Contaminant Emission Rates from PVC Backed Carpet Tiles on Damp Concrete

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ABSTRACT

Concrete slabs with elevated vapor emission rates and pH have the potential of hydrolyzing the plasticizers from the PVC backing of carpet tiles and creating higher order alcohols, which can be odoriferous and/or irritating. We measured the emissions water vapor from a concrete slab and contaminants from PVC backed carpet tiles in a building, which had heavy white and green/grown deposits on the backs of the carpet tiles. The water vapor emission rates ranged from 2.3 lbs/1000 ft^2/24hrs to 4.8 lbs/1000 ft^2/24hrs. The pH of the slab ranged between 7.0 and 11.0 pH. The emissions of the following compounds were measured using the FLEC sampler; hexanal, pentanal, nonanal, and decanal, 2-ethyl-1-hexanol, an aliphatic alcohol D, acetone and 1,1,1 trichloroethane**.** The concentrations of compounds were observed to be at elevated indoor concentrations that, while well below occupational health guidelines, collectively may cause some occupants to experience odor and/or irritation. *Aspergillus* fungus was observed to have colonized the back of the carpet tiles but had not caused contamination of the indoor air.

KEYWORDS: concrete, dampness, fungi, material emission, plasticizer

INTRODUCTION

This study was implemented as, the result of a request by a building owner to conduct an indoor air quality (IAQ) evaluation in response to employee concerns. A total of 56 of 900 employees responded to an employee administered survey of occupant complaints/observations. The physical symptoms reported in this survey included dry, itching or irritated eyes, unusual tiredness, fatigue, or drowsiness, sinus problems, stuffy or runny nose, headache, sneezing fits, dry or itchy skin, and sore or dry throat.

During this evaluation we discovered heavy white and green/brown deposits on the backs of the carpet tiles used throughout the building. The carpet tile system in the main building is a PVC backed laydown carpet tile system. Concrete slabs with elevated vapor emission rates and pH have the potential of hydrolyzing the plasticizers from the PVC backing of carpet tiles and creating higher order alcohols, which can be odoriferous and/or irritating. The carpet tiles lay directly, without adhesive, on top of a concrete subfloor. As result of these observations we collected in situ measurements of the emissions water vapor from the concrete slab and contaminants from the carpet tiles.

The building is approximately 330,000 square feet, which includes a main building and service wing. The building is a three-story structure with a basement level below the service wing. The main building primarily consists of office space and the service wing consists of a cafeteria, printing facility, library, offices, field laboratories and other field equipment services and storage. The building is approximately six years old. The main building is served by six air handlers; located on the roof. These systems are variable air volume (VAV) systems, which have an outside air economizer controls, which varies the percentage of outside air in the supply air according to the outside air temperature.

METHODS

Water vapor emission rates through concrete slabs are effected by factors such as the moisture content of the soil underlying the slab, the condition of the capillary break and the vapor-retarder beneath the slab, the porosity of the slab, the material composition of the slab, as well as environmental conditions of the building environment above the slab. To quantify the water vapor emission rates we installed 10 anhydrous calcium chloride domes [1] on concrete surfaces beneath the carpet tile system throughout the building to quantify the water vapor emissions from the concrete slab surface. Results are reported in pounds of water vapor emission per 1,000 square feet in 24 hours (lbs/1000 ft^2/24hrs). The domes were applied on all three floors of the building including the basement. We also measured the pH of the slab at each measurement location. These samplers were retrieved between 69 and 72 hours later for analyses.

We measured the concentrations of volatile organic compounds using a solid phase multi-sorbent sampler and a gas chromatograph with a mass spectrometer detector for analysis. We used a FLEC (Field Laboratory Emission Cell) to measure the emissions of volatile organic compounds from the carpet tiles. The FLEC is a 15 cm diameter, 35 cm^3 volume stainless steel test cell that is placed over surfaces to measure the emissions of contaminants from surfaces of materials. A carpet tile was selected on the first floor. There was no adhesive on the back of the carpet tile at this location and there were deposits covering the back of the carpet tile similar to those found throughout the building. The FLEC was placed over the center of the carpet tile and air was withdrawn from the center port and into a multi-sorbent sampler at a rate of 21.7 cc/min. Room air was allowed to naturally make up through the perimeter port and sampler edges. We simultaneously measured the concentrations in the outdoor air and in the indoor air adjacent to the FLEC. Samples were collected over a one-hour period. We calculated the emission rates from the carpet tile as the product of the flowrate of air withdrawn from the FLEC and the difference in the concentrations of the FLEC and the indoor air and then normalized this by the area of carpet tile covered by the FLEC.

