Estimating the Concentrations of Soil Gas Pollutants in Housing

A Step-by-Step Method

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NOTE: **DISPONIBLE AUSSI EN FRANÇAIS SOUS LE TITRE:**

Estimation des concentrations de gaz souterrains polluants dans les habitations

ESTIMATING THE CONCENTRATIONS OF SOIL GAS POLLUTANTS IN HOUSES

"Estimating the indoor concentration of soil gas pollutants in houses is a basic requirement for a complete site risk assessment."

This view was reinforced recently by the results of a CMHC study which showed significant variation among assessments performed on the same hypothetical site. Experts felt that one of the reasons for this variation could be that many environmental consultants do not consider the effect that housing can have on soil gas concentrations at a specific site. This is partly because the consultants may not fully understand how a building can affect the soil gas concentrations, and partly because they may not know how to incorporate these impacts in their risk calculations.

The purpose of this guide is to assist site risk assessors by taking them step-by-step through a method for estimating the concentration of soil gas pollutants in houses (see Fig. 1). The method is not intended to provide a rigorous technical analysis, but rather to provide a technique for identifying potential problems at specific sites.

Important Note: The approach described is applicable to all buildings; however, the design data presented are specific to low rise housing. The data required for estimates in large buildings are not available at this time. A detailed engineering assessment would be required.

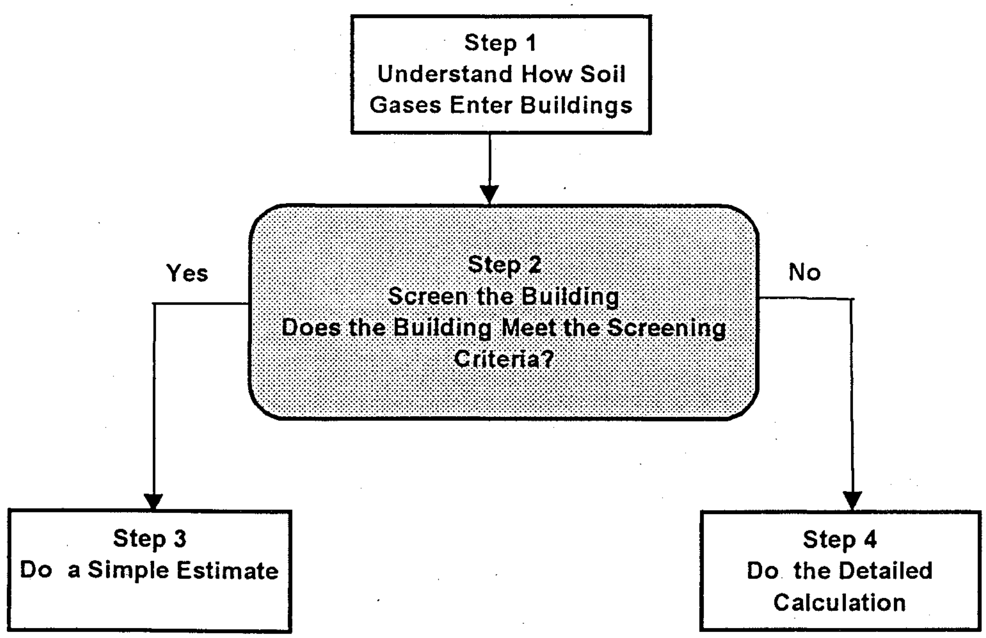

Figure 1: The Step-by-Step Method

STEP 1. UNDERSTAND HOW SOIL GASES ENTER BUILDINGS

Soil gases enter buildings in several ways, for example:

#1. They enter through **below grade** cracks, construction joints, and other openings in the basement such as floor drain systems (see Figure 2).

#2. They move to the soil surface, become **airborne** and enter the building through windows and doors.

#3. They enter in the **groundwater** that is transported into the building by means of foundation drainage systems or seepage, and in water used for showering and cooking and for other domestic activities.

