

NARRATIVE REPORT

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Report Date: July 2, 2005
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RE: Sum High-back / All adjustable chair with arms

OBJECTIVE

This study was conducted to apply a small-scale test protocol to measure the emissions of volatile organic compounds (VOCs) from individual components used to produce office seating. In this report, the VOC emission data for the components of the Sum, high-back, all adjustable chair with arms (Allsteel, Inc.) are summarized and analyzed with objective of predicting VOC emissions from the finished Sum chair. The results of this analysis then are compared to the requirements of U.S. Green Building Council LEED® for Commercial Interiors, EQ Credit 4.5 and to the requirements of California Specification 01350.

SUMMARY OF METHODS

Samples of the primary components used to produce office seating products were selected and collected directly from the manufacturing facility either by a representative of Scientific Certification Systems, Inc. (SCSI) or by the client. Broadly, the samples consisted of fabrics with adhesive; seat foam; molded seat frames and backs; and molded arms. These were packaged to preserve their chemical integrity and shipped to the laboratory for VOC emissions testing. This testing uses small-scale environmental chambers and is conducted following the guidance of ASTM D 5116-97, "Standard Guide for Small-Scale Environmental Chamber Determinations of Organic Emissions from Indoor Materials/Products."

The emission tests and the results of these tests are described in laboratory reports submitted to the client. The relevant laboratory reports are referenced herein, and the data contained in the reports forms the basis of this analysis.

In the case of the Sum chair, the components of potential importance with respect to VOC emissions consist of the fabric with a water-based adhesive for the seat and back cushions; polyurethane foam cushions with rigid polypropylene backing for the seat and back; molded Nylon for the backrest, exposed underside of seat, arm supports, seat suspension bracket, and legs (12 individual pieces); molded rubber armrests; and a rubber block in the seat suspension. Representative samples of these were collected and tested. It was assumed that the rubber block had similar emissions as the rubber armrests. The seat support bracket and suspension are painted metal. Several components were hard plastic. Metal components painted or coated by different processes have been tested previously and have been found to negligible sources of VOC emissions. Hard plastic pieces, other than Nylon, also have been found to be negligible sources of VOC emissions. Thus, the metal and the other plastic components of the chair were

not collected or tested. Because the VOC emissions from chair components have been found to be generally low with respect to the allowed limits of programs against which the emissions are evaluated, the tests were limited to a 72-h period.

The prediction of emissions and room concentrations from a piece of office furniture based on the results of small-scale tests of individual components is a multi-step process. The tests yield emission factors for each chemical substance, which may be stated in terms of mass of VOC emitted per unit area of the product per hour, e.g., $\mu\text{g}/\text{m}^2\text{-h}$, or mass emitted per individual product unit per hour, e.g., $\mu\text{g}/\text{unit-h}$. The piece of furniture is then measured to determine the areas of the individual components. Some components, such as molded chair arms are counted. The client may provide the dimensional information to the laboratory. The emission factors are then multiplied by the areas or numbers of their respective components. This yields a per-furniture unit emission rate, i.e., mass of VOC emitted per hour ($\mu\text{g}/\text{h}$), for each substance from each component. Next, the emission rates are summed by substance to get the whole furniture unit emission rate for each substance. These whole-furniture emission rates are used in the steady-state mass balance model shown below to estimate the impact of installing the furniture in a specified room with defined ventilation characteristics on the VOC concentrations in the room.

Steady state VOC concentrations C ($\mu\text{g}/\text{m}^3$) in a room are calculated using Equation 1:

$$C = (EF \times \text{No. Units}) / (V \times a) \quad (1)$$

Where, EF is the furniture unit emission rate ($\mu\text{g}/\text{m}^2\text{-h}$); No. Units is the number of furniture units installed in the room; V is the volume of the room (m^3), and a is the outdoor air ventilation rate in air changes per hour. If a portion of the space is occupied by objects, the total volumetric flow rate is the product of Va and the ventilated volume fraction.

ANALYSIS

The samples and the test specimens that are applicable to the Sum chair are listed and described in Table 1. There were two fabric samples; one was 100% wool, the other was 60% nylon / 40% polyester. Both were treated with a water-based adhesive.

The measured or estimated quantities of the components of the chair are listed in Table 2. There were representative samples of fabric with adhesive, polyurethane foam cushion, molded rubber armrest, and molded Nylon backrest.

The VOC emission factors for individual components (i.e., either $\mu\text{g}/\text{m}^2\text{-h}$ or $\mu\text{g}/\text{unit-h}$) and the calculated per-chair unit emission rates by chemical substance and component are shown in Table 3. Data are only shown for those substances specifically listed as chemicals of concern by CA Specification 01350 (see below). Two fabric samples with adhesive emitted the same substances at nearly identical rates; the maximum measured value for each substance is used in this analysis. Results for substances emitted by more than one component are summed.