We collected surface samples from the back surfaces of the carpet tiles to see if there was evidence of fungal growth. Tape impressions were lifted from the back surfaces of 18 carpet tiles and mounted directly onto a microscope slide for analyses. Samples were analyzed microscopically with quantities of molds observed with underlying mycelial and/or sporulating structures graded as 1+ to 4+, with 4+ denoting the highest numbers observed. Sterile swab samples from the backs of two carpet tiles were wiped over a 10 cm^2 surface and immersed into a malt extract agar for incubation and culturing of viable fungal spores and analyses reported in colony forming units (cfu/100 cm^2). In addition, we measured the concentrations of airborne viable fungal propagules with an Anderson N6 particle impactor loaded with malt extract agar and airborne fungal spores using an Air-o-Cell inertial impactor/tackified glass slide. Airborne samples were collected once in the morning and once in the afternoon at five indoor locations and one outdoor location.

RESULTS AND DISCUSSION

The measured water vapor emission rates for the 10 domes were calculated to range from 2.3 lbs/1000 ft^2/24hrs to 4.8 lbs/1000 ft^2/24hrs. The pH of the slab ranged between 7.0 and 11.0 pH. According to the manufacturer, this PVC backed carpet tile system is recommended for installation on concrete slabs with a water vapor emission rate of no more than 3.0 lbs/1000 ft^2/24hrs and a pH of nor more than 10. Thus, the moisture emission rates of the concrete slab were <u>above</u> the recommended maximum guideline of 3.0 lbs/1000 ft^2/24hrs at eight of ten locations of the main building and the pH levels were <u>equal to or above</u> the recommended maximum guideline of 10 at three of ten locations.

The results of our analyses of volatile organic compounds are summarized in Table 1. The Permissible Exposure Limits (PEL) established by the Occupational Safety and Health Administration (OSHA) for the volatile organic compounds typically found in building materials range from 375,000 µg/m^3 to 1,050,000 µg/m^3. Since OSHA limits are established for the protection of industrial workers exposed to single substances, a more appropriate guideline for non-industrial office spaces is 1/40th of the occupational health standards for the non-industrial irritant guidelines. This guideline was established to minimize eye, nose, and throat irritation in environments with sensitive occupants.

The indoor concentrations; were dominated by C14-C17 aliphatic compounds. The concentration of these compounds totaled 151 µg/m^3, which is 42% of the total of 363 µg/m^3. These compounds are not known to be especially irritating. The OSHA PEL is 2,000,000 µg/m^3 and the recommended irritant guideline (i.e. 1/40th of the PEL) is 50,000 µg/m^3. Thus, the indoor concentration is well below the occupational health standard and less than 0.3% of the recommended irritant guideline. A comparison of all of the other compounds indicates that these are also all well below the occupational health standard and less than 1% of the recommended irritant guidelines, with the exception of the indoor concentration of benzene which was less than 3% of the recommended irritant guideline and lower indoors than outdoors.

The second highest indoor concentration was 2-butoxyethanol. This is a compound commonly found in cleaning materials and was indicated in the building services materials MSDS sheet for a disinfectant.

The third highest indoor concentration was trichlorofluoromethane, which is R-11 refrigerant and was identified in the MSDS that was submitted for the ventilation maintenance materials.

Comparison of the concentrations measured indoors and outdoors gives insight into which compounds have sources inside of the building while comparison of the concentrations measured in the headspace air by the FLEC and the indoor air gives insight into which compounds are being emitted by the carpet tile system into the indoor air. Of the 31 compounds quantified in Table 1 for the indoor air, 18 were determined to significantly higher than the outdoor air and thus indicative of an indoor source. These compounds are identified in Table 1 with bold lettering followed by a "*".

