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Effects of Airflow on Emissions of Volatile Organic Compounds from Carpet-Adhesive Assemblies

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ABSTRACT

The effects of local air velocity and turbulence on the emissions from carpet-adhesive assemblies have been studied in a small-scale chamber. Velocities in the range of approximately 0.01 m/s to 0.25 m/s were imposed along with either a low or a high turbulence level. The concentrations of total volatile organic compounds (TVOC) and of nonane, decane, and 4-phenylcyclohexane (4PC) were measured as a function of time from which emission rates for each were computed.

For the conditions studied, it was found that increased velocities generally resulted in increased emission rates during the first 30 hours of a test in the higher velocity range of those studied and that increased turbulence levels also enhanced the early emission rates at lower average velocities. However, for the cases with the increased peak emission rates during the first 30 hours of a test, there were no perceptible corresponding reductions of the long-term emission rates as would have been desirable from an indoor air quality perspective.

INTRODUCTION

The emissions of volatile organic compounds (VOCs) from carpets and carpet adhesives in office buildings are of concern because of their potential influence on the wellness of building occupants. Many studies have been conducted to investigate the emissions of VOCs from carpets, adhesives, and building materials. The local air temperature, relative humidity (RH), and air change rate were usually kept constant, while the concentrations of VOCs from different carpets, adhesives, and building materials were measured (Black 1990; Colombo et al. 1990; Black et al. 1991; Hawkins et al. 1992; Wallace et al. 1987; Little et al. 1994; Nielsen 1985; Bayer and Black 1986). A study published by Sollinger et al. (1993) found that air velocity had little effect on the rate of emissions of VOCs from a carpet. Data on the effect of air velocity and turbulence on the VOC emissions from a carpet-adhesive-concrete assembly (a typical case for office buildings) have not been reported previously.

This study investigated the effects of local air velocity and turbulence on the emission rates of TVOCs, nonane, decane, and 4-phenylcyclohexane (4PC) from carpet-adhesive assemblies. The carpets and adhesives tested were typical commercial products normally installed in office buildings. They were tested at several velocities and turbulence levels in a test chamber (Zhang et al. 1996).

When new material is introduced to a building, it is generally found that the emission rate of materials increases, which reduces the indoor air quality. If the cause of this increased emission rate of undesirable material could be altered or enhanced during a short period of time while the building was unoccupied so that longer-term emission rates were reduced for the periods during which the building was occupied, this would be considered an improvement on the present situation. Although it is known that increasing the air change rate can improve air quality, this is done with an associated energy cost. Consequently, the aim is to reduce emissions during the occupancy period without incurring a significant penalty in terms of energy costs. This study was initiated to determine if increasing air velocity and turbulence in the early stages of the emission process (i.e., before occupancy of the space where the new material was introduced) would result in a reduction of undesirable emissions in later stages of the emission process when the space was occupied.

The results of this study will also help to increase understanding of the emission processes and their characteristics for carpet-adhesive assemblies, which will be helpful for the development of a suitable model to predict emission rates.

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EXPERIMENTS

Test Materials

The primary test materials, which are carpet and adhesives, were donated by their respective manufacturers. The 28 oz level-loop nylon (polypropylene) carpet was of a graphic construction, made using 100% nylon fiber (space dyed) and a synthetic jute textured back. It was stored in mylar bags from the time it was manufactured until the time it was used for a test. Vapor samples extracted from the mylar bags containing the carpet were analyzed and found to contain a TVOC concentration of 4.45 mg/m^3. This was taken as the headspace test result for the carpet. The synthetic latex base adhesive had a 3% mineral spirit content. Headspace tests on the adhesive consisted of placing a small amount of adhesive in a glass vial and sampling the vapor above the adhesive after 72 hours, which yielded a TVOC concentration of 1661 mg/m^3. The concrete substrate slab (250 mm × 500 mm × 40 mm) used for a test was placed in a 50 L static chamber for 24 hours, after which a sample of the vapor in the chamber was analyzed indicating a (headspace) TVOC concentration of 0.43 mg/m^3.

Facilities

A 1.0 m × 0.8 m × 0.5 m stainless steel chamber (Zhang et al. 1996) was used to test the carpet-adhesive assemblies. A schematic diagram of the measurement system is shown in Figure 1, with the test chamber schematic diagram in Figure 2. The chamber consisted of an inner and outer chamber. The outer chamber, which housed the inner chamber, was located in the test room. The inner chamber housed the test assembly. An axial fan was used to circulate the air through the inner chamber. The fan's DC motor was mounted outside the outer chamber to avoid introducing contamination from the motor. A TFE-sealed bearing was used to support the fan-to-motor shaft where it penetrated the wall of the outer chamber. Holes were drilled through the cylindrical housing of the fan to discharge the air drawn from the inner chamber into the outer chamber. The inner chamber had screened attachments at the air inlet and outlet to provide uniform airflow and to create several levels of turbulence. Two parallel fine mesh screens spaced 20 mm apart were used for a low turbulence flow. A higher turbulence level in the flow was achieved with 13 mm holes spaced 22 mm center to center. Before the emission tests, the airflow characteristics over the material specimen were measured.

