DRAFT TECHNICAL NOTE

A Builder's Guide to Selecting Building Materials:

Making Informed Choices to Improve Indoor Air Quality

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Disclaimer

The procedures described in this guide represent a simplification of current IAQ modelling research, in order to provide builders with a simple tool for assessing the impacts of their material selections. Natural Resources Canada (NRCan) recognizes that more sophisticated models are presently under development and that these procedures will need to undergo future revisions to enhance their accuracy and scope. Additional resource materials and recommendations included in this guide are based on available current knowledge. Since the study of material emissions is still in its infancy, the information and recommendations will undoubtedly change in response to future research findings.

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A Builder's Guide to Selecting Building Materials
Making Informed Choices to Improve IAQ

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Introduction: Indoor Air Quality and the Builder's Role

Home buyers are increasingly interested in housing which offers "healthy" indoor environments. Interest is particularly strong among those with allergies or sensitivities. This change in consumer attitudes creates opportunities for builders to expand into a new market niche. Builders also have legal and economic interests in ensuring that their homes are safe, comfortable and acceptable to their customers.

During the past twenty years, concern over indoor air quality (IAQ) in Canadian housing has been fueled by the greater use of synthetic building materials and consumer products which release pollutants into the air, and also by the trend toward more airtight homes (but often without adequate mechanical ventilation).

Focus on Source Control

Most initial efforts to improve indoor air quality focussed on diluting or removing pollutants through ventilation and filtration. While these are important, it is now widely recognized that the best strategy for improving indoor air quality is through **controlling pollutant sources**. As the Chair of CHBA's Technical Research Committee, Rod Parsons, noted in his 1996 annual report to TRC, ventilation has achieved what it can and "the focus is moving to a more rigorous examination of materials as sources of pollution in the indoor environment."

Chemical emissions from building materials and furnishings represent a major pollutant source, particularly in new homes and recently retrofitted homes. Reducing these emissions decreases the need for excessive ventilation and associated energy consumption, and improves the quality of the indoor environment.

Natural Resources Canada (NRCan) has recognized that concerns over IAQ can be an obstacle to energy efficiency and has therefore undertaken IAQ monitoring and research as part of its efforts to improve the energy performance of Canadian housing. The R-2000 Program pioneered the development of controlled mechanical ventilation systems. The Advanced Houses Program, launched in 1991, included requirements to improve IAQ through source control. Based on the successes of the Advanced House demonstrations, the R-2000 technical requirements were updated in 1994, including specific measures for reducing indoor pollutants through the use of low-emission materials.

Builders' Information Needs

However, a common problem plaguing builders interested in reducing pollutant sources has been the lack of information on material emissions and their impact on IAQ. An analogy could be drawn with the early period of super energy efficient home demonstrations in the 1970s, when builders were faced with a lack of information on the energy performance of various products and systems. The answer was HOTCAN, a simple model which allowed builders to predict the energy performance of their designs and which later evolved into HOT-2000, the performance assessment tool for the R-2000 Program.

NRCan has recognized that a similar need exists now for a simple model which can be used by builders and designers to assess the impact of their material selections on the indoor environment. The development of this model — sometimes referred to as "CleanAir-2000" — was initiated in 1994. Research has only begun to scratch the surface of many of the scientific challenges. However, builders' information needs are immediate. Therefore, rather than waiting for of the questions to be answered, NRCan wishes to provide builders with a simple procedure for predicting IAQ. NRCan acknowledges that this procedure is incomplete and will need to be refined as research results emerge. This builders' guide has been prepared to describe a simplified procedure for assessing the impact of material selections on indoor air quality in new homes. Also included in this guide are a "primer" on material emissions to help builders sort out the jargon and scientific concepts, two examples of applying these procedures, and various resource materials.

I. First — A "Primer" on Material Emissions

If you listen to emission researchers talking, you might think that they have deliberately made their field as complicated as possible to prevent builders from understanding any of it! There's certainly no shortage of acronyms and jargon. This section tries to demystify the basic concepts and defines some common terms.

If you are already familiar with the subject of material emissions, you may wish to skip to the next section.

Emissions From Building Materials

Emissions refer to the chemical compounds which are released from building materials into the indoor air. This process is often called "offgassing".

Both synthetic and "natural" materials have emissions. There are a great many sources of emissions in a typical new home, with the greatest concern being for those materials with the largest exposed surface areas, such as floorings, paints and finishes, and cabinetry. The homeowners' furnishings and consumer products also contribute emissions.

All emissions decrease with time. "Wet" materials, such as paints or adhesives, release the vast majority of their emissions immediately after application, as part of the drying process. "Dry" materials, such as particleboard or vinyl flooring, release their emissions more slowly over a longer period of time, sometimes several years. The time of most concern to a builder is the initial occupancy period when the homeowner moves in, since pollutant levels in the home are likely to be highest.

The rate of emissions also depends on environmental factors. Emissions tend to be greater at higher temperatures and humidities. Emissions will be reduced if a material is covered or sealed.

Emission Rates and Concentrations: The Confusing World of Units

Unfortunately, there are many different ways of expressing emissions.

Emission Rate or Emission Factor

The rate at which pollutants are being emitted from a material is expressed as the quantity of pollutant (usually in milligrams, mg, or micrograms, μg) per area of material (usually in square metres, m^2) per time (usually in hours, hr). So a typical emission rate could look something like this: 0.35 mg/m^2hr or 350 $\mu g/m^2hr$. A microgram is 1/1000th of a milligram.

Pollutant Concentration

Sometimes emissions are expressed as the pollutant concentration which results from an emissions test in an environmental chamber after a certain period of time, using an amount of material similar to a real building and under specified conditions (air change rates, temperature, humidity). Such concentrations can be expressed as the quantity of pollutant (again in milligrams, mg, or micrograms, μg) per volume of air (usually in cubic metres, m^3) and would look like this: 0.2 mg/m^3 or 200 $\mu g/m^3$.

Concentrations can also be expressed in parts per million (ppm) or parts per billion (ppb), as is often the case for formaldehyde. For example, Canadian particleboard is tested against a maximum formaldehyde concentration of 0.3 ppm, which is roughly equal to 360 $\mu g/m^3$. It is possible to convert from chamber concentrations to emission rates (see below), but only if the details of how the tests were carried out are known.

