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CHEMICAL EMISSIONS DURING RECARPETING OF A CANADIAN OFFICE BUILDING

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One floor of a large office building in the Ottawa area was monitored during a month-long recarpeting project in which nylon carpet and latex adhesive were used. Total volatile organic chemical (TVOC) samples were collected in several locations at various times after carpet was installed. The TVOC concentration due to the recarpet process showed the expected exponential decrease with time. Emission rates calculated from TVOC concentrations and measured air change rates agreed well with values determined in laboratory studies, and were much greater than the emission rate of the carpet alone. Some information was collected that provided a link between occupant discomfort symptoms and exposure to the recarpet process.

INTRODUCTION

During the last few years, recarpeting of office spaces has caused a number of indoor air quality complaints in buildings owned and managed by Public Works Canada (PWC).

Most recarpeting projects in PWC buildings are carried out while the building is occupied. To minimise disruption to tenants' work, and cut down exposure to the noise and chemicals generated during the process, the task is usually carried out at night. Furniture is removed beforehand then replaced on the new carpet. Many buildings turn off their ventilation systems overnight to save energy, and this has sometimes resulted in installation being carried out with no ventilation to remove glue and carpet chemicals. Chemical emissions do not stop when the new carpet is in place. Thus, to reduce chemicals in recarpeted areas to what they were before recarpeting requires extra ventilation after installation also. However, no information has so far been available to indicate over what period this should be necessary.

The purpose of the work described here was to monitor release of chemicals during and after carpet installation in order to justify ventilating during the procedure, and to determine for how long afterwards the extra ventilation should be continued.

The building selected for the study is a large office building in the Ottawa area that is owned by PWC. The building has 14 floors, and is tapered in shape. The lower floors, including the third floor used for this project, have a large area, arranged mainly as open offices with privacy screens. Because of the large interior space, cooling is required during all seasons.

Only one floor of the building was monitored. About 300 sq yd (230 m^2) of carpet were laid each night, and the entire installation took 21 nights. About 3/4 of the total area of the floor was recarpeted. The carpet was nylon with a primary backing of polypropylene. The principal glue used was a spray-on water-based adhesive containing 5-10% mineral spirits. The building ventilation system was run continuously throughout the installation, and continued afterwards as carpet was being installed on another floor. A floor plan indicating the recarpeting schedule is shown in Figure 1.

METHOD

It was assumed that the major factor controlling TVOC concentrations in any recarpeted section was the time elapsed since carpet installation. This implies several other assumptions, namely:

1. Carpet emissions are the same for all rolls (or differences are unimportant)
2. Carpet glue emissions are the same for each section
3. Other TVOC sources are insignificant
4. All sections receive the same amount of ventilation air
5. There is little air flow between sections

The first assumption is reasonable, since the carpet all came from the same batch. Also, laboratory studies (Black, Pearson and Work, 1991) indicated that carpet emissions were much less than glue emissions when water-based adhesive was used. The second assumption is more questionable. The glue was manually sprayed onto the floor, which resulted in some variability. Also, small quantities of different glues were used on the perimeter edge and for seams, and perimeter length and seam length varied from night to night. The third assumption was found not to be true. Measurements before recarpeting started indicated a building background concentration due mostly to liquid process photocopier fluids. To minimize this source of error, background concentrations were measured and subtracted as described below.

The fourth assumption is also not true, since the building was designed to deliver more air to the perimeter than to the interior. In addition, it was noted that carpet and glue odours persisted longer in closed offices. To reduce this source of error, most air samples were collected in open office areas away from the perimeter. The fifth assumption is considered reasonably good in view of the large number of privacy screens used on this floor.

Since contaminant concentrations in air are dependent on the amount of dilution provided by the ventilation system, the amount of outdoor air entering the system was measured immediately before samples were collected.

The ventilation system serving the third floor uses both hot and cold supply air and controls temperatures at the workstations by varying the relative quantities of each. The hot deck contains 100% recirculated air, and the cold deck both recirculated and outdoor air. To determine the amount of outdoor air in the cold deck, carbon dioxide concentrations were measured in the hot and cold deck supply, and in the outdoor air intake. To determine what fraction the cold deck flow was of the total flow, the hot and cold deck flows were obtained from a computer printout of the sensor readings. The fraction of outdoor air (OA) in the supply air was then calculated using the equation:

$$OA = \frac{(CO_2)_{hot\ deck} - (CO_2)_{cold\ deck}}{(CO_2)_{hot\ deck} - (CO_2)_{outdoor\ air}} \times \frac{(\text{cold deck air flow})}{(\text{hot + cold deck flow})}$$

