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Carpets and Indoor Air

Carpet and its effects on IAQ have been getting plenty of attention lately. Special news programs have been devoted to the subject. Papers on carpet emissions and installations are given at conferences and scientific meetings. A union of EPA employees has complained to the Federal Trade Commission that the Carpet and Rug Institute's (CRI) new carpet "green label" program is misleading. The Consumer Products Safety Commission has released a major research report on carpet emissions. And, there has even been a special hearing in the Congress before the Senate Ad Hoc Subcommittee on Consumer and Environmental Affairs. Why all this focus on carpet? Is carpet really that important to indoor air? A major reason for all this attention was an announcement of findings by Anderson Laboratories in Deedham, Massachusetts.

Anderson Labs publicized the results of their tests on nine samples of used carpet submitted by people who experienced health problems after the carpet was installed in their home or workplace. The nine complaint carpets were tested using a modified version of the ASTM bioassay for respiratory irritation. Anderson Labs' Rosalind Anderson, Ph.D., reported that the tests resulted in the inexplicable deaths of several test animals. Death is not a normal outcome of the ASTM bioassay, which is intended to measure changes in respiratory rate as an indication of the irritation potency of an exposure atmosphere.

- Do the lab mice deaths tell us anything useful about carpet's impact on people?
- What does carpet do to affect indoor air that makes such a big difference to so many people?
- Do we know the real effects of the various volatile organic compounds (VOC) associated (rightly or wrongly) with new carpets?

VOC Emissions from Carpet

VOC emissions from most carpet are relatively small compared to those from the many other sources found in buildings. And, the emissions usually decline rapidly during the first day or two after installation. Indeed, emissions from solvent-based adhesives (traditionally used to install carpet in "glued-down" applications) are often 100- to 1000-times higher than the emissions from the carpets themselves. However, newer, solvent-free carpet adhesives now widely available may emit only a hundredth as much VOC as traditional products.

Carpet cushions (padding installed under the carpet in most residential applications) constitute an additional, poorly characterized source of VOC emissions. Solvents used as "seaming" compounds to join separate pieces of carpet or as cleaning compounds to prepare surfaces to receive carpet adhesives also may be sources of significant VOC emissions.

To complicate matters further, the same product may vary, chemically, from one batch to another. This occasionally occurs in the backings used to hold carpets together, and, in some carpet and rug products, to form an integral cushion. It happens due to slight differences that can occur in the critical variables that control the formation of the chemical compounds used in the backings. Various chemicals are used for backings, but styrene butadiene rubber (SBR) latex dominates the U.S. carpet market. Other less-commonly used materials are polypropylene in the primary backing, polyurethane used as a secondary and, sometimes, a primary backing material, and polyvinyl chloride (PVC) used frequently on carpet tiles.

Of course, there are a variety of carpet fibers used as well, although nylon is currently the most popular. Other

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commercial fibers include olefin and wool. The fibers may be dyed using different processes, and chemicals may be added to provide stain resistance, static control, or biocidal properties (mold resistance). Manufacturers of two major biocides have each told the ***IAB*** about the limitations and defects of their competitor's product. Indeed, the products are chemically different and behave differently.

VOCs and Health

Although carpet VOC emissions may generally be low, the impact on human health and comfort of any VOC or of the total emissions may still be significant. The potencies of different VOCs vary over several orders of magnitude as illustrated by the wide range of threshold limit values (TLVs) for occupational exposure to chemicals. The range of odor thresholds spans more than five-orders-of-magnitude; and, irritation potencies as measured by the mouse bioassay cover several orders of magnitude. Some compounds have effects at very low concentrations, and combinations of chemicals may result in various responses that differ from their individual or even their additive effects.

Therefore, according to Lawrence Berkeley Laboratory (LBL) researchers, "[i]t is essential to identify and quantify the individual VOC that are emitted by carpets when attempting to evaluate the potential for health and comfort effects." It is important to consider both the quantity of each emitted VOC as well as what is known about the qualitative effects of the VOC on exposed humans.

Carpet Odor

Carpet odor strongly influences people's perceptions of carpet and its perceived influence on their health. The majority of commercial carpets release the chemical 4-phenylcyclohexene (4-PC) which is responsible for the distinctive "new carpet smell." Since 4-PC, a constituent of SBR latex, has an easily detectable odor even at low parts per billion concentrations – some people can detect its odor at less than one ppb – building occupants often immediately recognize the presence of new SBR latex-backed carpet.

However, it is important not to assume that what is odorous is also toxic or irritating. It is at least as likely that many reported health effects result from chemicals released from other products such as carpet cushions, adhesives, and seam sealants. And, when painting and other finishes have been applied, many other chemicals may be present. Yet carpet is usually assumed to be the source of any chemicals causing health or comfort problems.

Far too little research has been done on 4-PC to conclusively describe its potential irritancy or toxicity. However, the limited research to date does not strongly suggest toxicity at the concentrations of concern in new carpet installations.

Other Carpet Factors

Building occupants can track in particulate matter on their shoes or clothing and deposit it on carpets. Such sources are important contributors to pesticide residues found in household dust collected from carpeted floors. High-efficiency particulate arrestance (HEPA) vacuuming removes and collects even very small particles from carpets; however, ordinary commercial and residential vacuums re-suspend a very large number of very small particles into the air. Cleaning with shampoos or solvents can remove soiling, but it may contribute volatile and semi-volatile compounds to the air and the carpet materials. Chemicals in the air can be sorbed and re-emitted into the air by carpets, depending on the environmental conditions, the type of chemicals and carpet fibers involved, and airborne concentrations of the chemicals of concern.

Do Carpets Kill Lab Mice?

Anderson Labs tested nine carpet samples taken from homes where occupants reported significant adverse reactions that they believed were caused by the carpet. Anderson Labs reported that some of the mice died and many mice displayed unusual neurological responses not typically seen during the types of tests that they have conducted on many other products.

Some scientists have told the ***IAB*** that Dr. Anderson's research results are ambiguous due to the lack of characterization of the mixture used for the mice exposure. We have long held that view and have communicated it to Anderson and her colleague Mark Goldman.

The ASTM irritancy test is a valid predictor of human irritancy based on the correlations between irritancy responses to measured concentrations of specific chemicals and TLVs for irritating chemicals. However, Anderson Labs exposed the mice to the mixture of chemicals emitted by the carpet samples without measuring the concentrations or identifying the chemical substances involved.

Comparing results from mouse bioassays for many chemicals with the TLVs established to protect against irritation yields a fairly consistent ratio across chemicals. Some scientists view this fact as evidence of the validity of the mouse bioassay. (See the ***IAB***, Volume 1, Number 1 for a discussion of the ASTM standard for the mouse bioassay.)

Other scientists have criticized Anderson Labs' use of a modified version of the ASTM mouse bioassay method. ASTM test results provide information on the irritation potential of the chemicals to which the lab mice are exposed by measuring changes in the respiratory rate of the mice. Significant decreases in respiratory rate indicate that the test substance or mixture has the potential to cause irritation in humans. By measuring the concentration of a chemical to which the mice are exposed, scientists can calculate the concentration that is likely to cause irritation in humans.

Anderson Labs exposed mice twice a day for two days in a row. This is not consistent with the ASTM test protocol. Further, critics say that determining neurotoxic and other clinical effects are not a part of the ASTM method. First we need to know what these neurotoxic effects mean in terms of human health, they say.

Anderson Labs either did not measure or report several critical experimental variables; the characterization of the exposure mixture is only one of the missing datum. Instead, they characterized the test specimen (carpet size) and the conditions in the tank where the specimens are held to generate the test atmosphere. They heated the tank air to at least 37° C and the carpet sample was probably considerably warmer than that. Mark Goldman told the ***IAB*** that this temperature was reasonable since a person could lie on top of the carpet and subject it to body temperature in actual installations. Some scientists (more familiar with Anderson's work than we) have suggested that the carpet could have reached 55° C or even higher given the way Anderson Labs ran their test.

More importantly, the test atmosphere was generated in a sealed tank: the mice were exposed, at least briefly, to an atmosphere that was essentially a headspace sample. As the following article on a Lawrence Berkeley Laboratory - Consumer Product Safety Commission study suggests, different compounds will be found in a headspace sample than in an environmental chamber because headspace samples are collected under static conditions. More volatile compounds will collect and reach much higher concentrations in headspace samples than in actual building environments or in dynamic (ventilated) environmental chambers. The mice were apparently being exposed to a very concentrated dose of the headspace compounds at the beginning of their exposure period. This exposure is simply not representative of the exposures people receive from carpets in virtually any actual building installation.