Volatile Content

"Wet" materials, such as paints, finishes, sealants and adhesives, often have their emissions expressed as the total content of volatile compounds (usually in grams, g) per volume of material, not including water (usually in litres, L). For example, the EcoLogo requirement for the maximum VOCs in water-based paints is 250 g/L. Knowing the volatile content does not help in determining emission rates, but can be useful in comparing similar products.

Converting From Emission Rates to Pollutant Concentrations
For materials with long-term, relatively constant emissions, such as composite wood products, a simple equation can be used to relate emission rates to pollutant concentrations in either a test chamber or a real building.

$$\text{emission rate} = \frac{\text{pollutant concentration x air change rate}}{\text{material loading ratio}}$$

In this equation, the emission rate is usually expressed in mg/m^2hr, the concentration in mg/m^3, the air change rate in air changes/hr and the material loading in m^2 of material per m^3 of chamber or room.

For materials with rapidly decreasing emissions, such as paints, more complicated equations are necessary.

Complicating Factors

Unfortunately, the emission of pollutants from building materials is a very complex process and there are many complicating factors:

Emission rates vary with time.
Emissions from wet materials, such as paints, are very high immediately after application, but then drop quickly. Emissions from dry materials, such as composite wood panels, decline more slowly. Emission rates will be very different for those materials which have just come off the production line in comparison with those that have been sitting in a supplier's warehouse for several months. It is not possible to add emissions together without knowing <u>when</u> the emission rates were measured. For example, Sweden has a voluntary labelling program for flooring materials in which manufacturers report on their products' emission rates at 4 weeks and at 26 weeks after production.

Some materials absorb emissions from other materials.
Porous, rough or fleecy materials can act as "**sinks**", absorbing pollutants from the air and then re-releasing them later. The positive impact of sinks is to reduce peak concentrations of pollutants, while the negative impact is to prolong such emissions over a longer period. For example, preliminary results of formaldehyde testing undertaken by the U.S. National Particleboard Association suggests that formaldehyde concentrations from pressed wood products in new homes may be only half as high as expected due to sink effects. Carpet and drywall are two of the most important sinks in a typical house.
Assemblies behave differently than individual materials.

In assemblies, materials may be partially covered or enclosed, reducing the rate of emissions but extending the emissions over a longer period of time. For example, recent testing by NRC suggests that the emission rate from carpet underpad, when installed as part of an entire carpet assembly, is less than when the underpad is tested by itself.

How Emissions are Measured

Material emissions are usually evaluated in **environmental chambers** under controlled conditions.

Small chambers, which are usually in the range of 50 litres to 1 cubic metre (1000 litres), are the most common. Materials are loaded into the chamber in roughly the same proportion as would occur in a building. Air flow rates simulate real-building ventilation. Temperature and humidity is controlled. Pollutant concentrations are measured using sophisticated sampling and analysis equipment and the results are used to calculate the emission rate from the material. Small chambers are well suited for testing material samples, such as carpeting, but obviously cannot be used for larger products, such as furniture, or for studying application processes, such as painting.

Room-sized **large chambers**, which are usually in the range of 20 to 55 cubic metres, are less common and, more expensive to build and operate, but offer the advantages of being able to simulate real building conditions and test large assemblies.

Unoccupied **test houses** are also used occasionally to measure the combined effects of many materials on the indoor air and to study the effects of "sinks".

Emissions can also be measured in the field, using a **field and laboratory emission cell** (FLEC), which was developed in Scandinavia. The FLEC is a very small chamber which can be applied directly to the surface of a material to measure its emission rate.

See page 21 for a list of Canadian labs that perform emission testing.

Pollutants to be Concerned About

There are hundreds of different chemical compounds emitted from building materials. Unfortunately, health data is available for only a few.

The two pollutant groups most commonly encountered in residential indoor environments are volatile organic compounds and formaldehyde.

Volatile organic compounds (VOCs) normally exist as liquids or solids, but vaporize easily, becoming gases. About nine hundred different VOCs have been found in the indoor air. Many cause irritation. Some are cancer-causing. Because of the difficulty in measuring and identifying so many compounds, each with their own properties and health effects, the concept of **total volatile organic compounds (TVOC)** is often used, based on the sum of the most common VOCs. While not perfect, the TVOC approach provides an indicator of indoor VOC levels.

Research has demonstrated that there are always irritation and discomfort effects when the concentration of TVOC exceeds 3 mg/m^3 and no effects when the TVOC level is less than 0.2 mg/m^3. In between these two levels — which is where most buildings are! — there may or may not be any effects, depending on the mix of VOCs and the people involved. The typical level in new Canadian homes is about 0.6 mg/m^3. At present, there are no Canadian guidelines for TVOC. Health Canada's "Indoor Air Quality in Office Buildings: A Technical Guide" notes that a target level of 1.0 mg/m^3 is being discussed for office environments. The European Community has prepared a draft guideline of 0.3 mg/m^3. This guide proposes a preliminary guideline of 0.5 mg/m^3 for home environments.

Formaldehyde is a gas which is released from urea-formaldehyde glues in manufactured wood products and urea formaldehyde foam insulation. Formaldehyde also results from human metabolism, combustion and numerous household products. It is a respiratory and eye irritant and is classified by Health Canada as being possibly cancer-causing. Formaldehyde is perhaps the most studied chemical in the world and yet its health effects remain controversial. Health Canada's "Exposure Guidelines for Residential Indoor Air Quality" recommends an action level of 120 µg/m^3 or 0.1 ppm, and a target level of 60 µg/m^3 or 0.05 ppm.

Other chemicals or chemical groups of concern include:

Chlorinated hydrocarbons can irritate eyes and lungs, and can damage the skin, liver, kidneys and central nervous system. Primary sources include solvents and cleansers. Health Canada recommends that exposure to these chemicals be kept to a minimum.

Polycyclic aromatic hydrocarbons (PAHs) are primarily associated with combustion and tobacco smoke, but small quantities may be emitted from building materials. Some PAHs are or are suspected of being cancer-causing, and so Health Canada recommends minimizing exposure.

Styrene is emitted from latex backings on carpets and also from various foamed or synthetic materials.

Styrene irritates the eyes and nose, can cause sickness at high levels, and classified by Health Canada as being possibly cancer-causing.

4-phenylcyclohexene (4-PC) is also released from latex backings on carpets and is the chemical which gives new carpet its characteristic odour.

