Indoor Air Quality Update™

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

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News and Analysis

State of Maine Moves to Improve IAQ

The State of Maine Bureau of Public Improvements now requires all new school construction and significant renovation to meet ASHRAE Standard 62-1989. As of six months ago, whenever a lease for state office space is renewed or a new lease written, it must also meet the current ASHRAE ventilation standard, now Standard 62-1989. ♦

In This Issue

Congressional Committee Scores EPA, GSA

At the September 27 hearing on the IAQ legislation pending in Congress, House Natural Resources Subcommittee Chair James Scheuer (D., NY) attacked EPA and GSA for their failure to act on their respective IAQ responsibilities. Both agencies opposed the legislation although they said they supported its goals and were working to implement them.

In the case of EPA, Scheuer noted that the occupants of EPA's headquarters in Washington were in the audience in silent protest of EPA's failure to provide good air quality. They sported buttons which said "Protect the Environment of EPA Employees." Scheuer said the buttons symbolized EPA's lack of concern for the health of its own employees.

Ironically, just two days earlier, half the employees in the building were sent home when paint fumes entered the building through an air handling unit on the roof.

Scheuer told EPA Deputy Administrator Henry Habicht: "You tell us you do not need new authority or funding, that you are working to address IAQ problems, yet you cannot even provide good air quality in your own building." He said EPA officials want us to trust them, but EPA's long-term neglect of IAQ problems at EPA headquarters shows the agency's lack of trustworthiness without Congressional supervision. Trust does not exist, Scheuer told Habicht.

Scheuer extracted a number of commitments from GSA Assistant Commissioner Thomas Walker; one indicated that IAQ provisions would be written into future leases for government offices.

Scheuer was joined by committee members Joseph Kennedy (D., MA) and Claudine Schneider (R., RI) in attacking the administration officials. Kennedy asked Habicht how much EPA spends on toxic waste cleanup, outdoor air, and indoor air. Habicht's answer was $7 or $8 billion, more than $100 million, and about $2.5 million, respectively. Kennedy insisted that this was outrageous considering the EPA itself had said in its Report to Congress that indoor air represents a significant public health problem. Kennedy said that EPA Administrator Reilly himself had told him that IAQ was a very high priority problem.

The committee did agree to work at the staff level to remove provisions of the bill objectionable to the administration. Sources in EPA have told *IAQU* that there is particular unhappiness with the health advisory requirements in the bill.

In our own testimony (*IAQU* Editor Hal Levin was also an invited witness at the hearing) we suggested that the health advisory provisions were a great idea but absolutely unworkable. There simply is insufficient knowledge to disseminate on most contaminants. We did argue that more fact sheets of the sort that EPA has been publishing should be issued. These fact sheets should say what we know and what we don't know about the major indoor air contaminants and how to control them.

More importantly, we said that the proposed legislation was a cost-effective measure. The cost of lost productivity in office workers and their associated health care costs for avoidable indoor air quality related illnesses is more than $6 billion per year. ♦

ASHRAE Releases Ventilation Standard

At long last, ASHRAE has released Standard 62-1989. While it is far from perfect, it reflects the best efforts of many knowledgeable individuals from industry, engineering, architecture, health science, and academia.

Ventilation Rate Versus Other Requirements

We think simply relying on the outside air requirements (in Table 2 of the standard) without sufficiently considering the other provisions in the standard will not do much to improve indoor air quality. We addressed many of these considerations previously (*IAQU*, February 1989 and September 1989). The important features of the standard are listed below in their order of importance, as we see them.

Key Features of ASHRAE Standard 62-1989.

1. The minimum outside air requirement is 15 cfm/p and in most cases will be 20 cfm/p or more. Specific requirements depend on occupant density and the types of activities for which the ventilated space is intended.
2. The required outside air quantities must be delivered to the occupants' breathing zone. Ventilation effectiveness must be considered in designing the air distribution system.
3. Design documentation is required. This should include the air quality and thermal load assumptions on which the design is based, the HVAC system performance criteria, and the HVAC system description.
4. Ready accessibility of HVAC systems is required for inspection, maintenance, and cleaning.
5. Outside air used for ventilation must meet federal ambient air quality standards. Where practical control technology is not available (as is the case for carbon monoxide), outside air supply should be curtailed during periods of outdoor air contamination (such as during rush hour). In these cases, recirculated air must be filtered and cleaned to meet the requirements in the standard's air quality procedure.
6. Control of unusual or strong indoor air contaminant sources is required. Exhaust ventilation systems located close to such sources are suggested.
7. HVAC design and operation must respond to indoor air pollution loads and not just thermal loads. The system must be operated to achieve the design objectives.

The standard is a rich resource of information about known sources of IAQ problems and their remedies or prevention. In the remainder of this article we discuss only the outside air ventilation rate requirements.

By far, the most widely used portion of the standard is Table 2, ventilation rates for various types of occupancies. A sampling of values is presented in our Table 1.

Significant Changes in Ventilation Requirements

There is one very significant change from Standard 62-1981 in the table: the deletion of the distinction between smoking-permitted and nonsmoking spaces. Many of the values in Standard 62-1989 are quite similar to the values in the earlier standard for smoking-permitted environments.

Several Important Decreases

However, there are some notable exceptions. Requirements for several types of spaces went from 35 cfm/p where smoking was allowed and 7 cfm/p for nonsmoking in Standard 62-1981 to 20 cfm/p for all such spaces in Standard 62-1989. Some of these spaces are for uses where the amount of smoking can vary significantly.

For example, these values apply to dining rooms and cafeterias (Food and Beverage Services); to conference rooms (small), assembly rooms (large), and gambling casinos (a classification that includes Hotels, Motels, Resorts, Dormitories, and Correctional Facilities); meeting and waiting spaces (Offices); and lobbies (Theaters).

