Indoor Air Quality Update™

A Guide to the Practical Control of Indoor Air Problems, from Cutter Information Corp.

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EPA RELEASES LANDMARK STUDY

Most *IAQU* readers accept the idea that building materials, furnishings, and consumer products emit chemicals to indoor air and that they are responsible for a significant fraction of indoor air pollution. We also know that indoor air levels of many volatile organic compounds (VOC) are higher than outdoor levels, sometimes 10 to 100 times higher. EPA has just released a two-volume, 1,221-page report that provides ample evidence supporting these ideas. The EPA report helps us understand the role that selected building materials and products play in contributing to the levels of various VOC found indoors. It also gives clear evidence of the dramatic changes that occur in building air over time, from construction and finish work to initial occupancy and during normal use patterns.

In This Issue

EPA released the massive report on November 10, reporting on a pair of indoor air studies. The studies focused on VOC and other air pollutant measurements in 10 buildings and on measurements of emissions from building materials, maintenance, and consumer products used in some of the buildings.

Research Triangle Institute in North Carolina prepared the report, which describes work under two separate contracts over a period of about three years. The whole two-part project is the largest and most comprehensive survey of its type ever done in the United States.

We are extracting the important findings and interpreting them for practical application to indoor air problems in buildings. This is the first *IAQU* article on the report, and we plan to examine details of the study in future articles.

Summary

Researchers investigated 10 public access buildings: three offices, a school, a combined university school/office building, two homes for the elderly, two nursing homes, and a hospital. The buildings were monitored for about three days on each site visit, and the number of visits ranged from one to three for each building, usually with several weeks or months between visits. The researchers measured new buildings immediately after completion and again after occupancy; they were thus able to compare air pollution levels and determine the effects that may be attributable to either emissions from new materials or to occupant activities.

Separate monitoring was done during daytime and nighttime periods. For most visits, the four sample locations included three indoors and one outdoors. And at each location during the second study (six buildings), triplicate samples were collected for VOC using different flow rates. Thus, multiple measurements are available for any given location during each trip.

On each visit the researchers measured indoor air concentrations of various chemicals and particles, and on most visits they measured ventilation rates at the same time. They collected and tested a variety of building materials from some of the study buildings and tested the emissions of VOC from those materials. The results of the emissions tests were compared to the levels found in the buildings.

Study Methods

For those of you interested in air sampling for research or investigations, here's a brief description of how the EPA studies were performed:

VOC: Air samples were collected in Tenax cartridges, thermally desorbed, and analyzed by GC-MS (gas chromatography-mass spectrometry). Sample volumes were 20 liters during the first study (four buildings) and triplicate samples of 10, 15, and 20 liters for the second study (six buildings).

Particles: Dichotomous samplers, using virtual impaction, collected air samples for particles in both fine (0.5μ) and coarse (2.5-10μ) fractions.

Emissions from materials: In the first study, several materials were studied by headspace vapor collection from samples in heated bell-jars, using Tenax adsorption and GC-MS analysis. Based on these results, several materials were then studied in a room-sized chamber. In the second study, 31 materials collected from a new office building were studied using headspace sampling. Based on these results, nine materials were selected for detailed study in 12-liter glass chambers. Again, Tenax and GC-MS were used for VOC collection and analysis.

Ventilation: SF_6 (sulfure hexafluoride), an inert gas, was released into the building air supply and allowed to mix and equilibrate; air samples were collected using sequential syringe samplers. Analysis was by GC-ECD (gas chromatography-electron capture detection).

Study Objectives and General Results

The objectives and summary results for the two studies included the following:

Identify all VOC that could be collected from the air by the Tenax adsorbent, and perform GC-MS detection on a subset of samples.

Of the 500 chemicals identified, half occurred only once. Thus, many small VOC sources are probably present in a typical building rather than a few dominant ones. Aliphatic hydrocarbons predominated, followed by aromatic hydrocarbons and chlorinated (halogenated) hydrocarbons (see Table 1). Alcohols, acids, ketones, aldehydes, and esters were also present. However, the chemicals observed were limited by the collection and analysis methods, and represent only a portion of all VOC present. The triplicate samples showed extremely small differences; this indicates that the method was reliable and that sample volume is not a critical factor.