Table 4 lists the emission factors of individual VOCs that were detected in the tests of the individual components, but which are not specifically listed as chemicals of concern.

The VOC emission test results for the Sum chair were evaluated with respect to the requirements of the U.S. Green Building Council, 2004, LEED® for Commercial Interiors, v.2, EQ Credit 4.5. The results also were evaluated with respect to the requirements of California Architectural Specification 01350 as described in "Standard Practice for the Testing of Volatile Organic Emissions from Various Sources using Small-scale Environmental Chambers," California Department of Health Services (CHDS), July 15, 2004, CA/DHS/EHLB/R-174 (accessible at http://www.dhs.ca.gov/ps/ehlb/IAQ/VOCS/Section_01350_preface.htm). This practice supersedes previous versions of the environmental chamber testing portion of California Specification 01350.

The room and office furniture parameters for predicting the impact of the furniture on indoor air concentrations of VOCs in a room have been defined by BIFMA (2003). As shown in Table 5, it is assumed the furniture is installed in a room with a volume of 33 m³ that is continuously ventilated at 1 air change per hour with clean outdoor air. The environmental parameters are 23 ± 2 °C and 50 ± 5% relative humidity. The final time point of interest for the Environmental Technology Verification Test Protocol, Large Chamber Test Protocol for Measuring Emissions of VOCs and aldehydes (RTI, 1999) is 168 hours. This time point has been used by the U.S. EPA in purchase requirements for office furniture systems. The BIFMA modeling scenario is used to determine compliance with LEED® EQ Credit 4.5.

The room parameters for predicting the impact of a product (e.g., a floor covering) on indoor air concentrations of VOCs in an individual office space are defined in CA Specification 01350. As shown in Table 6, it is assumed the product is installed in a 30.6 m³ room that has a 0.9 ventilated volume fraction and is continuously ventilated at 0.75 h⁻¹. The time point of interest is 336 h determined as a ten day conditioning period followed by a 96-h test in an environmental chamber at 23 ± 1° C and 50 ± 5% RH. For the purposes of this modeling exercise, it was assumed there are two chairs in the space, a task chair for the occupant and a visitor chair.

The indoor air concentration limits for VOC emissions from seating listed in Option B of LEED® for Commercial Interiors, EQ Credit 4.5 are reproduced in Table 7. These values are one-half the allowed values for systems furniture.

For Specification 01350, the chemicals of concern are those with established Chronic Reference Exposure Levels (CRELs) plus chemicals on the California Air Resources Board Toxic Air Contaminant List and chemicals on the California Safe Water Drinking Water and Toxic Enforcement Act of 1986 (Prop. 65) list. Only volatile organic chemicals that can be analyzed by the HPLC and thermal desorption GC/MS methods are considered. Specification 01350 requires that the modeled indoor air concentration not exceed one-half the CREL, with the exception of formaldehyde. For formaldehyde, no single product's modeled concentration can exceed one-half the interim Indoor Reference Exposure Level of 33 µg/m³.

The predicted concentrations of TVOC, formaldehyde and 4-phenylcyclohexene for the BIFMA office scenario are presented in Table 8 and are compared to the LEED® EQ Credit 4.5 requirements. Since formaldehyde was the only aldehyde detected, the emissions of total aldehydes and formaldehyde are the same. The modeled concentrations at 72 h are well below the requirements of EQ Credit 4.5 and, thus, are compliant with the requirements.

Among the chemicals emitted by the components of the Sum chair, formaldehyde, toluene, styrene, ethylbenzene, and xylene isomers are classified as a chemicals of concern with guideline concentrations under Specification 01350. The modeled formaldehyde concentration of <1 µg/m³ (Table 9) is negligible relative to the requirement of 16.5 µg/m³. The concentrations of toluene, styrene, ethylbenzene and xylenes were well below the required levels. Caprolactam emitted by the Nylon components is listed as a Toxic Air Contaminants but does not have a guideline concentration. TVOC concentrations are reported, but are only considered to be advisory under Specification 01350.

CONCLUSIONS

The modeled concentrations at 72 h of total VOCs, formaldehyde, total aldehydes, and 4-PCH emitted from the primary components of the Sum chair are in compliance with the requirements of USGBC, LEED® for Commercial Interiors, EQ Credit 4.5. It is expected that emissions measured at 168 h would trend lower from values measured at earlier time points.

The components of the Sum chair emitted small amounts of formaldehyde and other chemicals of concern under California Specification 01350. However, the modeled concentrations at 72 h of these chemicals all are well in compliance with the requirements of Specification 01350.