Outside air requirements for bars and cocktail lounges went from 50 cfm/p and 10 cfm/p for smoking and nonsmoking areas respectively to 30 cfm/p. Spectator areas (Sports and Amusement Facilities) and waiting rooms (Transportation Facilities) went from 35 cfm/p and 7 cfm/p respectively for smoking and nonsmoking spaces to 15 cfm/p. Of course the anti-smoking

Table 1 — Extracts from Table 2,* ASHRAE Standard 62-1989

Application	Estimated Maximum Occupancy P/1000 ft²	cfm/ person	cfm/ ft²
Food and Beverage Service			
Dining rooms	70	20	
Cafeteria, fast food	100	20	
Bars, cocktail lounges	100	30	
Kitchen (cooking)	20	15	
Offices			
Office space	7	20	
Reception areas	60	15	
Conference rooms	50	20	
Public Spaces			
Smoking lounge	70	60	
Elevators			1.00
Retail Stores, Sales Floors, and Show Room Floors			
Basement and Street	30		0.30
Upper floors	20		0.20
Malls and arcades	20		0.20
Smoking lounge	70	60	
Sports and Amusement			
Spectator areas	150	15	
Game rooms	70	25	
Playing floors	30	20	
Ballrooms and discos	100	25	
Theaters			
Lobbies	150	20	
Auditorium	150	15	
Transportation			
Vehicles	150	15	
Education			
Classroom	50	15	
Music rooms	50	15	
Libraries	20	15	
Auditoriums	150	15	
Hotels, Motels, Resorts, and Dormitories			
			cfm/room
Bedrooms			30
Living rooms			30
Lobbies	30	15	
Conference rooms	50	20	
Assembly rooms	120	15	

* Table 2 prescribes supply rates of acceptable outdoor air required for acceptable indoor air quality.

advocates are rather upset with these changes, and not without reason. No rationale for the changes is provided in the standard itself.

Effect of Room Volume

In many rooms, the volume of the space can vary significantly depending upon the ceiling heights. Most rooms have ceiling height ranging from eight or nine feet up to 30 or 40 feet or even higher. Thus, a threefold to fivefold variation in volume could be found with similar occupant density. It may be necessary to increase the amount of airflow in the space, even if the outside air quantity is held constant, in order to adequately remove contaminants generated in the space. On the other hand, a large volume provides a considerably larger dilution capacity for contaminants generated by occupants and their activities.

Particular attention is warranted to determine the delivery of outside air or ventilation air to the occupied zone. While Standard 62-1989 specifies delivery to the occupied zone (between six inches and six feet above the floor), no mechanism for its measurement is provided or referenced. We fear that measurements will be made at the supply diffusers regardless of the ventilation efficiency of the installed system or other important characteristics of the space. What is worse, some engineers may simply look at the space as a whole and design the system based on average requirements throughout the space.

Reduction Allowance May Cause Problems

Standard 62-1989 allows two types of reductions in the Table 2 outside air requirements. One is where occupancy is intermittent or variable. In these cases, ventilation may lag behind occupancy as long as the source of contaminant generation is associated with occupants or their activities. When contaminants are generated in the space independent of occupants and their activities, ventilation must lead occupancy. When peak occupancies occur for less than three hours, outdoor air flow rates are determined based on the average occupancy of the building for the duration of operation of the system as long as the average occupancy is not less than one-half the maximum.

For buildings with multiple spaces of divergent occupant densities or types, reductions are allowed under Section 6.1.3.1, Multiple Spaces, which states the following: "Where more than one space is served by a common supply system, the ratio of outdoor to supply air required to satisfy the ventilation and thermal control requirements may differ from space to space. The system outdoor quantity shall then be determined using $y = x/(1+x-z)$ where y is the corrected fraction of outside air in the supply system, x is the uncorrected fraction of outdoor air in the supply system, and z is the fraction of outdoor air in the space with the greatest required fraction of outdoor air in its supply."

This provision, borrowed from the Australian ventilation code, makes sense for applications where supply air for bathrooms or kitchens might come from adjacent spaces. However, many other situations exist where application of the reduction allowance results in some unreasonable results. Analysis of the provisions for reduction in outside air requirements permitted under Standard 62-1989 reveals a defect in the standard and, perhaps, in most ventilation system designs.

We looked at three hypothetical office buildings to understand what the application of this formula might mean. The first case is an office building containing a classroom. In the second case, we varied the proportion of space in open and in private office areas. In the third case, we varied the proportions of densely occupied open space areas and sparsely occupied private offices.

Case 1

If a classroom space were located in an office building with a single outside air supply, the following calculation would provide the reduction factor. Using a design assumption of one cfm/sq ft total air supply and using the design values for occupant density and outside air requirements from Table 2 in the standard, the classroom would have 20 sq ft per person, and 15 cfm/p outside air resulting in $z = 3/4$.

If the rest of the building were only office space (for the sake of simplicity), then x for the rest of the building would be based on 143 sq ft/p and 20 cfm/p, or $x =$ about $1/7$. If the building is very large, x will be close to $1/7$, and as the amount of office space in relationship to the classroom space decreases, x will increase with an upper bound just less than $3/4$.

In the case of a building with classroom space for half the office workers, $y = 42\%$. Thus, the office spaces that would require 14% outside air in the base case would actually receive 42% (60 cfm/p) outside air. The classroom which would require 75% outside air would also receive only 42% (8.4 cfm/p).

The application of the reduction formula makes little sense for this case. But not applying it results in an even greater oversupply to the office spaces if the minimum required for the classroom is used for the single outside air supply volume. This case illustrates a basic dilemma where a single air supply serves spaces with very different occupant densities. No single quantity works well for either case.

Case 2

In this example, there are equal areas of open office space work stations and of private offices; but, the work areas are arranged with very different occupant densities. Using the design values from Table 2 in the standard, 20 cfm/p would be required for each occupant. Assuming 60 sq ft/p in the open space work stations and 300 sq ft/p in the private offices with 20 cfm/p in both cases, $x = 1/5$ and $z = 1/3$ (in the open space offices). This results in a $y = 3/13$. Thus, each work station area would receive only about 14 cfm/p outside air supply ($3/13 \times 60$) while private office occupants would each receive almost 70 cfm/p ($3/13 \times 300$).

Case 3

If, instead, we assumed equal numbers of open space office work stations and private offices with the same densities used in the preceding example, we would have $x = 1/9$, $z = 1/3$, and $y = 1/7$. Thus, open office work station occupants would receive about 8.6 cfm/p, less than half of the 20 cfm/p indicated by Table 2. Private office occupants would receive 42.9 cfm/p.

Standard Overlooks Alternative Solutions

The resulting outside area supply distribution creates apparent shortfalls and excesses. But this is not the result of the "Australian" averaging procedure alone. It is the result of any approach that averages loads from different zones supplied by a common supply system. This problem has not been addressed by the standard. Averaging outdoor air requirements for all spaces served by a system will result in these sorts of distortions of supply requirements unless some explicit approach is used to avoid them.

Varying the types of systems used might provide some solutions. Induction systems with outside air and cooling coils (or, where required, heating coils) at the distribution terminal can be used. Separate outside air supply and recirculation distribution networks might also provide a solution. But for systems that employ economizer cycles for a significant part of the day or year, these approaches are less cost effective. Alternatively, we might use a variable outside air supply and constant volume space air distribution system or another system utilizing proportional control approaches.

