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Indoor Air Quality Update®

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

FLOOR COVERINGS & IAQ:

Health Impacts, Prevention, Mitigation & Litigation

by Anne Wagner

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Table of Contents

Introduction

The issue of indoor air quality (IAQ) has been around for a long time, but two trends in the last 20 or 30 years have brought media attention, scientific scrutiny, and public concern to bear on IAQ: 1) the advent of synthetic organic building, furnishing, and consumer products and their increased use; and 2) the emphasis on energy conservation that has led to a decrease in building ventilation (Tucker 1986).

Statistics have shown that people spend more than 16 hours per day at home and, adding time spent at work in commercial buildings and in cars or subways, more than 90% of their time indoors (Spengler and Sexton 1983). Thus, even very low levels of indoor pollutants may have a disproportionately significant impact on health given the extent of most people's exposure to them. According to one expert, "indoor air presents risks far exceeding those from environmental conditions afforded a much higher priority," such as hazardous waste dump sites (Cross 1990). Tucker (1986) groups the sources of indoor air pollution into four categories:

- Combustion (including heaters, stoves, and smoking);
- Human activity (such as cooking, painting, using machines, and using spray products);
- Infiltration from the outdoors (such as radon, pesticides applied to the soil, and auto emissions); and
- Materials (including structural, HVAC, and furnishing materials).

Among the many products implicated in the last category are a variety of floor coverings. They are sources of a wide variety of volatile organic compounds (VOCs), fibers (including asbestos), and biological contaminants, such as mites, bacteria, and fungi. Some floor coverings, most notably carpets, also act as sinks for pollutants from other sources, adsorbing the pollutants onto their surfaces or absorbing pollutants into their fibers and later releasing them into the air (Tichenor et al. 1991; Borazzo, Davidson, and Andelman 1990). They may also act as sinks in a different respect, trapping particulate pollutants such as soil and dust that are contaminated with lead or pesticides (Camann, Harding, and Lewis 1990; Raloff 1990).

This report examines the literature on five commonly used floor covering materials:

- Synthetic carpets
- Adhesives
- Vinyl
- Linoleum
- Parquet and associated coating materials

It describes the emissions characteristics of each of these materials, the biological contaminants associated with them, and their role as pollutant sinks, if any. It also examines the health effects generally ascribed to these and other material sources.

With the increase in public awareness of IAQ issues has come an increase in litigation. A few landmark cases are examined here. While the US Congress considers new legislation to control indoor air pollution and establish regulatory authority, the US government and industry recently reached a consensus on a voluntary testing program for the carpet industry (see Chapter 8 — Regulation and Legislation below).

The last chapter of this report is a review of the techniques for remedying the indoor air pollution from floor coverings. These techniques roughly fall into five categories:

- Prevention through selection of low-emitting products and materials;
- Pre-installation conditioning;
- Post-installation treatments; and
- Maintenance techniques.

"In the fifties and sixties," writes architect Carlo Testa (1990), "we concentrated on [building] quantity. In the seventies and eighties we concentrated on energy efficiency. In both cases we created harmful and serious side effects. We are now faced with the challenge of curing existing sick buildings and building healthy new ones."

Chapter 1
Carpets

Carpets and carpet-related products are sources of a variety of pollutants. Carpet fibers, backing materials, and the adhesives used to anchor carpets to the floor emit a myriad of VOCs, organic compounds that volatilize at room temperature. In addition to off-gassing VOCs, carpets may act as sinks for biological pollutants such as bacteria, mites, and fungi, and carcinogens such as lead, chlordane, and even DDT. Sorption of organic compounds to carpet fibers and subsequent remission can significantly affect the concentrations of indoor air pollutants as well. Carpet dyes and topical treatments such as antistatic, bactericidal, fungicidal, fire retardant, and soil resistant additives have undergone almost no testing as to their polluting potential.

Emissions Measurement Techniques

Research into emissions testing has gained momentum as architects, designers, and the public increasingly demand information about the quantity, composition, and decay rate of a product's emissions (***Indoor Air Quality Update*** [*IAQU*] March 1990). In addition, the rising incidence of building-related illness (BRI) (see Chapter 6 — Health Effects) has underscored the need for reliable, reproducible, and cost-effective methods to identify the sources of indoor air pollutants and analyze their emissions. The search for such methods has focused primarily on VOCs, given the diversity, complexity, and frequency with which they appear in indoor air.

In the recent past, researchers have analyzed VOCs by collecting samples on solid sorbents, removing the sorbed samples using solvents or heat, and analyzing the resulting material in a chromatograph. This method has several limitations, however. Sometimes the sample reacts with the sorbent or binds irreversibly with it. Occasionally only part of the sample is recovered or decomposes when it is heated to remove it from the sorbent. Finally, the sample is sometimes diluted by the solvent used to remove it from the sorbent (Bayer and Black 1989).

Researchers have now turned to dynamic environmental chamber technology to analyze source emissions and their chemical composition. The wood product industry first used environmental chambers to measure formaldehyde emissions from particleboard. It was later used as the standard technology in the industry's voluntary certification program for minimizing formaldehyde emissions from the pressed wood products used in prefabricated housing (Black 1990).

Use of the technology to test consumer products such as carpet has gained momentum in the last five to ten years. In 1989, Bayer and Black connected a small-scale (0.24 m^3) chamber to a capillary gas chromatograph and measured the VOC emissions from a variety of consumer products. The chamber environment was set at 50% relative humidity (RH) and 25°C (approximately 77°F). The narrow, sharp, single peaks on the resulting chromatograms indicated "quantitative, efficient trapping of the volatile components." Bayer and Black noted that this technology combines sampling and analysis in one step, improving over the traditional two-step procedure of on-site sampling followed by off-site analysis. In addition, the chromatographs provide a quantitative, product-specific emission profile that can be incorporated into a database for use in IAQ and health impact assessments (Bayer and Black 1989).

In 1989 the US Environmental Protection Agency (EPA), in an effort led by Bruce Tichenor at the Air and Energy Engineering Research Laboratory in Research Triangle Park, North Carolina, developed a "Standard guide for small-scale environmental chamber determinations of organic emissions from indoor materials/products" (*IAQU* March 1990). The following year, the American Society for Testing and Materials (ASTM) adopted Standard D5116-90, which has the same title as Tichenor's guide (*IAQU* November 1990). The ASTM standard describes the physical parameters, measurement, and control systems for small-scale chambers, sample collection and analysis techniques (including sample collection media), experimental design and procedures, data analysis, and quality assurance and control (ASTM 1990).

The low (ppb) emission levels of VOCs from manufactured products such as carpets and the diversity of factors that affect emission rates mandate the need for testing standards. Black (1990) has described an environmental chamber technology and a testing protocol designed to measure total volatile organic compounds (TVOC) emissions from new carpet products.[1]

1 Because of the very low levels of VOCs emitted in the indoor environment and the difficulty of identifying specific compounds, researchers and investigators often express measurements of outgassed organic compounds as a summary measurement called total volatile organic compounds (TVOC). While they do not provide compound-specific information, TVOC measurements allow relative measures of VOC emissions without the expense of identifying and quantifying individual compound emissions.

Table 1 — Environmental Chamber TVOC Emission Rate Measurement Specifications for Carpet

Internal minimum volume of 0.05 m^3
Construction materials of inert, smooth such as stainless steel and glass
Internal construction free of obstructions and contamination
Internal air velocity reproducible at 0.05 - 0.2 m/sec
Internal mixing within 5% of theoretical model
Recovery rates > 95% for representative compounds at 25 $\mu g/m^3$
Standard environmental controls of 1.0 ach ± 0.05, 25°C ± 0.2°C, 50% RH ± 1%
Positive pressure operation relative to atmosphere
Operation quality control procedures for packaging, storing, conditioning, and testing

Source: Black 1990

The environmental chamber specifications required to obtain accurate and comparative data from carpet, listed in Table 1, closely parallel those specified in the ASTM standard.

Black (1990) also lists the following product-specific factors that affect TVOC emission rates from carpet and thus should be standardized or controlled closely: product history (including unexposed and exposed age), packaging, storage, conditioning (e.g., airing out before installation), loading factor (the ratio of the carpet area to the chamber volume), and environmental factors (such as temperature and humidity). She notes that with respect to packaging materials, mylar and polyethylene emit over a dozen measurable VOCs each, potentially contaminating the product enclosed. They also pose adsorption and permeability problems. She also notes that product homogeneity and variations in manufacturing within and between products affect emission rates, as does a product's sink behavior (see The Sink Effect — Sorption and Rerelease below).

As part of her research, Black examined the correlation between large (26.1 m^3) and small (0.05 m^3) environmental test chamber data to determine whether a smaller sample size distorts the emissions data, particularly if product homogeneity is in question. She reports that "the correlation between the large chamber study and the small chamber study was very good, with a correlation coefficient of 0.90."

Volatile Organic Compounds (VOCs)

The prevalent groups of VOCs that carpets emit include aliphatic and oxygenated aliphatic hydrocarbons, and aromatic hydrocarbons (Sheldon et al. 1988). Bayer and Black (1989) reported that in a small-scale environmental chamber at 50% RH and 25°C, using a standard loading of 0.43 m^2/m^3 with one air change per hour (ACH), an unspecified carpet sample emitted toluene, benzene, and n-decane, among other VOCs. Bayer and Papanicolopoulos (1990), using environmental chamber technology, analyzed 30 carpet samples and found 32 frequently emitted VOCs. They also reported finding "heterocyclic compounds such as furans and pyridines, nitrogenated compounds such as ethanamines, and sulfur-containing compounds such as dimethyldisulfide."

Schröder (1990) heated sample pieces of new carpets to 95°C to enhance emissions and measured "nearly 200 substances," 80 of which he subsequently identified using gas chromatography/mass spectrometry (GC/MS). The compounds found in highest concentration were aromatic compounds (styrene, toluene, and xylene), aliphatic hydrocarbons, 4-phenylcyclohexene (see following section), 4-vinylcyclohexene, and some sulphur-containing compounds, and amines such as diethylamine. According to Schröder, most of the compounds originated from the backing and finishing materials and not the fibers themselves.

In 1989, *IAQU* reported on the research of Bern Seifert, D. Ullrich, and R. Nagel, who analyzed the emissions from a fabric-backed nylon carpet in an environmental chamber and rank-ordered the ten most prevalent VOCs, shown in Table 2 (*IAQU* December 1989).

IAQU also reported on the work of EPA researchers Joachim Pleil and Robert Whiton, who tested seven carpet types for volatile as well as semivolatile and nonvolatile compounds, which they extracted with methylene chloride (*IAQU* October 1990). They found measurable amounts of about 30 compounds, the most common of which were 4-phenylcyclohexene (4-PC),

Table 2 — Relative concentrations of 10 of the most important compounds in the gas phase above new carpeting at 0.6 ACH

Number	Compound	Percentage of total emission*
1	4-Phenylcyclohexene	30
2	Styrene	7
3	n-Dodecane	6
4	n-Undecane	5
5	1,2,4-Trimethylbenzene	5
6	unidentified	4
7	4-Methylethylbenzene	3
8	2-Ethylhexanol	3
9	unidentified	2
10	n-Propylbenzene	2

*100% = total area counts of the gas chromatograms

Source: ***IAQU*** December 1989

styrene, and toluene. Among the semivolatile compounds they identified in one sample was triethyl phosphate, a moderately toxic compound used in insecticides, and two suspected human carcinogens: dichlorobenzene and bis(2-ethyl-hexyl)phthalate. While these semi- and nonvolatile compounds might not be found in the air, Pliel and Whiton suggested that they could be volatilized during carpet cleaning or vacuuming. They could also be adsorbed onto particulates in the carpet or absorbed through skin.

VOCs in textile products are outgassed through three mass-transfer processes: diffusion within the source product, desorption of adsorbed or absorbed VOCs, and evaporation (ASTM 1990; Bayer and Papanicolopoulos 1990). The emission profiles are "strongly dependent upon the generation mode and the concentration of the VOC within the material." Temperature and vapor pressure gradients between the emitter's surface and the surrounding air enhance emission rates, particularly of free or weakly bound compounds such as unreacted formaldehyde. These appear in the short term at high levels. Bound VOCs, such as formaldehyde from N-methanol resins, are released more slowly over the long term and in low levels as resins and polymers undergo hydrolysis. Hydrolysis of the plasticizers (polymer additives) in polyvinylchloride (PVC) backed carpet can release higher alcohols such as 2-ethyl-1-hexanol and heptanol as well (McLaughlin and Aigner 1990; Engström 1990).

While Black (1990) concludes that these data "[indicate] that these carpet products are a very low, decaying emitter of TVOCs, and significantly less of an emitter than other known VOC sources," and Pliel and Whiton (*IAQU* October 1990) also conclude that rapid offgassing of VOCs from carpet suggests that they may exert little long-term impact on IAQ in buildings, Engström (1990) points out that "separate materials form only part of the total furnishing, which means that the total dose in reality will be much greater." In addition, the complex mixture of VOCs emitted by various materials could produce a health effect that exposure to individual concentrations might not (Samet, Marbury, and Spengler 1988b).

Research has tended to focus on two particular VOCs emitted from carpet, formaldehyde and 4-PC, because of their prevalence in carpet emissions and their known or suspected impact on health.

4-phenylcyclohexene (4-PC)

4-PC is an odorous VOC produced as a by-product of the reaction between styrene and 1,3-butadiene in the manufacture of styrene-butadiene latex (SB latex). SB latex is used to bind carpet fibers to backing (*IAQU* December 1989; Singhvi et al. 1990). Little was known about this VOC and its presence in carpet emissions before 1982, when R.R. Miksch, C.D. Hollowell, and H.E. Schmidt published a paper describing a GC/MS analysis of the headspace vapor from five carpet samples. Among the major organic contaminants they identified was 4-PC (Singhvi et al.

1990). In 1987, Mark VanErt linked 4-PC to complaints about new carpeting and reported some preliminary test results on the compound's toxicology in rats (Hirzy and Morison 1991).

The compound received considerably more attention in January 1990, when the National Federation of Federal Employees (NFFE), Local 2050, petitioned the EPA under Section 21 of Toxic Substances Control Act to initiate rulemaking proceedings to control exposure to 4-PC and other VOCs emitted from carpets (*IAQU* September 1990; *IAQU* July 1990; *Federal Register* April 24, 1990). Federal office workers at the EPA's headquarters in Washington, DC's Waterside Mall had reported a variety of symptoms such as headaches, dizziness, memory loss, and irritation of the eyes and respiratory tract after new carpets were installed in the building in late 1987 and early 1988. In its petition, the NFFE claimed that exposure to 4-PC and other VOCs from the new carpet had caused the workers' illnesses. (See Chapter 8 — Regulation and Legislation.)