Don't Forget...
Material emissions are just one source of IAQ problems. Don't forget to consider other pollutant sources, such as:

- combustion gases from improperly vented fuel-burning appliances;
- moulds growing in walls, attics, basements or mechanical systems from moisture problems;
- radon entering basements from the soil;
- leaded paints and asbestos insulations in older homes.

II. Next — A Simplified Procedure for Predicting IAQ

This section outlines a procedure for assessing the impact of material selections on the indoor environment. The procedure has been greatly simplified in comparison with the complex scientific models currently under development and therefore builders should note the limitations summarized on page 12.

This procedure will begin to move builders toward thinking about IAQ the way they now think about energy. It will help builders present alternatives to clients, trading off performance and costs, and will also assist in determining optimum ventilation strategies during construction and the early months of occupancy.

A Performance Approach
The procedure uses a performance-based strategy, similar to the use of HOT-2000 as a compliance tool for the R-2000 Program. The strength of a performance strategy lies in the diversity of approaches which can be pursued, reflecting regional differences, house types, and consumer and builder preferences, while at the same time allowing a common target to be met.
Potential trade-offs between different materials can be explored, allowing the builder and client to come to an agreement regarding expected results and costs. For example, if a client insists upon using a certain high-emission product, this can be balanced by the use of a low-emission material elsewhere to meet overall pollutant target levels. After a few examples, builders will gain an appreciation of which components of the house are the most significant in having an impact on IAQ.

The procedure is based on manual calculations, but can easily be automated to speed the process. NRCan has developed a preliminary spreadsheet for this purpose.

Overview
These five steps are described in greater detail in the following pages:

Step 1 Pick an emissions "budget", based on health/irritation guidelines, material contribution factors and ventilation rates.
Step 2 Identify emission rates for the materials selected.
Step 3 Estimate emissions from each material to be used, based on emission rates and loadings.
Step 4 Estimate total emissions.
Step 5 Compare total emissions with the emissions budget and revise material selections as necessary.

Step 1: Pick an Emissions "Budget"

This first step involves determining a budget for material emissions, based health/irritation guidelines, material contribution factors and expected ventilation rates.

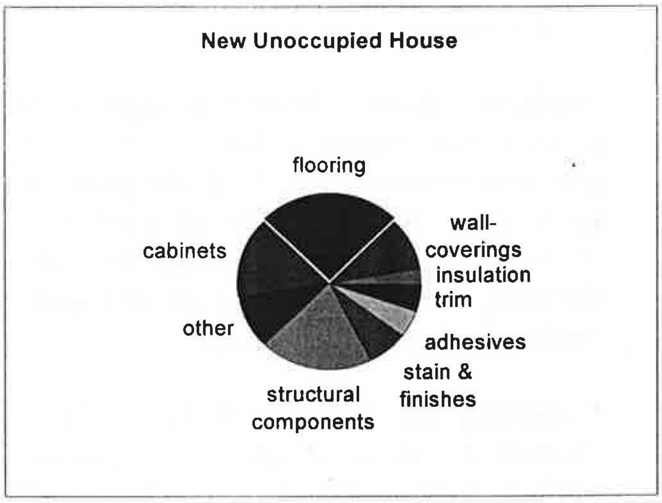
Health and Irritation Guidelines: There are a number of sources for maximum allowable indoor air chemical concentrations. These include Health Canada, various European guidelines and "working values" which represent some of the current thinking about reasonable levels.

Health and irritation guidelines are presented in Table 1 for some of the common compounds that are found in indoor air. Health Canada's target level of 60 $\mu g/m^3$ has been selected for formaldehyde. For total volatile organic compounds, 500 $\mu g/m^3$ is proposed as a preliminary target level in the absence of any Canadian guideline.

Where emission test data show high emissions of a specific chemical, the predicted concentration of that chemical can be checked against some screening criteria, such as 1/1000th of the time-weighted average concentrations allowed in industrial workplaces, as set by agencies such as the American Conference of Governmental Industrial Hygienists (ACGIH). This approach has been used for the proposed target level for styrene.

For some compounds, there are no current screening criteria and further analysis is not possible. Over time, it is expected that an enhanced knowledge of the health effects of various air contaminants will allow for a more comprehensive listing of guideline levels.

Material Contribution Factor: Since occupants bring additional sources of chemicals into their houses through their furniture, furnishings and consumer products, a material contribution factor must be established to limit the contribution of building materials to the overall pollutant levels in the home. The little field data which is available suggests that a notional contribution of 50% be allocated to building materials for most chemical compounds and 80% for formaldehyde.



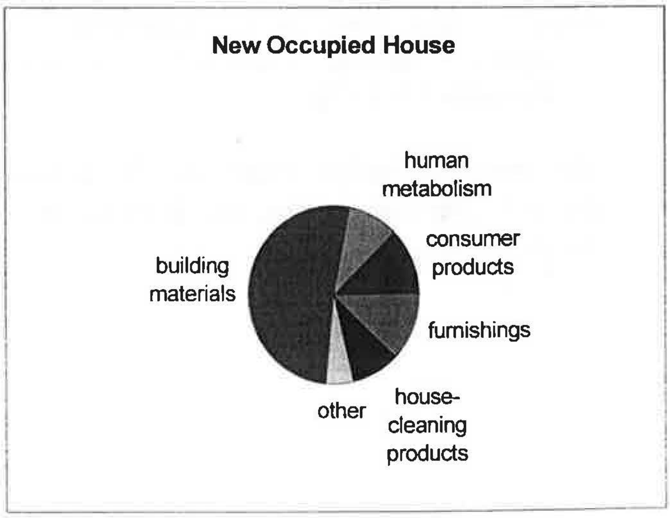


Figure 1. Typical Sources of Indoor Air Pollutants in Houses

Chemical Compound	Health/Irritation Guideline Concentration (μ/m^3)	Material Contribution Factor
Total Volatile Organic Compounds (TVOC)	500*	50%
Formaldehyde	60	80%
Styrene	213	50%
4-Phenycyclohexene (4-PC)	**	50%
Polycyclic Aromatic Hydrocarbons (PAH)	**	50%
Others	1/1000 of limits for industrial environments	50%

Table 1. Listing of Guideline Concentrations for Target Chemicals

* Proposed as preliminary target level.

** Many chemicals have been identified in various product emission tests for which there is little or no known health effect data that is relevant to residential buildings. Additional studies are required to assess the significance of these chemicals.

