

Indoor Air Quality Update™

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An Office Building Bake-out: Methods and Analysis

Bake-outs have probably generated more talk and less study than any other important indoor air

quality topic. However, we are slowly learning more facts about bake-outs. Major contributors to our understanding of bake-outs are John Girman and his colleagues at the State of California's Indoor Air Quality Program (Department of Health Services, Berkeley). They presented their second paper on a controlled building bake-out in June at the latest meeting of the Air & Waste Management Association, in Anaheim, California. The results are encouraging for those who wish to use the bake-out process, and the paper teaches some important lessons.

The state program performed bake-outs on five buildings and documented the tests thoroughly. The purpose was (1) to determine whether a bake-out is a practical technique to reduce volatile organic compounds (VOC) and improve air quality in newly constructed buildings, and (2) to determine optimal methods and procedures for conducting bake-outs.

Girman is a responsible scientist who has focused much of his research on practical, useful indoor air quality issues. His work on bake-outs includes several papers not yet published. He has told *IAQU* that he believes bake-outs

can be effective. Our respect for his opinion leads us to agree.

However, Girman is a cautious researcher. He sees the need for considerably more research on bake-outs before finalizing his opinion on the subject. Readers contemplating a bake-out might do well to contact Girman before proceeding. *IAQU* welcomes any letters or reports from readers concerning building bake-outs.

In this article, we describe:

- The building studied by Girman, et al.;
- Bake-out procedures;
- Sampling methods;
- Test results.

We then discuss the implications of Girman's report and draw conclusions based on the report and our own experience with bake-outs. Our thanks go to John Girman for allowing us to present his work.

The Building

The building has a floor area of 4,800 m² (52,000 ft²) and is located just northeast of San Francisco Bay. Temperatures vary moderate-

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ly through the year. Freezing rarely occurs. Most rainfall occurs only in the winter months.

The wood-framed building has a stucco exterior with a shed roof. Metal roofing is installed around the building perimeter, with flat built-up roofing in the center. The first floor is built on a concrete slab poured on grade. The second floor is built on a plywood sub-floor. R-19 insulation is used with a 4-mil vapor barrier. All windows are double glazed.

The interior of the building consists of a foyer, a large reception area, large open office spaces, small enclosed offices, conference rooms, an employee break room with a small food preparation area, two supply rooms, and several classrooms. Glued-down carpet was installed in most nonutility building areas one month before the bake-out. The exception was a 74-m² conference room that was carpeted on the second day of the bake-out.

A penthouse above the second story contains the HVAC mechani-

cal room and an access hallway that serves as a return-air plenum. An enclosure on the far side of the employee parking lot houses the boiler and a/c compressors; associated plumbing runs underneath the parking lot to the building. The variable-air-volume, terminal-reheat ventilation system uses a T-bar suspended ceiling as the air return from the conditioned area.

Bake-out Procedures

A bake-out is controlled by adjusting three parameters:

- duration of the bake-out;
- indoor air temperature during the bake-out;
- ventilation rate during and after the bake-out.

Duration

From an engineering perspective, the duration of a bake-out should be as long as possible. In a sense, baking out is simply artificially aging the building. The more conditioned the materials, the less VOC are emitted. However, the cost of

keeping a building empty usually dictates a short bake-out period. Also, construction and interior furnishing often run behind schedule, pressuring the builder to get the building operational quickly.

This bake-out lasted 3½ days. Figure 1 shows temperature profiles collected from three locations during the study. Notice that it took several days for air temperatures to reach 38°C (100°F), the desired maximum temperature.

Temperature

Elevated temperatures speed VOC emission in several ways. Heat raises vaporization rates; VOC evaporate significantly faster at higher temperatures. Residual solvents diffuse toward material surface areas quicker. Researchers elevated indoor temperatures with lighting (both artificial and natural), boiler modification, and portable heat sources.

All building lights were on during the bake-out period. Although individual fluorescent lights do not produce a lot of heat, the cumulative effect is significant. Also, the researchers opened and closed venetian blinds to take advantage of any possible greenhouse effect. They modified the boiler by installing a higher temperature control and disconnected thermostats throughout the building so that heaters would stay on regardless of outside temperature. Twenty space heaters (1,500 watts each) placed throughout the building contributed about 13% of the building's heat and enhanced indoor air circulation with their built-in fans.

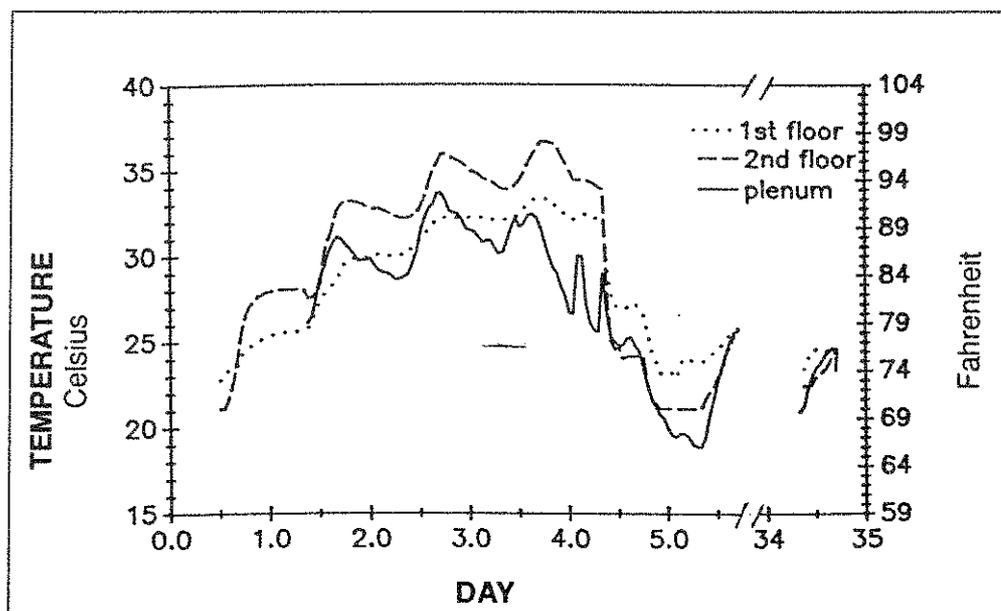


Figure 1 — Temperature Profiles Collected from Three Locations

At the first floor, researchers kept temperatures above 27°C (80°F) for 87 hours and above 32°C (90°F) for 79 hours. At the second floor, they kept temperatures above 27°C for 65 hours and above 32°C for 35 hours (see Figure 1). Predictably, temperatures were higher during the day due to solar heat gain and lower during the night due to leakage from the building envelope. Heat loss was greater from the second floor at night. The return air plenum, located on the roof, was also responsible for nighttime heat loss.

Ventilation

Bake-out ventilation must be limited enough to permit a high indoor temperature. At the same time, there must be a sufficient flow of air to flush out VOC. Without sufficient venting, indoor materials will simply re-adsorb VOC.

Before the bake-out, the ventilation rate was 0.49 air changes per hour (ACH). During the bake-out, the rate was 0.43 ACH. One day after, the rate was 0.54 ACH. One month after, the rate was 0.47 ACH and four months after, the rate was 0.35 ACH.