Research confirms that 4-PC is a major component of the emissions from most synthetic carpets. In their investigation of seven carpet types, Pleil and Whiton measured headspace concentrations of 4-PC in the range of 0 to 100 parts per billion by volume (ppbv) (*IAQU* October 1990). Methylene chloride extracts of the same samples correlated well with the headspace analysis: the carpet that emitted 100 ppbv of 4-PC contained 115 micrograms of 4-PC per gram of carpet. The carpet emitting 25 ppbv of 4-PC contained only 20 micrograms per gram.

Schröder (1990) reported that, in Germany in 1989, 650 carpets prompted complaints of odors and associated symptoms such as headache, runny eyes, irritation of mucous membranes, and fatigue. He identified 4-PC as a primary source of the odor.

Singhvi et al. (1990) examined eight different carpet samples, including the carpet installed in the EPA headquarters at the Waterside Mall, and reported 4-PC emissions in the range of 0.2 to 6.65 ppbv. An air sample obtained by "poking a hole in the plastic wrapping around a new roll of carpeting" contained 70 ppbv of 4-PC. All of the carpets that emitted 4-PC had jute backings bound to the carpet with SB latex, while the three carpets that did not emit the VOC had foam backings.

While 4-PC emissions from some carpets may be high initially, they tend to diminish quickly over time and they are very dependent on carpet type. In an environmental chamber study of the emissions from eight samples of new styrene-butadiene rubber (SBR)-latex-backed nylon carpet, Black (1990) calculated that the half-life of 4-PC at 1.0 ACH was three days. Pleil and Whiton found the 4-PC half-life of the seven carpets they tested to be about eight days at 2.0 ACH.

The EPA headquarters case, however, has raised considerable concern about the health effects of short-term exposure to 4-PC. Hirzy and

Morison (1991), reviewing the data obtained by the NFFE and the EPA following the installation of the carpet in the Waterside Mall, "theorize that the introduction of a source of [4-PC] into a marginal indoor air environment in which approximately 5,000 people work for 8 to 10 hours per day is responsible for the outbreak [of illness]." Of the 122 people who reported symptoms after the carpet was installed, six appeared to have acquired multiple chemical sensitivities (MCS), a poorly defined illness characterized by hypersensitivity to a range of environmental agents (see Chapter 6 — Health Effects).

According to Hirzy and Morison (1991), the number of symptoms that employees in the EPA building reported increased proportionately to the amount of new carpet installed. Employees working in the newly carpeted area were exposed to initial 4-PC concentrations of 1 to 15 ppb, the authors state, and hypersensitivity began to appear in some employees after several days or weeks of exposure.

Based on VanErt's toxicity studies and their own literature analysis, Hirzy and Morison (1991) conclude that "the likely primary metabolite of 4-PC [3,4-epoxycyclohexyl-1-benzene] would be expected to be a fairly potent inhibitor of certain enzymes and to be reactive toward DNA and/or cellular proteins;" i.e., it would likely be carcinogenic. The authors also note that 4-PC is structurally similar to phencyclidine, the compound popularly known as "angel dust," which might explain some of the neurologic effects of 4-PC (e.g., dizziness, memory problems, and difficulty concentrating). The authors thus recommend:

1) Establishing an indoor air standard for 4-PC between 0.005 and 0.017 ppb;
2) Requiring testing of finished SB latex adhesive and carpeting "to establish a product-content standard for 4-PC that will assure compliance with the indoor air standard";
3) Maintaining quality-control records and establishing procedures "to assure compliance with product-content standards";
4) Notifying the public of the risks associated with 4-PC levels exceeding the standards; and
5) Recalling products containing 4-PC levels that exceed the standards.

Formaldehyde

Writing in the September 27, 1987 issue of the *New York Times Magazine*, reporter Susan Gilbert noted, "It is almost impossible to avoid formaldehyde gas. It's in the resins used to make most particleboard, plywood, and wood paneling; the foam in urea formaldehyde insulation; the sizing applied to upholstery and drapes; the adhesives used with carpeting and wallpaper; the 'permanent press' resin in clothes; the germ killer in toothpaste — and the ink in the dollar bills that pay for all these things."

Formaldehyde, "the VOC of greatest public and regulatory concern" (Samet, Marbury, and Spengler 1988), is a colorless gas at room temperature. Because of its high solubility in water, it is an irritant of the mucous membranes in the eyes and respiratory tract (Samet, Marbury, and Spengler 1988). Eye discomfort occurs in the range of 0.1 to 0.4 parts per million (ppm) in chamber studies, and 0.02 ppm in residential exposures (Spengler and Sexton 1983). This wide range of concentrations that provoke a response may be due to 1) a broad spectrum of sensitivities in the general population, 2) increased sensitivity at the low-level but prolonged exposures experienced in the home, or 3) adaptation of the subjects in the chamber studies to elevated formaldehyde concentrations (Spengler and Sexton 1983).

Neurophysiological effects such as short-term memory loss, increased anxiety, and sensitivity of dark-adapted eyes to light have been reported at concentrations ranging from 0.05 to 1.5 ppm, although how formaldehyde affects the nervous system is not clear (Samet, Marbury, and Spengler 1988; Spengler and Sexton 1983). While the carcinogenicity of formaldehyde in humans is disputed (Cross 1990; Godish 1990), it has been shown to produce cancers in rats and mice (Spengler and Sexton 1983).

Average outdoor levels of formaldehyde are about 0.0004 ppm. Indoor levels are much higher, averaging 0.5 ppm in Europe and 0.1 ppm in the US (Cross 1990). Pressed wood products such as particleboard, plywood, and fiberboard are the primary sources of indoor formaldehyde (Black and Bayer 1986), but carpets, carpet backing, and carpet adhesives also emit this VOC (Engström 1990; Mølhave 1982; Samet, Marbury, and Spengler 1988a,b; Spengler and Sexton 1983). According to Spengler and Sexton (1983), the half-life for formaldehyde emissions is approximately 4.4 years, although humidity and temperature greatly affect the rate of emissions.

In a small (0.06 m^3) environmental chamber study of the emissions from 277 building materials, including 14 carpets, Engström (1990) reported that formaldehyde was the most common compound emitted. Four of the 14 carpets she examined emitted formaldehyde, although she does not state the emission rates for any. In their study of a synthetic carpet "removed from a public school where health complaints had originated following installation of the carpet," Black and Bayer (1986) found the formaldehyde level "nondetectable at less than 20 ppb." The carpet was six months old. Similarly, Bayer and Papanicolopoulos (1990), Bayer and Black (1989), and Schröder (1990) did not identify formaldehyde among the VOC emissions they measured from the carpet. Wolkoff, Nielsen, Hansen et al. (1990) reported a formaldehyde emission concentration of 26 μg/m^3 of chamber space and a formaldehyde emission rate of 5.6 μg/m^2 of carpet per hour from a nylon carpet with a rubber mat.

In a study of the emissions from building materials and furnishings used in a new office building, Levin (1987) found that the formaldehyde content of newly manufactured carpet declined tenfold during the first three to six weeks of airing. He suggests that this rapid decay in emissions could account for some of the reported observations that carpets are weak emitters of formaldehyde.

Biological Contaminants

In a 1985 evaluation of 356 building-related illnesses (BRIs), the National Institute for Occupational Safety and Health (NIOSH) found that 5% were associated with biological contaminants (Samet, Marbury, and Spengler 1988b). Biological contaminants affect health primarily by infecting the respiratory system and triggering immune responses (Samet, Marbury, and Spengler 1988b).

Among the numerous biological agents that contaminate indoor air (e.g., viruses, bacteria, actinomycetes, fungi, algae, and amoebae), the two most often associated with carpet in the literature are fungi and dust mites. Carpets can collect as many as 10 million such organisms per square foot (Cross 1990). Carpeting on cement floors where humidity is high presents a particular risk for increasing the levels of house dust mites and fungal contamination (Burge 1990a) as well as microbial growth (American Conference of Governmental Industrial Hygienists 1989).

Fungi

Substrate type (e.g., carpet, wood, or wallpaper) determines which species of fungi will grow in a particular location. The extent of that growth is determined in turn by the amount of nutrient in the substrate, the ambient moisture, and the temperature (*IAQU* August 1990).

Fungi produce three chemicals that affect IAQ: mycotoxins, synergizers, and VOCs. Mycotoxins are generally secondary metabolites that can cause a range of illnesses in humans. Synergizers are compounds that may not be toxic themselves but that can enhance the potency of other toxins. The more than 500 fungal VOCs identified include ethanol, an extremely volatile alcohol that can act as a strong synergizer (*IAQU* August 1990).

Fungi themselves, particularly the propagules (reproductive structures) of filamentous fungi, are allergenic and can cause respiratory illnesses. While 10%-15% of the human population is allergic to fungi, research has not yet demonstrated a clear connection between the presence of fungi in indoor air and the occurrence of allergic reactions.

Inhaling large concentrations (i.e., 10^8 colony forming units [CFU]/m^3 of air) of airborne fungal spores can cause hypersensitivity pneumonitis, an illness characterized by inflammation of the interior lining of the lung (*IAQU* August 1990). Chronic exposure to low levels of airborne spores may also produce symptoms, however. According to one expert, the best remedy for fungal contamination is good ventilation and moisture control (*IAQU* August 1990).

Mites

Inhaling dust contaminated with mites can produce asthma (Samet, Marbury, and Spengler 1988b). Bischoff et al. (1990) report that the mites themselves are not harmful. It is the fecal pellets they excrete, which amount to about 200 times their body weight per lifetime, that contain allergens. In a study of a carpet taken from a children's bedroom in France, the researchers counted 100 live mites in the carpet dust and between 30,000 and almost 50,000 live mites in the carpet itself. (The live mites were counted by heating the carpet from the back thus driving the mites toward the surface where they were collected on an adhesive film.) Following treatment with an acaricide (mite killer), the population declined to 248 live mites. The researchers point out that although acaricides are effective in removing live mites, the dirt containing the allergenic pellets remains in the carpet. Removal takes much longer and depends on the dirt and the carpet type.

As is the case with fungi, substrate type is an important variable in determining mite growth. Irie et al. (1990) studied the concentration of mites on different floor coverings, taking into account seasonal variations in temperature and humidity. They found that in summer, mites were most numerous in carpeted rooms (23 mites/adhesive sheet) and least numerous in rooms with bare wooden floors (4 mites/sheet).

The best way to reduce mite allergen levels in carpets appears to be autoclaving (heating the carpet to 110°C for 10 minutes), which kills live mites as well as destroying the mite allergens and the food that sustains mite population growth (mostly shed human skin flakes) (de Boer 1990). However, this remedial method is largely impractical. Wet cleaning with carpet shampoos and detergents applied by machine are also effective. The shampoo and detergent residues may affect mite reproduction, egg viability, and food availability. This method has, however, been connected with Kawasaki syndrome (see Chapter 6 — Health Effects). Vacuuming also removes food sources and allergens, but must be intensive (12 minutes/m^2) to be effective (Boer 1990).

The Sink Effect — Sorption and Rerelease

As noted above, in addition to emitting VOCs, carpets can affect IAQ by acting as sinks for chemical and biological contaminants. Compared to smooth floor coverings, carpets have a higher surface area per unit mass. Borazzo, Davidson, and Andelman (1990) measured the extent and rate of sorption of several VOCs to two fiber types commonly used in carpets: a nylon/acrylic blend, and wool. For comparison they also used undyed cotton and glass fibers. The VOCs included three aromatic compounds (benzene, toluene, and m-xylene), six halogenated hydrocarbons, and p-dichlorobenzene (PDB). Sorption was measured using gas-solid chromatography (GSC).

From their results, the researchers conclude that, as expected, less volatile VOCs (such as PDB) sorb more extensively to carpet fibers than do more volatile VOCs, and the extent of sorption depends on the surface area of the carpet. Cotton, which has a surface area roughly an order of magnitude greater than the surface area of nylon/acrylic, sorbed more of the VOCs than the other fibers. While some of the data suggest that the VOCs were adsorbed to the fibers, other data suggest a two-step process: initial fast diffusion of the VOCs into the spaces between fibers (i.e., adsorption) followed by a slower diffusion into the intrafiber spaces (i.e., absorption).

To study the kinetics of sorption, the researchers exposed eight samples of nylon carpet of varying thickness and fiber weight to the same concentration of trichloroethylene (TCE), a compound that volatilizes from residential water. They calculated the concentration of TCE sorbed by the carpet from the vapor phase concentrations measured in each of eight closed chambers over time. They found that the sorbed phase concentrations reached 90% of their equilibrium values in less than two hours.

Tichenor et al. (1990, 1991) used small environmental test chambers (53 liters) to measure the adsorption and release of VOCs using a nylon carpet with a jute backing bound with SB latex, as well as other indoor surface materials. For VOCs the researchers used tetrachloroethylene, a common cleaning solvent, and ethylbenzene, a component of petroleum-based solvents. The sink materials were exposed to the VOCs under a variety of concentrations and temperatures. The researchers originally hypothesized that the VOCs adsorb to surfaces in a process described by Irving Langmuir in 1916. Langmuir's model — the Langmuir adsorption isotherm — is based on several assumptions, among them that:

1) The solid surface contains a fixed number of adsorption sites and that at equilibrium (at any temperature and pressure) a fraction are occupied by adsorbed molecules while another fraction are not;
2) Each site holds one molecule and each site is identical to another; and
3) The adsorbed molecules do not react with each other (i.e., the chance that a molecule attaches to or leaves a site does not depend on whether a neighboring site is occupied).

The research of Tichenor et al. shows, however, that the kinetic data for carpets did not fit the Langmuir isotherm, which better described the behavior of the smooth-surfaced sink materials such as ceiling tiles and wallboard. Desorption in particular deviated from the Langmuir assumptions. In all cases, however, "carpet was a significantly stronger sink" for both VOCs tested than were any of the other sink materials, including a fabric pillow. And carpet adsorbed both VOCs equally (while ceiling tile and wallboard showed significantly different adsorption for one VOC compared with the other). The authors thus concluded that the type of sink material and the type of VOC adsorbed affect both the *rate* of adsorption and desorption as well as the *amount* of adsorption. In addition, higher temperatures increase the adsorption and release rates.