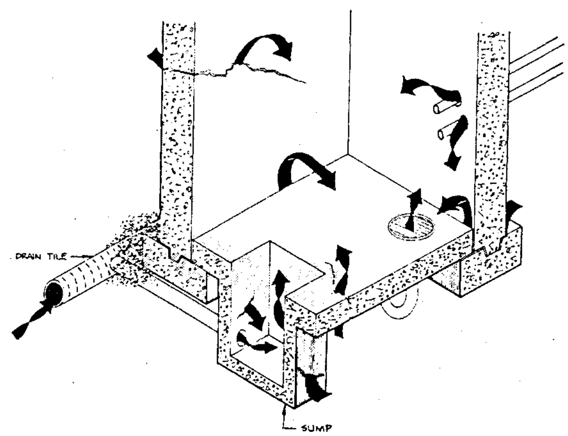

Figure 2: Typical Basement Entry Pathways

Pollutants can also be carried into buildings by its occupants and pets on contaminated footwear and clothing, and by other means of **direct transport**.

Due to the current shortage of data on transportation in the groundwater and direct transportation, only #1 and #2 above are considered in the calculations.

The extent of soil gas entry into buildings will depend on certain building features and how these interact. These features are taken into account in the method described in this guide.

Useful terms

Natural Ventilation: Air change occurs due to natural forces such as wind or convection; air moves into and from the building through windows or through cracks and seams.

Mechanical Ventilation: Reliable ventilation is assured and is controlled by equipment such as fans or heat recovery ventilators.

Balanced Mechanical Ventilation: The amount of air supplied to the building equals the amount of air exhausted from the building.

Air Change Rate: The number of air changes that take place per hour (ac/h) in a particular building

Ventilation Rate: The total building air change rate (m^3/hr). It includes both natural and mechanical ventilation, but will not necessarily equal the sum of these two rates.

STEP 2. SCREEN THE BUILDING

If the building meets certain criteria, a simple estimate can be used to screen the application for risk (Step 3); no detailed calculations will be required. If the estimate does not meet the screening criteria, the detailed calculation procedure (Step 4) should be followed.

The screening criteria ...

- The building has a well-designed and well-constructed foundation.

- Major below grade air leakage pathways are minimized through building design and construction.
- The foundation drainage system does not permit soil gas movement into the building interior.
- The building has a balanced mechanical ventilation system or it has a system with no major continuous exhaust equipment.

Examples of this type of building would be ***a new house that appears to be designed to code with no apparent flaws in the below-grade building envelope. The building would probably have a cast-in-place concrete or preserved wood foundation and a cast-in-place floor slab with a well-sealed below grade envelope and a foundation drainage system.***

> Note: For Steps 3 and 4, the pollutant concentration in the soil gas adjacent to the foundation below grade can be calculated or measured.

STEP 3. DO A SIMPLE ESTIMATE

In houses that meet the screening criteria (see Step 2), the indoor air concentration of soil gas pollutants may be calculated as follows:

$$C_i = 0.05 \cdot C_{sg} \quad (1)$$

where

C_i = indoor air concentration of soil gas pollutants (mg/m^3)

C_{sg} = outdoor air concentration of the soil gas pollutants.

This formula assumes that ...
... the outdoor air concentration of soil gas pollutants is negligible and
... the soil gas flow rate into the building = 5% of the building ventilation rate.

Equation 1 shows that in new houses that meet the screening criteria (see Step 2), the indoor air concentration of soil gas pollutants is typically not greater than 5% of the soil gas concentration of the pollutant. This is a conservative estimate. Most houses will have soil gas entry of less than 5% and the indoor concentrations will consequently be lower. Use the detailed calculation (Step 4 below) if you feel that the 5% soil gas infiltration rate is too high.

