Air Cleaning in Practice – School Sustainability and Commercial Building Field Study Results

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Abstract

School Sustainability
The North East Independent School District (NEISD) is located in the Hot and Humid Climate Zone of San Antonio, Texas. The student population is 62,000 with growth of 2,000 students each year - 100 new classrooms. Under this type of growth, the school district sought ways to accommodate additional students, deal with moisture and humidity, provide acceptable air quality, and limit energy consumption. Beginning in 2003, the school district began using air cleaning and the Indoor Air Quality (IAQ) Procedure of ASHRAE Standard 62.1 as part of a plan to address these issues. Four elementary schools previously housed a total of 106 portable classrooms. School additions replaced these classrooms with permanent buildings using the IAQ Procedure to design the HVAC outdoor air requirements. These designs reduced outdoor air requirements from a total of 41,856 cfm to 14,375 cfm, a difference of 27,480 cfm. They also evaluated air quality by modeling acetone, ammonia, carbon monoxide, formaldehyde, hydrogen sulfide, methyl alcohol, nitrogen dioxide, ozone, phenol, sulfur dioxide, and total volatile organic compounds. Positive results included the reduction of many contaminant concentrations, lower inhaler usage, and operational savings.

Commercial Building Field Study Results
Air cleaning and air filtration are present in many commercial buildings. The two main applications for sustainability are:

1. Reduction in Contaminants of Concern to improve indoor air quality and
2. Reduction of building exhaust through contaminant removal.

With this being the case, a lack of data exists for air quality in buildings using filtration and air cleaning devices to improve air quality and reduce energy consumption. In order to provide such information to building owners, engineers, and IAQ professionals, field studies evaluated air quality at several building types using filtration and air cleaning – lecture hall, retail store, movie theater, and office spaces. The results will compare contaminant, particle, and viable particle concentrations within building spaces to those in the outdoor air and within other building air streams. These results will also compare the effects of filtration and air cleaning within various building air streams – particularly re-circulated exhaust air streams.

School Sustainability

The American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) first published their ventilation standard in 1973. The original version prescribed minimum ventilation air quantities in terms of volumetric flow rates per person (ASHRAE 1981). In 1981, the standard added the Indoor Air Quality (IAQ) Procedure as a performance based approach for determining minimum ventilation rates. The standard called the original method of using prescribed ventilation rates the Ventilation Rate Procedure (VRP). In 2004, the standard modified the IAQ Procedure to improve enforceability. In 2007, the standard added an informative appendix summarizing documentation requirements for the IAQ Procedure. The current version has the title ASHRAE/ANSI Standard 62.1-2013 Ventilation for Acceptable Indoor Air Quality (ASHRAE 2013).

According to the *62.1 Users Manual,* engineers have used the Ventilation Rate Procedure more often than the IAQ Procedure and the same was true for the NEISD. The district began to use the IAQ Procedure in school renovations and new buildings and it incorporated Purafil's gas-phase air filtration technology with the IAQ Procedure to reduce outdoor air requirements, improve building IAQ, and increase sustainability.

NEISD resides in the United States Department of Energy's Hot and Humid Climate Zone. It is one of thirteen school districts in San Antonio, TX. The student population is 62,000 and grows at a rate of 2,000 students per year. This population growth is equivalent to adding 100 new classrooms each year.

In 2006, seven elementary schools surpassed their classroom and core capacity and five schools placed caps on new enrollment. By 2010, three middle schools expect to exceed their classroom and core capacities. Under this type of growth, the school district sought ways to accommodate the additional students, handle the moisture and humidity of their climate zone, meet classroom needs for acceptable air quality, and limit energy consumption.

NEISD used the Ventilation Rate Procedure for many projects before using the IAQ Procedure. A series of schools bonds for new schools and renovations to existing schools used only the Ventilation Rate Procedure as the basis of design for determined the outdoor air ventilation rates for the heating, ventilation, and air-conditioning (HVAC) systems. Subsequent school bonds for new construction provided for the use of both the Ventilation Rate Procedure and the IAQ Procedure for comparison of the two design approaches. The Ventilation Rate Procedure was used for four elementary schools and the IAQ Procedure was used for four elementary schools, two middle schools, and one high school. The most recent bond used the IAQ Procedure for four elementary schools and four school additions.

