TECHNIQUES FOR REDUCING EXPOSURES TO VOLATILE ORGANIC COMPOUNDS ASSOCIATED WITH NEW CONSTRUCTION AND RENOVATION

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ABSTRACT

Chamber experiments were conducted with a combination of latex paints and new carpet and vinyl flooring assemblies. The first objective was to characterize the emissions of volatile organic compounds (VOCs) from the assemblies at simulated residential conditions. The second objective was to evaluate the effectiveness of techniques that homeowners and building managers might employ during new construction or renovation to reduce concentrations of VOCs and exposures to these VOCs. The techniques included: increased ventilation for three days following installation (each source); airing out of materials for two days prior to installation (carpet and vinyl flooring); and mild heating for three days following installation (combined sources). Short-term ventilation typically reduced VOC concentrations in room air only during the period of increased ventilation. Airing out of materials generally reduced the emissions of VOCs from carpet materials but was ineffective for VOCs emitted by vinyl flooring. Heating applied after materials were installed had mixed results.

INTRODUCTION

Paints and many materials used to finish the interiors of houses and other buildings emit volatile organic compounds (VOCs), including toxic air contaminants (TACs). These emissions result in exposures to occupants. The California Air Resources Board (ARB) is required to consider such indoor exposures in assessing risks from TACs to public health. Thus, it is necessary for the ARB to identify indoor sources of VOCs and to characterize their emissions. The ARB also provides information to the public regarding ways to reduce both indoor and outdoor exposures to TACs.

Numerous techniques for reducing occupant exposures to indoor sources of VOCs have been proposed. The California Department of Health Services developed guidelines for reducing exposures to VOCs from construction materials used in office buildings [1]. Tichenor and Sparks employed an indoor air quality model to predict occupant exposures for different source scenarios, building parameters and occupant activity patterns [2]. The current study was designed to evaluate selected exposure reduction techniques in environmental chambers. Emphasis was placed on practical techniques that homeowners and building managers might use to reduce occupant exposures to VOCs associated with new construction or renovation. The study is fully described in a recent report [3].

METHODS

A variety of interior latex paints, carpets, carpet cushions, and vinyl floor installation materials widely used by California homeowners were selected for study. Newly manufactured specimens of 24 materials were individually screened for emissions of VOCs in small-scale environmental chambers following standard practice [4]. VOCs emitted by the materials were identified, and the emission rates of selected VOCs were determined.

In the 2nd phase, 13 large-scale experiments were conducted with realistic assemblies of new materials that were selected based on the screening results. The chamber facility with dual, 25-m^3 compartments was designed and operated to simulate a residential room environment. The walls and ceiling of each compartment were painted gypsum board. The floor was either carpeted or covered with sheet vinyl; and furnishings (*i.e*., two upholstered chairs and a drapery panel) were installed to mimic typical "sink" effects. The study materials were installed following construction industry practice. For experiments with paint, a fast-drying latex primer sealer (LPS) was first applied to gypsum board and plywood substrates. This was followed by a flat latex paint (FLP) applied to 14.9-m^2 of gypsum board and a semi-gloss latex paint (SGLP) applied to 1.1-m^2 of plywood. The carpet and vinyl flooring assemblies were installed to cover the entire 10.4-m^2 floor area of a compartment. For the two experiments with the combined source assemblies, the paints were applied three days prior to the installation of the flooring materials, which consisted of two-thirds carpet and one-third sheet vinyl. Air samples for the analysis of VOCs and aldehydes were collected from a compartment throughout the first day of an experiment, daily over the next nine days and finally on day 14 following installation of the materials.

The exposure reduction techniques that were investigated included: additional ventilation for three days following installation (each source assembly); additional air mixing combined with additional ventilation (paint combination); airing out of materials for two days prior to installation (carpet and vinyl flooring assemblies); and room heating to 33^o C for three days after painting and installing the flooring materials (combined source assemblies). The results for the treatment experiments were compared to the results for base-case experiments conducted at standardized conditions for ventilation, air mixing and temperature. For the base-case experiments, the ventilation rate was held at 2 h^{-1} during material installation and for the next two hours. Then it was reduced to 0.5 h^{-1} and held at that condition. For experiments with additional ventilation, the rate during material installation and the next two hours was 5 h^{-1}. The rate was then reduced to 2 h^{-1} and held at that condition until 72-h elapsed time when it was further reduced to 0.5 h^{-1}.