STEP 4. DO THE DETAILED CALCULATION

For houses that do not meet the screening criteria in Step 2, a more detailed calculation is required. The indoor air concentration of soil gas pollutants, for any set of operating conditions, may be calculated as follows:

$$C_i = \frac{C_o \cdot Q_b + F}{Q_b + Q_s} \quad (2)$$

where:

C_i = indoor air concentration of soil gas pollutants (mg/m^3)

C_o = above grade outdoor air concentration of soil gas pollutants (mg/m^3)

Q_b = building ventilation rate from outdoor air (m^3/hr)

Q_s = below grade soil gas flow rate into building (m^3/hr)

F = below grade pollutant flux into the building (mg/hr)

Where possible, field test data should be used in the calculation. Tables of estimated values are provided in this guide to assist where field test data are not available; these are relatively conservative.

Users should note that when using field test data, single field samplings are not representative of the full range of characteristics; to be assured of a satisfactory level of accuracy, multiple samplings are required.

MORE ABOUT THE VARIABLES

Soil Gas Pollutant Flow into the Building Above Grade ($C_o \cdot Q_b$)

These flows depend on the concentration of the pollutants above grade and the building's ventilation rate. The product $C_o \cdot Q_b$ represents the flow of a soil gas pollutant that is drawn into the building together with outdoor air, by means of natural and mechanical ventilation.

Above Grade Outdoor Air Concentration of Soil Gas Pollutants (C_o) *(Use in Equation 2)*

This can be non-existent, or it can reach significant levels particularly near ground levels. The soil gas pollutant concentration should always be carefully assessed when the building has windows close to the ground. This is because if soil gases are present and if the building has ventilation air intakes or large air infiltration openings (such as windows) at that low level, it is relatively easy for the soil gases to enter the building and cause a problem. Although outdoor air concentrations are usually much lower than soil concentrations, relatively high ventilation rates can result in a significant pollutant mass flow into the house.

Building Ventilation Rate -- Low Rise Housing (Q_b) *(Use in Equation 2)*

A building's ventilation rate is the sum of air infiltration (natural ventilation) and mechanical ventilation. Unless you know the rate of use of mechanical ventilation, it is more conservative to ignore its contribution to the building ventilation rate.

It is best to use field values, but where none are available, use the air change rate estimates provided in Table 1 columns 1 and 2 as the basis for your calculation, and then calculate the ventilation rate. The values in the table are considered typical for prairie winter conditions; suggestions for making adjustments to account for other conditions are also provided below.

Table 1.Typical Air Change Rates for Canadian Prairie Houses

House Type	(1) Estimated Heating Season Natural Ventilation Rate (ac/h)	(2) Estimated Mechanical Ventilation Rate (ac/h)
Wood Frame - pre 1945	0.5 - 1.0	none
Wood Frame - 1946-1960	0.2 - 0.4	none
Wood Frame - 1961-1980	0.15 - 0.3	maybe 0.2 intermittent
Airtight New House	0.05 - 0.1	0.3 installed capacity

Calculating ventilation rates from the air change rates ...

... The ventilation rate (m^3/hr) is the product of the air change rate (ac/h) and the building volume (m^3), that is, ***ventilation rate (m^3/hr) = building volume (m^3) x air change rate (ac/h)***. If the volume is not available, assume $350m^3$ for a small house, $550m^3$ for a medium-sized house, and $800m^3$ for a large house.

Suggested adjustments

- In certain situations (for example in warm weather in houses with closed windows and air-conditioning), naturally ventilated houses can have very low ventilation rates, with associated high pollutant levels. Under these conditions, the values shown in Table 1 column 1 should be reduced by 50% to represent typical annual values.

- In more temperate climates, natural ventilation rates will be also be lower than those shown in Table 1. The estimated values in Table 1 column 1 should be multiplied by the factors in Table 2 to adjust for different climate zones.

Table 2. Adjusting for Climate Zone

Climate Zone	Natural Ventilation Multiplier
Mild	0.6
Moderate	0.8
Severe	1.0

Soil Gas Pollutant Flow into Building BELOW GRADE (Q_S) *(Use in Equation 2)*

Soil gases will enter a building below grade if the following conditions exist:

- Entry pathways such as leaks, cracks or other openings make infiltration possible.
- The pressure in the basement is lower than that in the surrounding soil.