Figure 3 shows the mean airflow velocity and turbulence kinetic energy distributions above the carpet surface for the velocity and turbulence level range of the six test cases discussed in this paper, which are documented more specifically in Table 1. The air velocity across the carpet sample was measured with a TSI hot-wire anemometer that was placed above the mid-point location of the carpet sample and 4 cm above the carpet surface for the emission tests.

Methods

The chamber was cleaned and purged with clean air (see Figure 2) for a minimum of eight hours before each test. This purging resulted in a VOC concentration of less than 0.01 mg/m^3 (0.015 ppm). The carpet-adhesive assemblies were prepared for testing as follows. First, the carpet was removed from the mylar

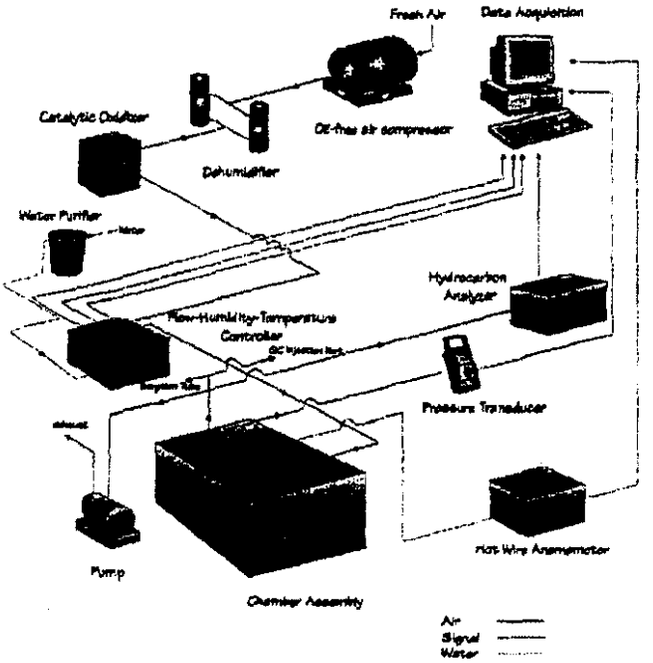


Figure 1 Schematic of the small chamber test system.

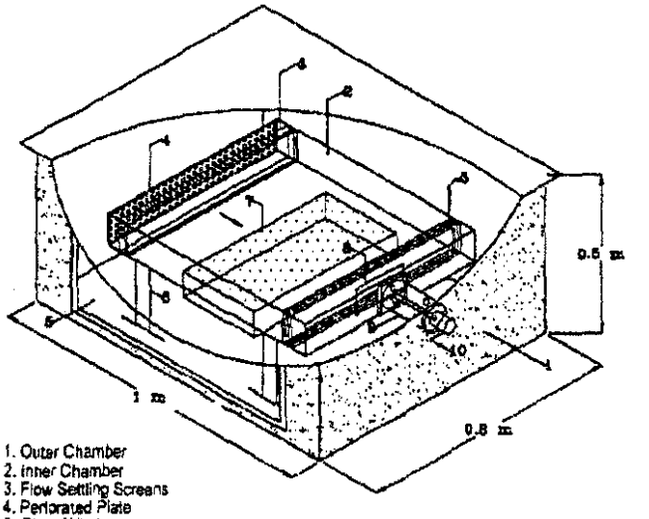
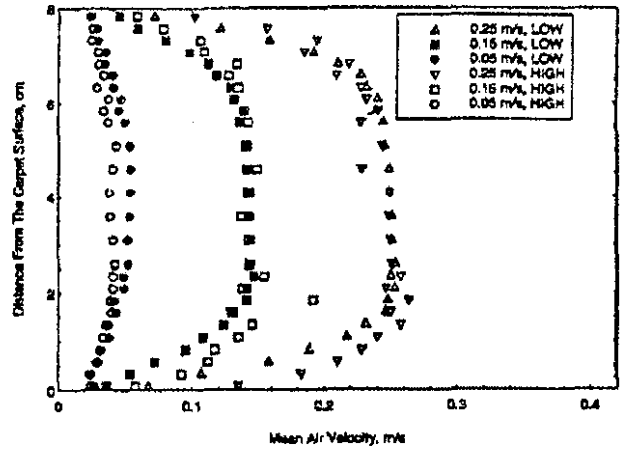


Figure 2 Schematic of the outer and inner chamber assembly.

bag in which it was stored, a piece suitable for the test was cut (250 mm by 500 mm), and the remainder was placed in the mylar bag. Adhesive was spread onto the substrate and allowed to get "tacky" for about 20 minutes before the carpet was placed on the adhesive. The carpet sample covered the entire surface of the substrate coated with adhesive, and, if any adhesive was inadvertently left uncovered by the carpet, it would have had a film formed over the new adhesive by the time the test was conducted. In addition, any area of edge would have been much smaller than the surface area of the carpet sample so that edge effects were considered minimal. The carpet mass, carpet area, and the adhesive mass used were measured and recorded for each sample assembly. The test assembly was placed in the inner chamber and the chamber sealed in preparation for gas sampling to begin. The test conditions of air change rate, air velocity range, and turbulence range were selected for each test, and the TVOC concentration, air velocity and turbulence data, air temperature and relative humidity, chamber pressure, and airflow rate were continuously measured and recorded for each test.

