LE PLAN VERT DU CANADA
CANADA'S GREEN PLAN

BUILDING MATERIALS - VOLATILE ORGANIC CHEMICAL EMISSION CHARACTERIZATION AND DATABASE DEVELOPMENT

PREPARED FOR:

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EXECUTIVE SUMMARY

This report outlines the results of a project which developed environmental chamber test procedures for characterizing the volatile organic chemical (VOC) emissions from residential construction materials. These procedures were used to measure the VOC emission characteristics from various construction materials used in the Advanced Houses and R2000 Healthier Homes in Halifax.

The environmental chamber test procedures were modelled after recent standards issued by the Canadian General Standards Board (CGSB). Similar standards formats are currently being developed within the ASTM D22.05 Indoor Air Quality Sub-committee. The standard test procedure focused on the use of small environmental chambers for measuring the volatile organic chemical emissions from building material samples. The approach taken in developing the test methods was to develop a single general test method to describe the chamber operating criteria, chemical sampling and analysis protocols and data analysis methodology that would be common to all of the building materials tested. For each of the specific building material types, a test parameter and methodology sheet was developed to record product specific information, type of test to be performed, sample preparation and conditioning procedures, laboratory test procedure including product loading ratio and chamber operating criteria and chemical analysis. For each material classification, a rationale was developed to explain the specific interpretation of the general test method for each application.

The second project objective was to conduct laboratory tests to characterize the volatile organic chemical emissions from a variety of currently available building materials. Product samples were selected from materials obtained from the Advanced Houses and from the Halifax houses. Materials selected from the Advanced Houses were representative of currently available materials that had been aged for a period of six to eighteen months. The materials from the Halifax R2000 were new, un-aged materials that should be representative of the emission characteristics of products installed in typical new homes. Material classification included carpets, carpet foam underpad, vinyl flooring, engineered wood materials, cellular plastic insulation, gypsum board and latex paint.

The focus for the testing of the Advanced Houses materials was to gather engineering data on emission characteristics that can be expected in newer homes and to provide data for use in computer simulations to estimate the resulting indoor air quality parameters based on source emission and house ventilation characteristics. The Halifax data can be used in engineering algorithms to estimate the initial indoor air quality characteristics of newly constructed houses. Another end-use of the building material emission will be to assist builders in identifying low emitting materials for use in buildings and to highlight the importance of obtaining product-specific information rather than relying on generalized data from tests of "similar" materials. In total, 37 materials were tested for VOC emissions and 20 materials were tested for formaldehyde (HCHO) emissions.

The results of the materials emission characterization testing indicated an extremely wide range in emission characteristics among material classifications and within a material type. For instance, with the carpet samples tested, the total volatile organic chemical (TVOC) emission factors varied from a low of 18 $\mu g/m^2 \cdot h$ to a high of 56,000 $\mu g/m^2 \cdot h$. For most other product classification, the range of emission factors was lower but typically one to two orders of magnitude.

The material test results also indicated that although specific materials could be problematic, the total emission source in new houses was distributed amongst a variety of commonly used construction materials. This highlights the importance of developing a rational framework for evaluating the impact of specific materials on the overall indoor air quality in buildings. This methodology will assist builders in making careful choices regarding the materials used in construction and will allow them to assess the relative impacts of the material choices on the overall indoor air quality.

RÉSUMÉ

Le présent rapport résume les résultats d'un projet qui avait pour but l'élaboration de méthodes d'essai en chambre de simulation de l'environnement en vue de la caractérisation des émissions de composés organiques volatils (COV) par les matériaux utilisés dans la construction résidentielle. Ces méthodes d'essai ont été employées pour mesurer les caractéristiques d'émission de COV de divers matériaux de construction utilisés dans les maisons performantes et dans les maisons plus saines R2000 à Halifax.

Les méthodes d'essai en chambre de simulation de l'environnement ont été établies en tenant compte des normes récemment publiées par l'Office des normes générales du Canada (ONGC). Des normes similaires sont actuellement élaborées par le sous-comité en charge de la norme ASTM D22.05 sur la qualité de l'air intérieur. La méthode d'essai normalisée portait essentiellement sur l'emploi de petites chambres de simulation de l'environnement pour mesurer les concentrations de composés organiques volatils émis par des échantillons de matériaux de construction. Dans le présent projet, il a été convenu de mettre au point une méthode d'essai générale unique dans laquelle sont décrits les paramètres de fonctionnement de la chambre, les méthodes d'échantillonnage et d'analyse des produits chimiques ainsi que la méthode d'analyse des données qui seraient communs à tous les matériaux de construction mis à l'essai. Pour chaque type particulier de matériau de construction, une feuille d'essai a été préparée sur laquelle sont consignés les renseignements suivants : données relatives au produit, type d'essai à effectuer, méthodes de préparation et de conditionnement de l'échantillon, méthode d'essai de laboratoire incluant le rapport de chargement du produit, les paramètres de fonctionnement de la chambre et l'analyse chimique. Pour chaque classe de matériau, un exposé raisonné explique comment interpréter la méthode d'essai générale pour l'appliquer à cette classe de matériau.

Le deuxième objectif du projet était de réaliser des essais de laboratoire pour caractériser les émissions de composés organiques volatils par divers matériaux de construction actuellement disponibles. Des échantillons ont été choisis parmi les matériaux utilisés dans les maisons performantes et les maisons de Halifax. Les matériaux provenant des maisons performantes étaient représentatifs de matériaux actuellement disponibles qui ont été vieillis pendant une période de six à dix-huit mois. Les matériaux provenant des maisons R2000 de Halifax étaient des matériaux neufs, non vieillis, qui devraient être représentatifs des matériaux installés dans les maisons neuves ordinaires. Les échantillons ont été choisis dans les classes de matériaux suivantes : tapis, matelassure en mousse, couvre-plancher en vinyle, produits du bois de haute performance, isolant en plastique alvéolaire, placoplâtre et peinture au latex.

Le but des essais réalisés avec les matériaux provenant des maisons performantes était double : recueillir des données techniques sur les caractéristiques des émissions que l'on peut prévoir dans les maisons plus récentes et fournir des données qui seraient utilisées dans des simulations sur ordinateur pour estimer les paramètres relatifs à la qualité de l'air intérieur en fonction des caractéristiques d'émission de la source et des caractéristiques de l'aération dans la maison. Les données relatives aux maisons d'Halifax peuvent être utilisées dans des algorithmes techniques pour estimer les caractéristiques initiales de la qualité de l'air intérieur dans les maisons nouvellement construites. Les données sur les émissions par les matériaux de construction peuvent également aider les constructeurs à identifier les matériaux de construction qui émettent

peu de COV. De plus, les constructeurs se rendront mieux compte qu'il est important d'obtenir des données spécifiques plutôt que de se fier à des données générales provenant d'essais réalisés sur des matériaux "similaires". En tout, 37 matériaux ont été soumis aux essais relatifs aux émissions de COV et 20 matériaux ont été soumis aux essais relatifs aux émissions de formaldéhyde (HCHO).

Les résultats des essais de caractérisation des émissions couvrent une vaste gamme de valeurs, à la fois entre les différentes classes de matériaux et à l'intérieur d'une même classe. Par exemple, pour les tapis, les concentrations de composés organiques volatils totaux (COVT) varient de 18 $\mu g/m^2$ à 56 000 $\mu g/m^2$. Pour la plupart des autres classes de matériaux, la fourchette est plus étroite, avec un facteur de variation généralement égal à 10^1 ou 10^2.

Les résultats des essais ont également montré que, malgré le fait que certains matériaux spécifiques puissent poser des problèmes, les émissions totales dans les maisons neuves proviennent de divers matériaux couramment utilisés dans la construction. Il est donc très important d'établir une méthode rationnelle pour évaluer les conséquences de l'utilisation de matériaux spécifiques sur la qualité globale de l'air intérieur. Une telle méthode aidera les constructeurs à choisir judicieusement les matériaux utilisés et elle leur permettra d'évaluer les conséquences relatives des matériaux choisis sur la qualité globale de l'air intérieur.

