Chemical Insights

April 2023

SUMMARY REPORT

Extreme Weather Impact on Indoor Material Emissions

Table of Contents

List of Figures

List of Tables

1. Introduction

Chemical pollution exposure, largely stemming from the prolific presence of synthetic or anthropogenic sources in the indoor environments, brings toxicity and human health concerns. Studies show that chronic exposure may lead to cognitive, reproductive, and carcinogenic effects, depending on specific chemicals and their exposure levels.[1, 2] Indoor sources of these chemicals include materials used to construct and furnish buildings such as manufactured wood, paint, adhesives, insulation, and drywall.[3]

CIRI has conducted a pilot research study addressing “resiliency” in relation to building materials. We define resiliency broadly to mean the physicochemical integrity of a substance to resist breakdown in the environment. As climate change continues to be one of the most pressing environmental concerns today, not only is the outdoor environment affected, but also the indoor environment. Temperature intensification and adverse weather events will continue to occur. However, few studies have looked at the effects of rising global temperature and other weatherization occurrences within the chemical landscape of homes and the indoor environment.[4-7] In seeking a preliminary view of the resiliency of physical structure and materials, we investigated the effect of temperature on chemical emission releases from a limited set of conventional building materials. Our goal was to identify how chemical emissions from indoor materials might change with increasing indoor temperatures and potentially affect human health.

2. Methods and Materials

Five common building materials were chosen as a best representation of popular choices in modern home design (Figure 1). The products studied included: (1) gypsum drywall panel; (2) medium-density fiberboard (MDF) panel; (3) engineered wood flooring; (4) vinyl flooring; and (5) batted fiberglass insulation. Each material was available in the retail marketplace. Products were purchased new and stored within individual airtight packaging prior to analysis. The prior history and product handling of the product was not known.

Figure 1: The five building materials for the study. Clockwise from the top right: drywall, MDF, engineered wood flooring, vinyl flooring and batted fiberglass insulation.

A stainless-steel test chamber (80 L, or 0.08 m^3) was utilized for the emission measurements (Figure 2). A product sample was loaded into the chamber and clean air was provided to the chamber at a flow rate of 1.1 Liters/min (Lpm) to provide 80% make-up air flow pulled for analysis, resulting in an air change rate of 0.825 $hour^{-1}$. A tee-shaped adapter was attached to an outlet port to capture sampled air from the chamber for both VOC and aldehyde emissions. Tenax® TA and 2,4-dinitrophenylhydrazine (DNPH) sorbents, were used to collect VOCs and aldehydes respectively, while a separate port on another side of the chamber was used as an exhaust outlet.

