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# Case Studies

# Organic Vapor Emissions from Wall-to-Wall Carpets as a Source of Indoor Air Pollution

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## Introduction

Indoor air pollution should be considered to be a source of exposure for many contaminants, as most people in North America spend 80 to 90 percent of their time indoors.[1] Indoor air quality problems may occur because buildings have reduced amounts of make-up air for energy efficiency and/or air flow patterns are disturbed by interior renovations.[2]

The National Institute for Occupational Safety and Health (NIOSH), the Occupational Safety and Health Administration (OSHA), other governmental agencies, and private consultants have investigated numerous incidents of poor indoor air quality with effects ranging from offensive odors to nonspecific illnesses, such as dry throats, coughing, watery eyes, headaches, and runny noses. There are even anecdotal reports of chemical hypersensitivities.[3,4]

Many of these complaints are similar to symptoms reported from exposure to low levels of refined petroleum solvents.[5] NIOSH has found that the primary causes of indoor air quality problems are inadequate ventilation and generation of contaminants from inside the building.[6]

As a source, wall-to-wall carpets should be considered because they are a common feature in modern buildings. These materials have a large surface area and mass, and they may be bonded to the floor surface by a mastic that contains refined petroleum solvents.[7] Investigators have identified formaldehyde as a contaminant released from wall-to-wall carpeting.[8] There have been lab studies but only limited field studies, of solvent emissions from new wall-to-wall carpet installations.[9–13]

## Materials and Methods

For this study, four new wall-to-wall carpet installation sites were selected where direct glue-down synthetic nylon pile carpeting with chemically similar styrene/butadiene-based latex mastic was being installed. Sites were also evaluated to ensure that no other sources of organic vapors were present.

The sites selected were in offices and a library at a university. The areas were occupied during the 2-week sampling period. Rooms ranged in area from 14.5 to 37 $m^2$ and in volume from 55.4 to 136 $m^3$.

The buildings' heating and air conditioning systems provided ventilation to the study sites. In addition, employees in these offices provided supplemental air flow through open windows and doors where possible (sites 2 through 4). In one office the employees used a portable fan for additional ventilation (site 3).

Temperature and relative humidity at each site were measured before and after each sampling period. A recording hygrothermograph was left at the site for the entire sample period to gather changes in the temperature and relative humidity.

Room ventilation, in terms of air changes per hour, was determined before each sample period with a Miran IA infrared analyzer and a Beckman chart recorder using dichlorodifluoromethane as a tracer gas. Each tracer gas procedure was repeated in triplicate.[14] Table 1 summarizes the environmental conditions at each site.

Ambient air samples for organic vapors were collected at flow rates between 0.19 and 0.22 L/min with precalibrated and postcalibrated sampling pumps using standard charcoal tubes for collections media. The opening of the charcoal tube was suspended 1 m off the floor surface to represent the occupied zone. Sample times were from 2 to 4 hours, depending on the expected concentration. Sampling and analysis were consistent with the NIOSH analytical methods and were reported as an air concentration (milligrams/meter$^3$).[15]

To collect and concentrate organic vapors emitted from the carpet and glue, air samples were collected using a simple dynamic head space chamber shown in Figure 1. Methods of sampling and analysis were identical to the ambient air samples. The chamber covered a known area; the results were reported as an emission rate (milligrams/meter$^2$/hour).

Ambient air and head space samples were collected simultaneously. The samples were collected the day after the carpet was installed, and then on days 2, 8, and 13 after installation.

## Data Analysis

Each set of gas chromatographic analysis included a hydrocarbon standards series of *n*-octane to *n*-pentadecane, *d*-limonene, toluene, and the three isomers of xylene, run under the same conditions to confirm the identity of the sample mixture and to allow for quantitative analysis of mass. The average response of the standards was used as the response of the sample mixture.[16]

Chromatograms from the ambient air samples and the head space chamber samples from each site were compared for a similar pattern of peaks and a recognizable chromatographic signature. Standard compounds in each sample were identified based on retention time. The patterns were compared between days within the same site and, finally, between sites.