Quantify the indoor and outdoor levels of a subset of the organic compounds, selected on the basis of potential health effects, production volume, and ease of collection on Tenax. These compounds were selected using information from previous EPA studies of indoor and outdoor VOC.

Indoor concentrations exceeded outdoor concentrations for all of the target compounds (see Table 2 for a typical case). These VOC were emitted by one or more of 19 materials studied in chamber tests during the first study.

Determine the effect of building aging on the concentrations of VOC in newly constructed buildings.

Newly installed or applied finishes in the new buildings resulted in VOC air levels 10 to 100 times higher than those measured in the same buildings months later. And new buildings had generally higher levels than older buildings. The effect of building aging on the VOC concentrations appeared to be dramatic, and there was a shift in the predominant types of VOC found from new to aged buildings.

Measure emissions from building materials and processes used in some of the buildings.

The results showed clearly that most of the VOC found in building air are emitted from common building materials. This should not be interpreted to mean that the only source of the VOC were building materials.

Measure concentrations of other air pollutants, including inhalable particles, metals, radon, formaldehyde, pesticides, PCBs, carbon monoxide, nitrogen dioxide, polynuclear aromatic hydrocarbons, and asbestos.

The studies found fine (inhalable) particle air levels to be significantly higher in smoking than in non-smoking areas, and they were clearly related to the number of

Table 1: Most Common Organic Compounds at Four Buildings

Class/Compound	N[a]	Class/Compound	N[a]
Aromatic Hydrocarbons		**Aldehydes**	
benzene	16	n-nonanal	13
toluene	16	n-decanal	10
xylenes	16		
styrene	16	**Miscellaneous**	
ethylbenzene	16	acetone	16
ethyl methyl benzenes	16	acetic acid	10
trimethyl benzenes	16	dimethylphenols	6
dimethylethylbenzenes	15	ethylene oxide	4
napthalene	15		
methyl napthalenes	15	**Aliphatics**	N[b]
propylmethylbenzenes	14	undecane	10
n-propyl benzene	13	2-methylhexane	9
diethyl benzenes	12	2-methylpentane	9
		3-methylhexane	9
Halogenated Hydrocarbons		3-methylpentane	9
tetrachloroethylene	16	octane	9
1,1,1-trichloroethane	15	nonane	9
trichloroethylene	14	decane	9
dichlorobenzenes	12	dodecane	9
trichloroflouromethane	12	tridecane	9
dichloromethane	11	methylcyclohexane	9
chloroform	10	heptane	8
		tetradecane	8
Esters		2-methylheptane	8
ethyl acetate	8	cyclohexane	8
m-hexyl butanoate	4	pentadecane	7
		4-methyldecane	7
Alcohols		2,4-dimethylhexane	7
2-ethyl-1-hexanol	9	pentane	6
n-hexanol	8	hexane	6
2-butyloctanol	7	eicosane	6
n-dodecanol	6	3-methylnonane	6
		1,3-dimethylcyclopentane	6

[a] Number of samples (of 16) with compound present
[b] Number of samples (of 10) with compound present

cigarettes smoked. Other measured variables were not remarkable.

Characterize ventilation in order to relate chemical air levels to air exchange.

Ventilation rates were generally low (less than one air change per hour [ACH]) in all visits to all ten buildings, except during one visit to an elderly home during extremely cold outdoor temperatures. VOC levels did not appear to be affected strongly by ventilation rates.

Other Discoveries

VOC

All 10 buildings had higher concentrations of VOC indoors than outdoors. In the newly constructed buildings, indoor-outdoor (I/O) total VOC concentration ratios measured shortly after construction were 50 to 1. For some VOC, the I/O ratios were as high as 400 to 1. After two months the I/O VOC ratio dropped to about 10 to 1, and several months later was closer to 5 to 1. The older buildings had I/O ratios of 2 or 3 to 1. The concentrations measured in one new office building fell from 1,300 $\mu g/m^3$ to 326 $\mu g/m^3$ in two months and to 150 $\mu g/m^3$ in another three months. (See Tables 2 and 3.)