TVOC concentrations were continuously monitored during each test with a hydrocarbon analyzer with a flame ionization detector (FID) to obtain the information needed to choose appropriate sample sizes for the more detailed gas chromotograph with a mass spectrometer analyzer (GC/MS) analysis, which was done from samples taken at discrete time intervals. For the GC/MS analysis, sorption tube samples were taken from the chamber's exhaust air. The sorption tube used had a 4 mm inside diameter and was 229 mm long with a bed consisting of glass beads, 150 mg of Tenax TA of 25 to 35 mesh, and 150 mg of Ambersorb of 25 to 35 mesh. During the first hour, samples were taken every 15 minutes, then every 20 to 30 minutes for four hours followed by sampling at one- to two-hour intervals until the TVOC concentration began to decrease. Samples were then taken in the morning and late afternoon for the next two days, followed by one sample per day until the seventh day when the test sequence was terminated. The sampling frequency used depended on the measured rate of change of TVOC concentration in the chamber. The sorption tube samples were analyzed using a gas chro-

a. Mean air velocity:



b. Turbulence kinetic energy:

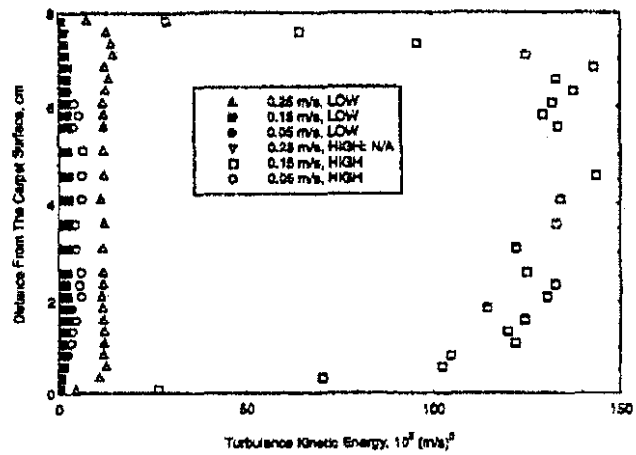


Figure 3 Airflow characteristics above the carpet surface measured at three velocity levels: 0.05 m/s, 0.15 m/s, and 0.25 m/s, and two turbulence levels: low, with screens, and high with the perforated plate.

TABLE 1
Actual Test Parameters

Test	Carpet Area	Carpet Mass	Adhesive Mass	Airflow	Average Velocity	Average Turb.
	m^2	g	g	Lpm	m/s	k/u^2
4	0.124	297.7	59.1	6.67	0.04	0.003-L
5	0.124	301.5	55.2	6.67	0.10	0.004-L
6	0.123	300.0	51.35	6.65	0.22	0.008-L
6r1	0.124	328.3	50.6	6.65	0.26	0.008-L
6r2	0.123	300.8	55.0	6.65	0.26	0.008-L
7	0.124	299.5	59.0	6.65	<0.04	0.077-H
8	0.122	299.2	58.0	6.67	0.26	0.212-H

matograph (GC) equipped with a flame ionization detector (FID). The reference compound used for the GC calibration was cyclohexane. The GC results of the gas samples taken from the chamber tests of the carpet-adhesive-substrate assemblies were compared with the results of analysis of the individual components taken as headspace tests to identify the individual compounds and determine their concentrations. The concentrations of TVOC were calculated by summing the area under all the peaks of the gas chromatogram and using cyclohexane as the calibration standard.

Seven tests were preformed to investigate the velocity and turbulence effects on the emissions of VOCs from carpet-adhesive assemblies. Table 1 is a summary of the actual test parameters. All tests were run at 23 ±1.3°C and 45.5 ±3% RH. Tests 6r1 and 6r2 were repeat tests of test 6, performed to verify the repeatability of a typical test.

RESULTS AND DISCUSSION

The measured TVOC concentration data vs. time and the TVOC emission rate vs. time calculated from the measured TVOC-time record are shown in Figures 4 and 5, respectively. The results indicate that Test 6 (with an average velocity of 0.22 m/s, average turbulence/relative kinetic energy $k/(u^2)$ of 0.008) and Test 8 (velocity of 0.26 m/s, turbulence K.E. of 0.212) have higher peak concentrations and emission rates than those of Tests 4 (velocity of 0.04 m/s, turbulence K.E. of 0.003), 5 (velocity of 0.10 m/s and turbulence K.E. of 0.004), and 7 (velocity of <0.04 m/s, turbulence K.E. of 0.077). Based on this observation, it appears that the emission rates during the initial 30 hours of testing are increased by increasing the velocity of air blowing over the sample assembly. However, after this initial 30-hour period, the emission rates are not noticeably affected by the airflow velocity or turbulence level for the range of conditions examined here.

