to unacceptably low satisfaction levels—and how many building operators want even 10 percent of the occupants complaining about odor? Again, setting a perceived IAQ minimum satisfaction target places a judgment burden on the designer.

Mass balance calculations. With pollutants established, along with sources, source strengths and target limits, and perhaps air-cleaning efficiencies for some pollutants, it's time for some calculations. The standard requires mass balance calculations for every contaminant of concern identified for the project, which logically includes both individual contaminants and constituents of impact mixtures. For single-zone systems, Appendix D of Standard 62.1 shows steady-state equations relating source strength, OA rate, air-cleaning efficiency, contaminant (or constituent) concentration and so on. These equations can be algebraically manipulated to solve for the minimum OA rate given concentration limits, or for air-cleaning efficiencies given OA rate.

Designers use mass balance equations primarily to find the minimum required breathing zone OA rate for each contaminant and for each impact mixture. (Remember source mixtures should be prevented from entering the building.) Individual contaminants usually have established limits to use in calculations. And while impact mixtures don't have established limits, they can be "controlled" to acceptable levels (see insets pp.4-5) based on the concentration and TLV of individual constituents, and using the "additivity" of concentration ratios.

Most designers using the IAQP don't address mixtures—they simply focus on the concentration limits for specific contaminants, and assume that they need only introduce the OA needed for the "worst case" contaminant. Additivity adjustments aren't made in spite of clear advice to do so in Informative Appendix B. (The VRP, on the other hand, is based on the principle of adding OA rates for odors and irritants from two major sources, occupants and the building itself.) By ignoring the additive nature of impact-mixtures, the IAQP often results in inappropriately low OA rates.

Remember, many studies in office buildings show that the effective OA rate must be between 15 to 20 cfm per person as prescribed by teh VRP. It seems like good practice to find the minimum breathing zone OA rate without air cleaning, as a check. If the rate without air cleaning is substantially below the VRP rate for the zone, it's likely that a pollutant has been missed or mischaracterized or the additive quality of impact mixtures has been overlooked. Failure to follow the Appendix B analysis for mixtures can lead to under-ventilation and complaints, which can haunt a building design for years.

For multiple-zone systems, mass balance calculations become more complicated and usually require the use of spreadsheets or software. Mass

What about outdoor air quality?

Outdoor air introduced into a building can dilute and remove indoor-source pollutants. But since it can also add outdoor-source pollutants, it must be considered as a potential source. Some outdoor pollutants (such as ozone, particulate matter, and odors) can be reduced by air cleaning before they enter the building, but some (carbon monoxide, for instance) cannot. In any case, pollutants from outdoors must be considered both as individual contaminants and as mixtures or constituents of mixtures when using the IAQP. But, remember that most indoor pollutants are not present in the outdoor air, so even "dirty" outdoor air always dilutes and removes indoor-source contaminants. Some amount of outdoor air is always used for indoor air quality control.

balance software used to find air-cleaning efficiencies must be based on the minimum OA rates and procedures in Standard 62.1-2004 (or later), since both rates and procedures changed significantly in the 2004 version of the standard.

Each IAQP zone in a multiple-zone system must be treated individually, using the contaminant and mixture concentration levels in the primary air supplied to the zone, instead of OA levels. Although local (in the zone) air cleaning can be used, central air cleaners located in the air handler are much more common. To find system-level outdoor air intake flow while accounting for both zone and outdoor pollutant sources, as well as central air cleaning, designers must either derive new equations to find contaminant levels or use analysis software, such as CONTAM[10]. The single-zone equations in Appendix D do not apply.

Subjective evaluation. The mass-balance calculations described above result in a minimum zone OA rate for each contaminant or impact mixture. Each zone requires the highest of these rates to ensure acceptable "objective" IAQ. But any minimum OA rate must also ensure acceptable "perceived" IAQ in terms of occupant or visitor satisfaction. This requires a subjective evaluation of air quality using either of two approaches:

a. Based on the results of mass-balance calculations, experience, knowledge of air cleaning devices, and so on, designers may choose to determine an initial minimum zone OA rate for design purposes. After construction and building occupancy, a subjective evaluation must be conducted in each IAQP zone. While the standard does not require a specific subjective evaluation procedure, Informative Appendix B describes one such procedure. To evaluate *visitor* satisfaction, a group of untrained subjects enters the zone and renders a judgment on IAQ acceptability within 15 seconds; to evaluate *occupant* satisfaction, the group renders a judgment on acceptability after spending more than six minutes in the zone. If the initial zone OA rate results in a satisfaction rating below the target percentage specified, action must be taken (e.g., increase the OA rate, reduce emissions by replacing some building materials or furnishings, or increase air cleaning for odors). The subjective evaluation must be repeated and corrective action taken until the specified level of acceptability is achieved. On the other hand, if the initial zone OA rate results in excessively high levels of occupant satisfaction, it may be possible to reduce the zone OA rate, provided the subjective evaluation is repeated to ensure compliance.

b. Alternatively, designers may identify a "substantially similar" zone in a previously constructed building that was successfully evaluated using the subjective evaluation approach described above. The OA rate used in the similar zone establishes the minimum OA rate needed to satisfy the subjective evaluation requirement, without actually using a group of untrained subjects to evaluate perceived IAQ in the "new" zone. Of course, identifying a similar zone can be difficult, especially for zones in one-of-a-kind buildings. A substantially similar zone has similar pollutant sources and emission rates, similar or identical contaminants, source mixtures and impact mixtures, identical concentration limits, identical air-cleaning efficiency for each pollutant, and an identical specified level of perceived acceptability. Finding a zone with identical air cleaning efficiency might be the most difficult part because no widely accepted rating method yet exists for comparing gaseous air-cleaner efficiency for specific contaminants or impact mixture constituents.

