II 6

BREVENT - A VENTILATION MODEL

R.P. Hartless
Building Research Establishment, Garston, Watford, WD2 7JR, UK.

The Building Research Establishment (BRE) has developed a theoretical model, BREVENT, to predict the ventilation rate for a dwelling represented by a single zone. It can be used to model extract fans, vertical ducts (passive stack ventilation), windows and other openings, and a separate subfloor void. Alternatively, it can function as a model of infiltration only. The uses of BREVENT are numerous, and two of its possible applications are described in this paper: developing simple relationships between the infiltration flow rate of a dwelling and the leakage of its envelope at 50Pa, and calculating the change in radon levels in dwellings in order to assess radon remedial measures.

1. INTRODUCTION

This paper describes a model, BREVENT, for predicting the ventilation rate of a dwelling under specified meteorological conditions, given its leakage characteristics and the characteristics of its immediate surroundings. BREVENT can be used as a simple single zone model, and is used here to explore the relationship between the typical infiltration rate of a dwelling and the leakage measured in fan-pressurisation tests. It has been adapted to provide a two-zone model, representing a ventilated subfloor void. The paper uses this to assess the effect of various options for reducing indoor radon levels. Other applications not explored in detail here include the evaluation of mechanical and natural ventilation devices.

2. INFILTRATION MODEL

Air can enter a dwelling through a multitude of paths, cracks around doors and windows for example. The overall airtightness of a dwelling can be measured by the fan-pressurisation method and BRE have produced a recommended procedure for taking such measurements (1). The volume flow rate of air, obtained from a series of pressure differences, can be fitted to a power law:

$$Q = Q_T(\Delta P/\Delta P_T)^n \qquad ....(1)$$

Q is the volume flow rate at an applied pressure difference ΔP. Q_T is the volume flow rate at an arbitrarily chosen reference pressure difference ΔP_T (in this case 50Pa, following International Convention): it is a convenient measure of the leakiness of a dwelling. The flow exponent, n, generally lies in the region 0.5 to 0.7, with a mean of approximately 0.6.

The infiltration flow rate, Q_V, of a dwelling is a function of wind speed, U, the difference between internal and external air temperature, ΔT, and wind direction. The BREVENT infiltration model represents the dwelling by a single (cuboid) zone of height h, and aims to relate Q_V to Q_T by including these key variables. This is achieved by extrapolating equation (1) to the lower pressures generated by the wind and temperature difference (stack effect). The other assumptions behind the model and a full derivation of the flow equations can be found in a paper by Warren and Webb (2). As part of an IEA task (3) the predictions of the BREVENT infiltration model (as well as several other models) were tested against measurements made in three different houses. Averaged over the three houses, 83% of the BREVENT predictions were within 25% of the measurement.

From this infiltration model Warren (4) proposed a simple equation which relates Q_V for a dwelling to meteorological conditions:

$$Q_V = Q_T\{[\beta^2.F_B{}^2.(\Delta T)^{2n}] + [\gamma^2.F_W{}^2.U^{4n}]\}^{\frac{1}{2}} \qquad ....(2)$$

$\beta = (\rho.g.h/\Delta P_T.T_I)^n$
$\gamma = (\rho/\Delta P_T)^n$
F_B = Infiltration rate function (stack dominated infiltration)
F_W = Infiltration rate function (wind dominated infiltration)
ρ = External air density (kg/m³)
g = Acceleration due to gravity (m/s²)
T_I = Internal temperature (K)

F_B is a constant for a particular dwelling and is determined by its shape and the distribution of leakage among the exposed external surfaces; F_W in addition depends upon the surface pressure coefficients which in turn depend upon the shape of the dwelling, its surroundings and the wind direction. Warren and Webb (2) and Warren (4) show how values of F_B and F_W may be calculated.

Using equation (2) and substituting average values for U and ΔT it is possible to produce an even simpler expression for estimating average infiltration:

$$Q_V = (Q_T/K) \qquad ....(3)$$

The divisor, K, is a constant which can be computed for a range of parameters, including dwelling type, location and density of surrounding buildings.

Using BREVENT a series of values of K were calculated for a typical UK detached house. An arbitrary Q_T was distributed around the exposed external surfaces of the dwelling on an area-weighted basis. Three different flow exponents were used: 0.5, 0.6 and 0.7. Pressure coefficient data for a series of surrounding housing densities (defined as the ratio of the plan area of the dwelling to the area of the immediate surroundings) were taken from BRE wind tunnel measurements made on housing models. As a first step values for F_B and F_W (averaged over all wind directions) for the house were calculated and these were then used in equation (2) with average UK values for the meteorological data, in this case: $U=3.5m/s$ and $\Delta T=12°C$ ($T_I=293K$). These data represent the winter months when variable openings such as windows and doors are closed and infiltration dominates. The results are given in Table 1.