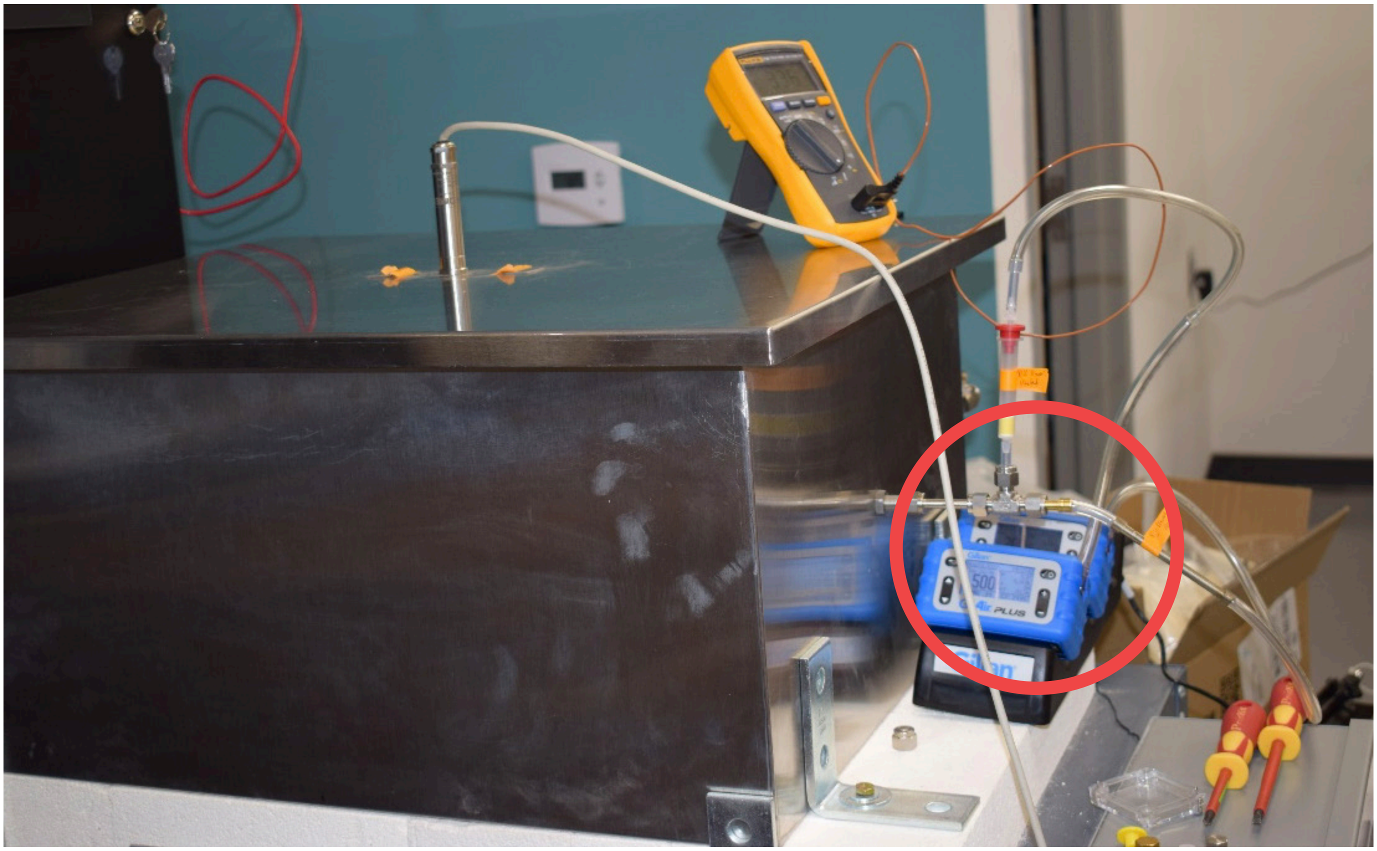

Figure 2: Chamber setup, including a tee-adaptor (highlighted with a red circle) for concurrent VOC and aldehyde sampling.

Product emissions were studied at two temperatures, an average room temperature of 23°C (73°F) and an elevated temperature of 35°C (95°F) designed to simulate an extreme climate weatherization event. This could simulate a rise in temperature inside a home due to the lack of air conditioning or poorly functioning HVAC system. The temperature inside the chamber was monitored and controlled by an electronic infrared thermostat while a heating apparatus underneath the chamber provided a heat source.

VOC and aldehyde emissions were sampled using calibrated vacuum pumps for each material at each temperature point for 90 minutes at respective flow rates of 0.2 Lpm for VOCs and 0.5 Lpm for aldehydes to give final sampled volumes of 18 L and 45 L total. The VOC emissions were quantified by thermal-desorption gas chromatography-mass spectrometry outlined in the standards documents ASTM D6196 and EPA TO-17 [8, 9], and the aldehyde emissions were analyzed by high performance liquid chromatography coupled with an ultraviolet detector per standard guidance documents ASTM 5197 and EPA TO-11A.[10, 11]

Chemical emission rates of materials were calculated based on measured chamber concentrations, the environmental chamber air change rate, and material loadings, while assuming a steady-state condition inside the chamber.[12]

An emission rate is described as the mass of chemical emitted per surface area of material per hour. These emission rates were used in a residential indoor air model as described in ANSI/CAN/UL 2904.[13] For the single-family residential model home, exposure concentrations were calculated based on use of the materials in a bedroom environment with an area of 11.58 m^2, a room volume of 28.24 m^3, and an air change rate of the house of 0.23 $hour^{-1}$. The model assumes a well-mixed indoor environment with the target material as the only emission source.

3. Results

TOTAL VOLATILE ORGANIC COMPOUNDS (TVOCS) AND ALDEHYDES

The chamber concentrations of total VOCs (Figure 3) and aldehydes (Figure 4) released from each material were quantified and found to be generally greater at the higher temperature. Wood flooring showed the greatest emission increase for both total VOCs and aldehydes (Tables 1 and 2), with respective concentrations increasing 405% and 387% between room temperature and heated samples. Vinyl flooring emissions increased by 67% for total aldehydes and 37% for total VOCs. MDF was the second largest emitter of aldehydes with a 74% increase. Among the products evaluated, drywall, MDF, and batted insulation remained the lowest emitters overall.