Given the impact that desorption can have on IAQ, Tichenor et al. (1991) recommend that further research be done to develop sink models that explain the non-Langmuir desorption they found. They add that "such models should be capable of predicting re-emissions from sinks over long periods (e.g., weeks or months)." The authors also recommend incorporating sink models into IAQ models.

Particulate Deposits

Carpets act as sinks in another sense: they collect tracked-in soil and dust that often contain pesticides, lead, and other toxic chemicals. Furthermore, they may contain such chemicals for years after the original source of contamination has been removed, thereby prolonging exposures. For example, a 1989 study of carpet dust from four homes revealed the presence of DDT, even though the pesticide was removed from the market in 1972 (Raloff, 1990).

More recently researchers examined the carpet dust from a home regularly treated inside and out with pesticides to determine the extent to which the carpet dust contributed to the pesticide concentrations in the indoor air (Camann, Harding, and Lewis 1990). Dust from the living room carpet contained detectable levels of 16 pesticides, "including eight of the ten pesticides frequently found in the room air." By sampling dust from the living room carpet, front door step, entry carpet, sidewalk, and garden, the researchers discovered a gradient of pesticide concentrations from outdoors to in. They concluded that tracked-in soil was the major source of half the pesticides (including chlordane, heptachlor, heptachlor epoxide, dieldrin, and DDT) found in the indoor air. The pesticides found in high concentrations in the carpet dust were also found in high concentrations in the indoor air, suggesting that the carpet acted as a significant source of the indoor air pesticide concentrations. The authors suggest shoe removal before entry, walk-off (entry) mats, and efficient vacuuming as remedial measures to reduce the amount of tracked-in soil.

Lead trapped in carpets from tracked-in soil is a health threat primarily to small children (i.e., infants and toddlers) who frequently put their hands in their mouths (Roberts, Camann, and Spittler 1990). Lead poisoning impairs metabolism and growth and causes learning disabilities. According to one estimate, 17% of small children in the US have lead poisoning (Roberts, Camann, and Spittler 1990). The two principal sources of lead in soil are car emissions (despite the recent ban on leaded gas) and leaded paint chipping off or removed from old buildings.

In their study of dust collected from rugs in 42 homes in Washington State built before 1950, Roberts, Camann, and Spittler (1990) report that "data suggests that 25% of older homes with a canister cleaner, with a plush or shag rug, a vacuum with a loose belt or full bag, vacuuming once a month, or no vacuum cleaner will have high dust levels and rug Pb (lead) above 10,000 $\mu g/m^2$ (micrograms per square meter)." Two simple measures are effective in reducing the lead in carpet dust: removing shoes and providing a long walk-off mat.

In three of the homes studied, the residents began removing their shoes before entering for a period of five months following the initial carpet dust sampling. The level of lead in the dust fell from a geometric mean of 17,100 $\mu g\ Pb/m^2$ to 250 $\mu g\ Pb/m^2$. However, data from these houses were obscured by the fact that one had undergone remodeling just before the sampling began, another had installed a new carpet, and a third had initiated more frequent cleanings. To further test the importance of shoe removal, the authors compared data from 32 other homes in which shoes were not removed, to data from 5 homes in which they were. The lead loading in the carpet dust samples were 2,900 $\mu g\ Pb/m^2$ and 240 $\mu g\ Pb/m^2$, respectively.

A comparison of the lead loading in carpet dust from homes with and without walk-off mats was equally compelling. Twenty-nine homes without mats had lead levels averaging 5,000 $\mu g\ Pb/m^2$. In six apartments off a corridor whose carpet provided the equivalent of a 10- to 60-foot mat, the level of lead in the interior carpet dust was about 440 $\mu g\ Pb/m^2$. In addition to removing shoes and providing walk-off mats, the authors suggest cleaning and efficient vacuuming as low-cost means of reducing lead exposures.

Chapter 2

Adhesives

Floor covering adhesives are a significant source of volatile organic compounds (VOCs) in indoor air, particularly when they are applied and for a short time thereafter. According to one expert, "The quantity of floor adhesive used in most interior spaces makes it one of the most significant products that can generate poor IAQ" (*IAQU* October 1990).

The factors that affect VOC emissions from adhesives include (*IAQU* October 1990):

- VOC content (quantity and characteristics) of the adhesive;
- Emission rate of the adhesive on application and emission rate decay (change over time) after application *in situ*;
- Ventilation and air flow characteristics;
- Room temperature;
- Sink effects (available surface area, TVOC adsorbed on available surfaces, and remission rate and quantity); and
- Permeability of the floor covering to each of the VOCs the adhesive emits.

In an early report on the emissions from adhesives, Girman et al. (1984) studied 15 solvent- and water-based adhesives. After one week of drying, eight of the adhesives continued to emit "significant" amounts of VOCs. The most abundant VOC emitted was toluene, followed by styrene and "a variety of cyclic, branched, and normal alkanes." The authors were surprised to find that three of the water-based adhesives emitted a large variety of alkanes. After a drying period of 9 to 14 days, five of the eight high-emitters still emitted VOCs at detectable rates (the minimum detectable rate for a single VOC was 0.1 μg/g per hour [μg/g = ppm]). The emission rates for total alkanes ranged from 610 to 780 μg/g per hour. Based upon the recommended coverage for the adhesives, the authors calculated the emission rates per surface area to be in a range from 0.14 to 7.4 mg/m^2 per hour for toluene, and 140 to 180 mg/m^2 per hour for total alkanes.

Bayer and Black (1989) analyzed the emissions of a floor tile adhesive in a small-scale environmental chamber and reported identifying "a large number of VOCs, including benzene, toluene, ethylbenzene, ethyl acetate, and styrene." As was the case with the solvent-based adhesives used in the study by Girman et al. (1984), toluene was the prevalent VOC in the adhesive analyzed by Bayer and Black (Table 3).

In December 1989, *IAQU* reported on the research of Bern Seifert, D. Ullrich, and R. Nagel who analyzed the emissions of a nylon carpet with a fabric backing. In addition to the carpet, the researchers tested two adhesives used in installing the carpet. Analyzing the VOC content of the gas phase above the product (headspace) in the container, the researchers compared their results with the information they got from the manufacturer with respect to the adhesives' content. Their results (Table 4) indicate that the VOCs present in the greatest amount in the adhesive are most likely to prevail in the indoor air where the adhesive is applied. These concentrations also greatly exceeded those reported by the manufacturers.

The 1988 US Environmental Protection Agency (EPA) study of the emissions from materials used in the construction of an office building showed that carpet adhesive outgassed VOCs at a rate (234 $\mu g/m^2$ per hour), far higher than carpet (36 $\mu g/m^2$ per hour) (Sheldon et al. 1988). Field tests of emissions from the same products installed in the building

Table 3 — VOC emissions from adhesive material

Compound	Chamber Concentration, ppmv	Emission Rate* mg/m^2h
Benzene	8.2	62
Ethyl acetate	3.6	31
Ethylbenzene	2.0	21
Styrene	2.4	24
Toluene	442	4,175

*Emission rate = [(mg/m^3, concentration)(m^3/h, chamber air flow)]/(m^2, product area)

Source: Bayer and Black 1989

Table 4 — Composition of adhesives and related products obtained from the manufacturer and determined by static headspace analysis

Product	Manufacturer's specification			Analysis	
	Compounds	Content (%)	Other ingredients	VOC in headspace	Content* (%)
Adhesive I (water-based)	Xylene Methanol Phthalates Polyglycol	4 2 1 1	Acrylate copolymer Colophonium resin Filler Thickener	m-Xylene Ethylbenzene o-Xylene Toluene Methyl acetate	51 23 14 7 2
Adhesive II (water-based)	Toluene	4.5	As Adhesive I, plus Emulsifier (0.3%), Antifoaming agent (0.2%)	Toluene Ethyl acetate	98 0.5
Wash primer	Styrene/acrylate dispersion	no info	Antifoaming agent Detergent (0.1% each)	Toluene 2-Chloro-1,3,-butadiene Styrene 1,2,4-Trimethylbenzene 1-Methyl-4-1-methyl-ethyl benzene	82 2 1 1 1
Filler (2-component acrylic resin)	Methylmethacrylate Benzoyl peroxide	no info no info		Methylmethacrylate 4-Methyl 2-pentanone	99.9 0.1

* 100% = Total area counts of the gas chromatograms

Source: ***IAQU*** December 1989

correlated highly with the headspace and chamber analysis. In accordance with the findings of Seifert, Ullrich, and Nagel, the three aromatic hydrocarbons present in the highest concentrations in the indoor air (ethylbenzene, m-ethyltoluene, and 1,2,4-trimethylbenzene) "generally showed highest emission rates from all of the building materials." Aromatic hydrocarbon emissions from carpet adhesive were 98 $\mu g/m^2$ per hour (compared to carpet emissions, which were 9.4 $\mu g/m^2$ per hour).

VOC emissions from adhesives generally outgas in a two-step process. Initially, when the adhesive is still wet, organic compounds in the solvent volatilize rapidly into the air. As the surface of the adhesive dries, however, it creates a layer that effectively encapsulates the wet solvent in the deeper layers (*IAQU* December 1989). The trapped organic compounds must diffuse through an ever-thickening dry layer before volatilizing, accounting for the continued though slowed rate of emissions after drying described above.

In addition to emitting VOCs, adhesives can affect IAQ by reacting with the plasticizers used in some carpet backings. Plasticizers, which consist of alcohol bound to phthalic acid, may degrade into their components under alkaline conditions. McLaughlin and Aigner (1990) report that in the case of a PVC-backed nylon carpet, adhesives increased the outgassing of alcohols by 20% to 180%. Adhesive facilitated plasticizer migration two- to seven-fold in the carpet samples studied. According to the researchers, "PVC carpets which cause no acute odor problems may contribute significantly to indoor air pollution by plasticizer migration and subsequent hydrolysis in the substrate" (in this case, concrete).

Chapter 3
Vinyl

Vinyl floor coverings generally fall into two categories: sheets and tiles. While different manufacturing processes are used to make the two products, their composition is similar, if not identical. According to specifications recommended by the Resilient Floor Covering Institute (1987, 1988a), the materials used in vinyl sheet and tile consist of polyvinyl chloride (PVC) or a copolymer of vinyl chloride "not less than 85% of which is vinyl chloride," a binder made of vinyl resins and plasticizers, plus fillers, and pigments. The binder, fillers, and pigments are stabilized to resist deterioration when exposed to heat and light. Vinyl sheet also includes a foam interlayer and a backing of either organic fiber, other fibrous material, nonfoam plastic, or foam plastic, depending on where the product is used (e.g., floors without excessive moisture or alkali, or floors with underlying cross-ventilated space).

Vinyl is implicated as a source of three IAQ pollutants: asbestos, VOCs, and biological contaminants. For approximately 40 years, between the 1940s and the 1980s, vinyl floor tiles were made with asbestos. The adhesive used to anchor the tiles also contained asbestos. Concern over the dangers of airborne asbestos have focused on the more friable asbestos-containing materials (ACMs) such as pipe insulation and ceiling tiles. These friable materials crumble or flake easily because the binding material holding the asbestos fibers is weak (Strange 1987). Research indicates, however, that worn or damaged vinyl asbestos tiles also pose a risk, particularly when they are removed. Vinyl also has been implicated as a source of VOCs, including formaldehyde. Finally, because of its resin content, vinyl can act as a substrate for microbial growth, which is implicated in sick building syndrome (SBS).

Asbestos

Asbestos is a term used to describe a family of natural fibrous stones called hydrated silicates (Cross 1990). The inorganic mineral fibers give asbestos its insulating and fire retardant qualities and high tensile strength. Asbestos use is not new. "The Romans wove asbestos into tablecloths that could be tossed into the fire for cleaning," writes Joseph Hooper in the *New York Times Magazine*. "In one of Genghis Khan's northern provinces, Marco Polo saw inhabitants weaving an indestructible cloth out of fibers dug from the earth."

Asbestos embedded in the matrix of a product or material cannot be inhaled and therefore poses little risk. When the matrix is mechanically disrupted, however, the fibers are released into the air where, given their submicroscopic size and weight, they can float for up to 80 hours (Strange 1987).

Asbestos has been ranked as a principal indoor pollutant because of the large potential for human exposure (Samet, Marbury, and Spengler 1988a; Spengler and Sexton 1983). The US Environmental Protection Agency (EPA) has estimated that 20% of US buildings (about three-quarters of a million buildings) contain friable ACMs (Energy and Environmental Policy Center 1989). The US Consumer Products and Safety Commission estimates that 75% of American homes contain ACMs (Mannix 1991). While acute exposure to asbestos causes severe skin irritation, much lower exposures are linked to lung disease and cancers (Samet, Marbury, and Spengler 1988b). Most of the research on the health hazards of asbestos has been done on workers exposed to asbestos at work, family members living with such workers, and people living near asbestos production sites. On the basis of this research, three forms of disease have been associated with asbestos inhalation: asbestosis (also known as scarring of the lungs), lung cancer, and mesothelioma, a malignancy of the tissue that lines the chest and abdominal cavities. Asbestosis is usually associated with extremely high occupational exposures. Given the much lower levels of asbestos now found in the nonindustrial workplace, this disease — when it does appear — progresses so slowly that it rarely causes serious disability or death (Energy and Environmental Policy Center 1989).

Until recently, scientists believed that asbestos in any form could cause cancer, but a new study suggests that differences in asbestos fiber shape play a critical role in asbestos-induced mesotheliomas (Hooper 1990; *Science News* 1990). Ninety-five percent of the asbestos used in buildings in the US is composed of *chrysotile* fibers, which have a curly or serpentine shape. The other major fiber group in the asbestos family is the *amphiboles*, which are needle shaped. A group of researchers headed by Brooke Mossman at the University of Vermont in Burlington discovered that the curly nature of the chrysotile fibers apparently makes them less likely to penetrate lung tissue and thus more likely to be cleared from the lungs without causing damage. The needle-like amphiboles, on the other hand, are associated with the majority of asbestos-related mesotheliomas (*Science News* 1990; Energy and Environmental Policy Center 1989). Paradoxically, the cellular toxicity of chrysotile fibers is higher than that of amphiboles, which may add to chrysotile's lower carcinogenic potential: the exposed cells die before they become malignant (*Science News* 1990).

Mossman and her colleagues have touched off a storm of controversy by suggesting that chrysotile asbestos, handled properly, is not a health hazard. Those who agree with Mossman contend that other health hazards, such as exposure to toxic chemicals in ambient air or radon exposure pose much greater risks than asbestos exposure (Energy and Environment Policy Center 1989).