It is suggested that this first period in which the emission rates are influenced by the velocity of the air over the sample is a period during which the release of the volatiles to the surroundings is not being controlled solely by diffusion effects internal to the carpet or adhesive layers but rather by a combination of the internal diffusion effects and the external convective transfer effects. This result is not quite the same as is observed in the case of drying large slabs of wood (Rohsenow and Choi 1961). In the case of the wood drying, as long as the air at the surface of the slab is saturated with water vapor,

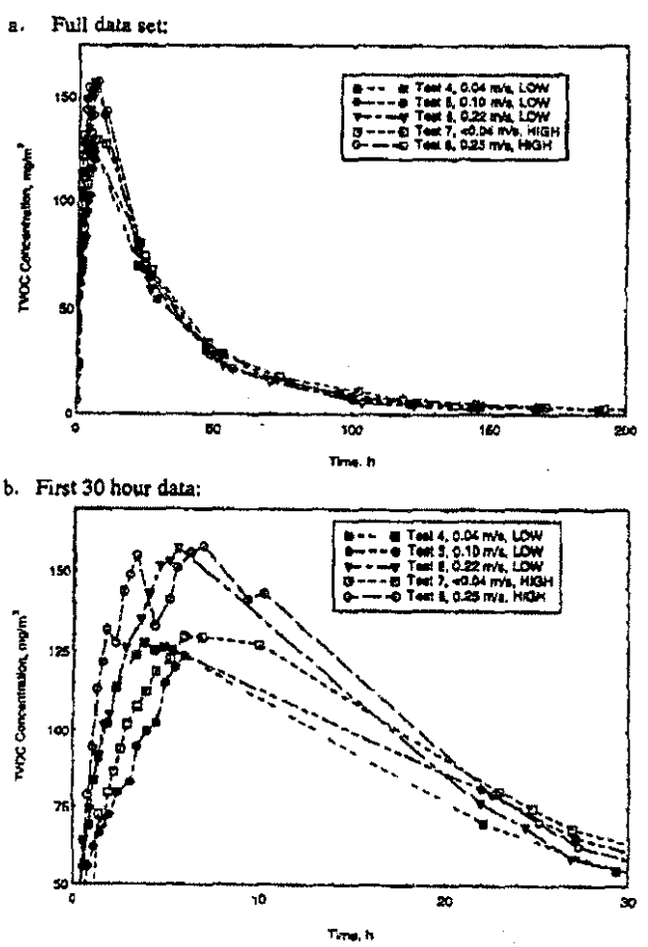


Figure 4 Measured TVOC concentration vs. time.

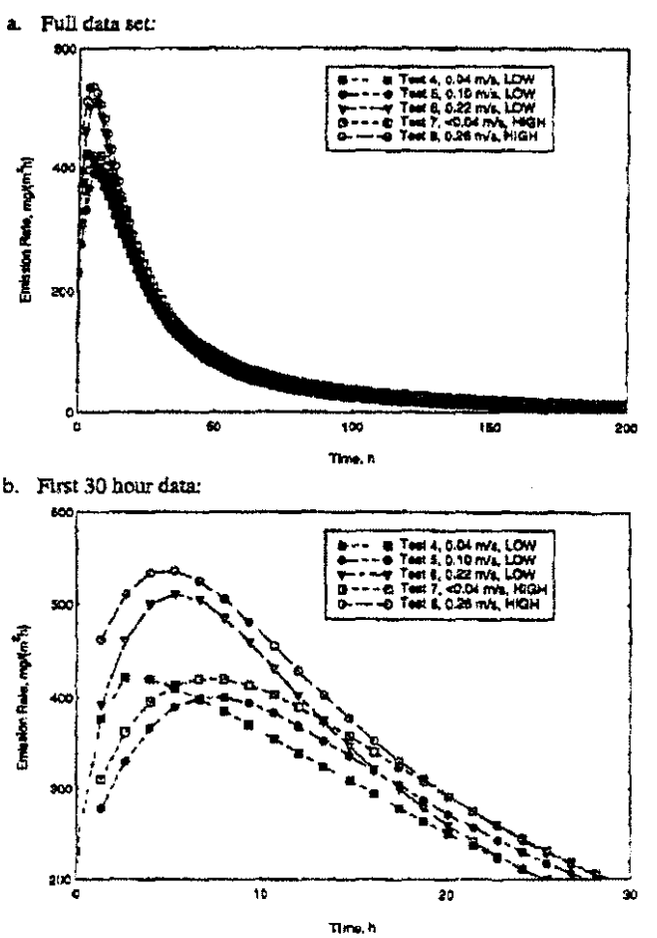


Figure 5 TVOC emission rate vs. time.

external convective effects determine the rate of drying, during which time the transfer rate is constant if the convective coefficient is constant. Thereafter, the rate of diffusion of water to the surface determines the drying rate, as long as the external convection continues to remove the water as it finds its way to the surface. In the case under study here, the emission of volatiles from the adhesive-carpet assembly, there is no period during which the mass transfer rate is constant in spite of the fact that the conditions determining the convective coefficient are held constant. Since the emission rate during this early period is affected by the change of convective conditions, however, it would suggest that the rate of emission during this period is influenced by both the external convection rate and the rate of diffusion of volatiles to the surface. The physical changes that occur in the adhesive-carpet assembly that cause these two distinct regimes are the focus of an ongoing study.