Quantitative analysis of the ambient air samples consisted of a determination of emission rate in terms of mass/unit area/time for each sampling date. A plot of the decay of the emission rate was prepared for each site. A natural log transformation of the emission rate was performed along with a linear regression to determine if the decay of the emission rate was exponential.

## Results

In all cases, qualitative examination of chromatograms from the ambient air and

TABLE 1. Environmental Conditions During Sampling

| Site | Sample Day | Temperature[A] | RH[B] | Ventilation[C] |
|---|---|---|---|---|
| 1 | 1 | 74 | 60 | 19.19[D] |
| 1 | 2 | 74 | 52 | 17.75[D] |
| 1 | 8 | 72 | 50 | 8.13[E] |
| 1 | 13 | 72 | 50 | 10.52[E] |
| 2 | 1 | 68 | 60 | 5.51[E] |
| 2 | 2 | 68 | 70 | 3.64[E] |
| 2 | 8 | 70 | 56 | 3.27[E] |
| 2 | 13 | 72 | 54 | 4.20[E] |
| 3 | 1 | 75 | 61 | 15.05[D] |
| 3 | 2 | 77 | 50 | 16.38[D] |
| 3 | 8 | 78 | 61 | 18.01[D] |
| 3 | 13 | 77 | 61 | 17.26[D] |
| 4 | 1 | 72 | 63 | 10.91[D] |
| 4 | 2 | 68 | 62 | 8.02[D] |
| 4 | 8 | 75 | 62 | 9.36[D] |
| 4 | 13 | 82 | 60 | 8.58[D] |

[A]Average temperature for the sampling period in °F.
[B]Average relative humidity (%).
[C]Average room ventilation for the sampling period in terms of air changes per hour.
[D]Doors/window open.
[E]Doors/window closed.

head space chamber from samples obtained within a site showed similar patterns of peaks, with the ambient air concentration decaying to near the detection limit by the last sampling date, 13 days after the carpet was installed. Table 2 shows the pattern of the selected hydrocarbon standards in air and chamber samples for site 1 for the four sampling days. Other sites showed similar agreement. Tables 3 and 4 present the ambient air concentration and emission rate on each day for each sampling location. Table 5 presents the calculated half-lives for the ambient air concentration and emission rate. Figures 2 and 3 show the air and chamber results in graphical form (natural log of air concentration versus day sampled).

## Discussion

It appears that the chamber collected and concentrated emissions from the carpet, as evidenced by the similarities on qualitative examination and comparison of the ambient air and chamber samples within a site and by identification of the standard compounds in both the air and chamber samples. Further, there is good correlation between the calculated half-lives of the ambient air concentration and the emission rate at each site.

High ventilation air exchange rates were features of all of the sites. The American Society of Heating, Refrigeration, and Air Conditioning Engineers (ASHRAE) has developed a standard for minimum ventilation to achieve acceptable indoor air quality. ASHRAE Standard 62-1989 sets a ventilation rate of 10 L/s per person in smoking areas of office spaces. This figure is based on a design occupancy of seven persons per 100 $m^2$ of floor area and 100 percent make-up air of acceptable quality from outside.[17] Assuming this density, the measured air exchange rates at the study sites ranged from 6 to 28 times the ASHRAE standard.

The ASHRAE standard also recommends that levels of contaminants be maintained at less than one-tenth the OSHA permissible exposure limits (PELs). This is because the general population may be continuously exposed to the substance and have greater variability in age, health status, and susceptibility to toxic effects of a substance than industrial workers. The OSHA PEL is 1350 $mg/m^3$ (300 ppm) for VM & P naphtha,

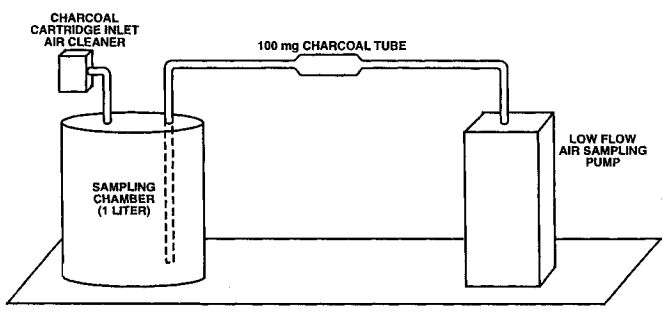


FIGURE 1. Dynamic head space chamber.