Specific *IAB* Recommendations

- The emission conditions should be more realistic – heating of the chamber or sample should not be above 32 to 35° C. Carpets rarely reach temperatures above that (unless exposed to intense direct sunlight) because they are installed on floors which act as thermal sinks and maintain fairly stable temperatures (at least for the portion of the carpet in contact with the floor).
- The test atmosphere should be generated in a dynamic chamber with realistic ventilation rates. This will avoid exposing the animals to compounds that simply would not be present in measurable concentrations in real building situations.
- Anderson Labs should characterize the chemical mixture and report the results as part of its research reports. Otherwise, the exposure is characterized only by the description of the size and some temperature conditions of the tested product.
- If the test is to be used to evaluate toxicity, then there must be a demonstration of a dose-response relationship. The test atmosphere should be presented at no less than two and preferably three different concentrations, and the animals' responses should be documented. This will allow more positive association of the carpet emission products with the animals' deaths (if that continues to be the result of the studies). The chemical mixture concentration should be determined and dilutions used to evaluate the dose-response relationships.

A frequently expressed criticism of Anderson Lab's methods is that it uses the ASTM mouse bioassay for irritation to test for toxicity. The ASTM test has not been validated for such use, and no published papers exist on this application of the test. Thus, although we know that the father of the ASTM test and Dr. Anderson's graduate advisor, Yves Alarie, is also applying the mouse bioassay to evaluate toxicity, until the method is validated, its results must be interpreted extremely cautiously. Under the circumstances, we question the appropriateness of Anderson's press releases before the results are replicated and the work is published in a scientific journal or otherwise subjected to scientific peer review procedures.

EPA Will Attempt To Replicate Mouse Test

Responding to considerable pressure from Congress and the media, EPA is now in the process of establishing a testing program to attempt to replicate Anderson's work. There must be a quality-assurance plan before EPA can proceed, and that is expected within the next couple of weeks. However, EPA officials told the ***IAB*** not to expect any data for awhile. Before the results of EPA's tests are released, the data will be reviewed thoroughly.

Possible Explanations for the "Deadly" Carpet

Researchers and industry scientists agree that there may be some "bad batches" of carpet. Manufacturing process controls may not be quite right, or, chemicals used in a batch may vary. Tests conducted by Air Quality Sciences (AQS) for the Carpet and Rug Institute (CRI) showed variations of a factor of three between the lowest and highest emitters of 4-PC and of TVOC. We have learned from CRI that about one out of seven tested carpets do not meet their criteria for 4-PC and TVOC emissions to receive CRI's green label. While one out of seven is not a particularly high fraction of carpets, when translated to a fraction of total yards produced or an absolute number of carpet installations, it is certainly significant. Just a few bad batches of carpet could account for the number of building occupants who have reported their carpet-associated problems to the CPSC.

Additional variations among carpet batches from the same or different manufacturers may result from insufficient drying before rolling and packaging the finished carpet for shipping. This allows for mold growth, and people are exposed to the metabolic products and spores from the mold. A significant fraction of the population is likely to have allergic reactions to certain mold spores. Storage and shipping at different temperatures and ventilation conditions also affects mold growth.

Another explanation is the possible effects of products associated with carpet installations such as seaming compounds, adhesives, carpet cushions, and floor preparation chemicals. Laboratory and field studies have shown that the emissions from some of these products, particularly emissions of solvents from adhesives and seaming compounds, can be 100- to 1000- times greater than emissions from the carpets themselves. In a poorly ventilated space, the concentrations of these solvents could easily reach levels known to cause health and comfort problems.

Possible Benefits of All The Attention

Due to the widespread publicity, the new administration in Washington will need to deal with the indoor air/carpet issue quickly. The new EPA Administrator will become familiar with IAQ issues and will receive briefings regarding agency indoor air programs and research. A ripple effect will bring an enhanced awareness of IAQ to top EPA officials early in their tenure.

It is also possible that the research about to be conducted will identify important new research topics and issues related to carpet or other indoor air concerns. That concern about carpet and indoor air may lead to increased funding for federal government IAQ research, outreach programs, and product development.

If EPA's tests of the mouse bioassay applied to neurotoxicity demonstrate the validity of the method, we will have gained a valuable tool to understanding the health implications of pollutant sources indoors. And, while EPA has not been in a regulatory mode since the election of President Reagan in 1980, a newly active agency may have a major impact on the carpet industry and the public.

Hopefully, carpet manufacturers will learn that concern about their products will not diminish with the new "green label" program and that they must initiate industry and corporate research to improve their products' performance and impacts on IAQ.

Carpet Emissions

CPSC Releases Detailed Carpet VOC Emission Study

Accurately evaluating health and comfort problems that may result from the volatile organic compounds (VOC) emitted from carpets is difficult at best. There are a great many variables that distinguish one carpet installation from another. These variables include the many different types of carpet, carpet cushion, adhesive, and their combinations; the ventilation and other characteristics of the indoor environment where the carpet is installed; and, the age, cleaning, and maintenance of the carpet itself.

In this article, we discuss at length a recently released report of some very careful carpet VOC emissions measurements conducted at Lawrence Berkeley Laboratory (LBL) for the Consumer Product Safety Commission (CPSC).

The CPSC compiled 335 health-related complaints from 206 households after announcing its intention to study carpet-related health problems. During the study period, from 1988 to 1990, two-thirds of the complaints they received were from people who had symptoms starting immediately or a few days after a carpet installation. The symptoms people reported included upper-respiratory problems as well as headache, eye irritation, rashes, and fatigue. Twenty-five of the complainants reported that they were hospitalized. The CPSC never attempted

Parameter	Carpet 1	2	3	4
Construction	Cut pile	Cut pile	Textured loop	Textured loop
Fiber type	100% Nylon	100% Nylon	100% Nylon	75% Olefin, 25% Nylon
Pile height, mm	14	6	5	5
Dye method	Piece dyed	Beck dyed	Solution dyed	Solution dyed
Fiber treatments	Static control	NS*	Scotchguard antimicrobial	NS
Primary backing	Polypropylene	Polypropylene	Polypropylene	Polypropylene
Secondary backing	Polypropylene	Polyurethane	Polyvinyl chloride	Polypropylene
Backing adhesive	SBR latex	NS	NS	SBR latex
Total weight, kg m^{-2}	3.0	2.6	5.5	2.0
Form	Roll	Roll	Tiles, 46 x 46 cm	Roll

* NS = Not specified by manufacturer

Table 1 - Descriptions of the four carpets sampled by the CPSC.

to determine whether there was any relationship between the complaints and emissions from carpets.

The study design was not intended to correlate complaints with carpet emissions. A significant fraction of the complaint carpets were identified as being from the same source, but the CPSC never followed up on these complaints or investigated the carpets further. However, the CPSC did decide to study carpet emissions and contracted with LBL at the University of California, Berkeley. It is not clear whether the CPSC included the questionable carpets from its consumer study in the LBL VOC emissions tests.

The LBL-CPSC Carpet VOC Study

Most published studies of carpet emissions have measured the chemicals in the air of a chamber or room after installation of a carpet sample. The major objective of the LBL-CPSC study was to measure the emission rates of selected individual VOC including low molecular weight aldehydes. According to LBL-CPSC, it was designed "to measure the emission rates of selected VOC released by samples of new carpets that are typical of the major types of carpets used in residences, school classrooms, and offices."

Study Methods

The study compared emissions measured in small chambers, room-size chambers, and a residence. Researchers selected the study compounds based on the dominant compounds emitted during a preliminary screening study. The CPSC used the screening study to select carpets most used in residences, schools and offices. The researchers studied four carpet types including three "action back" carpets: two of them had a styrene butadiene rubber (SBR) latex adhesive secondary backing and one had a polyurethane foam secondary backing. The fourth carpet was a so-called "hardback" with a polyvinyl chloride secondary backing. They did not select the four carpets as statistically representative samples of carpet products.

Test carpets were collected directly from manufacturers' mills. They were carefully packaged and shipped immediately to the lab. In order to follow changes in the emissions, measurements were made for a one-week period following installation of the carpets in a room-sized (20 m^3) environmental chamber designed to study VOC. Additional measurements were made for seven weeks following installation of new carpet in a residence. Chamber measurements were made under conditions similar to typical indoor environments.

Table 1 shows the characteristics of the four study carpets. Table 2 shows the specified chamber conditions for operation of the testing chambers.

Results

The four carpets in the laboratory study emitted 40 VOC that were positively identified in the screening study based on authentic standards. The researchers targeted 21 of the 40 identified VOCs for quantification. They considered eight of them dominant. These dominant compounds were formaldehyde, vinyl acetate, 2,2,4-trimethylpentane (isooctane), 1,2-propanediol (propylene glycol), styrene, 2-ethyl-1-hexanol, 4-phenylcyclohexene (4-PC), and 2,6-di-*tert*-butyl-4-methyl phenol (BHT).

Comparison of Results in Different Test Environments

Tables 3 through 6 show the compounds identified in each of the three tests (headspace, small chamber, and

Parameter	Chamber Type Small-volume	 Environmental
Volume, m^3	3.78×10^{-3}	20.0
Ventilation rate, h^{-1}	6.3	1.0 ± 0.1*
Temperature, °C	Room (20-25)	23 ± 1
Relative humidity, %	Dry N_2	50 ± 5
Loading ratio, $m^2\ m^{-3}$	2.65	0.44
Air velocity, cm sec^{-1}	<1	5-10

* Uncertainties are quality assurance objectives shown as one standard deviation.