1.0 INTRODUCTION

Volatile organic chemical emissions from indoor building materials can be significant sources of indoor air pollutants in many buildings. Of particular concern are residential buildings since they can contain a high loading of materials when compared with the total building volume and outdoor air exchange rate. Since residential indoor air quality guidelines are typically the most stringent, it is important for home builders and home owners to be able to select materials with known chemical emission characteristics and to use them in a manner which will ensure that indoor air quality meets acceptable levels.

Evaluation of the VOC emission characteristics of building materials is a developing area of research. Currently, there are a number of different methodologies used, each one giving different results and application. In order to conduct a meaningful material evaluation, the test methodology must be consistent and provide results which can be applied to the final analysis. For this project, a methodology was required which could evaluate the individual chemical emission factors for a broad range of building materials used in houses. These site emission factors can be used in subsequent analysis to estimate the resulting indoor pollutant concentrations in houses.

The Advanced Houses Program and Healthier R2000 Houses Program in Halifax outlined specific indoor air quality objectives intended to meet the Health and Welfare Canada Guidelines for Residential Indoor Air Quality(1). The house design teams were challenged to consider the impact of building materials on the overall indoor air quality and to select materials that would provide acceptable performance. In most cases, the teams had to select the materials using intuition and supplier guidance rather than specific test data. The field monitoring protocol for the houses was developed to evaluate the resulting indoor air quality parameters. Further analysis comparing the field performance with the predicted performance using emission factor data will provide insight into the practical application of indoor air quality estimation models.

The objectives of this project were: 1) to develop environmental chamber test procedures for characterizing the volatile organic chemical (VOC) emissions from residential construction materials and, 2) measure the VOC emission characteristics of various construction materials used in the Advanced Houses Program and R2000 program houses in Halifax.

2.0 METHODOLOGY

2.1 *Development of Environmental Chamber Test Procedures*

Currently, there are a number of test procedures being used in Canada, the United States and internationally to evaluate VOC emissions from building materials. The ASTM D22.05 sub-committee on indoor air has provided a focal point for discussion and development of building product emission standards for carpeting, spray-in-place polyurethane foam, caulks and sealants, paints, wood products and a number of other building materials. This committee has also developed ASTM Standard D5116-90 ***Standard Guide for Small-Scale Environmental Chamber Determinations of Organic Emission from Indoor Materials/Products***(2) which has helped to standardize the small chamber methodology used by various organizations to develop product-specific test protocols.

Currently, environmental chamber tests represent the best, most established method for evaluating VOC emissions from materials.

The basic methodology used to develop the test protocols for this project was to model them on two ASTM product standards that are currently under development[3,4]. Since these documents have received extensive editing and discussion from the ASTM sub-committee, they represent a good consensus for draft standards of this type.

The approach taken in developing the test methods was to develop a single general test method to describe the chamber operating criteria, chemical sampling and analysis protocols and data analysis methodology that would be common to all the building materials tested (see Appendix I).

For each of the building material types (e.g. paint, carpet), a test parameter and methodology sheet was developed to record product-specific information, type of test to be performed, sample preparation and conditioning procedure, laboratory test procedure including product loading ratio and chamber operating criteria and chemical analysis. These documents ensured that each product sample within a product type was tested in a standardized way. Each of the product type test methods was developed with consideration of the intended use of the product in a real building and, therefore, assumptions were made regarding product preparation, aging and product loading. The rationale for the development of the specific conditions is included with the specific test parameters and methodology sheets in Appendix II.

In general, the products to be tested included sheet goods (e.g. wood composite boards, floor coverings, carpets), homogenous product assemblies (e.g. cupboard doors, countertops) and field applied materials (e.g. paints, foam-in-place insulations, caulks and sealants). Each of these classes of materials (and individual product samples within the class) would have a unique product history.

Sheet goods (e.g. flooring, subfloor) that would be cut and assembled into the final field use may be obtained from supplier inventory that ranged in age from days to months or even years depending on specifics of the supplier and construction industry demand. Further, many of these materials have emission characteristics which change relatively slowly with time. Because of this, a specific time frame for sampling was not considered critical in the overall life of the product to date. The focus of the testing was to measure the emissions of actual products used in the house construction and results for the samples tested are presented "as is". The same issues may be relevant to the product assemblies which typically used raw sheet materials that were then assembled into finished components either at a secondary manufacturing operation or directly on-site (e.g. particleboard). The test program was not designed to assess quality control of products and did not include replicate samples or specify in detail the method of obtaining samples.

The third category of materials are ones produced by components which are not expected to age and change characteristics significantly until applied in the field (e.g. paint, spray-in-place insulation). Many of these "wet" application materials have a very rapid change in initial emission characteristics. For these materials, more specific information on the product use, condition, age and history would be required to characterize the chemical emission profile with time.

For most materials, a multi-sorbent sampling tube and gas chromatograph/mass spectrometer detector (GC-MSD) analysis was used to measure for a broad spectrum of VOCs commonly emitted from building materials. While this analysis is widely accepted as being the most appropriate technique for screening material emissions, it does not identify every known VOC, including formaldehyde. Therefore, for some specific materials where prior knowledge or product components suggested that formaldehyde may be emitted, specific additional testing for formaldehyde was conducted.

Where unfinished or "raw" product samples were larger than the size required for the specified product loading, test specimens were cut from the product samples. Some product samples received were undersize and the desired loading ratio could not be obtained. These samples were tested "as is" and the actual product loading ratio noted in the results.

For some monolithic building material samples (e.g. prefinished cupboard door), the assembly was tested as supplied and the actual product loading ratio noted in the test results.

2.2 *Building Material Emission Characterization*

The building material samples were obtained from a number of houses built through the Advanced Houses Program (Group I) and the R2000 program (Group II).

The Group I material samples were collected at various stages of construction throughout the Advanced House Program house construction. The elapsed time from obtaining the product samples from the house construction sites was between 6 and 18 months.

The testing of the Group I samples had two major objectives: 1) to create a database of information on the VOC emission characteristics of new materials which had been in service for a short period of time (but greater than the traditional "airing out" period normally associated with building materials), and, 2) to characterize the VOC emissions of the building materials used in the Advanced Houses for future comparison with the unoccupied house indoor air quality monitoring data being collected[5].

At the project planning stage, it was recognized that the quality of the material samples obtained from the Advanced House Program would not be to the standard expected of materials randomly selected from production lines or product supplier inventory. The Group I products will have been exposed to various conditions prior to purchase for use on the job site and also exposed to the diverse environmental conditions associated with the house construction.

Despite these shortcomings, the individuals supplying the building material samples were asked to complete product information sheets (see Appendix III) to assist in providing as much information on the product history up to the time of shipping as was available. The method of product sample collection, packaging, and shipping is also given in Appendix III. The packaging material was selected to be chemically inert and relatively impervious to the range of chemicals expected to be emitted. Once packaged in the tightly sealed containers, the material sample emissions would be minimized, thereby reducing the effect of product aging due to offgassing. Some changes in chemical composition due to internal aging may still occur.

The type of product samples selected for Group I was left to the discretion of the individual Advanced House project teams. The teams were asked to select products which they felt would contribute significant chemical emissions to their specific house.

In total, 37 product test samples were received from the Advanced Houses Program. The matrix of product samples received is given in Table 1. Product samples tested are indicated with a V (VOC) or F (HCHO) following the house code and sample number.

From the initial matrix of products, each product sample was reviewed for confirmation of its physical integrity, adequacy of packaging for shipping and completeness of required documentation. Fourteen product samples were rejected for testing on the basis that these above criteria were insufficiently met to ensure meaningful test results. Some types of materials were submitted by a number of teams and therefore not all samples of each product type were tested if it was felt to create unnecessary replication. The final test matrix is also indicated in Table 1.