Ventilation Rates: Ventilation reduces indoor pollutant concentrations. Determine the expected continuous ventilation rate, in air changes per hour, for the house. A reasonable default would be a third of an air change per hour. Knowing the volume of the house, convert the air change rate to a ventilation rate in cubic metres per hour, m^3/hr.

Calculating the Emissions Budget: For each chemical or group of chemicals, calculate an emissions budget as follows:

Emissions Budget (µg/hr) = Health/Irritation Guideline (µg/m^3) x Material Contribution Factor (%) x Ventilation Rate (m^3/hr)

This emissions budget represents the maximum allowable chemical emission rate from all building material sources.

Cautions and Complications

- There is little data on the health effects of residential exposures and even less data on irritation effects.
- Emissions from non-building-material sources, such as furnishings, furniture and consumer products, have not been sufficiently studied to allow Material Contribution Factors to be assigned with any certitude.
- The effect of materials acting as "sinks", absorbing pollutants and re-releasing them later, is not considered here.
- Builders do not control the actual ventilation rates in the home.

Step 2: Identify Emission Rates for the Materials Selected

The second step involves collecting information on the emission rates (or emission factors) of materials to be used in the house, based on product-specific or generic data.

Chemical emission data is becoming increasingly available for a wide range of commonly used building materials. However, it is still difficult to obtain data on specific products, and so "generic" data may have to be used, such as the upper limits set by product labelling programs or the average emissions data determined by testing programs.

Table 2 provides a summary of the range of TVOC and formaldehyde emission rates of typical Canadian building materials, based on two recent studies by Saskatchewan Research Council and Ortech. The table also lists the number of samples which have been tested, which at this point is still quite small.

Material	TVOC Emissions ($\mu g/m^2hr$)			Formaldehyde Emissions ($\mu g/m^2hr$)		
	Max	Min	#	Max	Min	#
Carpet	652	< 1	11	48	< 1	6
Carpet Undercushion	856	< 1	6	12	< 1	4
Sheet Vinyl Flooring	9,40 8	948	5			
Medium Density Fibreboard	835	37	5	1000	42	6
Composite Wood (structural lumber)	290	67	3	85	4	8
Composite Wood (structural panel)	386	55	3	655	3	7
Composite Wood (cabinetry, coated)	1,37 8	459	4	177	6	4
Gypsum Board	25	< 1	4	250	60	2
Foam Insulation	68	< 1	3	< 1	< 1	1
Glass Fibre Insulation	150	< 1	6	105	< 1	4
Latex Paint	308	9	4			

Table 2. Range of TVOC and Formaldehyde Emission Rates for Common Materials

Labelling program requirements provide another source of information on emission rates. Table 5 on page 18 lists the emissions requirements of various Canadian labelling programs.

Cautions and Complications

- Recent research has found that TVOC emission rates vary enormously from product to product within a given category of materials, often by a factor of 100 or more. This means that using "generic" data has limited value. Always use product-specific data where available.
- Emission rates decrease over time and so the rates used should be approximately those at the time the house becomes occupied.
- Methods used to measure emissions vary from lab to lab and will influence the range of chemicals and rates reported. Test chamber conditions, such as temperature, humidity and air change rate, may be different from the house being analyzed.
- When component materials are assembled into more complex products, such as cabinets or flooring systems, their emission rates will change.

Step 3: Estimate Emissions From Each Material

The third step involves estimating the expected emissions from each material, based on the material's emission rate and the quantity of material to be used in the house.

Material Loading: For each major material, calculate the surface area exposed to the indoor air. This includes hidden surfaces, such as the underside of countertops.

Estimate Material Emissions: Calculate the emissions from each material as follows:

$$\text{Emissions } (\mu g/hr) = \text{Emission Rate } (\mu g/m^2hr) \times \text{Surface Area } (m^2)$$

Cautions and Complications

- Adjustment factors should probably be applied to surface areas when materials are fully or partially enclosed. Field research is required to determine such factors.

Step 4: Estimate Total Emissions

The fourth step involves adding together the emissions from individual materials in order to determine the total emissions in the house. This should be done for TVOCs, formaldehyde and any other major pollutant group of concern.

$$\text{Total Emissions } (\mu g/hr) = \text{Emissions}_{\text{Material A}} + \text{Emissions}_{\text{Material B}} + \text{etc.}$$

Cautions and Complications

- Recent research has discovered many "surprise" sources of emissions, such as from form oil residue on concrete foundations and from factory-finished cabinet doors that hadn't cured properly. Therefore, it is important to check all materials.

Step 5: Compare Total Emissions With Emissions Budget

The final step involves comparing the estimated total emissions for each major chemical group with the emissions budget identified in Step 1 and then revising the design as necessary.

If the emissions budget is exceeded, the "worst offenders" should be identified and lower emission alternatives incorporated into the house design. The total emissions can then be recalculated.

III Applications: Let's Try Some Examples

To illustrate the procedures outlined above, two examples are provided in the following pages. For simplicity, only TVOCs are considered, since the TVOC "budget" will probably be the most difficult to achieve in most homes.

Example 1: A Typical New House

This example considers the "worst" and "best" case scenarios to illustrate the range of outcomes possible in a typical small house, and then discusses some design considerations which may lead the builder to change some of the material selections.

Design Characteristics:

- 120 m^2 bungalow
- undeveloped basement (assume no emissions)
- main floor 50% carpet and 50% vinyl flooring
- interior walls and ceilings painted: 450 m^2 total area
- built-in cabinets and vanities: 10 m lower and 8 m upper, assume to be equivalent to 50 m^2 of exposed net area
- structural wood composites (subfloor & joists): 250 m^2 exposed
- pre-finished trim: equivalent to 5 m^2
- continuous ventilation rate of 0.3 air changes per hour: equivalent to 180 m^3/hr

Steps:

1. Pick an Emissions "Budget"

Emissions $Budget_{TVOC}$ = Health/Irritation Guideline x Material Contribution Factor x Ventilation Rate
= 500 x 50% x 180
= 45,000 μg/hr

2. Identify Emission Rates for Materials Selected
3. Estimate Emissions from Each Material
4. Estimate Total Emissions

Maximum and minimum emission rates, surface areas, maximum and minimum material emissions and the corresponding totals are listed in Table 3.