The disadvantages of this approach are as follows:

- It measures the amount of outdoor air supplied by the air-handling system not the amount delivered to specific floors or locations (the system serves floors 2-6)
- It does not include the effects of infiltration
- It does not include the effects of interzonal movement of air

A 1988 balancing report for this ventilation system indicated that the third floor was receiving the correct fraction of air flow for the floor area, but local variations on the floor due to different cooling demands cannot be taken into account using this method of estimating outdoor air. Interzone movement is probably not important in this series of tests, since all of the third floor, and the floors above and below, are served by the same ventilation system. Infiltration or exfiltration will have more effect at the perimeter of the building, and this provides an additional reason for avoiding sampling near the perimeter.

Contaminant concentrations in air can be mathematically related to the emission rate of a material or process using mass balance equations. This approach has previously been used by PWC to study photocopier emissions (Kerr and Sauer, 1990), and is valid when air in the space is perfectly mixed, and when adsorption and desorption effects involving furnishings can be ignored.

If the rates of emission and removal of TVOC remain constant, the concentration eventually reaches a constant level known as the steady state concentration, C_{ss}. If the outdoor air concentration of TVOC is zero, the mathematical relationship reduces to the simple equation

$$C_{ss} = Q_c / Q_a,$$

where Q_c is the rate of emission of TVOC, and Q_a is the outdoor air flow rate. The units used here are: mg/m^3 for C_{ss}, mg/m^2•hour for Q_c, and m^3/m^2•hour for Q_a.

This equation can be used to adjust concentrations to different ventilation rates assuming a constant emission rate, or to determine emission rates corresponding to specific concentrations and outdoor air rates.

To determine the relative contributions of carpet and adhesive, the TVOC emitted by a sample of the carpet was measured by Air Quality Sciences Inc. using the method described by Black, Pearson and Work (1991).

Conversations with occupants during sampling revealed that a number of people were suffering symptoms such as eye irritation and headache after installation of carpet in their work areas. Because little data is available linking symptoms and chemical concentrations, a short questionnaire was prepared to gather information on symptoms and their duration. The questionnaire forms were distributed to the occupants of the recarpeted areas by tenant managers, and completed forms returned to PWC.

EQUIPMENT

The carbon dioxide measurements were made with a non-dispersive infrared analyser, Fuji model ZFP5. The instrument was calibrated with zero gas (carbon dioxide-free air) and span gas (approximately 1000 ppm carbon dioxide in ultrazero air). Precision is estimated to be about ± 20 ppm, and accuracy ± 30-40 ppm.

Real-time measurements of TVOC were made using a photoionisation detector, HNU Systems model PI 101. This was equipped with an 11.7 eV UV lamp and calibrated to read mg/m^3 of toluene. The instrument zero was established using outdoor air, since commercial ultrazero air contains small quantities of hydrocarbons that cause non-zero instrument response. With the 11.7 eV lamp, the PI 101 responds to most VOC commonly found in office air.

To obtain more accurate estimates of TVOC, air samples were collected, and these were analysed by the National Research Council. Sample tubes containing three adsorbents (glass beads, tenax and ambersorb) were used. These trap a wide range of low and medium polarity VOC effectively. Sample analysis involved flame ionisation detector (FID) measurement of TVOC quantity and gas chromatograph/mass spectrometer (GC/MS) separation and identification of some of the chemicals. The method is described more fully elsewhere (Tsuchiya, 1988). The measurement accuracy is about ± 20%.

RESULTS

The photoionisation detector was used to detect local variations in concentration in recently recarpeted areas. This was useful in selection of representative sampling locations. Measurements at different heights above the floor indicated that there was a vertical concentration gradient. To minimise the effect of this, all sampling in recarpeted areas was done at desk top level.

31 air samples were collected and analysed for TVOC quantity as described above. These included a field blank (0.03 mg/m^3), an air intake sample (0.2 mg/m^3), samples on the second and third floors before recarpeting started (both 0.6 mg/m^3), one sample per day at a third floor location that had not been recarpeted (0.9-2.0 mg/m^3), and 18 samples spread over 11 of the 21 recarpeted sections (0.8-16.9 mg/m^3). The third floor sampling locations are identified in Figure 1.

For the 18 samples from recarpeted areas, the building background concentration was assumed to be equal to the concentration measured that day in a non-recarpeted location, and this was subtracted to yield TVOC concentrations due to the recarpeting process.

Outdoor air percentages were measured immediately before sample collection using the method described above. On five of the sampling dates, percentages fell in the range 30±3%, and on the remaining three dates were 24%, 38% and 42%. For these three dates, the TVOC concentrations due to recarpeting were converted to 30% outdoor air equivalents using the steady state equation.