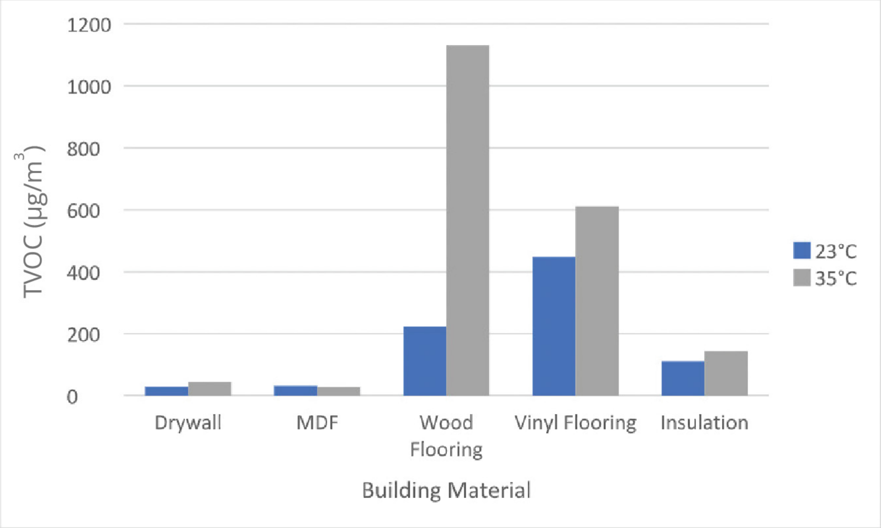

Figure 3: Total VOC (TVOC) chamber concentrations for each building material.

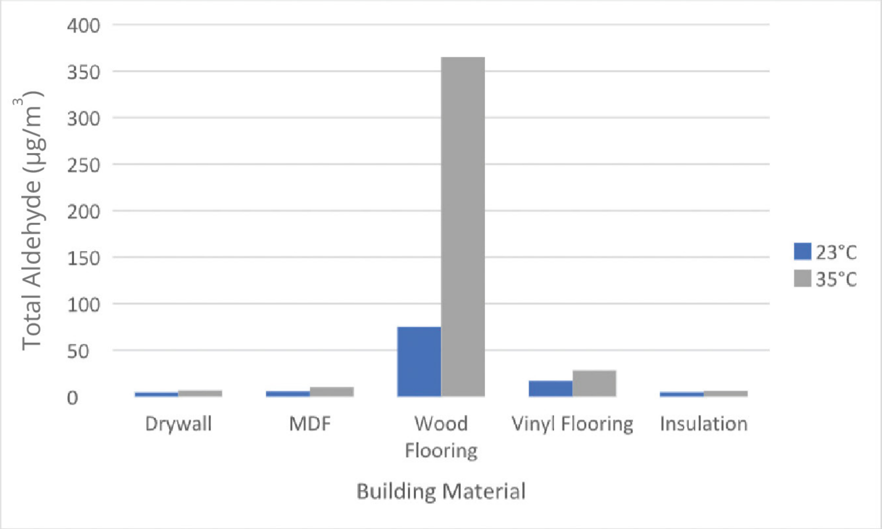

Figure 4: Total aldehyde chamber concentrations for each building material.

TABLE 1. TOTAL VOC (TVOC) CHAMBER CONCENTRATIONS FOR FIVE GENERIC BUILDING MATERIALS

Material	TVOC Concentration (μg/m^3) RT	TVOC Concentration (μg/m^3) Heated	% Difference
Drywall	29.2	45.1	54.5
MDF	31.9	28.1	-11.9
Wood Flooring	224	1130	405
Vinyl Flooring	447	611	36.7
Insulation	111	144	29.7

TABLE 2. TOTAL ALDEHYDE CHAMBER CONCENTRATIONS FOR FIVE GENERIC BUILDING MATERIALS

Material	Total Aldehyde Concentration (μg/m^3) RT	Total Aldehyde Concentration (μg/m^3) Heated	% Difference
Drywall	4.7	6.7	42.6
MDF	5.8	10.1	74.1
Wood Flooring	75.0	365	387
Vinyl Flooring	16.8	28.1	67.3
Insulation	4.9	6.3	28.6

INDIVIDUAL VOLATILE ORGANIC COMPOUNDS (IVOCS) AND ALDEHYDES

Individual VOC (Table 3) and aldehyde (Table 4) emissions were quantified at the two temperatures studied (23°C and 35°C) for drywall, MDF, wood flooring, vinyl flooring, and batted insulation. The number of individual VOCs identified for all five materials were higher in the heated samples. Unlike the VOCs, larger numbers of aldehydes were not always seen upon heating except in the wood and vinyl flooring materials. Acetaldehyde and formaldehyde were the only short-chain aldehydes identified in drywall, MDF, and insulation and it was interesting to note that the acetaldehyde concentrations were higher (by 2-3 μg/m^3) in all five building material samples than the formaldehyde levels. This may suggest a modified formulation influenced by industry.