REFERENCES

BIFMA, 2003, *White Paper on Office Furniture, Office Furniture – Test Protocol for Emissions of Formaldehyde, Total Aldehydes, and TVOC*. Grand Rapids, MI, BIFMA International

California Department of Health Services, 2004. *Standard Practice for the Testing of Volatile Organic Emissions from Various Sources using Small-scale Environmental Chambers*. Report CA/DHS/EHLB/R-174, July 15, 2004

RTI. 1999. *Environmental Technology Verification Test Protocol. Large Chamber Test Protocol for Measuring Emissions of VOCs and Aldehydes*. Research Triangle Park, NC, Research Triangle Institute, EPA Cooperative Agreement No. CR 822870-01

USGBC. 2004. *LEED Green Building Rating System for Commercial Interiors, Version 2*. Atlanta, GA, U.S. Green Building Council

Table 1. Descriptions of samples and test specimens for Sum chair

Sample	Laboratory Specimen ID	Report Date	Exposure Parameter Area, One Side (m ²)	Unit (No.)	Description
100% Wool fabric, QRS45	221-005-02A	5/20/05	1.12		Sprayed on 1 side with water-based Henkel adhesive
60% Nylon / 40% polyester fabric, FWK 65	221-005-03A	5/20/05	1.12		Sprayed on 1 side with water-based Henkel adhesive
Polyurethane seat foam with polypropylene backer	221-005-04A	5/20/05	0.029		Foam with plastic backer, 1.5-in thick
Portion of Nylon back rest	221-005-05A	5/20/05	0.035		Section cut from backrest
Molded rubber armrest	221-010-04A	5/20/05		1	Molded black rubber over metal plate

Table 2. Components of Sum chair

No.	Description	Quantity (m ²)	No.
1	Fabric with adhesive for upholstered seat and back cushions	1.5	--
2	Polyurethane foam for seat and back cushions	0.50	--
3	Formed Nylon backrest, underside of seat, arm supports, suspension bracket, and legs	1.1*	--
4	Molded rubber armrests	--	2
5	Rubber suspension component	--	1**
6	Painted metal seat bracket and suspension miscellaneous hard plastic pieces	--	1

*Estimated exposed surface area for 12 individual pieces

**Assumed to have similar emissions as molded rubber armrests

Table 3. Emission factors (EFs) for listed chemical substances emitted by Sum chair components at 72 h

Substance	Component	Report No.	Emission Factor		
			($\mu\text{g}/\text{m}^2\text{-h}$)	($\mu\text{g}/\text{unit-h}$)	($\mu\text{g}/\text{chair-h}$)
Formaldehyde	Fabric with adhesive	221-005-03A	1.8		2.7
4-Phenylcyclohexene	Fabric with adhesive	221-005-03A	0.7		1.0
Toluene	Rubber armrest	221-010-04A		0.9	2.7
Styrene	Rubber armrest	221-010-04A		5.1	15.3
Ethylbenzene	Rubber armrest	221-010-04A		1.0	3.1
Xylenes	Rubber armrest	221-010-04A		1.6	4.6
1,2,4-Trimethylbenzene	Rubber armrest	221-010-04A		0.1	0.3
2-Butanone	Rubber armrest	221-010-04A		0.2	0.6
Caprolactam	Molded Nylon	221-005-05A	118		130
TVOC	Fabric with adhesive	221-005-02A	73.2		110
TVOC	Polyurethane foam	221-005-04A	1,770		885
TVOC	Rubber armrest	221-010-04A		103	309
TVOC	Molded Nylon	221-005-05A	84.8		93
Total TVOC					1,400

Table 4. Non-listed chemical substances emitted by Sum chair components at 72 h

Substance	CAS	Report	Emission Factor	
	No.	No.	($\mu\text{g}/\text{m}^2\text{-h}$)	($\mu\text{g}/\text{unit-h}$)
2-(Dimethylamino)ethanol	108-01-0	221-005-02A	14.3	
1-Chloro-5-(1-chloroethenyl)cyclohexane	13547-07-4	221-005-02A	1.0	
1-Chloro-4-(1-chloroethenyl)cyclohexane	13547-06-3	221-005-02A	0.8	
Longifolene	475-20-7	221-005-02A	4.3	
n-Tetradecane	629-59-4	221-005-02A	1.8	
n-Pentadecane	629-62-9	221-005-02A	1.6	
n-Hexadecane	544-76-3	221-005-02A	0.5	
n-Heptadecane	629-78-7	221-005-02A	0.3	
2-(Dimethylamino)ethanol	108-01-0	221-005-03A	6.1	
1-Chloro-5-(1-chloroethenyl)cyclohexane	13547-07-4	221-005-03A	1.1	
1-Chloro-4-(1-chloroethenyl)cyclohexane	13547-06-3	221-005-03A	0.9	
Longifolene	475-20-7	221-005-03A	4.5	
n-Tetradecane	629-59-4	221-005-03A	1.5	
n-Pentadecane	629-62-9	221-005-03A	1.9	
n-Hexadecane	544-76-3	221-005-03A	0.7	
n-Heptadecane	629-78-7	221-005-03A	0.3	
2-(Dimethylamino)ethanol	108-01-0	221-005-04A	163	
Triethylenediamine	280-57-9	221-005-04A	211	
2-Propenoic acid, 2-(dimethylamino)ethyl ester	2439-35-2	221-005-04A	263	
Siloxane compound	--	221-005-04A	261	
Siloxane compound	--	221-005-04A	110	
2,6-Bis(1,1-dimethyl)-4-(1-oxypropyl)phenol	14035-34-8	221-005-04A	231	
Triethylamine	121-44-8	221-010-04A		4.1
Decamethyltetrasiloxane	141-57-9	221-010-04A		2.6
Triethelenediamine	280-57-9	221-010-04A		6.4
Mixture containing C ₈ H ₁₇ N ₃ O ₂ S Compound	--	221-010-04A		22.6
Mixture of nitrogen containing compounds	--	221-010-04A		31.6
2,6-bis(1,1-dimethylethyl)-4-methylphenol (BHT)	128-37-0	221-010-04A		10.1