Researchers closed outside air dampers to minimize outside air to the HVAC resulting in virtual 100% air recirculation. The only fresh air to get in leaked past the dampers or infiltrated the building envelope.

Sampling Methods

Researchers took air samples for VOC before and during the bake-out and one day, one month, and four months after the bake-out. At each sampling location, they collected three samples of three to seven liters each, using Tenax at a flow of about 50 cc/minute. A

back-up sampler, included in one sample at each location, checked for sample breakthrough. Girman and his coworkers later thermally desorbed the VOC samples and field blanks onto a gas chromatograph/mass selective detector (GC/MSD) for identification and quantification. Researchers collected formaldehyde samples using midget impingers. Seven-day recorders provided temperature and relative humidity data for each sampling period.

If adjustments were made to the ventilation system, researchers waited several hours before sampling to ensure ventilation rates had stabilized. They kept ventilation rates constant for all the sampling periods by adjusting outdoor and return air dampers. Researchers measured ventilation rates before and after each sampling using sulfur-hexafluoride tracer gas decays.

Comparing mass spectra with the NBS/NIH Mass Spectral Data Base provided tentative identification of VOC in the air samples. Thereafter, researchers ran standards for 18 selected VOC using selected ion monitoring with the GC/MSD. They then quantified and determined concentrations of the 18 VOC. Also, they obtained total mass spectral counts when using the GC/MSD to scan identification samples. Total mass spectral counts thus obtained were normalized by sample volume, providing a measure of total VOC concentration at each sample location. Formaldehyde samples were analyzed by the modified chromatographic acid method.

Results

The results from the bake-out fall into four categories:

1. The effect on formaldehyde concentrations;
2. The effect on other VOC concentrations;
3. The effect on building materials;
4. The costs of the bake-out.

Formaldehyde

Formaldehyde is a major constituent of many building materials, especially pressed wood. It is not a trace compound that can be readily aged out of a material. Also, formaldehyde is not generally recognized as a major contributor to IAQ problems in office buildings. Concentrations are usually much higher in residential buildings.

The study tried to see if formaldehyde concentrations might actually increase after a bake-out. A bake-out's higher temperatures could conceivably increase the hydrolysis of urea-formaldehyde resins in formaldehyde-containing materials. As we see in Figure 2, this didn't happen.

The bake-out did not seem to raise or lower formaldehyde concentrations after materials had cooled. Concentrations rose during the actual bake-out, but returned to levels consistent with predictions based upon temperature and initial concentrations in the building. Apparently the bake-out did not increase hydrolysis.

Other VOC

We don't know which individual VOC contribute the most to IAQ problems. Perhaps combinations of certain compounds create the biggest problems. Therefore, along with measurements of individual VOC, Girman's group also computed total VOC concentrations. They normalized total

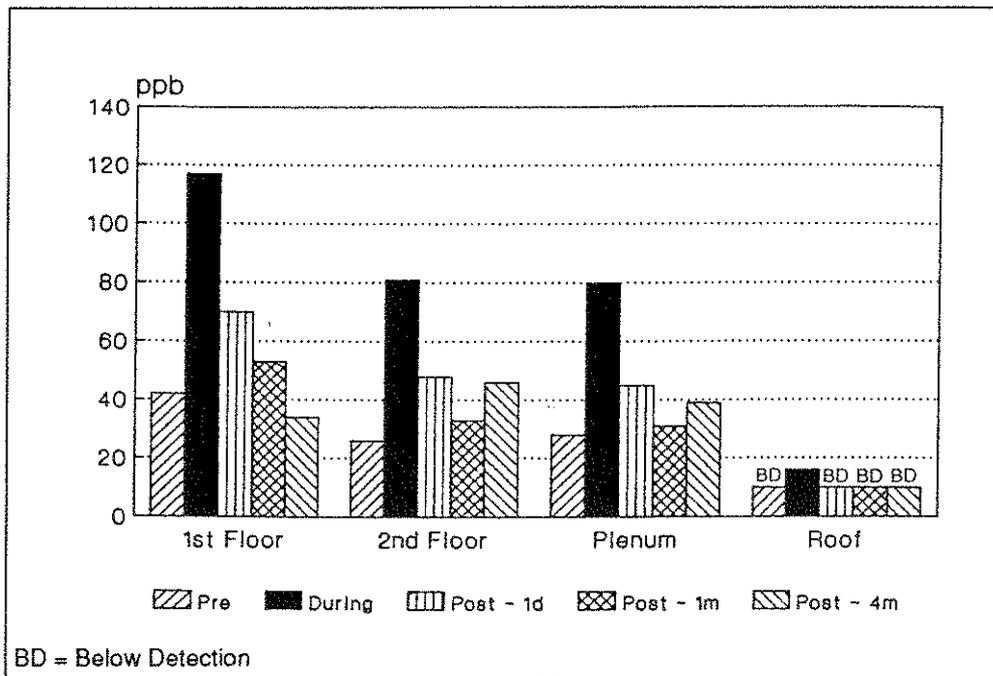


Figure 2 — Formaldehyde Concentrations

mass spectral counts of individual samples by sample volumes, and Girman used them as surrogates for the total VOC concentrations. This way, researchers could make comparisons of bake-out induced changes in VOC concentrations at various locations.

As shown in Figure 3, total VOC concentrations one day after the bake-out were significantly lower than before the bake-out. The first-floor value was 62% of the original concentration. The second-floor value was 68% of the original concentration. These concentrations were, in fact, elevated because interior materials had not cooled completely. One month after the bake-out, total VOC concentrations had dropped to 5-7% of pre-bake-out levels. This constituted 1.8 to 2.5 times the outdoor con-

centrations despite an air exchange rate of only 0.48 ACH. The indoor/outdoor ratio of VOC was 35 before the bake-out.

Researchers quantified 19 individual VOC including formaldehyde. The quantified compounds represented the most

abundant VOC. Table 1 shows these VOC concentrations. Concentrations are listed for before and one month after the bake-out.

The individual VOC concentrations showed much less of a decrease than the total VOC concentrations. However, the quantified, individual VOC represent less than 3% of the mass of the total VOC indoor concentration. Many VOC were initially present in low concentrations; after the bake-out, their concentrations fell below measurable levels, thus producing a large decrease in total VOC statistics.