For More Information

To obtain a copy of the standard, contact: ASHRAE, 1791 Tullie Circle NE, Atlanta, GA 30329; (404)636-8400. The price is $42/copy ($28 for ASHRAE members). ♦

Canadian Committee Reports on IAQ

An interagency committee in Canada has prepared a comprehensive guidance document for government inspectors, occupational health professionals, and property managers. It has been released in draft form. The report focuses on commercial buildings and excludes residential and industrial environments. It includes a discussion of health hazards related to IAQ, a detailed protocol for investigations, and recommended acceptable criteria for IAQ including environmental tobacco smoke. The report also addresses lighting, noise, vibration, and thermal factors as well as the traditional IAQ concerns.

Gyan Rajhans, the chairman of the committee that developed the report, has been a leading advocate of using CO_2 as an indicator of acceptable ventilation. Rajhans formulated the much-used guideline of 1,000 ppm CO_2 indicating potential ventilation inadequacies.

Investigatory Protocol

Like most investigators, the Canadian group has recommended a multistage investigation beginning with a preliminary assessment, then a questionnaire, simple measurements, and finally, if required, complex measurements.

The report contains detailed survey guidance forms for the preliminary assessment, investigation of the HVAC system, maintenance operations, and a complaint area observation sheet. It also contains extensive guidance for interpreting the results, something that is missing from many of the other available publications and guidance documents for investigating IAQ complaints. It also contains a survey form to be administered to occupants with instructions for its administration and scoring.

The Ontario group has not broken new ground. What it has done is review what was available and collect it into a fairly compact and accessible document. The group also translated its findings and field experience into a set of comprehensive recommendations for new and existing buildings.

The Report's Recommendations

Most of the recommendations are consistent with the requirements of the new ASHRAE standard. However, if the standard is not codified, then the recommendations could be important. The report suggests incorporating its recommendations into the building code.

The committee recommends classifying all building areas normally occupied by the working population as nonsmoking. As an interim measure, designated smoking areas should be created and they should be provided with 60 cfm/person outside air. Exhaust air from designated smoking areas should not be recirculated.

For More Information

Report of the Inter-ministerial Committee on Indoor Air Quality, Ontario: Ministry of Labour, Government of Canada.

To obtain a copy, contact: G. S. Rajhans, Health and Safety Support Services Branch, Ontario Ministry of Labour, 400 University Avenue, Toronto, Ontario, M7A 1T7 Canada; (416)965-3610. ♦

From the Field

Is Benzene Regulation Off Target?

Lance Wallace of the EPA has published a paper on benzene exposure in the United States. He reports that traditional sources of atmospheric emissions (auto exhaust emissions and industrial emissions) account for only about 20% of total human exposure.

Table 2 — Benzene exposures and risks

Activity	Intake, µg/day	Population at risk	Cases/ year[a]
Smoking	1800[b]	53×10^6	500
Passive smoking	50[c]	200×10^6[d]	50
Outdoor levels	120[e]	240×10^6	150
Driving/riding auto	40[f]	200×10^6	40
Filling gas tank	10[g]	100×10^6	5
Occupational	10,000[h]	240×10^3[i]	10
Other personal	150	240×10^6	200[j]
Total			960

[a]Using a unit risk of 8×10^{-6} $(\mu g/m^3)^{-1}$.
[b]57 µg/cigarette (Higgins) x 32 cigarettes/day.
[c]3 µg/m³ x 17 hr/day indoors x m³/hr respiration.
[d]Approximately 80% of persons exposed to environmental tobacco smoke.
[e]TEAM outdoor average in eight locations — 6 µg/m³ x 20 m³/day.
[f]Few data available, assumed 40 µg/m³ in vehicle x 1 hr/day.
[g]1 ppm x 70 min/year.
[h]Assumed 1,000 µg/m³ x 10 m³/8 hr workday.
[i]NIOSH estimate of number of workers exposed to benzene.
[j]Obtained by subtraction from published estimate of 460 nonsmoking cases/year (*26*). Includes emissions from surface coatings, consumer products, evaporative emissions from autos in attached garages, etc.

The most important source for 53 million smokers nationwide is the mainstream smoke from cigarettes. This, Wallace says, accounts for about 50% of all benzene exposure in the United States. Another 20% comes from personal activities such as driving and using attached garages. Emissions from consumer products, building materials, paints, and adhesives are also important, but data are lacking on their magnitude. Environmental tobacco smoke is an important source accounting for 5% of total exposure nationwide. (See Table 2.)

These data are interesting since most of the regulatory activities related to benzene target industrial sources and gasoline pumping. However, Wallace writes that these sources plus occupational exposures and contamination of food, water, and beverages "account for no more than a few percent of total nationwide exposure to benzene."

The case of benzene illustrates that regulatory efforts might be aimed at the wrong targets, at least by the criterion of maximum protection of public health. Wallace has made significant contributions to our understanding of where humans are exposed to chemicals in the environment. His Total Exposure Assessment Methodology (TEAM) studies provide important benchmarks for evaluating exposures to environmental hazards.

A conference planned for the end of November in Las Vegas is the first to focus on the TEAM approach. It will broaden the information base and, Wallace told ***IAQU***, might lead to the publication of a journal on total human exposure. For more details, see the announcement in the Calendar section of this issue.

Reference: Wallace, Lance, 1989, "Major Sources of Benzene Exposure." *Environmental Health Perspectives*, Vol. 82, pp. 165-169. ♦

Feature

Report from Europe — SBS and Indoor VOC

Although volatile organic compounds (VOC) are not often proven to cause SBS complaints, they are often suspected. Investigators using many complex measurements have frequently failed to demonstrate a causal relationship between indoor VOC concentrations and complaints. The attention VOC receive may result from the important role formaldehyde and some pesticides play in focusing public attention on IAQ issues.

In a recently released paper, Helmut Knöppel and Maurizio De Bortoli of the European Community's Joint Research Centre in Ispra, Italy, outline some basic considerations regarding organic chemicals as causes or cofactors of SBS symptoms. They recommend approaches to measuring VOC based on those considerations and on their experience measuring VOC in European Parliament offices. They conclude that VOC levels should be minimized in suspect air quality situations even without substantiated problems.