NEISD uses the Purafilter™ combination gas-phase + particulate filters in their IAQ Procedure designs. These filters contain adsorptive and chemisorptive media for the removal of gases and an integral particulate filter medium for the removal of particles. Contaminant modeling determined minimum outdoor air requirements based on filter efficiencies, contaminant sources, and operational conditions of the HVAC systems. The design approach employed was the Mass Balance Analysis of the IAQ Procedure (see the *62.1 Users Manual* for more details).

Four School Examples of the IAQ Procedure

Comparison of four example schools provides an overview of the NEISD's experience. The example schools include two currently operating high schools and two currently operating elementary schools.

One school uses constant volume systems and three use variable air volume systems. The schools achieve various levels of outdoor air reduction, various levels of contaminant control, and various sustainable impacts based on the specific system parameters. Table I provides an overview of each school broken out into total building and typical classroom properties.

Table I - Overview of Example School Buildings

Parameter	**High Schools**		**Elementary Schools**	
	School 1 [Madison]	**School 2 [Roosevelt]**	**School 3 [Ridgeview]**	**School 4 [Colonial Hills]**
Total Building				
Area (ft^2)	15,255	19,780	25,866	28,684
Occupants	258	434	627	774
Supply (cfm)	29,600	19,313 - 7,367	35,305 - 8,830	37,035 - 9,259
Type	constant volume	variable air volume	variable air volume	variable air volume

Parameter	High Schools		Elementary Schools	
	School 1 [Madison]	**School 2 [Roosevelt]**	**School 3 [Ridgeview]**	**School 4 [Colonial Hills]**
Typical Classroom				
Area (ft^2)	2,100	850	730	730
Occupants	31	31	26	26
Occupants/(1000 ft^2)	15	36	36	36
Supply (cfm)	3,650	1,270 - 420	960 - 240	980 – 245
Zone Types				
classroom	x	x	x	x
conference			x	x
corridor	x	x	x	x
electrical closet		x		
janitor's closet		x		
lobby		x		
office	x		x	x
restroom	x	x	x	x
storage	x	x	x	x
workroom				x

Comparison of Example School Outdoor Air Rates by Both Procedures

Engineers calculated minimum outdoor air flows for these schools by the Ventilation Rate Procedure and by the IAQ Procedure. The additional gas-phase and particulate filtration allowed the IAQ Procedure to use less ventilation air. Outdoor air amounts for the Ventilation Rate Procedure were 15 – 43% of supply. Dividing these outdoor air amounts by the total occupancies of each school yields overall per person ventilation rates of 15 – 20 cfm per person. Outdoor air amounts for the IAQ Procedure were 4 – 14% of supply. Dividing these outdoor air amounts by the total occupancies yields overall per person ventilation rates of 5 – 7 cfm per person. The average reduction in outdoor air amounts for these schools was close to 70%. Table II details the outdoor air amounts for each school.

Comparison of Example School Contaminant Concentrations Rates by Both Procedures

Contaminant modeling compared the concentrations of several contaminants at the two outdoor air amounts, one amount for the Ventilation Rate Procedure and one amount for the IAQ Procedure. The models were multiple zone systems, considering the effect of recirculation from other zones on the final concentration within classrooms. Comparison of the model results with target concentration limits provides information on each design's ability to remove contaminants.

Table III displays classroom concentration results for formaldehyde and nitrogen dioxide. In this model, formaldehyde represents contaminants having a source within the building and a constant emission rate. Nitrogen dioxide represents contaminants having a source outside the building with a steady concentration in the outdoor air. Each design procedure affects these two contaminant types differently.

Formaldehyde Concentrations

At design flow conditions, the formaldehyde classroom concentrations under the IAQ Procedure were less than those under the Ventilation Rate Procedure. This is true for every school. The IAQ Procedure provided a filtration and dilution rate *greater than* the dilution only rate of the Ventilation Rate Procedure at design flow.

