DEVELOPING MODEL WITH BREEZE TO STUDY RADON MIGRATION AND MITIGATION IN A SINGLE FAMILY HOUSE *

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ABSTRACT

A multi-cell computer model of a family house with cellar was developed with the ventilation and contaminant movement computer prediction program BREEZE. The model was used to simulate the movement of radon gas from the cellar to the living areas of the house. Field measurements were also carried out under various controlled ventilation strategies. The paper outlines the development of the computer simulations from a simple model to a more complex flow analysis. The results obtained from the simulation model and the measured values were compared. A parametric study has subsequently been carried out to investigate the movement of the gas for a range of natural and mechanical ventilation strategies.

INTRODUCTION

Computer models have been developed in domestic radon researches since the middle of the 80's. Parametric modelling has been used to study a variety of physical processes for a better understanding on mechanisms in this area or to examine the effectiveness of a proposed remedial measure to a given building before pragmatic application.

Among those models, a complex model was developed in Lawrence Berkeley Laboratory, USA(Loureiro 1987; Loureiro et al. 1990) to simulate the process of soil radon entering a simplified house and examine quantitatively at the relationships between indoor concentration and other parameters. It helped us to gain a better knowledge on radon transport in soil and entry into houses.

In pragmatic application, a preliminary multi-cell model was developed with BREEZE to study the effects of substructure ventilation strategies on air movement and radon dispersion in a real house with cellar, which was geometrically complex from the view point of radon migration. The modelling suggested that both supplying and extracting ventilation would be effective when a mechanical ventilation system was installed in the cellar, which is commonly believed as the main radon source for the house(Ward et al. 1994).

Further research found that the initial model was too simple to yield result consistent with that of the field measurement carried out later. It even did not bear the basic features of relationship between radon distribution patterns and air change rates.

Firstly, the model did not correctly simulate the air flow through the staircase which was an important vertical route of indoor radon migration(fig. 2 a). The staircase was simplified as a vertical shaft started from the cellar to the top floor of the house (fig. 2 b). Although two open doors were at the sides of the shaft on the first and ground-floor respectively, the air flowed via these two floors carrying radon with it, until reached the top when no wind disturbed. The radon in the lounge came through the crack linking cellar and lounge directly. Consequently, most rooms were uncontaminated, which was rather different from the real situation.

Secondly, a fixed feed rate was set in the cellar which was contrary to reality. The truth found and supported by researches is that radon entry from the surrounding soil depends on many factors including the differential pressure between the cellar and the outdoors(Nero 1987). The feed rate in the model should not be given to a constant value before calculation the pressures in the house.

Lastly, the model failed to give a reversed radon distribution pattern found in the measurement, in which supplying ventilation resulted in higher radon levels on upperfloors than that in cellar. This pattern, which was also found in the testing basements in Princeton University by Cavallo and his colleagues, suggested that there was another radon entry route additional to the cracks linking cellar and ground floor.

Obviously, a more precise modelling is needed which should be validated by the field measurement. The interpretation of measured results suggested that the features was because of geometric complexity of the house, whose ground floor covered the cellar and soil as well. This geometric complexity increased the difficulty in modelling the radon entry appropriately and consequently resulted in the shortcomings of the initial model.

METHODOLOGY IN MODEL DEVELOPMENT

The model of the house was developed in of two parts: structural modification and parameter adjustment. When adjustment of the parameters in the initial model failed to yield acceptable results, structural modification was made with further adjustment of the parameters in the next model. The process repeated until the calculated results came close to the field measured ones.

The structural modification were aimed at modelling air flow in the staircase and radon entry from the soil while the parameter adjustment focused on the characteristics of the cracks linking the house with soil.

General Features of Radon Distribution Pattern

The article (Wang et al. 1995) discusses the results of the field measurement and outline the general features of the radon distributions varying with the air change rate in the cellar. The features can be summarised as follows .

In the cellar, the radon levels were higher in de-pressurisation than those in pressurisation; The radon level rose as the speed of extracting fan slowed down and reached the maximum when the fan was running at speed 3 de-pressurisation. As the fan was slowed further, the radon level dropped the extracting was weak compared to stack effect. It decreased continuously in natural ventilated condition and pressurised condition as more outdoor air was introduced into cellar.