Types of Organic Chemicals and Their Potential Role in SBS

We can classify organic air pollutants in four categories based on their volatility, as indicated by their boiling points and the methods used to collect them (see Table 3). In practice, the cate-

Table 3 — Classification of organic indoor pollutants[A]

Description	Abbreviation	Boiling point range[B] from °C	to °C	Sampling methods typically used in field studies
Very volatile (gaseous) organic compounds	VVOC	< 0	50-100	batch sampling, adsorption on charcoal
Volatile organic compounds	VOC	50-100	240-260	adsorption on Tenax®, graphitized carbon black or charcoal
Semivolatile organic compounds	SVOC	240-260	380-400	adsorption on PUF[C] or XAD-2
Organic compounds associated with particulate matter (particulate organic matter)	POM	> 380		collection on filters

[A] Adapted from World Health Organization (1989)
[B] Polar compounds are at the higher side of the range
[C] Polyurethane foam

gories are defined by the methods by which the chemicals are collected. Most indoor air quality investigations focus on the very volatile organic compounds (VVOC), VOC, and sometimes on the semivolatile organic compounds (SVOC).

Many suspected or known effects of VOC are associated with SBS complaints and symptoms. Table 4 lists these effects.

Many of the effects of specific organic compounds found in indoor air occur above certain thresholds or limit values. Therefore, it is useful to know the range of concentrations found in buildings. Most of the effects for which thresholds are known refer to single compounds; however, indoor air usually contains complex mixtures of organic compounds. For the sake of simplicity, researchers usually report total concentrations except for certain compounds such as formaldehyde and the common solvents. Table 5 lists the ranges found by the authors and other investigators for total concentrations of the various classes of organic compounds listed in Table 3. Note the excellent agreement between the total VOC in 500 homes (values represent two-week averages) and 10 office buildings (10-minute averages).

Several organic chemicals are known to cause effects associated with SBS complaints. These general categories of effects are: odor annoyance, sensory effects, mucosal irritation and other acute effects, and effects caused by long-term exposure.

Odor Annoyance

While odor annoyance is frequently associated with SBS symptoms and IAQ complaints, measuring organic contaminants is not useful for identifying the cause of the complaints for the following reasons:

Table 4 — Effects of Organic Chemicals Associated with SBS-type Symptoms

Effect	Compounds
<u>Acute effects</u>	
Odor annoyance	Wide range of compounds, mostly VOC
Sensory effects	(Total) volatile organic compounds
Mucous membrane irritation and other acute effects	Wide range of compounds (VVOC, VOC, SVOC)
<u>Chronic effects</u>	
Sensitization	Little knowledge, mostly on SVOC
Chronic intoxication	Little knowledge (some indications for PCP and PBB)

- Odor thresholds of organic compounds vary by more than 10 powers of 10 (a factor of 10 billion). The thresholds for the most intense and most common indoor pollutants are relatively high (0.1 to 100 mg/m^3).
- We do not have a generally accepted model for determining the odor intensity of complex mixtures like organic compounds in indoor air.
- According to the World Health Organization, we can estimate the perceived strength of an odorous mixture with an accuracy of ±50% based on the strength of the strongest smelling compound. Therefore, a minor but strongly odorous constituent in indoor air may determine our perception of its odor.

Thus, chemical measurements are not generally useful for predicting or detecting the presence or source of compounds resulting in odor annoyance. Other approaches such as Fanger's are necessary and preferable. (See *IAQU*, October 1988.) An exception is formaldehyde. It has the lowest odor threshold and the highest potential for mucous membrane irritation among the frequently detected indoor air contaminants. It is frequently the cause of indoor air quality complaints. Therefore, we should measure formaldehyde and other aldehydes where odor or suspected sources suggest their presence.

Sensory Effects

We usually experience the acute nonolfactory sensory effects of indoor VOC through the interaction of these chemicals with the trigeminal nerve. The trigeminal nerve arises from the brain stem and divides into three main branches which subdivide into a complex network of nerves. These nerves transmit signals to and from the face, scalp, nose, teeth, lining of the mouth, upper eyelid, sinuses, and front two-thirds of the tongue. They control saliva production by the salivary glands and tear production by the lachrymal glands. They also stimulate the jaw muscles for chewing. Damage to one area of the network may cause "referred pain" in another area. For example, a sinus infection may cause a toothache.

European researchers have shown that sensory effects in humans depend on the total concentration of VOC. Exposure to a representative mixture of 22 VOC typically found in indoor air may cause us to feel irritation in the eyes, nose, and throat; headache and general malaise; sensation of insufficient ventilation; and sensation of poor air quality. These symptoms usually occur at concentrations of 8-25 mg/m^3. The researchers observed no effects at concentrations less than three mg/m^3.

The similarity of these effects and SBS-type symptoms suggest that measuring individual VOC and total VOC concentrations may be helpful in some circumstances — for example, in new buildings where total concentrations may exceed three mg/m^3.

Sensory effects alone do not usually justify measuring VOC in older buildings because VOC concentrations found there are usually low. (See Table 5.) However, if a source inventory reveals potential sources of organic compounds,

Table 5 — Concentrations of Various Groups of Organic Compounds in the Outdoor Environment

Compound Group	Concentration (µg/m^3)			
total VVOC[A] (16 offices)	mean: 34% ± 2% of total VOC; range: 11%-90%			
total VOC	Min	50%ile	90%ile	Max.
500 homes,2 wk. avg.B	72	330	710	2670
10 office buildings 84 offices, 10 min. average[A]	13	220	870	3930
new buildings[C]				25,000
SVOC				
total in "dirty" sample[D]			80	
various pesticides[E]			0.01-28	

[A] data measured by the authors
[B] total of quantified compounds (60-80% of total VOC): Krause et al. (1987)
[C] highest value detected in new Danish buildings: Mølhave, Bach, and Pederson (1986)
[D] Oehme and Knöppel (1987)
[E] Sterling (1987)

measurements are warranted. An excellent example is the Portland East Federal Building (described in *IAQU*, June 1989). There, the solvent used in wet-process photocopiers and in plotters was the major VOC found in indoor air. The airborne concentrations were reasonably predictable from the quantities used according to purchasing invoices.

A different theory of the relationship of VOC concentrations and sensory effects was presented by Elliot Noma and his Swedish colleagues (see *IAQU*, January 1989). They studied VOC patterns of distribution in one "healthy" and one "sick" Stockholm preschool by using sophisticated statistical methods. Their hypothesis is that high concentration gradients within a building may trigger SBS symptoms rather than mean concentrations. They attribute adverse reactions to a lack of adaptation to gradients. This hypothesis should be investigated further.

Mucosal Irritation and Other Acute Effects

Mucosal irritation and acute effects on the central nervous system (CNS) both produce SBS-like symptoms. Knowledge in this area is limited to the effects of single substances and generally is developed for establishing threshold limit values (TLV) for occupational exposures.

Threshold limit values are inadequate for assessing the potential effects of indoor pollutants because people working in industrial environments are usually healthier than the general population. The general population includes children, the elderly, the infirm, and individuals with pre-existing conditions which make them more susceptible to the adverse effects of exposure to pollutants. Furthermore, TLVs do not account for simultaneous or serial exposure to complex mixtures of pollutants, which is usually the case with exposure to indoor air.