Researchers again measured individual VOC concentrations in the building four months after the bake-out. They took samples on a Sunday to minimize the effects of occupancy. Four-month levels were essentially the same as one-

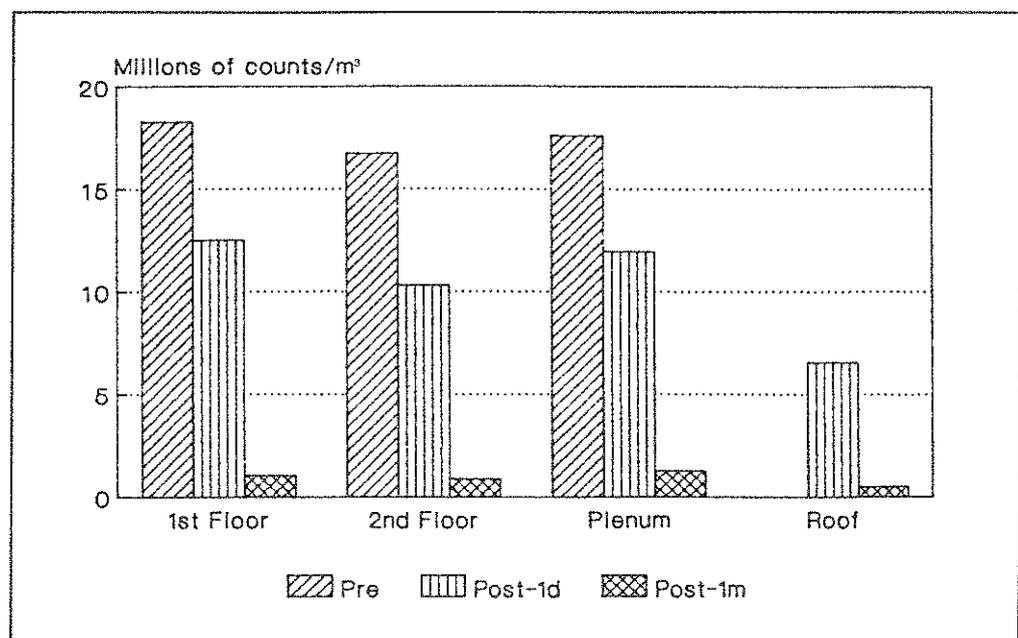


Figure 3 — Total Volatile Organic Compounds without TCA

month levels. The VOC reduction was permanent and had taken place within the month during and after the bake-out.

Building Materials

Effects of the bake-out on building structures and materials were minimal. Minor damages were limited to floors and doors. Of 18 expansion joints in the concrete slab, five moved inward. In four cases, carpet buckled slightly. A casual

observer would probably think the buckling was a carpet seam. The carpet was not replaced or re-installed. In one case, vinyl flooring buckled in a supply room. Because the vinyl had less "give" than the carpet, the buckling was pronounced. Damaged sections of the vinyl were replaced.

However, the bake-out was probably not directly responsible for the buckling. The slab had been

poured during a cold week in December, was wetter than normal, and was rained on during curing. The bake-out probably just accelerated the movement of the slab.

Of 225 double-glazed windows, one developed a crack starting at a screw closure. The builder felt the window was defective and replaced it without cost.

Interior doors had been propped open to facilitate air circulation

Table 1 — 19 Specific VOC Concentrations

	CONCENTRATIONS ($\mu\text{g}/\text{m}^3$)							
	Pre-Bake-out				Post-Bake-out			
	First Floor	Second Floor	Plenum	Roof (Outdoor)	First Floor	Second Floor	Plenum	Roof (Outdoor)
Formaldehyde	51	32	34	BD	65	40	38	BD
Methylcyclopentane	24	30	27	9.4	14	20	17	7.0
n-Octane	12	7.3	7.9	1.6	2.3	1.3	2.7	1.1
n-Undecane	16	14	17	6.6	13	15	14	5.5
n-Dodecane	9.0	3.7	7.8	0.6	2.5	1.7	1.0	BD
Benzene	2.8	3.0	3.0	1.0	0.8	1.5	BD	BD
Toluene	35	38	28	8.9	19	22	12.0	3.7
Ethylbenzene	7.5	7.6	7.3	3.0	6.1	7.1	6.1	2.6
i-Propylbenzene	11	11	11	4.8	9.2	11	10	4.0
m,p-Xylene	15	14	7.3	4.4	11	12	8.1	1.4
o-Xylene	7.7	7.7	7.3	2.8	5.7	6.4	5.4	1.0
1,4-Methylethylbenzene	7.4	3.8	7.0	2.8	5.0	5.9	2.2	1.1
1,2,3-Trimethylbenzene	6.6	5.3	6.6	2.3	4.3	5.1	4.4	0.9
1,2,4-Trimethylbenzene	8.6	6.7	8.2	3.3	5.1	5.9	5.1	1.0
Naphthalene	31	3.7	24	9.9	21	19	24	BD
a-Pinene	89	77	76	10	65	75	60	7.8
1,1,1-Trichloroethane	23	26	6.1	BD	BD	BD	BD	BD
Perchloroethylene	13	14	35	3.1	9.4	11	10	4.5
Dichlorobenzene	6.2	3.0	6.6	17	5.1	7.0	15	4.9

BD = below detection

during the bake-out. Spring closures at the top of the doors pulled on the doors while jams at the bottom of the doors held them open. The resulting torque, combined with the bake-out heat, warped some of the doors. These doors were straightened. In subsequent bake-outs of other buildings, researchers removed spring closures and warpage was eliminated.

Costs

The costs to the building owner for conducting the bake-out are listed in Table 2. Of the total cost, 59.5% went for contractors and operating engineers, 39.5% went for utilities, and 8% went for building damage.

Our Conclusions

Planning — Conditions vary greatly from one building to another; there is no "master plan" for bake-outs. Careful planning is a must before undertaking any bake-out program. However, unpredictable and/or uncontrollable conditions

are the rule rather than the exception with these kinds of programs.

Anyone managing a bake-out must be flexible and ready to modify plans as required. A qualified individual capable of operating the building ventilation system should be on hand or on call during the bake-out process to deal with unexpected contingencies.

Duration — We think a week is the minimum time required to properly and safely conduct a bake-out. A bake-out of only a day is probably not enough to achieve any significant results. Effective bake-outs require several days and elevation of the building temperature above 90°F. The time allotted for a bake-out will depend on many factors, most having little to do with IAQ. Allow the most time possible.

Overheating — Do not overheat a building to the point where damage might occur. Overheating or elevating temperature too rapidly can cause drying and subsequent shrinkage of wood framing,

excessive expansion of steel framing, and rapid drying of finishes such as newly applied paint.

Warranties — Be certain that the conduct of a bake-out will not violate manufacturers' warranties. Many building products and materials are warranted only under "normal conditions of use." A bake-out might be deemed a violation. If you are in doubt, contact the manufacturer or contractor who provided the warranty. This is particularly important for ventilation system components, millwork, art works, caulks, and sealants.

Ventilation — Maintain some ventilation during the bake-out period, but 0.4 or 0.5 ACH should be enough. After completing the bake-out and prior to re-occupancy, provide a purge cycle (100% outside air supply) for at least 24 hours. Thereafter, supply maximum feasible outside air.

Construction Activity — Frequently, some construction activity occurs up to the last minute before occupancy. The bake-out plan should take into account the likelihood that some workers will need access to the building, that elevated VOC levels might be created by the last minute construction, and that acceptable working conditions must be provided for any workers in the building during the bake-out.

