ESTIMATION OF RADON CONCENTRATION IN HOUSE USING A SIMPLE VENTILATION MODEL

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The aim of this study is to evaluate the efficiency of different ventilation strategies for a house and for a subfloor void to reduce the radon concentration level of the indoor air.

A steady-state analytical ventilation model is derived to estimate the indoor air radon concentration in houses on ground floor or with subfloor voids. It enables to analyse the influence of different environmental and construction parameters on this concentration, in a way to better define and dimension technical solutions to reduce radon concentration in indoor air.

First main results obtained with this model are presented in this article. The model developed could also be a help to dimension natural ventilation of a void equipped with specific duct to use stack effects.

INTRODUCTION

The soil is recognised to be the main source of radon in indoor air of buildings. Its entry into buildings is mainly due to pressure difference between the soil beneath the house and the house. It depends on many environmental parameters such as radon concentration in the soil, permeability, humidity and cracks of the soil. It depends also on characteristics of the building considered (type of construction and basement, cracks on floors in contact with soil or a void, ventilation system…).

In this context and in order to improve the efficiency of different ventilation strategies to reduce the indoor air radon concentration, we have developed a steady-state analytical ventilation model. After a description of our model, we present in this article the main results obtained with this model.

DESCRIPTION OF THE MODEL

On the basis of the ventilation code developed at C.S.T.B. called SIREN95 (Simulation of air RENewal), and taking into account previous work like Woolliscroft (1994), a steady-state analytical ventilation model is derived to estimate the indoor air radon concentration in houses on ground floor or with subfloor voids. This code enables to analyse the influence of different environmental and construction parameters on this concentration. The house can be ventilated by natural ventilation or by mechanical ventilation.

Stack effect

The stack effect describes an air flux resulting from the pressure difference between the columns of warm and cold air inside and outside the house. In our model, hydrostatic fields for internal and external pressures are assumed and calculated to take into account the stack effect. This means that we consider an homogeneous field for the pressure with the air density which is varying as a function of temperature. The equation of ideal gas leads to:
\[ \rho_1 T_1 = \rho_2 T_2 \]

and permits to calculate the density for the associated temperature. So, for a considered height \( H \), we have:

\[
\begin{align*}
P_{H, ext} &= P_{0, ext} - \rho_{ext} \cdot g \cdot H \\
P_{H, int} &= P_{0, int} - \rho_{int} \cdot g \cdot H
\end{align*}
\]

**Wind effect**

The wind effect induces a dynamic air pressure acting on building walls. This dynamic pressure is added to the static pressure to determine the external pressure field.

The dynamic pressure term is calculated as follows:

\[ P_{dyn} = \frac{1}{2} C_p \cdot \rho \cdot v^2 \]

\( \rho \) is the density of external air and \( v \) its velocity. \( C_p \) is the pressure coefficient in the range \(-1 \) to \(+1 \) which describes the distribution of wind induced pressure over building house. Positive values of \( C_p \) relate to the winward side of the building and describe air compression. Negative values relate to the rear side of the building. In our calculation, we consider conventional values of \( C_p \) of \(+0.6\) and \(-0.35\) for the winward and rear sides of the building respectively.

**Ventilation**

Once we know the hydrostatic fields for internal and external pressure, we can determine the air fluxes incoming and outgoing the building.

For the house, air leakage, air inlets and cracks, are characterised by their flow rate curves as a function of pressure difference (power lows):

**Air flow through air leakage**

\[ Q_p = k_p \cdot (\Delta P)^{2/3} \]

With
- \( Q_p \): air flow rate circulating through air leakages (m\(^3\)/h),
- \( k_p \): coefficient function of level of permeability of the enveloppe,
- \( \Delta P \): pressure difference between inside and outside at the level of the considered air leakage.

**Air flow through air inlets**

\[ Q_{ai} = k_{ai} \cdot (\Delta P)^{1/2} \]

With
- \( Q_{ai} \): air flow rate circulating through air inlets (m\(^3\)/h),
- \( k_{ai} \): coefficient function of size of air inlet,
- \( \Delta P \): pressure difference between inside and outside at the level of the considered air inlet.

**Air flow through cracks**

The considered cracks are those on the floor between the house and the soil (house on ground floor) or the subfloor void.
\[ Q_c = k_c \cdot (\Delta P)^{0.8} \]

With \( Q_c \) : air flow rate circulating through cracks (\( m^3/h \)),
\( k_c \) : coefficient function of size and type of cracks,
\( \Delta P \) : pressure difference between inside the house and the ground or the void.