Given the absence of adequate health effects information for most indoor air pollutants, TLVs or no observable effect levels (NOELs) are often divided by a protection factor to establish a value that can be used to determine whether a given indoor exposure might adversely affect people. The protection factor used is usually between 10 and 100, depending on the reliability of the dose-response data and the importance of the effect on which the TLV or NOEL is based.

Table 6 compares some measured VOC indoor air levels for some common indoor air contaminants with two guideline numbers. The first guideline (TLV/10) is based on various TLVs divided by 10. The second guideline is from the levels established by the World Health Organization in its 1987 "Air Quality Guidelines for Europe" (AQG); they are based on protection factors ranging from 50 to 100 applied to the NOEL for CNS and mucosal irritant effects.

With the exception of formaldehyde, all measured values (both 90 percentiles and maximum values) were below the guideline values. The VOC closest to the guidelines were n-hexane, tri-, and tetra-chloroethylene — all commonly found indoor air pollutants.

Based on available knowledge and the assumptions made in establishing guidelines, these data indicate that only in exceptional cases will organic compounds other than formaldehyde in indoor air cause acute effects leading to SBS symptoms.

Effects Caused by Long-term Exposure

Long-term effects such as sensitization and chronic intoxication affecting the CNS may contribute to SBS-like symptoms. However, there is little empirical evidence that the types and concentrations of organic chemicals which have been observed in indoor air cause such effects.

The researchers believe that organic indoor pollutant measurements are not useful for identifying situations in which sensitization may occur. They base this conclusion on the following evidence:

- A list of chemicals classified as sensitizers of respiratory organs by the European Economic Community contains mostly SVOC. The list contained none of the 307 organic chemicals detected in indoor air by Swedish researcher Birgitta Berglund and her co-workers. (Berglund, Berglund and Lindvall, 1986, "Assessment of Discomfort and Irritation from the Indoor Air" in *Proceedings of IAQ '86, Managing Indoor Air for Health and Energy Conservation.* Atlanta: ASHRAE, Inc.)
- We have insufficient knowledge about the mechanisms of nonallergic hypersensitivity reactions and whether any organic indoor pollutants cause such reactions.

However, once people are sensitized for allergic or nonallergic hypersensitivity reactions to some chemicals, they may show SBS symptoms at concentrations far below those believed capable of causing the reactions. Measurements are only useful in these situations where we know the hypersensitivity state and the stimulating chemicals. The avail-

Table 6 — Comparison of concentrations of frequently detected indoor pollutants with estimated lower concentration limits for irritation

	Concentrations ($\mu g/m^3$)				
	WHO (1989)	80 offices (10 buildings)		TLV/10 (TWA)	AQG (WHO 1987)
Compound	90%ile	90%ile	max	(mg/m^3)	(mg/m^3)
n-hexane	20	10	1730	18	—
n-heptane	15	24	210	160	—
cyclohexane	100	n.d.[A]	n.d.[A]	105	—
methylcyclohexane	100	<15	27	16	—
toluene	150	45	280	37.5	8[B]
m,p-xylene	40	10	20	43.5	—
trichloroethylene	20	—	640	27	1[C]
1,1,1-trichloroethane	20	40	3,670	190	—
tetrachloroethylene	20	160	1,250	33.5	5[C]
i-butanol	5	<14	59	15	—
formaldehyde	60	122	139	0.15[D]	0.1
acetaldehyde	30	25	57	18	—
n-hexanal	5	<14	19	(13.8[E])	—

[A] n.d. = not detected.
[B] Protection factor of 50 applied to NOEL for CNS and mucosal irritant effect.
[C] Protection factor of 100 applied to estimated NOEL for CNS effect.
[D] Suspected human carcinogen.
[E] Value corresponding to 0.003-RD50 (concentration expected to cause a 50% decrease in respiratory rate of mice resulting from sensory irritation) reported in the Danish list of sensory irritants (Andersen 1989).

able evidence suggests that we should consider the aldehydes and chlorinated hydrocarbons first in such cases. Formaldehyde may cause respiratory-tract sensitization, according to Danish researchers who controlled exposure conditions of subjects with and without prior occupational exposure to formaldehyde.

German researchers suspect chronic intoxication may result from prolonged exposure to vapors from pentachlorophenol-impregnated wood. The effects are generalized lethargy and tiredness, mental fatigue, headaches, dizziness, and irritability.

Pentachlorophenol (PCP) is no longer used for indoor applications in West Germany, and its complete ban is under consideration. (Its use indoors has been restricted in the United States.) However, the low volatility of PCP (and other wood preservatives) means it will remain in the environment for many years after initial application. PCP has been used in many consumer products resulting in widespread population exposure.

Recent exposure of dairy farmers to polybrominated biphenyls (PBB, a chemical used as a flame retardant) resulted in neurological symptoms similar to those reported above for PCP exposure.

These and other incidents suggest that prolonged exposure to elevated levels of biocides and related compounds may lead to SBS-type complaints.

We have insufficient dose-response information to make a firm association of complaints with measured air concentrations. The researchers also point out that indoor air concentrations of SVOC are not necessarily indicative of exposure. Many researchers have found significant contamination of household objects and dust with PCP, and occupants' urine PCP levels correlate well with dust levels. Therefore, skin contact is

Table 7 — Summary of stepwise investigations of buildings with problems

Step	Type of investigation	Performed by (Proposals)	Actions (Examples)
1	Technical survey and use of questionnaire	Industrial physician Safety representative Maintenance engineer	Contact experts for evaluation; organize new actions; inform
2	Inspection and guiding measurements of climate indicators	Safety engineer Ventilation engineer	Clean and adjust ventilation; stop humidifiers; (re)move smokers and pollution sources
3	Measurements of ventilation; climate indicators; and other implicated factors	Safety engineer Industrial hygienist Ventilation engineer	Increase ventilation; arrange sun-shielding
4	Medical investigation, specific measurements of suspected components	Medical doctor Industrial hygienist	Renew furniture; change on-going activities or building materials; move staff; mount local exhaust

also considered an important exposure route.

Strategy for Measuring VOC in Office Buildings

Based on the data we've described above, researchers have developed strategies for SBS investigations that recommend chemical measurements only at late stages of such investigations. A working group of the European Concerted Action "Indoor Air Quality and Its Impact on Man" prepared a guide for SBS investigations. (See reference by Molina et al. at the end of this article.)

The recommendations are summarized in Table 7. They suggest that you make VOC and formaldehyde measurements for orientation purposes in the early stages of investigations only in new or refurbished buildings if strong odors are present. Otherwise, make overall measurements at the third step and detailed chemical analysis only at the fourth step.