Table 2 - Conditions specified for the operation of the small-volume chambers and the environmental chamber.

Compound	Headspace	Small Chmbr.	Environ. Chmbr.
n-Propane	***		
2-Methyl-1-propene	***		
2-Propanone (Acetone)	*		
Dichloromethane	*		
1,1,1-Trichloroethane	*		
n-Pentanal	*		
Toluene	*		
C_9 Alkane	*		
4-Ethenylcyclohexene	**	*	**
Ethylbenzene	*	*	*
m-,p-Xylene	*	*	*
N,N-Dimethyl acetamide	**	**	**
Cyclohexanol	**	**	**
Styrene	**	**	***
o-Xylene	*	*	
Phenol	*		
Dihydro-4-dimethyl furanone		*	
Unsaturated HCs, $C_{10}H_{18}$	*	*	*
3-Hexenedinitrile	*		
Unsaturated HCs	*	*	*
Alkane HC	*	*	
4-Phenylcyclohexene	**	***	***
1-Dodecanol	*		**

Headspace:
* = Present at ~100 $\mu g\ m^{-3}$ or greater.
** = Present at ~250 $\mu g\ m^{-3}$ or greater.
*** = Dominant compound.

Small Chamber:
* = Present at ~10 $\mu g\ m^{-3}$ or greater.
** = Present at ~25 $\mu g\ m^{-3}$ or greater.
*** = Dominant compound.

Environ. Chamber:
* = Present at ~20 $\mu g\ m^{-3}$ or greater.
** = Present at ~50 $\mu g\ m^{-3}$ or greater.
*** = Dominant compound.

Table 3 - VOC emitted by Carpet 1 as determined by measurements of headspace emissions and emissions in small-volume chambers and the environmental chamber.

environmental chamber) for each of the four carpets. Compounds are listed in order of ascending retention time. Multiple identical compound entries reflect distinct peaks at different retention times. A couple of things popped out at us from looking at these tables. First of all, the identifiable compounds are not the same in the three tests. The compounds identified in the headspace test were clearly different from those identified in the small and environmental chamber tests. The headspace tests tend to be dominated by lighter (lower molecular weight, more volatile) compounds compared to the small and environmental chamber tests. In the headspace tests, the researchers found low or no identifiable concentrations of some of the heavier compounds identified in the small and environmental chamber tests.

The researchers reported that the headspace samples generally contained the most volatile compounds. Because these compounds have high equilibrium vapor pressures (i.e., are most volatile) at room temperature, they can reach the highest concentrations in a static (sealed) container. Additionally, they rapidly evaporate from materials in the dynamic conditions of environmental chambers (and in actual building environments).

Figures 1 through 4 show comparisons of small chamber and environmental chamber concentrations of three selected VOCs at 1, 3, and 6 hours. The researchers noted that comparing VOC emissions in the small and large chambers, although not done rigorously due to differences in ventilation rates and air velocities, "clearly demonstrated that experimental parameters can have a dramatic impact on measured emission rates." The researchers attributed further differences in emissions to extra handling of samples from identical carpets.

Comparison of the Chambers

An important question partially addressed by the study is the comparison of emissions in small chambers, room-size environmental chambers, and actual buildings. Previous experiments by Air Quality Sciences (AQS) of Marietta, Georgia, showed good agreement for selected compounds and TVOC between small (50 L) environmental chamber experiements and full-scale carpet installations. (See the reference to Black *et al.* at the end of this article).

The LBL-CPSC study report states that, in general, there was not good agreement between the small and environmental chambers. The researchers hypothesized that most of the differences were attributable to differences in the volatility of the studied compounds and the effects of varying ventilation rates on emissions and

Compound	Headspace	Small Chmbr.	Environ. Chmbr.
2-Methyl-1-propene	***		
2-Propanone (Acetone)	**		*
2-Propanol	**		
1-Propanol	**		
Trimethyl silanol	**	*	*
1,1,1-Trichloroethane	**	*	*
C_7 Alkane HC	*		
1-Butanol	*	*	*
C_7 Alkane HC	*		
Hexamethyldisiloxane	*		
C_7 Alkane HC	*		
Alkane HC		*	
Toluene	*	*	*
2,2,5-Trimethylhexane		**	
Siloxane	*		*
C_8 Unsaturated HCs		*	
Hexamethylcyclotri-siloxane	**	**	***
Octamethyltrisiloxane	*		
Alkane HC		*	
Octamethylcyclo-tetrasiloxane	*		
Dipropylene glycol methyl ether	*	*	*
Dipropylene glycol methyl ether	*	*	*
Dipropylene glycol methyl ether	*	*	*
Dipropylene glycol methyl ether	*		
1,2-Dichlorobenzene	*	*	*
Decamethyltetra siloxane	*		
Triethylphosphate	*	*	
Glycol ether	*	*	*
Glycol ether	*	*	*
Hydrocarbon, $C_{15}H_{24}$	*	*	*
2,6-Di-*tert*-butyl-4 methylphenol (BHT)	***	***	***

Headspace: * = Present at ~50 µg m^{-3} or greater.
** = Present at ~125 µg m^{-3} or greater.
*** = Dominant compound.
Small Chamber: * = Present at ~10 µg m^{-3} or greater.
** = Present at ~25 µg m^{-3} or greater.
*** = Dominant compound.
Environ. Chamber: * = Present at ~20 µg m^{-3} or greater.
*** = Dominant compound.

Table 4 - VOC emitted by Carpet 2.

chamber concentrations. Actually, we did not view the differences as being consistently different.

An additional qualitative result of the experiment allowed for comparing compounds identified in the headspace screening experiment with the the more dynamic small chamber and environmental chamber tests.

Compound	Headspace	Small Chmbr.	Environ. Chmbr.
Chloromethane	*		
2-Methyl-1-propene	*		
Acetaldehyde	*	**	*
Methyl acetate	*	*	
Vinyl acetate	***	***	***
Acetic acid	***	**	
Alkane HC	*		
2,2,4-Trimethylpentane	***	***	**
C_8 Alkane HC	*	**	*
Alkane HC	*	**	*
1,2-Propanediol		*	***
Alkane HC	*	**	
Alkane HC	*	**	
Alkane HC		*	
Unsaturated HCs		*	
3-Heptanone		**	*
Isopropylbenzene (Cumene)		*	*
Unsaturated HCs		*	*
Oxidized cmpd.		*	*
Alkane HC		**	*
Unsaturated HC		*	
Benzaldehyde		*	
Alkane HC		*	
1-Methylethenyl benzene		*	
Alkane HC		*	
Alkane HC		*	*
Alkane HC		**	*
2-Ethyl-1-hexanol		**	**
Alkane HCs		**	*
Phenylethanone		*	*
Alkane HC		**	*
C_{11} Unsaturated HC		**	**
n-Undecane		**	**
E-Caprolactam			**
Oxidized cmpds.		**	**
Unsaturated HC			*
Alkane HC			*
Hydrocarbon, $C_{15}H_{24}$			*
2,6-Di-*tert*-butyl-4 methylphenol (BHT)			*

Headspace: * = Present at ~10 µg m^{-3} or greater.
*** = Dominant compound.
Small Chamber: * = Present at ~10 µg m^{-3} or greater.
** = Present at ~25 µg m^{-3} or greater.
*** = Dominant compound.
Environ. Chamber: * = Present at ~20 µg m^{-3} or greater.
** = Present at ~50 µg m^{-3} or greater.
*** = Dominant compound.

Table 5 - VOC emitted by Carpet 3.

As discussed above, the emissions identified in the headspace tests were significantly different from those observed in the small and environmental chambers. This

Compound	Headspace	Small Chmbr.	Environ. Chmbr.
2-Methyl-1-propene	***		
2-Methylbutane	*		
2-Propanone (Acetone)	**	*	**
Carbon disulfide	*		
Dichloromethane	*		
Methylcyclopentane	*		
1,1,1-Trichloroethane	*		
1,2-Diethenylcyclobutane	*		
Alkane HC	*		
Hexamethylcyclotrisiloxane	*	*	*
Alkane HC	*	*	*
4-Ethenylcyclohexene	*	**	**
C_9 Alkane HC	*		
Ethylbenzene	*	*	*
m-,p-Xylene	*	*	*
Styrene	*	***	***
o-Xylene	*	*	*
Isopropylbenzene (Cumene)	*	*	*
Alkane HC	*	*	*
n-Propylbenzene		*	*
Alkane HCs	*		
Alkane HC	*		
3-Hexenedinitrile			*
Alkane HC			*
Alkane HC		*	*
4-Phenylcyclohexene	*	*	**
Nonanedioic acid, dibutyl ester			*

Headspace:
* = Present at ~100 μg m^{-3} or greater.
** = Present at ~250 μg m^{-3} or greater.
*** = Dominant compound.