The predominant chemical species released from drywall, MDF, and insulation were siloxanes, a few short-chain alcohols, and several longer-chain aldehydes. The range of concentrations for VOCs, additionally, was lower for the drywall, MDF, and insulation materials compared to the two flooring samples. Overall, these three materials also had the lowest total number of VOCs, varying in count from 13 to 19 total compounds above the limit of quantitation.

TABLE 3. VOC CHAMBER CONCENTRATIONS FOR FIVE COMMON BUILDING MATERIALS. (DW: DRYWALL; MDF: MEDIUM-DENSITY FIBERBOARD; WF: WOOD FLOORING; VF: VINYL FLOORING; IN: INSULATION)

Compound (concentration in $\mu g/m^3$)	DW 23°C	DW 35°C	MDF 23°C	MDF 35°C	WF 23°C	WF 35°C	VF 23°C	VF 35°C	IN 23°C	IN 35°C
1,2-Propanediol (Propylene glycol)						3.2		1.1		
1-Butanol (N-Butyl alcohol)					1.1	7.1	0.4	1.0		
1-Hexanol (N-Hexyl alcohol)					0.4	84.3				
1-Hexanol, 2-ethyl	2.9	2.5	0.6	0.6	7.4	29.4	16.0	42.0	0.8	1.6
1-Pentanol (N-Pentyl alcohol)					1.6	11.0		0.2		
2,2,4-Trimethyl-1,3-pentanediol monoisobutyrate	2.4	3.9	2.4	1.2	5.0	19.4	5.0	5.9	2.1	3.8
2-Butanone (Methyl ethyl ketone, MEK)						1.2				
2-Cyclohexen-1-one, 3,5,5-trimethyl- (Isophorone)						2.0				
Acetate, ethyl					1.3	8.0	0.3	0.7		
Acetic acid						4.8				
Acetic acid, 2-ethylhexyl ester				0.2	4.2	20.6		2.8		0.4
Acetic acid, propyl ester (Propyl acetate)				0.3		0.9	2.0	6.5		
Acetophenone (Ethanone, 1-phenyl)	0.5	0.6					11.8	34.2	1.3	1.5
Benzene, 1-methyl-4-(1-methylethyl) (p-Cymene; 4-Isopropyltoluene)							1.0	1.7		

Compound (concentration in $\mu g/m^3$)	DW 23°C	DW 35°C	MDF 23°C	MDF 35°C	WF 23°C	WF 35°C	VF 23°C	VF 35°C	IN 23°C	IN 35°C
Benzene, 1-methylethyl (Cumene)					0.1	0.4	0.5	1.5		
Benzene, ethyl					0.2					
Benzothiazole		1.3								
Cyclohexanone					1.5	6.5	3.7	10.4		
Cyclohexasiloxane, dodecamethyl	0.5	0.9								
Cyclopentasiloxane, decamethyl	0.4	0.7	0.3	0.2			1.7	3.1	0.3	0.4
Cyclotetrasiloxane, octamethyl	0.1	0.5	0.1							
Cyclotrisiloxane, hexamethyl	0.1	0.1	0.2	0.2	0.3	0.8	0.2	0.4	0.1	0.2
Decanal	1.6	2.6	1.4	1.9	4.3				3.6	5.3
Dodecane	0.2	0.8			2.0	8.1	3.2	12.3	1.0	1.8
Ethanol, 2-(2-butoxyethoxy)							10.4	58.1		
Ethanol, 2-butoxy							0.6	2.2		
Ethene, 1,1,2,2-tetrachloro (Tetrachloroethylene)						0.4				
Heptanal (Heptaldehyde)		0.2			2.6	13.2				0.3
Hexadecane (Cetane)	0.3	0.6	0.7	0.5	1.1	5.6	1.7	4.1	0.7	2.0
Hexanoic acid	1.2	1.2			66.1	400	12.2	11.7	3.4	3.3
Hexanoic acid, 2-ethyl				0.2						
Limonene (Dipentene; 1-Methyl-4-(1-methylethyl) cyclohexene)				0.1	5.7	17.5				