European Parliament Buildings Survey Strategy

Knöppel and De Bortoli conducted an initial survey in 50 representative offices of the European Parliament in buildings where occupants had complained about air quality. They detected no unusually high VOC concentrations in the 10 buildings surveyed. In a few offices formaldehyde levels were slightly above the WHO guideline value of 100 $\mu g/m^3$. In those offices the investigators recommended increased outdoor air ventilation.

Interestingly, the administration perceived that the measurement program had a beneficial effect on occupants' attitudes, so it requested measurement on a regular basis. The investigators then sought a strategy to reduce the number of measurements, relate measurements to complaints, and argue against measurements where no relation to complaints existed.

The investigators administered a questionnaire to the occupants about SBS-type complaints and perceptions of the indoor environment and climate. Figure 1 shows the symptoms portion of the questionnaire. The researchers used the answers to the symptoms questions to calculate a "complaint index" by attributing scores to the symptoms and weighting the different responses. By summing the products of weights and scores, the researchers calculated the "complaint index" for each worker or space.

They used the questionnaire responses to select six buildings for further study. Two or four offices were selected in each building (a total of 20). Half had complaint index values near the maximum and half near the minimum. The researchers say this is a more rational basis for selecting sampling locations than selecting "representative" locations which, they claim, is always ambiguous, especially if only a few measurements are to be made.

Figure 2 shows the results of VOC measurements (using Tenax as the

Have you suffered from any of the following symptoms in the last fortnight?

	No	Occasionally	Frequently, i.e. at least once a week	If frequently — do the symptoms persist at home	
				Yes	No
Itchiness, prickling sensations or other forms of irritation affecting: • the eyes • the nose • the throat — including the symptoms of colds and chills					
Dry skin or rash					
Headaches or headachiness					
Unaccustomed lethargy or fatigue					
Malaise or dizziness					
Other					

Have you consulted a doctor on these symptoms . . . .

Figure 1 — Symptom's part of the questionnaire used for the investigation of EP buildings.

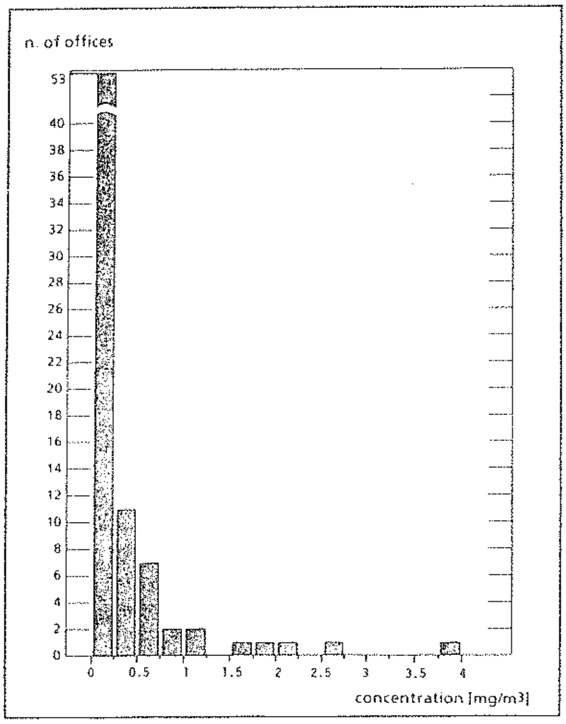

Figure 2 — Distribution of total VOC (≥ C_6) concentrations measured in EP buildings.

sorbent and gas chromatographic analysis) in all 10 buildings. Apart from a single high value (four mg/m^3), all samples were well below three mg/m^3. From this, the researchers concluded that there was no significant difference between offices with high and low complaint indexes. A plot of complaint index values against total VOC concentrations showed the absence of a correlation.

There was also no relationship between the complaint index and the measured formaldehyde values. All the reported formaldehyde values were well below the established threshold for effects.

Use of a PID for Initial VOC Surveys

The researchers sought means to reduce the effort and expense of VOC surveys. They tested a lightweight, portable photoionization detector (PID), which has promising advantages for this application. They compared measurements obtained using a TIP I instrument (Photovac Inc., Thornhill, Ontario, Canada) with Tenax sampling and GC analysis in 55 offices.

The overall correlation was good, but there was considerable scatter in the values, especially at the low VOC concentrations. There was also a considerable difference between the TIP readings and the calibration mixture, which was composed of six common indoor VOC: benzene (37%), toluene (27%), m-xylene (12%), n-butanol (0.35%), n-heptane (20%), and hexanal (3.8%). The researchers continue to evaluate these differences and investigate the contribution of VVOC to the TIP reading.

The Authors' Recommendations

Knöppel and De Bortoli make the following recommendations to investigators of SBS-type complaints in office buildings:

- Make chemical measurements only after completing a technical survey of the ventilation systems, a questionnaire inquiry of the type and prevalence of complaints, measurements of ventilation and indoor climate parameters, and an assessment of odors.

- VOC measurements are warranted in a new building within the first two months after completion when there are indications of strong sources.
- If no indications of high-exposure locations are present, make comparative measurements in locations with high and with low complaint levels.
- If information regarding specific sources does not suggest otherwise, initial chemical measurements should be of total VOC and of aldehydes.

For More Information

The European Economic Community is engaged in several interesting indoor air research projects. It has issued several reports and guideline documents for use by its member nations. You can obtain information by writing the Commission of the European Communities — Joint Research Centre, Institute for the Environment, I-21020 Ispra (Varese), Italy.

Helmut Knöppel and Maurizio De Bortoli, "Experiences with Indoor Measurements of Organic Compounds," presented at American Industrial Hygiene Conference, May 21-26, 1989, St. Louis, Missouri.

Molina, C, CAC Pickering, O Valbjorn, and M De Bortoli, 1989. *Sick Building Syndrome, A Practical Guide* (Report nr. 4 of the COST-Concerted Action *Indoor Air Quality & Its Impact on Man* [COST Project 613], Report nr. EUR 12294 EN). Luxembourg: Commission of the European Communities, Office for Official Publications of EC. ♦

Products and Services

Johnson Controls Introduced Personal Environments

Johnson Controls has produced a revolutionary new environmental control module for office work stations. The unit supplies and provides individual office workers with control of the air flow, temperature, lighting level, and "white noise." A movable desktop control module allows each occupant to adjust his or her immediate environment. The unit also monitors the workstation temperature and sends data to a PC-automated control system that matches the occupant's demand for cooling or heating.

