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ASHRAE 62-89 Analysis
Part II: Ventilation Rate Procedure

Many HVAC system designers view ASHRAE Standard 62-89, Ventilation Standard for Acceptable Indoor Air Quality, as the minimum ventilation standard to be met, regardless of local codes. This is the second of three ***Engineers Newletters*** *that attempt to interpret the standard and offer suggestions for complying with it.*

The purpose of ASHRAE Standard 62-89 is to specify **minimum ventilation rates** and **indoor air quality** acceptable to human occupants; both specifications "are intended to avoid adverse health effects." The standard attempts to accomplish this dual purpose by presenting a series of general requirements for systems and equipment (Section 5.0), then offering two alternative procedures for providing acceptable indoor air quality (Section 6.0). The following analysis is presented to aid designers and installers when interpreting the various requirements of the standard. It is based on our best judgment of the meaning and purpose of the various provisions. **Ultimate responsibility for interpretation and compliance, however, rests with the individual designer and installer.**

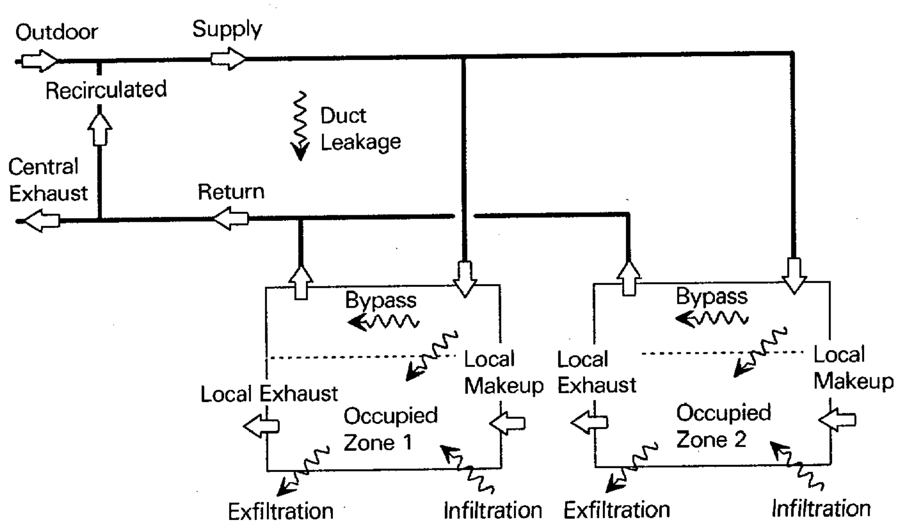
Section 5.0, Systems and Equipment, was the subject of a previous **Engineers Newsletter.** Section 6.0, Procedures, contains three subsections: Section 6.1, Ventilation Rate Procedure, Section 6.2, Indoor Air Quality Procedure, and Section 6.3, Design Documentation Procedures. Section 6.1 is discussed below. Sections 6.2 and 6.3 will be covered in a subsequent issue.

General Terms

Throughout the standard, both **suggestions** (signalled by use of the words **should** and **may**) and **requirements** (denoted by **shall** and **must**) are presented. Requirements must be met to claim conformance with the standard. On the surface, it seems that suggestions need not be met for compliance. However, ignoring these suggestions may not be **prudent**. After all, they reflect the consensus of experts in the HVAC industry and might, therefore, be viewed as the minimum criteria a prudent designer would follow when designing a ventilation system.

ASHRAE 62-89 makes several references to the **occupied zone**. This zone is a defined region within the occupied space ". . .between planes 3 and 72 inches above the floor

Figure 1: Ventilation System Airflows



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and more than 2 feet from the walls." The **occupied space** is assumed to refer to inhabited areas of the building. . . usually rooms. Figure 1 shows the typical airflow paths in a ventilation system. Two occupied spaces are shown; the occupied zone in each occupied space is below the dashed line.

The terms **outdoor air** and **ventilation air** are often used interchangeably. However, outdoor air is (obviously) air from outside the building, while ventilation air is that portion of supply air whose purpose is maintaining acceptable indoor air quality. Ventilation air usually consists entirely of outdoor air when the Ventilation Rate Procedure is used. However, it may be a mixture of outdoor air and treated recirculated air when multiple spaces are served by a single air handler.

Analysis of Section 6.1: Ventilation Rate Procedure

Section 6.1 presents ". . .one way to achieve acceptable indoor air quality". space ventilation with outdoor air of specific minimum quality and quantity. Some have described this method as the "dilution solution." It dictates both the condition and amount of ventilation air necessary to assure adequate dilution of contaminants in the occupied zone. Specifically, it prescribes:

1
The quality of acceptable outdoor air.
2
The treatment of outside air necessary to make it acceptable
3
The minimum volumetric flow rate of outdoor air required to adequately ventilate various occupied space types.

Furthermore, within its discussion of ventilation rates, Section 6.1 prescribes outdoor airflow rate requirements for systems with multiple spaces served by one air handler, such as VAV systems, and for spaces with intermittent occupancy, such as conference rooms and auditoriums. It also discusses the use of recirculated air for ventilation and ventilation effectiveness within the occupied zone.

Figure 2: Summary of Outdoor Air Quality Standards

Outdoor Air Quality Standards							
	Outdoor Standards Long-Term			Outdoor Standards Short-Term			
Contaminant	Concentration		Time	Concentration		Time	ASHRAE Table
	ug/m³	ppm	years	ug/m³	ppm	hours	
Sulfur Dioxide	80.0	0.030	1.00	365	0.14	24	1
Total Particulate	50.0		1.00	150		24	1
Carbon Monoxide				40,000	35.00	1	1
Carbon Monoxide				10,000	9.00	8	1
Oxidants (ozone)				235	0.12	1	1
Nitrogen Dioxide	100.0	0.055	1.00				1
Lead	1.5		0.25				1
Asbestos							
National Emmissions Std	No Visible Emmissions						C-1
State of Connecticut				0.001		8	C-1
State of New York	5.0		1.00				C-1
State of Virginia				2.000		24	C-1
Formaldehyde							
No Federal Standards							C-1
State of Connecticut				12.000		8	C-1
State of New York	2.0		1.00				C-1
State of Virginia				12.000		24	C-1
Radon	25 mrem/y whole body						C-1

Key points presented in Section 6.1 are arranged by topic and discussed below.