At minimum flow conditions, the formaldehyde classroom concentrations under the IAQ Procedure were greater than those under the Ventilation Rate Procedure. The decreases in supply air flow decreased the amount of filtration performed in the building - the filters contacted less air. The IAQ Procedure provided a filtration and dilution rate *less than* the dilution only rate of the Ventilation Rate Procedure at minimum flow.

Table II –Outdoor Air Amounts for Example School Buildings

Parameter	High Schools		Elementary Schools	
	School 1 [Madison]	School 2 [Roosevelt]	School 3 [Ridgeview]	School 4 [Colonial Hills]
Design Supply (cfm)	29,600	19,313	35,305	37,035
Occupants	258	434	627	774
Ventilation Rate Procedure				
Outdoor Air (cfm)	4,295	6,921	9,405	16,000
OA % of Supply	15%	36%	27%	43%
OA Overall per Person	17	16	15	21
Indoor Air Quality Procedure				
Outdoor Air (cfm)	1,290	2,170	3,135	5,160
OA % of Supply	4%	11%	9%	14%
OA Overall per Person	5	5	5	7
Total Outdoor Air Reduction				
Flow (cfm)	3,005	4,751	6,270	10,840
%	70%	69%	67%	68%

Table III – Contaminant Concentrations for Example School Classrooms

Contaminant & Condition	High Schools		Elementary Schools	
	School 1 [Madison]	School 2 [Roosevelt]	School 3 [Ridgeview]	School 4 [Colonial Hills]
Formaldehyde % of Limit				
Design Flow				
Ventilation Rate Procedure	36%	13%	15%	12%
Indoor Air Quality Procedure	17%	9%	11%	9%
Min Flow				
Ventilation Rate Procedure	n/a	12%	17%	17%
Indoor Air Quality Procedure	n/a	17%	24%	20%
Nitrogen Dioxide % of Limit				
Design Flow				
Ventilation Rate Procedure	30%	32%	30%	30%
Indoor Air Quality Procedure	4%	8%	7%	9%
Min Flow				
Ventilation Rate Procedure	n/a	32%	30%	30%
Indoor Air Quality Procedure	n/a	15%	17%	19%

Nitrogen Dioxide Concentrations

At all flow conditions, the nitrogen dioxide classroom concentrations under the IAQ Procedure were less than those under the Ventilation Rate Procedure. The Ventilation Rate Procedure has no filtration of nitrogen dioxide. The source of nitrogen dioxide is the outdoor air, the Ventilation Rate Procedure's clean air source. The IAQ Procedure filtered nitrogen dioxide from the outdoor air and the re-circulated air. With no internal source, the IAQ Procedure provided a removal rate *greater than* the Ventilation Rate Procedure at all flows.

Comparison of Example School Energy Requirements and Emissions

The different outdoor air amounts require different energy amounts to cool or heat the outdoor air appropriately. Energy estimates compared the Ventilation Rate Procedure's energy requirement to the IAQ Procedure's energy requirement. The bases of these estimates were local weather bin data, school run hours, and the different amounts of outdoor air. The estimates also included the associated carbon dioxide emissions. The IAQ Procedure produced savings and reductions for each school's heating, ventilation, and air conditioning systems. Table IV displays the amount of savings and reductions for each school. The cooling energy reductions averaged 61%. The heating energy reductions averaged 54%. The carbon dioxide emission reductions averaged 59%. The annual monetary savings averaged 58%.