The emission characteristics of nonane and decane, which originate from the adhesive, and 4PC, emitted by the carpet, were examined to determine whether these specific compounds followed the trend described above for the TVOC concentrations in terms of the effect of velocity and turbulence. Figures 6 and 7 show the emission rate vs. time plots obtained for nonane and decane, and Figure 8 shows the measured concentration for 4PC as a function of test time for the same tests for which the TVOCs are shown in Figures 4 and 5.

Tests 4, 7, and 8 had adhesive masses of 59.1 g, 59 g, and 58 g, respectively. Figure 6 indicates that Test 4 exhibited a very high nonane emission rate during the first two to three hours, but then its emission rate dropped rapidly, whereas the emission rate for Test 8 did not peak quite as high as that of Test 4 but remained higher than that of Test 4 after the crossover of the two curves at about three hours. Except for Test 4, the nonane emission rates vs. test time consistently show that during the first 20 to 30 hours, a combination of air velocity and turbulence level determine the rate of emissions, as observed with the overall TVOC emissions. The two tests with the highest velocities (Tests 6 and 8) exhibited the highest emission rates during the first 30 hours, with Test 8 showing slightly higher rates during this period, perhaps because of the higher turbulence levels. Then, as the velocity was reduced, Test 7, with a lower velocity but higher turbulence level than

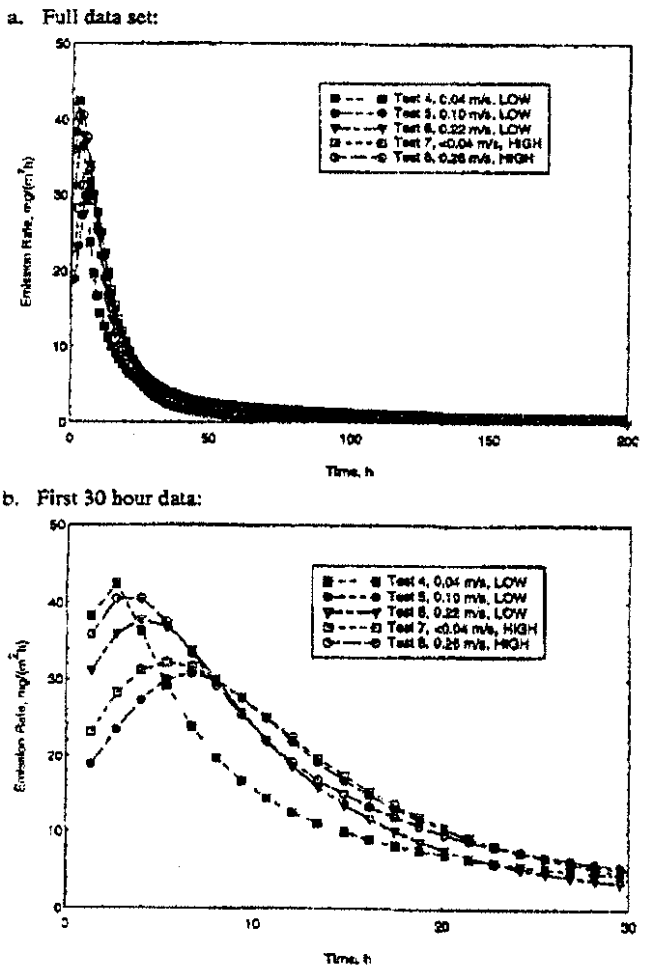


Figure 6 Nonane emission rate vs. time.