The plot of TVOC concentration due to recarpeting (corrected to 30% outdoor air as necessary) as a function of time since recarpeting is shown in Figure 2. Concentrations less than zero (due to building background concentrations greater than recarpet area concentrations) are shown as zero. The plot has the expected exponential shape. A least squares fit of the natural logarithm of the non-zero concentrations against time yielded the result:

TVOC concentration = 14.2 Exp (-0.42t) t = time in days

The line calculated with these constants is also shown in Figure 2. The root-mean-square deviation of the data was 0.4 mg/m^3.

TVOC emission rates for the recarpeting process were determined using concentrations calculated from the fitted constants along with data on the building floor area and airflow rates.

The total floor area served by the system that ventilates the third floor is 38,364 m^2. The average of the total supply airflows recorded on the sampling dates, 125.5 m^3/sec, was used with an outdoor air percent of 30%, to yield an average air exchange rate of 0.3 x 125.5 x 3600 = 135,540 m^3/hour. This corresponds to about 1.5 air changes per hour, or 3.5 m^3/m^2•hour.

The calculated TVOC concentration at the one-day mark (9.4 mg/m^3) was used to compute the emission rate to allow comparison with the laboratory emission data of Black, Pearson and Work which were taken 24 hours after the material was placed in the test chamber. The steady state equation was used with the air exchange rate of 3.5 m^3/m^2•hour, and TVOC concentration of 9.4 mg/m^3 to obtain an emission rate of 33 mg/m^2•hour.

The method used by Air Quality Sciences for measuring carpet emission uses a chamber ventilated at 1.0 air changes/hour, a temperature of 23 °C and relative humidity 50%. The loading factor of the sample is 0.41 m^2/m^3. This factor is the same as carpet experiences in a building of ceiling height 2.4 m, approximately the same as in the building studied here. The temperature and air change rate in the building were similar to the chamber, though the relative humidity was lower, about 20%.

The emission rate measured for the carpet used in this study, 0.43 mg/m^2•hour, is considerably smaller than the TVOC emission rate from the recarpeting process in the building, 33 mg/m^2•hour. This indicates that the chemicals emitted during recarpeting are mostly from the adhesive, not the carpet.

The emission rate of 33 mg/m^2•hour found for the recarpeting is lower than the emission rates of 88-153 mg/m^2•hour determined by Black, Pearson and Work (1991) for carpet directly glued down on concrete using latex adhesive. However, their adhesive was trowelled onto the concrete, not sprayed. The installer on this carpet job indicated that the amount of sprayed glue required is about one third of the amount of trowelled. This could explain the difference between the emission rates measured in building and laboratory .

Measuring emission rates in buildings is considerably more complicated than using a laboratory test chamber. A number of potential sources of error in the building study were identified early in the project, and the test procedure was adapted to minimise their effects. This has resulted in measured concentrations precise enough to allow determination of a good decay curve and an emission rate for the recarpeting process. However, the accuracy of the data has not been fully established.

The major source of inaccuracy is thought to be the incomplete mixing of the air in recarpeted areas. This caused a steady decrease in TVOC concentration with height above the floor. Taking all samples at desktop height ensured that they were all at the same point on the concentration gradient, but it is not known whether this point represents the average concentration. This problem needs to be addressed in future studies. Adsorption and desorption effects on the furnishings were not taken into account during this study. It is possible that they contribute to the observed concentration gradient.

Another possible source of inaccuracy considered was measurement of outdoor air rate, because differences in carbon dioxide concentrations in the intake, hot deck and cold deck were small, and because there were concentration changes across the cold deck duct due to incomplete mixing of return and outdoor air. However, this is not considered a serious source of error in practice for the following reasons:

- the system is designed to introduce a minimum of 20% outdoor air, and the air change rate was measured to be 22% on the coldest day of winter (-28 °C)
- the system design should result in outdoor air rates that change linearly with outdoor temperature in cold weather, and an approximately linear relationship was observed.

Although the emission rate changes continuously with time, use of the steady state approximation is not considered to be an important source of error because the rate of change is slow. Using the fitted constants, TVOC concentrations are predicted to change at less than 2% per hour, which is about the same as the change in outdoor air rate that occurred due to fluctuations in cooling demand and outdoor air temperature.

244 questionnaire forms were distributed to occupants of the recarpeted area within two weeks of completion of the work. Of these, 124 were returned completed, a 51% response rate. Respondents were asked how strongly they were affected by the installation, what the symptoms were, how long symptoms lasted, and were also encouraged to comment on how the installation was carried out.