Table IV – IAQ Procedure Energy Savings and Emission Reductions for Example School HVAC Systems

Contaminant & Condition	High Schools		Elementary Schools	
	School 1 [Madison]	School 2 [Roosevelt]	School 3 [Ridgeview]	School 4 [Colonial Hills]
Total Outdoor Air Reduction				
Flow (cfm)	3,005	4,751	6,270	10,840
%	70%	69%	67%	68%
Cooling Energy Reduction				
Annual Total (kWh/yr)	18,073	32,486	21,780	39,449
Annual Reduction (%)	57%	63%	59%	63%
Heating Energy Reduction				
Annual Total (therms/yr)	1,177	1,860	707	1,269
Annual Reduction (%)	70%	69%	37%	39%
Associated CO_2 Emission Reductions*				
Annual Total (tons/yr)	20	34	20	35
Annual Reduction (%)	61%	65%	53%	56%
Total HVAC Energy Savings**				
Annual ($/yr)	$3,246	$5,535	$3,079	$5,564
Annual Reduction (%)	62%	65%	51%	54%

* Carbon dioxide emission reductions used Texas carbon dioxide emission factors for electricity generation and the Environmental Protection Agency's carbon dioxide emission factors for gas heating (EIA Nov. 2007, EPA 2006).
** The total energy savings used average retail electricity prices for Texas and commercial natural gas prices for the United States (EIA Nov. 2007; EIA Dec. 2007).

Lessons Learned

First, the effectiveness of gas-phase filtration depends on the amount of air the filters contact. When the primary air flow decreases, the contaminant concentration increases; the filtration system removes less of the contaminant because it is cleaning less air. Examples here contained minimum primary flows ranging from 25-35% of the design flow. These equated to primary flows per unit area of 0.32 – 0.49 cfm/ft^2. Designs using the IAQ Procedure and gas-phase filtration must keep minimum primary flows above certain limits to provide contact time with the filters.

Second, lowering outdoor air rates with the IAQ Procedure can affect building pressurization. The reduced outdoor air amount needs to make up the air exhausted from the building, or other means of acceptable transfer air must make up the difference. Examples here limited the outdoor air rate of air handlers. These designs also provided transfer air from other systems when one system could not make-up all the exhausts in its area. The IAQ Procedure's overall design must provide enough outdoor air to exhaust locations and keep the building under a positive pressure.

Third, internal sources with higher emission rates may prevent the use of re-circulated air with typical gas-phase and particulate filtration. These sources require local exhausts or stronger gas-phase and particulate filtration equipment. Some examples of internal sources with higher emission rates may include art classrooms, janitor's closets, kitchen areas, science laboratories, and woodwork shops. The examples here excluded certain air handling systems from re-circulating air with the IAQ Procedure because they contained internal sources higher emission rates. Designs using the IAQ Procedure should consider the sources within various spaces and exhaust or filter strong sources appropriately.

Commercial Building Field Study Results

For many buildings, the IAQ Procedure is an option that provides direct control of indoor air contaminants not possible under the Ventilation Rate Procedure. This provides improved indoor air quality as well as reducing the amount of energy spent on conditioning the ambient air. This makes it a powerful tool for building owners and engineers to employ.

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

Energy analysis calculations for a specific building can be performed independently or with a number of commercially available software packages. Different geographic locations will require the use of several different sets of data (weather data, utility costs, etc.) that can affect the operation and performance of the HVAC system.

Many different applications can be designed using the IAQ Procedure. The most common applications, and those with the greatest potential for capital cost savings and operational cost reductions, involve new construction and renovation. Examples are described below.

Example 1 - lecture hall, new construction, single zone modeling
The IAQ Procedure was applied in a new construction application where the design criteria included an outdoor air intake rate of 5 cfm/person[1], perceived IAQ acceptability of 80% of occupants, an air handler with constant outdoor and supply airflows, the air cleaner location in the supply (mixed) airstream, and a supply airflow of 20,000 cfm. Given these design criteria, the outdoor air intake flow required using the VRP would be 6,584 cfm as compared to 3,000 cfm using the IAQ Procedure.

