Table 2 — Benzene exposures and risks

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

[a]Using a unit risk of 8 x 10^{-6} $(\mu g/m^3)^{-1}$.
[b]57 µg/cigarette (Higgins) x 32 cigarettes/day.
[c]3 µg/m^3 x 17 hr/day indoors x m^3/hr respiration.
[d]Approximately 80% of persons exposed to environmental tobacco smoke.
[e]TEAM outdoor average in eight locations — 6 µg/m^3 x 20 m^3/day.
[f]Few data available, assumed 40 µg/m^3 in vehicle x 1 hr/day.
[g]1 ppm x 70 min/year.
[h]Assumed 1,000 µg/m^3 x 10 m^3/8 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-

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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
Acute effects	
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)
Chronic effects	
Sensitization	Little knowledge, mostly on SVOC
Chronic intoxication	Little knowledge (some indications for PCP and PBB)

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- 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]	mean:	34% ± 2% of total VOC		
(16 offices)	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)

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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-

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

	Concentrations (μg/m³)				
	WHO (1989)	80 offices (10 buildings)		TLV/10 (TWA)	AQG (WHO 1987)
Compound	90%ile	90%ile	max	(mg/m³)	(mg/m³)
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

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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

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