Small Chamber:
* = Present at ~10 μg m^{-3} or greater.
** = Present at ~25 μg m^{-3} or greater.
*** = Dominant compound.

Environ. Chamber:
* = Present at ~20 μg m^{-3} or greater.
** = Present at ~50 μg m^{-3} or greater.
*** = Dominant compound.

Table 6 - VOC emitted by Carpet 4.

has important implications for developing ventilation strategies to minimize the impact of carpet installations on building air quality and occupant responses. It is especially important if some of the more volatile compounds are strong irritants or toxins.

Major Compounds Emitted

The two carpets with styrene butadiene rubber (SBR) latex adhesive (Carpets 1 and 4) emitted styrene and 4-phenylcyclohexene (4-PC). It is 4-PC that produces the characteristic "new carpet" smell. The commercial "hard-back" with a PVC secondary backing (Carpet 3) emitted formaldehdye along with fairly high concentrations of vinyl acetate and propylene glycol. Butylated hydroxytoluene (BHT) was the most abundant low-volatility compound emitted by the polyurethane backed carpet (Carpet 2). The dominant compound emitted by Carpet 2 was isobutylene.

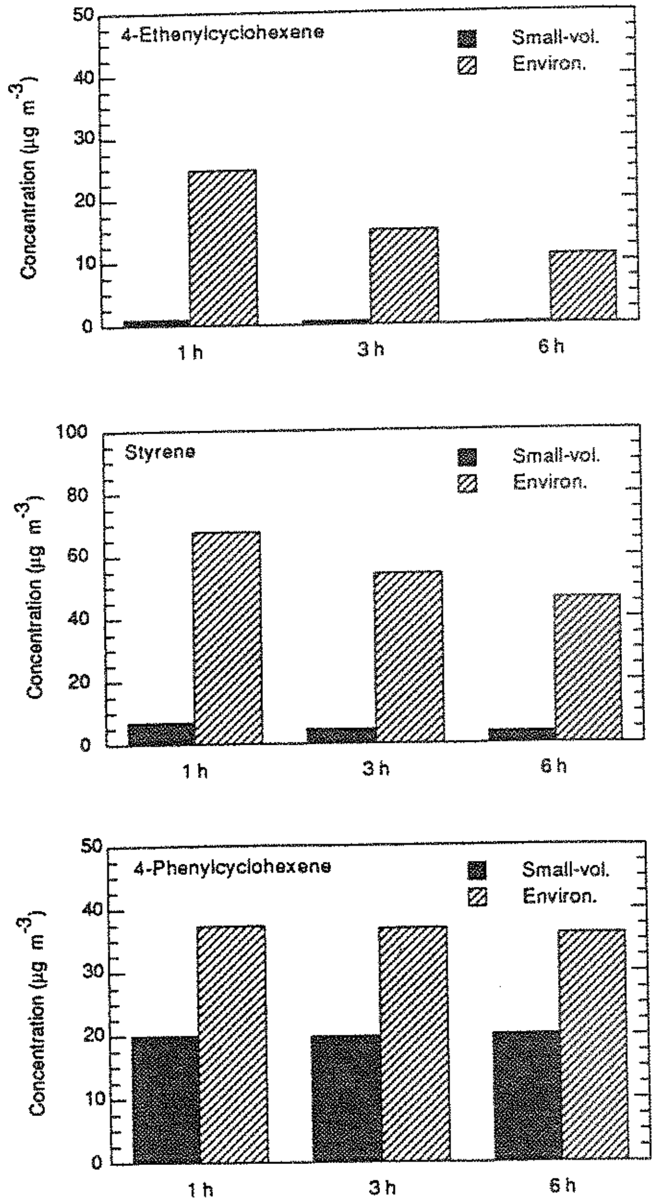

Figure 1 - Comparison of the small-volume and environmental chamber concentrations at 1, 3, and 6 hours of three selected VOC emitted by Carpet 1 in experiment b.

Formaldehyde is the only one of these compounds for which there is any more than very limited toxicity and irritation data available for low concentrations. Thus, it is difficult to determine the potential magnitude of the

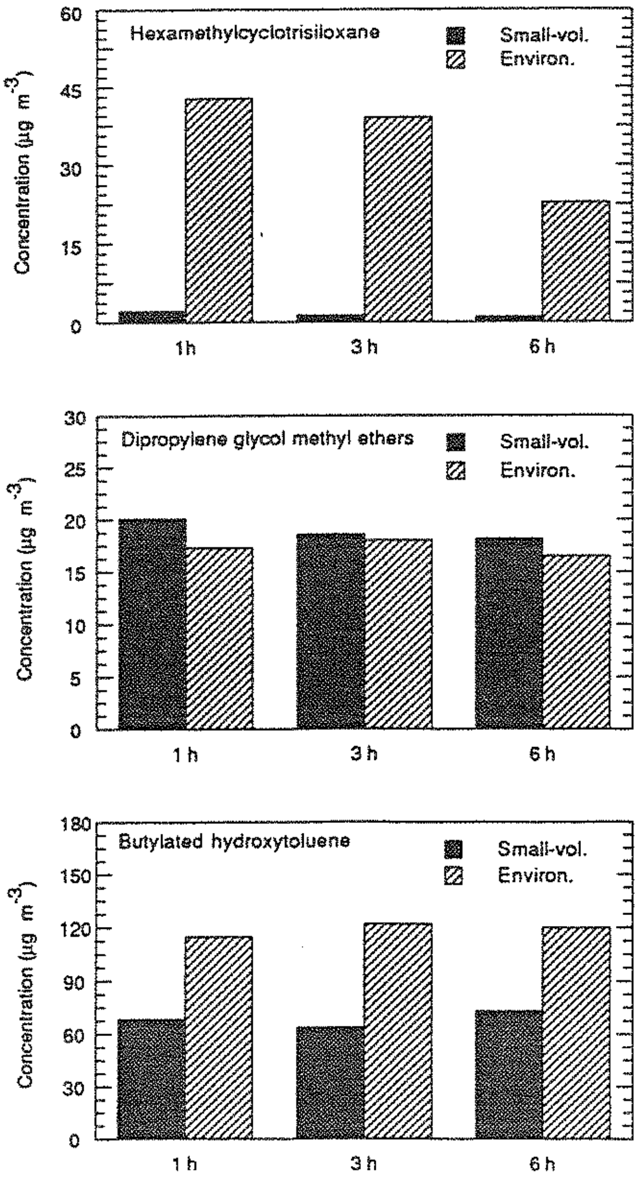

Figure 2 - Comparison of the small-volume and environmental chamber concentrations at 1, 3, and 6 hours of three selected VOC emitted by Carpet 2.

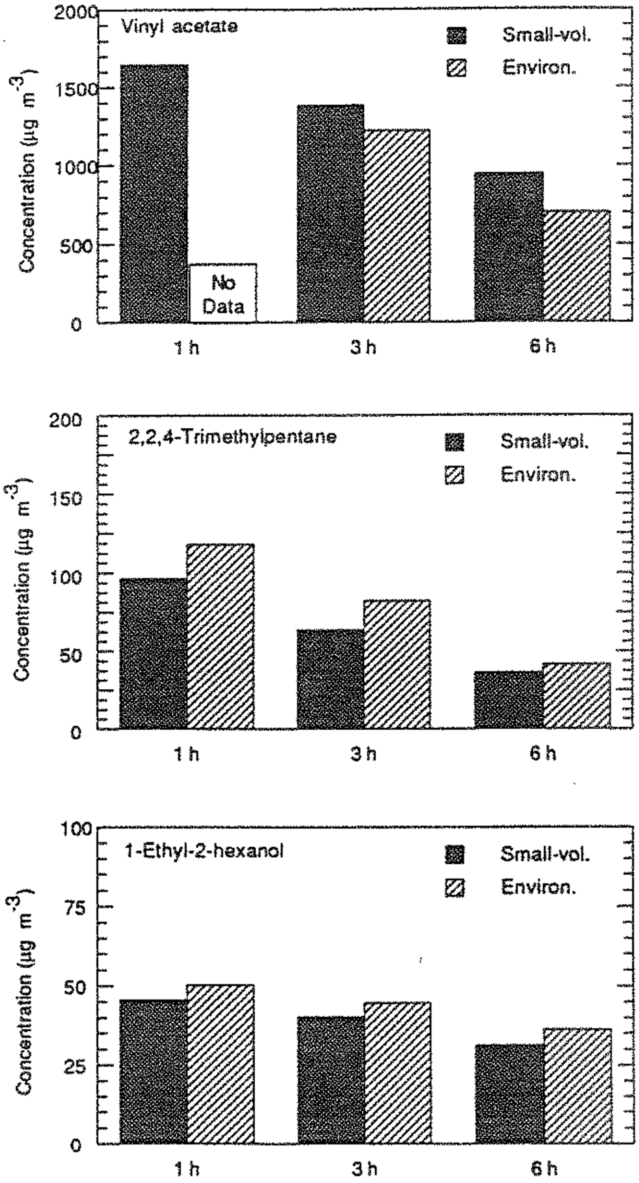

Figure 3 - Comparison of the small-volume and environmental chamber concentrations at 1, 3, and 6 hours of three selected VOC emitted by Carpet 3. The environmental chamber concentrations were multiplied by 1.2 to correct for the lower loading ratio used in this test.

health and comfort effects that exposure to these carpet emissions may cause in the general population.