For indoor contaminants, the "contaminants of concern" (COCs) must be chosen as well as the generation rates of these contaminants from occupants, materials, and processes. Acetone, ammonia, hydrogen sulfide, methyl alcohol, and phenol were chosen to be indicators of human activities (Wang 1975). The contaminants from building materials and processes were selected to be formaldehyde and total volatile organic compounds (Offerman et al. 1993).[2] The outdoor air contaminants; carbon monoxide, nitrogen dioxide, ozone, and sulfur dioxide were obtained from the Air Quality System database (EPA 2003). Each of these contaminants is representative of compounds in indoor and outdoor air and there is much data in the public domain from which concentrations and generation rates could be obtained (Brightman et al. 1995; Girman et al. 1995; Womble et al. 1995).[3]

The mass-balance equations from Appendix D of ASHRAE 62.1 were used to determine the space contaminant concentration for this particular system configuration and to determine if the resulting space contaminant concentrations would be acceptable using the lower outdoor air quantities. Calculations confirmed that an outdoor air intake rate of 2.4 L/s (5 cfm)/person was sufficient to provide space concentrations of the COCs below the established target concentration limits would therefore comply

[1] The choice of the outdoor air intake rates to use with the IAQ Procedure can be based on a simple reduction of those prescribed by the VRP (i.e., 25%, 50%, 75%, etc.), based on some fixed value necessary to recover exhaust air volumes and maintain pressure differentials in the space (building), or based on economic considerations due to estimated HVAC system capital and/or operational savings possible by a reduction in heating and cooling requirements.
[2] TVOC was chosen due to the fact that many of the published building studies include this as an air quality indicator – and sometimes as the sole indicator of air quality.
[3] For this example, the COCs were chosen using the best available information and based upon agreement between the HVAC system designer, the building owner/operator, and the authority having jurisdiction. This could include published building studies and general IAQ studies, review of IAQ standards and guidelines, etc.

with the requirements of the IAQ Procedure. The mass balance analysis results for all COCs used in this example are shown in Table V.

Table V – Space (Zone) Contaminant Concentration Results For COCs

Contaminant	Units	Conc. Value	Target Conc. Limit	% Target
Acetone	[mg/m^3]	0.134	7	2%
Ammonia	[mg/m^3]	0.202	0.5	40%
Carbon monoxide	[ppm]	2.2	9	24%
Formaldehyde	[mg/m^3]	0.0178	0.12	15%
Hydrogen sulfide	[mg/m^3]	0.00708	0.04	18%
Methyl alcohol	[mg/m^3]	0.189	1.5	13%
Nitrogen dioxide	[ppm]	0.00434	0.053	8%
Ozone	[ppm]	0.0261	0.08	33%
Phenol	[mg/m^3]	0.0242	0.1	24%
Sulfur dioxide	[ppm]	0.000621	0.03	2%
TVOC	[mg/m^3]	0.248	1	25%

Summary of Estimated Savings for Reduction of Conditioned Outside Air[4]

Capital Equipment: US$8,643.00 Operational: US$1,136.00 / year

Example 2 - retail store, new construction, multizone modeling

A retail store being built had the following space types: corridors, fitting rooms, and sales areas. A mass balance analysis could be used for the application of the IAQ Procedure for this multizone system; however, the recirculation of air between zones is not easily accounted for using the mass balance equations from Standard 62.1. For multizone systems such as this, the software tool CONTAM (Anon 2007) was utilized to perform the mass balance analysis.

For this example, the same indoor and outdoor contaminants, air change effectiveness, and air cleaning efficiency data as in Example 1.[5] The additional information necessary to perform the mass balance analysis for this example is shown in Tables VI and VII below.

The CONTAM software was used with the information provided above to calculate the space/zone concentrations based on outdoor air of 7 cfm/person at the outdoor air intake, i.e. 7 cfm/person multiplied by total occupancy. The results are displayed in Table VIII as a percent of the target concentration limit for each contaminant. The outdoor air contaminants and concentrations were obtained from the AIRS database (EPA 2007, 2008) for the monitoring station nearest the site. All calculations were carried out at steady state.

As in Example 1, all of the contaminants of concern are less than the target concentration limits when using a mass balance analysis design approach. Therefore, using a total system outdoor airflow of 7 cfm/person would comply with the requirements of the IAQ Procedure of Standard 62.1.

