Compliance with the IAQ Procedure of ASHRAE® Standard 62.1-2016

IAQP updates and example

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Introduction

In 2011, Trane published an *Engineers Newsletter (EN)* that described how to determine minimum outdoor airflow using the Indoor Air Quality Procedure (IAQP) of ASHRAE® Standard 62.1.[1]

This white paper serves as a supplement to that previous EN, updates the procedures based on the 2016 version of Standard 62.1, and includes an example to help users through the requirements and design considerations of the IAQP.

ASHRAE Standard 62.1-2016

ASHRAE Standard 62.1, *Ventilation for Acceptable Indoor Air Quality*, prescribes requirements meant to ensure acceptable indoor air quality for the human occupants that minimize adverse health effects.[2] The standard is written in code-enforceable language to help streamline its adoption into building codes. There are three procedures available for compliance with Standard 62.1: the Ventilation Rate Procedure (VRP), the Indoor Air Quality Procedure (IAQP), and the Natural Ventilation Procedure (NVP). Project teams can choose one, or a combination, of these procedures to comply with the standard.

The VRP is the most-commonly used procedure for determining the minimum outdoor airflow requirements. (To learn more about how to apply the VRP, refer to the Trane *Engineers Newsletter Live* program for details.[3]) Use of the IAQP is not as common in the marketplace, in large part because of the assumptions and documentation required.

The intent of this white paper is to share an example, similar to the one included in the *Standard 62.1-2016 User's Manual* (pp. 119-122), so that project teams can better understand and apply the IAQP successfully.[4] The 2011 EN explained the following steps of the Indoor Air Quality Procedure:

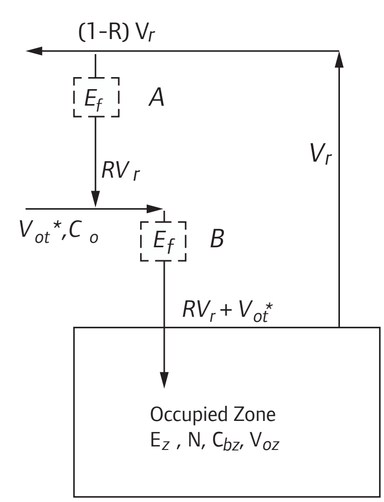
1. Identify all pollutants (contaminants-of-concern and mixtures-of-concern) for the zone
2. Identify both indoor and outdoor sources for each contaminant-of-concern
3. Determine the emission rate for each contaminant-of-concern from each identified source
4. Specify a concentration limit for each contaminant-of-concern
5. Specify the design limit for perceived IAQ criteria, in terms of percentage of occupants or visitors expressing satisfaction with the air quality
6. Using mass balance calculations, determine the minimum breathing-zone outdoor air flow rate necessary to meet the specified concentration limits for each contaminant-of-concern and mixture-of-concern
7. Perform either a subjective evaluation in the completed zone or a comparison to a "substantially similar zone" known to achieve the performance criteria

Example: IAQ Procedure

The example below demonstrates how to use IAQP for an auditorium that is served by a single-zone ventilation system.

- New construction
- Desired outdoor air intake flow rate of 3 cfm/person
- Perceived IAQ acceptability for 80% of occupants
- Single-zone air handler with a constant-speed supply fan, constant outdoor airflow, and an air cleaner mounted in location B (Figure 1)
- Net occupiable floor area of the zone, A_z = 2000 ft^2 (186 m^2)
- Zone volume = 20,000 ft^3
- Peak zone population, P_z = 300 people
- Design supply airflow, for both cooling and heating = 6000 cfm
- Location of supply-air diffusers = ceiling
- Location of return-air grilles = ceiling
- Zone air-distribution effectiveness (cooling), E_z = 1.0
- Zone air-distribution effectiveness (heating), E_z = 0.8

Figure 1. Figure E-1 from ASHRAE Standard 62.1-2016



Given these design criteria, the minimum required outdoor air intake flow (V_{ot}) required if using the VRP would be 2025 cfm:

$$V_{ot} = V_{oz} = V_{bz}/E_z = (5 \text{ cfm/person} \times 300 \text{ people} + 0.06 \text{ cfm/ft}^2 \times 2000 \text{ ft}^2)/0.8 = 2025 \text{ cfm}$$

Since reducing the outdoor air intake flow can potentially save energy, we will use the IAQP to see if we can reduce the intake to 900 cfm (3 cfm/person × 300 people).