Costs — The costs of a bake-out add up. It costs to heat the building, to operate the building's lights, to adjust or modify the HVAC system, and to monitor the building during the bake-out. However, these costs are small compared with the total building cost, and the rewards are significant: happier occupants, greater productivity, and less ill-

Table 2 — Costs Incurred for the Bake-out of a New Office Building

Item	Itemized Costs	Total Costs
Contractor		
General Contractor	\$1,267	—
Mechanical Contractor	\$1,750	—
		\$ 3,017
Operating Engineers (monitoring building during bake-out)	\$3,381	\$ 3,381
Utility Costs		
Gas	\$1,370	—
Electric	\$3,449	—
		\$ 4,819
Vinyl Floor Repair		\$ 980
		<u>\$12,197</u>

ness due to indoor air contaminants.

For More Information

To learn more about this study, contact: John Girman, Indoor Air Quality Program, Calif. Dept. of Health Services, 2151 Berkeley Way, Berkeley, CA 94704; Phone: (415)540-3130.

John Girman, et al., "Bake-out of a New Office Building to Reduce Volatile Organic Concentrations," Paper 89-80.8. Presented at the 82nd Annual Meeting of the Air and Waste Management Association, in Anaheim, California, June 25-30, 1989. Available from Air and Waste Management Association, P.O. Box 2861, Pittsburgh, PA 15230; (412)232-3444.

California Office of the State Architect, "Building Closeout Procedure," California Department of General Services, Office of the State Architect, Sacramento, CA, 95814, 1984.

J. Girman, L. Alevantis, G. Kulasingam, M. Petreas and L. Webber, "Bake-out of an Office Building," *Proceedings of the 4th International Conference on Indoor Air Quality and Climate*, W. Berlin, Germany, 1:22 (1987). ♦

News and Analysis

ASHRAE to Publish Ventilation Standard

At its June meeting, the ASHRAE Board of Directors adopted the proposed Standard 62-1981R, Ventilation for Acceptable Indoor Air Quality. The standard is being typeset now and should be available in September.

The board made only minor changes in the version acted on at the

January meeting in Chicago, and it has already instructed the committee to prepare an addendum to restore the prior version. For details of the standard, see *IAQU*, February 1989.

ASHRAE plans to broadly publicize the adoption and publication of the new standard. We hope that publicity will encourage architects, engineers, and interior designers to become familiar with the standard. Responsible professional practice to control indoor air quality means that design professionals should recommend compliance with the standard to their clients.

As of our publication deadline, cost information for copies of the standard was not available. For information and to order copies of the standard, contact: ASHRAE Publications, 1791 Tullie Circle NE, Atlanta, GA 30324, (404)636-8400. ♦

HVAC System Commissioning Guidelines

The staff at ASHRAE expects HVAC commissioning guidelines to be ready for distribution in four to six months. As we understand the contents of the guidelines, they will not differ significantly from the previously published Public Review Draft. We had hoped that the final guidelines would incorporate more detail than was in the draft. It could benefit by inclusion of some of the outstanding information presented by guideline committee members at the ASHRAE Winter Meeting in Chicago earlier this year. Readers interested in more detailed guidance on commissioning should obtain those papers or look for them in *ASHRAE Transactions*. Our article in the February 1989 *IAQU*

gives a summary of the more useful papers.

For more information, contact ASHRAE Standards, 1791 Tullie Circle NE, Atlanta, GA 30324, (404)636-8400. ♦

CIAR Solicits Grant Applications

The Center for Indoor Air Research (CIAR) has announced the availability of funds to support indoor air quality research in three topical areas. The CIAR lists the following topics as research priorities:

1. Environmental tobacco smoke (ETS), including respirable particulate and vapor-phase components.
2. Chemical contaminants from all sources, organic and inorganic.
3. Biological agents, including aeroallergens and aeropathogens.

CIAR lists the following projects that it has already funded:

- The Role of Foliage Plants in Indoor Pollution Control.
- The Effects of Smoking Regulations and Building Ventilation on Indoor Air Quality and Employee Comfort and Health in Offices.
- The Pulmonary Effects of Environmental Tobacco Smoke Exposure on Asthmatic Subjects.
- Monograph on the Chemistry of Environmental Tobacco Smoke
- Comparison of a Personal and Area Monitor for the Measurement of Ambient Nicotine.

The last two projects were reported in *Environmental Science and Technology* recently (see *IAQU*, May and June 1989).

CIAR will provide grants twice annually. Applications for July 1, 1990, funding are due December 31, 1989.

Concerns about the objectivity and independence of scientists often surface when tobacco industry funding is involved in research or public policy debates involving IAQ. We have heard from several respected researchers that those who accept funding from CIAR will be tainted because the organization is sponsored by the tobacco industry.

There seem to be three issues for potential applicants to consider. First, will the grant applications be fairly and objectively evaluated on the basis of their scientific merit and public health significance? Second, will the research results and their publication be affected by the funding source? Third, will the investigator's reputation or conscience be affected by the funding source?

To try to answer some of these questions, we called CIAR. We asked about the nature of the grant application review process and about approval of reports for publication. We spoke with Lynn Kosak-Channing, Ph.D., staff scientist at CIAR, who had originally sent us the CIAR "Request for Applications" and asked that we publish an announcement. Dr. Kosak-Channing told us the reviews will be conducted by competent scientists and based on objective criteria. Publication of results is the responsibility of the investigators, and it will not depend on CIAR approval of results.

Subsequently, CIAR Executive Director Dr. Max Eisenberg called us to offer some additional information.

Eisenberg told us that CIAR has already received more than 70 letters of intent from virtually every major U.S. research institution. This is not surprising, since there really are no other significant sources of funding for unsolicited research proposals on indoor air quality. Also, most of the public agencies and private organizations that fund extramural research are having difficulty obtaining funding to support the work they have started.

Whether funding by CIAR will affect an investigator's reputation or conscience is not easily addressed by anyone but the individual involved. While the tobacco industry clearly has a point of view and a large economic interest, much good science has come from direct industry-funded research. All industries conduct research to enhance their own position, and the concerns raised here are not limited to the tobacco industry by any means. Even funding from certain government agencies carries the potential for bias; good science is often a matter of point of view or underlying values.

For more information, contact: Center for Indoor Air Research, 1099 Winterson Road, Suite 280, Linthicum, MD 21090; (301)684-3777. ♦

On the Horizon

Ozone and Indoor Air: Myth and Reality

Last year, the prestigious journal *Science* published an article that stated, in part, that "human exposure ... [to ozone] is limited to time out of doors because structures protect occupants" (Milton Russell, 9 September 1988, p.

1275). Now Morton Lippman of the New York University Medical Center has reinforced the myth that people's exposure to ozone is primarily outdoors.

Writing in the May 1989 issue of *JAPCA (Journal of the Air Pollution Control Association)*, Lippman states: "Indoor concentrations of O₃ are almost always substantially lower than those outdoors due to the efficient scavenging by indoor surfaces and the lack of indoor sources." The truth of this statement depends on two factors: (1) how one understands the word "substantially," and (2) how much time is spent in well-ventilated versus poorly-ventilated structures; the more time spent indoors in a well-ventilated room, the greater the fraction of ozone exposure.

High Indoor Ozone

Research at Bellcore (Bell Communications Research in Red Bank, New Jersey) has recently demonstrated that indoor ozone concentrations are frequently a significant fraction of outdoor values. These findings are supported by a number of earlier studies. Since most people spend greater than 90% of their time indoors, the Bellcore researchers hypothesize that indoor ozone exposure (concentrations x time) is usually greater than outdoor exposure.