Outdoor Air Quality

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Can the building designer simply assume that outdoor air is acceptable for ventilation? No. The designer is **required** to evaluate the outdoor air at the building site.

"This section describes a three-step procedure by which outdoor air shall be evaluated for acceptability" (Section 6.1.1).

Only acceptable outdoor air can be used for ventilation. Therefore, outdoor air quality at a building site must be evaluated to assure acceptability. A three-step procedure is prescribed for outdoor air evaluation. All three steps are required for compliance:

Step 1: Assure that ". . .contaminants in the outdoor air do not exceed the concentrations listed in Table 1."

Outdoor air must not contain contaminant levels exceeding those listed in Table 1 of the standard, as shown in Figure 2. Table 1 lists air quality standards for outdoor air, as set by the Environmental Protection Agency (EPA). To determine whether outdoor air complies with ASHRAE Table 1, the building designer has four options:
A
Check government pollution-control agency monitored data for the building location (direct data check);
B
Check monitored data for a location with similar population, geography, weather and industrial patterns (indirect data check);
C
In lieu of monitored data checks, simply assure that the building location is in a community of less than 20,000 people, with no "substantial" air contamination sources, or
D
Monitor the air for three consecutive months. Any one of these options may result in considerable effort for the building designer. Incidentally, Table 1 lists concentration levels for only seven contaminant levels: sulfur dioxide, total particulate, carbon monoxide (one hour), carbon monoxide (eight hours), oxidants (ozone), nitrogen dioxide and lead.

Step 2: If the outdoor air is ". . . thought to contain any contaminants not listed in Table 1. . . guidance on acceptable concentration levels may be obtained by reference to Appendix C." In other words, **assure** that non-Table 1 contaminants do not exceed acceptable concentration levels.

If the outdoor air "is thought to contain" any contaminants not listed in Table 1, acceptable levels for additional contaminants are presented in tables found in Appendix C of ASHRAE 62-89 also shown in Figure 2. The building designer bears the burden of judgment at this step. And, although it is unclear who is ultimately responsible for **thinking** that non-Table 1 contaminants are present, it is likely to be the building designer. Regardless of who suspects that the air contains them, Table C-1 lists acceptable outdoor levels (Outdoor Standards) for only three additional contaminants: asbestos, formaldehyde, and radon. Table C-2 lists no additional contaminants under Outdoor Guidelines. Neither Table C-3 nor Table C-4 is related to outdoor air contaminant levels.

In summary, ASHRAE 62-89 defines acceptable outdoor air in terms of 10 contaminant concentration levels: sulfur dioxide, total particulate, carbon monoxide (one hour), carbon monoxide (eight hours), oxidants (ozone), nitrogen dioxide, lead, asbestos, formaldehyde and radon.

Step 3: If Steps 1 and 2 are completed (all 10 contaminant concentration levels are acceptable) and ". . . there is still a reasonable expectation that the air is unacceptable, **sampling** shall be conducted in accordance with NIOSH procedures. . . . Finally, acceptable outdoor air quality should be **evaluated** using the definition for acceptable indoor air quality in Section 3."

Step 3 places an additional judgment burden on the building designer. If the building designer has assured that none of the 10 contaminant levels listed by the standard is unacceptable (Steps 1 and 2), but ". . . there is still a reasonable expectation" that the outdoor air is **bad** (perhaps because of odors or prior experience in the area), Step 3 must be performed. Step 3 **requires** that air samples be taken and evaluated, apparently for the hundreds of materials listed in the National Institute for Occupational Safety and Health (NIOSH) "Manual of Analytical Methods." Step 3 goes on to **suggest** that the suspected bad outdoor air be further qualified per the definition of acceptable indoor air quality. In other words, it recommends that the building designer carry out a subjective test to demonstrate that ". . . a substantial majority (80 percent or more) of the people exposed do not express dissatisfaction" with the outdoor air.

Many building designers would benefit from a more quantitative prescriptive procedure for assuring acceptable outdoor air quality.

Outdoor Air Treatment

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If the outdoor air is unacceptable, must it be cleaned or filtered? No. The standard **suggests** that bad outdoor air be treated, but, as written, it does not require treatment.

"If the outdoor air contaminant levels exceed those values given in 6.1.1 (Table 1), the air should be treated to control the offending contaminants" (Section 6.1.2).

Although this statement only refers to the evaluation of outdoor air based on the seven contaminant levels of Table 1 (Step 1 in Section 6.1.1), it seems reasonable to apply it to all three evaluation steps required in Section 6.1.1. In other words, if the concentration of any of the identified contaminants (Steps 1 and 2 above) or any other pollutant (Step 3) exceeds the acceptable level. . . or if a subjective test fails to accept the air quality. . . treatment of the outdoor air is suggested.

The building designer, faced with unacceptable outdoor air, is encouraged to treat the outdoor air before it enters the occupied space. Some building designers interpret this suggestion as a requirement for outdoor air treatment (filtering), either in the outdoor air path, before mixing with recirculated air, or in the supply air path. Consequently, air filtration systems (filters, dust collectors and/or air cleaners for particles) and gaseous contaminant removal systems (activated carbon filters for gases and vapors) are often specified.