TABLE 2. Sampling Site 1

| Compound | Day 1 | Day 2 | Day 8 | Day 13 |
|---|---|---|---|---|
| Standard compounds present in ambient samples | | | | |
| Isooctane | √ | | | |
| Toluene | √ | √ | √ | √ |
| *n*-Octane | √ | √ | √ | |
| *p*-Xylene | √ | √ | √ | |
| *m*-Xylene | √ | √ | √ | |
| *o*-Xylene | √ | √ | √ | √ |
| *n*-Nonane | √ | √ | √ | √ |
| *d*-Limonene | √ | √ | | |
| *n*-Undecane | √ | √ | √ | √ |
| *n*-Tridecane | | √ | √ | √ |
| *n*-Tetradecane | | | | |
| *n*-Pentadecane | | | | |
| Standard compounds present in chamber samples | | | | |
| Isooctane | √ | √ | | |
| Toluene | √ | √ | √ | √ |
| *n*-Octane | √ | √ | √ | |
| *p*-Xylene | √ | √ | √ | |
| *m*-Xylene | √ | √ | √ | |
| *o*-Xylene | √ | √ | √ | √ |
| *n*-Nonane | √ | √ | √ | √ |
| *d*-Limonene | √ | √ | √ | √ |
| *n*-Undecane | √ | √ | √ | √ |
| *n*-Tridecane | | √ | √ | √ |
| *n*-Tetradecane | | | | |
| *n*-Pentadecane | | | | |

TABLE 3. Air Concentration (Milligrams/Meter[3])

| Day | Site 1 | Site 2 | Site 3 | Site 4 |
|---|---|---|---|---|
| 1 | 40.69 | 21.12 | 4.73 | 3.40 |
| 2 | 6.56 | 2.95 | 2.40 | 2.16 |
| 8 | 3.38 | 4.43 | 1.76 | 1.12 |
| 13 | 0.64 | 0.83 | 0.74 | 0.23 |

TABLE 4. Chamber Emission Rate (Milligrams/Meter$^2$/Hour)

| Day | Site 1 | Site 2 | Site 3 | Site 4 |
|---|---|---|---|---|
| 1 | 213.53 | 79.14 | 11.24 | 12.51 |
| 2 | 141.81 | 3.95 | 5.93 | 2.73 |
| 8 | 8.03 | 2.34 | 2.77 | 2.32 |
| 13 | 2.53 | 0.76 | 1.23 | 0.21 |

1600 mg/m$^3$ (400 ppm) for petroleum distillates (naphtha), and 525 mg/m$^3$ (100 ppm) for Stoddard solvent.[18] Some researchers use 1 ppm, equivalent to between 4 and 7 mg/m$^3$, depending on the molecular weight of the solvent, as the criterion level for determining acceptable indoor air quality.[4,19]

The odor threshold of mixtures of petroleum solvents has been tentatively established at approximately 4 mg/m$^3$, with a range of 0.5 to 5 mg/m$^3$. Sensory thresholds—levels at which persons begin to experience the acute toxic symptoms—have been estimated to be above 320 mg/m$^3$.[5,20,21] The ambient air concentrations of volatile organics in three of four sites were in the range of or above the reported odor thresholds on the last sampling day, 13 days after the carpet was installed.

None of the measured air concentrations approached the reported sensory thresholds for refined petroleum solvents. However, when discussing responses to indoor air pollutants, the psychological response may be as important as the toxic effects of the pollutant. Noxious odors may produce alterations in mood and demeanor independent of toxic effects associated with acute exposures.[22] Thus, office workers exposed to odors from new carpet installation may experience adverse effects at levels above the odor threshold but below the levels that evoke a toxic response.