Air samples for VOCs were collected on Tenax®-TA sorbent tubes. These were analyzed for VOCs by thermal desorption GC/MS using a modification of U.S. EPA Method TO-1. Emission rates of the target VOCs were calculated by a steady-state mass-balance model [4].

Predicted exposure was calculated for two different time periods or scenarios. The 1st scenario was for an occupant who was present during the first 48 hours following installation. The 2nd scenario was for a full-time occupant who vacated the residence during the first 48 hours and then returned. Occupancy for 20 hours per day (*i.e*., an occupancy factor of 0.83) was assumed for both scenarios. The cumulative exposure for a target VOC was calculated as the product of the concentration profile, the exposure time in hours, and the occupancy factor.

RESULTS

The screening measurements generated a large amount of qualitative and quantitative data. The VOC emissions from conventional latex paints principally consisted of a solvent component (ethylene glycol and/or propylene glycol) and the Texanol® coalescing aid. The 96-h emission rates of SigmaVOC (*i.e*., the sum of the rates for individual VOCs) from eight conventional and two non-VOC latex paints are compared in Figure 1. The LPSs and FLPs were applied to gypsum board. The SGLPs were applied to plywood. The two non-VOC paints, FLP4 and SGLP4, had substantially lower emission rates than did the conventional paints. These emissions consisted of small amounts of oxidized compounds. Paints LPS2, FLP3 and SGLP3 were selected for use in the large-scale experiments.

Approximately 3.6 kg of the combined paints was applied in each large-scale experiment. Ethylene glycol (EG) and Texanol® were the dominant emitted compounds (Table 1). Other compounds included acetaldehyde, propylene glycol and di(ethylene glycol)butyl ether. The maximum concentrations of the target compounds occurred within the first few hours after paint application. The experiments were compared over elapsed time periods of only 240 h since one experiment was terminated early. There were ~98% reductions in the concentrations of EG over this period. For all cases, 60% of the total cumulative exposures to this compound occurred within the first 48 h. The concentrations of Texanol® decreased by a factor of ~3.5 over the course of the experiments. The use of additional initial ventilation resulted in small decreases in exposures to EG and Texanol® over both the 0- to 48- and the 48- to 240-h time periods (Table 1). The small effect in the initial period was due to increased emission rates in response to additional ventilation. Additional air mixing created with two oscillating fans pointed at the painted surfaces in combination with additional ventilation resulted in somewhat greater exposure reductions relative to the base-case condition.

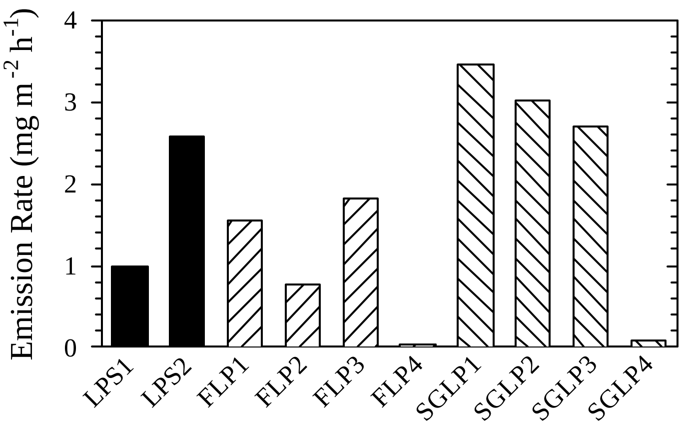

Figure 1. Specific emission rates of SigmaVOC at 96 h in screening measurements of latex paints.