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Is any filter acceptable? Strictly speaking, yes. The standard only **suggests** use of an appropriate filter.

"Air-cleaning systems suitable for the particle size encountered should be used. For removal of gases and vapors, appropriate air-cleaning systems should be used" (Section 6.1.2).

If the total particulate level is too high, Figure 2, use of properly selected filters, suitable for the particle size, is recommended, but not required. Similarly, if the offending contaminants are gaseous, use of **appropriate** air cleaning systems, such as activated carbon filters, is recommended, but not required. These recommendations are often interpreted (and perhaps were intended) as requirements. It seems reasonable to clean the outdoor air before introducing it into the occupied space. . . especially since the outdoor air contaminant levels of Table 1 also apply to indoor air. As a result, building designers often specify some type of outdoor air treatment.

Ventilation Rates

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Can acceptable indoor air quality (conformance to the standard) be achieved via adequate ventilation rates alone, without measuring contaminant levels? Yes. In fact, to conform to the standard using the Ventilation Rate Procedure, the ventilation rates presented by the standard are **required**.

"Indoor air quality shall be considered acceptable if the required rates of acceptable outdoor air in Table 2 are provided for the occupied space" (Section 6.1.3).

In effect, using the **Ventilation Rate Procedure**, an occupied zone has acceptable indoor air quality if it is ventilated at the minimum outdoor airflow rate specified in Table 2 of the standard. Table 2, summarized in Figure 3, specifies the minimum rate of outdoor airflow required for 81 occupied-space types. In general, these rates were determined by assuming levels of human *occupancy and* CO_2 *production*, then calculating the dilution rate required to maintain the CO_2 concentration level below 1000 ppm. To use Table 2, the building designer must first determine the type of facility and planned use (application) of each space within the facility. The minimum outdoor air requirement for the occupied zone within the space, as found in Table 2, is usually expressed as volume flow rate per person. Knowing design occupancy, the actual required minimum outdoor airflow rate for each space is calculated by multiplying the design occupancy by the outdoor air requirement. For some space applications, the required minimum outdoor airflow rate is calculated by multiplying the floor area being served by the outdoor air requirement expressed as volume flow rate per unit area, also Table 2. In either case, the designer has a defined method for calculating the minimum outdoor airflow rate required to comply with the standard.

The flow rates listed in Table 2 are based on mass balance calculations, briefly summarized in Appendix D of ASHRAE 62-89. From the mass balance equation, the outdoor airflow rate per occupant is determined based on an established CO_2 generation rate per person (N) for specific activities, a maximum allowable CO_2 concentration level (C_s = 1000 ppm) in the space, and an assumed average CO_2 concentration level in the outdoor air (C_o = 300 ppm). Note that neither the calculations in Appendix D nor the values in Table 2 indicate any tolerance for the required outdoor airflow rates. In other words, the building designer is given no guidelines or requirements for the accuracy of flow calculations or sensor measurements.

Do the Table 2 values always apply, even when unusual contaminant sources are found in the occupied space? No. This is one of two exceptions to the airflow rates listed in Table 2. The standard **requires** that the air quality in spaces with unusual contaminants or sources be controlled by some means other than the outdoor airflow rates prescribed in Table 2.

Figure 3: Partial Summary of Outdoor Air Requirements

Occupied Space		Minimum Outdoor Airflow Rate	
Facility/Application	**Space Type**		
		cfm/ person	*cfm/ ft²*
	Commercial (Table 2.1)		
Food/Beverage	Bar, cocktail lounge	30	
	Dining room, cafeteria, fast food	20	
	Kitchen	15	
Hotel, Motel, Dorm	Baths		35.00
	Bedrooms, living rooms		30.00
	Gambling casinos	30	
	Conference rooms	20	
	Lobbies, assembly rooms, dorm sleep areas	15	
Offices	Office space, conference rooms, etc.	20	
	Reception areas	15	
Public Spaces	Elevators		1.00
	Locker and dressing rooms		0.50
	Corridors and utilities		0.05
	Smoking lounge	60	
	Public restrooms	50	
Retail Store, Showroom	Basement and street		0.30
	Upper floors, dressing rooms, malls, arcades		0.20
	Storage rooms, shipping and receiving		0.15
	Warehouse		0.05
Theater	Ticket booths, lobbies	20	
	Auditorium, stages, studios	15	
	Institutional (Table 2.2)		
Education	Corridors		0.10
	Laboratories, training shop	20	
	Classrooms, music rooms, libraries, auditoriums	15	
Hospital, Nursing Home	Autopsy rooms		0.50
	Operating rooms	30	
	Patient rooms	25	
	Medical procedure, recovery, ICU, therapy	15	
	Residential (Table 2.3)		
Private Dwelling	Kitchens	25 cfm/room	
	Baths, toilets	20 cfm/room	
	Living areas	15	

"Where unusual indoor contaminants or sources are present or anticipated, they shall be controlled at the source or the procedure of (Section) 6.2 shall be followed" (Section 6.1.3).

The standard does not define an unusual contaminant or source. However, since the Table 2 rates are based on human occupancy and activities, some building designers conclude that ventilation for spaces with nonhuman sources, such as copy machines, or with unusual human activity, such as jogging in an office area, must be determined by means other than Table 2. Once the designer concludes that Table 2 cannot be used as the path to acceptable indoor air quality, one of two other paths must be used: **either source control** or the **Indoor Air Quality Procedure.**

Source control is not defined by the standard. For some building designers, a source control system includes local exhaust airflow with corresponding local make-up airflow. For other designers, local make-up airflow is not included in the source control system; instead, the space outdoor airflow rate is increased to provide both the required ventilation airflow and local make-up airflow. In either case, dilution (mixing ventilation air with zone air) is abandoned in favor of replacement of contaminated air with ventilation air. Said another way, outdoor air is used to replace exhausted air rather than to lower the contaminant concentration level in the space through dilution. Contaminants are exhausted locally, at their source, rather than mixed with return air to be exhausted centrally.