Over 600,000 metric tons of vinyl asbestos tile (VAT) or asbestos-containing asphalt tile were installed in US buildings between 1977 and 1983 (DeLisle 1989). In 1976, asbestos flooring represented the third largest use of asbestos in the US and Europe, after roofing and pipe insulation (Sebastien, Bignon, and Martin 1982). Given that asbestos-containing floor coverings were undoubtedly put in commercial and residential buildings as early as the 1940s or 1950s, exposure to asbestos from VAT is likely very high.

While VAT is a nonfriable ACM less likely to release fibers into the air than friable ACM, some evidence suggests that it does. In 1982, three French researchers examined a building that had deteriorating ceiling material they suspected contained asbestos. Polarized light microscopy (also known as phase-contrast microscopy or PCM) of the ceiling material revealed that it contained exclusively amphibole asbestos fibers (Sebastien, Bignon, and Martin 1982). However, air samples taken in the building during periods of activity (when airborne asbestos concentrations tend to be highest) had both amphibole and chrysotile fibers. An examination of the air conditioning system revealed no chrysotile fibers, which did occur in the air outside the building, as is usual for an industrial city (in this case, Paris).

The researchers eventually traced the chrysotile asbestos to the VAT which, under transmission electron microscopy examination, was found to contain "abundant chrysotile fibers." The building's owner confirmed that the floors were laid with 5400 m^2 of VAT. Further examination of the indoor air showed that the third floor, where activity was greatest, contained the highest concentration of chrysotile fibers. The researchers hypothesized that "breakdown forces such as walking, scraping, and machine scrubbing" had released the asbestos fibers from the vinyl matrix. They concluded that "the weathering of asbestos flooring under normal use patterns can yield concentrations of indoor asbestos similar to those measured in sprayed buildings."

One method for remediating the asbestos problem is removal, an increasingly controversial approach in the face of the new evidence that most exposures are not as hazardous as previously believed (Corn 1990). In addition, recent research suggests that removal of ACM often results in higher indoor concentrations of airborne asbestos during and after removal than existed before (Energy and Environmental Policy Center 1989).

The extent of fiber release during removal of VAT depends on the technique used. The four commonly used VAT removal techniques are (DeLisle 1989):

- **Dry ice** — crushed dry ice is spread over the tile to be removed until the surface temperature reaches approximately -20°F, which freezes the underlying mastic and releases the tile. Workers remove the tile with ice scrapers. The advantages to this technique are that 1) the tile fragments are fairly large (3 to 4 inches) and many tiles remain intact, 2) the dry ice works quickly, minimizing the time required to complete the removal; and 3) dust levels are low.

- **Flooding** — water mixed with a surfactant (in a ratio of 100 to 1) is flooded over the tiled area, which is left to soak for several hours (depending on such factors as the time available and possible leaking to other floors). When the tiles appear to be loose, workers mop up the water scrape the tiles free. This method produces smaller fragments and higher airborne levels of dust and particulates than does the dry ice method.

- **Heat** — hand-held electric heat guns are applied to each tile until it is free. The advantage to this methods is that tiles are removed in one piece. However, the heat also greatly increases the release of VOC from the adhesive (mastic), posing another health hazard. Another disadvantage is that the method is extremely time consuming.

- **Scraping** — workers use ice scrapers or mechanical devices to manually dislodge and remove each tile. This method is time consuming and physically demanding. It also leaves behind very small fragments of tile embedded in the mastic, requiring rescraping.

In a comparison of the four VAT removal techniques, DeLisle (1989) found that use of a mechanical chipper resulted in the highest release of asbestos fibers (as determined by transmission electron microscopy (TEM) analysis of air samples). He recommends that workers removing VAT wear protective clothing and air-purifying respirators. He concludes that "although VAT is described as nonfriable, the amount of fibers generated [during removal] indicates that a negative-pressure containment area should be used." He also notes that VAT removal should incorporate a separate technique for removing the mastic and the fragments that adhere to it, since all of the techniques described above leave behind most of the mastic, which can contain 20% chrysotile fibers.

The Resilient Floor Covering Institute formerly recommended the dry ice method for VAT removal, but it has since developed a set of "Recommended Work Practices" that expose workers to asbestos levels that fall well below the limits set by the US Occupational Safety and Health Administration for occupational exposures (ENVIRON 1990). The practices state that "removal should be considered the last alternative," recommending instead the installation of a new vinyl floor over a vinyl asbestos floor (Resilient Floor Covering Institute 1990). The practices also recommend 1) *never* sanding any resilient floor covering, 2) using a wet/dry vacuum equipped with a High-Efficiency Particulate Air (HEPA) filter to clean the floor before removal, 3) using a garden sprayer filled with a dilute solution of liquid dishwashing detergent containing non-ionic, anionic, and amphoteric surfactants to constantly wet vinyl asbestos sheets as they are removed, and 4) wet scraping any residual backing materials or adhesive. For VAT (as opposed to sheets), the practices recommend prying up whole tiles and loosening stuck-down tiles with a hot air blower.

Encapsulation, an alternative to VAT removal, involves spraying the floor with a chemical bonding agent that penetrates the vinyl matrix and dries to form an airtight seal (Cross 1990; Strange 1987). One drawback of this technique is that moisture may eventually collect beneath the seal, rupturing it. Also, the bonding agent may not sufficiently penetrate the matrix to form an airtight seal (Strange 1987). Finally, the application process itself can damage the ACM, increasing fiber release (Cross 1990).

VOCs

Vinyl flooring is a significant source of VOCs. In a chamber study of 42 building materials under standard atmospheric conditions (1 ACH, 21°C, and 35% to 40% RH), Mølhave (1982) measured an average concentration of 54 mg VOC/m^3 for a homogeneous PVC floor covering. The product outgassed 62 compounds, 5 of which were carcinogenic, 15 of which were airway irritants, and 6 of which were odorous compounds. By comparison, a synthetic fiber carpet produced an average concentration of 1.95 mg VOC/m^3 comprising 28 compounds. The logarithmic average (geometric mean) concentration of VOCs for all 42 building materials studied was 3.2 mg/m^3.

A trained panel judged the odor quality from the PVC flooring to be 0.33 (on a scale of -1 [totally unacceptable] to 0 [indeterminable] to 1 [totally acceptable]). They rated the odor intensity at 0.85 (a 1 rating was "overwhelming, strong odor").

Based on a mathematical formula that relates the amount of a material used with the indoor air concentration of organic gases and vapors, Mølhave (1982) rated PVC floor covering as one of the "10 most important sources" of VOC. (The synthetic fiber carpet was rated one of the 10 least important sources.)

Researchers have identified a number of VOCs outgassing from PVC flooring materials, including toluene, methyl cyclohexane, heptane, isododecane, formaldehyde, phenol, and ketones (Wolkoff et al. 1990; Engström 1990). In a large-scale (15 m^3) environmental chamber study of two polyvinyl floor coverings (at 1 ACH, 23°C, and 50% RH), van der Wal, Steenlage, and Hoogeveen (1990) identified (in addition to toluene and some of the compounds listed above) 2-ethylhexanol, formaldehyde, ethylbenzene, xylene isomers, ethyltoluene isomers, and a series of alkanes and iso-alkanes. The two products emitted very different VOCs. One outgassed primarily 2-ethylhexanol, an odorous polymer additive that likely resulted from the degradation of the di-2-ethylhexyl phthalate plasticizer used in the polyvinyl. The other emitted mostly aromatic and aliphatic hydrocarbons, plus a compound ($C_{16}H_{30}O_4$) identified as a "low volatile glycoether" that decayed at a rate considerably slower (15% in 24 hours) than the other hydrocarbons (60% in 24 hours). Engström (1990) also reported finding glycol ethers (and esters) in the emissions from vinyl flooring.

One researcher (Rosell 1990), in a study of "sick" buildings in Sweden, measured significant levels (100 to 1000 $\mu g/m^3$) of one compound, a semi-volatile ester (2,2,4-trimethyl-1,3-pentanediol-di-iso-butyrate) that he later traced to the vinyl flooring in the buildings. The compound, a plasticizer sold under the trade name TXIB, is used in the manufacture of PVC products. Rosell reports that he and his colleagues have continued to find TXIB in concentrations exceeding 100 $\mu g/m^3$ in buildings that occupants report as "sick." The buildings with the highest levels of the ester had the same brand of vinyl flooring. Perhaps the most alarming of Rosell's data on TXIB is the fact that the compound remains present in the air at noticeable concentrations (20 to 80 $\mu g/m^3$) for over six years.

In his study, Rosell cites a 1983 paper in which researchers identified TXIB as one of the compounds most frequently emitted from 15 building materials tested. These researchers, says Rosell, "predicted that TXIB would be detected in future indoor air samples." While toxicological data indicate that TXIB has no deleterious health effects at the concentrations measured, Rosell nonetheless concludes that TXIB use in vinyl floorings should be limited.

Biological Contaminants

Microorganisms are introduced into a building on or in some of the building materials. Under ideal conditions, particularly a good supply of moisture, these background bacteria and fungi can fluorish into a huge population that produces high levels of volatile metabolic by-products, such as ketones, organic acids, and alcohols, that have strong odors and irritate the respiratory tract (Ström et al. 1990).

In a study comparing the growth of bacteria and fungi on a variety of building materials, Ström et al. (1990) report that plastic materials such as sheeting and flooring (presumably PVC), support an extremely high growth of both types of microorganisms. While plastics themselves do not support such growth, the plasticizers in them serve as a good source of carbon and nitrogen, nutrients that fungi and bacteria require. The bacteria and fungi themselves usually do not cause allergic reactions when they are present in building materials because they are trapped *within* the materials and therefore do not contribute to the airborne concentrations. They do, however, produce low molecular weight VOCs that are unlikely to trigger allergic reactions but likely act as mucous membrane irritants.

Chapter 4
Linoleum

Linoleum, according to an article in the July 1990 *Economist*, "may become trendy again because it turns out to have many environmental virtues." The article refers to the fact that linoleum is made from "natural" ingredients: linseed oil, wood flour, cork flour, and jute, which are biodegradable.[1] During manufacturing, the linseed oil is slowly oxidized and mixed with natural pine resin to form jelly-like slabs. These are mixed with the wood and cork flours and pigment granules are added for color. The material is then calendered (passed through rollers) onto a jute backing to produce sheets that are cured in heated drying rooms. The resulting product is extremely long-wearing because the linseed oil continues slowly to oxidize, even after curing, forming additional chemical bonds that add to the material's strength over time (*Economist* July 1990).

VOCs

Despite the oven curing, linoleum is an emitter of VOCs. Wolkoff et al. (1990) report identifying toluene, hexanal, propanal, and butyl formiate from a headspace analysis of linoleum flooring in two Danish apartments. The linoleum was laid on particleboard, however, and the report does not indicate whether the authors eliminated it, or the adhesive presumably used to anchor the linoleum to it, as possible sources of the VOCs.

Mølhave (1982) measured an emission concentration of 5.19 mg VOC/m^3 in the air around linoleum flooring. He detected around 20 compounds, one of which was a suspected carcinogen, three of which were airway irritants, and two of which were odorous. The odor measurements for linoleum were comparable to those Mølhave obtained for PVC flooring (see Vinyl). The intensity was rated 0.80 (1 is "overwhelming, strong odor"), and the quality was rated -0.37 (-1 is "totally unacceptable").

According to a leading manufacturer of linoleum in the US and Europe, however, new linoleum removed from a roll, aired for one day, and "loose-laid" (i.e., placed without adhesive) emits 2 μ/m^3 at 0.5 ACH (roughly a hundredth of the concentration reported by Mølhave).[2]

Biological Contaminants

The residual oxidation of the linseed oil gives linoleum a bactericidal quality not found in other floor coverings. One linoleum product is reported to have "a sterile zone" that inhibits the growth of *Staphylococcus aureas*, a bacterium that frequently contaminates buildings.[3] According to one report, a "properly cleaned" carpet contained 1 kg of dirt, mites, and other biological contaminants, while a comparably sized linoleum floor contained "just three grams of dirt and mites" (*Economist* 1990).

Chapter 5
Parquet

The principal source of emissions from hardwood parquet floors appears to be the urea-formaldehyde (U-F) or polyurethane coating applied to the surface, although the adhesive used to glue the parquet to the subfloor may also contribute emissions (Schriever and Marutzky 1990).

VOCs

Wolkoff et al. (1990) report that emissions from lacquered parquet contain primarily butyl acetate, ethyl acetate, ethylbenzene, and xylenes. In a study of two rooms undergoing renovation of the parquet flooring, Schriever and Marutzky (1990) also identified high headspace concentrations of i-butyl acetate, n-butyl acetate, n-butanol, and ethyl acetate, as well as lower concentrations of toluene and xylene. Many of these VOCs persisted for months after the initial installation of the flooring.

The acid hardeners used with the coating materials emit a VOC concentration of 3.50 mg/m^3, while the varnish or coating alone emits a concentration of 28.9 mg/m^3 (Mølhave 1982).

Formaldehyde

Schriever and Marutzky (1990) conducted a small (1 m^3) environmental chamber study (at 25°C, 45 RH, and 0.5 ACH) to measure the formaldehyde emissions from a parquet floor. The parquet consisted of a U-F-bonded particleboard glued with an acetate adhesive to a four-millimeter oak veneer. The product was coated with an acid-hardened lacquer. After four days, the formaldehyde emissions measured just over 1 ppm; after more than a month, they had declined to roughly 0.2 ppm. (Recall that formaldehyde causes eye irritation in the range of 0.02 to 0.4 ppm and neurophysiological effects in the range of 0.05 to 1.5 ppm [Spengler and Sexton 1983].)

The authors concluded that although the particleboard and adhesive may have emitted formaldehyde, the coating was the dominant source. This finding agrees with the results of a chamber study by Godish and Guindon (1990) who found that the initial formaldehyde emissions from a brushed-on U-F coating ranged from 0.70 ppm at 1 ACH to 1.25 ppm at 0.5 ACH (at 23°C and 50%-55% RH). In four to six months, that concentration declined 82% to 96% (to levels of 0.19 to 0.03 ppm, respectively) depending on the rate of ventilation. (The authors identify the substrate on which the coating was applied as "wood materials." These may have added to the formaldehyde emissions from the coating material.)

To reduce emissions from parquet floors, Schriever and Marutzky (1990) recommend using low-formaldehyde coating materials. They comment that workers often close the windows in a room when they apply the surface coatings to reduce the amount of dust settling on the wet surface. In view of the high formaldehyde concentrations that such coatings emit, the authors stress the importance of adequate ventilation during installation and for the first few days after application of coatings.