In the living areas, the average concentration levels were lower in extracting ventilation than with supplying ventilation, when fan was running at same speed. All seven rooms monitored were almost evenly polluted.

Interestingly, the average levels in living areas were higher than those in the cellar in pressurisation.

Basic Assumption

An assumption suggested in the article was that there were other routes for radon entry into the house beside the one into cellar (dashed lines in figure 1). The measured results can be reasonably interpreted with this assumption and the model could be developed on this basis. The simulation with final model also supports the assumption, which will be discussed later.

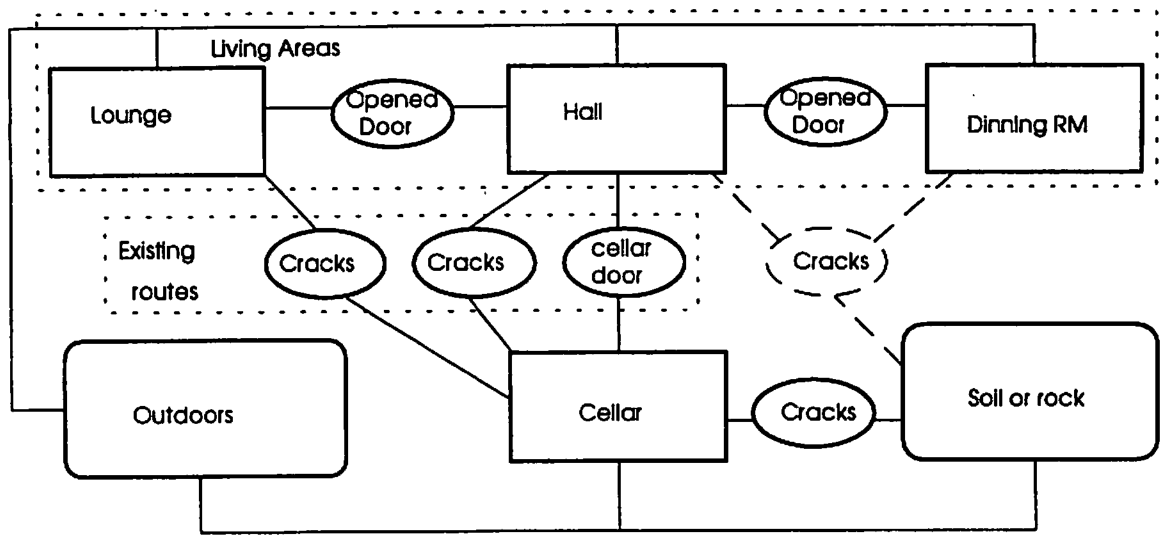


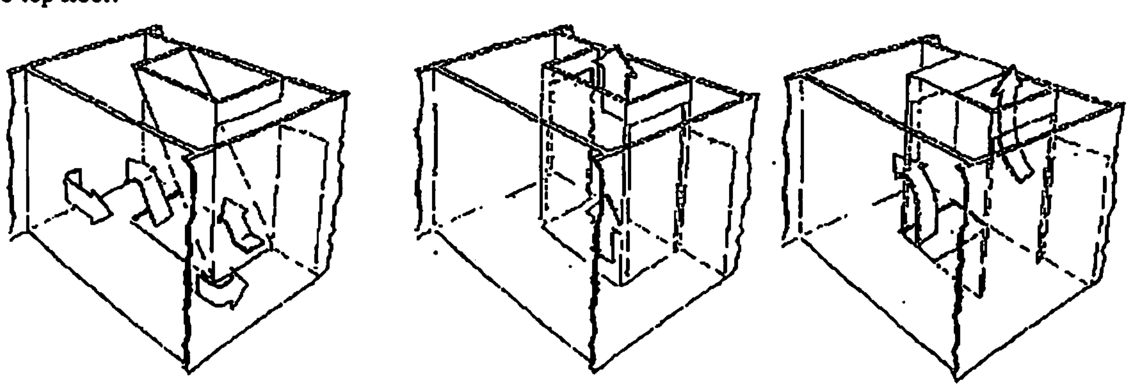
Fig. 1 Schematic diagram of the air flow routes between the cellar and rooms on ground floor. The solid lines and ovals represent the air flow routes while the dished denote the possible air flow routes proposed by the assumption.