The Indoor Air Quality Procedure will be the subject of an upcoming **Engineers Newsletter**. Many building designers are uncomfortable applying the IAQ Procedure because it includes both objective design criteria and subjective post-design criteria. Therefore, source control is usually specified for unusual contaminant sources, allowing compliance via the Ventilation Rate Procedure.

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Do the Table 2 values always apply, even for areas in industrial facilities not covered by Table 2? No. This is the second of two exceptions to the airflow rates listed in Table 2. The standard **requires** that acceptable air quality in industrial facility areas not mentioned in Table 2 be accomplished as described in a reference source.

"For those areas within industrial facilities not covered by Table 2, refer to footnote 15 of Threshold Limit Values and Biological Exposure Indices for 1986-87, American Conference of Governmental Industrial Hygienists. . ." (Section 6.1.3).

The standard cannot be used to determine the outdoor airflow required to achieve acceptable indoor air quality in industrial facilities. Table 2 addresses only commercial, institutional and residential facilities. Building designers must use another reference source to find acceptable contaminant concentration levels and, presumably, required dilution rates for industrial facilities.

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Does the standard effectively prescribe just one ventilation rate for each specific space type by listing estimated maximum occupancy and volume flow rate per person? No. Use of actual occupant density at design is **required** when calculating the minimum outdoor airflow rate for a space.

"Where occupant density differs from that in Table 2, use the per occupant ventilation rate for the anticipated occupancy load" (Section 6.1.3).

This statement is somewhat confusing, but it seems to mean that the actual value of design occupant density is to be used to calculate the minimum outdoor airflow rate. The building designer determines the design (anticipated) occupancy load (total number of persons) for a space by multiplying the design occupant density (persons per 1000 square feet) by the occupiable area (square feet) of the space. Then, the required minimum outdoor airflow rate for the occupied zone is found by multiplying the design occupancy load (total number of persons) by the volume flow rate per person from Table 2. These steps are used regardless of whether the design occupant density matches the estimated maximum occupancy listed in Table 2.

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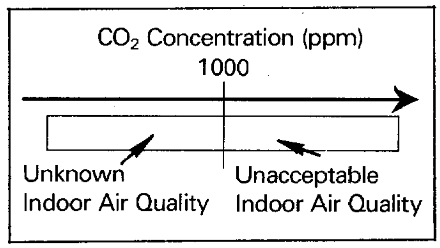
Does a CO_2 concentration below 1000 ppm in a ventilated space mean that acceptable indoor air quality has been achieved? No. The standard merely **observes** that odors are likely to be acceptable if the space is ventilated at a rate which maintains the CO_2 concentration below 1000 ppm.

"Comfort (odor) criteria are likely to be satisfied if the ventilation rate is set so that 1000 ppm CO_2 is not exceeded" (Section 6.1.3).

This is an observation, not a requirement or suggestion. It informs the building designer that odors are likely to be adequately controlled if a space is ventilated as prescribed in Table 2. Remember that the outdoor airflow rates presented in Table 2 are calculated to provide sufficient dilution to maintain the in-space CO_2 concentration level below 1000 ppm. The ventilation rate is "set so that 1000 ppm CO_2 is not exceeded" when the outdoor airflow rate to the space is at least as high as the outdoor air requirements listed in Table 2.

This observation is often misinterpreted to mean that acceptable indoor air quality is achieved by maintaining the CO_2 concentration level in the occupied zone below 1000 ppm. Many experts, however, claim that there is a very weak correlation between low CO_2 levels and acceptable indoor air quality. A CO_2 level below 1000 ppm **does not** mean indoor air quality is acceptable, but a CO_2 level above 1000 ppm **does** indicate unacceptable indoor air quality. Figure 4 illustrates this relationship.

Figure 4



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If a CO_2 concentration below 1000 ppm is maintained at outdoor airflow rates lower than those listed in Table 2, has acceptable indoor air quality been achieved? No. If the Ventilation Rate Procedure (that is, dilution at the rates presented in Table 2) is not used, other contaminant concentrations may rise, and the designer is **required** to consider this effect.

"In the event CO_2 is controlled by any method other than dilution, the effects of possible elevation of other contaminants must be considered" (Section 6.1.3).

If the CO_2 concentration level in a space is maintained below 1000 ppm by any means other than dilution at the rates prescribed by the Ventilation Rate Procedure, other possible contaminants in the space are less diluted, so their concentration levels may rise. If the building designer chooses to use the IAQ Procedure rather than the Ventilation Rate Procedure, the designer is required to consider this effect. This opens the door for another judgment by the designer: What does "consider the effects" mean?

This excerpt also seems to imply that demand-controlled ventilation schemes . . . which may result in minimum outdoor airflow rates below the Table 2 values. . . cannot be based on CO_2 level measurements alone. Other possible contaminant concentration levels may also rise; therefore, it seems that these other contaminant levels must also be sensed and incorporated into the control scheme. Litigation-conscious building designers avoid the risk of elevating unknown (and unsensed) contaminant concentrations to unacceptable levels by using the Ventilation Rate Procedure and adhering strictly to the minimum outdoor airflow rates prescribed by Table 2.

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Can the Table 2 rates ever be reduced below the values listed? Yes. The standard allows **(suggests)** temporary reduction in outdoor airflow rates if the outdoor air quality is unacceptable for brief periods.

". . . the amount of outdoor air may be reduced during periods of high contaminant levels, such as those generated by rush-hour traffic." (Section 6.1.2).