The carpet assembly selected for the large-scale experiments consisted of a carpet with olefin face fibers and a bonded urethane carpet cushion. This assembly had substantially lower emissions of VOCs than the paint and vinyl flooring. (Note that the concentrations and exposures for the carpet and vinyl flooring assemblies are presented in ppb and ppb-h units.) The carpet emitted styrene, 4-ethenycyclohexene, 4-phenylcyclohexene (4-PCH), isomers of di(propylene glycol)methyl ether (DPGME) and N,N-dimethylacetamide. The cushion emitted butylated hydroxytoluene (BHT), 2,2'-azobisisobutryonitrile and a complex mixture of unsaturated hydrocarbons. Data for 4-PCH, DPGME and BHT are shown in Table 2. There were five-fold or more reductions in the concentrations of DPGME over the course of the experiments. The concentrations of 4-PCH only decreased by a factor of two or less while the concentrations of BHT increased with time. The concentrations of the individual VOCs at the ends of the experiments were ~1 ppb or less. The use of additional initial ventilation resulted in decreases in the exposures to most VOCs over 0-48 h (Table 2). However, the 48- to 336-h exposures to most VOCs were affected by less than 10% due to use of higher initial ventilation. Airing out of the carpet and cushion in a well-ventilated space for two days prior to installation substantially reduced the exposures to all VOCs in both time periods relative to the base-case experiment.

The vinyl flooring assembly selected for the large scale experiments consisted of residential "no-wax" sheet vinyl, low-VOC full-spread adhesive, liquid seam sealer, rubber cove base and cove base adhesive. Use of the seam sealer produced high (ppm) initial concentrations of tetrahydrofuran (THF) and cyclohexanone. The full-spread adhesive emitted toluene. The dominant compounds emitted by the sheet vinyl were n-tridecane (n-C13), other alkane hydrocarbons, 1,2,4-trimethylbenzene, benzyl alcohol, phenol and TXIB® plasticizer. The cove base emitted benzothiazole. Data for n-C13, toluene, THF and phenol are shown in Table 3. There were rapid 100-fold or more reductions in the THF and cyclohexanone concentrations over the course of the experiments. There were also substantial rapid reductions in the toluene concentrations in all experiments. The use of additional initial ventilation clearly reduced the exposures to most VOCs over 0-48 h (Table 3). However, the apparent emission rates of benzyl alcohol, phenol, TXIB® and benzothiazole, all relatively low volatility compounds, increased in response to additional ventilation. Thus, the exposure to TXIB® was only reduced by 22% and the exposures to the other three compounds were affected by less than 10% during the initial period. The 48- to 336-h exposures to most VOCs were affected by less than 10% as the result of additional ventilation during the first 72 h. The most impacted compounds were toluene, THF and phenol with 16-30% reductions. Airing out of the sheet vinyl and cove base reduced the 0- to 48-h exposures to most VOCs by 25% or less. The most impacted compounds were phenol and benzothiazole with ~40% reductions. This treatment was less effective for reducing exposures over the longer period.

Heating the compartment to 33^o C for three days following the installation of combined assemblies resulted in increases in the chamber concentrations of most VOCs during the heating period. At the onset of heating, there were rapid, typically three-fold concentration increases, which declined over the 72-h heating period. When the heat was turned off, the concentrations typically returned to values similar to the base-case values. Texanol® was a notable exception. Subsequent to heating, the concentrations of Texanol® were lower relative to the reference case. The cumulative exposures to selected VOCs in the heating and base-case experiments are compared in Figure 2. Occupancy was assumed to begin after the compartment temperature returned to normal. There was an increase in the exposure for THF and a more than two-fold decrease in the exposure for Texanol® due to heating.

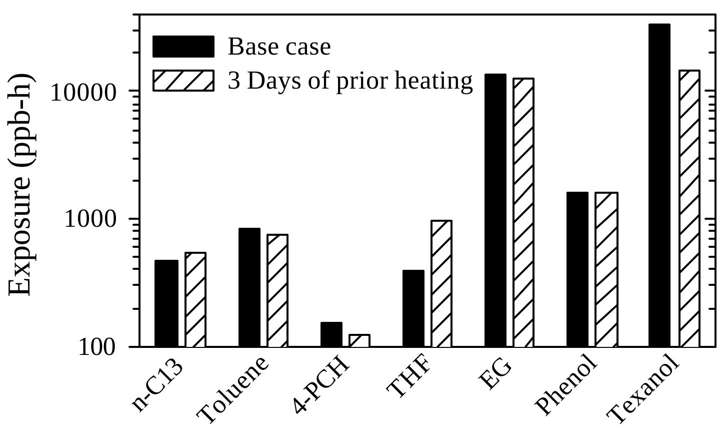

Figure 2. Cumulative exposures to selected VOCs over 96-336 hours in experiments with combined sources.