Table VI – Air Handler Description

Supply Airflow Type	Outdoor Airflow Type	Filtration Location	Supply Air	Outdoor Air VRP	Outdoor Air IAQP[6]
Constant	Constant	Supply	3,900 cfm	1900 cfm	525 cfm

[4] HVAC system cost / savings information using bin method.

[5] NOTE: Each application of the IAQ Procedure requires a separate determination of contaminant sources and concentrations as well the appropriate design approach to use.

[6] The desired limit was 1,900 cfm (897 m^3/hr) which resulted in an outdoor airflow rate at the intake of 7 cfm (3.3 L/s) per person based on total occupancy.

Table VII – Zone Information

Zone #	Room Designation	Area (ft^2)	Volume (ft^3)	No. People	Supply Air (cfm)			Supply Location	Return Location	Air Change Effectiveness
					Cooling	Heating	Min			
1	Corridor	301	3,355	0	84	42	21	Ceiling	Ceiling	0.8
2	Fitting room	485	4,308	5	192	96	48	Ceiling	Ceiling	0.8
3	Fitting room	540	4,875	5	258	129	65	Ceiling	Ceiling	0.8
4	Sales 1	6,040	66,420	60	934	467	233	Ceiling	Ceiling	0.8
5	Sales 2	1,625	17,900	16	233	117	58	Ceiling	Ceiling	0.8
6	Sales 3	9,825	108,100	98	1,105	553	277	Ceiling	Ceiling	0.8
7	Sales 4	8,790	96.600	88	1,105	553	277	Ceiling	Ceiling	0.8

Table VIII – Resulting Zone Contaminant Concentrations as Percent of Target Concentration Limit

Zone Number	1	2	3	4	5	6	7
Acetone	1	1	1	1	1	1	1
Ammonia	26	27	27	29	29	30	30
Carbon monoxide	71	71	71	71	71	71	71
Formaldehyde	23	21	21	26	27	30	28
Hydrogen sulfide	8	9	9	12	12	13	12
Methyl alcohol	6	7	6	8	8	9	9
Nitrogen dioxide	4	4	4	4	4	4	4
Ozone	34	34	34	34	34	34	34
Phenol	11	13	12	16	16	18	17
Sulfur dioxide	6	6	6	6	6	6	6
TVOC	30	28	27	35	36	39	38

Summary of Estimated Savings for Reduction of Conditioned Outside Air

Capital Equipment: US$8,845.00 Operational: US$2,641.00 / year

Example 3 - Movie Theater, new construction, single zone modeling

The IAQ Procedure was applied in the construction of a movie theater where air cleaning and recirculation would be used in an effort to reduce the outdoor air below the 20 cfm per person prescribed by the VRP. The HVAC system used in this case supplied a constant volume of supply and outdoor air while varying the temperature to meet comfort criteria. The air cleaning system was located in the recirculation airstream. Input of the appropriate design criteria showed that a reduction to 5 cfm per person would be possible. This would result in a much smaller HVAC system being specified for the theater and result in an immediate capital savings of US $68,000 for the owner.

A reduction in the amount of outside air also meant that less air would have to be tempered by the HVAC system. This would result in an additional operational savings (energy savings – air cleaner media replacement, etc.) of approximately US$15,000/year. This takes into account energy cost savings of US $23,000/year (as compared to the VRP) and maintenance and energy costs for the air cleaning system of US$8,000/year.

The same mass-balance equation used in Example 1 was used to determine the space contaminant concentration for this particular system configuration (Table IX). These resulting concentrations were be compared against ambient air quality standards (EPA 2001) for the outdoor air contaminants and against referenced guidelines for acceptable indoor levels of indoor levels of acetone, ammonia, hydrogen sulfide, and phenol. According to the mass balance model used, all contaminants would be below their listed limit values.

Table IX – Calculated Space Contaminant Concentrations for New Theater Project

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

[a] U.S. EPA National Primary Ambient Air Quality Standards [b] ASHRAE Standard 62.1 [c] Not Available

A cost/benefit analysis was performed using the IAQ Procedure which determined this would allow the owners maintain their current outdoor air intake rates and avoid the entire upgrade cost altogether. The only additional cost would be for the additional air cleaning required.