Similarly, of the 31 compounds quantified in Table 1 for the FLEC/carpet sample, 8 were determined to significantly higher than the indoor air and thus indicative that the carpet tile system is emitting these compounds into the air. These compounds are identified in Table 1 with bold lettering followed by a "*". Four of these eight compounds are aldehydes, hexanal, pentanal, nonanal, and decanal, two are higher order alcohols, 2-ethyl-1-hexanol and one probable alcohol, aliphatic alcohol D, and the other two compounds are acetone and 1,1,1 trichloroethane. The aldehydes are most likely oxidation products of other volatile organic compounds in the carpeting. The higher order alcohols are most likely hydrolysis products of the plasticizers in the PVC backing of the carpet caused by the carpet being in contact with the moist high pH concrete slab. The 1,1,1 trichloroethane may be the result of the use of the Gum and Spot Remove for which this compound is indicated in the MSDS submitted by the carpet maintenance contractor.

Six of the eight compounds identified as being emitted by the carpet are present in the indoor air of the building at a significantly higher concentration than the outdoor air. There are occupational health standards for only two of these compounds, pentanal and 1,1,1 trichloroethane. The concentrations of both of these compounds were well below the occupational health guidelines and less than 0.08% of the recommended non-industrial irritant guideline. There are no occupational health standards for hexanal, nonanal, decanal, 2-ethyl-1-hexanol and the one probable alcohol, aliphatic alcohol D. These compounds are known to be relatively potent irritants.

While there are no occupational health standards to compare the exposure to for these compounds we can compare these concentrations to those observed in the EPA Building Assessment and Survey Evaluation (BASE) study [2] for four of these compounds. An analysis of the indoor concentrations collected 56 randomly selected non-problem office buildings indicated the following concentrations: hexanal (0.8-12 $\mu g/m^3$ range, median 3.2 $\mu g/m^3$), pentanal (0.5-3.3 $\mu g/m^3$ range), nonanal (1.2-7.9 $\mu g/m^3$ range, median 3.1 $\mu g/m^3$), and 2-ethyl 1-hexanol (0.3-48 $\mu g/m^3$range). Thus the indoor concentrations exceeded the reported maximum concentration for pentanal (3.4 $\mu g/m^3$ vs 3.3 $\mu g/m^3$) and nonanal (12 $\mu g/m^3$ vs 7.9 $\mu g/m^3$).

We can also compare these concentrations to the odor thresholds for these compounds. The odor thresholds are: hexanal (58 $\mu g/m^3$), pentanal (22 $\mu g/m^3$), nonanal (14 $\mu g/m^3$), decanal (6 $\mu g/m^3$), and 2-ethyl 1 hexanol (1,318 $\mu g/m^3$). While none of the individual concentrations of these compounds exceed their respective odor thresholds, the combination of the concentrations of the five compounds: is calculated to exceed the calculated odor threshold for the mixture by more than a factor of two.

Our microsocopy analyses of the tape samples collected from the back side of the carpet tiles indicated on the backs of 16 of the 18 carpet tiles sample, 3+ to 4+ *aspergillus* with underlying mycelial and/or sporulating structures, which is indicative of past and/or present fungal growth. Analyses of the cultures of the samples collected from the backs of two carpet tiles indicated no viable spores (i.e. < 10 cfu/100cm^2).

On a genus-by-genus basis, the concentrations of airborne viable fungal propagules were measured to be significantly below the concentration measured outdoors except at one location where the indoor concentrations of *curvularia* and *penicillium* were slightly elevated (i.e. *curvularia*; 21 cfu/m^3 indoors and < 3 cfu/m^3 outdoors, and *penicillium*; 99 cfu/m^3 indoors and 14 cfu/m^3 outdoors).

On a genus-by-genus basis, the concentrations of airborne fungal spores at all five indoor sites were measured to be below or not significantly above the concentration measured outdoors.

CONCLUSIONS

The concentrations of some aldehydes and higher order alcohols were observed to be at indoor concentrations that, while well below occupational health guidelines, collectively may cause some occupants to experience odor and/or irritation. Some of these compounds appear to be coming from the carpet tile system in the main building. Hydrolysis of the plasticizers to higher order alcohols resulting from contact with the damp high pH concrete subfloor is suspected. The emission rates measured using the FLEC are much less than the total emissions calculated for the building. Emissions at the seams of the carpet tiles may be significantly higher than those that we measured at the center of the carpet tile. In addition the ventilation rates in the building may have been changing and thus effecting the equilibrium concentrations indoors.