Table 1. NRCan - Advanced Houses Building Products (Group I)

House Code	Insulation (iso-cyanate)	Insulation (polyurethane foam)	Carpet	Ceiling tile	Wood (composite)	Carpet underpad	Wood (MDF)	Wood (veneer plank)
S			S-4					
B			B-1-V			B-2-V	B-3-VF	
H	H-1-V	H-2-V	H-3	H-6 H-4-VF	H-5-F	H-7	H-8-F	H-9-VF
N			N-3-V			N-8	N-1-V	
W			W-1-V			W-5	W-6	
I			I-1-V I-2-V				I-4-F	

House Code	Particle-board	Plywood	Ceramic Tile	Hardwood	Wood	Linoleum	Fibreboard	TJI joist	OSB
S		S-1 S-2				S-3-V			
B									
H									
N	N-4	N-2-VF	N-5	N-6	N-7				
W	W-2-VF W-3-F								W-4-VF
I	I-6-F			I-5			I-3-VF	1-7-F	

HOUSE CODE S - Saskatchewan H - Hamilton W - Waterloo
N - Nova Scotia B - British Columbia I - Innova

SAMPLE NUMBER CODE:

House code - Sample no. - Test (V = VOC test, F = Formaldehyde test, no letter (V, F) indicates sample not tested)

The Group II product samples were selected by a single individual with overall knowledge of the Halifax R2000 housing project. The Group II product samples were selected to provide information on typical building materials that were currently being incorporated into new housing. Although the materials themselves would be prone to the same prior-to-site aging, storage, and environmental conditions that could confound the data, the samples themselves would be considered "fresh" from a builder's perspective.

All of the samples were obtained from specific houses at the time of construction or from "identical" product inventory at the material suppliers who supplied the original materials to the houses. For the paint samples, paint types were identified by the local project co-ordinator and transmitted to the testing laboratory. The laboratory purchased identical product types from local suppliers.

The initial proposed and final material test matrices selected for the Group II products are shown in Table 2.

Table 2. Halifax R2000 Product Samples Requested and Received (Group II)

	Paint-low emission	Paint - conventional	Carpet	Carpet/wood underpad	Wood Composite	Prefabricated assemblies	Vinyl flooring	Wood flooring	Gypsum Board
Number of each requested	2	2	4	3	4	4	4	-	-
Received and Tested	HAL-1-V HAL-7-V	HAL-14-V HAL-15-V	HAL-2-V HAL-5-V	HAL-9-V HAL-12-V	HAL-3-VF HAL-4-VF	HAL-13-VF HAL-18-VF HAL-19-VF HAL-20-VF	HAL-8-V HAL-10-V HAL-16-V HAL-17-V	HAL-11-V	HAL-6-V

2.3 *Data Collection and Analysis*

The environmental chamber test procedures were developed to provide measurement of the chamber airflow and resulting indoor air concentration for specific chemicals under defined operating parameters.

For the purposes of this testing program (recognizing that the age of the building materials could vary significantly) a single point in time equilibrium environmental chamber test was conducted for most materials. In the case of the Group II paint product samples, environmental chamber tests were conducted with chamber concentrations measured at specified time intervals to assist in evaluating the temporal emission characteristics from painted surfaces.

For the equilibrium tests, the data was analyzed to calculate chemical emission factors using equation 1.

$$EF = C \cdot N/L \qquad (1)$$

where:

EF = emission factor, (milligrams/$m^2 \cdot$ hour)
C = equilibrium chamber concentration, (milligrams/m^3)
N = chamber air exchange rate, (ach^{-1})
L = product loading (m^2/m^3)

The product loading is calculated by dividing the entire exposed surface area of the product specimen by the chamber volume.

As calculated in equation 1, the emission factor can represent individual chemical compounds or the summation of certain classes of compounds or total volatile organics, depending upon the chamber concentration data used.

For results reported as TVOC, EF represents the emission factor for the total of all volatile organic compounds identified in the chemical analysis (TVOC). The TVOC concentration was calculated using the sum of the masses of the individual chemicals identified in the analysis. The analyst reviewing the GC-MSD output for the analysis would identify and quantitate all of the significant peaks. Small peaks (below the mass detection level) were not reported. This analysis reports greater than 95% of all of the volatile mass recovered from the sample.

Typically the chemical analysis for the individual test specimens would identify three to ten volatile organic compounds, each of which could be expressed with an individual emission factor for that test specimen and that compound. For the purposes of this report, emission factors are presented for the following compounds or classes of compounds: formaldehyde (HCHO), total volatile organic compounds (TVOC), styrene (S), 4-phenylcyclohexene (4-PC) and polycyclic aromatic hydrocarbons (PAH) since these compound groups are specifically referenced in Clean Air-2000.[6]

For some of the data obtained in this method, experience or empirical correlations obtained from the literature may be used to estimate the change in emission factor with time. For wood composite products where the emission of formaldehyde is known to be a function of temperature, humidity and time, empirically derived correlations such as the Berge[7] equation or the correlations developed by Wanner and Kuhn[8] can be used to estimate the time dependent emission characteristics. For other materials, long term testing may be required to adequately characterize the emission profile.

For the case of wet applied materials (paints only) chamber concentration data was collected at a number of points in time as shown in the attached test protocol (Appendix I). Since these materials would be applied on site, accurate analysis of their impact on the indoor environment requires more detailed information on the temporal emission characteristics. The analysis for the results from these products was conducted using equation 1 for various times following their application and emission factors are presented accordingly.

Another method of analysis could assume a first order exponential decay of the emissions from the materials. To date, a number of researchers have shown various emission characteristics from wet process materials including evaporative transport (initial drying), diffusion limited transport (after the initial product has skinned over) and long term emissions (limited by diffusion and containing some aging/catalyzing processes). At this point in time, however, it is felt that a simple expression will give meaningful results for estimating the impact of paints on the overall indoor air quality in housing.

3.0 RESULTS

The calculated emission factors for TVOC, HCHO, Styrene, 4-PC and PAH for all of the samples tested are presented in Table 3.

Table 3. Calculated VOC Emission Factors

Specimen identification and specimen number	Specimen surface area (m2)	TVOC emission factor ug/(m2-h)	HCHO emission factor ug/(m2-h)	Styrene emission factor ug/(m2-h)	4-PC emission factor ug/(m2-h)	PAH emission factor ug/(m2-h)
LATEX PAINT - "LOW EMITTING"						
Low emitting 1 - 12 hr	0.1716	161.6	--	--	--	--
24 hr	0.1716	163.5	--	--	--	--
120 hr	0.1716	41.9	--	--	--	--
360 hr	0.1716	7.1	--	--	--	--
Low emitting 2 - 12 hr	0.1716	55.6	--	--	--	--
24 hr	0.1716	26.5	--	--	--	--
120 hr	0.1716	9.1	--	--	--	--
LATEX PAINT - "CONVENTIONAL"						
Conventional 1 - 12 hr	0.1716	259.3	--	--	--	--
24 hr	0.1716	363.3	--	--	--	--
120 hr	0.1716	243.4	--	--	--	--
Conventional 2 - 12 hr	0.1716	334.2	--	--	--	1.3
24 hr	0.1716	376.1	--	--	--	--
120 hr	0.1716	308.1	--	--	--	--
PARTICLEBOARD						
Particleboard 1	0.1934	114.4	6.1	--	--	--
Particleboard 2	0.1447	--	6.6	--	--	--
CARPET						
Carpet 1	0.0702	153.1	--	--	--	--
Carpet 2	0.0210	47118.1	--	--	36.9	6.4
Carpet 3	0.0210	651.7	--	--	--	--
Carpet 4	0.0210	56222.9	--	--	29.4	--
Carpet 5	0.0702	17.5	--	--	--	--
Carpet 6	0.0702	21.3	--	--	--	--
Carpet 7	0.0700	87.1	--	23.6	--	--
SHEET VINYL FLOORING						
Vinyl floor 1	0.0106	9408.5	--	--	--	483.6
Vinyl floor 2	0.0665	3586.1	--	--	--	--
Vinyl floor 3	0.0554	1607.1	--	--	--	78.7
Vinyl floor 4	0.0702	1576.8	--	--	--	--
Vinyl floor 5	0.0702	948.2	--	--	--	--
MEDIUM DENSITY FIBERBOARD (MDF)						
MDF 1	0.0737	56.8	354.9	--	3.1	--
MDF 2	0.0731	107.9	--	--	--	--
MDF 3	0.0737	360.0	364.9	--	--	--
MDF 4	0.0737	834.9	42.0	--	--	--
MDF 5	0.0221	--	180.1	--	--	--
CELLULAR PLASTIC INSULATION						
Insulation 1	0.0424	45.1	--	--	--	--
Insulation 2	0.0256	68.1	--	--	--	--
COMPOSITE WOOD PRODUCT ASSEMBLIES						
CWPA 1	0.0275	--	155.2	--	--	--
CWPA 2	0.2556	--	2.7	--	--	--
CWPA 3	0.0740	459.1	487.4	--	--	13.8
CWPA 4	0.0736	1378.1	639.2	--	--	--
CWPA 5	0.1083	612.1	35.2	--	--	--
CWPA 6	0.0734	499.3	464.2	--	--	--
CARPET UNDERPAD						
Underpad 1	0.0210	33.2	--	--	--	--
Underpad 2	0.0702	855.8	--	--	--	117.3
STRUCTURAL COMPOSITE WOOD PRODUCTS						
SCWP 1	0.1003	243.2	<5.4	--	--	--
SCWP 2	0.0888	54.6	5.8	--	--	--
SCWP 3	0.0262	--	10.2	--	--	--
SCWP 4	0.0920	--	<5.4	--	--	--
SCWP 5	0.0704	386.4	84.5	--	--	72.9
GENERAL INTERIOR FINISHING MATERIALS						
GIFM 1	0.0587	347.6	<8.5	--	--	--
GIFM 2	0.0220	29.9	<6.1	--	--	--
GIFM 3	0.1716	20.8	--	--	--	0.4
GIFM 4	0.0701	479.1	--	--	--	174.0
INTERIOR PLYWOOD (COATED)						
Plywood 1	0.0283	170.1	654.8	--	--	--