Chapter 6

Health Effects

In the last decade, the issue of indoor air quality and its effect on health has received a rising tide of attention. Because they contribute significantly to the VOCs, biological contaminants, and other pollutants that degrade IAQ, floor coverings play an important role.

Carpets

In a report released in 1990, the US Consumer Product Safety Commission (CPSC) evaluated the health effects associated with carpets (Schachter 1990). Based on complaints the CPSC received on new carpet installations from 335 residents in 206 households, the report categorized health problems according to the affected body parts, which included:

- Upper respiratory (ear, mouth, nose, and sinus)
- Eyes
- Lower respiratory (including lungs)
- Head
- Face
- Gastrointestinal
- Central nervous system
- Limbs and trunk
- Other

The symptoms reported under those categories included rashes, hives, itching, and swelling; eye, nose, and throat irritation (which the affected individuals attributed to the carpet odor); and headache and fatigue.[4]

4-PC

As discussed above (see 4-phenylcyclohexene, Chapter 1 — Carpets), 4-PC is a major component of the emissions from most synthetic carpets. It appears to produce a variety of symptoms including headaches, dizziness, memory loss, fatigue, and irritation of the eyes and respiratory tract. Data from exposed persons also suggest that the compound can induce multiple chemical sensitivities (MCS), an illness whose validity and significance has only recently begun to be appreciated (see Multiple Chemical Sensitivities below).

Formaldehyde

Formaldehyde, an irritant of the mucous membranes in the eyes and respiratory tract, is a ubiquitous pollutant of indoor air. While carpets do not appear to be as important a source of formaldehyde in indoor air as furnishings and building materials made of particleboard, they do contribute to the total formaldehyde concentration (see Formaldehyde, Chapter 1 — Carpets).

Formaldehyde also produces neurophysiological symptoms such as short-term memory loss, increased anxiety, and sensitivity of dark-adapted eyes to light. While the carcinogenicity of formaldehyde in humans is disputed, it is a suspected carcinogen.

Kawasaki Syndrome

Kawasaki syndrome or disease is the popular name for mucocutaneous lymph node syndrome, a little-understood illness that has been linked with carpets, specifically with carpet *cleaning*. Named after the Japanese pediatrician who first reported the disease in 1967, Kawasaki syndrome is extremely difficult to diagnose because it mimics the symptoms of measles and scarlet fever (*Harvard* 1990). It generally strikes toddlers, although some cases in children as old as 12 years have been reported. The symptoms of the disease include:

- Sudden high fever that spikes and subsides daily for up to 20-odd days;
- Swollen eyelids and red eyes (conjunctivitis);
- Swollen and reddened lips, tongue, and throat;
- Swollen and reddened palms and soles (which may later peel);
- A measles-like rash;

- Swollen glands (lymph nodes) in the neck (in half of reported cases); and

- Extreme irritability.

While none of these symptoms is life-threatening, the unseen effect of the disease is. The disease causes the production of large numbers of lymphocytes (a class of white blood cells that are part of the immune system), which inexplicably attack the walls of the coronary arteries carrying blood to the heart. Weeks after having the fever and rash, a child may develop an aneurysm, an area of the blood vessel wall that has weakened and dilated. One in five children develop aneurysms as a result of Kawasaki syndrome. In about 10% of US cases, the aneurysms are large enough to cause blood clots that can subsequently lead to heart attacks (*Harvard* 1990). Thus, children with the disease are usually treated with aspirin (to reduce the incidence of clots) and gamma globulin (which boosts the immune system's response to disease).

The incidence of Kawasaki syndrome is still rare in the US — about 3,000 cases are reported annually — although pediatricians suspect that many cases go undiagnosed or are misdiagnosed given the lack of a definitive diagnostic test (*Harvard* 1990). Diagnoses are done on the basis of clinical evidence (i.e., how many of the above symptoms a child exhibits) (Klass 1991).

Recently, researchers at the Baylor College of Medicine in Houston, Texas, reported developing a blood test for diagnosing the disease (Fackelmann 1988). They discovered that all patients with Kawasaki Syndrome have elevated levels of interleukin-2 receptors. Interleukin-2 is a protein that helps the body's immune response by activating certain lymphocytes. To activate the lymphocytes, interleukin-2 must attach to specific receptors on the cells' surface. The elevated levels of these interleukin-2 receptors in a Kawasaki patient's blood can serve as an early, rapid, and definitive diagnostic test that can help doctors treat their patients before the disease damages the coronary arteries.

The cause of Kawasaki syndrome remains unknown, but epidemiologic evidence has linked the occurrence of the disease with shampooing, beating, or other vigorous cleaning of rugs (or, in Japan, tatami mats) (*Harvard* 1990). One child even developed the disease twice, each time after the rugs in the house were cleaned. Researchers speculate that cleaning releases some agent — perhaps a retrovirus like the one responsible for Acquired Immune Deficiency Syndrome (AIDS) — that triggers the immune response characteristic of the disease. Dust mites, which were suspected early on, generally have been ruled out. Adding to the puzzling nature of the disease is the observation that it has a seasonal pattern: reported cases peak in late winter and spring.

Adhesives

Given that floor covering adhesives are arguably one of the most significant source of VOCs in indoor air (see Chapter 2 — Adhesives), they are likely agents in the development of sick building syndrome (SBS), discussed in detail below.

Vinyl

Vinyl asbestos tile has been shown to release chrysotile asbestos fibers (see Asbestos, Chapter 3 — Vinyl). However, recent research suggests that chrysotile asbestos is unlikely to cause mesothelioma, a cancer of the tissue that lines the chest cavity and abdominal walls. Given the extremely low concentrations of asbestos fibers that originate from nonfriable ACMs such as vinyl, it is also unlikely to cause asbestosis, a disease that results in extensive scarring of the lungs.

Vinyl also emits VOCs, including formaldehyde, and is thus implicated in SBS (see below). Finally, because of its resin content, vinyl can act as a substrate for microbial growth, which also is implicated in SBS.

Linoleum and Parquet

Linoleum and the U-F coatings applied to parquet floors both emit a variety of VOCs. In the case of coated parquet floors, these include formaldehyde. These floor coverings therefore cannot be ruled out as potential causative agents for SBS and MCS (see below).

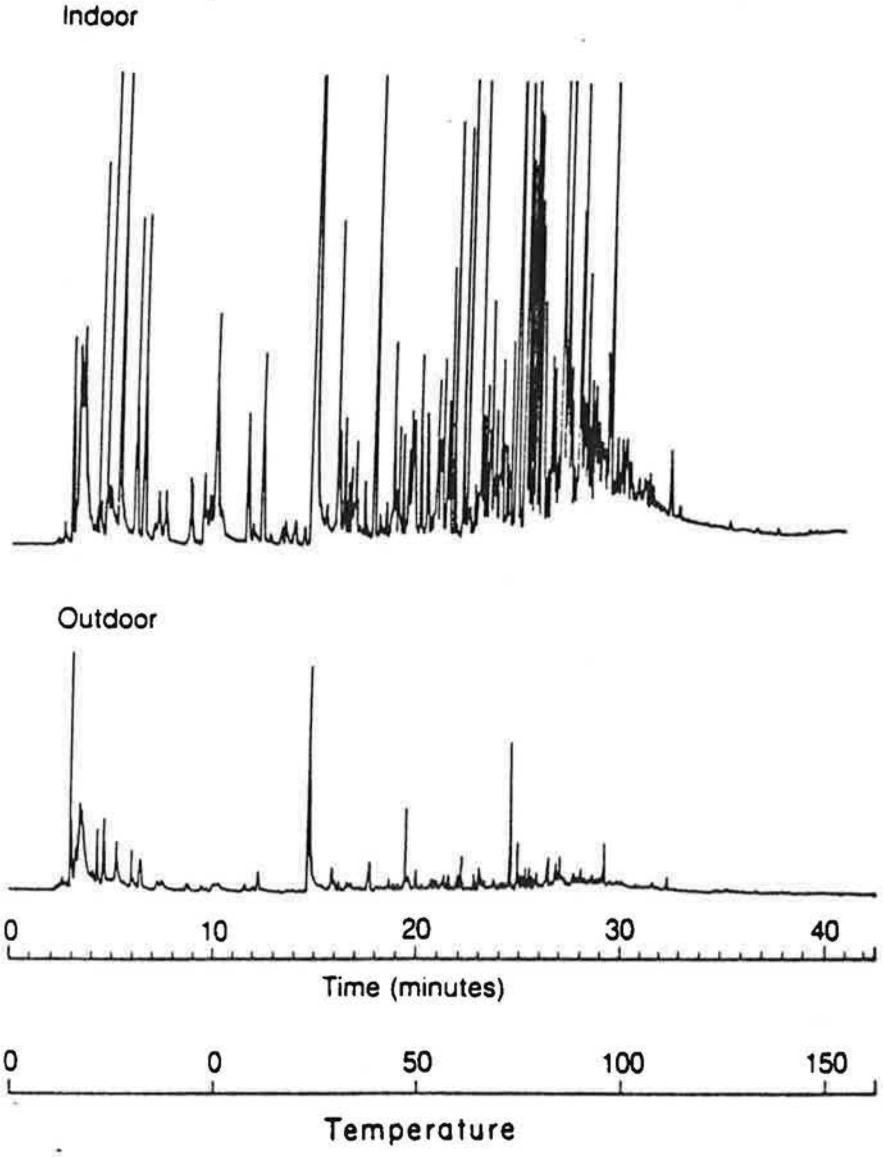
General Effects

While studies on 4-PC, asbestos, and formaldehyde concern specific pollutants to which floor coverings contribute, other studies have focused on the broader issue of how the "chemical soup" that includes all of these indoor air pollutants in varying concentrations affects the people exposed to it. The literature on IAQ has fairly well established that "the levels of exposure to many contaminants, particularly [VOCs] (many of which are uncharacterized and whose health effects are unknown) are much higher indoors than out-of-doors" (Ashford and Miller 1991). (See Figure 1.) With increasing frequency, the literature contains reports of building-related illnesses (BRIs), which IAQ consultant Shirley Hansen has described as "illnesses or symptoms traced to a specific building problem" (*IAQU* May 1991).

Sick Building Syndrome (SBS)

Sick building syndrome (SBS) is an ill-defined condition that arises from being in a building with suspect IAQ. Environmental psychologist and IAQ pioneer Birgitta Berglund has defined a sick building as one with

Figure 1 — Gas chromatographs of equal volume air samples taken indoors and outdoors near a "sick" building



Note: each peak represents a specific organic compound.
Source: Ashford and Miller 1991

"physical anomalies affecting human health" (***IAQU*** January 1991). Cross (1990) states that "a building is generally described as 'sick' if 20% or more of its occupants report building-related illness of one sort or another." According to Cross, the Consumer Federation of America estimates that lost work and medical expenses attributed to SBS may cost $100 billion annually.

SBS, say Spengler and Sexton (1983), comprises "health symptoms (for instance, irritation of mucous membranes, headaches, dizziness, nausea, diarrhea, rashes, and abdominal and chest pain) that affect occupants of a building." Comparing data from occupants of a "sick" building with that from a trouble-free control building, Berglund established a list of eight critical symptoms associated with SBS (***IAQU*** January 1991):

- Fatigue;
- Sensation of pressure in the head;
- Headache;
- Difficulties in concentrating;
- Itching, smarting, irritated eyes;
- Sore, dry, or hoarse throat;
- Redness of the skin around the face caused by capillary congestion (erythema); and
- Itching, stinging, tightness, and a feeling of warmth in the face without the appearance of a rash.

Burge (1990b) divides the symptoms of SBS into four groups, the most common and general of which include tiredness, lethargy, headache, and nausea. The other three are 1) dryness, running, or blocking of the nose or eyes, thirst, and dry throat; 2) skin dryness; and 3) occupational asthma (chest tightness, wheezing, and breathlessness).

VOCs and SBS

While a causal relationship between the chemical composition of indoor air and building "health" has yet to be clearly established (Berglund, Berglund, and Lindvall 1986), many studies support the theory that VOCs contribute to SBS (Kærgaard, Mølhave, and Pedersen 1990). For example, in one study (Hudnell et al. 1990) 66 healthy males between the ages of 18 and 39 years were exposed in an environmental chamber to a mixture of 22 commonly encountered VOCs. The exposure concentration was 25 mg/m^3 (concentrations 500 times as high as average exposure levels in indoor air) and the exposure time was 2.25 hours. Before being exposed to the VOCs, the subjects received 75 minutes of clean air in the chamber.

Computerized questionnaires that the men filled out during the experiment revealed that exposure significantly affected the subjects' perception of six parameters: odor intensity, eye and throat irritation, headache, drowsiness, and air quality (compare with Berglund's list of critical SBS symptoms, given above). Exposure did not significantly affect the subjects' perception of five environmental variables that remained constant during the test: light and noise levels, temperature, humidity, and air movement. Also not affected by exposure were the subjects' perceptions of nose, face, and body skin irritation; face and body temperature; eye, face, and body moisture; sluggishness; coughing; and concentration.

Mølhave (1990) distinguishes the health effects of VOCs as 1) effects common to most VOCs as a group and 2) effects common to a particular compound. In many cases, a metabolite of a particular compound cause specific effects (for example, certain ketones are neurotoxic and some chlorinated hydrocarbons cause liver damage).

According to Mølhave, VOCs most frequently have the following effects in humans:

- **Acute effects**, such as the surface reactions in tissues exposed to air, i.e., the mucous membranes in the eye, nose, and airways and the skin on the face, neck, and hands.
- **Subacute effects**, which include headaches and drowsiness, weak subjective effects related to nerves (e.g., changes in skin temperature, pain), and weak inflammatory responses (e.g., dilation of peripheral blood vessels).
- **Chronic effects** caused by absorption or metabolism of certain VOCs. Such effects may be systemic, genetic, or immunologic, however they are infrequent given the low levels of exposure generally associated with VOC concentrations in indoor air (which rarely exceed 50 μ/m^3).