TABLE 5. Linear Regression on Ln Total Mass

| Site | Correlation | Slope | Half-Life |
|---|---|---|---|
| Ambient air | | | |
| 1 | 0.955 | −0.309 | 2.26 |
| 2 | 0.907 | −0.220 | 2.72 |
| 3 | 0.967 | −0.123 | 5.63 |
| 4 | 0.982 | −0.150 | 4.62 |
| Chamber Sample Emission Rate | | | |
| 1 | 0.938 | −0.301 | 2.30 |
| 2 | 0.856 | −0.304 | 2.28 |
| 3 | 0.964 | −0.160 | 4.32 |
| 4 | 0.953 | −0.206 | 3.45 |

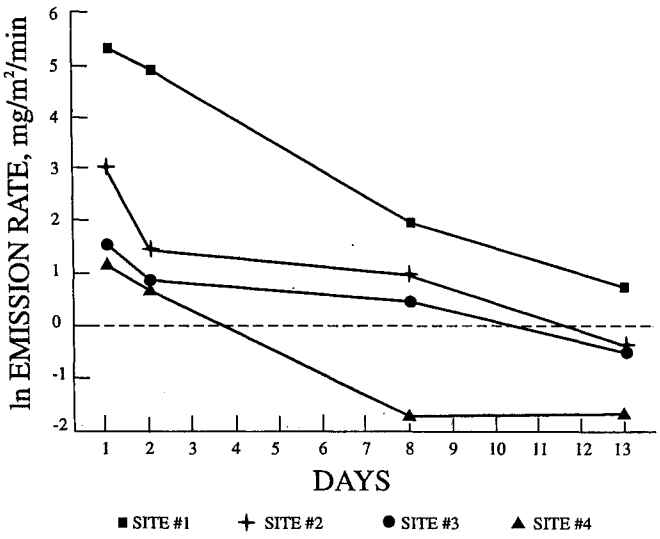


FIGURE 2. Graph of Ln of air concentrations.

## Conclusions

The most useful information from this study is the consistent types of volatile organic compounds identified at each site. New carpets and mastics emit a complex mixture of refined petroleum solvents. Within a site, the chromatograms from the ambient air and chamber samples appeared to have similar patterns, indicating that the carpet and mastic are the main contributors to the organic vapor burden at the site.

The data indicate that the majority of solvents are emitted within the first few days after the carpet is installed. This information can be used to develop control strategies. It is probably unwise to occupy spaces the day after installation of new carpet. Furthermore, carpet installations are often scheduled over the weekend to minimize impact on employees. If the carpet is installed on a Friday or Saturday while the office ventilation system is shut down to conserve energy, solvent vapors may accumulate over the weekend. Then, the employees arriving on Monday morning could receive a truly objectionable dose.

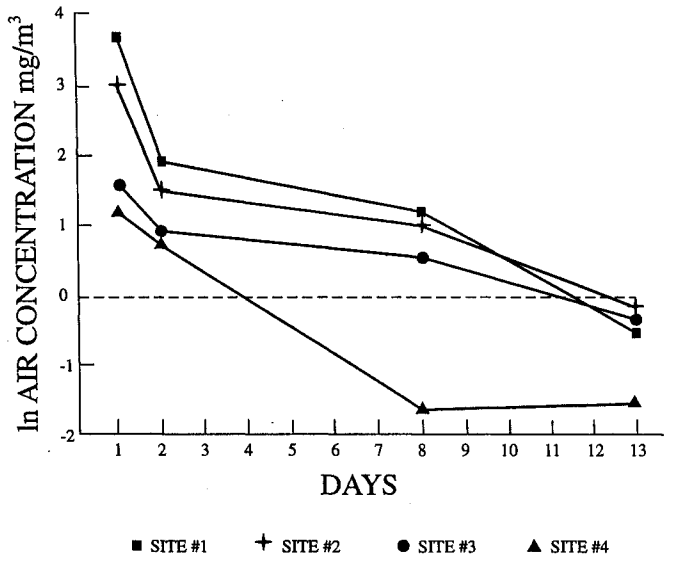


FIGURE 3. Graph of Ln emission rates.

It appears from this study that at least 2 weeks, with good ventilation, is the minimum time required for organics to decay to a level below the odor threshold for most individuals.

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