Average VOC concentrations for the six buildings in the second part of the study for all samples (except the very high, post-construction levels at the new office building) ranged widely, from about 18 $\mu g/m^3$ to 220 $\mu g/m^3$, with the levels distributed rather evenly over that range. (See Table 4.)

Ventilation Rates

Typical average three-day ventilation rates were from 0.3 to 0.9 ACH, and the range was from about 0.14 (mostly at night in buildings with HVAC turned off for most of the night) to 1.7 ACH. The high level was in the elderly home mentioned above, when the indoor/outdoor temperature dif-

Table 2: Volatile Organics in a New Office Building

	Concentration ($\mu g/m^3$)			
	Indoors[a]			Outdoors[b]
Chemical	**July**	**Sept**	**Dec**	**All Trips**
Aliphatics				
decane	380	38	4	2
undecane	170	48	13	1
dodecane	47	19	5	0.2
Aromatics				
m+p-xylene	140	19	9	2
o=xylene	74	8	4	1
ethylbenzene	84	6	5	1
benzene	5	7	7	3
styrene	8	7	4	1
Halocarbons				
1,1,1-trichloroethane	380	100	49	6
tetrachloroethylene	7	2	3	1
trichloroethylene	1	38	27	0.3
carbon tetrachloride	1	1	1	1
chloroform	1	2	18	6
p-dichlorobenzene	1	1	1	ND
Total of 14 organics	**1,300**	**326**	**150**	**25**

[a] Mean of six 12-hour averages at five indoor locations
[b] Mean of 18 12-hour averages at one outdoor location

ferences were very large and caused high infiltration air exchanges.

In Table 4 we see the VOC concentrations and air exchange rates for all trips to the six buildings in the second study. There does not appear to be any consistent relationship between air exchange rates and VOC concentrations, while the age of buildings does appear to be related to VOC levels. The age of buildings and the activities within them seem to be better predictors of VOC levels than does ventilation rate.

The lowest air exchange rates were at a new hospital, where some measured day and night values fell below 0.1 ACH, many were below 0.5 ACH, and only one location exceeded 1.0 ACH (for one day) during all three 3-day visits. The measurements were made in July, October, and the following August. The spaces monitored were a visitors lounge, a nurses station, and a patient's room. These rates seem rather low, especially for the nurses station and the visitors lounge.

Typical daytime ventilation rates ranged from 0.7 to 1.0 ACH. Nighttime rates were usually slightly to significantly lower than daytime rates, depending on the building. Some buildings were not used at night, so ventilation system operation might have been unusual in order to provide researchers with the distribution and mixing of the tracer gas needed for the ventilation rate measurements.

We would expect considerable differences in air concentrations of VOC at different ventilation rates, but the measurements were made during the first few hours of the twelve-hour periods they reflect. Actual spot rates or average rates might have varied more than is indicated. In fact, ventilation rates could and normally would vary even more than the measured and reported range during typical daily operation of many building types under normal climate conditions.

Generally, ventilation rates above 1.0 ACH significantly reduce air levels of most contaminants, with the reduction increasing as the ventilation rate approaches the typical building maximum around 5 or 6 ACH. Rates below 1.0 ACH and down to the usual minimum around 0.2 tend to less dramatically affect air levels.

Materials Emissions

The quantities and types of chemicals emitted from the building materials tested varied enormously. The VOC emissions were consistent with what was found in the building air. Total VOC emission rates for a cove adhesive, as measured in the study, exceeded 5,000 $\mu g/m^2$ per hour! Rates above 600 $\mu g/m^2$ per hour were found for one latex caulking compound, while emission rates of 200 to 300 $\mu g/m^2$ per hour were found for a latex paint and a carpet ad-

Table 3: Concentration Data for Volatile Organic Compounds Summarized by Class and Compound