Importance

Why is this important to those concerned about indoor air quality? One reason is that research has recently shown that deleterious health effects occur at ozone exposure levels far lower than previously believed. Effects of short-term exposure to elevated levels of ozone include increased pulmonary irritation. There is mounting evidence of chronic ef-

fects from longer-term or recurring exposures at lower levels.

Lower Standards?

Another reason is that scientists (Lippman included) are calling for lower ambient air quality limits for ozone. Some scientists suggest reducing the current one-hour limit of 120 ppb to 80 ppb. Building ventilation complying with ASHRAE Standard 62-1981 (or the soon-to-be-published Standard 62-1989) will need to control ozone when outdoor levels exceed legal limits. If the limit is lowered, buildings in most inhabited areas of the United States will be subject to ozone control requirements if they are to comply with ASHRAE Standard 62.

Furthermore, ozone levels exceeding the present outdoor limits now occur in rural as well as urban areas. An article in the June 20, 1989, issue of the *Journal of Geophysical Research* reported that ozone levels frequently exceeded 80 ppb in nearly every site monitored and occasionally exceeded 120 ppb in most sites.

Ozone Formation

Ozone forms when atmospheric NO₂ and hydrocarbons interact in the presence of strong sunlight. Hydrocarbon sources are abundant; plant metabolism, industry, consumer products, and fossil fuel combustion are among the major sources. NO₂ sources are primarily motor vehicle emissions. While most high ozone level episodes occur in the summer, ozone values exceeding 90 ppb were found in October and November in some rural sites.

Ozone "Scavenging"

In his article, Lippman cites "efficient scavenging by indoor surfaces" as a major ozone control.

However, "scavenging" by indoor surfaces requires a significant contact time between the ozone and the surfaces. Ozone scavenging by indoor material surfaces usually requires a time scale of an hour or more, depending on the materials involved, the ratio of material surface area to volume, and the ozone air concentration. There is also some "natural" decay of ozone in a confined space that occurs through interaction of the ozone with other constituents of the air. However, this decay is negligible in even minimally-ventilated buildings.

A simple equation to characterize indoor ozone levels looks something like this:

Indoor ozone level = [(rate of supply of outside air) (ozone concentrations in outside air)] - [(decomposition rate for each material) (surface area) (contact time)]

This oversimplified equation ignores indoor sources of ozone such as copying machines, laser printers, electrostatic precipitators, and other electrical arcing devices. These sources are not normally major contributors to indoor ozone levels, although they can be under certain circumstances.

Table 3 shows relative decomposition rates for several common materials. The "K" values represent an experimentally derived rate constant, and the numbers allow comparisons of the listed materials. The values at the left are the decomposition rates at the beginning of the test. The values

Table 3 — Measured Values of Ozone Decomposition Rates for Several Common Surfaces

Material	K ft ³ /ft ² - min
Cotton muslin	0.214 → 0.029
Lamb's wool	0.208 → 0.008
Neoprene	0.19 → 0.03
Plywood (1 side varnished)	0.06 → 0.01
Nylon	0.063 → 0.001
Polyethylene sheet	0.048 → 0.020
Linen	0.0185 → 0.0107
Lucite	0.012 → 0.001
Aluminum	0.002 → 0.001
Plate glass	0.002 → 0.001

at the right are the rates after the materials had been exposed to ozone in the test chamber for several hours.

These results indicate that a rapid reaction occurs when materials are initially exposed to ozone, and that the reaction products slow subsequent ozone decomposition. These longer-term rates that indicate a slower decomposition are the ones that interest us. They show us that Lippman has overstated the removal effectiveness of material surfaces, especially where a reasonable ventilation rate is maintained.

Ventilation and Ozone

The ventilation rate is critical to ozone removal by material surfaces. Where ventilation rates are very low, say less than 0.4 or 0.5 air changes per hour (ACH), indoor ozone levels will stay substantially lower than outdoor levels. This is because there is less new ozone-filled air overwhelming the capacity of material surfaces to remove ozone.

Indoor ozone decomposition was identified more than 15 years ago. Research done since the early 1970s shows that indoor levels often range from 20 to 80% of outdoor levels. With people spending

about 90% (on average) of their time indoors, even where indoor ozone is only 20% of outdoor levels indoor ozone exposure is significant. With indoor levels usually ranging from 30 to 70% of outdoor levels, it is clear that the greatest total human ozone exposure is indoors.

The relevance of this otherwise picky point is that recent research, some of it cited by Lippman, shows that adverse health effects occur at ozone concentrations as low as 80 ppb for time periods as short as one hour. Outdoor ozone levels often exceed 100 ppb in many urban and some rural U.S. locations. Therefore, a large portion of the U.S. population is exposed to unhealthy ozone levels, particularly when building ventilation rates exceed one ACH or more. At this ventilation rate, indoor ozone will usually exceed 50% of outdoor levels.

Ozone Control

There are practical ways to remove ozone, particularly through the use of charcoal filters. However, the technology is not commonly used in commercial and residential structures. Adding the cost of ozone filtration to a building construction and operating budgets will arouse considerable resistance from building owners and developers. The cost of constructing and operating a building will increase due to the costs associated with large fans to overcome the resistance of added filters. Furthermore, the effectiveness of filters will need to be monitored.

Potential Problems

Also, collecting moisture and particulate matter on charcoal filters may lead to microbiological contamination. Controlling this poten-

tial problem will require frequent inspection and periodic evaluation of microbial emissions from the charcoal filters. The problem can be lessened by reducing the particle and moisture loading on the charcoal. This is done by filtering air more efficiently upstream from the charcoal filters. Limiting humidity in the air stream will also extend the useful life of the filters and reduce the potential microbial contamination.

All of these solutions require further investigation. Designers and building operators must become more aware of the ozone problem, and reliable performance evaluations of commercially available products such as filters must become available. Ozone is a significant problem; however, control is within the means of current knowledge.

For more information:

Rolf Sabersky et al., "Concentration, Decay Rates, and Removal of Ozone and Their Relation to Establishing Clean Indoor Air," *Environmental Science and Technology*, Vol. 7, No. 4, April 1973, pp. 347-353.

Marjorie Sun, "Tighter Ozone Standard Urged by Scientists," *Science*, Vol. 240, (24 June 1988) pp. 1724-1725.

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Practical Research Briefs

NASA's VOC Emissions Database

Designers, researchers, product manufacturers, and policy-makers are all interested in obtaining information on the volatile organic compound (VOC) emissions of building materials, furnishings, and consumer products. The number of potential sources is enormous. Testing products and developing a useful database is an overwhelming task. Indoor air researchers and industry have investigated only a fraction of the products used indoors.