Table 5. Parameters for predicting room air concentrations for chairs (BIFMA, 2003; RTI, 1999)

Parameter	Symbol	Units	Value
Room volume	V_R	m^3	33
Loading ratio	L_R	unit m^{-3}	1 Chair/33 m^3
Outdoor air flow rate	Q_R	$m^3 h^{-1}$	33
Ventilation rate	A_R	h^{-1}	1
Temperature	T	$^{\circ}C$	23 ± 2
Relative humidity	RH	%	50 ± 5
Time point of interest*	--	hours	168

*From RTI, 1999, *ETV Large Chamber Test Protocol for Measuring Emission of VOCs and aldehydes*

Table 6. California Specification 01350 parameters for predicting room air concentrations in an individual office space (CA/DHS/EHLB/R-174, 2004)

Parameter	Symbol	Units	Value
Office space volume	V_R	m^3	30.6
Loading ratio	L_R	unit m^{-3}	2 Chairs*/30.6 m^3
Outdoor air flow rate	Q_R	$m^3 h^{-1}$	20.7
Ventilation rate	A_R	h^{-1}	0.75
Ventilated volume fraction			0.9
Temperature	T	$^{\circ}C$	23 ± 1
Relative humidity	RH	%	50 ± 5
Time point of interest**	--	hours	336

*Not specified; calculation assumed one task chair and one visitor chair per workstation

**96-h Sampling point following a 10-day conditioning period (i.e., total time 336 h)

Table 7. Indoor air concentration limits for VOC emissions from seating (USGBC, 2004, LEED® for Commercial Interiors, EQ Credit 4.5)

Chemical Contaminant	Emission Limit
TVOC	0.25 mg/m ³ (250 µg/m ³)
Formaldehyde	25 parts-per-billion (ppb)
Total aldehydes	50 ppb
4-Phenylcyclohexene (4-PCH)	0.00325 mg/m ³ (3.25 µg/m ³)

Table 8. Sum chair: Predicted room air concentrations for BIFMA/ETV scenario of TVOC, formaldehyde and 4-phenylcyclohexene at 72 hours attributable to summed emissions. Modeling parameters are listed in Table 5. No aldehydes other than formaldehyde were detected. Acceptability of concentrations is determined relative to the requirements of USGBC, LEED® for Commercial Interiors, EQ Credit 4.5. Note that measurements were made at 72 h rather than 168 h

Chemical Contaminant	Concentration Limit	Predicted Concentration	EQ Credit 4.5 Compliant?
TVOC	0.25 mg/m ³	0.042 mg/m ³	Yes
Formaldehyde	25 ppb	<0.1 ppb	Yes
4-PCH	0.00325 mg/m ³	0.00003 mg/m ³	Yes

Table 9. Sum chair: Predicted room air concentrations for CA Specification 01350 scenario of individual VOCs on lists of toxic chemicals and TVOC at 72 hours attributable to summed emissions. Modeling parameters are listed in Table 6. Acceptability of concentrations is determined relative to the requirements of CA Specification 01350. Note that measurements were made at 72 h rather than 336 h

Chemical Contaminant	Concentration, $\mu\text{g}/\text{m}^3$		Spec. 01350 Compliant?
	$\frac{1}{2}$ Chronic REL	Predicted	
Formaldehyde	16.5*	0.3	Yes
Toluene	150	0.3	Yes
Styrene	450	1.5	Yes
Ethylbenzene	1,000	0.3	Yes
Xylenes	350	0.4	Yes
TVOC		135	Na

*For formaldehyde, requirement is $\frac{1}{2}$ indoor REL of $33 \mu\text{g}/\text{m}^3$ rather than $\frac{1}{2}$ chronic REL

**Na = Not applicable