MODEL DEVELOPMENT

Staircase Modelling

In the new geometry, instead of one single shaft linking all floors, three shafts were created. Each linked only two neighbouring floors. The air came out through the door when it reached the top of each shaft, then went via the landing into the door at the bottom of next shaft, finally arrived at the top floor(fig. 2c). If the travelling air flow carried radon, it polluted the landings and hence polluted other rooms on the floor by either wind disturbance or stack effect.

The route for vertical air movement in new model can be seen more clearly in figure 4. The air went from the cellar into shaft 1 which connected with shaft 1 on ground floor, then came out through the closed door. Via the hall into shaft 2 on the floor. The air then went up through shaft 2 linking ground floor with the first floor. On the first floor, the air turned out from the shaft door to the landing then went into the door of shaft 3 leading finally to top floor.



a) Staircase and landing b) Single shaft in the old model c) Two shafts in new model

Fig. 2 One section of Staircase on middle floor of the house. One single shaft in old model, in which air flow passing through that floor. Two shafts linking other floors separately.

Crack linking the Cellar with Outdoors

The crack (C8 in fig. 3) represents the leakage on the cellar's walls to outdoors. The crack provided an easier air inlet for a de-pressurised cellar than the perimeter crack of the cellar door, where the stack effect created lower pressure outside the door. Without the crack, there would be a lower pressure with same power setting of extracting fan, thereby the radon level would vary in a larger range than observed in the field measurement when the fan changes from full power de-pressurisation to full power pressurisation.

Cracks linking living Areas and Radon Source

At least one route for radon entry into cellar should be created in the model. It was the crack (C4 in fig. 3) linking cellar with soil. Through it there was an air flow, which depended on differential pressure. It may enter the cellar from soil with radon or from the cellar into soil.

Based on the assumption, other routes (C2 and C3 in fig. 4) were added in later structural modification.

Single Dummy Cell

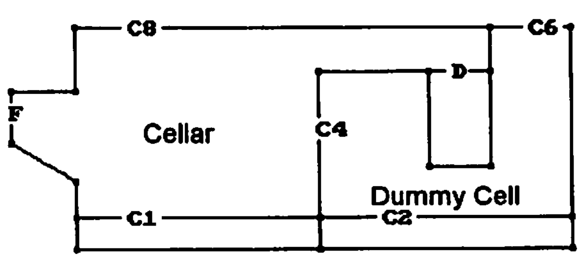
In order to simulate radon feeding rate that depended on differential pressure, next to the cellar, a dummy cell was added, in which the feeding was constant. It had two air paths, one is crack linking it with outdoors and the other with the cellar.

When the cellar was being de-pressurised, air with radon in dummy cell would be sucked in to the cellar and when it was being pressurised, the fresh air flow went from cellar into the dummy cell and resisted the radon entry to the cellar. During the de-pressurisation, radon entry rate depended on the radon level in the dummy cell, area of the crack, and pressure difference between these two cells.

This model gave a good results bearing some basic features mentioned above. Pressurisation prevented the radon into cellar but pushed the radon in the dummy entering living areas via the crack linking dummy cell with the hall. This resulted in a higher radon level in living area than that of cellar.

The model, however gave some unreasonable calculation as well. The radon level in the dummy cell is too sensitive to power change of the fan system so that it decreased dramatically when the fan was extracting at full power. This resulted in a lower radon level in cellar than the level when the fan was working in low power. Although a small decrease was normal according to the modelling of Loureiro if the soil permeability was high, a drop of 75% calculated by model seemed too much to be accepted.

The reason is quite clear. all cells in BREEZE are free space for air movement, no pressure and concentration gradient. Hence the model with a single dummy cell can not simulate precisely the radon gas from soil underneath building. Further modification is necessary.