If no air cleaning system can adequately clean the outdoor air at contamination-level peaks, the amount of outdoor air introduced to the building can be reduced during such periods. This suggestion places yet another burden of judgment on the building designer since the amount and duration of reduced outdoor airflow is not specified. It may lead some designers to specify outdoor air quality monitoring equipment so that the outdoor airflow rate is only reduced when the outdoor air is indeed unacceptable.

Multispace Systems

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How do the Table 2 outdoor airflow requirements apply to systems with multiple occupied spaces? When multiple occupied spaces are served by a common supply air system, as shown in Figure 1, the building designer is **required** to calculate the system-level minimum outdoor airflow rate (based on the space-level outdoor airflow rates listed in Table 2, using a prescribed equation.

"Where more than one space is served by a common supply system, the ratio of outdoor air to supply air required. . . may differ from space to space. The system outdoor air quantity shall then be determined using Equation 6-1" (Section 6.1.3.1).

This requirement applies to both constant volume and variable air volume systems. Many constant volume air handlers serve more than one space (both interior and exterior office areas, for instance), and almost all VAV air handlers serve multiple spaces. When a common supply air system serves more than one occupied space, each space is likely to require a different ratio of outdoor airflow to supply airflow. This is a multispace system. The system-level outdoor airflow rate could be determined directly from Table 2 by finding the outdoor-to-supply-airflow ratio for each space and using the largest ratio (the critical space ratio) to determine the outdoor airflow needed.

However, this would result in overventilation of most spaces and, furthermore, is not allowed by ASHRAE 62-89. Instead, the building designer must use Equation 6-1 to calculate a system-level outdoor airflow rate based on the individual space outdoor airflow rates from Table 2.

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What is Equation 6-1? Presented below and mandated by ASHRAE 62-89, Equation 6-1 is used to calculate the fraction of outdoor air needed in the system-level supply air for a multispace system.

Equation 6-1 is: $Y = X/(1 + X - Z)$

Where:
$Y = V_{ot}/V_{st}$ is the corrected fraction of outdoor air required in the system-level supply air; $X = V_{on}/V_{st}$ is the uncorrected fraction of outdoor air in the system-level supply air; and

$Z = V_{oc}/V_{ac}$ is the fraction of outdoor air required in the air supplied to the critical space, i.e., the largest outdoor-to-supply airflow ratio.

And, where:

V_{ot} is the system-level outdoor airflow required by the standard (our ultimate calculation objective);

V_{st} is the total system-level supply airflow, either at maximum or minimum system load;

V_{on} is the sum of all space minimum outdoor airflows (from Table 2 for each space);

V_{oc} is the minimum outdoor airflow required for the critical space (again from Table 2); and,

V_{sc} is the supply airflow to the critical space, either at maximum or minimum load.

Also:

$F_i = V_{oi}/V_{si}$ is the fraction of outdoor air required in the air supplied to space i;

V_{oi} is minimum outdoor airflow required for space i (from Table 2); and,

V_{si} is the supply airflow to space i, either at maximum or minimum load.

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How is Equation 6-1 used to calculate system-level outdoor airflow required for multispace systems? A three-step procedure is presented to help the building designer calculate the corrected fraction of outdoor air needed.

"1. Calculate the uncorrected outdoor air fraction by dividing the sum of all the branch outdoor air requirements by the sum of all the branch supply flow rates" (Section 6.1.3.1).

Each space requires a minimum outdoor airflow, V_{oi}, per Table 2; these airflows for all spaces are added to find V_{on} for the system.

For constant volume cooling-only systems, each space requires a constant supply airflow, V_{si}, these supply airflows are added to find V_{st} for the system. For variable air volume cooling-only systems, each space requires a maximum supply airflow at design cooling load, and a minimum supply airflow at minimum cooling load.

ASHRAE 62-89 does not indicate which space supply airflow to use for VAV systems. The prudent building designer, therefore, adds the design cooling airflows (corrected for design load diversity) to find the maximum V_{st} for the system, and adds the minimum cooling airflows (corrected for minimum load diversity) to find the system's minimum V_{st}.

The uncorrected outdoor air fraction, X, is found by dividing V_{on} by V_{st}. (Again, for VAV systems, it is wise to find two values for X, one at maximum flow and another at minimum flow.)

"2. Calculate the critical space outdoor air fraction by dividing the critical space outdoor air requirement by the critical space supply flow rate" (Section 6.1.3.1).

Each space has a required minimum outdoor-to-supply-airflow ratio, F; find F for each space by dividing V_{oi} by V_{si}. The highest F ratio becomes the critical space outdoor air fraction, Z. (Again, for VAV systems, the prudent building designer calculates F and Z at both design cooling load and minimum cooling load, as discussed above.)

3. Evaluate Equation 6-1 . . . to find the corrected fraction of outdoor air to be provided in the system supply" (Section 6.1.3.1).

Using ratios X and Z found above, solve Equation 6-1 for ratio Y. To find the corrected system-level outdoor airflow rate, V_{ot}, multiply ratio Y by V_{st}. (As above, for VAV systems, the careful building designer finds two values for V_{ot} and uses the largest value to assure acceptable indoor air quality.)

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Do spaces with local exhaust need independent make-up airflow? No. Make-up airflow can be provided by the common supply air system, but the airflow rate to each space in a multiple-space system is **required** to comply with the requirements of Table 2.

"Rooms provided with exhaust air systems . . . may utilize air supplied through adjacent . . . spaces to compensate for the air exhausted. The air supplied [from the adjacent spaces] shall be of sufficient quantity to meet the requirements of Table 2" (Section 6.1.3.1).

Each space in a multiple-space system must be provided with the outdoor airflow rate listed in Table 2. Table 2 presents the outdoor airflow which must enter a space, that is, be supplied to the occupants. If air is supplied to a high-exhaust space via two paths . . . both directly to the space and from an adjacent space . . . the total outdoor airflow to the high-exhaust space must equal the airflow listed in Table 2. As a result, the outdoor airflow rate to the adjacent space must be increased by the amount of additional outdoor airflow needed in the high-exhaust space.