It is possible that 4-PC is an irritating compound based on its chemical structure. But there is no convincing evidence of 4-PC's irritation potential from the few animal tests familiar to us.

Emission Profiles

Figures 5 through 8 show results of the environmental chamber measurements of selected compounds for each of the four carpets. Table 7 shows the quasi steady-state emission rates of the target compounds at 24 and 168 hours after the start of the experiments. Figures 9 - 11 show TVOC and the sums of individual VOC emitted over one week for three of the environmental chamber studies. The investigators found that the emissions and concentrations of most of the emitted compounds decreased rapidly during the first 12 hours of their tests. The

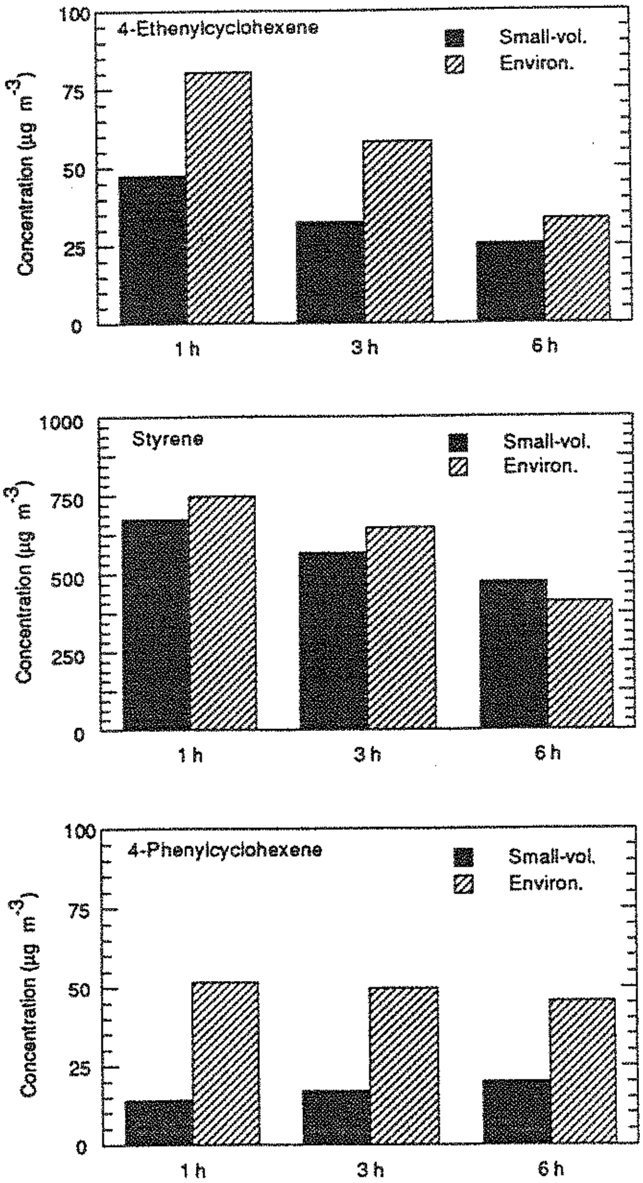

Figure 4 - Comparison of the small-volume and environmental chamber concentrations at 1, 3, and 6 hours of three selected VOC emitted by Carpet 4 in experiment b.

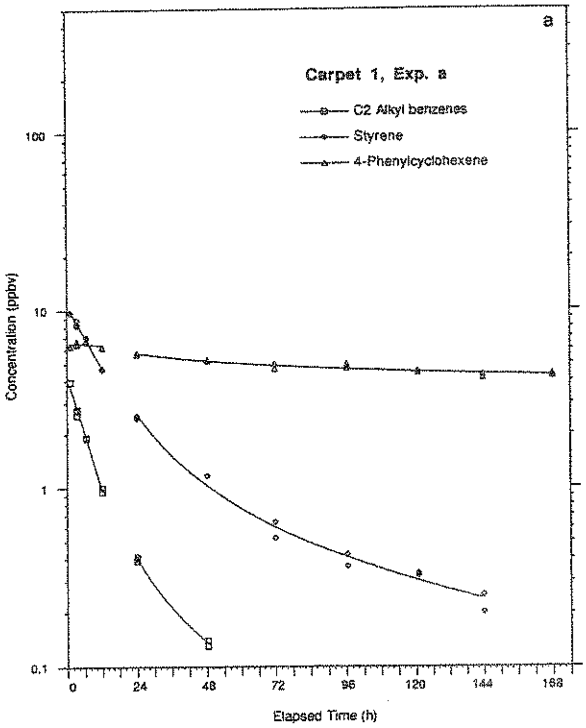

Figure 5 - Chamber concentrations of VOC emitted over one week by Carpet 1 in experiment a.
C2 Alkyl benzenes = ethylbenzene + xylene isomers.

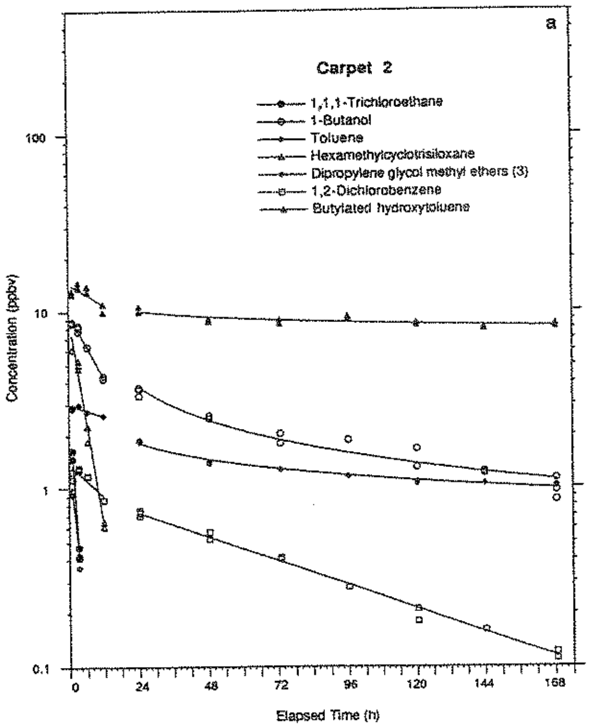

Figure 6 - Chamber concentrations of VOC emitted over one week by Carpet 2.

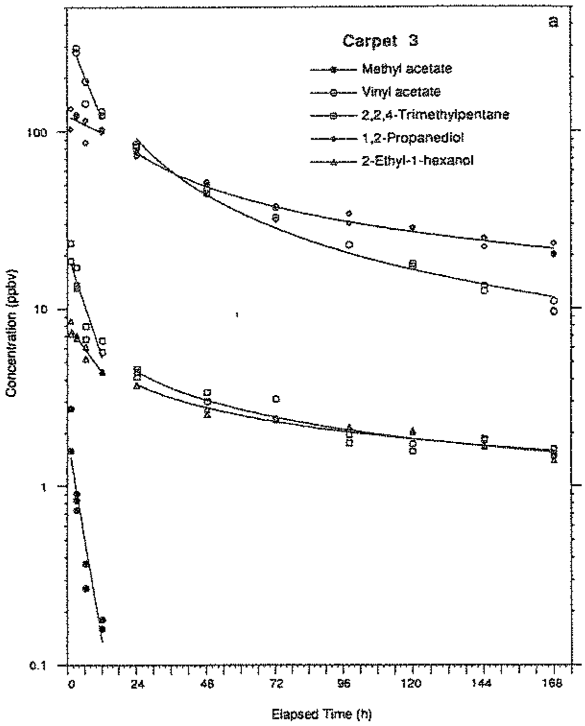

Figure 7 - Chamber concentrations of VOC emitted over one week by Carpet 3.