75 respondents indicated that they experienced slight, moderate or strong effects and the remaining 49 had no effects. The symptoms reported most frequently were headache, tiredness, eye, nose and throat problems and nausea. The majority of people slightly affected experienced symptoms only for 1-3 days, whereas the moderate sufferers peaked at 3-5 days. Overall the number of people experiencing symptoms is roughly constant over the first three days, decreases somewhat by the 5 day mark, and is fairly small after 7 days. From Figure 2, the TVOC concentration due to recarpeting is less than 1 mg/m^3 after 7 days. The building background concentration averaged slightly more than 1 mg/m^3 so that the total concentration after 7 days was approximately 2 mg/m^3.

Molhave has verified that people can suffer mild respiratory irritation, loss of concentration etc. as a result of exposure to low concentrations of mixtures of chemicals. His analysis of several building studies indicated a complaint threshold of about 2 mg/m^3 (Molhave, 1986), and controlled exposure studies using a chemical mixture typical of Danish homes showed measurable effects at a concentration of 5 mg/m^3 (Molhave, 1987). The data obtained here from the TVOC measurements and the questionnaire survey support Molhave's conclusions, although it should be borne in mind that contributions to symptoms from the effects of particulates and low humidity have not been ruled out.

In spite of their symptoms, the majority of occupants were very positive about the way the installation was conducted. They noticed the extra ventilation, and several described previous experiences with recarpeting that were much worse.

CONCLUSIONS

The work presented here proves that it is possible to obtain emission rates from studies in buildings. While there are more variables than in laboratory measurements, and potentially larger errors, it is possible to reduce the effects of some of these by careful planning.

The TVOC emission rate measured for the nylon carpet and latex glue was about 80 times higher than the emission rate of the carpet alone. Thus the chemicals emitted during recarpeting come mostly from the adhesive. Since a significant percentage of the occupants experienced some discomfort following the installation even though continuous ventilation was used, continuous ventilation should be used every time latex adhesive is applied.

The numbers of occupants still reporting discomfort a week after installation was small. Also, by that time, TVOC concentrations had fallen to about the same level as the background TVOC concentration in the building. Therefore, in this building, continuous ventilation was necessary for a week after installation to provide a productive work environment for occupants. A different length of time may be necessary in buildings which introduce different amounts of outdoor air, or where carpet adhesives are different or are applied by another method.

The data obtained here from the TVOC measurements and the questionnaire survey are consistent with Molhave's conclusions that people can experience symptoms of discomfort when exposed to TVOC concentrations in the range 2-10 mg/m^3. However, possible contributions to symptoms from the effects of low humidity or particulates released during carpet installation have not been ruled out.

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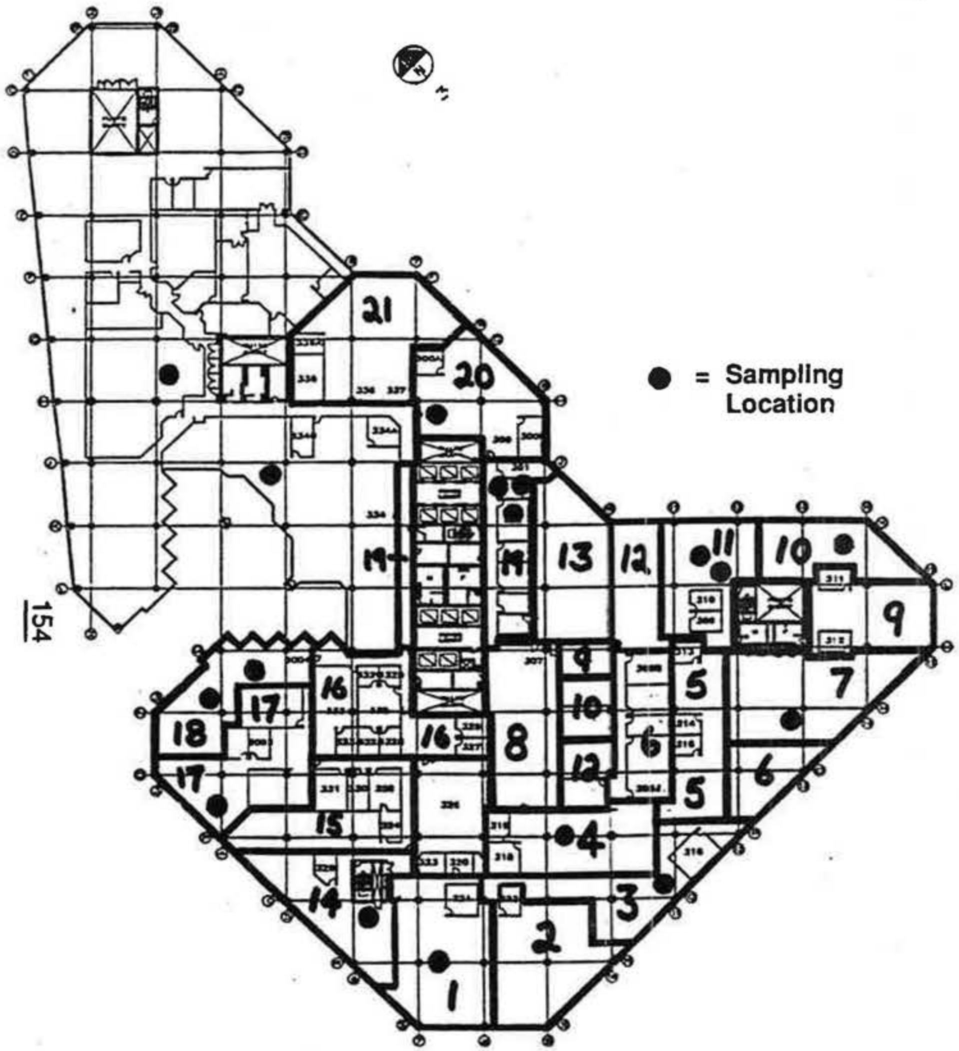