When all the results are averaged, K has a value of about nineteen which agrees with the rule that states that the ratio between the average air infiltration and the air leakage measurement of a dwelling at 50Pa is twenty (5). But there are large variations of F_W with wind direction, housing density and flow exponent. Table 1 is useful in that it gives a range of values of K for predicting Q_V from Q_T for a detached house for a variety of surroundings. This is important when assessing the balance between airtightness (a tighter house will have reduced ventilation heat losses) and indoor air quality.

Repeating this procedure for a semi-detached house again gives an average value for K of nineteen. A similar exercise for a large building represented by a single zone (dimensions: 50m x 50m x 50m) gave a value for K of about ten, although the quantity of data was limited by the lack of suitable pressure coefficient data.

TABLE 1. BREVENT Predictions for a Detached House.

	n=0.5			n=0.6			n=0.7		
Housing density (%)*	F_W	F_B	K	F_W	F_B	K	F_W	F_B	K
0	0.12	0.26	8.1	0.17	0.23	10.8	0.15	0.21	14.3
5	0.15		9.9	0.13		13.9	0.11		19.1
10	0.12		11.6	0.09		17.0	0.07		24.6
20	0.09		13.4	0.06		20.3	0.05		30.5
25	0.07		14.4	0.05		22.0	0.04		33.5
30	0.05		15.5	0.04		23.8	0.03		36.3

Average value of K (All n) = 18.8 ± 8.0
Average value of K (n=0.6) = 18.0 ± 4.5

*0% density represents an isolated house, 30% a house in a dense urban environment.

3. THEORETICAL ASSESSMENT OF RADON REMEDIAL MEASURES IN HOUSES

An indoor pollutant that has been identified in recent years is naturally occurring radioactive radon gas. In this model the indoor radon concentration is related to a 'Radon Parameter', RP, which is calculated from ventilation rates, air flow through the floor and the difference in pressure between soil gas and air within the dwelling (the level of 'depressurisation' of the dwelling). These are all output variables of BREVENT. Using BREVENT we can examine two house types, one with a suspended timber floor (two zone model) and the other with a concrete floor without a void beneath (one zone model).

Extending the model of Mowris and Fisk (6) with the principal assumptions of well mixed zones at steady-state, pressure driven flow of radon dominating over diffusion, and removal of radon by ventilation dominating over removal by its decay, the indoor radon concentration, Rn_i (Bq/m^3), can be expressed (for the two zone model) as:

$$Rn_i = Rn_o + k.(Q_f.|\Delta P_f|/\lambda_i.\lambda_f) = Rn_o + k.RP \qquad ....(4)$$

Rn_o = Ambient radon concentration (Bq/m^3)
Q_f = Volume flow rate of air through the floor (m^3/hr)
ΔP_f = Pressure diff. between soil gas and air in the subfloor void (Pa)
λ_f = Ventilation rate of the subfloor void (m^3/hr)
λ_i = Ventilation rate of the dwelling (m^3/hr)
k = A constant
RP = Radon Parameter

ΔP_f is the pressure difference that is actually drawing the radon into the subfloor void of the dwelling. With the one zone model i.e. no subfloor void, the form of equation (4) remains the same but the radon parameter simplifies to $|\Delta P_i|/\lambda_i$, where ΔP_i is the pressure difference between the soil gas and air in the dwelling.

This model does not predict actual indoor radon concentrations because the constant, k, represents many different factors such as soil type, radon source strength etc. and calculating a value for it is not straightforward. But the model does estimate removal of radon (by ventilation) and it calculates the driving force for radon entry (by pressure driven flow). Therefore the effect of radon remedial measures such as additional ventilation and floor tightening can be assessed by calculating the change in the radon parameter.

A remedial measure may aim to remove radon by increasing the ventilation rate in either the subfloor void or the dwelling itself, or limit entry of the gas through the floor by some form of floor tightening. But a higher ventilation rate in a dwelling can increase the radon entry rate because the possible resulting pressure drop will draw more radon into the dwelling. On the other hand increasing the pressure in the house with respect to the soil gas will limit radon entry but the risk of interstitial condensation may have to be considered. It is acknowledged that validation of models using experimental data will be essential before confidence can be placed in particular remedial measures.