Based on evidence from field and experimental studies, Mølhave has established a tentative dose-response range for VOC exposure (Table 5). At levels below 0.2 mg/m^3 VOCs have shown no effect. At concentrations exceeding 3 mg/m^3 odors are significant and symptoms are

Table 5 — Volatile organic compounds, indoor air quality, and health

Total Concentration mg/m^3	Irritation and Discomfort	Exposure Range
<0.20	no irritation or discomfort	the comfort range
0.20-3.0	irritation and discomfort possible if other exposures interact	the multifactorial exposure range
3.0-25	exposure effect and probable headache if other exposures interact	the discomfort range
>25	additional neurotoxic effects other than headache may occur	the toxic range

Source: Mølhave 1990

prevalent. In the range from 0.2 mg/m^3 to 3.0 mg/m^3 other factors (temperature, dust, or the age, sex, and smoking habits of the subjects) appear to exert their own effects, interacting with the effects attributable to the VOCs. Mølhave calls this the "multifactorial exposure range." In this range, "odor irritation and discomfort may appear as a consequence of VOC exposure if other exposures contribute to the etiology." At exposure levels exceeding 3.0 mg/m^3, VOCs almost invariably produce symptoms, and at levels exceeding 25 mg/m^3, VOCs generally are toxic.

Multiple Chemical Sensitivities (MCS)

A direct connection between floor coverings and multiple chemical sensitivities (MCS) has proven to be more difficult to make. In large part this is due to the diversity of definitions used to describe MCS (also called "ecological illness" or "petrochemical disease").

The journal *Clinical Ecology* describes the disorder as:

> "a chronic multi-system disorder, usually polysymptomatic, caused by adverse reactions to environmental incitants, modified by individual susceptibility and specific adaptation.

Ashford and Miller (1991) prefer a more operational definition:

> The patient with multiple chemical sensitivities can be [diagnosed] by removal from the suspected offending agents and by rechallenge, after an appropriate interval, under strictly controlled environmental conditions.[5] Causality is inferred by the clearing of symptoms with removal from the offending environment and recurrence of symptoms with specific challenge.

The lack of a universally accepted clinical definition of this syndrome has proved to be an obstacle to its acceptance as an illness (*IAQU* April 1991).

Human sensitivities and reactions to the same concentrations of the same substance cover a wide range. For example, the CPSC reported in its study of carpet-related health problems that in about 50% of the households with two residents, one person reported symptoms while the other remained asymptomatic (Schachter 1990). Furthermore, the appearance of the symptoms was immediate or within a few days of the carpet installation for 65% of the affected residents, within a couple of weeks for about 16% of those affected, within a month for about 5%, and not until over a month after the installation for 10% of the affected residents.

IAQ pollutants can be the original cause of MCS (i.e., the inductive or sensitizing agent) or the trigger that activates a pre-existing condition (*IAQU* April 1991). Again, in the cases reported to the CPSC, some residents said that new carpet installation had aggravated an already existing condition, such as asthma, while others reported that "the carpet induced a generalized sensitivity to many substances to which the person was not previously sensitive" (Schachter 1990). In the case of the US Environmental Protection Agency (EPA) workers exposed to 4-PC (see 4-phenylcyclohexene, Chapter 1 — Carpets), Hirzy and Morrison (1991) reported that "Hypersensitivity to a range of environmental factors began to appear in some of the most severely affected people after several days to several weeks of exposure." Initial exposures had been in the range of 1 to 15 ppb.

An additional complicating factor is the phenomenon of adaptation, in which an affected person develops an apparent tolerance for the causative agent, masking the person's sensitivity. Miller describes adaptation as a two-edged sword: on the one hand it allows the affected person to continue to function and live in a particular environment, on the other, that tolerance allows the person to prolong his or her exposure to an environment that may be causing physical damage (*IAQU* April 1991).

The physiological and psychogenic mechanisms underlying MCS are also a matter of some dispute and may include the immune system, biochemical disorders, the vascular system, and the central nervous system (*IAQU* April 1991).

Recently the National Academy of Scientists sponsored a workshop on MCS to evaluate research needs in the areas of case evaluation, mechanisms, and epidemiology. The case evaluation group proposed developing an MCS database that would record the symptoms, dietary, medical, and psychological histories of affected people as well as their sensitivities to food, chemicals, and drugs (*IAQU* April 1991). This database would facilitate a nationwide comparison of MCS characteristics. The working group on mechanisms stressed the need for research on adaptation and de-adaptation and methods for identifying chemical irritants (e.g., double-blind, placebo-controlled studies). The epidemiology group developed a strategy for assessing the prevalence of MCS in the general population based on a comparison of cases reported to clinics across the US.

Epidemiology

The EPA's Office of Toxic Substances has begun to examine the feasibility of conducting epidemiological studies to determine the response characteristics of individuals exposed to carpets and carpet products (*IAQU* May 1991). According to Karen Hogan, a researcher at the EPA, if the agency decides such studies are feasible, it will require "involved industries" such as carpet and adhesive manufacturers and installers to conduct them.

The feasibility assessment is based on three considerations:

1) Whether one of the "health end-points" the agency has identified as the most serious one resulting from exposure to carpet emissions — MCS — can be defined clearly and concisely enough to support conclusions about exposure.

2) Whether the agency can identify a study group of people who are more likely to have prolonged exposure to components of carpet installations that lead to the health end-point.

3) Whether or not current diagnostic technology is sufficient to make such a study possible.

The agency expected to have an internal draft memorandum of the feasibility assessment by May 1991 but had not set a date for public release of the information.

Chapter 7
Litigation

Indoor air pollution and the illnesses associated with it, such as sick building syndrome (SBS) and multiple chemical sensitivities (MCS), have established a new legal arena in which the issue of liability is beginning to be fought. According to Baltimore attorney Robert Katz, "a whole body of law, involving the participation of doctors, engineers, industrial hygienists, and environmental-quality experts, is on the rise" (Anderson 1990).

In 1990, "thc first pure SBS case to go to trial," *Call et al. v. Prudential Insurance Company of America et al.*, was settled for an undisclosed sum in the plaintiffs' favor (*IAQU* November 1990). The case was brought by the occupants of a building undergoing improvements in adjacent, unoccupied areas. They claimed that they had incurred temporary and permanent health problems as a result of being exposed to pollutants (solvents and VOCs off-gassed from sealants) introduced into the building's HVAC system during ductwork. They further claimed that the efficacy of the ventilation system itself had been impaired by the improvement work. The defendants in the case included the building's owner (Prudential), the property management company, and a host of contractors, consultants, and architects. After settlement the plaintiffs' attorney predicted that SBS lawsuits would continue to appear in the courts.

Floor coverings, specifically new carpet, have been the focus of two lawsuits — one tried and one about to go to trial — that illustrate how knowledge and awareness of indoor air pollution has grown in the last decade.

Beebe v. Burlington Industries

In May 1980, Glenn and Sharon Beebe had 79 yards of commercial carpeting installed in a new addition they had just built onto their existing business. The carpet, manufactured by Burlington Industries, was laid over rubber padding on a concrete floor and attached with tack strips, not adhesive (Beebe 1988). By August, the Beebes began to have difficulty concentrating while they were in the office. Their lips were chapped, puffy, and irritated. In September they began to experience headaches and nausea and an unshakable thirst caused by dry mouths. Shortly after that they say their eyes, noses, and sinuses began to burn. "Our symptoms seemed to come and go," they wrote in a self-published monograph relating their experience (Beebe 1988). "When we left the office, we felt better and tried to forget about the problem; however, when we re-entered the office area, within three to four hours our health problems recurred."

Their health continued to degenerate. Six months after the carpet installation they became depressed and their thinking and speaking became incoherent. Sharon, who was in the carpeted office more frequently than Glenn, began to experience shortness of breath, itchy skin, and a severely sore throat. Both experienced severe lethargy.

After seeking help from a variety of sources, the Beebes — following the advice of an industrial hygienist from the National Institutes for Occupational Safety and Health (NIOSH) — hired a private firm to test the carpet. The results indicated the presence of "an unidentified volatile amine" in the carpet.

In January 1981, the Beebes removed the carpet and pads and stored them in an older section of their building. After two days of "90% improvement," their symptoms reappeared and they hypothesized that the stored carpet may be the source. They wrapped the rolls of carpet in plastic and sealed them with duct tape. A subsequent chemical analysis by another independent testing company revealed that the carpet outgassed ethylbenzene, formaldehyde, methacrylic acid, toluene, amines, and styrene. "By the time the toxic carpet was removed, after nine months exposure, we discovered that we were hypersensitive to almost all irritants," they wrote. In April 1981 they filed suit against Burlington Industries for $250,000.

The Beebe's suit, one of the first indoor air pollution suits to go to trial (Cross 1990), accused Burlington Industry of a breach of warranty because the carpet "was not free from defects," one of the defects being that the carpet contained "a volatile amine compound" — later alleged to be 4-PC — that had damaged their health (Beebe v. Burlington Industries 1981). The case took eight years to resolve and ended with a judgment in favor of Burlington Industries. The defendants' lawyer said that he believed the key issue that swayed the jury in Burlington's favor was that the Beebe's symptoms had not appeared until three months after the carpet had been installed (Anderson 1990).

One of the Beebe's attorneys, Catherine Adams, said that she tried to introduce into evidence the studies that had come to light as a result of the US Environmental Protection Agency (EPA) Waterside Mall headquarters case, which identified 4-PC as the cause of symptoms remarkably similar to those of the Beebes (see 4-phenylcyclohexene, Chapter 1 — Carpets).[6] According to Adams, the judge would not allow the studies entered into evidence because the brand of carpet installed at Waterside Mall was different from the brand installed in the Beebe's building, despite the fact that both carpets off-gassed 4-PC. Cross (1990) sums up the case as follows, "The Beebes apparently lost their case because evidence on the harms of 4-PC was not conclusive" and because medical experts cannot agree on whether MCS is an actual illness, much less what causes it.

Bahura et al. v. S.E.W. Investors et al.

In June 1986, Joanne Bahura became an employee with the EPA and began working in the agency's headquarters located in the Waterside Mall complex in Washington, DC. The agency had moved into the Waterside Mall in December 1971, and the building owners and managers had been continually renovating and remodeling the space to accommodate the large number of EPA employees (Bahura et al. v. S.E.W. Investors et al. 1990). From October 1987 through April 1988, the work included the installation of 27,000 square yards of synthetic carpet manufactured in a Georgia mill. About 3,600 employees worked in the newly carpeted areas (Hirzy and Morison 1991).

After she started to work in the Waterside Mall, Bahura began to suffer from "influenza type symptoms together with abdominal pain," which persisted until the EPA moved her, in October 1987, to another location (Bahura et al. v. S.E.W. Investors et al. 1990). Her symptoms disappeared until March 1988, when she returned to the Mall offices and began to suffer from respiratory and other problems. Her health continued to deteriorate until July 1988 when she could "no longer tolerate being in the Waterside Mall" and quit. In September 1990, she filed suit against the building owners, designers, and constructors as well as a group of companies with ownership interest in the complex.

Since filing the suit, Bahura has been joined in her action by 19 other workers from the Waterside Mall plus 5 of their spouses. The plaintiffs' case is that the defendants acted negligently when they began the remodeling work without regard to local, district, and federal IAQ and occupational safety standards. They blame the failure of the complex's HVAC system to adequately flush chemical toxins introduced into the air during the remodeling and to provide adequate fresh air to the occupants. The suit further alleges that the defendants failed to monitor the air quality while the work was being done, allowed the use and installation of unsafe and dangerous products (including furnishings and cleaning materials), and failed to respond to the occupants' complaints concerning IAQ in the complex.

In contrast to the Beebe case, the defendants have not disputed the legitimacy of the plaintiffs' illnesses. Instead, they are trying to identify the specific sources of the toxic emissions, which they claim are responsible for the injuries. In June 1991, they filed third-party suits against the carpet manufacturer, the manufacturer of the adhesive used to glue the carpet down, and the manufacturer of the cubicle partitions (which, the defendants say, in addition to off-gassing toxic chemicals also impaired the air circulation in the building).

The case, which is currently in the discovery phase, should go to trial early in 1992. "We look at this as a seminal case," says the plaintiffs' attorney Thomas Glancy, "not only because of the number of people who have gotten sick and the seriousness of their injuries, but also because this occurred at the national headquarters of the [EPA]. If the organization that's entrusted with making our environment safe is itself unsafe, then it's indicative of the fact that this is a serious and far-reaching problem. It's one of the serious environmental problems of the '90s."[7]

Chapter 8

Regulation and Legislation

Recently state and federal legislators have begun to take a hard look at the issue of indoor air quality and the impact of indoor air pollution. According to the US Environmental Protection Agency (EPA), people spend approximately 90% of their time indoors, where pollutant levels are two to five times higher than they are outdoors. The short- and long-term health impacts of this exposure are significant, and the economic impact is estimated in the tens of billions of dollars annually (Axelrad 1991). Many of the pollutants associated with floor coverings are included in the EPA's list of major indoor air pollutants, namely biological contaminants, VOCs, formaldehyde, and asbestos.

In 1987, Senator George Mitchell introduced the Indoor Air Quality Act, a bill that would have the directed EPA to list all indoor air contaminants and publish health advisories setting safe exposure levels for each. It also would have established a Council on Indoor Air Quality to coordinate all IAQ-related federal activities across relevant agencies (Cross 1990). Two years later, Representative Joseph P. Kennedy introduced a House version which, in addition to establishing most of the provisions of the Mitchell bill, would also have required affected industries to label the emissions from products that posed significant health threats and established ventilation standards for public and commercial buildings (Axelrad 1991). Neither bill has become law.

While these bills address the problems of IAQ in general, little if any legislation has dealt with the emissions from floor coverings in particular. This may change. In April 1991, the New York Attorney General Robert Abrams petitioned the US Consumer Product Safety Commission (CPSC) to make mandatory "warning labels, posters in stores, and free pamphlets to alert consumers to the potential health hazards of new carpeting" (*IAQU* May 1991). Abrams cited complaints to the CPSC (see Chapter 6 — Health Effects), as well as reports of two deaths and a number of multiple chemical sensitivities (MCS) cases as the basis for his petition. He demanded that all new rugs and carpets carry labels warning of the potential health threats associated with them. He also wanted such warnings posted in all carpet stores and departments.

In September 1991, the CPSC responded to that request, denying a hearing of the petition. According to a spokesperson for the CPSC, the agency chose to deny the request because the petition failed to provide sufficient data to warrant a hearing. In particular, the CPSC determined that while the petition lists chemicals contained in carpet products, along with epidemiological studies of carpet workers and anecdotal health effects evidence, it provides no information relating specific chemical emissions from carpets to specific health effects. The Attorney General's office has announced that it is resubmitting the petition and that it will sue for a hearing if it is again denied.

Carpet Policy Dialogue Group

Following the incident at the EPA's Waterside Mall headquarters when a group of employees became ill after new carpets were installed in the building in late 1987 and early 1988 (see Chapter 1 — Carpets), the National Federation of Federal Employees (NFFE) petitioned the EPA to 1) require testing to determine how 4-PC and other carpet emissions affect building occupants; 2) limit acceptable indoor air levels of 4-PC to five parts per trillion (ppt) to prevent MCS or 17 ppt to prevent acute irritancy effects; and 3) specify reporting requirements for carpet manufacturers (*IAQU* July 1990).