However, one large database exists that could provide a great deal of information. NASA conducted the largest known investigation into VOC sources to test for potential contaminants in spacecraft. NASA was more interested in the possibility that VOC would plate out on electrodes in spacecraft equipment and cause operational problems than in any possible health impact on the astronauts. But the rationale for doing the work is unimportant; NASA created a large body of data that may impact IAQ work greatly. Michael Baechler and his colleagues at Harvard University have partially evaluated the NASA database for its usefulness for IAQ control. It is hard to compare much of the NASA data with existing data because the testing methodologies are very different. However, once the database is thoroughly evaluated and "translated" to conform with existing measurement standards, we think it will make a substantial contribution to IAQ knowledge.

NASA Test Methods

NASA tested over 5,000 materials that might be used in spacecraft or carried on board by astronauts. These materials included many paints, adhesives, epoxies, and cosmetics: known sources of VOC in indoor air. NASA investigators placed the test materials in a chamber, and heated the chamber to 120°F for 72 hours. They then sampled and analyzed products offgassed in the chamber. This is a "headspace" test. Although it is a reasonable way to test for dominant compounds emitted by a material, indoor air researchers do not consider the headspace test a useful way to evaluate emission rates. Also, the high, 120°F temperature is a potentially confounding factor, the 72-hour time period could allow chemical reactions to occur among the various VOC in the chamber, and VOC may react with the chamber walls.

NASA reported its tests in $\mu\text{g/g}$ — weight of emissions per unit weight of the original material. This differs from most emissions testing, which reports results in weight of emissions per unit area of material during a unit of time: for example, $\mu\text{g}/\text{m}^2$ per hour.

Baechler's Evaluation

Michael Baechler of Battelle Pacific Northwest Laboratories in Portland, Oregon, presented an analysis of the NASA data at the Air and Waste Management Association (formerly APCA) 82nd Annual Meeting in Anaheim. Baechler and his former colleagues at Harvard University compared NASA's results to two studies in EPA's Total Exposure Assessment Methodology (TEAM) Study and to a German residential study (see references for more information).

Baechler's comparative work was part of a larger project that involved sorting and reorganizing the NASA data base to make it more useful for indoor air quality work. The purpose of the sort was to identify the most commonly emitted compounds from materials identified as potential sources of indoor air contaminants. Haluk Ozkaynak of Harvard presented preliminary results in Berlin at Indoor Air '87. The group also prepared a summary report for EPA, which funded the project.

Results of the Evaluation

The results are interesting, and the values from the various studies are worth comparing. Table 4 shows the results of comparisons between NASA paint emissions data calculated as room concentrations and the measured indoor concentrations from various studies.

Two items are worth noting while evaluating this table. There are few compounds for which data are available from both the NASA work and the other studies. There are also very large differences between the NASA results and those obtained in the other studies.

Bear in mind that the NASA data are calculated from chamber tests while other data are from field measurements. Also note that the NASA data are from paint emissions only while the others are from all sources which might have been present. Finally, note that the NASA data were obtained under high temperatures and might better represent initial emissions rather than longer-term emissions. Therefore, we would expect them to be higher, at least compared to emissions from other measurements.

Table 5 is, perhaps, the most useful. It shows the comparison of the NASA data to paint emission

tests by Wallace and by Sheldon. Baechler's calculated total VOC concentrations from the NASA tests ($1,070.57 \mu\text{g}/\text{m}^3$) fall within the range of values measured by Wallace ($189.98 \mu\text{g}/\text{m}^3$) and Sheldon ($1,863.75 \mu\text{g}/\text{m}^3$). Baechler relies heavily on this comparison to draw his conclusion that the NASA data may be useful for other indoor air work.

For comparison purposes, here are some values reported in other work. Wallace had reported VOC concentrations from $18 \mu\text{g}/\text{m}^3$ to $1,300 \mu\text{g}/\text{m}^3$ in the various public buildings he studied. The higher values were in a newly finished building. Emissions from paints studied by Sheldon varied by a factor of almost 80 ($249 \mu\text{g}/\text{m}^2$ per hour and $3.2 \mu\text{g}/\text{m}^2$ per hour). Thus, a wide range of values does not by itself suggest any inherent difficulty in Baechler's comparisons. However, there are so many problems with the comparisons that the results must be interpreted very cautiously.

Nevertheless, Baechler has recognized the difficulties and attempted to deal with them, and the report details the approaches he used. Even his identification of the problems is instructive to researchers if not to professionals. The interested reader can obtain his paper and judge the methodology.

Methodological Differences

Many problems are involved in converting the measurements from one test method in order to compare them to another. The various studies did not use uniform measurement methods and reporting formats. Baechler did not deal with the emission rates per unit of time. He was challenged enough by the need to convert his comparison

data to airborne concentrations, reported as $\mu\text{g}/\text{m}^3$. He also had to convert NASA measurements from sample mass to sample area. Of course, the conversion depends on the thickness of the paint application either in a test chamber or in an actual room. Baechler had to make important assumptions in order to develop the numbers in his comparisons.

Another limitation of the NASA database is the fact that it lumps products into broad categories, thereby masking much of the detail of greatest interest for indoor air quality. Baechler chose to use only paints for the comparison reported in the paper.

Baechler also points out the difficulties in making comparisons due to the different measurement methods and measured chemicals in the various studies. Comparing the results of the different studies is difficult due to differences in handling, conditioning, applying, and curing of the products. There are also differences in environmental conditions including temperature and humidity during the tests. He has identified these problems in the paper and qualified his conclusions appropriately. Finally, the measurement of VOC itself is not standardized. Different sorbents can collect different compounds. Researchers use different desorption methods, concentration methods, analytical equipment and methods, identification procedures, quantification procedures, and confirmation procedures. And they use different methods to calculate "total VOC," which can vary considerably depending upon the way it is reported. In a word, comparisons are extremely difficult without a complete report of the investigators' methods; even

Table 4 — Indoor VOC Concentrations Found by the TEAM Study and Krause and Estimated VOC Concentrations ($\mu\text{g}/\text{m}^3$) from Paint from the NASA Database.

NASA Compounds	NASA ^a	TEAM Study ^b	TEAM Study ^c	Krause 1987 ^d	Krause 1987 ^e
1,2,3-Trimethylbenzene	—	—	—	3.5	6.6
1,2,4-Trimethylbenzene	—	—	—	11	18
1,3,5-Trimethylbenzene	—	—	—	3.9	75
2-Ethoxyethylacetate	66.43	—	—	—	—
2-Ethylhexanol	0.30	—	—	—	—
2-Methyl - 1 - Propanol	0.03	—	—	—	—
Benzene	0.66	15	30	9.3	17
Butanol	19.93	—	—	7	13
Carbon Tetrachloride	—	0.65	1.1	—	—
Chloroform	—	1.5	5.0	—	—
n-Decane	—	2.0 ^f	5.9 ^f	14	31
Dichlorobenzenes	—	2.6 ^g	54.0 ^g	22 ^h	17 ^h
Ethylacetate	3.32	—	—	—	—
Ethylbenzene	—	7.9	16.0	10	16
n-Heptane	—	—	—	7	11
n-Hexane	—	—	—	9	15
Limonene (j)	—	—	—	25	67
Methyl-Chloride	0.14	—	—	25	67
Methylethylketone	332.17	—	—	25	67
Naphthalene	—	—	—	2.3	3.9
n-Nonane	—	—	—	9.7	26
n-Octane	—	3.7 ⁱ	8.4 ⁱ	4.9	8.3
Styrene	0.15	2.8	6.7	2.5	4.2
Terpenes	—	—	—	42	97
Tetrachloroethylene	0.003	8.3	22	12	14
Toluene	83.04	—	—	76	127
Trichloroethylene	—	1.1	6.9	13	12
Undecane	—	2.3	7.1	10 ^j	24 ^j
Xylenes	564.68	31.7 ^k	59 ^k	30	54
TOTAL	1070.57	79.55	222.10	374.10	723.50

a Total of four estimates made in this analysis based on 95th percentile emissions.

b Median VOCs in overnight indoor air in Los Angeles, Fall 1981.

c 90th percentile VOCs in overnight indoor air in Los Angeles, February 1981.

d Mean concentration.

e 90th percentile

f As decane

g As m,p-dichlorobenzene

h As 1,4-dichlorobenzene

i As octane

j As n-undecane

k As m,p-xylene and o-xylene

with it, comparisons may be misleading or inappropriate.