Building	Time since completion (weeks)	Concentration (µg/m^3) aromatic HC	aliphatic HC	chlorinated HC	oxygenated HC	Total Indoor	Total Outdoor	I/O Ratio
Hospital (new)								
Trip 1 (7/84)	34	18	7.0	8.1	1.3	34	9.1	3.7
Trip 2 (10/84)	48	11	4.7	6.0	ND	21	10	2.1
Trip 3 (8/85)	1.5 yr	26	5.1	26	ND	57	9.4	6.1
Office (new)								
Trip 1 (1/85)	1	270	810	13	ND	1,100	17	65
Trip 2 (4/85)	14	54	98	56	8.5	220	16	14
Office (old)								
Trip 1 (8/84)	1 yr	74	5.1	46	4.3	130	58	2.2
Office/School (old)								
Trip 1 (2/85)	2 yr	30	18	26	1.5	75	16	4.6
Nursing Home (new)								
Trip 1 (4/85)	4	93	173	9.9	9.6	286	11	26
Trip 2 (8/85)	23	22	7.3	3.9	1.2	34	20	1.7
Nursing Home (old)								
Trip 1 (7/84)	8 yr	12	1.9	4.1	ND	18	9.1	2.0

HC = Hydrocarbons
ND = Below the quantifiable limit

hesive. About one-third of the materials emitted between 20 and 100 µg/m^2 per hour, and another third emitted from 6 down to less than 1 µg/m^2 per hour.

Some of the emitted chemicals (such as benzene, styrene, p-dichlorobenzene, carbon tetrachloride, and trichloroethylene) are suspected or believed to be toxic or carcinogenic, and many of them are known irritants and odorants.

Comments on the Methodology

VOC measurements were made continually during twelve-hour periods. Building ventilation systems normally cycle through the daytime hours, and average ventilation rates or the integration of twelve-hour VOC measurements can give a misleading picture of the contaminant levels present at any point in time. Sampling was usually conducted separately for day and night periods for two or three days. This gave a large number of samples, but they are still twelve-hour averages. Aggregating them for the three days is, however, useful for determining total exposure of the occupants in the hospitals and nursing homes, and the purpose of the project was to characterize human exposure to indoor air pollutants.

Looking at the day and night VOC levels separately and in relation to ventilation rates is also useful, although ventilation rates could not be measured using tracer gas injection into the air supply when ventilation systems were turned off. So, either systems were run when they might not be in normal practice, or no ventilation rate data was collected. In either case, the data needs to be looked at carefully and in detail to determine the true meaning of the results. This has not yet been done.

While the researchers collected a very large (and therefore costly) set of VOC samples, many of them were for quality control purposes rather than for additional locations and sampling times. Typically they sampled only three indoor locations and one outdoor location in each building. Significant variations in ventilation rates, source

Table 4: Total VOC and Air Exchange Rates for Six Buildings in Study Phase 2

Building	Time since completion (weeks)	Total HC (µg/m^3) Indoor	Outdoor	I/O Ratio	Air Exchange Rate ACH (±S.D.)[a] Overall	Day	Night
Hospital (new)							
Trip 1 (7/84)	34	34	9.1	3.7	0.94 (0.73)	0.93 (0.86)	0.95 (0.64)
Trip 2 (10/84)	48	21	10	2.1	0.14 (0.12)	0.19 (0.14)	0.08 (0.08)
Trip 3 (8/85)	1.5 yr	57	9.4	6.1	0.44 (0.12)	0.50 (0.12)	0.37 (0.08)
Office (new)							
Trip 1 (1/85)	1	1,100	17	65	0.60 (0.08)	0.58 (0.08)	0.61 (0.08)
Trip 2 (4/85)	14	220	16	14	0.30 (0.10)	0.38 (0.07)	0.21 (0.03)
Office (old)							
Trip 1 (8/84)	1 yr	130	58	2.2	0.44 (0.19)	0.49 (0.14)	0.39 (0.23)
Office/School (old)							
Trip 1 (2/85)	2 yr	75	16	4.6	0.50 (1.10)	0.57 (0.08)	0.45 (0.08)
Nursing Home (new)							
Trip 1 (4/85)	4	286	11	26	0.54 (0.14)	0.65 (0.10)	0.43 (0.08)
Trip 2 (8/85)	23	34	20	1.7	NC	NC	NC
Nursing Home (old)							
Trip 1 (7/84)	8 yr	18	9.1	2.0	0.43 (0.27)	0.54 (0.33)	0.35 (0.19)

HC = Hydrocarbons
NC = Not calculated
[a] = air changes per hour ± standard deviation

strengths, and air concentrations typically occur in going from one space to another within a building, especially in large buildings with diverse activities and spatial characteristics, so the samples may not reliably represent average or peak levels for the whole building.