In April 1990, the EPA denied the NFFE's petition on the grounds that data to support the NFFE's claim that carpet emissions made occupants ill were insufficient. However, recognizing that "an absence of scientific certainty does not necessarily mean an absence of risk," the agency took three actions (*Federal Register* August 3, 1990). First it asked the carpet industry to undertake a program for periodically analyzing TVOC emissions "on a company-by-company and product-by-product basis," thereby providing consumers with comparative information on TVOC emissions. Second, it invited "all interested parties" to participate in a one-year dialogue process that would help design the voluntary testing program, in part by working toward a consensus on how best to sample, analyze, and characterize carpet emissions. The dialogue would also suggest "cost-effective process changes to reduce emissions." Finally, the EPA stated its intention to continue its "ongoing exposure reduction and research activities on indoor air quality issues generally and on the potential health effects of exposure to low-level VOC mixtures, in particular."

To implement these initiatives, the EPA formed the Carpet Policy Dialogue Group (CPDG), which comprised representatives from NFFE, the Carpet and Rug Institute (CRI), consumer and public interest groups, Federal agencies, and emissions researchers, among others (*IAQU* May 1991). Three subgroups report to this plenary group. The Product Testing subgroup is charged with identifying analytical test methods for measuring TVOC, taking into consideration the study design characteristics. This subgroup is designing TVOC emissions tests for the carpet industry, the carpet cushion industry, and the carpet adhesive industry separately. The Process Engineering subgroup is evaluating potential process or engineering changes for reducing TVOC emissions. It is identifying the information needs for assessing the potential emission reduction strategies, including information on installation and other commercial activities. The Public Communications subgroup disseminates the plenary group's findings.

In a recently released report, the Public Communications subgroup listed the following accomplishments of the CPDG from August 1990 through April 1991 (Leurkroth 1991):

- Acceptance of a carpet testing program for measuring TVOC from a representative set of carpet products (see below).

- Contribution (through the Product Testing Subgroup) to the development of an ASTM standard analytical test method for determining TVOC emissions from carpet-related products (see Emissions Measurement Techniques, Chapter 1 — Carpets).

- Agreement by the CRI to release previously obtained data on TVOC emissions decay from carpets backed with styrene-butadiene rubber (SBR) latex. (The data will be reviewed to determine the correct time-point for conducting emissions tests.)

- Agreement by the CRI to fund an industry-wide profile study to provide comparative TVOC emissions data for currently available SBR-latex-backed and nonSBR-latex-backed carpet product types.

- CRI funding of a TVOC emissions decay study for nonSBR-latex-backed carpet product types.

In addition to the programs and activities listed above, the CRI has also agreed to have its members conduct periodic monitoring of TVOC levels in carpet products with a view toward generating a trend analysis. It also plans to establish a certification program that would motivate carpet manufacturers to institute voluntary quality assurance measures to reduce TVOC emissions from their products. In addition, the CRI is pursuing a public education campaign. As part of its commitment to the EPA, the institute is developing consumer information packages that include procedures for manufacturing and processing carpets and ancillary products, installation guidelines, and recommendations for cleaning and maintenance. The CRI also will be developing guidelines for chemically sensitive individuals.

During the course of the CPDG meetings, the floorcovering adhesives industry also reached several milestones. The National Association of Floorcovering Distributors organized the Floorcovering Adhesive Manufacturers Committee to help determine ways in which the industry can develop information that may lead to a voluntary testing program similar to the one developed for carpet products. The floorcovering adhesives industry also plans to conduct preliminary testing studies to measure TVOC emissions from carpet adhesives and carpet seam sealants. They will help finalize analytical test methods for those products.

The Carpet Policy Dialogue Group noted during its meetings that the trend toward low-emitting, multipurpose carpet adhesives is accelerating and that eight manufacturers now produce such products (Leukroth 1991). Similarly, the Styrene Butadiene Latex Manufacturers Council reported that its manufacturers had reduced VOC emissions from their products in recent years. It also reported that it had completed a series of toxicity tests for 4-PC, a major VOC emitted from SB latex backing (see 4-phenylcyclohexene, Chapter 1 — Carpets and Chapter 6 — Health Effects).

The Carpet Cushion Council, which also participated in the dialogue process, agreed to prepare a testing program for its products as well. It has formed technical task groups in each product area to investigate methods for reducing VOCs. In a parallel effort, the Dialogue Group's Process Engineering subgroup is compiling information about manufacturing processes for carpet, carpet cushion, carpet adhesives, and SB latex, as well as carpet installation procedures for the purpose of evaluating potential process or engineering changes that could reduce those products' TVOC emissions.

Carpet Testing Program

The CRI's carpet testing program has five components (Leukroth 1991):

1) Generation of a TVOC emissions database for new carpets, which fall into two principal categories: softback carpet (broadloom) comprising 94% of the total market share, and hardback carpet (tiles), with a thicker backing, comprising 6% of the market share;
2) Preparation of a carpet emissions profile derived from the database;

3) Periodic TVOC monitoring to generate a history of TVOC levels that can be used for trend analysis and remedial action;

4) Establishment of a certification program that will motivate manufacturers to institute voluntary quality assurance measures for reducing TVOC emissions from their products; and

5) Development of a public communication program to inform customers of the carpet industry's quality assurance program.

The CRI selected as its analytical test method ASTM's Standard D5116-90 for small-scale environmental chambers (see Emissions Measurement Techniques, Chapter 1 — Carpets), which was refined to meet the particular needs of carpet products. The CRI method uses a "chemically inert stainless steel" chamber with a minimum volume of 0.05 m^3 (Leukroth 1991). Temperature and humidity are kept constant at 25°C and 50%, respectively. The chamber supply air must be purified to contain less than 2.0 μ TVOC/m^3. The CRI specifies the conditions for sample collection, packaging, delivery, and storage. The actual TVOC analysis is by capillary gas chromatography coupled with flame ionization detection (FID) or mass spectrometry. The calculated emissions factors, expressed as mg/m^2 per hour, are product specific.

The carpet testing program comprises two studies (Leukroth 1991). Phase I is designed to provide emissions decay data for six nonSBR-backed (hardback) carpet types. This data will then be compared with already existing data on emissions decay for 19 SBR (softback) carpet types and analyzed to determine the appropriate point (or points) in time in which to sample carpet emissions. The study will seek to confirm that 1) the time point(s) selected are of sufficient duration to ensure that "a carpet with higher emissions at an early point in time maintains its relative ranking with respect to other carpets at later points in time," and 2) the time point(s) selected are equally appropriate for hardback and softback products.

The second part of the carpet testing program will establish a database of TVOC emissions from a representative sample of carpet product types.[8] The database will represent "an industry-wide profile of TVOC emissions for carpet products currently available in commerce." The criteria used to select the carpet product types include face fiber, topical treatment, and backing, with the latter representing the key factor. The 25 commercially available product types to be sampled in the study include a combination of nylon, olefin, polyester, and wool fiber types with topical treatments for soil and insect resistance. The backings are either SBR latex or nonSBR latex (hardback) materials such as urethane foam, amorphous resin, PVC, or ethylene vinyl acetate (EVA), although the CRI notes that the latter is no longer manufactured (Leukroth 1991).

The testing program will include a total of 78 samples from a variety of product combinations (e.g., nylon with SBR backing and no topical treatment, nylon with SBR backing and soil resistant treatment, olefin with SBR backing and no topical treatment, etc.). The samples are divided among 54 SBR-backed products and 24 nonSBR-backed products. The wide selection of product types will allow the study to determine the effect of fiber type, topical treatment, and backing material on TVOC emissions. Repeat samples of the same product type will be collected on different days from the same manufacturing line as well as from different lines so that the study also can determine the variability in TVOC emissions that arises from differences among manufacturing lines producing the same product, and day-to-day differences in the same manufacturing line. One of the CPDG's goals is to create market pressure to reduce VOC exposures from new carpets.

Followup Activities

In addition to conducting the carpet testing program, the CRI will consult with the EPA to establish a carpet industry quality assurance program. The CRI will develop a manual that documents for its members the procedures they should use to obtain and report TVOC emission rate data for their product types. Using this information, the CRI plans to publish a list of member companies that have received TVOC performance certification within a given year.

The CRI also will use the submissions that companies make under the quality assurance certification program to generate an aggregate history of TVOC product performance. The data in these submissions "will be used to reveal trends over time relative to the overall industry-wide profile and, in future, to product types" (Leukroth 1991). The CRI plans to produce the aggregate history annually for at least three years.

Working with the EPA and the Carpet Policy Dialogue's subgroup on Public Communication, the CRI is offering to develop a consumer information program that will provide customers with appropriate information on TVOC emissions. The content of the public information program depends on the results of the carpet testing program. It may include product-specific or company-specific data on TVOC levels or "more generic information" derived from the aggregate history and quality assurance certification efforts (Leukroth 1991).

Chapter 9
Control and Remediation

"The buildings of the sixties and before were leaking like sieves," wrote architect Carlo Testa in a paper presented at Indoor Air '90, the Fifth International Conference on Indoor Air Quality and Climate. "In a standard dwelling, cracks in the walls [and] poorly sealing windows and doors allowed air exchanges equivalent to a wide-open window. We sealed the buildings and at the same time reduced mechanical air ventilation to 5 cubic feet per minute (cfm), compared to the pre-seventies 15 cubic feet (or the pre-thirties 100 cubic feet). The buildings became energy efficient; unfortunately, they also tend to make the inhabitant sick" (Testa 1990).

In the face of increasing attention to the burgeoning issues of IAQ, the architecture and interior design (A&D) industry has begun to look for ways to build energy efficient buildings while minimizing potential sources of indoor air pollutants (*IAQU* July 1991). This interest has resulted at least in part from a recent wave of lawsuits naming architects and interior designers among those liable for damages resulting from exposures to indoor air pollutants (see Chapter 7 — Litigation).

Methods to control and remedy indoor air pollution are diverse, ranging from source removal, substitution, and modification to behavioral adjustments (such as avoidance) that reduce exposures (Spengler and Sexton 1983).

With respect to floor coverings, remediation and control measures generally fall into four categories:

- Material or product selection

- Product changes
- Installation
- Maintenance

Material or Product Selection

To foster the A&D industry's growing interest in IAQ and channel it in a productive direction, consultant Karen Randal, a 20-year industry veteran, organized a series of colloquia designed to bring together key people from all of the industries potentially involved with sick buildings, industries Randal describes as representing "a slice through the liability pie" (***IAQU*** July 1991). The colloquia participants are "a cross-section of people who would be sitting on the opposite sides of a courtroom," according to Randal. They include not only the manufacturers of products used in building construction (e.g., carpet, paint, fabrics), but also the professionals specifying those products, the clients who use them, real estate executives, lawyers, and insurance companies. A&D industry consultants such as environmental engineers, industrial hygienists, and maintenance firms are also included.

Randal, who plans to publish the proceedings of the "Health in the Work Environment" colloquia in May 1992, says, "Our goal is to produce and make available to our peers, clients, and educational facilities a synthesis of all the miscellaneous information on IAQ, SBS, and BRI. We want to pull together all the varying points of view that exist in the industry as a whole, from manufacturers to clients, proposing feasible approaches and real solutions. We want to separate the glut of marketing information from the facts, empowering us as professionals to make the right decisions."

Asked to rate the importance of IAQ to A&D professionals, industry expert Randal says, "With the liability facing designer/specifiers for the choices they make in products, I see the awareness growing rapidly and IAQ issues rising to the top of the scale. The profession will respond to these issues either proactively or retroactively, but it is guaranteed it will have to respond."

In one such proactive response, the American Institute of Architects (AIA) has been working on a three-year contract with the US Environmental Protection Agency (EPA) to develop an Environmental Resource Guide that architects can use to select low-emitting and environmentally benign building materials.[9] The guide is based on a series of reports analyzing the environmental impact of such building materials as vinyl flooring and particleboard. The reports contain an update of any legislative action pertaining to the material, as well as position statements from industry representatives and environmental groups.

Characterizing Product Emission Strength

The advent of environmental test chamber technology has allowed researchers to characterize products bases on the quantity and composition of their emissions (see Emissions Measurement Techniques, Chapter 1 — Carpets). Emission rate or "source strength" is also commonly used. In addition to these, the *duration* of a product's emission is a significant characteristic that affects IAQ.

Generally, floor coverings have a "slow-decay" emission rate with a half-life ranging from weeks to months (Tucker 1991). By contrast, wet products such as adhesives and U-F or polyurethane coatings have "rapid" decay rates. Their emissions half-lives may be on the order of minutes, hours, or days after application.

The factors that affect VOC emissions from floor coverings and other surface materials are:

- Total content of VOC in the product or material;
- Distribution of VOC between the surface and interior layers of the material;
- Product age;
- Loading (product surface area per volume of space in which it is located); and
- Environment (temperature, air exchange rate, and relative humidity) (Tucker 1991).

Architects and designers now use mathematical models to predict the impact that sources of varying strengths will have on a building's IAQ. Such source models usually take into account the two or three major factors that most influence the emissions from a particular product or material. Using the models, the architect can not only predict the product's impact on IAQ, but also determine the most effective methods to accelerate the emissions and thereby reduce the product's source strength, a process known as "conditioning" (Tucker 1991) (see below).

Selection Criteria

To evaluate the acceptability of building materials such as floor coverings, experts have proposed several criteria. According to Tucker (1990), manufacturers or suppliers should provide product-specific emissions-rate test reports that document:

- Emission levels for the major organic compounds that the product contains and for compounds that are toxic or irritating at or below concentrations of 5 mg/m^3 air;

- Emission levels at three "ages" of the product (e.g., 1, 10, and 50 days post-production for solid products such as vinyl or carpet; and 1, 10, and 100 hours post-application for coatings and adhesives);[10]
- Test chamber conditions; and
- Product storage and handling conditions.

In addition to test reports, manufacturers or suppliers also should provide Material Safety Data Sheets specifying the chemicals used in each product's manufacture, Tucker (1990) advises.