Steps 1-4: Identify all contaminants-of-concern, indoor and outdoor source of each contaminant, emission rate of each contaminant from each source, and the concentration limit of each contaminant.

Indoor contaminants-of-concern (COC) might be generated from occupants, building materials, furnishings and finishes, and processes. Appendix C in Standard 62.1 is a useful reference for identifying indoor COCs.

The example in this white paper uses the same indoor and outdoor COCs as the example from the *Standard 62.1 User's Manual*.

- For this example, acetone, ammonia, hydrogen sulfide, methyl alcohol, and phenol were identified as human bioeffluent COCs in similar spaces.
- For this example, carbon monoxide, nitrogen dioxide, ozone, and sulfur dioxide were identified as outdoor COCs.
- For this example, formaldehyde was identified as a COC from both indoors (generated by building materials and furnishings) and outdoors.

The generation rate of each indoor COC and the concentration level of each outdoor COC are listed in Table 1, along with the concentration limit for each.

Table 1. Generation rates of indoor contaminants and concentrations of contaminants in outdoor air

Contaminant	Generation rate indoors	Concentration in outdoor air	Concentration limit
acetone	2.112 mg/h per person	0.007 ppm	7 mg/m³
ammonia	1.344 mg/h per person	0.005 ppm	0.5 mg/m³
carbon monoxide	0	2.2 ppm	9 ppm
formaldehyde	0.064 mg/h per m²	0.0068 mg/m³	0.009 mg/m³
hydrogen sulfide	0.114 mg/h per person	0.00033 ppm	0.04 mg/m³
methyl alcohol	3.102 mg/h per person	negligible	1.5 mg/m³
nitrogen dioxide	0	0.014 ppm	0.053 ppm
ozone	0	0.084 ppm	0.08 ppm
phenol	0.396 mg/h per person	0.000091 ppm	0.1 mg/m³
sulfur dioxide	0	0.002 ppm	0.03 ppm

Step 6: Using mass balance calculations, determine the minimum breathing-zone outdoor airflow rate necessary to meet the specified concentration limits for each pollutant.

Mass balance calculations are used to determine if the desired outdoor air intake flow (3 cfm/person × 300 people = 900 cfm, for this example) can sufficiently limit the indoor concentration of pollutants below the specified concentration limits.

Appendix E of Standard 62.1 lists mass balance equation for different types of ventilation systems. Following is the equation used to determine the concentration of each COC in the breathing zone (C_{bz}) for this example system—a single-zone ventilation system with a constant-speed supply fan, constant outdoor airflow, and an air cleaner mounted in location B (Figure 1):

$$C_{bz} = \frac{N + E_z V_{oz}(1 - E_f)C_o}{E_z(V_{oz} + RV_r E_f)}$$

where,

N = indoor generation rate of the contaminant

E_z = zone air-distribution effectiveness

V_{oz} = zone outdoor airflow

E_f = air cleaner efficiency

C_o = concentration of the contaminant in outdoor air

RV_r = flow rate of recirculated air

If needed, the following formula is used to convert units from ppm to mg/m³:

concentration (mg/m³) = concentration (ppm) × molecular weight (g/mol) / 24.45

Table 2. molecular weight of each contaminant-of-concern

Contaminant	Molecular weight, g/mol
acetone	58.08
ammonia	17.031
carbon monoxide	28.01
formaldehyde	30.031
hydrogen sulfide	34.1
methyl alcohol	32.04
nitrogen dioxide	46.0055
ozone	48
phenol	94.11
sulfur dioxide	64.066