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Is unoccupied ventilation always required for all spaces in a multiple-space system? No. But if contaminants can accumulate in the space when it is not inhabited, then unoccupied ventilation is **required** for that space.

"When spaces are unoccupied, ventilation is not generally required unless it is needed to prevent accumulation of contaminants injurious to people, contents, or structure" (Section 6.1.3.1).

Unoccupied ventilation of spaces in multiple-space systems is required to prevent the accumulation of contaminants. In this case, the term "contaminants" seems to include humidity (injurious to contents or structure) as well as the substances listed in ASHRAE 62-89 Table 1, Table 3, Table C-1, Table C-2 and Table C-3. These are substances with defined maximum **indoor** concentration levels; for a summary of them, see Figure 5.

Figure 5: Summary of Indoor Air Quality Standards

Indoor Air Quality Standards							
	Acceptable Exposure						
	Long-Term			Short-Term			
Contaminant	Concentration		Time	Concentration		Time	ASHRAE Table
	ug/m³	*ppm*	*years*	*ug/m³*	*ppm*	*hours*	
Aldehydes (total)				Sum $c_i / C_i < 1$			C-3
Asbestos	No indoor level given						C-1
Carbon Dioxide	6.3×10^6	3,500					C-3
Carbon Monoxide (USA)				40,000	35.00	1	1
Carbon Monoxide (CAN)					25.00	1	C-3
Carbon Monoxide (USA)				10,000	9.00	8	1
Carbon Monoxide (CAN)					11.00	8	C-3
Chlordane (maximum)	5.0						C-2
Formaldehyde (USA)		0.400					C-1
Formaldehyde (CAN)	60.0	0.050					C-3
Lead	1.5		0.25				1
Nitrogen Dioxide	100.0	0.055	1.00				1
Nitrogen Dioxide	100.0	0.050		480	0.25	1	C-3
Oxidants (ozone, USA)				235	0.12	1	1
Ozone (CAN)				240	0.12	1	C-3
Particulate (total, USA)	50.0		1.00	150		24	1
Particulate Matter (CAN)	40.0			100		1	C-3
Radon	4 p Ci/l		lifetime	200 p Ci/l		weeks	C-2
Sulfur Dioxide (USA)	80.0	0.030	1.00	365	0.14	24	1
Sulfur Dioxide (CAN)	50.0	0.019		1,000	0.38	.08	C-3
Water Vapor (summer)				30-80% R.H.			C-3
Water Vapor (winter)				30-55% R.H.			C-3
Other Contaminants of Concern:							
Biological agents	No indoor levels given						C-3
Chlorinated hydrocarbons	No indoor levels given						C-3
Pest control products	No indoor levels given						C-3
Product aerosols	No indoor levels given						C-3
Fibrous materials	No indoor levels given						C-3
Polycyclic aromatic hydrocarbons (PAHs)	No indoor levels given						C-3
Tobacco smoke	No indoor levels given						C-3

How much unoccupied ventilation is needed for a space? Apparently, enough to keep humidity below 70 percent, and enough to keep other contaminants below "threshold" concentration levels. Humidity can be sensed and controlled by mechanical systems. But the other contaminants are not easily detected, so the building designer typically specifies that unoccupied ventilation be controlled based on time-of-day or CO_2 level, or both. For instance, unoccupied ventilation may be started at 3:00 a.m. and terminated at 5:00 a.m. or when the indoor CO_2 level is virtually the same as the outdoor CO_2 level. Again, this is a requirement that places another judgment burden on the building designer since prescriptive guidelines are incomplete.

Recirculation

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Using the Ventilation Rate Procedure, can recirculated air from the occupied space be mixed with outdoor air to reduce the minimum outdoor airflow requirements listed in Table 2? No. Each occupied space **must** receive at least the outdoor airflow specified by Table 2.

"Under the ventilation rate procedure, for other than intermittent variable occupancy. . . outdoor airflow rates may not be reduced below the requirements in Table 2" (Section 6.1.3.2).

This is a **requirement**. The mandated ventilation airflow rate to a particular space (from Table 2 of the Ventilation Rate Procedure) must be entirely outdoor air, not a mixture of outdoor air and recirculated air. The building designer, using the Ventilation Rate Procedure, may specify an air-cleaning system for the recirculated air, but must not consider the use of recirculated air to reduce the requirement for outdoor airflow to each space.

Incidentally, this requirement seems to be in direct conflict with the required use of equation 6-1 for multiple-space systems, explained above. Equation 6-1 actually reduces the outside airflow to the critical space by taking **credit** for unused, recirculated air from over-ventilated zones. No filtration of recirculated air is specifically required when equation 6-1 is applied.

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Does the use of recirculated air for ventilation require use of the IAQ Procedure? Yes. If recirculated air is used to reduce the outdoor airflow rates in Table 2, the building designer is **required** to use the IAQ Procedure, rather than the Ventilation Rate Procedure, to provide acceptable indoor air quality.

"If cleaned, recirculated air is used to reduce the outdoor airflow rate below the values shown in Table 2, the [Indoor] Air Quality Procedure, Section 6.2, must be used" (Section 6.1.3.2).

Table 2 lists the outdoor airflow rate required to each occupied space. The building designer can only use cleaned, recirculated air to reduce the outdoor airflow rate to a space through use of the IAQ Procedure. This is necessary, since some contaminants may not be adequately cleaned from the recirculated air stream, and could accumulate in the space, eventually rising to unacceptable concentration levels. As mentioned above, this requirement conflicts with the multiple-space system requirements of Section 6.1.3.1. Equation 6.1 **requires** use of recirculated air in order to comply with the ventilation rate procedure! This is a dilemma for the building designer.