Compound (concentration in μg/m^3)	DW 23°C	DW 35°C	MDF 23°C	MDF 35°C	WF 23°C	WF 35°C	VF 23°C	VF 35°C	IN 23°C	IN 35°C
Nonane					0.2		0.2	0.5		
Nonyl aldehyde (Nonanal)	1.8	2.5	0.8	1.8	6.5	26.2	4.8	8.1	1.8	3.6
Octanal	0.4	0.6	0.3	0.5	6.8	29.8	2.3	4.3	0.7	2.2
Octane					0.4	1.3				
Pentadecane	0.2	0.5	0.3	0.6	1.9	8.7	2.0	3.9	0.8	2.2
Phenol	0.5						62	180	13.8	11.1
Pinene, alpha (2,6,6-Trimethyl-bicyclo[3.1.1]hept-2-ene)			0.1		1.8	6.5	0.6	1.6		
Pinene, beta (6,6-Dimethyl-2-methylene-bicyclo[3.1.1] heptane)			0.3							
Propanoic acid						1.7				
Propylene Carbonate	3.1	3.5		0.9						
Tetradecane				0.8	2.6	9.7	3.0	4.9	1.6	3.8
Tridecane						5.6				
Trimethylbenzene (All Isomers)						2.2	1.0	2.0		
TXIB (2,2,4-Trimethyl-1,3-pentanediol diisobutyrate)	4.4	5.7	11.9	6.4	6.4	13.6	9.0	13.1	6.0	7.6
Undecane					1.0	4.9				
Xylenes (Total)					0.3	0.9	0.6	1.1		

TABLE 4. ALDEHYDE CHAMBER CONCENTRATIONS FOR FIVE COMMON BUILDING MATERIALS. (DW: DRYWALL; MDF: MEDIUM-DENSITY FIBERBOARD; WF: WOOD FLOORING; VF: VINYL FLOORING; IN: INSULATION)

Compound (concentration in μg/m^3)	DW 23°C	DW 35°C	MDF 23°C	MDF 35°C	WF 23°C	WF 35°C	VF 23°C	VF 35°C	IN 23°C	IN 35°C
Acetaldehyde	3.6	4.2	4.1	6.8	7.6	20.2	3.3	3.6	3.4	4.2
Benzaldehyde						4.3	3.3	9.3		
Benzaldehyde, 3- and/or 4-methyl						2.8				
Butanal					5.3	28.1		2.0		
Formaldehyde	1.1	2.5	1.7	3.3	3.6	11.9	0.9	1.1	1.5	2.1
Hexanal					22.7	113				
Pentanal					34.7	181	9.3	12.0		
Propanal					1.2	3.9				

Wood and vinyl flooring had many more individual VOCs and aldehydes than the three other materials. As compared to the non-flooring products, the initial concentrations at room temperature were higher for many of the chemicals and increased to even higher concentrations at elevated temperature. The alcohols and aldehydes (both short- and long-chain) increased most in concentration when heated due to their chemical properties. However, some longer chain alkanes such as tetradecane and pentadecane as well as hexadecane showed appreciable increases upon heating. Many of the individual VOCs across classes of compounds that were present in the wood flooring were also present in the vinyl product. For example, a pentanediol isomer, an acetic acid ester, certain siloxanes, cyclohexanone, hexanoic acid, and TXIB were identified in both materials. Some of the noted differences between the materials were the presence of 1-hexanol, undecane, and tridecane in engineered wood only versus 2-butoxyethanol, 2-(2-butoxyethoxy)ethanol, and phenol in vinyl only. A naturally occurring terpene, *p*-cymene, was identified in vinyl flooring only, and α-pinene was found in both wood and vinyl. Limonene, another natural terpene, was present in wood only. The three highest emitting chemicals for wood flooring were hexanal, hexanoic acid, and pentanal, and vinyl flooring produced phenol, 2-ethyl 1-hexanol, and 2-(2-butoxyethoxy)ethanol at the highest concentrations.

Generally, the heated flooring samples had higher concentrations of individual short-chain aldehydes (Table 2) as well. Benzaldehyde was only quantified in wood flooring at elevated temperature, and butanal was identified in vinyl flooring only at high temperature. Propanal was only present in the engineered wood sample. Acetaldehyde and formaldehyde concentrations were found to be higher in wood flooring, but as with the drywall, MDF, and insulation, acetaldehyde was emitted at a higher level than formaldehyde.