4.0 DISCUSSION

Referring to Table 1, 14 of the 37 product samples received from the Advanced Houses were not suitable for testing. Common reasons for rejecting the samples were; improper packaging (potential leaks or contamination) or lack of detailed product information (product type of history could not be determined). An upgraded selection and packaging/shipping protocol was developed for the Halifax R2000 houses. This resulted in all of the samples received being tested.

This initial difficulty with the product samples highlights the importance of developing standardized procedures which cover all aspects of material testing including: sample acquisition, documentation, transportation and laboratory methodology.

Results from the building materials emission testing showed an extremely wide range in TVOC emission factors ranging from values below 10 $\mu g/m^2 \cdot h$ to in excess of 56,000 $\mu g/m^2 \cdot h$. The results from the individual product types are discussed below:

4.1 *Carpet*

All of the carpet samples tested (except Carpet 3) were synthetic, low carpets with synthetic or jute backing. Carpet 3 was a synthetic indoor-outdoor carpet with a composite rubber backing.

For the carpeting, three of the seven carpet samples had emission factors lower than 100 $\mu g/m^2 \cdot h$. Two samples had emission factors greater than 100 $\mu g/m^2 \cdot h$ but less than 1000 $\mu g/m^2 \cdot h$ and two samples had emission factors in the order of 50,000 $\mu g/m^2 \cdot h$. The laboratory analysis confirmed that the bulk of the TVOC measured from the two carpets with high emission factors was C_{10} to C_{13} hydrocarbons which are common constituents of many cleaning solvents and other petroleum-based products. Styrene was identified in one of the lowest TVOC emitting samples. The two carpet samples with the highest TVOC emission factors were the only samples with 4-PC emissions.

This tremendous variation in emission factors raises two issues: 1) whether the range of emission factors represents the range of potential emissions expected from current products and 2) whether the product samples obtained from the houses had become contaminated as a result of on-site handling.

The first issue relates to the quality control exercised within the manufacturing industry. Currently, the Carpet and Rug Institute (CRI) has established some voluntary emission requirements for labelling of carpet products[9]. The maximum emission requirements are:

TVOC	= 500 $\mu g/m^2 \cdot h$
Styrene	= 400 $\mu g/m^2 \cdot h$
4-PC	= 100 $\mu g/m^2 \cdot h$
HCHO	= 50 $\mu g/m^2 \cdot h$

For the carpets tested, four met the CRI guidelines for TVOC and all easily met the other chemical compound emission criteria. Of these four, two carpets (Carpets 6 and 7) were indicated by the supplier as meeting the CRI guidelines.

The second issue concerns the potential for carpeting materials to absorb chemicals and act as significant secondary emission sources of pollutants which can enter the carpeting during the construction process. This is an extremely important issue since it may affect the traditional work practice/on-site construction scheduling and the overall indoor air quality performance of new housing. For example, traditional work practice is to stain or paint baseboards and trim in the house after the subfloor is installed. During this process, stain, paint and cleaning solvents are often splattered onto the subfloor which is later covered with finish flooring materials. If, in fact, carpets are delivered on-site with relatively low emission factors but during the construction process can become heavily contaminated and act as secondary sources, the construction process may require significant changes to prevent this contamination from occurring.

4.2 *Carpet Underpad*

The carpet underpad samples were seven mm thick synthetic foam materials. One carpet underpad (Underpad 2) had a relatively high TVOC emission factor, 856 $\mu g/m^2 \cdot h$. An underpad with this level of emission may be overlaid by a relatively low emitting carpet which would initially suppress the overall emission from the underpad material; however, the underpad could also act as a strong contaminating source for the carpet material itself.

This phenomenon highlights the importance of testing material systems to obtain reliable field performance data for IAQ estimates, rather than relying solely on individual component test results.

4.3 *Cellular Plastic Insulation*

Both of the samples tested were spray-in-place polyurethane foam cellular plastic insulation materials. Sample H-1-V was a material foamed on-site using a two part system. This material is intended for large scale insulating projects including exterior walls and ceilings. The second product H-2-V was a self-contained batch product intended for use in air sealing around building envelope penetrations. The TVOC emission factors for both materials were relatively low ($<100\ \mu g/m^2 \cdot h$) which is typical for aged insulating materials of this type. Previous laboratory testing with these materials has shown that the majority of the emissions take place within the first few days of foaming and are typically reduced to very low levels within thirty days.

4.4 *Medium Density Fibreboard (MDF)*

Four MDF samples were tested for TVOC emission factors. All of the MDF samples were fully or partially coated with architectural finishing materials and were intended to be used as interior finishing materials. The TVOC emission factors ranged from a low of 57 μg/m² · h to a high of 835 μg/m² · h. Formaldehyde emission tests were conducted on four samples and the HCHO emission factors ranged from a low of 42 μg/m² · h to a high of 365 μg/m² · h. These data are comparable with other previously tested[10] products from the same manufacturer which had HCHO emission factors ranging from 79 to 200 μg/m² · h.

4.5 *Particleboard*

The particleboard samples were surface sealed components used for cabinet doors. One particleboard sample was monitored for TVOC emissions. The TVOC emission factor was 114 μg/m² · h, which was in the same general range as the other manufactured wood products which had secondary surface coatings or treatments. Formaldehyde emission tests were conducted on two particleboard samples. Both samples yielded very similar results ranging from 6 to 7 μg/m² · h. These values are significantly lower than results obtained by SRC[10] in an earlier test program where four new particleboard samples had HCHO emission factors ranging from 86 to 715 μg/m² · h.

4.6 *Structural Composite Wood Products*

Three structural composite wood products were tested for TVOC emissions. The OSB subfloor and wood flooring materials which would normally have one side exposed had TVOC emission factors of 243 and 386 μg/m² · h. The plank sample (SCWP 2) had a TVOC emission factor of 55 μg/m² · h. Five structural composite wood products were tested for formaldehyde emissions. The wood flooring had a HCHO emission factor of 84 μg/m² · h while the remaining products all had emission factors ≤10 μg/m² · h.

4.7 *Interior Plywood*

One interior plywood sample with a factory surface finish was tested. The TVOC emission factor was 170 μg/m² · h, however, the formaldehyde emission factor was 655 μg/m² · h. This sample had the highest formaldehyde emission factor of all the products tested.

4.8 *General Interior Finishing Materials*

Materials including ceiling tile, fibreboard wall panel, synthetic foam underpad for wood flooring and clean, unfinished gypsum board were investigated for TVOC emission factors. The ceiling tile had a TVOC emission factor of 347 μg/m² · h and a HCHO emission factor of 9 μg/m² · h. The fibreboard wall panel had a TVOC emission factor of 30 μg/m² · h and a formaldehyde emission factor of <6 μg/m² · h. The blank gyproc had a TVOC emission factor of 21 μg/m² · h. The wood flooring underpad had a TVOC emission factor of 479 μg/m² · h.