TABLE 2. Radon Parameters for a House with a Suspended Timber Floor

Airbrick Area (mm^2/m)	Floor Type	Housing density		
		0%	10%	20%
200	A	30	82	75
	B	33	65	48
1000	A	27	55	44
	B	14	30	21
3000*	A	16	40	23
	B	5	11	9

*Area recommended by UK Building Regulations for adequate ventilation beneath suspended timber floors to control water vapour.

(All values of RP have been multiplied by 10^4.)

TABLE 3. Radon Parameters for a House with an Extract Fan

Envelope leakage at 50Pa, Q_T (ach)	Housing density					
	0%		10%		20%	
	off	on	off	on	off	on
5	411	349	274	237	256	230
15	137	137	91	86	85	81

off = fan off
on = fan on

For the two zone model (dwelling with a suspended timber floor) two remedial measures were examined: floor tightening with increased natural ventilation of the subfloor void (extra air-bricks), and a powerful subfloor extract fan. The results are given in Table 2. (Air-brick area is mm^2 per metre of wall, floor type A is an unsealed timber floor and floor type B is draught-stripped.) The results show that, in this case, tightening the floor and increasing natural ventilation in the subfloor void will reduce indoor radon levels by a factor of about seven. The floor tightening used here is just simple draught-stripping (sealing skirting gaps); obviously, incorporating a continuous plastic sheet within the floor construction would be expected further to reduce indoor radon levels.

The second remedial measure, a powerful extract fan situated in the subfloor void, appeared to be extremely successful in decreasing indoor radon levels. In fact the fan was able to reverse the direction of the flow through the floor, Q_f, so that it was from the dwelling to the subfloor void. This was true for all wind speeds and temperature differences modelled. Therefore, any radon present in the subfloor void cannot be carried up into the dwelling. It is emphasised that this result may not be achievable in practice at reasonable flow rates because of leakage into the subfloor space, and that floor heat losses would increase in wintertime. It is intended to compare these predictions against experimental data within the next phase of the work.

One final remedial measure that was assessed was an extract fan in a house without a ventilated void (single zone). These results are given in Table 3. They show that an extract fan, such as might be found in a kitchen, is not suitable for reducing indoor radon levels. Although the fan will increase the ventilation rate (removing radon) the pressure difference between air in the soil and that in the dwelling is increased resulting in an increased radon entry rate.

4. CONCLUSIONS

BREVENT can be used for predicting infiltration rates in dwellings from pressurisation measurements and for assessing the effectiveness of radon remedial measures. For a house with a suspended timber floor the model predicts that indoor radon levels can be reduced by a factor of seven by tightening the floor and increasing ventilation openings. An extract fan in a dwelling does not appear to reduce indoor levels unless it is situated in a subfloor void.

Many other uses are planned for BREVENT including modelling of passive stack ventilation in dwellings, and it will be used in conjunction with indoor air quality and BRE domestic energy models. BREVENT is in a 'user-friendly' form and makes extensive use of on-line help, error trapping and graphics. Validation exercises carried out so far are encouraging and these include the comparison of predicted subfloor ventilation rates with experimental measurements (7). Further validation exercises are planned.

REFERENCES

(1) Stephen,R.K., Determining the airtightness of buildings by the fan-pressurisation method: BRE recommended procedure. BRE Occasional Paper, August 1988.

(2) Warren,P.R. and Webb,B.C., The relationship between tracer gas and pressurisation techniques. Proc. First Air Infiltration Centre Conference "Infiltration measurement techniques". Windsor, UK. 1980.

(3) Liddament,M. and Allen,C., The validation and comparison of mathematical models of air infiltration. AIC-TN-11-83, 1983.

(4) Warren,P.R., A simple method for predicting infiltration rates in housing. Proc. Building Research Scientists CIB W67 Conference. Dublin, UK. March 1982.

(5) Dubrul,C., 'Inhabitants' behaviour with regard to ventilation. AIC-TN-23-88, 1988.

(6) Mowris,R.J. and Fisk,W.J., Modelling the effects of exhaust ventilation on ^{222}Rn entry rates and indoor ^{222}Rn concentrations. Health Physics, Vol.54, No.5, pp.491-501, May 1988.

(7) Edwards,R.E., Hartless,R.P. and Gaze,A., Measurements of subfloor ventilation rates - Comparison with BREVENT predictions. 11th AIVC Annual Conference, Italy, September 1990 (to be published).