EXPOSURE MODELING

Following the ANSI/CAN/UL 2904 modeling method for indoor air quality concentration, concentrations in the modeled room were estimated for TVOCs and IVOCs for wood flooring and vinyl flooring materials to gauge potential occupant exposure.

The TVOC emission rate calculated for wood flooring at room temperature and its corresponding exposure concentration were 548 μg/m^2·h and 976 μg/m^3. At elevated temperature, the rate and concentration, respectively, were 2762 μg/m^2·h and

4925 μg/m^3. Vinyl flooring had a higher TVOC emission rate and exposure concentration at room temperature (820 μg/m^2·h and 1461 μg/m^3) but the elevated temperature rate and concentration (1120 μg/m^2·h and 1997 μg/m^3) fell below that of wood flooring. Figure 5 shows the estimated TVOC concentrations indoors for the two high-emitting flooring materials. Leadership in Energy and Environmental Design (LEED) has a TVOC limit of 500 μg/m^3 for green buildings[14], and the estimated concentrations for the two flooring materials at both room temperature and elevated temperature all exceeded the limit, ranging from approximately 2 to 10 times higher.

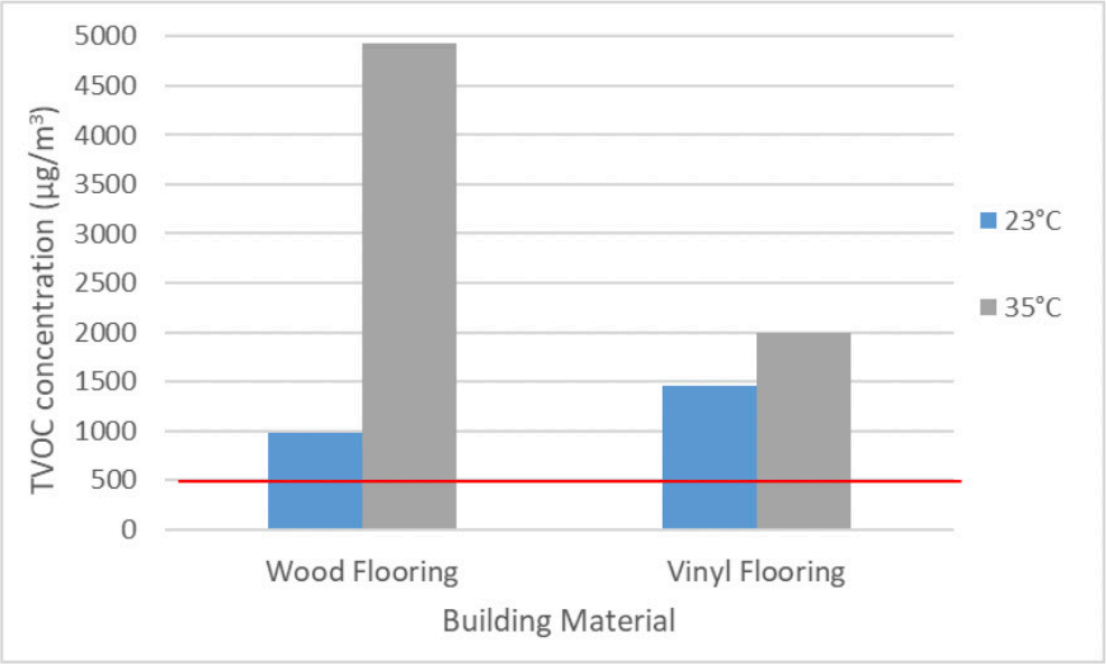

Figure 5: Model-estimated TVOC concentrations in a residential bedroom for wood flooring and vinyl flooring materials under two temperature conditions. The red line indicates the maximum concentration limit according to Leadership in Energy and Environmental Design (LEED).