Figure 1 **Recarpet schedule and sampling locations**

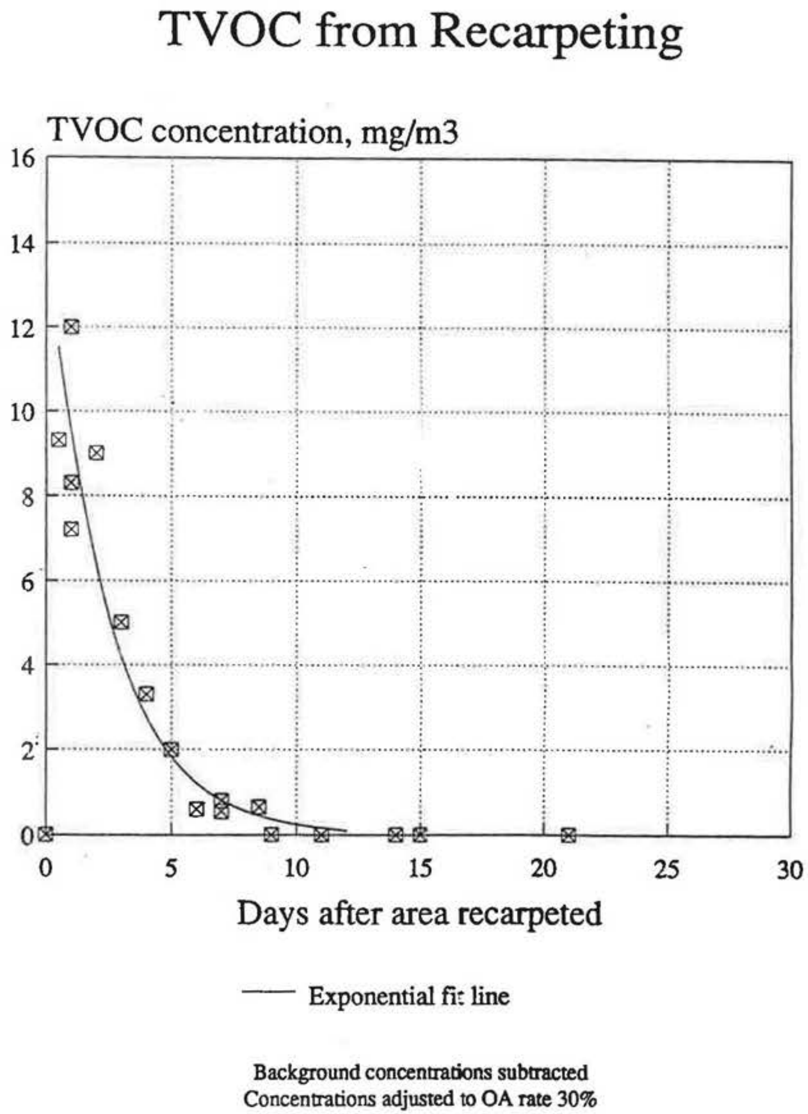

Figure 2 **Dependence of TVOC concentration originating from the recarpeting process on time since recarpet**