For this example, the concentration of formaldehyde in the breathing zone is calculated to be 0.0061 mg/m³:

$$C_{bz} = \frac{11.9\,\frac{mg}{h} + 0.8 \text{ x } 1530\,\frac{m^3}{h} \text{ x } (1 - 0.25) \text{ x } 0.0068\,\frac{mg}{m^3}}{0.8 \text{ x } (1530\,\frac{m^3}{h} + 8665\,\frac{m^3}{h} \text{ x } 0.25)}$$

where,

N = indoor generation rate of formaldehyde = 0.064 mg/h per m² × 186 m² = 11.9 mg/h

E_z = zone air-distribution effectiveness = 0.8

V_{oz} = zone outdoor airflow = 900 cfm (1530 m³/h)

E_f = air cleaner efficiency = 0.25 (25%)

C_o = concentration of formaldehyde in outdoor air = 0.0068 mg/m³

RV_r = flow rate of recirculated air =6000 cfm (supply) –900 cfm (OA) = 5100 cfm (8665 m³/h)

As listed in Table 1, the project team specified the concentration limit for formaldehyde to be 0.009 mg/m³, according to Table C-3 in Standard 62.1. Therefore, for this example, the desired outdoor air intake flow of 900 cfm (3 cfm/person) is sufficient to limit the concentration of formaldehyde in the breathing zone (0.0061 mg/m³) below this concentration limit.

This calculation is repeated for each contaminant-of-concern (Table 3). The resulting breathing-zone concentration for each contaminant is below the acceptable limit (% of limit < 100%), but we still need to analyze mixtures-of-concern.

Table 3. Breathing-zone concentrations for each contaminant-of-concern

Contaminant	Breathing-zone concentration, C_{bz}	Concentration limit	% of limit[a]	Affected organ systems[b]
acetone	0.2195 mg/m^3	7 mg/m^3	3%	mucous membranes, central nervous system
ammonia	0.1375 mg/m^3	0.5 mg/m^3	27%	respiratory
carbon monoxide	0.6828 ppm	9 ppm	8%	blood
formaldehyde	0.0061 mg/m^3	0.009 mg/m^3	68%	mucous membranes, carcinogen
hydrogen sulfide	0.0177 mg/m^3	0.04 mg/m^3	29%	mucous membranes, central nervous system
methyl alcohol	0.3148 mg/m^3	1.5 mg/m^3	21%	central nervous system
nitrogen dioxide	0.0043 ppm	0.053 ppm	8%	respiratory
ozone	0.0261 ppm	0.08 ppm	33%	respiratory
phenol	0.0403 mg/m^3	0.1 mg/m^3	40%	mucous membranes, central nervous system
sulfur dioxide	0.0006 ppm	0.03 ppm	2%	respiratory

a. % of limit = (C_{bz} / concentration limit) × 100

b. Agency for Toxic Substances and Disease Registry, www.atsdr.cdc.gov

Next, confirm that contaminant mixtures-of-concern comply with the following equation:

$$\sum_{i=1}^{n} \frac{C_i}{T_i} \times 100 < 100$$

where,

C_i = airborne concentration of contaminant

T_i = threshold-limit value if contaminant (Appendix C of ASHRAE 62.1)

In Table 4, individual columns were added for each affected organ system, and the calculated % of limit for each individual contaminant-of-concern (from Table 3) is summed in the last row of the table. For example, acetone impacts both the mucous membranes and the central nervous system, so the same 3% value is copied into each of these two columns. Then then values in each column are summed, showing the total impact on the respective organ system.

For this example, the total impact on irritation of the mucous membranes (140%) exceeds 100%, so this design does not satisfy the mixture equation.

Table 4. Contaminant mixtures-of-concern

Contaminant	% of limit	Affected organ system				
		Mucous membranes	Central nervous system	Respiratory	Blood	Carcinogen
acetone	3%	3%	3%			
ammonia	27%			27%		
carbon monoxide	8%				8%	
formaldehyde	68%	68%				68%
hydrogen sulfide	29%	29%	29%			
methyl alcohol	21%		21%			
nitrogen dioxide	8%			8%		
ozone	33%			33%		
phenol	40%	40%	40%			
sulfur dioxide	2%			2%		
Totals		**140%**	**93%**	**70%**	**8%**	**68%**

To address this, the ventilation system design might be improved by increasing the outdoor air intake flow, reducing the indoor emission rate of contaminants by selecting different construction materials, finishes, or furnishings, or selecting an air cleaner with a higher efficiency.