To ensure consistency with industry norms, a factor of 3.6 is included to account for conversion from seconds to hours, and from litres to cubic metres.

This phenomenon is expressed as:

$$Q_S = 3.6\,(C \bullet \Delta P^n) \qquad (3)$$

Where:

Q_S	=	below grade soil gas pollutant flow rate (m^3/hr)
C	=	soil gas flow coefficient ($L/s{\cdot}Pa^n$)
P	=	pressure differential (Pa)
n	=	flow coefficient (dimensionless)

C and n are physical properties of the building envelope related to the air leakage characteristics and can be estimated or determined through blower door testing.

Below Grade Building Envelope Air Leakage Characteristics (Use in Equation 3)

A value known as an equivalent leakage area, ELA (m^2) can be used to calculate the below grade soil gas flow into the building (C). The ELA represents the extent of the leakage in a building below grade. An approximate conversion of ELA to C can be calculated using equation 4.

$$C = ELA / 0.004 \qquad (4)$$

Table 3. Suggested ELA Values for Below Grade Building Envelope Components

Component	Typical ELA*
Floor/Wall Shrinkage Crack - no bond breaker - with bond breaker	 0.000003 m^2/m 0.000013 m^2/m
Lightweight Block Wall (unfinished interior surface)	0.0000034 m^2/m^2
Cast-in-place Concrete Floor or Wall	0 m^2/m^2
Service Penetration	0.00002 m^2
Floor Drain (untrapped connection to foundation drainage system)	0.005 m^2

* Total ELA for the component = Unit ELA multiplied by the total length or area of component

The total below grade building envelope soil gas flow coefficient, C_T, can be estimated using equation 5 and the values in Table 3. These values were developed for full depth basements with cast-in-place concrete floor slabs. They can also be used for basements and crawlspaces constructed with other well-sealed building materials provided that cast-in-place concrete floor slabs and careful design and installation practices are followed. For other foundation designs, inspection or testing will be required to assess the extent of the leakage.

The total soil gas flow coefficient for the house (C_T) may be calculated as follows:

$$C_T \quad = \quad \Sigma\, ELA_{components} / 0.004 \quad (5)$$

Below Grade Building Envelope Differential Pressures -- Low Rise Housing

(Use in Equation 3)

In most houses, air infiltration and soil gas entry due to pressure differentials is a complex phenomenon related to a range of factors.

The "stack effect" is often the primary factor. This occurs because buildings typically behave like chimneys. Warmer air rises and escapes at upper levels; the resulting low pressure in the basement causes the flow of soil gas into the house (see Figure 3).

Another factor is the action of mechanical ventilation systems (such as kitchen and bathroom exhaust fans), fireplaces, certain types of oil and gas furnaces, and other equipment that extract air from the house. The air that has been exhausted must be replaced. It may be replaced by contaminated soil gases that are drawn in through the basement.

Lastly, factors such as local wind conditions and changes in barometric pressure can cause soil gas flows into the building.

Figure 3: Pressure Distribution in a Typical House

Typical maximum winter differential pressures for houses are given in Table 4. These pressures, adjusted as necessary (see below), can be used in equation 3 to calculate the building soil gas flow rate.

Table 4. Maximum Pressure Difference Across Below Grade Building Envelopes (Pa)

House Type	Typical ΔP Mild Winter	Typical ΔP Moderate Winter	Typical ΔP Severe Winter
Slab-on-grade (no chimney)	1	2	3
Slab-on-grade (chimney)	3	4	5
1 or 2 Storey (no chimney)	4	5	6
1 or 2 Storey (chimney)	8	9	10
3 Storey (no chimney)	7	8	9
3 Storey (chimney)	13	14	15

Suggested adjustments

- It the house has a fresh air intake duct or combustion air supply, reduce the differential pressures in Table 4 by 2 Pa.
- If the house has a fireplace, central exhaust system or other large or frequently used exhaust equipment, increase the differential pressures in Table 4 by 2 Pa.