The estimated room concentrations of individual VOCs are listed in Table 5. For those chemicals of concern listed by Cal/EPA OEHHA (Office of Environmental Health Hazard Assessment) with a noncancer chronic reference exposure level (CREL)[15], CA 01350 exceedances[16] were found for acetaldehyde, formaldehyde, and phenol with modeled exposure concentrations. For the wood flooring, acetaldehyde at elevated temperature was over 1.5 times its CREL. Formaldehyde at both temperatures was also higher than its CREL, from over 2 to about 30 times higher, respectively. The vinyl flooring product examined in the current pilot study also exceeded the OEHHA CREL for phenol (100 μg/m^3) at 203 μg/m^3 (room temperature) and 588 μg/m^3 (elevated temperature).[15]

TABLE 5. MODEL-ESTIMATED INDIVIDUAL VOC CONCENTRATIONS IN THE RESIDENTIAL BEDROOM FOR THE WOOD FLOORING (WF) AND VINYL FLOORING (VF) MATERIALS UNDER TWO TEMPERATURE CONDITIONS. THE REFERENCE LEVELS ARE FROM CA 01350 METHOD.[16]

Compound (concentration in µg/m^3)	WF 23°C	WF 35°C	VF 23°C	VF 35°C	Reference level
1,2-Propanediol (Propylene glycol)		13.9		3.6	
1-Butanol (N-Butyl alcohol)	4.8	30.9	1.3	3.3	
1-Hexanol (N-Hexyl alcohol)	1.7	367			
1-Hexanol, 2-ethyl	32.2	128	52.3	137	
1-Pentanol (N-Pentyl alcohol)	7.0	47.9		0.7	
2,2,4-Trimethyl-1,3-pentanediol monoisobutyrate	21.8	84.5	16.3	19.3	
2-Butanone (Methyl ethyl ketone, MEK)		5.2			
2-Cyclohexen-1-one, 3,5,5-trimethyl- (Isophorone)		8.7			1000
Acetate, ethyl	5.7	34.9	1.0	2.3	
Acetic acid		20.9			
Acetic acid, 2-ethylhexyl ester	18.3	89.8		9.2	
Acetic acid, propyl ester (Propyl acetate)		3.9	6.5	21.2	
Acetophenone (Ethanone, 1-phenyl)			38.6	112	
Benzene, 1-methyl-4-(1-methylethyl) (p-Cymene; 4-Isopropyltoluene)			3.3	5.6	
Benzene, 1-methylethyl (Cumene)	0.4	1.7	1.6	4.9	
Benzene, ethyl	0.9				1000
Cyclohexanone	6.5	28.3	12.1	34.0	
Cyclopentasiloxane, decamethyl			5.6	10.1	
Cyclotrisiloxane, hexamethyl	1.3	3.5	0.7	1.3	
Decanal	18.7				

Compound (concentration in µg/m^3)	WF 23°C	WF 35°C	VF 23°C	VF 35°C	Reference level
Dodecane	8.7	35.3	10.5	40.2	
Ethanol, 2-(2-butoxyethoxy)			34.0	190	
Ethanol, 2-butoxy			2.0	7.2	
Ethene, 1,1,2,2-tetrachloro (Tetrachloroethylene)		1.7			17.5
Heptanal (Heptaldehyde)	11.3	57.5			
Hexadecane (Cetane)	4.8	24.4	5.6	13.4	
Hexanoic acid	288	1743	39.9	38.2	
Limonene (Dipentene; 1-Methyl-4-(1-methylethyl)cyclohexene)	24.8	76.3			
Nonane	0.9		0.7	1.6	
Nonyl aldehyde (Nonanal)	28.3	114	15.7	26.5	
Octanal	29.6	130	7.5	14.1	
Octane	1.7	5.7			
Pentadecane	8.3	37.9	6.5	12.7	
Phenol			203	588	100
Pinene, alpha (2,6,6-Trimethyl-bicyclo[3.1.1]hept-2-ene)	7.8	28.3	2.0	5.2	
Propanoic acid		7.4			
Tetradecane	11.3	42.3	9.8	16.0	
Tridecane		24.4			
Trimethylbenzene (All Isomers)		9.6	3.3	6.5	
TXIB (2,2,4-Trimethyl-1,3-pentanediol diisobutyrate)	27.9	59.3	29.4	42.8	
Undecane	4.4	21.4			
Xylenes (Total)	1.3	3.9	2.0	3.6	350

Compound (concentration in µg/m^3)	WF 23°C	WF 35°C	VF 23°C	VF 35°C	Reference level
Acetaldehyde	40.1	107	13.1	14.3	70
Benzaldehyde		22.7	13.1	36.8	
Benzaldehyde, 3- and/or 4-methyl		14.8			
Butanal	28.0	148		7.9	
Formaldehyde	19.0	62.9	3.6	4.4	9
Hexanal	120	597			
Pentanal	183	956	36.8	47.5	
Propanal	6.3	20.6			

4. FUTURE RESEARCH

Future work will seek to build upon not only temperature effect but also investigate humidity effects and extreme events such as combustion to simulate other possible weatherization occurrences. Additional building materials will be chosen to represent a broader portion of the indoor built environment across a range of physicochemical compositions.