The backs of the carpet tiles are colonized with *aspergillus* fungi, which is not at this time viable. The indoor and outdoor concentrations of airborne viable fungal propagules and airborne spores do not indicate that the carpet tile system is contributing to the contamination of the indoor air. Pulling up the carpet tiles may cause for spores on the backside of the carpet tiles to become airborne.

At this time the underlying source of moisture causing the fungal growth on the back of the carpet tiles and suspected of causing the formation of odoriferous volatile organic compounds is unknown. One suspected source is residual moisture from heavy use of carpet cleaning solution with the bonnet type carpet cleaning that was used for years in this building.

Table 1. Concentrations of volatile organic compounds simultaneously measured in the FLEC headspace over the carpet tile system, the indoor air, and the outdoor air.

	FLEC/Carpet [a] Air ($\mu g/m^3$)	Indoor [b] Air ($\mu g/m^3$)	Outdoor Air ($\mu g/m^3$)	Carpet Emission ($\mu g/m^2$-h)	Industrial / Non-Industrial [c] Guidelines ($\mu g/m^3$)
Acetone	**55** *	26	20	2.1	590,000 / 14,750
Aliphatic Alcohol A	0.8	1.4	<0.4	0.0	NA
Aliphatic Alcohol B	3.8	**4.1** *	<0.4	0.0	NA
Aliphatic Alcohol C	2.3	**2.7** *	<0.4	0.0	NA
Aliphatic Alcohol D	**3.8** *	1.4	<0.4	0.2	NA
C14-C17 Aliphatics	138	**151** *	7.0	-1.0	2,000,000/50,000
Benzene	2.3	2.0	3.5	0.0	3,000 / 75
1-Butanol	5.4	**5.5** *	0.8	0.0	300,000 / 7,500
2-Butanone	3.1	3.4	2.7	0.0	590,000 / 14,750
2-Butoxyethanol	3.8	**56** *	<0.4	-3.8	240,000 / 6,000
Butyl acetate	0.8	1.4	<0.4	0.0	710,000 / 17,750
Carbon tetrachloride	4.6	**4.8** *	2.3	0.0	63,000 / 1,575
Decanal	**6.9** *	**5.5** *	3.1	0.1	NA
n-Dodecane	0.8	1.4	<0.4	0.0	NA
Ethyl acetate	1.5	**2.0** *	<0.4	0.0	1,200,000 / 35,000
2-Ethyl-1-hexanol	**6.2** *	**4.1** *	0.4	0.2	NA
1-Heptanol	3.8	**3.4** *	<0.4	0.0	NA
Hexanal	**15** *	**7.5** *	0.8	0.6	NA
d-Limonene	1.5	**2.7** *	<0.4	-0.1	NA
4-Methyl-2-pentanone	1.5	1.4	<0.4	0.0	NA
Nonanal	**17** *	**12** *	3.1	0.4	NA
Pentanal	**5.4** *	**3.4** *	0.8	0.1	175,000 / 4,735
Phenol	3.1	**3.4** *	0.8	0.0	19,000 / 475
Texanol 1 & 3	0.8	1.4	0.4	0.0	NA
Toluene	5.4	5.5	5.5	0.0	752,000 / 18,800
1,1,1-Trichloroethane	**6.9** *	**4.8** *	0.8	0.2	1,900,000 / 47,500
Trichlorofluoromethane	45	**44** *	8.2	0.1	5,600,000 / 140,000
1,2,4-Trimethylbenzene	0.8	0.7	1.2	0.0	123,000 / 3,075
TXIB	1.5	**2.7** *	<0.4	-0.1	NA
n-Undecane	0.8	1.4	0.4	0.0	NA
m & p-Xylenes	2.3	2.0	2.7	0.0	435,000 / 10,875
TVOC (by GCMS TIC)	311	**363** *	99	-3.8	NA/1,000

a.) Carpet headspace concentrations in **bold** and with a "*" are significantly higher than the corresponding indoor air concentrations indicating the carpet is a source.
b.) Indoor air concentrations in **bold** and with a "*" are significantly higher than the corresponding outdoor air concentrations indicating there is a source in the building.
c.) Industrial exposure guidelines represented by the OSHA PEL for an eight hour work-shift except for pentanal and 1,2,4 trimethylbenzene for which there are no OSHA PEL and thus are represented by the ACGIH TLV for an eight hour work-shift. The non-industrial guidelines are 1/40th of the industrial guidelines. NA , means that there is no industrial exposure guideline for the compound.

REFERENCES

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