The minimum zone OA rate determined using the mass balance calculations must be compared to the rate determined using one of the two subjective evaluation approaches. To comply with the IAQP, the higher of these two values establishes the minimum zone OA rate per the IAQP.

Impact mixture calculations

According to the ACGIH, when two or more substances acting on the "… same organ system are present, their combined effect, rather than that of either individually, should be given priority." One way to do this is to: (1) find the steady-state concentration of each individual constituent, given an OA rate, generation rate, air cleaning efficiency, and so on, (2) find the ratio of each constituent concentration to its TLV, and (3) add all the ratios together. If the ratio sum exceeds 1.0, the concentration of one (or more) of the constituents must be lowered by increasing the OA rate, decreasing the generation rate, and/or increasing air cleaning efficiency for that constituent. With one or more new parameters, repeat steps 1 through 3 until the sum of the concentration ratios is less than 1.0. This results in an acceptable OA rate for the impact-mixture being considered. Of course, these calculations must be repeated for each identified impact-mixture.

Summary

The IAQP is a valid procedure that provides a valid performance-based alternative to the VRP and has been successfully applied for some building ventilation systems, especially where the same building design with substantially similar zones is repeated in multiple locations. However, for one-of-a-kind buildings, the IAQP requires designers to make many difficult judgments and to perform a subjective evaluation in the completed building. In so doing, the required minimum zone OA rate found using the IAQP is likely to vary considerably from one designer to the next, and may be too low in many cases due to incomplete evaluation of the additive nature of impact mixtures.

For these reasons, many designers are uncomfortable with this approach. Furthermore, most mechanical codes require a prescriptive procedure based on the VRP, and only allow the IAQP as an approved code variance. Although allowed by both ASHRAE Standard 189.1 and LEED 2009 to increase zone OA rates above the VRP minimums, the IAQP cannot be used to decrease zone OA rates below the VRP minimum rates.

Perhaps more designers will use a future version of the IAQP when comprehensive, accepted and published data about mixtures, sources, air cleaning and subjective evaluation are available so designers can make the necessary judgments with more confidence. But for now, most designers continue to use the prescriptive VRP to reduce design time, cost, and risk.

By Dennis Stanke, staff applications engineer, and Jeanne Harshaw, program manager, Trane. You can find this and previous issues of the Engineers Newsletter at www.trane.com/EN. To comment, e-mail us at comfort@trane.com.

References.

[1] Stanke, D. 2004. "Addendum 62n Breathes New Life Into ASHRAE 62." *Engineers Newsletter* 33-1. La Crosse, WI: Trane

[2] Stanke, D. 2005. "Standard 62-2001 Addendum 62n: Single-Path Multiple-Zone System Design." ASHRAE Journal 47(1):28-35.

[3] Stanke, D. 2005. "Standard 62.1-2004 Designing Dual-Path, Multiple-Zone Systems." ASHRAE Journal 47(5):20-31.

[4] American Society of Heating, Refrigerating and Air Conditioning Engineers, Inc. (ASHRAE) 2010. ANSI/ASHRAE Standard 62.1-2010. *Ventilation for Acceptable Indoor Air Quality*. Atlanta, GA: ASHRAE.

[5] *2009 ASHRAE Handbook-Fundamentals,* Chapter 11. Atlanta, GA. ASHRAE

[6] *2009 ASHRAE Handbook- Fundamentals*, Chapter 11: Tables 11,12. Atlanta, GA. ASHRAE

[7] *2009 ASHRAE Handbook- Fundamentals*, Chapter 11: Table 10. Atlanta, GA. ASHRAE

[8] *2009 ASHRAE Handbook-Fundamentals*, Chapter 10: p. 6. Atlanta, GA. ASHRAE

[9] *User's Manual: ANSI/ASHRAE Standard 62.1-2010.* Atlanta, GA. ASHRAE

[10] CONTAM Multizone Airflow and Contaminant Transport Analysis Software. http://www.bfrl.nist.gov/IAQanalysis/CONTAM/

New On-Demand Courses

High performance VAV Systems.

Variable-air-volume (VAV) systems have been used to provide comfort in a wide range of building types and climates. This ENL will discuss design and control strategies that can significantly reduce energy use and ensure proper ventilation in VAV systems.

ASHRAE 62.1: Ventilation Rate Procedure. This program covers the Ventilation Rate Procedure for calculating zone and system ventilation airflow, which still exists in the standard today. As a prerequisite to obtain LEED certification, this program will help viewers understand the requirements of the Standard.

Visit **www.trane.com/ContinuingEducation** to view courses or to see a complete list of courses.

TRANE®

Trane,
A business of Ingersoll Rand

For more information, contact your local Trane office or e-mail us at comfort@trane.com