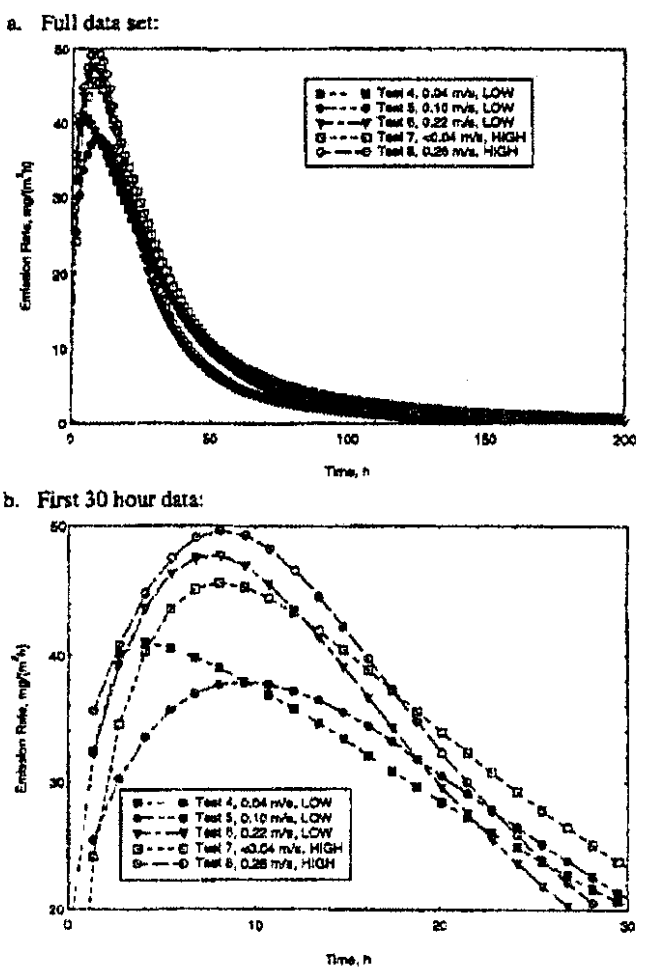


Figure 7 Decame emission rate vs. time.

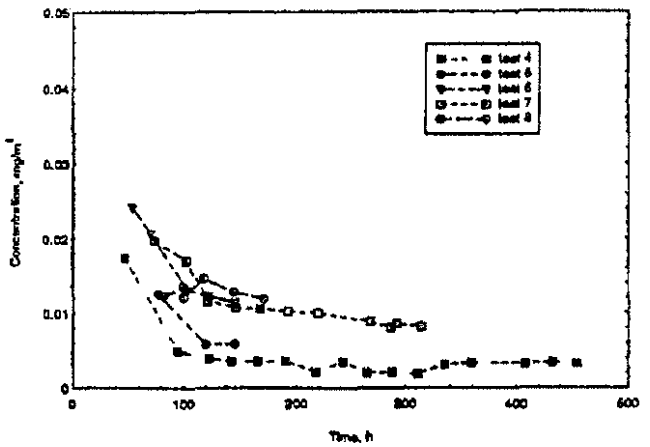


Figure 8 Measured 4-PC concentration vs. time.

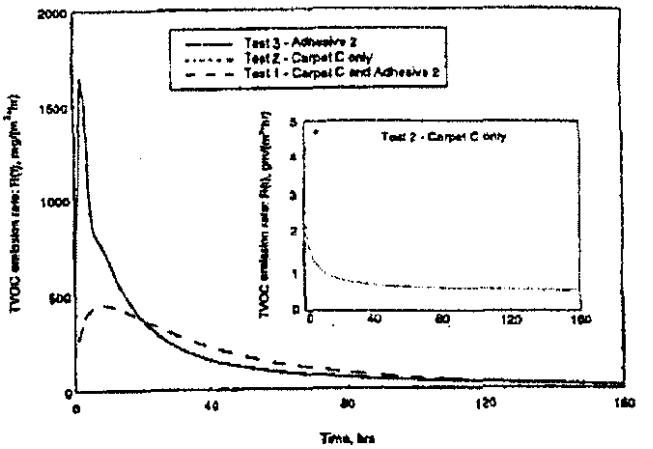


Figure 9 Comparison of TVOC emission rates between the material assembly and the individual materials.

that of Test 5, exhibited a higher emission rate than for Test 5 during the first ten-hour period with almost identical rates during the next ten-hour period.

Figure 7 shows that the emission rates of decane also show trends consistent with those observed for nonane and the TVOCs. In this case, Test 8, with the highest velocity and high turbulence levels, produced the highest emission rates during the first 20-hour period, followed by Test 6, with slightly lower velocity than Test 8 but with lower turbulence levels. Test 7, with much lower velocity than either Test 8 or Test 6 but with a high turbulence level, showed lower decane emission rates than Tests 8 or 6 during the first 12 hours or so but then crossed over both other rate trends to show higher emission rates after about 20 hours. Test 5, with low velocity and low turbulence levels, showed the lowest rates of decane emission during the first 20-hour period, but then it, too, joined the trend shown by the others. Test 4 began strongly, as with the nonane, but fell off sharply after a few hours.

Figure 8 shows that the 4PC (emitted by the carpet) concentrations were very low (by several orders of magnitude) by comparison with the nonane and decane (emitted by the adhesive as discussed earlier). It was noted that the 4PC became detectable only after approximately 50 hours due to the sampling volume and GC sensitivity chosen for quantifying the high levels of concentrations of VOCs from the adhesive. This indicates that the VOCs emitted by the carpet are of negligible concern relative to those emitted from the adhesive, at least during the first several hundred hours after the adhesive is applied, which is the duration of the observations in the tests reported here.