Calculating the average

The average differential pressure across the below grade building envelope during the heating season can be estimated as 50% of the maximum value given in Table 4, after the appropriate adjustments have been made.

Soil Pollutant Flux into the Building (F)
(Use in Equation 2)

The pollutant transport rate, or flux, into the building can be calculated as follows:

$$F = Q_s \bullet C_{sg} \quad (6)$$

Where:

C_{sg} = average pollutant concentration in the soil gas (mg/m³)

FOR MORE INFORMATION

CMHC has a wide variety of publications on topics such as

- sources and types of soil gases
- the health impacts of soil gases
- the movement or distribution of soil gases through the soil
- the factors that influence soil gas concentrations
- the prevention of soil gas entry into houses.

For more information, please contact CMHC's Canadian Housing Information Centre at
Phone: (613) 748-2367 or
E-mail: cmhc004@cmhc-schl.gc.ca

EXAMPLE

The following example illustrates how basic foundation air leakage data can be used to estimate whether a foundation design may be suitable for a specific site. The approach uses the *Detailed Calculation* described in Step 4.

House Description

New, single family bungalow in Saskatoon (severe climate) with 500 m^3 volume and having a conventional natural gas furnace and water heater. A combustion air duct is installed. A heat recovery ventilator supplies a balanced ventilation rate equal to 0.3 ac/h^{-1}.

The foundation is cast-in-place concrete with a perimeter of 40 m and ten service penetrations for plumbing and structural supports. A poly barrier has been installed under the concrete floor slab but no specific sealing measures have been taken. The foundation drainage system is isolated from the house interior.

Field test data gives an average soil radon gas concentration of 20,000 Bq/m^3.

Calculation Procedure (Step 4. Detailed Calculation)

$$C_i = \frac{C_o \cdot Q_b + F}{Q_b + Q_s}$$

where:

C_i = indoor air concentration of soil gas pollutants (mg/m^3)

C_o = above grade outdoor air concentration of soil gas pollutants (mg/m^3)

Q_b = building ventilation rate from outdoor air (m^3/hr)

Q_s = below grade soil gas flow rate into building (m^3/hr)

F = below grade pollutant flux into the building (mg/hr)

1) From Table 1, use an average natural ventilation rate of 0.075 ach^{-1} and a mechanical ventilation rate of 0.3 ac/h^{-1}. Since the house is in a severe climate region, the natural ventilation multiplier is 1.0. The total building ventilation rate, Q_b, is calculated to be 0.375 ach^{-1} or 187.5 m^3/hr.

2) From Table 3, select a floor/wall ELA of 0.000013 m^2/m and a service penetration ELA of 0.00002 m^2 per penetration. No other significant foundation air leakage sites are expected.

   The total foundation ELA is calculated to be,

$$ELA = 40\ m * 0.000013\ m^2/m + 10 * 0.00002\ m^2$$
$$= 0.00072\ m^2$$

3) Using equation 5, the foundation air flow coefficient is,

$$C_T = 0.00072/0.004$$
$$= 0.18\ L/s{\bullet}Pa^n$$

4) From Table 4, for a one storey house with a chimney, the maximum winter differential pressure is 10 Pa. Subtract 2 Pa for the presence of a combustion air duct and the net maximum winter differential pressure is 8 Pa. The average differential pressure is 50% of the maximum value, therefore 4 Pa.

5) Using equation 3 and assuming that n=1, the maximum winter soil gas flow into the below grade building envelope is,

$$Q_s = 0.18 * 8 * 3.6$$
$$= 5.2\ m^3/hr$$

6) The maximum winter pollutant flux into the building is calculated using equation 6,

$$F = 5.2 * 20{,}000$$
$$= 104000 \text{ Bq/hr}$$

7) Finally, the maximum winter indoor radon concentration is calculated using equation 2, (assuming the outdoor air concentration is negligible)

$$C_i = 104000 / (187.5 + 5.2)$$
$$= 560 \text{ Bq/m}^3$$

The average value will be 50% of the maximum winter concentration assuming that the ventilation remains constant.