4.9 Sheet Vinyl Flooring

Five sheet vinyl flooring samples were tested for TVOC emissions. The emission factors ranged from 948 $\mu g/m^2 \cdot h$ to a high of 9408 $\mu g/m^2 \cdot h$. This range in data has been noted in other studies[11] where TVOC emission factors from PVC flooring varied from 270 to 7034 $\mu g/m^2 \cdot h$. Two different samples obtained from one vinyl flooring manufacturer had TVOC emission factors that varied by a factor of three (Vinyl Floor 1 and 2) whereas the two samples from another manufacturer (Vinyl Floor 3 and 4) were virtually identical.

Both Vinyl Floor samples 1 and 2 were products from the same series. The sample collected from the Advanced House was a minimum of one year older than the other sample yet had a TVOC emission factor approximately three times higher than the sample obtained from the Halifax house. This again raises the question of variation in manufacturing quality or the potential for contamination from secondary sources.

For the vinyl floor coverings, all testing was done at a standardized chamber temperature of 23°C, however, it is reasonable to assume that for houses using in-floor (e.g. radiant) heating systems which could elevate the working temperature of the floor surface to approximately 25 to 30°C, the emission factors could increase significantly. This phenomena will be an important consideration when conducting air quality modelling and analysis using real house data.

4.10 Composite Wood Product Assemblies

These samples were architectural finishing materials and panels which were constructed of various composite wood substrate materials and prefinished with surface coatings.

Four composite wood product assemblies were tested for TVOC emissions and the emission factors ranged from 459 $\mu g/m^2 \cdot h$ to 1378 $\mu g/m^2 \cdot h$ with an average value of 737 $\mu g/m^2 \cdot h$. The formaldehyde emission factors for the six composite wood product assemblies tested ranged from 2.7 to 639 with an average of 297 $\mu g/m^2 \cdot h$. The TVOC emission factors for these materials were in the same order of magnitude as the structural wood products, medium density fibreboard and particleboard samples.

4.11 Latex Paint

For comparison purposes, the TVOC emission factors at 120 hours were selected for discussion. Very long term testing (360 hours) was only conducted on one sample and the emission factor decreased by a factor of six compared with the 120 hour value. Danish researchers[12] have shown that for many water-borne paints, the TVOC emissions decrease rapidly and are near zero within 10 - 20 days (240 to 480 hours).

The two paint samples advertised as low emitting products had TVOC emission factors of 9 and 42 $\mu g/m^2 \cdot h$. These values are significantly lower than the two conventional latex paint samples which had TVOC emission factors of 243 and 308 μg/m² · h. The average EF_{TVOC} for the conventional paints was an order of magnitude higher than the average for the low emitting paints.

4.12 *General Discussion of Test Results*

Table 4. Maximum, Minimum and Average TVOC Emission Factors for Each Product Classification

Product Class	**No. of Samples**	**Maximum EF_{TVOC} (μg/m² · h)**	**Minimum EF_{TVOC} (μg/m² · h)**	**Average EF_{TVOC} (μg/m² · h)**
Carpet	7	56223	18	14896
Vinyl Flooring	5	9408	948	3425
Particleboard	1	--	--	114
Composite Wood Product Assemblies	4	1378	459	737
Low Emitting Paint @ 120 hr	2	42	9	26
Conventional Paint @ 120 hr	2	308	243	276
Cellular Plastic Insulation	2	68	45	57
Structural Composite Wood Products	3	386	55	228
Interior Plywood (Coated)	1	--	--	170
Carpet Underpad	2	856	33	445
MDF	4	835	57	340
General Interior Finishing Materials	4	479	21	219

Table 5. Maximum, Minimum and Average HCHO Emission Factors for Each Product Classification

Product Class	No. of Samples	Maximum EF_{HCHO} (μg/m² · h)	Minimum EF_{HCHO} (μg/m² · h)	Average EF_{HCHO} (μg/m² · h)
Particleboard	2	7	6	7
Composite Wood Product Assemblies	6	639	3	297
MDF	4	365	42	235
General Interior Finishing Materials	2	<9	<6	<8
Structural Composite Wood Products	5	84	<5	22
Interior Plywood (Coated)	1	--	--	655

Referring to Tables 4 and 5 which contain the maximum, minimum and average TVOC and HCHO emission factors for each product classification, the diversity and range of the emission factors is apparent. The broad variation of emissions within a product classification shows the inherent weakness associated with indoor air quality analysis which uses only generic or "average" values. Within the product samples tested, it is apparent that the use of average values for some products such as carpeting could result in significant over or under predictions of the true TVOC concentrations in buildings. This highlights the importance of two basic requirements: 1) obtaining accurate application specific data on the materials being used and 2) having a rational analytical framework for using product emission data to predict indoor air concentrations in buildings.

Development of an analytical framework for using product emission test data to predict indoor air concentrations in buildings must consider not only the detailed technical issues and interactions but also the practical field application of the technology. Results of this test program indicate the importance of having an analytical framework which allows differentiation of product classifications and is also sensitive to the changes in various material emission factors over time.

When looking at the data in Table 4, the carpets tested stand out as having a high average TVOC emission factor. However, if the two high emitting carpet samples were removed from the analysis, the average EF would be in the same general range as many of the other product classes ranging from the tens through hundreds of μg/m² · h. This indicates that in most real world buildings, significant improvements in the indoor air quality will not be achieved by singling out individual product classes as "problem" materials, but rather through a careful and planned assessment of all of the potential components of the building.

The Nordic Countries have produced guidelines[11] for general material emission classes (MEC) based on the amount of ventilation required to achieve a certain IAQ classification.

These classes are:

Class	Maximum TVOC Emission Factor
MEC-A, low emission material	40 μg/m² · h
MEC-B, medium emission material	100 μg/m² · h
MEC-C, high emission material	hundreds

Referring to these classifications, it is obvious that most of the types of materials tested ranged through all of the MEC classifications. In countries where ventilation requirements are tied to emission criteria, the selection of building materials can have a major impact on the overall building design and construction.

It is noteworthy that most of the traditional building material classes investigated in this study had some products which would currently meet the Nordic low or medium emission criteria. However, the vinyl flooring and manufactured wood products classifications did not identify any products which would meet the low or medium emission criteria. The data indicate that the technology exists to produce many types of low emission building materials, but at the present time there are no consistent Canadian methods to specify or obtain these materials.

5.0 SUMMARY

The results from this testing program provide the building industry with basic data on the chemical emissions from some common building materials. The testing demonstrates that a rational process for selecting materials is available. This will assist homeowners, designers, builders and regulators to move forward from basic performance goals such as the Nordic Committee on Building Regulations recommended statement[13], "Building materials and surface finishes shall have the lowest possible emission properties" to specific prescriptive measures.

The variation observed in the chemical emissions from most of the classifications of building materials highlights the weakness of using "generic" or default values to estimate the impact of material usage on the overall indoor air quality in new houses. The appropriate use of building materials requires a rational, quantitative approach.

The test methodology developed can be used to structure test programs to evaluate other materials and components. Working from the general test method, application specific procedures can be developed which best represent the in-situ performance of the material or meet the needs of the testing program.

6.0 REFERENCES

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2. "Standard Guide for Small-Scale Environmental Chamber Determinations of Organic Emissions From Indoor Materials/Products, D5116-90", American Society for Testing and Materials, Philadelphia, PA, 1990.

3. "Standard Practice for Determination of Volatile Organic Chemical Emission Factors From Caulk and Sealant Products Using Small Environmental Chambers Under Defined Test Conditions", Figley Consulting Associates Ltd. and Saskatchewan Research Council, Building Science Division, Saskatoon, SK, Draft, October 25, 1994.

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14. "The R-2000 Technical Upgrade", Energy, Mines and Resources Canada, Ottawa, ON, June, 1993.