Conclusions

The report indicates that there is potential usefulness for the NASA database, but Baechler cautiously recommends considerably more investigation to improve our understanding of how to interpret the NASA results.

We agree with Baechler's conclusion that the NASA data may be useful, but we stress the need for obtaining disaggregated data from NASA and analyzing the results from individual products. A more practical approach would be to simply acquire samples of materials tested by NASA and test them by current emissions test methods. We need reports of such comparisons for products other than paints.

We feel that the work was a valuable first step in assessing the potential usefulness of the very substantial NASA database. It also provides the reader an opportunity to compare the other measurements to which the NASA data were compared. That comparison reveals that there are very large differences in the results obtained by different investigations. This indicates the need for more standardized test procedures.

For More Information

To learn more about NASA's database, contact: Michael Baechler, Battelle Pacific Northwest Laboratories, 500 N.E. Multnomah, Portland, OR 97232; (503)230-7479.

Lance Wallace et al., "Emissions of Volatile Organic Compounds from Building Materials and Consumer Products," *Atmospheric Environment*, Vol. 21, No. 2, 1987, pp. 385-393.

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TABLE 5 — Comparison of estimated VOC room concentrations ($\mu\text{g}/\text{m}^3$) from paints

NASA Compounds	NASA 1987 ^a	Wallace 1987 ^b	Sheldon 1987 ^b
1,2,3-Trimethylbenzene	—	—	34.05
1,2,4-Trimethylbenzene	—	—	56.18
1,3,5-Trimethylbenzene	—	—	54.48
2-Ethoxyethylacetate	66.43	—	—
2-Ethylhexanol	0.30	—	—
2-Methyl - 1 - Propanol	0.03	—	—
Benzene	0.66	12.26	28.94
Butanol	19.93	—	—
n-Decane	—	24.51	612.85
Ethylacetate	3.32	—	—
Ethylbenzene	—	—	20.43
Methylethylketone	332.17	—	—
Styrene	—	—	3.23
Tetrachloroethylene	0.003	—	491.99
Toluene	83.04	—	—
Trichloroethylene	—	—	3.23
Undecane	—	153.21	425.59
Xylenes	564.68	—	132.78x
TOTAL VOCs	1070.57	189.98	1863.75

a Estimates based on calculations using 95th percentile emissions.

b Estimates based on data from reference using one type of paint.

Law and Government

Legal Issues in IAQ

[IAQU Editor Hal Levin recently spoke at a forum on "Legal Issues and IAQ" at the ASHRAE Annual Meeting held in Vancouver, B.C., on June 26, 1989. The following is a summary of his remarks.]

Three Situations that Engender Lawsuits

Lawsuits related to sick building syndrome (SBS) and building-related illness (BRI) arise out of three types of situations: new buildings, buildings undergoing construction or remodeling, and existing buildings.

New buildings offgas considerable amounts of VOC from new finishes, materials, and furnishings. HVAC systems often don't work right due to incomplete or inadequate system balancing, faulty components or installation, and inappropriate operating procedures. Also, HVAC designs are often inadequate for actual loads and building use.

Buildings undergoing construction or remodeling have the same problem as new buildings: new materials offgas VOC. Occupants often are not protected from construction dust and offgassed fumes and emissions. Supply air recirculated from construction activity or newly finished areas into occupied areas elevates airborne levels of solvents, particles, and other air contaminants.

In speculative buildings, different tenants often share the same ventilation zones. If one tenant moves in before the other, and tenant improvements are made for the second tenant, the first tenant can be exposed to elevated levels of airborne contaminants.

Existing buildings can create bad IAQ in several ways. Load changes, deterioration of equipment, inadequate or inappropriate maintenance, poor housekeeping, reduced air flow for energy conservation, and contamination from building exhaust or other sources are just a few of the ways existing buildings can contaminate indoor air.

Why IAQ Lawsuits are Not Going to Trial

IAQ lawsuits are not going to trial; they are being settled after the discovery phase. The reasons for this have more to do with attorneys' fees than with IAQ concerns. The unfortunate result is that a considerable amount of IAQ information is never released to the public. Also, ambiguity persists about responsibility and liability regarding IAQ.

Plaintiff attorneys usually operate on a contingency basis. If they succeed in getting a judgment, the cost of the trial and any subsequent appeals substantially reduces the amounts available to them and their clients. They tell their clients that they won't get any more money by going to trial and that they run the risk of losing or getting less. Defendants are often national corporations; the negative publicity of a lawsuit is a substantial incentive to settle. Also, one adverse judgment might stimulate other lawsuits from others waiting for a precedent.

Precedents in IAQ cases are rare. Therefore, plaintiff and defense attorneys are anxious to reduce the risk and uncertainty of going to trial by agreeing to a mutually acceptable settlement. Attorneys for both sides are compensated this way.

Unfortunately, a settlement precludes a resolution of the issues under dispute. No responsibility or liability is established. Furthermore, the case record is often sealed as part of the settlement agreement, inhibiting access to the record by those who would wish to learn from it. Substantial resources are invested in investigations, testing, and expert testimony. This information would be valuable for both the indoor air quality community as well as other litigants. However, settlements keep these valuable records out of circulation.

Standard Argument of Defendants and Defense Experts

The standard defense argument of designers and experts for the defense is that the design in question met applicable codes and standards. The argument is clearly inadequate.

Original designs are often not clear and are either not executed or are modified. Validation that the building in question meets design specifications is usually not available. There are often no requirements that the building be operated according to the design. Nor is there evidence that it was, in fact, operated properly.

We have never seen a building that actually met the requirements of Section 6.1.1, "Acceptable Outdoor Air," of ASHRAE Standard 62-1981.

Specifically, that section requires that outside air used for ventilation meet ambient air quality standards. Outside air in major U.S. urban areas almost always exceeds National Ambient Air Quality Standards (NAAQS) levels for ozone, carbon monoxide, or particulates on several occasions each year. Yet, office buildings usually have no provisions to monitor and

remove ozone or to monitor carbon monoxide and reduce outside airflows during elevated CO episodes.