Component	Area (m^2)	Maximum Emission Rate ($\mu g/m^2hr$)	Minimum Emission Rate ($\mu g/m^2hr$)	Maximum Emissions ($\mu g/hr$)	Minimum Emissions ($\mu g/hr$)
Carpet	60	650	<1	39,000	<60
Underpad	60	860	<1	51,600	<60
Vinyl flooring	60	9,400	950	564,000	57,000
Painted walls/ceiling	450	310	10	139,500	4,500
Cabinets	50	1,380	460	69,000	23,000
Trim	5	480	20	2,400	100
Structural Components	250	390	60	97,500	15,000
Totals				**963,000**	**99,720**

Table 3. Maximum and Minimum TVOC Emissions From Various Building Components

5. Compare Total Emissions With Emissions Budget

The analysis suggests that the TVOC emissions budget cannot be met, even by using the best available materials! Using the highest emission materials (an unlikely but possible occurrence) could produce extremely high indoor TVOC concentrations.

A detailed examination of the individual component contributions to overall TVOC emissions, based on the lowest emission products, provides some insight as to some potential design options.

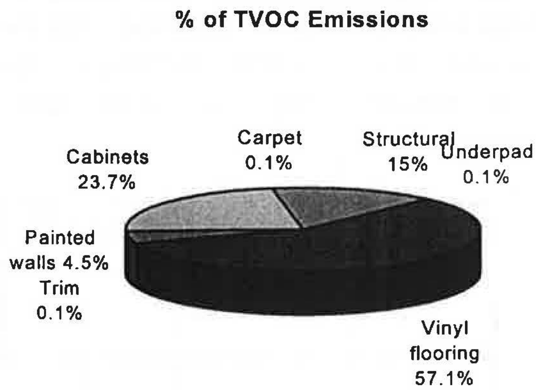


Figure 2. Component Contributions to TVOC Emissions

The values in the above pie chart show that major reductions in TVOC emissions can be achieved by lowering the emissions from vinyl flooring, cabinets and/or structural components. Since the carpet and underpad emission rates are lower, a higher ratio of carpet to vinyl flooring could be selected, or a more detailed search for a lower emission vinyl flooring or alternative product could be initiated. Similarly, a lower emission alternative could be sought for cabinet construction. Emissions from cabinets and structural components could also be reduced by applying a sealer.

Note that this example included a carpet sample with a very low emission rate when compared to the Canadian Carpet Institute's labelling standard of 500 $\mu g/m^2hr$ for TVOC.
The great range of emission rates in Table 2 highlights the importance of using actual data for products rather than industry averages. It is only with accurate data that "fine tuning" of any specific design will be possible.

Example 2: An Advanced House

This example considers one of the demonstrations recently constructed under the Advanced Houses Program. This house has a total heated volume of 641 m^3 and a design outdoor air exchange rate of 0.33 air changes per hour. The example uses emission test data from the actual materials used in construction, where available. Building parameters, such as volume, component surface areas and ventilation rate, are taken from the "as built" conditions. Estimated TVOC emission rates are used to calculate the indoor air TVOC concentration, which is then compared with the field-measured value for the new, unoccupied house.

Steps:

1. Pick an Emissions "Budget"

Emissions $Budget_{TVOC}$ = Health/Irritation Guideline x Material Contribution Factor x Ventilation Rate
= 500 x 50% x 212
= 53,000 $\mu g/hr$

2. Identify Emission Rates for Materials Selected
3. Estimate Emissions from Each Material
4. Estimate Total Emissions

Actual measured emission rates for components are used where available, otherwise typical values for similar components are used. These data, along with field-measured surface areas and total material emissions, are listed in Table 4.

Component	Area (m^2)	Actual Emission Rates ($\mu g/m^2hr$)	Typical Emission Rates ($\mu g/m^2hr$)	Actual Emissions ($\mu g/hr$)	Typical Emissions ($\mu g/hr$)
Carpet	70	400		28,000	
High density fibreboard	46	30		1,380	
Painted surfaces	762		8		6,096
Oriented strandboard	166		240		39,840
Laminated particleboard	70		460		32,200
Total				**107,516**	

Table 4. Estimated TVOC Emissions From Components Using Actual or Typical Emission Rates.

5. Compare Total Emissions With Emissions Budget

Again, this analysis suggests that the house, as built, would not meet its TVOC emission budget. Note also that not all of the potential TVOC sources have been included.

Unlike the first example, the contributions of individual building components are much more balanced. These are shown below.

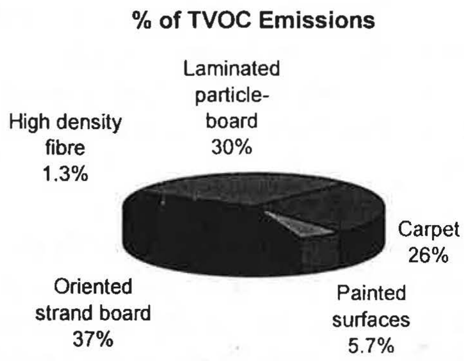


Figure 3. Component Contributions to TVOC Emissions

Looking at the results, it appears that the initial design is approximately double the emissions budget. This means that the TVOC concentration in the unoccupied house would already be equal to the proposed preliminary health/irritation guideline level of 500 $\mu g/m^3$. From a builder's perspective, this design would have a high risk of exceeding such guideline levels once the home was occupied.

However, the actual measured TVOC concentration for the unoccupied house was 250 $\mu g/m^3$ — only half of the level which was estimated. In other words, the house did meet its emissions budget. This example therefore highlights the current limitations of these procedures. As further research provides a better understanding of material emissions and as more complex models are validated, these procedures will be refined.

With respect to this example of the Advanced House, the discrepancy between the estimated and measured TVOC concentrations may be due to the following factors:

1) Almost 75% of the total emissions calculated were based on typical test data rather than specific data for the materials used in the house.
2) Field measurements of indoor air pollutant concentrations can vary significantly with changes in temperature, humidity, atmospheric pressure and ventilation rate.
3) Product assemblies, such as cupboards, may have lower overall emission rates than the individual sheet stock components.
4) Emissions from some of the materials may have decreased by the time the house testing was done.
5) Emissions may have been absorbed by "sinks", such as carpet and drywall, lowering the peak pollutant concentrations.

Summary of Current Limitations

The procedures outlined in this guide have been developed in response to builders' immediate need for information and it is recognized that much research remains to be undertaken before such an approach can be relied upon for a detailed and accurate analysis of a home's indoor environment. The following summarizes some of the current limitations.