APPENDIX I

GENERAL METHOD FOR DETERMINATION OF VOLATILE ORGANIC CHEMICAL EMISSION FACTORS FROM ADVANCED HOUSES PROGRAM AND R2000 PROGRAM HOUSE BUILDING PRODUCTS USING SMALL ENVIRONMENTAL CHAMBERS UNDER DEFINED TEST CONDITIONS

General Test Method for Determination of Volatile Organic Chemical Emission Factors From Advanced House Program and R2000 Program House Building Products Using Small Environmental Chambers Under Defined Test Conditions

1. Scope

1.1 The test provides the basic methodology for measuring the volatile organic chemical (VOC) level from home building products (carpet and underlay, insulation, ceiling tile, wood products and vinyl flooring) under conditions designed to simulate product use in residential buildings. The VOC emission rates are determined by observing airborne VOC concentrations in a small chamber under defined temperature, relative humidity, air exchange and product loading test conditions. Specific test parameters and methodology for individual products must be established prior to conducting tests. The general VOC concentrations in the chamber air sample are determined by adsorption on a solid sorbent tube followed by thermal desorption and combined gas chromatography/mass spectrometry (GC/MS) or equivalent. The formaldehyde concentration in the chamber air sample is determined by bubbling the air sample through midget impingers filled with deionized distilled water. NIOSH Method 3500 is used to analyze the collected sample. Other specific air sampling procedures may be required if product literature or previous experience suggests specific compounds may be present.

1.2 The building products applicable to this method are intended to be used in residential buildings which may have a variety of loading ratios and environmental conditions. The test method specifies a loading ratio, air exchange rate and temperature and humidity conditions that are expected to represent typical new home construction practice. These standardized test conditions provide a basis for comparison of the performance of various products. The test method can be applied to a variety of product loading and environmental conditions to assist in predicting indoor VOC concentrations. However, this analysis is beyond the scope of this method.

1.3 Values stated in SI units shall be regarded as the standard.

1.4 The standard may involve hazardous materials, operations and equipment. The standard does not purport to address all of the safety problems associated with its use. It is the responsibility of the user of the standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use. For specific hazard statements see Section 6.

2. Referenced Documents

2.1 ASTM Standards

D1356 Definitions of Terms Related to Atmospheric Sampling and Analysis

D1605 Practices for Sampling Atmospheres for Analysis of Gases and Vapours

D1914 Recommended Practice for Conversion Units and Factors Related to Atmospheric Analysis

D3195 Recommended Practice for Rotameter Calibration

D3609 Practice for Calibration Techniques Using Permeation Tubes

D3686 Practice for Sampling Atmospheres to Collect Organic Compound Vapours (Activated Charcoal Tube Adsorption Method)

D3687 Practice for Analysis of Organic Compound Vapours Collected by the Activated Charcoal Tube Method

D5116-90 Standard Guide for Small Scale Environmental Chamber Determinations of Organic Emissions from Indoor Materials/Products.

E355 Recommended Practice for Gas Chromatography Terms and Relationships

E380-93 SI Standards

E741-83 Standard Test Method for Determining Air Leakage Rate by Tracer Dilution.

2.2 Other Documents

ACGIH Threshold Limit Values for Chemical Substances and Physical Agents and Biological Exposure Indices

ASHRAE 62-89 Ventilation for Acceptable Indoor Air Quality

CGSB Standards, CAN/CGSB-51.23-92, Spray-Applied Polyurethane Cellular Plastic Thermal Insulation

3. Terminology

3.1 *Definitions* - For definitions and terms used in this guide, refer to Definitions D1356. For an explanation of units, symbols, and conversion factors, refer to Practice D1914.

3.2 *Descriptions of Terms Specific to This Standard:*

3.2.1 *Air exchange rate (AER)* - the volume of clean air brought into the chamber in one hour divided by the chamber volume measured in identical volume units, normally expressed in air changes per hour (ach^{-1}).

3.2.2 *Chamber loading ratio* - the total exposed surface area of each building product specimen divided by the environmental test chamber volume.

3.2.3 *Clean air* - air which does not contain any VOC at a concentration in excess of the allowable background level of less than 0.02% of the Threshold Limit Value for each compound identified and does not contain a TVOC concentration of above 50 $\mu g/m^3$.

3.2.4 *Building product sample* - a sample (a complete unit or cutting) provided to the testing agency for testing.

3.2.5 *Chemically inert* - a material that provides a recovery rate for toluene at a concentration of 40 $\mu g/m^3$ of greater than 95% and does not contribute to VOC concentrations exceeding the prescribed background concentrations.

3.2.6 *Environmental test chamber* - a chamber into which a material can be placed and tested to determine the VOC emission rate under controlled environmental conditions.

3.2.7 *GC/MS-SCAN* - gas chromatograph/mass spectrometer operated in scan mode.

3.2.8 *Internal standard* - a VOC that is not present in the building product specimen which can be injected at a known rate into the environmental test chamber to verify and compare sample collection techniques and analytical procedures.

3.2.9 *Building product specimen* - a specimen of the building product which is placed in the environmental chamber for testing.

3.2.10 *Threshold limit value (TLV®)* - the ACGIH eight hour time weighted average concentration.

3.2.11 *Total volatile organic chemical (TVOC) concentration* - the total concentration of all VOCs identified in an air sample.

3.2.12 *Tracer gas* - a gaseous chemical not emitted by the building product specimen but which can be used to study the mixing characteristics of the environmental test chamber and provide a cross-check of the air exchange rate measurements.

3.2.13 *Volatile organic chemical (VOC)* - any organic chemical compound that has a boiling point below 260°C.

4. Significance and Use

4.1 The interaction of VOC sources on the indoor air quality in buildings has not been well established; however, a wide variety of concerns have been raised. One basic requirement that has emerged from indoor air quality research is the need for well characterized test data on the emission rate characteristics of pollutants from building materials. These emission rate data can be used by building designers and researchers to estimate and study the effects of indoor air concentration levels of various chemicals using methodology such as the ASHRAE Indoor Air Quality Procedure.

4.2 The test method incorporates a small environmental test chamber to evaluate the level of VOC emissions from building product specimens over a specified duration of time. Conditions controlled in the procedure are:

4.2.1 conditioning of products prior to testing;

4.2.2 exposed surface area and method of support of the building product specimens in the test chamber;

4.2.3 test chamber temperature and relative humidity;

4.2.4 number of air changes per hour; and

4.2.5 air circulation within the chamber.

4.3 At the end of a specified time period in the test chamber, the air is sampled and the concentration of VOCs in the air are evaluated.

4.4 The test method establishes a single set of conditions in order to provide a uniform basis of comparison for the products.

4.5 Care should be exercised in using the test data and predicting the end results of any specific indoor conditions.

5. Apparatus

5.1 *General* - All materials and components in contact with the building product specimens or air sample prior to collection shall be chemically inert and cleanable. Suitable materials include glass and stainless steel. All parts and components when used shall meet these requirements. All gaskets and flexible components shall be Teflon® or other chemically inert material when required.

5.2 *Environmental Test Chamber* - The chamber shall have a volume of approximately 30 - 500 L. The size and shape are not critical but any reasonable compromise between sample size and complexity of testing will be acceptable.

The chamber shall be equipped with an opening large enough to allow specimen loading or unloading and for chamber cleaning. Ports for temperature and humidity probes as well as gas supply and exhaust connections must also be provided. The chamber design shall permit a complete mixing of the air and this must be assured with a specimen in place using a tracer gas decay test. The tracer gas decay test shall agree within 5% of a theoretical well mixed model.

5.2.1 The surface velocity shall be measured at the geometric center of each emitting surface at a distance of 1 cm above the surface. The values shall be multiplied by the area represented and averaged to produce an area weighted average surface velocity.

5.2.2 The average surface velocity should be between 0.05 - 0.1 m/s.

5.3 *Sample Storage Enclosure* - The enclosure shall be large enough to contain the building product and the other storage vessels and associated equipment. Line the enclosure with chemically inert, cleanable material. Provide environmental control and monitoring systems capable of maintaining a temperature of 23°C ± 1°C, a relative humidity of 50% RH ± 5% RH, and a clean air exchange rate of 0.3 ± 0.015 air changes per hour.

5.4 *Environmental Enclosure* - The enclosure shall be of sufficient size to accommodate the emission test chambers and all associated equipment, including air sampling equipment, and bottled gas supplies. The enclosure shall be lined with cleanable material and shall be provided with environmental control systems capable of maintaining a temperature of 23°C ± 1°C.