Software systems developed by Johnson Controls monitor the occupants' requests at three-minute intervals. Sensors detect each user's temperature requests, the current workstation air temperature, and whether or not the radiant panel is being used. The constant monitoring assists in providing more even temperatures, an antidote to the significant fluctuations that often result from modern variable air volume HVAC systems. The monitoring eliminates common office worker complaints about air that quickly changes from too hot to too cold and back again.

System Also Saves Energy

An infrared occupancy sensor detects the presence of the worker. When the employee leaves the office for more than a few minutes, the system shuts off all unnecessary fans, lighting, and equipment. This would save a considerable amount of energy. When the employee returns, the system goes back on at the former levels.

The local work system computer feeds data to the building mechanical system master computer to provide the required volume and temperature of supply air. Locally the supply air is mixed with recirculated room air to achieve the desired temperature. In effect, each workstation has its own VAV control and thermostat; the big difference is that the occupant can adjust it to fit his or her individual needs.

The air supply is delivered just above the desktop by one or two personal diffusers and filtered locally by an individual workstation electrostatic precipitator mounted on the underside of the work surface. Air arrives at the unit through ducts in access floors or is dropped down from the ceiling in integrated furnishing system panels. A radiant panel located under the work surface provides supplemental heat where required. (See Figure 3.)

The control unit can be replaced by the telephone keypad to reduce desktop clutter, an objective of many interior designers. Such telephone-based control was demonstrated in an energy-efficient lighting project at the World Trade Center several years ago and has been widely used since. That project allowed individual occupants to override the programmed light dimming when they worked through lunch or after hours. The telephone lines can also transmit data to the central computer when not used for normal telecommunications.

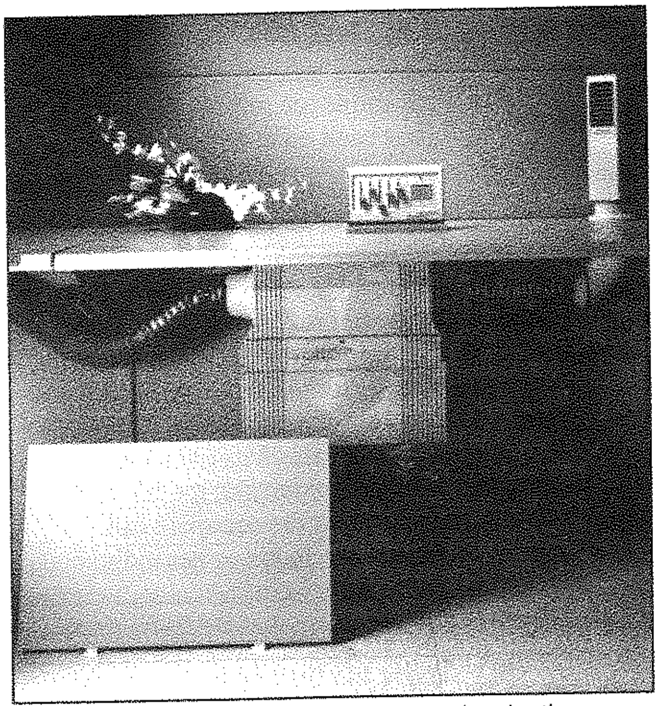

Figure 3 — A radiant panel located under the work surface provides supplemental heat where required.

Local Control Will Boost Worker Satisfaction

User control of the personal work environment can go a long way toward reducing dissatisfaction by more closely matching the environment to worker preference. It is also clear that user control will enhance satisfaction. Perhaps the only way to improve significantly on ASHRAE's baseline of 80% occupant satisfaction is through personal work environments.

We have written about the concept of individual control of air quality before (*IAQU*, October 1988). Johnson Controls has developed a system that does virtually everything we had hoped for. Several of the largest workstation component manufacturers have participated in the model installation of 24 units at the Johnson Controls communications department.

There has not been enough use of the system to provide evaluation results. Johnson Controls is looking for more opportunities for installations. Real-world applications will provide case study material for researchers and users. Like much of what occurs in buildings, individual reactions will vary and evaluation will be more a comparison with the prior environment rather than an independent assessment.

Johnson Controls is marketing Personal Environments on the basis of its potential to improve productivity. Its product brochure starts out: "Creating a happier, more stable, more productive work force through individual comfort."

The comprehensiveness of the system is impressive. No data are available yet to determine whether it will live up to its promise. Johnson Controls expects to see more units in place soon. Competitor's products soon will appear as well. Several workstation manufacturers have told *IAQU* about related product development activities of their own. User control of the work environment is the wave of the future. How far off? It's hard to say.

Productivity Gains Would Justify Cost

The cost of the Personal Environment system (about $2,000 per unit, according to Johnson Controls) along with traditional resistance to new technologies will inhibit rapid introduction.

On the other hand, workstation furnishings often cost several times the $2,000 price tag. There is a potential for energy cost savings which can soften the economic burden.

The important thing for designers and IAQ consultants to remember is that the extra cost of the system is almost insignificant compared to the salaries for the average employee. (See "Productivity" in *IAQU*, August 1989, and the correction related to that article in this issue.) Most of the marketing is based on the notion that productivity will increase and pay for the system.

Using data from our August article on productivity, and amortizing the $2,000 cost over a ten-year period at 10% interest, the annual per-square-foot cost is between $1 and $5, depending on the area of each workstation. The $5/sq ft/yr cost applies to a 63-sq-ft workstation, an absolute minimum. Typically, the costs will be closer to half that, with typical workstations at about 120 square feet. If $2.50/sf/yr is the cost, and employee salaries run about $265/sf/yr, then a 1% increase in productivity would easily pay for the system over the ten year period.

Another cost factor is the reduction in floor-to-floor height by eliminating some of the depth for air supply ducts in the ceiling. It also eliminates the need for much of the ceiling-mounted lighting by relying heavily on task lighting integrated into the workstation. These savings can pay for a substantial portion of Personal Environments.

Adequate Maintenance of ESPs?

One concern that we have is about proper maintenance of the electrostatic precipitators (ESP). These units function well only when properly maintained. As the collector plates get dirty with use, the efficiency of the unit goes down. If collector plates get too heavily loaded, charged particles will escape from the unit and plate out on surfaces in the occupied space.

Conceptually, having lots of ESPs (or any filtration system requiring maintenance) distributed around the building will cost more for maintenance and will more likely be neglected than a single or small number of central systems. However, there may be a sales advantage for office environments where smoking is permitted; at least the fine particulate matter is removed. And ESPs are far more effective than traditional building filters at removing the small particles which compose environmental tobacco smoke. Therefore, nonsmoking workers can be afforded some protection. This might make sense in a retrofit situation where modifications to the central air handling system or separation of smoking and nonsmoking areas are not feasible.