A preliminary set of tests was conducted to examine the effect of the carpet placed over the adhesive, as compared with the adhesive alone, on the rate of emission of the volatile compounds that originate with the adhesive. Three tests were conducted, one with adhesive only, another with carpet only, and a third with the carpet placed over the adhesive as it would be on a floor assembly. Figure 9 shows the TVOC emission rates computed from concentrations measured at selected time intervals for these three cases. The TVOC emission rates from the carpet alone are too low to show meaningfully on the same scale used to show the emission rates from the adhesive or the adhesive-carpet assembly. Examination of the emission rate for the adhesive alone and comparing it with the emission rate for the carpet-adhesive assembly indicates that the carpet creates a delay to the escape to the air of the volatiles being released from the adhesive layer beneath the carpet. Since the emission rate with the carpet over the adhesive is lower during the first 20 hours but later is higher than that with the adhesive alone, it would suggest that the volatiles are somehow trapped for a short while in the carpet and subsequently released. This process is being examined further.

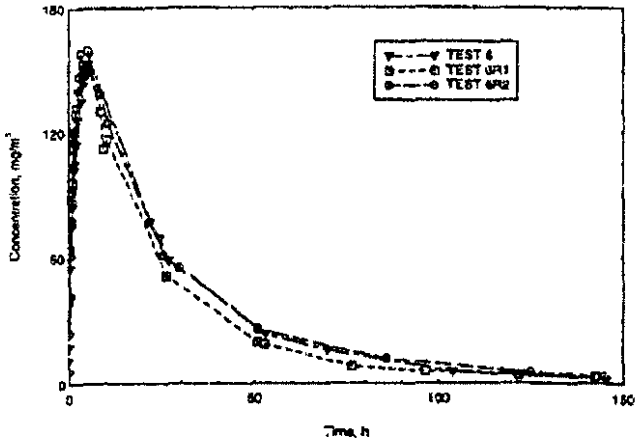
The concentration vs. time for Test 6 and the two repeat tests, 6r1 and 6r2, are shown in Figure 10. The band of measured results gives an indication of the repeatability of the measurements reported in this paper.

CONCLUSIONS

The primary focus of this research was to determine whether local air velocity and turbulence levels had an effect on the emission rates of volatile organic compounds from carpet-adhesive assemblies.

Tests with higher velocities (Tests 8 and 6) exhibited higher TVOC emission rates during the first 30 hours than tests at lower velocities. As the velocities were reduced slightly, turbulence levels had a greater impact on the early emission rates than did the average velocities. After the initial 30-hour period (which may be a different period with different adhesive-carpet assemblies), the velocity and turbulence levels had no observable effect on the volatile emission rates. It is suggested that the resistance to release of the volatiles internal to the carpet-adhesive assembly became dominant after this initial period (30 hours in this case), whereas during the early period, external

a. Full data set:



b. First 30 hour data:

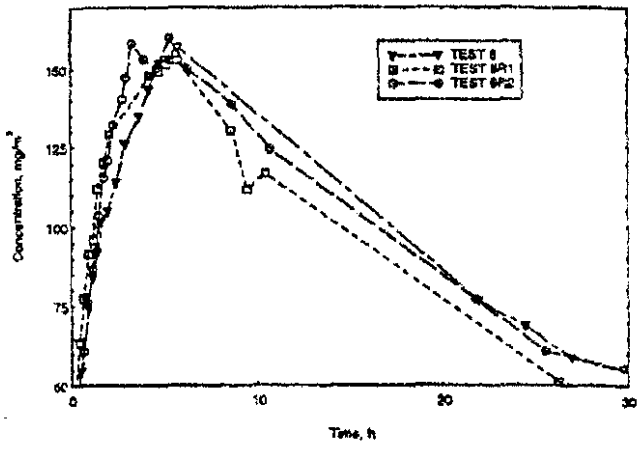


Figure 10 Measured concentrations vs. time for the repeat tests.

convective effects, characterized by parameters such as velocity and turbulence level, played an important role in determining the rate of emission and mass transfer from the surface.

The implications of these findings for indoor air quality in buildings in which new carpet has been installed with the type of adhesive used here is that higher purge rates during the first day, or slightly more, will hasten the emission rates slightly during the period for which the emission rates are very high already but will not affect the emission rate and, hence, the curing time significantly when the second phase of the process sets in. This study is continuing to seek a better understanding of the mechanisms involved in the hope of developing some practical means of accelerating the overall curing process in order to make an office habitable, with good air quality, in a shorter period of time after new material has been added.

The results reported here were somewhat preliminary in the sense of providing qualitative results as well as insights into the parameters that may be of importance in the phenomena being studied. They do not provide a final quantitative set of data. Further tests to achieve this end are being done. Some quantitative inferences can be drawn by noting that all effects discussed are more significant than error bars that could be inferred from the test case repeated three times, as illustrated in Figure 9.

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REFERENCES

Bayer, C.W., and M.S. Black. 1986. Formaldehyde and other VOC exposures from consumer products. *IAQ '86, Managing Indoor Air for Health and Energy Conservation*, pp. 454-468. Atlanta: American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.

Black, M. 1990. Environmental chamber technology for the study of volatile organic compound emissions from manufactured products., *Indoor Air '90, July 29 - August 3, Toronto*, Vol. 3, pp. 713-718.

Black, M.S., W.J. Pearson, and L.M. Work. 1991. A methodology for determining VOC emissions from new SBR latex-backed carpet, adhesives, cushions, and installed systems and predicting their impact on indoor air quality. *IAQ 91, Healthy Buildings*, pp. 267-272. Atlanta: American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.