In this renovated office building, the filters were located in the supply air stream cleaning both recirculated air and make-up air. The mass balance model used for calculation of space contaminant concentrations showed similar results as in the previous example – limit values were not exceeded.

For this application, the outdoor air contaminants were taken, as before, from the EPA Air Quality System database. The internally generated bioeffluents were taken from the same classroom study, which was considered to be a conservatively high generation rate for office spaces. A study that measured levels during installation of office equipment and furniture was used to estimate generation rates for the office building (Grot et al. 1990). Levels were expected to decrease over the life of the building, and were also considered to be conservatively high. These parameters as well as resulting contaminant concentrations are shown in Table X. The air cleaners used were combination particulate / chemical filters.

Table X – Calculated Space Contaminant Concentrations for Office Renovation Project

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

[a] US EPA National Primary Ambient Air Quality Standards [b] ASHRAE Standard 62.1 [c] Not Available
[d] Generation rates in mg/min [e] Converted from 1 mg/m^3 target level recommended by EPA [Tucker, 1998]

The resulting concentrations in the space were compared with published limit concentrations. Even using high initial contaminant levels, all resulting levels were below the corresponding limit concentrations.

The mass balance analysis proved the assumption of acceptable IAQ in this space through direct control of those contaminants most often implicated as being causes or major contributors to poor IAQ and IAQ complaints. The application of the IAQ Procedure would cost an additional US$10,000 per year over current operating costs (energy savings of US$11,000/year – when using 5 cfm/person versus 15 cfm/person minus the annual replacement cost of the filters US$21,000). However, avoiding the cost to fully upgrade the HVAC system would pay for 28 years of the additional operating cost.

Summary and Conclusions

The IAQ Procedure in ASHRAE Standard 62.1-2013 may be used as an alternative to the Ventilation Rate Procedure (VRP) for the determination of outdoor air ventilation rates. While the VRP is a prescriptive procedure that determines minimum outdoor air ventilation rates for typical applications, the IAQ Procedure is a performance-based design approach that focuses on controlling the concentrations of contaminants to certain levels and maintaining a specified percentage of occupant satisfaction. The VRP is an indirect solution to achieving acceptable IAQ in that it assumes that the outdoor air being used for ventilation is of acceptable quality. The IAQ Procedure is a more direct approach to the goal, but it requires different methods, knowledge, evaluations, decisions, and documentation than those of the VRP.

The IAQ Procedure requires the building and its ventilation system to be designed to achieve both objective and subjective criteria and allows ventilation air to be reduced below rates that would have been required by the VRP, when it can be reliably demonstrated that the resulting air quality meets the required criteria for contaminant sources and concentrations and the perceived indoor air quality. Designing for compliance using the IAQ Procedure requires:

1. Identifying contaminants of concern (COC);
2. Determining acceptable concentrations of these contaminants;
3. Specifying the perceived indoor air quality criteria; and
4. Applying an acceptable design approach to achieve the performance criteria.

Whereas the VRP focuses primarily on assuring acceptable indoor air quality, the IAQ Procedure provides a way to reduce HVAC system operating costs while still providing a healthy environment. It provides an approach in which the building and its ventilation system are designed to maintain the concentrations of specific contaminants identified during the building design at or below certain limits and to achieve the design target level of perceived IAQ acceptability by building occupants and/or visitors. It also provides for a direct solution for reducing and controlling contaminants to specified acceptable levels through air cleaning.

The IAQ Procedure is often neglected as a method for complying with the ventilation requirements of ASHRAE Standard 62.1-2013. Practical applications of the IAQ Procedure have been presented to show that air cleaning can effectively achieve acceptable air quality as well as reduce outdoor air requirements thus saving energy required to condition ambient air. These examples illustrate that significant capital and HVAC equipment and system renovation savings as well as ongoing energy savings can be realized by employing the IAQ Procedure. In times when energy conservation and sustainability are at the forefront of many peoples' minds, the IAQ Procedure should be considered as a proven option to achieve these goals.

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