Table 5 shows the impact of each of these design changes.

- For Alternative 1, the outdoor air intake flow was increased from 900 cfm to 2025 cfm, which is the flow rate required by the VRP. Increasing the OA intake decreased the impact on irritation of the mucous membranes, but it still exceeds the 100% threshold for this organ system. It also increased the impact of the respiratory, blood, and carcinogen organ systems.

- For Alternative 2, the indoor emission rate of formaldehyde was reduced from 0.064 to 0.021 mg/h per m^2 by selecting different construction materials, finishes, or furnishings. While this decreased the impact on irritation of the mucous membranes, it still did not reduce the mixture % below the 100% threshold for this organ system.

- For Alternative 3, an air cleaner is selected that is more effective (50% air cleaner efficiency) at removing these contaminants. This successfully decreased the mixture % below the 100% threshold for all affected organ systems.*

* Note: Air cleaner efficiencies for different types of contaminants are rarely similar. However, to simplify our example, we use a blanket 25% (original design) and 50% (Alternative 3) of air cleaner efficiency for all contaminants-of-concern.

Combining these design decisions, and conducting a life-cycle cost analysis, can help determine the best solution for IAQP intended projects.

Conclusions

The IAQP is a viable procedure that can be used to demonstrate compliance with Standard 62.1. However, many designers are uncomfortable with the approach due to lack of experience with it. The Standard 62.1 committee has formed a special technical resource group to work on further defining the requirements and helping to reduce uncertainties. And the U.S. Green Building Council has issued a pilot credit, called "Performance-Based Indoor Air Quality Design and Assessment," that allows the IAQP to be used and earn up to seven points for LEED v4 projects.[5]

By following the steps outlined in the EN and this white paper, a single-zone ventilation system can be designed to comply with the IAQP. However, successful application of the IAQP requires more than just understanding the mass-balance calculations:

- Project goals: Does the project team wish to focus on energy efficiency, acceptable IAQ, installed cost, operating costs, required maintenance, or all of the above? The project goals will influence the investment decisions into the types of HVAC equipment, building materials, or air cleaning equipment.

- Local code variance: The VRP is still the dominant procedure used for complying with Standard 62.1. To ensure acceptance when using the IAQP, discussions with local code officials should happen early in the design process. Some local officials may have established a list of indoor and outdoor COCs, emission rates and concentration limits, as well as reputable third-party references for these rates and limits. A mutually agreed upon statement on how to document and measure acceptable IAQ is a crucial step.

Table 5. Impact of system design modifications on contaminant mixtures-of-concern

Affected organ system	Original design	Alternative 1: increase OA intake to 2025 cfm	Alternative 2: reduced emission of formaldehyde to 0.021 mg/h per m^2	Alternative 3: increase air cleaner efficiency to 50%
mucous membranes	140%	123%	111%	84%
central nervous system	93%	68%	94%	59%
respiratory	70%	89%	70%	35%
blood	8%	12%	8%	3%
carcinogen	68%	70%	38%	38%

- Materials: The project team should investigate the cost, availability, and emission rates of different construction materials, finishes, and furnishings.

- Air cleaning products: Filters that are intended to reduce the concentration of particulate matter should be tested according to ASHRAE Standard 52.2, *Method of Testing General Ventilation Air-Cleaning Devices for Removal Efficiency by Particle Size*. The contaminant removal efficiency of other air cleaning devices should be tested according to ASHRAE Standard 145.2, *Laboratory Test Method for Assessing the Performance of Gas-Phase Air-Cleaning Systems*, or other methods supported by relevant cognizant authorities.

- Documentation and final acceptance of IAQ criteria: The project team should clearly document the local code variance (if applicable), as well as third-party references, COC limits, and mass balance calculations. Compiling this information could help speed up the building permit process. Since the design criteria is to reach perceived IAQ acceptability for at least 80% of occupants, the occupancy permits may be issued based on the outcome of the survey.

Further strengthening the IAQP through comprehensive, accepted, and published data about sources, mixtures, air cleaning effectiveness, and subjective evaluations will help this procedure receive broader adoption.

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