- **Lack of definitive health and irritation data.** Health Canada researchers have estimated that it may take decades to determine the health impacts for the various individual chemicals present in indoor air. Very few guidelines currently exist, making it difficult to establish emission "budgets" for materials.

- **Lack of product-specific emissions data.** Emissions vary too much for generic data to be of much value. Labelled materials may have emission rates considerably lower than the upper limits set by labelling programs.

- **Effect of time on emission rates**. Wet materials have high initial rates of emissions which decrease rapidly as the material dries or sets, while dry materials have emission rates which decrease more slowly over time.

- **Effect of "sinks".** Materials with chemically reactive surfaces can absorb pollutants, re-releasing them slowly over time, which lowers peak concentrations, but prolongs exposures. Sink effects are currently not considered.

- **Lack of emissions data on assemblies.** Emissions from assemblies will be different (usually lower) than emissions from individual components by themselves.

- **Unknown actual ventilation rates.** Air change rates directly influence pollutant concentrations. These procedures assume that homeowners will run their mechanical ventilation systems so that a minimum level of continuous ventilation will be provided.

- **Emissions from multiple sources.** These procedures assume that emissions from different sources can simply be added. However, as overall indoor concentrations increase, emission rates from individual materials may decrease.

- **Unknown contributions from occupants.** These procedures assume that building materials are responsible for 50-80% of total pollutant emissions in a new home. However, very little is known about emissions from the occupants' furnishings, furniture and consumer products. These sources are also largely beyond a builder's control.

NRCan welcomes any comments, criticisms and suggestions for improvement from builders, manufacturers and researchers, and will consider these when undertaking further revisions.

What's Coming?

The study of material emissions is a very new field. Our knowledge can be expected to change greatly over the next few years as further research is completed.

Over the next five to ten years, we can expect to see an improved understanding of the science of material emissions, including standardized test methods and an abundance of emissions data. Further research on the health and irritation effects of indoor pollutants, particularly those on Health Canada's "Priority Substances List", will hopefully lead to an expansion of current guidelines on acceptable levels of pollutants.

The procedures outlined in this guide for predicting indoor air quality will likely undergo considerable refinement. One project, which has been launched in the Spring of 1996 by NRCan and CMHC, will assist in this process. In collaboration with CHBA, case studies are being undertaken of three new R-2000 houses employing many low-emission materials and three new conventional homes. These six units will be field tested over a six month period, both before and after occupancy, to determine emission source strengths, pollutant levels, the effectiveness of ventilation strategies and the impact of occupant furnishings and activities. The data collected will help to validate and refine current procedures for predicting IAQ.

Another major initiative which will likely impact these procedures is the three-year emissions research program being led by the National Research Council and guided by a Consortium of private and public agencies in Canada and the U.S. This work will result in an extensive database of emissions data and the development of a sophisticated, yet "user-friendly" model for predicting IAQ and analyzing problems.

IV. What Can Builders Do Now?

While much research remains to be done, consumer demand for "healthier" indoor environments is steadily increasing. Builders need practical advice on what they can do to reduce pollutant levels in new and renovated homes.

Select Low-Emission Materials

To encourage the availability of low-emission materials in the marketplace, builders should continually ask manufacturers and suppliers for emissions data on their products and work with them to develop lower-emission alternatives. For example, during the Advanced Houses demonstrations, some manufacturers were willing to modify their existing materials to meet a niche market.

Voluntary labelling programs should be supported by selecting materials which have met Green Label, EcoLogo and other program criteria.

Builders should focus their efforts on priority areas. Large interior surfaces, such as floor coverings, cabinetry, and paints and finishes have a correspondingly large impact on the surrounding air. Low-emission alternatives are increasingly available and these should be specified wherever economically possible.

The following provides some general directions. See section V. for sources of information on low-emission materials.

Floor Coverings: Choose carpets with latex-free backings, such as fusion-bonded, needle-punched or horizontally woven carpets. Natural fibre (e.g. wool) carpets and nylon carpet tile have lower emissions. Avoid carpets with chemical treatments. For carpet undercushion, jute, felt, polyethylene and cork offer alternatives to latex. Carpet installation should involve a VOC-free adhesive or be done mechanically through tacking. Linoleum or composite vinyl tiles offer lower emissions than sheet vinyl. Relatively inert — although more expensive — flooring alternatives include ceramic tile, hardwood and terrazzo.

Paints and Finishes: Zero-VOC paints are now available. All interior paints, wood finishes and other coatings should be water-based. In general, prefinished materials, providing they have cured adequately, are preferred to on-site finishing. Cellulose wallpaper is available. Sealers should be water-based acrylic or urethane.

Composite Wood Products: Formaldehyde-free medium density fibreboard (MDF) is available. Phenol-formaldehyde or MDI bonded panels (e.g. softwood plywood, oriented strand board) and cement-bonded particleboard or fibreboard represent alternatives to conventional particleboard and MDF.

Adhesives, Sealants and Fillers: Acrylic latex and polyvinyl acetate adhesives are recommended. Water-based contact cement and low-toxicity tile and vinyl adhesives are also available. Preferred caulkings include water-based, acrylic latex and neutral-cure silicone. Gaskets should be PVC or urethane. Choose grouts with the least odour and allow them to fully cure before occupancy. Low-toxicity gypsum joint compound is available.

Adopt Construction Strategies Which Will Lower Emissions

In addition to choosing low-emission materials, care needs to be taken during construction to minimize the impact of emissions.

Protect Materials From Contamination: In particular, protect carpeting from spills during construction and remodelling. Also, ensure that suppliers are aware of the need to protect products from becoming contaminated when they are stored or transported.

Seal Emitting Materials: For example, an acrylic sealer can be used to seal exposed surfaces of particleboard (e.g. underside of countertops).

Air Out Materials: Products, especially those with high initial emission rates, such as floor coverings, can be aired out for a few days prior to installation to eliminate their peak emissions.

Increase Ventilation During Installation: Ensure that houses are very well ventilated during construction and renovation activities and prior to occupancy.

Educate Homeowners on Their Role in Controlling Emissions

There are many additional sources of emissions in houses which lie beyond the builder's control. Some of these can be addressed through homeowner education.