5.5 *Air Exchange System* - The system shall be capable of supplying a controlled flow of clean air through the test chamber and associated equipment. Clean air can include air supplied from compressed gas cylinders or from ambient air which is conditioned by removing moisture and trace organics through charcoal filtration or other means. Any background test conducted with the chamber fully operational but with no specimen installed, shall confirm that the system is operating without contamination.

The air exchange system equipment shall include:

5.5.1 A humidification system capable of maintaining the relative humidity of the air flow at 50% RH ± 5% RH, using deionized water (Type II D 1193), and a humidity indicator/recorder accurate to ± 5% RH.

5.5.2 A temperature recorder/indicator system, capable of measuring air flow temperature to an accuracy of ± 1°C at 23°C.

5.5.3 An air pump(s) or a compressed air supply system capable of supplying the air flow at a rate equivalent to 0.3 air changes per hour, based on the volume of the sample storage enclosure and the environmental test chamber. The flow rate shall be controllable to within 5% of the determined value. The chamber shall be operated at a positive pressure of 10 Pa to prevent contamination of the test chamber and sampling systems.

5.5.4 A flow indicator/recorder, accurate to within 5% of the flow rate.

5.5.5 Particulate filter system where applicable.

5.6 *Air Sampling System* - The air sampling system shall be placed in the environmental enclosure and connected to the exhaust port of the environmental test chamber and shall direct the required amount of exhaust flow through the VOC collection media.

All system components from the chamber to the VOC collection media must be constructed of chemically inert materials.

The system shall include an air sampling pump and a device or devices which can measure and control the general VOC through the sampling system to within 5% of the specified value. The pump shall be operated in suction mode downstream of the sorbent tube to avoid contamination of the air sample.

5.6.1 For collection of the general VOC samples, multi-sorbent tubes or alternative collection media shall be used. The air sampling rate shall be selected based on the specifications of the sorbent tubes; generally a sampling rate of 0.2 L/min is recommended. Sorbent tube manufacturers' recommendations shall be followed regarding sample air flow rates and sampling time periods. For the formaldehyde samples, NIOSH method 3500 shall be used.

The exhaust air shall be sampled close to the exit from the chamber to ensure that the air sample is well mixed and represents the chamber concentration.

The air sampling system design and operation shall be sufficiently sensitive to ensure that the overall chemical analysis is consistent with the required VOC detection levels.

5.7 *Clock/Elapsed Time Indicator* - A precision timing device (5.1) shall be used to measure the sample collection interval. The device shall be capable of measuring an elapsed time period of up to eight hours ± 2% of the elapsed time. The timing system shall be capable of indicating and recording the elapsed time from the beginning of each test (hours, minutes, seconds).

5.8 *Chemical Analysis System* - The recommended equipment for identifying general VOCs is GC/MS-SCAN but other approved equivalent techniques may be used.

5.8.1 For measuring the chamber concentrations, the sampling and analysis procedure and equipment shall have a detection limit of 0.01% of the ACGIH TLV - TWA concentration for the VOCs.

5.8.2 The air sample shall be analyzed for all VOCs which exceed the detection limit of the system. Mass recovered and equivalent chamber concentration for each compound shall be provided.

5.9 *Building Product Specimen Holder(s)* - Provide an open support or pan type holder, for the building product specimen, made of chemically inert material (as per 5.1). The open support shall allow unobstructed air circulation over the entire building product specimen surface and the support contact points shall cover less than 1% of the total specimen surface area. The pan type holder shall be sealed on the sides and at the bottom, allowing VOC emissions into the chamber only through the top surface of the specimen.

The type of specimen holder will be selected based on the installation method used for the product in typical housing. The individual product test sheets shall specify the holder type.

6. Hazards

6.1 The transportation, handling, preparation, cutting, testing and clean-up of building product specimens involves a number of chemical and physical hazards.

6.2 Proper workplace health and safety and good laboratory practice procedures must be developed and implemented.

6.3 *Cleaning Chemicals* - Appropriate precautions shall be taken when physical and chemical hazards are present.

7. Sampling, Test Specimens, and Test Units

7.1 *Sampling* - The method by which the testing agency secures the product samples must be specified in the test report.

7.2 The following information must be identified and included in the test report:

a) manufacturers handling and use procedures;

b) storage temperatures of the building product samples after receipt by the testing agency;

c) building materials data sheet and collection protocol sheet (attached);

d) product information sheet (attached);

e) specific test parameters and methodology sheet (attached).

7.2.1 Test parameters, specific conditions and rationale shall be specified in the test report.

7.2.2 The product samples shall be supplied in packaging as specified in the building materials data sheet and collection protocol.

7.2.3 The product sample shall be conditioned for a minimum 20 - 24 hours in the sample storage enclosure.

7.3 *Building Product Specimen Cutting and Sizing* - After the product sample has conditioned for a minimum of 20 - 24 hours, all building product specimens shall be obtained from the sample.

7.3.1 Specimens shall be cut (as required) from a typical center area of the building product sample using a clean, fine-bladed saw or clean stainless steel knife. Specimens shall be obtained away from any visually anomalous areas.

7.3.2 The specimen size shall be selected to obtain the required product loading ratio.

7.3.3 The specimens shall be cut to provide a length to width ratio of not >2.

7.3.4 All dimensions shall be measured with an accuracy of ± 1 mm.

8. Procedure

8.1 *Cleaning* - Prior to testing, the environmental test chamber, together with all internal hardware and equipment that will be in contact with the building product specimen or test apparatus must be cleaned by scrubbing the interior surfaces with an alkaline detergent, followed by a thorough rinsing with clean and potable tap water, scrubbing with methanol and then rinsing with deionized water. The chambers and equipment shall be dried by placing them in position in the environmental enclosure, and purging with clean conditioned air for a minimum 12 hours prior to use.

8.2 *Background Contamination Check* - Background test measurements shall be conducted to ensure that no contamination exists within the quality assurance limits.

8.2.1 The air sampling procedure can be initiated after the 12 hour clean air purge cycle. The background contamination check involves conducting an environmental chamber test (8.3) before the specimen is installed in the chamber.

8.2.2 The chemical analysis shall confirm that no VOCs exceed background levels. If required to remove background contamination, the chamber sampling lines and associated equipment shall be purged with clean air for an appropriate time and/or re-cleaned with detergent.

8.2.3 A follow-up background measurement must confirm that no contaminants exceed the background levels.

8.2.4 Always exercise care and avoid contamination of the system apparatus with emphasis on responsible operator use.

8.3 *Environmental Test Chamber Test* - The environmental test chamber test includes the following steps;

a) clean and dry the chamber (8.1) and periodically check for background contamination (8.2),

b) install the conditioned building product specimen,

c) activate the air exchange system and operate the chamber under test conditions

d) measure the chamber concentration at 24 hours. The exact time is not critical but the exact time at sampling must be recorded.

9. Calculations

9.1 The calculation procedure uses the environmental test chamber data to provide estimates of the indoor air concentration of VOCs. The effects of surface adsorption/desorption, variable product applications, changes in environmental conditions, aging, product decomposition and interior wall finishing can not be completely quantified in a laboratory evaluation. However, good laboratory information can lead the way toward product improvements.

9.2 The steady state emission factor (EF) for each compound based on a steady state mass balance model is:

$$EF = C \cdot N/L \tag{1}$$

where:

EF = emission factor, $mg/(m^2 \cdot h)$

C = chamber concentration, mg/m^3

L = product loading, m^2/m^3

N = air exchange rate, h^{-1}

and

$$L = A/V \tag{2}$$

where:

A = exposed surface area of building product specimen, m^2

V = chamber volume, m^3

10. Report

10.1 The test report shall provide and define the project objectives and:

10.1.1 The test laboratory name, address, phone/fax numbers and contact person.

10.1.2 The product name, manufacture date and specific identifiers from the manufacturer.

10.1.3 The sample supplier shall provide the testing agency with information regarding:

i) method of selection

ii) method of use within the intended building

iii) storage conditions at time of selection and previous product history (where known).