Further discussion of recirculation requirements will be the subject of an upcoming **Engineers Newsletter** related to the IAQ Procedure.

Ventilation Effectiveness

This section of the standard is descriptive more than prescriptive. It doesn't really tell a building designer what to do so much as it explains, to some extent, ventilation effectiveness.

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How is outdoor air used in the occupied space to control contaminant concentrations? ASHRAE 62-89 **allows** the use of outdoor air delivered to the occupied space to either dilute contaminants to reduce concentration levels, or to transport them out of the occupied space.

"Outdoor air for controlling contaminant concentration can be used for dilution or for sweeping the contaminants from their source" (Section 6.1.3.3).

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What does Table 2 really show? It shows the minimum outdoor airflow rate **required** to reach the occupied zone, within the occupied space, to dilute the contaminants in that space.

"The values in Table 2 define the outdoor air needed in the occupied zone for well mixed conditions (ventilation effectiveness approaches 100%)" (Section 6.1.3.3).

Table 2 focuses on the dilution of contaminants, not their transport. It assumes that the air in the occupied zone is well mixed, with relatively uniform contaminate concentration levels throughout the space. It does not necessarily assume that all outdoor air entering the space also enters the occupied zone. Therefore, it seems that the building designer must first find the minimum outdoor airflow required in the occupied **zone** from Table 2, then determine the minimum outdoor airflow required to the **space** by multiplying the occupied zone airflow by the ventilation effectiveness factor (E_v), to account for supply air that bypasses the occupied zone.

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But what is ventilation effectiveness? It is clearly related to room air distribution, but it is not uniquely defined by ASHRAE 62-89.

"The ventilation effectiveness is defined by the fraction of the outdoor air delivered to the space that reaches the occupied space [zone]" (Section 6.1.3.3).

Section 6.1.3.3's definition of ventilation effectiveness is not crystal clear. Our interpretation of this definition is: ". . . the fraction of the outdoor air delivered to the **occupied space** that reaches the **occupied zone**." More precisely: $E_v = (1 - S)$, where S is the fraction of space supply air which passes directly from the supply air inlet to the return air inlet, without entering the occupied zone. By this definition, ventilation effectiveness is determined by the amount of air that bypasses the occupied zone within the occupied space. Another definition, however, is presented in Appendix F of the standard. Here, E_v is defined as ". . . the effectiveness with which the outdoor air is circulated to the occupied space." More precisely: $E_v = (1 - S)/(1 - R * S)$, where: S is the fraction of space supply air that bypasses the zone; and **R** is the fraction of return air recirculated at the air handler. By this definition, ventilation effectiveness is determined by both local occupied zone bypass and the central recirculation rate.

Unfortunately, the standard does not clearly state which definition to use, nor does it present a method to find **S** (and therefore E_v) for an occupied space of known geometry with known diffusers. As a result, building designers often assume that ventilation effectiveness is 100 percent, regardless of the performance of the room air diffusion system.

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Is ventilation effectiveness of 100 percent a requirement? No. ASHRAE 62-89 recognizes that air commonly bypasses the occupied zone (so ventilation effectiveness is commonly not 100 percent) and **suggests** that air distribution systems be designed to minimize that bypass.

"It is. . . not uncommon to find some of the ventilation air bypassing the occupants (moving from supply to exhaust without fully mixing in the occupied zone). . . Such flow conditions should be avoided" (Section 6.1.3.3).

This suggestion is directed primarily to the selection, placement and operation of supply air diffusers and return air grilles. Proper application of these devices is directly related to room air distribution and ventilation effectiveness. Building designers are encouraged to select supply and return (or exhaust) air diffusers to maximize space air mixing, minimize space air stratification and minimize direct bypass of supply air to the return or exhaust grilles. However, the Ventilation Rate Procedure does an inadequate job of prescribing a method or procedure for determining ventilation effectiveness, and sets no minimum value for ventilation effectiveness. The building designer must use his or her own judgment when designing for room air distribution.

Intermittent Occupancy

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Using the Ventilation Rate Procedure, can the outdoor airflow to a conference room, for instance, be reduced below the minimum outdoor airflow requirements listed in Table 2, regardless of contaminants? No. For spaces occupied intermittently, outdoor airflow may be reduced below the value listed in Table 2, but acceptable contaminant concentration levels are **required.**

"Ventilating systems for spaces with intermittent or variable occupancy may have their outdoor air quantity adjusted . . . to provide sufficient dilution to maintain contaminant concentrations within acceptable levels at all times" (Section 6.1.3.4).

The Table 2 minimum outdoor airflow rate is not required in variable-occupancy spaces, but acceptable contaminant concentration levels are required at all times. (This, of course, is the indirect intent of the Table 2 values for all spaces.) The building designer is allowed to incorporate controls that alter the actual flow of outdoor air to variable-occupancy spaces, as long as contaminant levels are acceptable.

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Does ventilation adjustment for variable occupancy simply mean lead/lag ventilation? Yes.

"Such system adjustment may lag or should lead occupancy depending on the source of contaminants and the variation in occupancy" (Section 6.1.3.4).

The control schemes suggested in this section don't alter the outdoor airflow rate required by Table 2. They simply offset the ventilation rate in time with respect to occupancy. In general, Table 2 outdoor airflow rates must be delivered to the spaces whenever they are occupied. However, this section recognizes that some spaces need ventilation prior to occupancy, while others only need ventilation after a period of occupancy. Though not stated, the apparent reason for allowing offset ventilation is to save energy and/or avoid space subcooling. Usually, building designers need this capability for conference rooms in office buildings, auditoriums in schools or theaters and so on. However, some building designers may use lead or lag ventilation control strategies for all spaces (except those which are occupied 24 hours per day) to save operating costs.