IAQ consultant Hal Levin advocates conducting inexpensive, quick, and reliable "sniff tests" of materials such as carpet, adhesive, and carpet pads as a means of evaluating their emissions potential (*IAQU* December 1990). The test consists of placing a representative sample of the product in a clean, tightly sealed glass jar that is left for 4 to 24 hours at 75°F or slightly warmer. The jar is then opened "in a reasonably odor-free space" and sniffed. According to Levin, while carpet odor and health effects may not necessarily be connected, "strong odors indicate relatively large emissions and can cause discomfort and heighten awareness of air quality problems." Levin also recommends doing a sniff test of a product sample after it has been aired out or conditioned to determine whether conditioning before installation is advisable (see below).

Tucker (1990) urges building designers to "reject, or evaluate conditioning of" products likely to raise indoor VOC by a factor of 0.5 mg/m^3 or more. With respect to floor coverings and floor coatings, he defines as low-emitting any material with a maximum emission rate of 0.6 mg TVOC/h per m^2. He notes that "values for particularly noxious compounds will be lower."

Emissions factors for wet coatings may be substantially higher than the level Tucker recommends. Coatings still can be considered low-emitting, however, if their emissions fall below 0.6 mg TVOC/h per m^2 "within several hours" of their application. The presence of VOC sinks that absorb and rerelease VOCs can complicate the classification of coatings.

To minimize the impact of adhesives on IAQ, Tucker suggests that manufacturers (a) provide an adhesive with the lowest content of toxic or irritating compounds; (b) specify the smallest quantity of adhesive possible to meet performance requirements; and (c) supply test results that document drying times, VOC emissions, or other data that will allow the specifier to evaluate the adhesive's potential impact on IAQ.

Despite these guidelines, Tucker strongly recommends that building designers use situation-specific IAQ modeling to account for the complex physical relationships among the emissions sources, the building occupants, and building parameters such as indoor air volume, air exchange rate, and air movement and mixing (*IAQU* August 1990). Recent research indicates that flooring is one of the features most often changed when homes are renovated or built to accommodate the needs of chemically hypersensitive people (*IAQU* September 1990). This usually means substituting ceramic or hardwood floors for carpeted floors. In one home designed and built for a family with two severely allergic and asthmatic children, for example, the designer chose ceramic and quarry tiles "for their inertness, eliminating the chemical offgassing of synthetic floor coverings and dusts and mites or mould growth from carpeting" (Salares, Allen, and Drerup 1990).[11]

Even the selection of nonflooring materials can affect the emissions from floor covering products. For example, darkened glass and shades minimize the amount of light impinging on surface materials, thereby minimizing the surface heating that favors VOC off-gassing (*IAQU* November 1990). Thus the careful selection of a combination of low-emitting and non-irritating products and materials with specific building envelope materials can greatly reduce the occurrence and extent of indoor air pollution from floor coverings.

Product Changes

Manufacturers of floor coverings have begun to respond to the A&D industry's — and consumers' — demands for low-emitting products. The carpet manufacturing industry is seeking to create market pressure to reduce VOC exposures from new carpets. One of its approaches is to use data from its carpet testing program to identify products that fall outside the normal distribution of TVOC emissions, so-called "outliers" or high emitters. Those products will then be singled out for remedial action. It will also look at the product emissions data for low emitters that could provide the industry with insights into manufacturing methods that provide an overall reduction in TVOC emissions.

The trend toward low-emitting products has reached other flooring-related industries as well. Already eight adhesives manufacturers are producing low-emitting, multipurpose carpet adhesives (Leukroth 1991). The W.F. Taylor Co. Inc. of Santa Fe Springs, California, for example, markets a line of solvent-free floor-covering adhesives (*IAQU* October 1990). One of its products, a tile adhesive, is reportedly VOC-free. Similarly, the Styrene Butadiene Latex Manufacturers Council reports that its manufacturers have reduced VOC emissions from their product in recent years (see Chapter 8 — Regulation and Legislation). The Carpet Cushion Council recently agreed to prepare a testing program for its products as well (see Chapter 8 — Regulation and Legislation).

In a parallel effort, the Process Engineering subgroup of the EPA-carpet industry Carpet Policy Dialogue Group is compiling information about manufacturing processes for carpet, carpet cushion, carpet adhesives, and SB latex also with the purpose of evaluating potential process or engineering changes that could reduce those products' TVOC emissions.

Installation

The installation of new floor coverings — from carpet to vinyl and linoleum, and even coated hardwood floors — is a major contributor to indoor air pollution. Two common techniques for reducing emissions before, after, and during installation are conditioning and ventilation.

Conditioning (Airing Out and Baking Out)

Floor products are conditioned by airing them out or baking them out before and after installation. Airing out simply refers to the process of unrolling or unwrapping the product, such as carpet or sheet vinyl, under conditions of maximal air circulation to enhance the off-gassing of residual VOCs. This airing out can take place at the installation site, at a specially rented site if the installation site is too small, or at the factory before the product is shipped (*IAQU* December 1990).

Airing out generally reduces the rate of VOC off-gassing from most carpets. For example, airing out new carpet for just one week before installation reduces 4-PC levels from 9 ppb to less than 4 ppb (*IAQU* December 1989). Airing out the same carpet for one month prior to installation at 1 ACH reduces peak 4-PC concentrations even further, to less than 1 ppb.

A bake-out involves gradually heating a product to raise vaporization rates and enhance the diffusion of residual VOCs toward the product's surface, thereby reducing the pool of VOCs available for subsequent outgassing. Three factors that control the bake-out process are:

- **Temperature**: Indoor temperature can be elevated using lights, the existing HVAC system, or portable space heaters. Girman et al. (1990) suggest that temperatures should reach at least 90°F to be effective. The temperature must be raised gradually and not to an excessive level to minimize damage such as carpet and vinyl floor buckling (*IAQU* July 1989; Girman et al. 1990).

- **Duration**: "From an engineering perspective," says Levin, "the duration of a bake-out should be as long as possible. However, the cost of keeping a building empty usually dictates a short bake-out" (*IAQU* December 1990). The longer times are desirable because heat transfer by air is limited and the heat capacity of a building is large. For example, baking out a carpet requires raising the temperature of the carpet itself, the carpet pad, the carpet adhesive, and the underlying flooring (e.g., cement slab) (Girman et al. 1990). Most experts concur that 24 hours are insufficient for a bake-out; recommended minimums range, however, from 48 or 36 hours (Girman et al. 1990; Hicks, Worl, and Hall 1990) to at least one week (*IAQU* July 1989).

- **Ventilation Rate**: Adjusting the ventilation during a bake-out is as critical as it is problematic. While ventilation levels must be sufficient to flush VOCs and prevent sorption by other materials, increasing ventilation tends to lower the temperature through increased heat loss. Girman et al. (1990) report that low to moderate rates (0.5 to 1.5 ACH) are sufficient. Levin recommends purging a building with 100% outside air for at least 24 hours after a bake-out and before the building is occupied.

Whether bake-outs significantly reduce VOC concentrations is not clear. In a study of a bake-out done in a new, five-story hospital wing with extensive vinyl floors and some carpeted floors, Hicks, Worl, and Hall (1990) found "few trends" when comparing pre-bake-out VOC levels with post-bake-out levels. In several cases, such as for toluene, concentrations in the air were higher 72 hours after the bake-out than they had been the day before the bake-out began. The researchers attribute this to a low ventilation rate that allowed for sorption and re-release without removal through air exchangers.[10] By contrast, Girman et al. (1990), in a study of five office-building bake-outs, reported that "decreases in individual, most abundant VOCs were modest, but a large decrease (95%) in the total VOC concentrations was observed inside the most extensively baked-out building." The maximum decrease in concentration for individual VOCs averaged 20% to 30%.

Bake-outs appear to have no effect on formaldehyde concentrations in particular. Raising the temperature might be expected to increase the hydrolysis of U-F resins in materials containing formaldehyde (*IAQU* December 1990). However, according to Girman et al. (1990), the effect of a bake-out is limited to the VOCs at the surface of materials. Thus, products containing formaldehyde as a major component distributed throughout would be little affected. In their study, Girman et al. indeed found no changes in formaldehyde concentrations before and after a bake-out. In contrast, Hicks, Worl, and Hall (1990) found consistently lower post-bake-out formaldehyde levels on all of the floors of the five-story hospital they studied.

Perhaps the most important effect of a bake-out, according to Girman et al. (1990), is the subjective response of the building's occupants:

> In the building receiving the most extensive bake-out, visitors to the building after the bake-out remarked that the building "did not smell like a new building." Odors in the building were minimal. This was true even in a room that was carpeted during the bake-out. According to the building architect, 11 months after occupancy of the building, not a single complaint about indoor air pollution had been lodged (by

an office population that had had numerous and extensive complaints at their previous locations).

Ventilation

In its December 1990 issue, ***IAQU*** reported "Ventilation alone cannot solve an odor or other problem associated with VOC emissions; however, it can reduce the degree and time frame of its occurrence." Ventilation is critical during the installation of VOC emitters. For example, Hirzy and Morison (1991) report that when ventilation was improved during the installation of new carpet in the US EPA headquarters building in Washington, DC (see 4-phenylcyclohexene, Chapter 1 — Carpets), airborne concentrations of 4-PC dropped from 6.5 ppbv to below 1 ppbv in one month. Some experts recommend using 100% outside air to ventilate spaces where significant VOC sources are installed (*IAQU* December 1990).

What constitutes an adequate ventilation rate is somewhat controversial. One expert comments, "Ventilation standards based solely on rates of outside air supply per occupant or building volume do not necessarily control unusual or strong contaminant sources. Adequate ventilation rates must be based not only on the human occupant density but also on the activities and sources that will be present" (*IAQU* November 1990). The American Society of Heating, Refrigerating, and Air Conditioning Engineers (ASHRAE) recommends 7 to 10 cfm (Samet, Marbury, and Spengler 1988b), although some experts believe that 15 cfm will become the new standard (Testa 1990).

In addition to adequately ventilating a building or a zone within a building where VOC sources such as carpet are being installed, experts suggest directly exhausting indoor air to the outside (*IAQU* December 1990). Recirculating air from installation spaces through ducts or plenums that contain materials with high surface areas (e.g., ceiling tiles and sprayed-on insulation) may favor sorption and rerelease of VOC after the installation is completed.

Maintenance

Because carpets can act as sinks for chemical and biological contaminants (see The Sink Effect — Sorption and Rerelease, Chapter 1 — Carpets), the carpet industry has begun to focus on maintenance (*IAQU* May 1991). Addressing the need for adequate bacterial and particulate control on the one hand, while considering the potential problems arising from the use of cleaning materials (and the cleaning methods themselves) on the other, requires a carefully balanced approach. The Carpet and Rug Institute has assembled a committee of over 30 representatives from the services and products industries to develop maintenance guidelines.

The institute plans to produce a two-part guideline, one for consumers and one for industry professionals.

[Note: Cutter Information Corp. is in the process of revising this section on carpet maintenance. We expect to ship an addendum to this report, on carpet cleaning, by November 1, 1992 to all purchasers of the report. We hope this does not cause you any inconvenience.]

Notes

[1] Forbo Floor Coverings, Inc., personal communication.

[2] personal communication.

[3] personal communication.

[4] Because most of the residents involved in the report did not collect air samples or test their carpets, and because medical data confirming their symptoms were inadequate, according to the CPSC, the agency could not conclusively show a causal relationship between the carpet installation and the reported symptoms.

[5] The "strictly controlled environmental conditions" are obtained by placing patients in an environmental unit, a space specially constructed without materials that emit any chemical pollutants, and having the patients avoid using any drugs, cosmetics, or other chemical substances. The patients are also required to fast until their symptoms disappear. Once the patients are asymptomatic, food items are reintroduced one at a time to determine which are safe and then chemicals are reintroduced at very low levels. Use of environmental units have been "dramatically successful" in identifying causative agents in the patient's environment, particularly because "once the patients have been de-adapted, the reactions from causative substances are often acute and distinct" (*IAQU* April 1991).

[6] personal communication.

[7] personal communication.

[8] In a "Minority report on carpet testing agreement" appended to the Interim Report, several of the Carpet Policy Dialogue participants expressed concern that the testing program was dealing only with total VOC instead of identifying the specific compounds contained in the emissions. The dissenters wrote that "if the dialogue is to take seriously its charge to evaluate potential engineering and/or process controls for reducing emissions it must generate knowledge as to the sources of those emissions. Unless it can be shown that emissions arising from spinning oils, dye-related chemicals, soil- and stain-resistance treatments, and backing materials are analytically indistinguishable from one another,

one must conclude that obtaining the identities of the compounds in the emissions 'package' is vital for an understanding of the sources."

[9] Douglas M. Greenwood, personal communication.

[10] As a note of caution, one expert warns that "Interpreting emissions test results is very difficult due to the lack of knowledge regarding health effects. Tradeoffs between the significance of toxicity and irritation must be determined. Researchers are determining whether high emissions over a short period are preferable to lower emissions over a long term" (*IAQU* November 1990).

[11] Testa (1990) notes that a problem with such "clean" materials is that they are "excellent transmitters of impact sound and vibrations" and that without wall-to-wall carpeting and acoustic ceiling tiles, "the open-plan office becomes a noise machine."

[12] Hicks, Worl, and Hall used an average ventilation rate of 0.2 ACH during the bake-out, which may have allowed for a high incidence of sorption and re-release, accounting for the post-bake-out increases in concentration. The authors themselves note that the TVOC concentrations before the bake-out were already quite low and that the carpet had been laid 60 days before the bake-out, all of which may have limited the effects of the bake-out.

Glossary

ACH: air change per hour

ACM: asbestos-containing material

AIA: American Institute of Architects

ASHRAE: American Society of Heating, Refrigerating, and Air Conditioning Engineers

ASTM: American Society for Testing and Materials

BRI: building-related illness

cfm: cubic feet per minute

CPSC: Consumer Product Safety Commission (US)

CRI: Carpet and Rug Institute

EPA: US Environmental Protection Agency

EVA: ethylene vinyl acetate

FID: flame ionization detection

4-PC: 4-phenylcyclohexene

GC/MS: gas chromatography/mass spectrometry

HVAC: heating, ventilating, and air-conditioning

IAQ: indoor air quality

NIOSH: National Institutes for Occupational Safety and Health

PCM: phase contrast microscopy

ppb: parts per billion

ppbv: parts per billion per volume

ppm: parts per million

ppt: parts per trillion

PVC: polyvinyl chloride

RH: relative humidity

SB: styrene-butadiene (as in SB latex)

SBR: styrene-butadiene rubber (as in SBR latex)

SBS: sick building syndrome

TEM: transmission electron microscopy

TVOC: total volatile organic compounds

U-F: urea-formaldehyde

VAT: vinyl asbestos tile

VOC: volatile organic compound

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