Furniture and Furnishings: Emissions can originate from composite wood products, fabrics and fabric treatment, vinyls and finishes. For example, the impact of the homeowner's furnishings in the Ottawa Innova House was to more than double the concentrations of VOCs. If homeowners are purchasing new furniture and drapes for their house, encourage them to ask about low-emission alternatives or to air out these products for a few days before having them installed.

Home Office Equipment: Equipment such as photocopiers, laser printers and fax machines are increasingly common in home offices and can be a major source of emissions. If the house design includes a home office, provide a quiet exhaust ventilation system. If the client is planning to purchase new equipment, encourage them to look for lower emission models.

Household Emission Sources: Educate homeowners about indoor air quality. Point out the steps you have taken to lower emissions from building materials. Encourage them to re-evaluate their use of household chemicals, such as cleaning and maintenance products and hobby materials. Recommend adding exhaust ventilation for hobby rooms and workshops. And if they smoke — there's not much point worrying about emissions from building materials!

Ventilation: Instruct the homeowners on the importance of using their ventilation system to maintain good indoor air quality. Advise them to run it continuously at a higher rate during the first couple of months after occupancy.

V. Resource Information

Where to Get Information on Low-Emission Materials

Creating healthier indoor environments may mean searching for alternative building materials. What builders need is product-specific information with names of manufacturers and brands. This section lists some of the current sources of information available in Canada and the U.S. on low-emission materials.

a) Canadian Publications

Building Materials for the Environmentally Hypersensitive
This recently published manual from Canada Mortgage and Housing Corporation is targeted to builders who are providing housing for hypersensitive clients, but the information is very useful to anyone interested in the impact of materials on the indoor environment. Oliver Drerup, one of the first builders to develop low-pollution homes, was part of the team that assembled the material. The book contains one-page product sheets on over 180 products. Product sections cover adhesives, barriers, structure, cabinetry, caulking and fillers, doors and windows, electrical wiring, exterior wall finishes, flooring, foundations, gaskets and weatherstripping, insulation, interior walls and ceilings, paints and coatings, plumbing products and roofing. *Available for $29.99 from CMHC Publications, P.O. Box 3077, Markham, Ontario L3R 6G4, tel: (800) 668-CMHC, fax: (800) 463-3853.*

Environmental By Design: Volume 1: Interiors
This sourcebook provides one-page product reports on about 150 materials, including carpeting and other flooring, thermal insulation, interior panels and ceiling tile, installation materials, finishes, wall coverings and furniture. The "Professional Edition" comes in a binder format with product update sheets and information guides, and is complemented by an annual update service. The primary author was David Rousseau, who was part of the team developing the Vancouver Healthy House. *Available for $24.95 from Environmental By Design, P.O. Box 95016, South Van C.S.C., Vancouver, BC, V6P 6V4, fax: (604) 266-7721. Professional Edition is available for $95, plus a yearly subscription fee of CAN$30 (US$25) for future updates.*

Environmental Choice^{M} Program Certified Products and Services
This lists manufacturers and products which comply with Environment Canada's "EcoLogo^{M}" requirements. Product categories with emission requirements include water-borne and solvent-borne paints, water-borne wood finishes and stains, adhesives, caulks and sealants, particleboard, fibreboard (MDF and hardboard), carpets, undercushion, resilient flooring, prefinished hardwood flooring, and office panels and partitions. The listing is currently dominated by paints, but is expected to be expanded as more products become certified. *Available from Lynne Patenaude, TerraChoice Environmental Services, tel: (613) 952-0264, fax: (613) 952-9465.*

Healthier Indoor Environments: Canadian Sources of Residential Products and Services
Prepared for CMHC by Cullbridge Marketing and Communications, this directory includes a section on "Low-Polluting Building Products, Materials and Technologies", which lists manufacturers of low-emission adhesives, carpets, hardwood flooring, paints, sealers, varnishes, wall coverings and wood products. Other sections list consultants who provide screening evaluations of materials and cleaning and maintenance products. *Available from Canadian Housing Information Centre, CMHC, tel: (613) 748-2367, fax: (613) 748-2098.*

R-2000 Procurement List
This list assists builders in selecting products which will meet the new R-2000 IAQ requirements. Included are carpet and undercushion, resilient flooring, paints and finishes, adhesives and composite wood products. *Available from John Broniek, Canadian Home Builders' Association, tel: (613) 230-3060, fax: (613) 232-8214.*

b) American Publications

E-House™ Indoor Air Quality Product Guide
This directory includes listings of hundreds of low-emission products and is available in both printed and electronic format. *Available for US$50.00 from E-House Environmental Building Consultants, 312A Jefferson Ave., Cheltenham PA 19012-2121, tel/fax: (215) 663-1611.*

Environmental Outfitters™
Customized lists can be prepared from over 1200 low-toxicity products carried by this firm specializing in the needs of the chemically hypersensitive. Included are building materials, furnishings, and cleaning and maintenance products. *For further information, contact:*

Environmental Outfitters, tel: (800) 238-5008, fax: (212) 226-8084.

The Healthy Household: A Complete Guide for Creating a Healthy Indoor Environment
This homeowners' guide was written by Lynn Marie Bower, who has suffered from multiple chemical sensitivity. Included are sources of lower emission paints, stains, home-workshop materials, flooring, wall coverings and window treatment, as well as furniture, clothing, bedding, toiletries and pest control. *Available for US$17.95 from The Healthy House Institute, 430 North Sewell Road, Bloomington IN 47408.*

IAQ Product and Service Guide
This comprehensive directory has been prepared by Cutter Information Corp., who publish the "Indoor Air Quality Update" newsletter. Included is a section on "Interior Construction Products", plus listings of air filters and cleaners, detection equipment, mitigation products and consultants. *Available for US$75 from Cutter Information Corp., tel: (800) 888-8939, fax: (617) 648-8707.*

c) Voluntary Labelling Programs

There are an increasing number of voluntary labelling programs in Canada which consider emissions. Builders are encouraged to select materials which have been labelled, since these programs cause manufacturers to examine their production processes, in many cases leading to no-cost or low-cost reductions in emissions. Table 5 summarizes the emissions requirements of current voluntary programs in Canada.

"Green Label" Carpeting
The Canadian Carpet Institute (CCI) started testing and labelling carpets in 1993, based on the U.S. Carpet and Rug Institute's program. At present, 70% of Canadian manufacturers are participating and the program has led to a significant reduction in emissions, particularly 4-PC which gives new carpeting its distinctive odour.