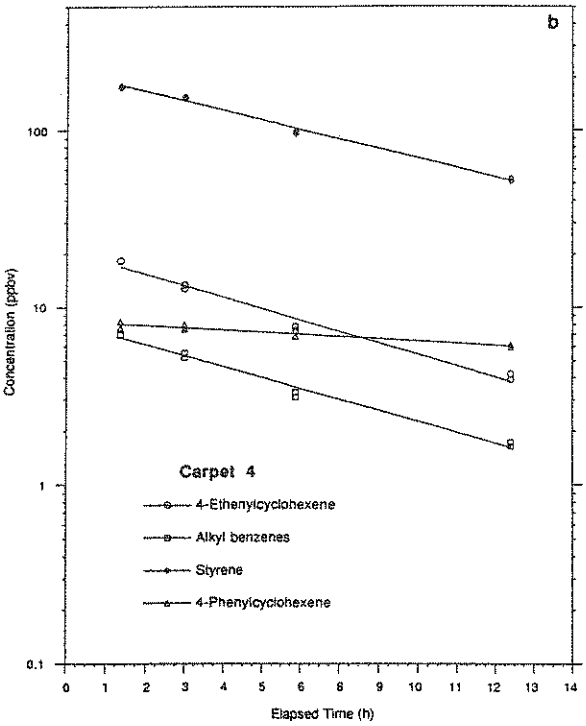

Figure 8 - Chamber concentrations of VOC emitted over 1-12 h by Carpet 4.
Alkyl benzenes = xylene isomers + n-propylbenzene

	Specific Emission Rate in ug m^{-2} h^{-1} (Mean ± 95% CI)		Fractional Reduction
Experiment/ Compound	**24 h**	**168 h**	**1-(168/24 h)**
1a			
C_2 Alkyl benzenes	4.1 ± 0.3	0.0	1.00
Styrene	24.7 ± 1.0	2.0 ± 0.2	0.92
4-Phenylcyclohexene	85.1 ± 2.3	64.0 ± 2.5	0.25
TVOC as carbon	213 ± 9.6	71.2 ± 9.9	0.67
1b			
4-Ethenylcyclohexene	7.3 ± 0.3	0.6 ± 0.1	0.91
C_2 Alkyl benzenes	6.5 ± 0.4	0.0	1.00
Styrene	34.7 ± 2.0	3.5 ± 0.2	0.90
4-Phenylcyclohexene	64.5 ± 3.1	48.5 ± 2.4	0.25
TVOC as carbon	178 ± 15.9	51.2 ± 15.0	0.71
2			
1-Butanol	25.2 ± 3.3	6.9 ± 2.3	0.73
Dipropylene glycol methyl ethers (3)	26.3 ± 0.8	14.4 ± 0.1	0.45
1,2-Dichlorobenzene	10.2 ± 1.0	1.6 ± 0.1	0.84
2,6-Di-*tert*-butyl-4-methylphenol	214 ± 20.5	173 ± 8.1	0.19
TVOC as carbon	83.3 ± 25.0	32.5 ± 12.5	0.61
3			
Formaldehyde	57.2**	18.2**	0.68
Acetaldehyde	26.7**	4.6**	0.83
Methyl acetate	0.8 ± 0.2	0.00	1.00
Vinyl acetate	853 ± 41.5	103 ± 20.2	0.88
2,2,4-Trimethyl pentane	60.0 ± 7.7	21.4 ± 2.9	0.64
1,2-Propanediol	690 ± 67.5	193 ± 40.3	0.72
2-Ethyl-1-hexanol	58.0 ± 0.6	22.6 ± 2.0	0.61
TVOC as carbon	602 ± 23.5	192 ± 48.4	0.68
4			
4-Ethenylcyclohexene	24.2*	2.7 ± 0.1	0.89
Alkyl benzenes	12.4*	3.1 ± 0.2	0.75
Styrene	260*	16.1 ± 0.6	0.94
4-Phenylcyclohexene	81.9*	50.2 ± 1.9	0.39
TVOC as carbon	399*	93.9 ± 14.1	0.76

* Two replicate samples.

** Single sample.

Table 7 - Quasi steady-state specific emission rates of the target compounds at 24 and 168 hours after the start of each experiment.

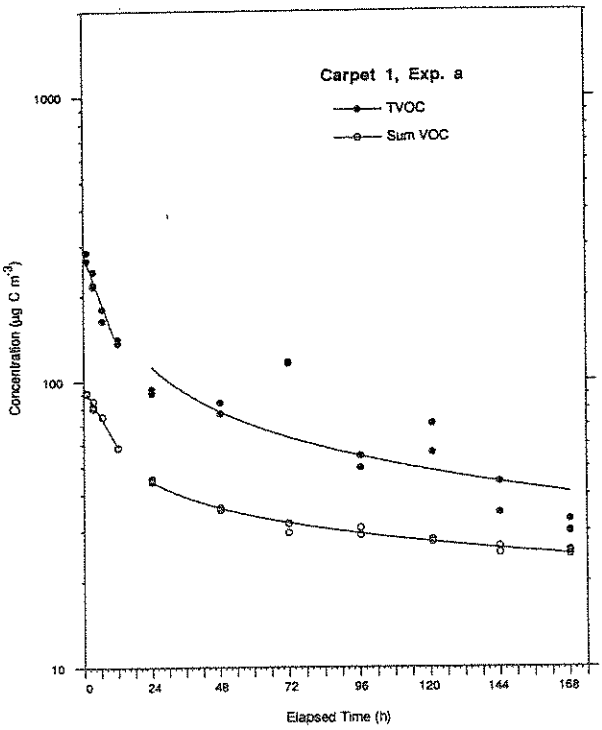

Figure 9 - Chamber concentrations of TVOC and the sum of the individual VOC emitted over one week by Carpet 1 in experiment a.

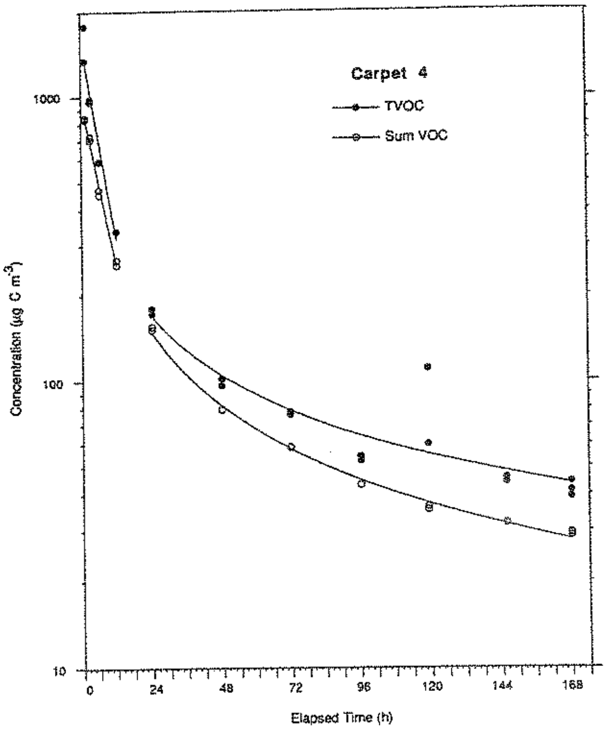

Figure 11 - Chamber concentrations of TVOC and the sum of the individual VOC emitted over one week by Carpet 4.

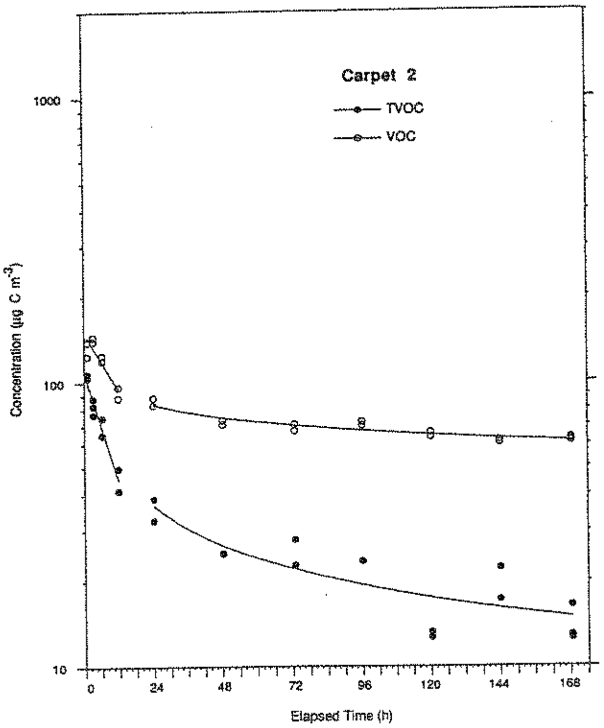

Figure 10 - Chamber concentrations of TVOC and the sum of the individual VOC emitted over one week by Carpet 2.

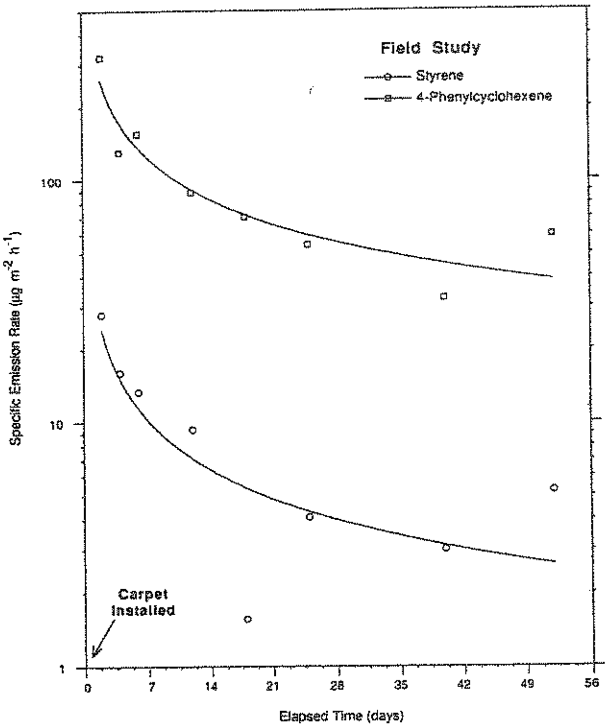

Figure 12 - Quasi steady-state specific emission rates of VOC emitted by a new carpet installed in a house.