DISCUSSION AND CONCLUSIONS

A moderate increase in building ventilation during and for a short period following the installation of an indoor VOC source is probably the most accessible and practical exposure reduction technique for consumers. VOC concentrations were reduced during the period of additional ventilation; however, the reductions were frequently not directly proportional to the magnitude of the ventilation increase. VOC concentrations following the termination of additional ventilation often quickly returned to base-case values. An alternative exposure reduction technique is to select materials for new construction and renovation that have low emissions of VOCs. However, the informed selection of low-emitting materials is frequently a complex and difficult task.

The results of the investigation have been generalized to formulate the following practices that homeowners and building managers can employ to reduce VOC concentrations and decrease cumulative exposures to VOCs for occupants of houses and other buildings.

1) Materials that emit lower amounts of toxic or odorous VOCs should be selected whenever possible. Lower emitting materials should reduce occupant exposures and decrease the need for subsequent control strategies. The substitution of non-VOC latex paints for conventional latex paints appears to be one viable choice for reducing exposures.

2) The most effective way to reduce occupant exposures to the dominant VOCs emitted by conventional latex paints is to delay occupancy for several days following painting. This strategy may also be effective for reducing exposures due to sheet vinyl installations.

3) Although carpets and carpet cushions are relatively low sources of VOCs, exposures to VOCs emitted by these materials can be reduced by airing them out in a well-ventilated, clean, dry environment for several days prior to their installation.

4) High mechanically induced ventilation rates should be used during the application or installation of high emitting materials such as paints and vinyl seam sealers to protect the installers and any occupants that are present.

5) Additional ventilation should be maintained for periods longer than three days to more effectively lower occupant exposures. The ventilation rate should be maximized since, in many cases, the beneficial effects of ventilation, are not in direct proportion to the increase in the ventilation rate.

ACKNOWLEDGEMENT AND DISCLAIMER

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Table 1. Effects of additional initial ventilation and air mixing on concentrations and exposures to selected VOCs emitted by latex paints.

Compound	Added Vent. (Yes/No)	Air Mixing (Yes/No)	Max. Conc. 1-48 h (ppm)	Conc. @ 240 h (ppm)	Exposure 0-48 h (ppm-h)	Exposure 48-240 h (ppm-h)
EG	No	No	6.7	0.148	72	37
	Yes	No	6.5	0.129	59	38
	Yes	Yes	4.0	0.118	45	28
Texanol®	No	No	0.48	0.138	14.1	36
	Yes	No	0.63	0.179	12.4	31
	Yes	Yes	0.49	0.164	10.8	26

Table 2. Effects of additional initial ventilation and airing out of materials on concentrations and exposures to selected VOCs emitted by carpet assembly.

Compound	Added Vent. (Yes/No)	Airing Out (Yes/No)	Max. Conc. 1-48 h (ppb)	Conc. @ 336 h (ppb)	Exposure 0-48 h (ppb-h)	Exposure 48-336 h (ppb-h)
4-PCH	No	No	1.9	0.9	70	320
	Yes	No	1.5	1.1	53	300
	No	Yes	1.4	0.8	46	260
DPGME	No	No	4.2	0.5	111	198
	Yes	No	3.2	0.6	66	187
	No	Yes	0.9	<0.5	32	<109
BHT	No	No	0.7	0.9	14	152
	Yes	No	0.8	1.2	17	220
	No	Yes	0.4	0.8	10	122

Table 3. Effects of additional initial ventilation and airing out of materials on concentrations and exposures to selected VOCs emitted by vinyl flooring assembly.

Compound	Added Vent. (Yes/No)	Airing Out (Yes/No)	Max. Conc. 1-48 h (ppb)	Conc. @ 336 h (ppb)	Exposure 0-48 h (ppb-h)	Exposure 48-336 h (ppb-h)
n-Tridecane	No	No	27	6.1	420	1,720
	Yes	No	11.3	6.8	220	1,620
	No	Yes	23	7.6	370	1,820
Toluene	No	No	60	8.2	870	2,800
	Yes	No	11.2	8.2	196	2,100
	No	Yes	44	8.8	580	2,200
THF	No	No	2,600	2.7	7,300	2,000
	Yes	No	330	3.4	1,400	1,400
	No	Yes	2,200	5.8	8,900	2,400
Phenol	No	No	32	16.9	930	4,700
	Yes	No	21	15.9	730	3,900
	No	Yes	18.7	15.9	510	4,000