The results indicate the "tip of the iceberg" of what is going on in the particular buildings tested; based on our experience, variations from the measured levels could easily reach a factor of two or greater during any particular time period for different spaces within the buildings. And during different time periods in a given day, you could find differences even greater than a factor of two.

All of the above notwithstanding, we think that the exact levels are not as important as the general nature of the conclusions that we can reach from the reported results.

Implications

1. Comparing VOC air levels in new buildings as they age provides a picture of the changes that occur over time. *Air levels of VOC emitted by new building materials appear to decrease between one and two orders of magnitude (10 to 100 times) in the first few weeks or months after construction is completed.* This reinforces the importance of aggressive ventilation during that period of time.

2. Comparing emission results from headspace tests and chamber tests is important. Headspace tests are considerably easier, quicker, and cheaper. They are currently used primarily for screening purposes prior to chamber testing. Headspace tests allow the investigator to determine the types of compounds and the general magnitude of the emissions from a suspect material.

The results from headspace tests are not reliable enough for predicting indoor air levels, but they may be adequate for comparing two or more products within a generic class, or for comparing differing classes of products. *Designers, contractors, and building owners could find this very useful in selecting products and materials for their buildings.*

As we learn more from headspace and chamber testing, headspace testing will become an adequate evaluative tool for most practical

Table 5 : Summary of Emission Results

Emission Rate (µg/m^2 h)

Sample [a]	Aliphatic and Oxygenated Aliphatic Hydrocarbons	Aromatic Hydro-carbons	Halogenated Hydro-carbons	All Target Compounds
Cove adhesive	a	a	a	5,000
Latex caulk	252	380	5.2	637
Latex paint (Glidden)	111	52	86	249
Carpet adhesive	136	98	-b	234
Black rubber molding	24	78	0.88	103
Small diameter telephone cable	33	26	1.4	60
Vinyl Cove Molding	31	14	0.62	46
Linoleum tile	6.0	35	4.0	45
Large diameter telephone cable	14	20	4.3	38
Carpet	27	9.4	-	36
Vinyl edge molding	18	12	0.41	30
Particle board	27	1.1	0.14	28
Polystyrene foam insulation	0.19	20	1.4	22
Tar paper	3.2	3.1	-	6.3
Primer/adhesive	3.6	2.5	-	6.1
Latex paint (Bruning)	-	3.2	-	3.2
Water repellant mineral board	1.1	0.43	-	1.5
Cement block	-	0.39	0.15	0.54
PVC pipe	-	0.53	-	0.53
Duct insulation	0.13	0.15	-	0.28
Treated metal roofing	-	0.19	0.06	0.25
Urethane sealant	-	0.13	-	0.13
Fiberglass insulation	-	0.08	-	0.80
Exterior mineral board	-	0.03	-	0.03
Interior mineral board	-	-	-	-
Ceiling tile	-	-	-	-
Red clay brick	-	-	-	-
Plastic laminate	-	-	-	-
Plastic outlet cover	-	-	-	-
Joint compound	-	-	-	-
Linoleum tile cement	-	-	-	-

[a] Emission rate for cove adhesive is a minimum value; sample was overloaded. It is estimated that cove adhesive is one of the highest emitters of volatile organics.

[b] No detectable emissions.

purposes. We think this type of testing will be dramatically increased in the next year or two, and architects, interior designers, engineers, product manufacturers, and regulators will increasingly rely on this type of testing. (See "Saskatchewan Developing Materials Emissions Testing Standard" on page 8 in this issue.)