Particleboard
The Canadian Particleboard Association's (CPA) formaldehyde testing program has been in place for more than a decade. Although the formaldehyde concentration limits are four to six times Health Canada's target level, CPA's program has succeeded in lowering emissions by a factor of ten since the early 1980s. All products produced by CPA members currently comply.

Environmental Choice^{M} Program
Indoor emissions are one of many environmental characteristics considered in assigning an EcoLogo^{M} label. Requirements were developed in the late 1980s for "wet" products such as paints, wood stains and finishes, adhesives, caulks and sealants. The Program has recently been expanded to include a broad range of building materials. For particleboard and fibreboard, lower levels of formaldehyde have been set than in CPA's program. Prefinished hardwood flooring and office partitions are evaluated in terms of their contribution to TVOC concentrations under typical conditions. Requirements for carpet and carpet undercushion use the CCI emission criteria as a minimum.

TVOC criteria are set for resilient flooring. However, for these three flooring products, a "total load point" approach is used which combines various environmental qualities, including recycled content, so the label is less useful to builders.

Envirodesic^{TM} Certification Program
This new labelling program is a partnership between the Lung Association and Green-Eclipse Incorporated, who specialize in the needs of the hypersensitive. The program has recently begun testing and certifying products in terms of their impact on the indoor environment.

Program	Material	Pollutant	Limit	Description
Canadian Carpet Association (CCI)	carpets	TVOC	500 $\mu g/m^2h$	emission rate
		4-PC	100 $\mu g/m^2h$	
		styrene	400 $\mu g/m^2h$	
		formaldehyde	50 $\mu g/m^2h$	
Canadian Particleboard Assoc. (CPA)	particleboard flooring	formaldehyde	0.2 ppm	concentration in test chamber
	other particleboard		0.3 ppm	
Environmental Choice (EcoLogo)	water-borne paints	VOC	250 g/L	VOC content of product (excl. water)
	solvent-borne paints		380 g/L	
	water-borne wood finishes		300 g/L	
	water-borne wood stain		250 g/L	
	adhesives		20 g/L	
	caulks and sealants		20 g/L	
	particleboard	formaldehyde	0.15 ppm	chamber conc.
	fibreboard: MDF, hardboard	formaldehyde	0.15 ppm	chamber conc.
	carpets	TVOC, 4-PC, styrene, formald.	CCI standards as maximum	emission rate
	undercushion	TVOC, 4-PC, styrene, formald.	CCI standards as maximum	emission rate
	resilient flooring	TVOC	1000 $\mu g/m^2h$	emission rate
	prefin. hardwood flooring	TVOC	500 $\mu g/m^2h$	emission rate
	office panels and partitions	TVOC	500 $\mu g/m^2h$	emission rate

Table 5.· Emission Requirements in Canadian Labelling Programs

d) Material Safety Data Sheets

Manufacturers and suppliers have material safety data sheets (MSDS) available for any products with health and safety risks. MSDS information includes the total content of volatile organic compounds, the presence of any cancer-causing substances, and threshold limit values (TLVs) which is the level at which a substance is regarded as toxic. While not always easy to read, the MSDS can be a starting point for comparing materials such as paint, adhesives and wood finishes.

e) Material Emission Databases

Many of the Canadian research agencies and labs which are studying material emissions are also assembling databases on emissions (see Canadian Labs Performing Emissions Testing). At this stage, most databases are quite limited, but they can provide a builder with a general

Canadian Labs Performing Emissions Testing

Builders can encourage manufacturers to have their products tested and emissions data published. The following lists research agencies and private labs which are currently undertaking material emissions testing in Canada.

Bovar Environmental, Toronto and Ottawa
Contact: Phil Fellin, tel: (416) 630-6331, fax: (416) 630-0506.

Canadian Institute for Research in Atmospheric Chemistry, York University, Toronto
Contact: David Halton, tel: (416) 736-5586, fax: (416) 736-5690.

Concordia University, Montreal
Contact: Fariborz Haghighat, tel: (514) 848-3192, fax: (514) 848-7965.

Forintek Canada Corporation, Sainte-Foy, Quebec
Contact: Jack Shields, tel: (418) 659-2647, fax: (418) 659-2922.

Health Canada, Environmental Health Directorate, Ottawa
Contact: Rein Otson, tel: (613) 957-1646, fax: (613) 954-2486.

National Research Council, Institute for Research in Construction, Ottawa
Contact: Jianshun Zhang or John Shaw, tel: (613) 993-9538 or 9702, fax: (613) 954-3733.

Ortech Corporation, Mississauga
Contact: Peter Piersol, tel: (905) 822-4111 ext.545, fax: (905) 823-1446.

Saskatchewan Research Council, Saskatoon
Contact: Rob Dumont, tel: (306) 933-6139, fax: (306) 933-6431.

References

Builders looking for more detailed information may be interested in some of the following reports and publications:

American Conference of Governmental Industrial Hygienists. Threshold Limit Values for Chemical Substances and Physical Agents. Cincinnati: ACGIH.

Cullbridge Marketing and Communications, for Canada Mortgage and Housing Corporation. 1994. Healthier Indoor Environments: Canadian Sources of Residential Products and Services. Ottawa: CMHC.

Federal-Provincial Advisory Committee on Environmental and Occupational Health. 1987 (rev. 1989). Exposure Guidelines for Residential Indoor Air Quality. Ottawa: Health Canada.

Jools Development, for Canada Mortgage and Housing Corporation. 1995. Building Materials for the Environmentally Hypersensitive. Ottawa: CMHC.

Leclair, K; Rousseau, D. 1992. Environmental By Design. Point Roberts WA and Vancouver BC: H&M Publishers.

Nathanson T. for the Federal-Provincial Advisory Committee on Environmental and Occupational Health. 1993 (rev. 1995). Indoor Air Quality in Office Buildings: A Technical Guide. Ottawa: Health Canada.

Ortech Corporation, for Canada Mortgage and Housing Corporation. 1995. Build Green and Conventional Materials Off-Gassing Tests. Ottawa: CMHC.

Robinson T and White J (editors). 1994-present, semi-annually. Healthy Materials: A Communiqué on Material Emission Testing and Standards Activities. Ottawa: CMHC.

Saskatchewan Research Council and Figley Consulting Associates Ltd., for Natural Resources Canada. 1995. Building Materials — Volatile Organic Chemical Emission Characterization and Database Development. Ottawa: NRCan.