**Air flow through the ground**

In the case of subfloor void, air is incoming in the void through the ground due to pressure difference between the ground and the void with the following law:
\[ Q_g = k_g \cdot \Delta P \]

With \( Q_g \) : air flow rate coming from the ground (\( m^3/h \)),
\( k_g \) : porosity coefficient of the ground,
\( \Delta P \) : pressure difference between the void and the ground.

Under equilibrium condition, the total amount of air entering the building should be equal to the total amount of air leaving the building. This condition leads to an equation which enables to determine the pressure at the soil of the building (\( P_{0, \text{int}} \)), and so all the different incoming and outgoing air flow rates, when we know external pressure on the ground, internal and external temperatures.

A constant air flow rate due to a mechanical exhaust or supply can be easily added to this equation.

**Model for house constructed on ground floor**

For house on ground floor, we consider a single volume. We suppose that radon only penetrates from the ground into the house through cracks in the floor by convection, due to pressure difference between the ground and the house. We assume a constant radon concentration in the soil beneath the house.

**Model for house with subfloor void**

For a house with subfloor void, we consider two volumes, one for the house and the other for the subfloor void. We suppose that radon penetrates from the ground into the void by convection, due to pressure difference between the ground and the void and by diffusion, and penetrates from the void into the house through cracks in the floor by convection. We assume a constant radon concentration in the soil beneath void and a constant radon diffusion source into the void (figure 1).

Due to strong hypotheses (steady state, constant radon concentration in soil and constant flux in the void, porosity of the soil and level of cracks in floor), results obtained with this model can only give tendencies. However they can point out the influence of different environmental and construction aspects. This model enables to make sensitivity studies on different parameters: exterior temperature, wind velocity, characteristic of the house such as type of basement, permeability, level of mechanical air change rate for the house and for subfloor void. It can also be an help to test and dimension technical solutions for existing and new buildings.
RESULTS

Increase of air renewal

Increasing the air change rate of the house is not very effective, and can reasonably be done only if the initial air change rate is too low, until a level of about 0.5 a.c.h. As mentioned in previous work like Bonnefous (1992), this measure will not generally be sufficient to reduce radon concentration until an acceptable level. Figure 2 shows the evolution of indoor radon concentration when mechanical exhaust of the house is accentuated until 2 a.c.h., for an airtight and a permeable house.

Use of supply mechanical ventilation for the house

The use of supply mechanical ventilation for the house to reduce its depressurisation can be effective to prevent the entrance of radon but depends on the air permeability of the house (figure 3).

Depressurisation of subfloor void

The most effective way to reduce radon concentration level of a house with subfloor void is to depressurise mechanically the void in order to have pressure in the void lower than pressure in the house. This is possible with not too high air change rate of the void only if it is sufficiently airtight (figure 4).

Ventilation of subfloor void

When the house is constructed with a subfloor void, a natural ventilation of this void will be generally insufficient to reduce radon concentration in it and so in the house, and one can't rely on wind effect because wind velocity is generally low at ground level (figure 5).

So, when the subfloor void is too permable, the most efficient way is to use supply or extract mechanical ventilation of the void (figure 6). At low level of ventilation of the void, supply ventilation is less efficient because it accentuates the air flow rate between the void and the house.

CONCLUSION

A steady-state analytical ventilation model is derived to estimate the indoor air radon concentration in houses on ground floor or with subfloor voids. It enables to analyse the influence of different environmental and construction parameters on this concentration. First main results are presented in this article. When it is possible, the most effective way to reduce radon concentration level of a house is to depressurise mechanically the ground beneath the floor or the subfloor void.

This work has been done to improve the efficiency of different ventilation strategies to reduce the indoor air radon concentration.

The model we have developed could also be a help to dimension natural ventilation of a void equipped with specific duct to use stack effects.

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REFERENCES


Figure 1: Example of model for a house with subfloor void.
Figure 2: Radon concentration function of a.c.h. (mechanical exhaust for airtight and permeable house).
Figure 3: Radon concentration and relative pressure on the floor, function of a.c.h. with mechanical air supply (airtight and permeable house).
Figure 4: Radon concentration and difference pressure between the floor and the void, function of a.c.h. with mechanical extract air from the void.
Figure 5: Radon concentration in a house as function of sizes of openings for the void, and different wind velocity.
Figure 6: Radon concentration in house function of extract or supply mechanical ventilation of the void.