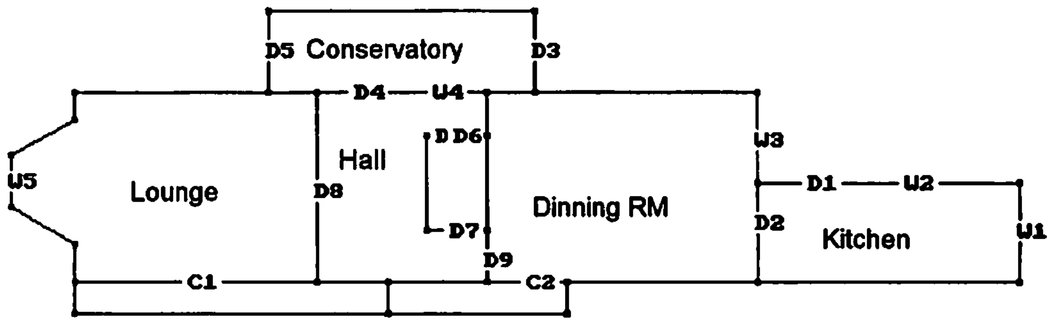


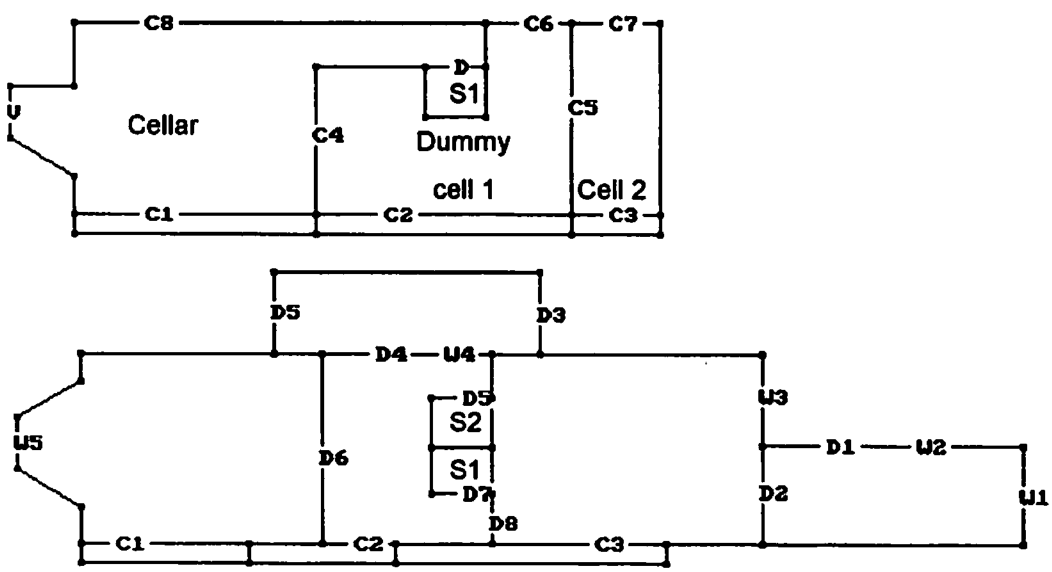
Fig. 3 Plans of floor one and two in the model with single dummy cell.

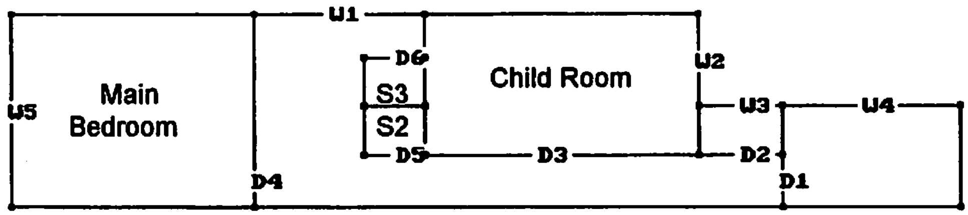
<u>Two Dummy Cells</u>

The aim of adding another dummy cell was to create a block representing the soil and possessing the relevant characteristics, such as unevenly distributed pressure and radon concentration. In these two cells there were differences of radon concentration and pressure which were, to some extend like the gradients of both concentration and pressure. A crack (C5 in fig. 4) linking the two dummy cells kept the concentration and pressure relatively steady in cell 2 while that in cell 1 relyed on the pressure in the cellar.