3. The air measurements collected during or shortly after interior finishing work indicate that *people in buildings where renovation or refinishing work is occurring can be exposed to very elevated levels of toxic chemicals. This may be one of the most dramatic implications of the study.*

Many complaints from occupants in remodeled buildings come during the application of paint, carpet, or cove molding, probably near the end of the process. The emissions measured from those products in this study show that some of them are very strong emitters of VOC, and some of the chemicals are extremely hazardous. Products are available that have much lower emissions than others in the same category. *It is essential that you carefully select products, ventilate during their application, and isolate occupied areas from work areas to control this problem.*

In the field we are strongly recommending that air from areas being finished, renovated, or furnished not be circulated into occupied spaces of the building. If possible, directly exhaust such work areas to the outdoors during installation and for several days afterwards. We have recommended this in previous issues of *IAQU*, but we are now even more convinced of the importance of this measure.

4. *Ventilation rates can vary considerably from one building to another,* although their designs and ventilation requirements might appear similar. Only measuring ventilation in the field can provide

reliable information on system performance.

The Report

The two volumes are not organized in very readable fashion, though they are full of descriptive details and data. The authors have focused much of their presentation, discussion, and analysis on the methodologies for future research and on numerical results rather than on the implications or for efforts to control indoor air pollution in public access buildings. However, a separate summary for each of the two volumes was prepared by Lance Wallace at EPA, and the summaries are far more readable than the report itself. Each summary consists of six pages of text and several pages of references, selected tables, and figures. We encourage readers to obtain these summaries, particularly for more details on the study methods and results.

We encourage you to submit comments or questions about the EPA report. We will share your thoughts and our responses with readers in future issues. There is plenty of substance in the study to merit further attention in future issues of ***IAQU***.

To Obtain the Report or Summaries:

The reports are titled ***Indoor Air in Public Buildings, Volume I and Volume II***, and are numbered EPA/600/6-88/009A and EPA/600/6-88/009B, Aug. 1988. The summaries are numbered EPA/600/S6-88/009A and EPA/600/S6-88/009B, September 1988. All of the documents are available from the Center for Environmental Research Information, EPA, 26 Martin Luther King Drive, Cincinnati, OH 45268.

You can call the Center at (513)569-7562 to request the reports or summaries, while the supply lasts. After the published supply runs out, they will be available through the National Technical Information Service (NTIS), 5285 Port Royal Road, Springfield, VA 22161. ♦

News and Analysis

Washington Scene: Legislative Update

With Senator George Mitchell's election as Senate majority leader, the future of his 1988 major indoor air legislation is up in the air. However, we expect that his increased visibility and authority bode well for the future of indoor air legislation. He was strongly committed to effective legislation during the 1988 session, and his bill was voted out of committee. In case you have not had an opportunity to hear or see Sen. Mitchell, he is an impressive speaker, extremely intelligent, and one of the best stand-up comedians we have heard.

The committee bill contained almost $50 million in new funding for indoor air quality research, technical assistance, investigations, and demonstrations. This would be a dramatic increase in funding for federal indoor air activities, mostly at EPA. A similar bill was introduced in the House by Rep. Joseph Kennedy, and Sen. Mitchell testified there strongly urging favorable action.

According to Senate Environment Committee staff, no decision has been made about what — if anything — to introduce in the coming session. However, authoritative sources told us that something is anticipated; it simply is impossible to say what right now.

On the House side, it is not clear whether Rep. Kennedy will reintroduce his clone of Mitchell's bill, whether Rep. Schneider will become active in developing legislation again, or whether Rep. Scheuer will be a key player in the 1989 session. ♦

On the Horizon

Saskatchewan Developing Materials Emissions Testing Standard

Under a grant from Energy, Mines and Resources Canada, the Saskatchewan Research Council is studying the use of caulks, sealants, and weatherstrip products for energy conservation. That study includes the examination of toxic hazards from caulks and sealants used in residential sealing work. Although the focus of the study is residential applications, the work has important implications for nonresidential construction as well.

The work not only provides a preliminary model for materials evaluation, it indicates that products can be rated for safety based on measurements and on toxicity data currently available.

The study used charcoal adsorption and carbon disulfide desorption for the chemical sampling and analysis. This limits the number and type of compounds that can be collected and runs counter to sampling method trends among most researchers in the U. S. during the past several years. However, many European investigators favor this method.