10.1.4 A general description of the facilities and equipment, including chemical sampling and analysis.

10.1.5 An outline of the experimental conditions and procedures including time and date of testing, as well as temperature, relative humidity, air exchange rate, material loading;

10.1.6 All variations in the experimental procedures.

10.1.7 The name of the air sample analyst and the identification of all VOCs and equivalent chamber VOC concentrations for each air sample.

10.1.8 Identify precision and detection limits of the system for each VOC under test.

10.1.9 Identify first order emission factors and indoor air concentration profiles for each VOC identified in each test.

10.1.10 Identify background chamber concentrations of VOCs.

APPENDIX II

PRODUCT SAMPLE TEST PARAMETERS AND METHODOLOGY

SPECIFIC TEST PARAMETERS AND METHODOLOGY SHEET

PRODUCT: *Carpet*

SUPPORT TYPE: ☑ PAN ☐ OPEN

PRODUCT LOADING RATIO: 0.41 m^2/m^3

SPECIMEN PREPARATION:

- carpet only - no underpad or substrate
- aluminum foil formed into pan to match sample sizes

CHEMICAL SAMPLING REQUIRED: (*check/complete as required*)

1) VOC (multi-sorbent tube) ☑

2) HCHO (midget impinger) ☐

3) Other (*specify*) ☐ ____________________

Rationale

The carpet product loading ratio was selected to match the value recommended in the US EPA carpet test protocol and draft ASTM carpet test guide.

The pan type specimen holder was selected to be consistent with field use (emission from the top surface only) and the draft ASTM carpet test guide.

The draft ASTM guide specifies a chamber air exchange rate of 1.0 ach^{-1}, however, it focuses on commercial applications. For these tests, the chamber was operated at 0.3 ach^{-1} to be consistent with typical residential applications.

SPECIFIC TEST PARAMETERS AND METHODOLOGY SHEET

PRODUCT: *Vinyl Flooring*

SUPPORT TYPE: ☑ PAN ☐ OPEN

PRODUCT LOADING RATIO: 0.41 m^2/m^3

SPECIMEN PREPARATION:

- vinyl flooring only - no substrate
- aluminum foil formed into pan to match sample sizes

CHEMICAL SAMPLING REQUIRED: (*check/complete as required*)

1) VOC (multi-sorbent tube) ☑

2) HCHO (midget impinger) ☐

3) Other (*specify*) ☐ ____________________

Rationale

The vinyl flooring product loading ratio was selected to match the value recommended for carpets in the US EPA carpet test protocol and draft ASTM carpet test guide.

The pan type specimen holder was selected to be consistent with field use (emission from the top surface only) and the draft ASTM carpet test guide.

The draft ASTM guide specifies a chamber air exchange rate of 1.0 ach^{-1}, however, it focuses on commercial applications. For these tests, the chamber was operated at 0.3 ach^{-1} to be consistent with typical residential applications.

SPECIFIC TEST PARAMETERS AND METHODOLOGY SHEET

PRODUCT: ***Wood Products - Particleboard, MDF, Cabinet Components***

SUPPORT TYPE: ☐ PAN ☑ OPEN

PRODUCT LOADING RATIO: 0.43 m^2/m^3

SPECIMEN PREPARATION:

- product sample only (as supplied) if area less than or equal to specified product loading ratio
- test specimen cut from product sample if sample size greater than specified loading ratio
- if pre-finished edges, test entire sample and note loading ratio

CHEMICAL SAMPLING REQUIRED: (*check/complete as required*)

1) VOC (multi-sorbent tube) ☑

2) HCHO (midget impinger) ☑

3) Other (*specify*) ☐ ____________________

Rationale

The composite wood product loading ratio was selected to match the value recommended in ASTM 1333-90 for large chamber testing of sheet materials. An open type specimen holder was selected to expose the entire surface area of the specimen.

SPECIFIC TEST PARAMETERS AND METHODOLOGY SHEET

PRODUCT: ***Wood Products - Plywood***

SUPPORT TYPE: ☐ PAN ☑ OPEN

PRODUCT LOADING RATIO: 0.95 m^2/m^3

SPECIMEN PREPARATION:

- product sample only (as supplied) if area less than or equal to specified product loading ratio
- test specimen cut from product sample if sample size greater than specified loading ratio
- if pre-finished edges, test entire sample and note loading ratio

CHEMICAL SAMPLING REQUIRED: (*check/complete as required*)

1) VOC (multi-sorbent tube) ☑

2) HCHO (midget impinger) ☑

3) Other (*specify*) ☐ ____________________

Rationale

The plywood product loading ratio was selected to match the value recommended in ASTM 1333-90. An open type specimen holder was selected to expose the entire surface area of the specimen.

SPECIFIC TEST PARAMETERS AND METHODOLOGY SHEET

PRODUCT: ***Cellular Plastic Insulation***

SUPPORT TYPE: ☑ PAN ☐ OPEN

PRODUCT LOADING RATIO: 0.50 m^2/m^3

SPECIMEN PREPARATION:

- cut product sample to fit specimen holder as per CAN/CGSB 51.23-92 if possible.
- use entire product sample and estimate surface area if product loading ratio is less than specified.

CHEMICAL SAMPLING REQUIRED: (*check/complete as required*)

1) VOC (multi-sorbent tube) ☑

2) HCHO (midget impinger) ☐

3) Other (*specify*) ☐ ____________________

Rationale

The insulation product loading ratio and specimen holder type was selected to match the requirements of CAN/CGSB 51.23-92. This standard is used to test for VOC emissions from spray-in-place cellular plastic thermal insulations.

SPECIFIC TEST PARAMETERS AND METHODOLOGY SHEET

PRODUCT: ***Paint***

SUPPORT TYPE: ☑ PAN ☐ OPEN

PRODUCT LOADING RATIO: 1.0 m^2/m^3

SPECIMEN PREPARATION:

Follow manufacturer instructions for coverage. New, unprimed 12 mm gypsum board is to used as the specimen substrate. Two coats are to be applied (one primer and one finish coat) according to manufacturer's instructions. The substrate is to be primed, allowed to dry in a conditioned enclosure for 24 hours, with the finish coat painted and emission tested after 12 hours.

Use aluminum foil to seal gypsum board edges and bottom surface.

CHEMICAL SAMPLING REQUIRED: (*check/complete as required*)

1) VOC (multi-sorbent tube) ☑ (tested at 12, 24, 120 and 360* hours following finish coat application)

2) HCHO (midget impinger) ☐ * one sample only

3) Other (*specify*) ☐ ____________________

Rationale

The paint product loading ratio was developed by estimating the typical painted wall surface area/volume ratio for bungalow, split level and two storey houses. An average value was arbitrarily selected. Ceiling areas were not considered due to the variation in finishes used.

APPENDIX III

PRODUCT INFORMATION SHEETS

PRODUCT INFORMATION SHEET

Name of House ______________________________

Date ______________________________

Person filling in information ______________________________

Manufacturer(s) (also enclose any available product literature)

____

____

Date of Manufacture (if known) ______________________________

Previous storage history (temperature, RH, location if known)

____

____

Date of Installation/Preparation ______________________________

Comments or Additional Information ______________________________

____

____

____

BUILDING MATERIALS DATA SHEET AND COLLECTION PROTOCOL

1. *For products suspected as formaldehyde emission sources. (e.g. composite wood products)*

   a) select a homogeneous sample of typical components such as a small drawer front or two 20 cm x 20 cm sections cut from large sheet products.

   b) individually wrap in new 6 mil polyethylene, fold seams and seal with packing tape (repeat to provide two layers).

   c) label sealed samples and attach product information sheet **for each sample**.

   d) pack all of the sample storage bags in a suitable protective shipping container, attach shipping label and ship to SRC prepaid.

2. *For products with unknown emission sources. (select four samples e.g. carpet, finished trim, painted wall/wood sample, vinyl flooring complete with adhesive, carpet underpad, synthetic materials, caulks, adhesives)*

   1. ______________________ 2. ______________________

   3. ______________________ 4. ______________________

   a) select representative samples that will fit in the sample storage bags provided.

   b) place sample in storage bag, fold open end twice and seal by sliding plastic retainer over fold.

   c) label sealed storage bag and attach product information sheet **for each sample**.

   d) pack all of the sample storage bags in a suitable protective shipping container, attach shipping label and ship to SRC prepaid.