Dummy cell 1 represented the soil adjacent to the cellar. The radon could be sucked into the cellar when the fan worked in de-pressurisation and pushed up to living areas and outdoors during pressurisation.

The other one, dummy cell 2 released radon gas for living area all the time, due to house depressurisation. The amount of radon entry depended on the pressure in the cellar. More radon entered living areas in pressurisation and less in de-pressurisation. The cell also supplied radon for dummy cell 1, where radon was diluted in de-pressurisation by incoming fresh air from crack 6 (see fig. 4).





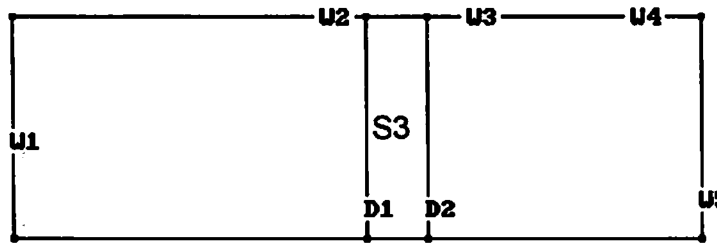


Fig. 4 The floor plans of the model with two dummy cells.

Constant Feeding Rate in Cellar

As it has been confirmed by other research(2), as well as radon entering houses drawn by differential pressure from soil, radon entering by difusion is independent on pressure difference. In the new model, about 5% of total feeding rate were set in the cellar and did not vary with the difference pressure. Hence even when the fan was running at full power pressurisation, there was radon in the cellar, which was confirmed in the measurement.

MODELLING, COMPARISION AND DISCUSSION

Modelling

The wind direction was SW, the dominant direction during the field measurement. The speed for modelling was 0.5 m/s to represent the average effect during the days.

The ambient temperature was 5 °C while indoor temperatures were 10, 18, 16 and 16 °C in the cellar, ground floor, the first floor and top floor respectively. The rooms with regular occupancy were set to gain 100 watt heat, two bedrooms on top floor were set to 10 watts. The heat gain created a stack effect resulting in air passing through a large opening like doors, hence the contaminant tends to be evenly distributed in both sides of the opening.

All external windows and door were closed and all internal doors were fully open except the cellar door (D7 on ground floor in fig. 4).

The feeding constants were 300, 400, 6000 in the cellar, dummy cell one and dummy cell two respectively.

The parameters for cracks linking radon sources with living areas were as follows;

C2	exponent 1.0;	crack length=1.0;	Crack constant=0.0001
C3	exponent 1.0;	crack length=1.0;	Crack constant=0.0001

The crack linking with the cellar;
C4 exponent 1.0; crack length=20.0; Crack constant=0.0001

It was difficult to estimate correctly the values of other parameters , such as crack constants, free areas on external doors and windows, contaminant feeding coefficients and so on. Some data were collected from ASHRAE Handbook, some by visual estimation in the house and others were from parameter adjustment with a vast combination of possible values.

Modelling under seven typical conditions were natural ventilation, full, medium and low power de-pressurisation and full, medium and low power pressurisation.

Comparison

The modelling results show all the features mentioned in section 2.1. This can be easily seen from the curves of radon level vs. air change rate. We compared to sets of data, the level in the cellar and the average level in living areas.