References

1. Naidu, R. B., B.; Willett, I.R.; Cribb, J.; Singh, B.K.; Nathanail, C.P.; Coulon, F.; Semple, K.T.; Jones, K.C.; Barclay, A.; Aitken, R.J. Chemical pollution: A growing peril and potential catastrophic risk to humanity. *Environment International* **2021**, *156*, 106616. DOI: 10.1016/j.envint.2021.106616.

2. Kanazawa, A. S., I.; Araki, A.; Takeda, M.; Ma, M.; Saijo, Y.; Kishi, R. Association between indoor exposure to semi-volatile organic compounds and building-related symptoms among the occupants of residential dwellings. *Indoor Air* **2010**, *20*, 72-84. DOI: 10.1111/j.1600-0668.2009.00629.x.

3. Lucattini, L. P., G.; Covaci, A.; de Boer, J.; Lamoree, M.H.; Leonards, P.E.G. A review of semi-volatile organic compounds (SVOCs) in the indoor environment: occurrence in consumer products, indoor air, and dust. *Chemosphere* **2018**, *201*, 466-482. DOI: 10.1016/j.chemosphere.2018.02.161.

4. Caron, F. G., R.; Robert, L.; Verriele, M.; Thevenet, F. Behaviour of individual VOCs in indoor environments: How ventilation affects emission from materials. *Atmospheric Environment* **2020**, *243*, 117713. DOI: 10.1016/j.atmosenv.2020.117713.

5. Haghighat, F. L., C.-S.; Ghaly, W.S. Measurement of diffusion coefficients of VOCs for building materials: review and development of a calculation procedure. *Indoor Air* **2002**, *12*, 81-91. DOI: 10.1034/j.1600-0668.2002.1e008.x.

6. Huangfu, Y. L., N.M.; O'Keefe, P.T.; Kirk, W.M.; Lamb, B.K.; Pressley, S.N.; Lin, B.; Cook, D.J.; Walden, V.P.; Jobson, B.T. Diel variation of formaldehyde levels and other VOCs in homes driven by temperature dependent infiltration and emission rates. *Building and Environment* **2019**, *159*, 106153. DOI: 10.1016/j.buildenv.2019.05.031.

7. Norris, C. L. E., R.; Ghoroi, C.; Schauer, J.J.; Black, M.; Bergin, M.H. A pilot study to quantify volatile organic compounds and their sources inside and outside homes in urban India in summer and winter during normal daily activities. *Environments* **2022**, *9*, 75. DOI: 10.3390/environments9070075.

8. ASTM. *Standard Practice for Choosing Sorbents, Sampling Parameters and Thermal Desorption Analytical Conditions for Monitoring Volatile Organic Chemicals in Air*; D6196-15; 2016.

9. EPA, U. S. *Determination of Volatile Organic Compounds in Ambient Air Using Active Sampling Onto Sorbent Tubes; Compendium Method TO-17*; Cincinnati, OH, 1999.

10. ASTM. *Standard Test Method for Determination of Formaldehyde and Other Carbonyl Compounds in Air (Active Sampler Methodology);* D5197-16; 2016.

11. EPA, U. S. *Determination of Formaldehyde in Ambient Air Using Adsorbent Cartridge Followed by High Performance Liquid Chromatography (HPLC) [Active Sampling Methodology];* Compendium Method TO-11A; 1999.

12. UL. *GREENGUARD Certification Program Method for Measuring and Evaluating Chemical and Particle Emissions*; UL 2823; 2013.

13. ANSI/CAN/UL. *Standard Method for Testing and Assessing Particle and Chemical Emissions from 3D Printers*; ANSI/CAN/UL 2904; 2019.

14. USGBC. *LEED Reference Guide for Building Design and Construction*; LEED v4; 2020.

15. OEHHA. Technical Support Document for Noncancer RELs, Appendix D1. CA OEHHA: 2013.

16. OEHHA. *Standard Method for the Testing and Evaluation of Volatile Organic Chemical Emissions from Indoor Sources Using Environmental Chambers*; California Specification 01350; CA, 2017.

Chemical Insights