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Can people occupy a space before it is ventilated? Yes. The standard **allows** ventilation to lag occupancy for some variable-occupancy spaces.

"When contaminants are associated only with occupants or their activities, do not present a short-term health hazard, and are dissipated during unoccupied periods to provide air equivalent to acceptable outdoor air, the supply of outdoor air may lag occupancy" (Section 6.1.3.4).

For some variable-occupancy spaces, this **suggestion** allows the building designer to delay supplying the outdoor airflow rate required by Table 2, even though the space is occupied. Ventilation delay is allowed only if the space contaminants are associated with the occupants, do not pose a short-term health threat and can be purged from the space during unoccupied periods. If these conditions are met, a control scheme can be used whereby delivery of the required outdoor airflow rate is delayed for a prescribed time after the space becomes occupied. Permissible lag time is prescribed by the standard based on occupant density and the required outdoor airflow rate.

This type of lag-ventilation control scheme is often used in conjunction with night purge operation. Night purge provides unoccupied ventilation. Variable-occupancy spaces are ventilated with outdoor air for a portion of the unoccupied time to remove accumulated contaminants. Night purge is usually terminated when the quality of the indoor air is essentially the same as that of the outdoor air, or when the indoor temperature reaches a low limit.

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Do some spaces require ventilation before occupancy? Yes. The standard **suggests** that ventilation lead occupancy for some variable-occupancy spaces.

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"When contaminants are generated in the space or the conditioning system independent of occupants or their activities, supply of outdoor air should lead occupancy so that acceptable conditions will exist at the start of occupancy" (Section 6.1.3.4).

For some variable-occupancy spaces, this suggestion encourages the building designer to supply the outdoor airflow rate required by Table 2 for a prescribed time period prior to occupancy of the space. If the contaminants in a variable-occupancy space are associated with the space itself, not the occupants, a control scheme should be used whereby delivery of the required outdoor airflow rate begins before the space becomes occupied. Required lead time is prescribed by the standard based on occupant density and the required outdoor airflow rate.

This type of lead-ventilation control scheme is similar to night purge operation. Preoccupancy purge, however, terminates at the time of occupancy.

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If short-term occupancy peaks occur in variable-occupancy spaces, can the required outdoor airflow rate be reduced from the Table 2 value? Yes. For some variable-occupancy spaces, the standard **allows** a calculated minimum outdoor airflow rate based on average building occupancy rather than peak space occupancy.

"Where peak occupancies of less than three hours duration occur, the outdoor airflow rate may be determined on the basis of average occupancy for buildings for the duration of operation of the system, provided the average occupancy used is not less than one-half the maximum" (Section 6.1.3.4).

This **suggestion** allows the building designer to use an average occupancy value when determining the required outdoor airflow rate for variable-occupancy spaces. Again, the apparent reason for this exception is to avoid overventilating some spaces, such as conference rooms and auditoriums, and thereby save energy. If our interpretation of this suggestion is correct, the building designer can calculate the minimum outdoor airflow for a variable-occupancy space using the per-occupant minimum required by Table 2, in conjunction with average building occupancy, rather than peak space occupancy. For example, peak space occupancy may be 8 people per 1,000 ft^2, while average building occupancy is only 5 people per 1,000 ft^2. In this case, the outdoor airflow rate for a 1,000 ft^2 conference room in a 10,000 ft^2 building can be reduced from 160 cfm (8 people times 20 cfm/person) to 100 cfm (5 people times 20 cfm/person). If peak conference room occupancy is 20 people, the outdoor airflow rate cannot be reduced since the average building occupancy (5) is less than half of the peak space occupancy (20).

Summary

Section 6.1 of ASHRAE 62-89 helps the building designer by presenting a prescriptive method for achieving acceptable indoor air quality. It is very concise and complete for some design issues, but unclear on others. Overall, it provides the building designer with a valuable, relatively well-defined procedure for designing and specifying ventilation systems that deliver acceptable indoor air quality by diluting contaminants with outdoor air.

Our analysis of ASHRAE 62-89 will continue in a subsequent Engineers Newsletter with a discussion of Section 6.2, "Indoor Air Quality Procedure"...a less prescriptive, procedural path to conformance.

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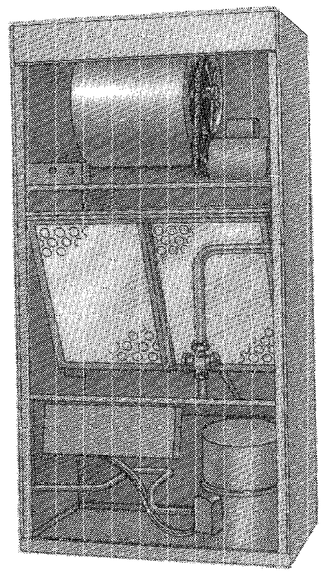

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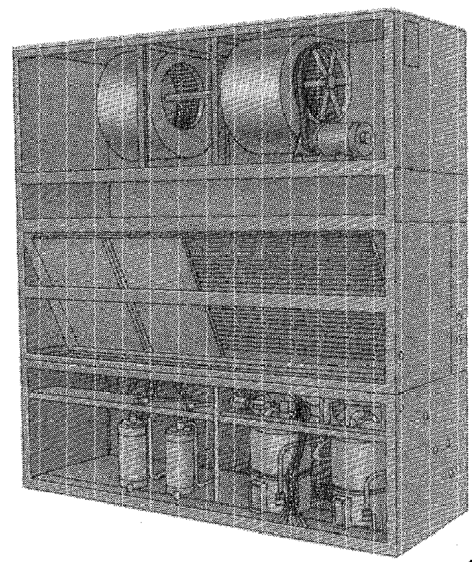

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