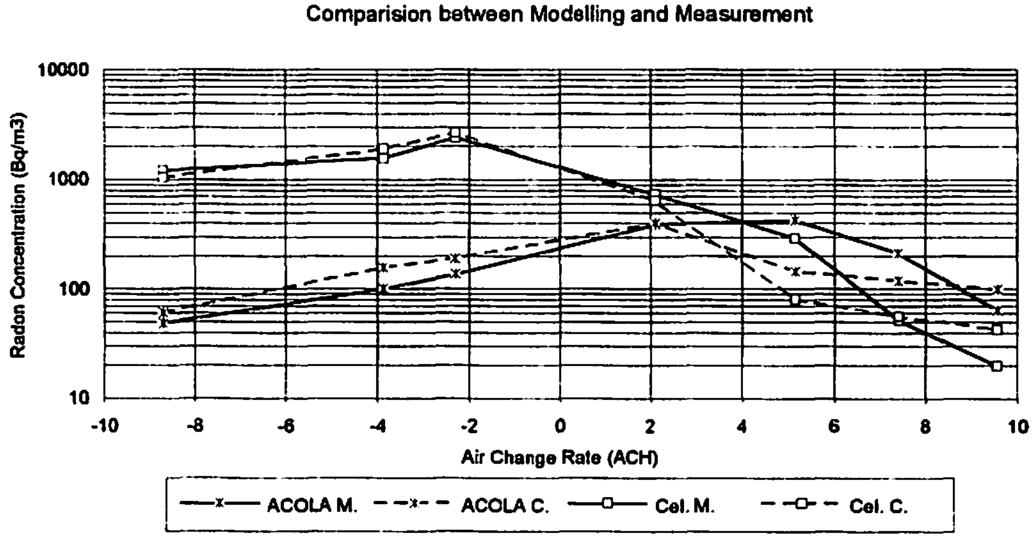


Fig 4.1 Comparison between measured results and modelling on Curves of Radon level vs. air change rate.

In table 1 we list some results from both field measurement and calculation based on the new model. We compared the calculated radon levels in seven rooms of the house with their measured correspondents. We found the consistency was good in general. Of 53 pairs of data, 10 standard deviations were less than 10%; 19 deviations were less than 20%; 27 less than 50%, and 7 had extreme values.

Table 1, The comparision between measured results and modelling

	Cel. Meas.	Cel. Cal.	Loun Mea	Cal	Hall Meas	Cal	Din Meas	Cal	Main Meas	BR Cal	ChRM Meas	Cal	BR Mea		ACOLA Meas	cal
-8.7	1200	1041	45	113	43	138	40.5	138	48	0	53.8	0	64.5	0	49	61
-3.9	1572	1904	86	186	138	218	86	218	141	120	91	119	220	112	101	157
-2.3	2432	2680	111	214	135	251	0	251	0	157	0	156	156	152	138	191
2.1	737	646	453	383	369	386	486	438	378	378	333	370	334	375	390	401
5.2	294	81	519	143	427	144	453	182	433	135	346	135	371	134	429	146
7.4	52	56	177	96	208	97	200	127	208	94	179	94	258	95	212	119
9.6	20	43	48.7	71	72	72	36	95	80.7	71	72	71	51.5	70	64	100

Discussion

The causes of the deviation may consists of three types, deviation of measured values, estimated parameters used in the model and the simplification of the model.

The field measurement has it own deviation. In addition to the deviation from the simultaneous monitoring, the monitor gave about 10% to 50% variation to each reading. Estimated parameters might be quite different from the real ones, particularly those from model adjustment. The most obvious cause should be the simplified structure of model itself. The two dummy cells can not represent exactly the soil underneath the house.

CONCLUSION

On the whole, the trial of developing a new model is worthwhile. The improvement is remarkable comparing to the initial model with BREEZE. The work shows that it is possible to use a existing computer code to study a ventilation strategy before real application.

The way of staircase modelling could be applied in other contaminant movement and dispersion modelling.

There is another application of the model is to examine if cellar pressurisation in one house will affect its neighbours. Because the study has shown that the pressurisation in cellar might push radon gas in adjacent soil into other rooms on ground floor. This may raise problem in other rooms of semidetached houses or terrace houses.

ACKNOWLEDGEMENT

The research was supported by BRE (Building Research Establishment*). The encouragement and comments from Mr. Martin Smith, BRE on the initial idea of new model is acknowledged. He also suggested to use the value 1.0 for the exponent of cracks linking the dummy cell with others.

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