Legal Issues of the New Ventilation Standard

The new ASHRAE Standard 62-1989, "Ventilation for Acceptable Indoor Air Quality," will complicate IAQ-related lawsuits. Three issues will raise questions of responsibility and standards: the design documentation requirement, ventilation effectiveness standards, and compliance with the Air Quality Procedure, Section 6.2.

Design Documentation Requirement

No ASHRAE guidance exists for the required design documentation. The imminent ASHRAE "Guideline on Commissioning HVAC Systems" requires documentation, but does not state exactly what is expected. At ASHRAE's 1989 Winter Meeting, members of the committee drafting the commissioning guideline provided a reasonable list of documentation requirements, but these are not met in current practice. Substantial changes in practice will be required. (See *IAQU* February 1989.)

Other changes in professional practice will be called for. These changes will come neither quickly nor easily. The documentation requirement will require that communications between owner, architect, ventilation system engineer, and tenant-improvement designers be formalized. The ability of a system to meet codes, standards, guidelines, and contract (design, construction, or lease) provisions will be testable against written standards. These changes in practice will produce more responsible professional work, but disputes

will arise about responsibility, fees, and liability. The requirement is ambiguous concerning who will be responsible for the documentation when the building is completed. If the building owner holds the documentation, new responsibilities may arise when tenancy changes. If a new tenant moves in and there is inadequate design capacity, the owner may be responsible for not sufficiently informing tenants of the inadequacy.

Ventilation Effectiveness Standards

Disputes will arise over (1) ventilation effectiveness measurement methods, and (2) responsibility and liability when completed systems fail to deliver outside air supply to the breathing zone as required by contract, code, or the ASHRAE standard.

Key ASHRAE ventilation standard committee members hold differing viewpoints regarding the standard's requirements for outside air delivery to the breathing zone. Individuals called as experts are likely to give conflicting testimony about the requirement's meaning. Such conflicting testimony will have a harmful impact on public and professional acceptance of the standard and on the resolution of lawsuits.

Compliance with the Air Quality Procedure

If a building reduces outdoor air quantities under the provisions of Section 6.1 in the new standard, the indoor air will need to meet the Air Quality Procedure, Section 6.2. We know of no buildings that have used the air quality procedure in Standard 62-1981, and we do not see either the product and equipment manufacturers or engineers eager to use the air quality

procedure. Among other things, inadequate guidance exists in the standard itself or elsewhere for the air quality procedure. Design professionals and product manufacturers will want to defend themselves by "state of the art" or current local professional "standards of care" arguments. Such arguments cannot be made when innovative approaches are used. Compliance with certain critical air quality provisions of the new standard is inherently risky. ♦

Information Exchange

Call for Papers: Indoor Air '90

Conference organizers have released the Second Announcement and Call for Abstracts for Indoor Air '90, The 5th International Conference on Indoor Air Quality and Climate, to be held in Toronto, July 29 to August 3, 1990. This is the preeminent IAQ conference world-wide. The Toronto conference will be the fifth in the ongoing series of triennial, international indoor air meetings. Previous meetings have been in Copenhagen (1978), Amherst, Massachusetts (1981), Stockholm (1984), and West Berlin (1987). There will be technical sessions and exhibits, as in the past. The announcement lists major topical areas for papers as: Human Health, Comfort and Performance; Characterization of Indoor Air; and Building and System Assessments and Solutions. The conference will include a series of forums on issues such as building investigations, environmental regulations, energy conservation, industry perspectives, and ventilation standards.

Abstracts are due by October 1, 1989. The scientific committee

will notify applicants of its decision on November 15, 1989. Papers on accepted abstracts will be due January 1, 1990. After review and revisions as necessary, papers will be published. Conference proceedings will be available at the conference.

Forms for abstracts and registration are in the conference announcement which you can obtain from the address listed below. Typed abstracts of no more than 2/3 page in length should indicate research hypothesis, approach, current status, main findings, and whether work has been published elsewhere.

The American Board of Industrial Hygiene will award four Certification Maintenance points for attendance.

If you are interested in submitting abstracts, contact: Indoor Air '90, c/o Canada Mortgage and Housing Corporation, 682 Montreal Road, Ottawa, Ontario, Canada K1A 0P7. Telephone: (613)748-2714; Telefax: (613)744-8458. ♦

Radon Video Is Available

Single copies of the New York State Energy Office's "Reducing Indoor Radon" videotape are now available for loan from the agency's Office of Communications. The 22-minute video presentation is copyrighted and, while not available for sale, can be borrowed by the public. Federal and state agencies, colleges, universities, and nonprofit research institutions can obtain the tape simply by writing to the State Energy Office, Office of Communications, Two Rockefeller Plaza, Albany, New York, 12223. ♦

IAQ Research at NIOSH

Richard Gorman, assistant chief of the NIOSH Industrial Hygiene Branch, said at the American Industrial Hygiene Conference in St. Louis in May, that NIOSH is now investigating indoor air a little less than it used to. He said one of the reasons for the decrease in IAQ activity is that there are a lot more private organizations doing it now. Gorman stated that IAQ is now about 20% of his branch's work.

The future direction of the branch depends on resource availability. The Mitchell Bill (See *IAQU*, April 1989) includes \$5 million to fund NIOSH investigations of IAQ problems. However, the money in the bill would be for investigations of government (local, state, and federal) buildings only; privately owned buildings are excluded by omission from the bill's language.

NIOSH "800" Number

For NIOSH Information, call 1-800-35NIOSH (356-4674). To get a copy of the NIOSH Guidance Pamphlet on indoor air quality investigations, contact Cutter Information Corp., 1100 Massachusetts Ave., Arlington, MA 02174; (617)648-8700; FAX: (617)648-8707. ♦

Asbestos Abatement Regulatory Service

In the May issue of *IAQU*, we described the Asbestos Abatement Regulatory Service offered by the National Insulation and Abatement Contractors Association (NIAC). We erroneously described their publication as "three volumes;" in fact, the publication consists of three sets of volumes. They contain a compendium of federal, state, and local laws; regulations; and case law summaries.

For more information, contact: NIAC, 99 Canal Center Plaza, Suite 222, Alexandria, VA 22314; (703)683-6422. ♦

IAQ Update '89 — IH Certification Maintenance Points

Attendees to the *IAQ Update '89* conference are eligible for Certification Maintenance Points (CMP) from the American Board of Industrial Hygiene. For more information, contact Kim Gay at Cutter Information Corp. Telephone: (617)648-8700 Fax: (617)648-8707

Editor: Hal Levin

Publisher: Karen Fine Coburn

Subscription Manager: Kim Gay

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List Manager: Doreen Evans

Production Manager: Karen Kunkel Pasley

EDITORIAL OFFICE:

Indoor Air Quality Update,
2548 Empire Grade
Santa Cruz, CA 95060;
Phone: (408)425-3846
Fax: (408)426-6522

SUBSCRIPTION OFFICE:

Cutter Information Corp.,
1100 Massachusetts Avenue,
Arlington, MA 02174, U.S.A.;
Phone: (617)648-8700,
Fax: (617)648-8707
Telex: 650 100 9891 MCI UW,

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