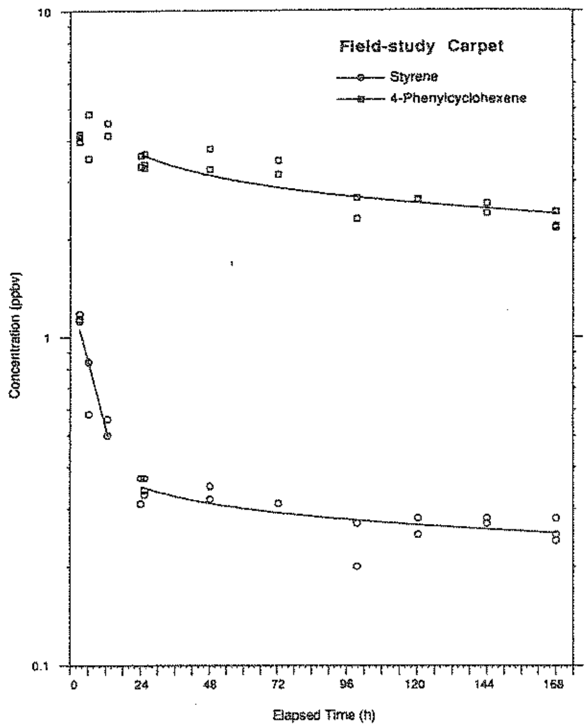

Figure 13 - Chamber concentrations of VOC emitted over one week by the field-study carpet.

Elapsed Time* Days	Vent. Rate (h^{-1})	Styrene Conc. (ppbv)	4-PCH** Conc. (ppbv)
-1	9.6	0.23	0
2	7.3	0.44	1.6
4	1.0	1.12	4.7
6	1.1	0.89	5.1
12	0.8	0.62	4.1
18	1.3	0.30	2.1
25	0.8	0.50	2.4
40	0.4	0.68	3.2
52	0.7	0.66	3.2

* Elapsed time = days relative to the installation of the new carpet.
** 4-PCH = 4-phenylcyclohexene.

Table 8 - Ventilation rates and concentrations of VOC in the field-study house.

rate of decay generally depended on the volatility of the compound – predictably, the most volatile compounds decayed the fastest. At the end of a week, all compounds except one had concentrations of 10 ppb or less.

Figures 12 and 13 show emission rates from field measurements and concentrations for chamber tests of the carpet installed in a house. Table 8 shows the ventilation rates and concentrations of VOC in the field-study house.

Compound	Occurrence	Emitted by SBR Carpets in Current Study
Styrene	19	Yes
4-Phenylcyclohexene	19	Yes
4-Ethenylcyclohexene	16	Yes
Undecane	13	Yes*
Propylbenzene	12	Yes
Decane	11	Yes*
Ethylbenzene	9	Yes
2-Butoxyethanol	9	No
Isopropylbenzene	8	Yes
1-Ethyl-3-methylbenzene	7	No
Toluene	7	Yes
p-Xylene	7	Yes

* Alkane hydrocarbons present in the volatility range of n-decane and n-undecane.

Table 9 - The 12 most frequently occurring VOC emitted by 19 SBR latex-backed carpets in small-scale environmental chambers (Data from Black *et al.*, 1991; as reported by Hetes *et al.*, 1992) and their presence in the emissions from the two SBR latex-backed carpets in the current study.

Note that the initial concentrations of 4-PC were not as high as reported elsewhere from other studies. This was due to the very high ventilation rate (7.3 air changes per hour) during the first two days after intallation. Even so, the 2-3+ ppb concentration during the second month after installation is still high enough for most people to easily detect and recognize as the "new carpet" odor.

Comparison with Emissions Measured in CRI Carpet Study

AQS has studied emissions in small environmental chambers from 19 representative SBR latex-backed carpets for the Carpet and Rug Institute (CRI). Table 9 compares the 12 most frequently emitted VOC from the AQS-CRI study with the compounds emitted by the two SBR latex-backed carpets in the small-scale chamber during the LBL-CPSC study. This table shows that only styrene and 4-phenylcyclohexene were found emitted from all samples in both studies. Perhaps more importantly, the table shows that there were significant differences in the other detected compounds emitted from the carpets tested in the two studies.

Comments

An important contribution of the LBL-CPSC carpet study was the identification and quantification of individual chemical compounds from four different carpet samples. Very few published data exist on the specific chemical compounds emitted from carpet samples in carefully controlled laboratory studies. The comparison with the published data from the CRI study shows that variations exist in the dominant compounds emitted from

Compound	Specific Emission Rate in μg m^{-2} h^{-1} 24 h Avg.	24 h Max.	140 h Avg.	140 h Max.	Fractional Reduction* 1-(140/24h)
4-Ethenylcyclohexene	3	27	<1	<1	1.00
C_2-C_3 Alkyl benzenes**	5	39	1	8	0.80
Styrene	37	173	3	18	0.92
4-Phenylcyclohexene	64	152	25	73	0.62

* Calculated using average emission rates.

** Data for propylbenzene, ethylbenzene, cumene, m-ethyltoluene and xylene were summed.

Table 10 - Average and maximum specific emission rates at 24 and 140 h for selected VOC emitted by 19 SBR latex-backed carpets in small-scale environmental chambers. These data are from Black *et al.* (1991), as reported by Hetes *et al.* (1992).

carpets that may be similar in construction. This should be a clear warning against generalizing about the composition and emissions from different carpets that may be generally similar.

One observer close to the project commented that really careful work is very expensive; perhaps that is why it is so rare. However, work not done carefully is not necessarily valuable, depending on the type of work involved. The implication is that understanding the chemical composition of carpet product emissions is not trivial and cannot be expected to be done quickly or cheaply. However, if we are to understand the health effects of carpet VOC emissions, we must be prepared to undertake costly and time-consuming studies.

It is unfortunate that the CPSC has not incorporated into the report its knowledge of the health effects for the emitted compounds. We look forward to a more complete documentation in the future – hopefully soon.

References:

A. T. Hodgson, J. D. Wooley, and J. M Daisey, Volatile Organic Chemical Emissions from Carpets, Final Report, prepared for Directorate of Health Sciences, U. S. Consumer Products Safety Commission, April, 1992, (LBL-31916, UC 600).

Black, M.S., Pearson, W.J. and Work, L.M. (1991) Volatile organic compound emissions from carpet and associated products, Appendix R, Carpet Policy Dialogue Compendium Report. R.W. Leukrothe, Jr., Ed., Office of Toxic Substances, U.S. EPA, Washington, D.C., Sept. 27.

Hetes, R.G., Womack, D.S., Pierson, T.K. and Naugle, D.F. (1992) Evaluation of Exposures to Volatile Organics Offgassing from New Carpets, U.S. EPA Contract No. CR-815509. Report 4479-001/12F, Research Triangle Institute, Research Triangle Park, NC.

For a copy of the report:

Write: Todd Stevenson, Freedom of Information Officer, Office of the Secretary, US Consumer Product Safety Commission, Washington, D. C., 20207, (301) 504-0785, fax (301) 504-0127.

For more information:

Alfred T. Hodgson, LBL, UC Berkeley, Berkeley CA 94720, (510) 486-5301.

Conference Announcement and Call for Papers

IAI VOC Conference

Indoor Air International (IAI) has issued a first announcement and call for papers for "Volatile Organic Compounds" to be held at the Royal College of Physicians, London, England. The announced conference date is October 27-28, 1992. The conference announcement states: "Specific studies and state of the art reviews should be sent to the Secretariat by 15 April 1993. Full manuscripts of accepted and invited papers will be required by 30 June 1993."

We are once again puzzled by the announcement of yet another conference sponsored by IAI. We note that the list of conference committee members again includes virtually no members of the established indoor air community.

For more information contact the Conference Secretariat, International VOC Conference, Unit 179, 2 Old Brompton Road, London SW7 3DQ, UK, +44 767 318 474, Fax +44 767 313 929.

Letters

Art Wheeler on Hospital HVAC

Dear Hal,

The role of recirculated air as described in the *IAB Vol 2, No. 5* article concerning ventilation protection against air borne tuberculosis could be underappreciated.