John Whitman, Johnson Controls' marketing manager, told *IAQU*: "Every customer sees this as a great idea. Those who have the primary interest are those companies who are forward thinking and have lots of professional employees such as the insurance and banking industries."

For more information, contact: Johnson Controls, Systems and Services Division, Milwaukee, WI 53201-0432; (414)274-4000.

Information Exchange

From Our Readers

Dr. Bernd Seifert of the Institute for Water, Soil and Air Hygiene in West Berlin has written with a correction on the cigarette emissions we presented in the June 1989 *IAQU*.

Dear Hal:
Your calculations on p. 13 are probably not correct. In Table 4 the yield is not in $\mu g/m^3$, but in μg. My calculation is (benzene):

10^9 cigarettes/day
0.5 mg/cigarette
10^9 x (0.5 x 10^{-6} kg/day ≈
1000 pounds/day.

Would you agree?

Bernd Seifert

Yes, Dr. Seifert is correct; the yield should be in µg/cigarette. Table 4 should be labeled µg/cigarette. The calculation reported in the text is simply wrong. One billion cigarettes per day times the yields in Table 4 would give about 1,100 pounds of benzene and 4,400 pounds of formaldehyde. Our

IAQ and Productivity Revisited

In the August *IAQU* we wrote about productivity and IAQ. We calculated the annual costs per square foot of amortizing and operating an office building and compared it to the salary costs for employees. We came out with annual costs per sq ft of $40.40 for the building (land, design, construction, furnishings, equipment, operation, and maintenance) and $240 to $290 per sq ft for the typical range of salaries. We then looked at the facility costs related to indoor air quality, and listed our assumptions in Table 3. Jim Woods pointed that Table 3 needed some units and legends to make sense. So here is a corrected Table 3, Facility Costs Related to Indoor Air Quality:

If you have data on productivity and indoor air quality, please send it to *IAQU*. We would very much like to know what kind of information is available.

Table 3 — Facility and Employee Costs Related to Indoor Air Quality

	$/sq ft	$/sq ft/yr
ACQUISITION:		
Design	$13.50	
Construction	$110.00	
TOTAL (amortized at 9.0% for 30 years)		$13.77
OPERATING EXPENSES:		
Utilities		$2.00
Janitorial		$1.00
TOTAL		$3.00
Non-employee IAQ-relatedTotal		$16.77

thanks to Dr. Seifert for his alertness and his note.

Shortly after we wrote the June article, EPA published a fact sheet on ETS. It provides an estimate of 50 million smokers in the United States (the same as our guess-timate), but EPA puts the number of cigarettes smoked at 32 per person per day. Using this number would raise our corrected total to 1,760 pounds of benzene and 7,080 pounds of formaldehyde. (For more on benzene, see the article on page 5 of this issue.)

We encourage you to let us know whenever you believe we have erred. We try to check for technical accuracy, but we do make mistakes. Send your letters to our editorial office at 2548 Empire Grade, Santa Cruz, CA 95060

Calendar

November 27-30. **Total Exposure Assessment Methodology: A New Horizon.** Las Vegas, Nevada. Contact: Dan Denne, Air and Waste Management Association, P.O. Box 2861, Pittsburgh, PA 15230; (412)232-3444. *There will be training courses on "Human sampling" and on "Personal exposure monitoring and quality assurance." Technical sessions will include multi-medial multi-pollutant exposures, Implications of Exposure and Dose in Health Effects Studies, TEAM and microenvironmental field studies, and others. The conference is designed for scientists and regulatory managers. Registration fee: $125.*

December 4-6. **ASTM Subcommittee D22.05 on Indoor Air.** Orlando, Florida. Contact: George Luciw, ASTM Headquarters, 1916 Race Street, Philadelphia, PA 19103; (215)299-5571.

February 6-8, 1990. **Georgia Tech. Research Institute Indoor Air Quality Symposium.** Atlanta, Georgia. Contact: Ann Harbert, GTRI, O'Keefe Bldg., Rm. 146, Atlanta, GA 30332; (404)894-7430.

February 9, 1990. **Georgia Tech. Research Institute Sampling and Analysis Workshop.** Atlanta, Georgia. Contact: Ann Harbert, GTRI, O'Keefe Bldg., Rm. 146, Atlanta, GA 30332; (404)894-7430.

February 11-14. **ASHRAE Winter Meeting.** Atlanta. Georgia. Contact: Judy Marshall, ASHRAE, 1791 Tullie Circle NE, Atlanta, GA 20239; (404)636-8400.

April 24-26, 1990. **ASTM Subcommittee D22.05 on Indoor Air.** San Francisco, California. Contact: George Luciw, ASTM Headquarters, 1916 Race Street, Philadelphia, PA 19103; (215)299-5571.

April 26-27, 1990. **Blueprint for A Healthy House Conference.** Cleveland, Ohio. Contact: Al Wasco, Housing Resource Center, 1820 W. 48 Street, Cleveland, OH 44102; (216)281-4663.

October 16-19, 1990. **Indoor Radon and Lung Cancer: Reality or Myth?** 29th Hanford Symposium on Health and the Environment. Richland, Washington. Inquiries should be addressed to Fred T. Cross, Symposium Chairman, Battelle PNL, P.O. Box 999, Richland, WA 99352; (509)375-2976.

INTERNATIONAL

April 24-26, 1990. **Indoor Air Quality and Ventilation in Warm Climates.** Lisbon, Portugal. Conference registration: Secretariat Inter-
national Indoor Air Quality & Ventilation Conference, British Occupational Hygiene Society, 1 St. Andrews Place, London NW1 4LB, UK.

June 13-15, 1990. **Roomvent '90.** Second International Conference on "Engineering Aero- and Thermodynamics of Ventilated Room," Oslo, Norway. Contact: Room Vent, c/o Norsk VVS Teknisk Forening, P.O. Box 5042, Maj N-0301 Oslo, Norway.

July 29-August 3, 1990. **5th International Conference on Indoor Air Quality and Climate.** Toronto, Ontario, Canada. Contact: Dr. Douglas S. Walkinshaw, Canada Mortgage & Housing Corp., 682 Montreal Road, Ottawa, ON K1A OP7, Canada; (613)748-2714.

September 3-6, 1990. **Energy, Moisture, Climate in Buildings.** Rotterdam, The Netherlands. Contact: Mr. G. de Vries, Bouwcentrum, Weena 760, P. O. Box 299, 3000 AG Rotterdam, the Netherlands. *The conference will consider three major topics: Heating, cooling, and ventilating efficiency; condensation and mold growth; and, indoor climate.*

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