Colombo, A., M. DeBortoli, E. Pecchio, H. Schauenburg, H. Schlitt, and H. Vissers. 1990. Chamber testing of organic emission from building and furnishing materials. *The Science of the Total Environment* 91, pp. 237-249.

Hawkins, N.C., A.E. Luedtke, C.R. Mitchell, J.A. LoMenzo, and M.S. Black. 1992. Effects of selected process parameters on emission rates of volatile organic chemical from carpet. *American Industrial Hygiene Association Journal* 53(5): 275-282.

Little, J.C., A.T. Hodgson, and A.J. Gadgil. 1994. Modeling emissions of VOCs from new carpets. *Atmospheric Environment* 28 (2): 227-234.

Nielsen, P.A. 1985. The influence of aging and air change on the emission rate of gases and vapours from some building materials. *CLIMA 2000*, Vol. 4, Indoor climate, pp. 207-213.

Rohsenow, W.M., and H. Choi. 1961. *Heat, mass and momentum transfer*, p. 392. Englewood Cliffs, N.J.: Prentice Hall.

Sollinger, S., K. Levsen, and G. Wunsch. 1993. Indoor air pollution by organic emissions from textile floor coverings: Climate chamber studies under dynamic conditions. *Atmospheric Environment* Vol. 27B, No. 14, pp. 183-192.

Wallace, L.A., E. Pellizzari, B. Leaderer, H. Zelon, and L. Sheldon. 1987. Emissions of volatile organic com-

pounds from building materials and consumer products. *Atmospheric Environment* 21(2): 385-392.

Zhang, J.S., C.Y. Shaw, J.M. Kanubus-Kaminska, R.A. MacDonald, R.J. Magee, E. Lusztyk, and H.J. Weichert. 1996. Study of air velocity and turbulence effects on organic compound emissions from building materials/furnishings using a new small test chamber. National Research Council Canada.

BIBLIOGRAPHY

ASTM. 1989. Standard guide for small scale environmental chamber determination of organic emissions from indoor materials/products, Draft #6 (12/89). Philadelphia: American Society of Testing and Materials.

Bayer, C. 1991. Carpet policy dialogue. *Progressive Architecture* 72(3): 127-128.

Davidson, J.L., M.S. Black, W.J. Pearson, L.M. Work, and D.P. Miller. 1991. Carpet installation during building renovation and its impact on indoor VOC concentrations. *IAQ 91, Healthy Buildings*, pp. 299-303. Atlanta: American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.

Girman, J.R. 1984. Volatile organic emissions from adhesives with indoor applications. *Indoor Air*, Vol. 4, Chemical characterization and personal exposure, pp. 271-276. Stockholm, Sweden.

Handbook of Chemistry and Physics, 52d ed. CRC.

Healthy Materials, Spring 1994, No. 1.

Low, J.M. 1996. A study of the velocity and turbulence effects on volatile organic compound emissions from carpet-adhesive assemblies. Master of engineering thesis, Carleton University, Ottawa, Ontario, Canada.

DISCUSSION

Francis Allard, Professor, LEPTAB, University of La Rochelle, France: Thank you for your interesting presentation. In your experiments, did you check the dependency of the emission rate vs. the Reynolds number? We know theoretically this dependency and your experiment should allow us to check it. The low influence of turbulence at low velocity can also be explained because, in this case, the boundary layer building up along the solid surface in laminar and this case is then very close to the pure laminar flow.

E.G. Plett: We have not specifically correlated the emission rates with the Reynolds number. The information to do so is contained on our graphs. Several questions must be addressed in order to do so meaningfully. For example, what length scale is appropriate and at what time in the curing process is of interest for the correlation. The length scale is simply a linear multiplier so would not change the nature of the relationship, but the time is crucial since at early times, there is an effect of flow velocity, but at later times, there is no noticeable difference of emission rates with change of flow velocity. Consequently, any correlation would be time dependent.

Xudong Yang, Massachusetts Institute of Technology, Cambridge, Mass.: This is a very interesting study. Understanding the effects of air flow rate on material emissions is especially important to indoor environment modeling. An important finding from the study is that for the carpet-adhesive assemblies, air velocity only affect the early stage emissions. This behavior looks quite similar to that of a typical wet material. In the experiments, did you make sure that the adhesive had no direct exposure to the chamber air so that the "edge effect" was indeed negligible?

E.G. Plett: The behavior at early times has some characteristics like wet materials, but not entirely. As noted in the paper, this does not behave as the simple drying of a solid when it is very wet on the surface. In the case of drying a porous solid that is wet on the surface, as long as the convection rate is constant and the surface remains wet, the rate of drying remains constant. That is not the case observed here. In the case of the carpet-adhesive combination, the rate of emission decreases with time even in this early period, suggesting a resistance to emission which is increasing with time, unlike the simple evaporation at the surface of a wet, porous solid. The edge effect was estimated to be essentially negligible in the test results reported here.