While a large system will distribute recirculated air from a stationary infection source site throughout a wider area and thereby expose more occupants than would a smaller local system, greater dilution is also afforded. The transmission risk via this path to those in the vicinity of the source is also reduced. The report that positive responses occurred remote from the infected person's work station did not rule out transmission paths other than recirculated air.

Regardless of system size, adequately filtered recirculated air could be quite beneficial in controlling airborne infection, approaching the effectiveness of outdoor air which is presumed to be free of the infectious agent.

If aerosolized tuberculosis bacteria form cluster particles of the size array of 1.8 to 4.3 microns, as described by Kuehn, *et al.*, in the report on ASHRAE RP625, medium and high efficiency filters should be capable of substantially reducing these particles in the supply air.

The particle efficiencies determined by Ensor et al (Proceedings of IAQ'88) show that an 85% ASHRAE dust spot efficiency filter is capable of 90% or higher removal for particles in this size range. Thus recirculated air so filtered should be 90% as effective as outdoor air. With a different perspective to permit use of the Soper equation, this filtered recirculated air, discounted 10%, is presumed equivalent to outdoor air.

If the occupancy in the office setting studied by the Massachusetts Department of Health can be characterized by the estimated occupancy rate of 7 persons per 1000 ft^2, per ASHRAE Standard 62-1989, an all air conditioning system typically would supply 140 cfm of conditioned air per person. With 85% efficiency filters 15 cfm of outdoor air (as indicated) plus .9 times 125 cfm recirculated air would yield 128 cfm of equivalent tuberculosis bacteria free air. The Soper equation then reveals that only 6% (vs 40%) or 1 or 2, not 27, individuals would have tested positive. This analysis suggests that in the instance studied the air system filters were of negligible effectiveness in removing the aerosolized bacteria not an unlikely condition. Effective filtration to remove infectious airborne particles generated within the building is, of course, more economical than significantly increasing the outdoor air component of ventilation in order to achieve dilution as hospital operating room practice demonstrates.

Higher efficiency filters belong in buildings that strive to be healthy.

Sincerely,

Art Wheeler

Reference:

Kuehn, *et al.*, ASHRAE Transactions 1991 Vol 97-2, paper #3505, "Matching Filtration to Health Requirements."

IAQ Information

Indoor Air Quality Information Clearinghouse

The United States Environmental Protection Agency (EPA) has opened an IAQ Information Clearinghouse. Funded by the Indoor Air Division of EPA, the Clearinghouse will function primarily as a toll-free source of information that will try to answer as many questions as possible by phone. It will also mail EPA Indoor Air Division publications, most of which are free. When appropriate, the clearinghouse information specialists will refer callers to other government agencies, public interest groups, and private sector organizations. The Clearinghouse may provide bibliographies on a topic for further caller reference.

The Clearinghouse announcement claimed citations and abstracts on more than 2,000 books, reports, newsletters, and journal articles. It has an inventory of federal government publications. And, information is available on more than 150 government and private sector organizations in the indoor air field.

The toll free number is 1-800-438-4318 and operates Monday through Friday from 9:00 AM to 5:00 PM Eastern Time. Voice mail messages or fax inquiries can be sent at any time. The local direct number is (301) 585-9020 and the fax number is (301) 588-3408. If you wish to write, the mailing address is P. O. Box 37133, Washington, DC 20013-7133.

IAB is anxious to receive reader feedback on the usefulness of the Clearinghouse's response to your inquiries. Please drop us a note by mail or fax, and we'll share your experience (anonymously, of course, unless you prefer attribution) with other readers.

Calendar

Domestic Events

January 23-27, 1993. **ASHRAE Winter Meeting and International Air-Conditioning, Heating, and Refrigerating Exposition**, Palmer House, Chicago, Illinois. Contact ASHRAE Meetings Department, 1791 Tullie Circle NE, Atlanta, GA 30329, (404) 636-8400.

February 9-12, 1993. **Indoor Air Quality Symposium**, Georgia Tech Research Institute, Atlanta, Georgia. Contact GTRI, Training Programs Office, (404) 894-7430.

March 29-31, 1992. **Indoor Air Pollution**, Sixth Annual Conference, Adam's Mark Hotel, Tulsa, Oklahoma. Sponsored by University of Tulsa. Contact: Division of Continuing Education, 600 South College Avenue, Tulsa, OK 74104-3189, fax (918) 631-2154.

April 21-23, 1993. **Indoor Environment '93**, Indoor Pollution Conference and Exhibition. Hyatt Regency On the Inner Harbor, Baltimore, Maryland. Sponsored by IAQ Publications, Inc. Contact Conference Director Lisa Markham, IAQ Publications, 4520 East-West Highway, Suite 610, Bethesda, MD 20814. (301) 913-0115, Fax (301) 913-0119.

May 3-7, 1993. **Air & Waste Management Association Annual Symposium**, "Measurement of Toxic and Related Air Pollutants," Omni Hotel and Convention Center, Raleigh, North Carolina. Contact Martha Swiss, A&WMA, P. O. Box 2861, Pittsburgh, PA 15230, (412) 232-3444, fax (412) 232-3450.

May 15-21, 1993. **American Industrial Hygiene Conference and Exposition**, New Orleans Convention Center, New Orleans, Louisiana. Contact: AIHA, 2700 Prosperity Avenue, Suite 250, Fairfax, VA 22031, (703) 849-8888, fax (703) 207-3561.

June 26-30, 1993. **ASHRAE Annual Meeting**, Radisson Hotel, Denver, Colorado. Contact: See listing above under January 23-27, 1993.

November 7-10, 1993. **IAQ '93: Operating and Maintaining Buildings for Health, Comfort and Productivity**, Philadelphia, Pennsylvania. Sponsored by ASHRAE. Contact: ASHRAE, see listing for Winter Meeting, January 23-27, 1993. *The press release states: "The symposium will focus on building system operation and maintenance practices, will bring together builders, designers, property managers and scientists to exchange experiences and solutions which provide acceptable indoor air quality." Deadline for paper abstracts not more than 300 words is December 18, 1992. Papers will be due April 23, 1993. ASHRAE has assembled a long and impressive list of virtually all relevant organizations in the U.S. to participate in this practice-oriented conference. If the past two ASHRAE IAQ conferences are a reliable indication, this should be an outstanding conference.*

International Events

February 17-19, 1993. **Building Design, Technology & Occupant Well Being in Cold and Temperate Climates**, Palais des Congrès, Brussels, Belgium. Contact: ATIC-CDH, chausee d'Alsemberg 196, B-1180 Brussels, Belgium, . 32-2-348-05-50; Fax 32-2-343-98-42.

March 4-6, 1993. **Second Spanish and Interamerican Air Conditioning and Refrigeration Congress—CIAR '93**, Madrid, Spain. Contact CIAR '93, Parque Ferial Juan Carlos 1, 238067, Madrid, Spain, 722-50 00, fax 722 57 90.

July 4-8, 1993. **Sixth International Conference on Indoor Air Quality and Climate, Indoor Air '93**, Helsinki, Finland. For more information, a copy of the conference announcement, or the call for papers, contact the confeence secretary at: Indoor Air '93, P.O. Box 87, SF-02151 Espoo, Finland, fax +358-0-451-3611. *This most important indoor air conference is held every three years and is always a very exciting and rewarding event. Make plans now to attend this most important of international indoor air conferences. Recent devaluation of Finnish currency will help make this a more affordable conference to attend.*

October 27-28, 1993. **Volatile Organic Compounds**, Royal College of Physicians, London, England. Sponsored by Indoor Air International (IAI). Contact: Conference Secretariat, International VOC Conference, Unit 179, 2 Old Brompton Road, London SW7 3DQ, UK, +44 767 318 474, Fax +44 767 313 929. *A first announcement and call for papers has been issued. "Specific studies and state of the art reviews should be sent to the Secretariat by 15 April 1993. Full manuscripts of accepted and invited papers will be required by 30 June 1993."*

November 1-3, 1993. **Clima 2000**, Queen Elizabeth Conference Centre, London, England. Contact: Anne Gibbins, CIBSE Headquarters, 222 Baltham High Road, London, SW 12 9BS, fax 44-1-6755449.

March 15 - 18, 1994. **Cold Climate HVAC '94 - International Conference on HVAC in Cold Climates**. City of Rovaniemi, Finland. Sponsored by FINVAC, Federation of Societies of Heating, Air Conditioning and Sanitary Engineers in Finland. Contact: FINVAC/Cold Climate HVAC '94, Mr. Ilpo Nousiainen, Sitratori 5, SF-00420 Helsinki, Finland, +358 0 563 3600, Fax +358 0 566 5093. *Abstracts are due March 1993; papers are due October 1993. The official conference language is English.*

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Hal Levin, Editor and Publisher
Subscription Manager: Gina Bendy
Editorial Office: 2548 Empire Grade, Santa Cruz, CA 95060; (408) 425-3946 FAX (408) 426-6522
Subscription Office: P.O. Box 8446 Santa Cruz, CA 95061-8446: (408) 426-6624 FAX (408) 426-6522

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