The Role of Ventilation
15th AIVC Conference, Buxton, Great Britain
27-30 September 1994

The Mechanical Ventilation of Suspended Timber Floors for Radon Remediation - A Simple Analysis

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Building Research Establishment PD208/94

THE MECHANICAL VENTILATION OF SUSPENDED TIMBER FLOORS FOR RADON REMEDIATION - A SIMPLE ANALYSIS

By M Woolliscroft

SUMMARY

Mechanical ventilation of the underfloor space is one of the most effective ways of reducing radon levels in buildings with suspended timber floors. There is a question however whether this ventilation should be supply or extract, sometimes extract is more effective, sometimes supply is more effective. This report presents a simple analysis of the problem and suggests the hypothesis that the relative effectiveness of supply or extract ventilation to the underfloor space depends on the relative airtightness of the floor and the soil or oversite surface. The analysis suggests that if the floor is relatively tight then supply ventilation may be more effective whereas if the floor is relatively leaky or there is oversite concrete then extract may be better. It is suggested that in either case it is better to keep the underfloor pressure low and that when mechanical ventilation is provided to the underfloor space it may be necessary to increase the number of airbricks.

This paper is to be submitted to the AIVC Conference September 1994

July 1994

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THE MECHANICAL VENTILATION OF SUSPENDED TIMBER FLOORS FOR RADON REMEDIATION

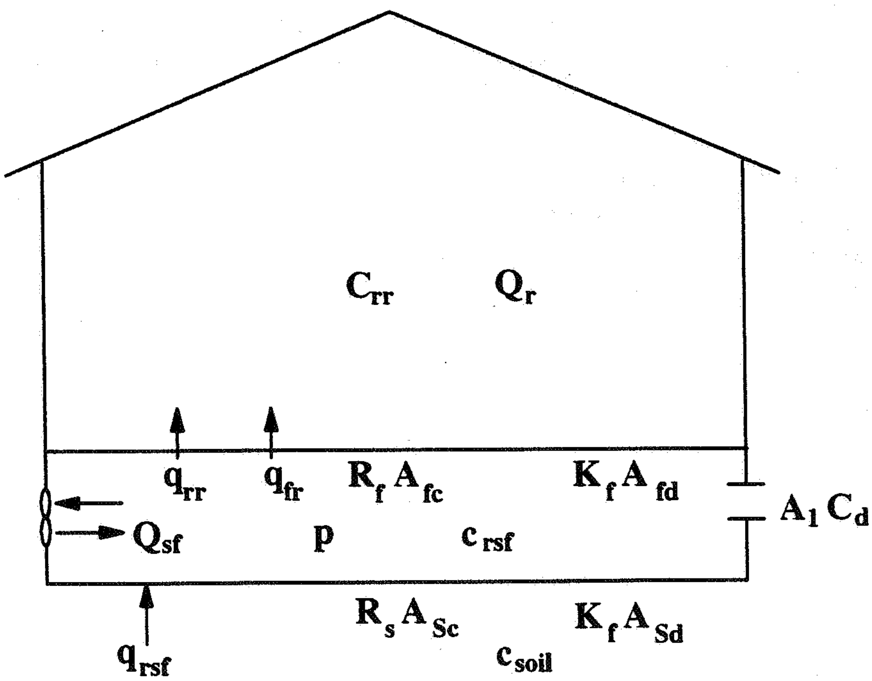
A note on the merits of Extract v Supply Ventilation.
by M Woolliscroft

INTRODUCTION

Mechanical ventilation of the underfloor space is generally one of the most effective ways of reducing radon levels in buildings with suspended timber floors. Where there is no concrete oversite it is often the only way. There is a question however whether this ventilation should be extract or supply. Whilst extract from the underfloor space will reverse the pressure gradient across the floor thus preventing radon laden air from entering the room it will also draw more radon in from the soil thus increasing the radon concentration in the underfloor space thus any radon which does get into the room will be of higher concentration. On the other hand supply ventilation by reversing the pressure gradient across the soil will prevent radon from getting into the underfloor space but any radon which does get into the underfloor space will be blown into the room. The purpose of this note is to try to determine analytically a broad outline for the conditions under which either supply ventilation on the one hand or extract ventilation on the other is the optimum solution.

THE ANALYTICAL MODEL

The simplified analytical model is shown diagrammatically in figure 1 below. Flow may be extract or supply.



SYMBOLS

p	is the pressure in the underfloor space with respect to outside
ρ	is the density of air
q_{rsf}	is the radon flow rate from the soil to the underfloor space
c_{soil}	is the radon concentration in the soil
K_s	is a diffusion flow constant soil to underfloor space. A diffusion flow constant $K = \frac{D}{L}$ has been defined where D is the diffusion coefficient, because although the characteristic length L is easy to define in the case of the floor (thickness of boards), it is more difficult to define in the case of the soil.
A_{sd}	is the flow area of the soil to diffusion
A_{sc}	is the flow area of the soil to pressure driven flow
c_{rsf}	is the radon concentration in the underfloor space
Q_{sf}	is the fan supply or extract rate to the underfloor space
A_1	is the opening area to the underfloor space
C_d	is the discharge coefficient of the air inlet/outlet to the underfloor space
q_{rr}	is the radon flow rate from the underfloor space into the room
K_f	is a diffusion flow constant for flow from the underfloor space to the room
A_{fd}	is the flow area of the floor to diffusion
A_{fc}	is the flow area of the floor to pressure driven flow
c_{rr}	is the radon concentration in the room
Q_r	is the ventilation flow rate in the room
R_s	is the flow resistivity of the soil
R_f	is the flow resistivity of the floor
q_{fr}	is the airflow rate from the underfloor space into the room

In the case of extract ventilation the process assumed is that radon enters the underfloor space under pressure driven flow from the soil. It is then diluted by the ventilation of the underfloor space but some radon enters the room by diffusion. Where pressure driven flow exists across a boundary diffusion flow is assumed to be much smaller and is ignored.

In the case of supply ventilation of the underfloor space radon is assumed to enter the underfloor space by diffusion from the soil. It is then diluted in the underfloor space and radon at a lower concentration is then blown into the room through cracks in the floor by pressure driven flow. Flows are taken to be steady state throughout.

EXTRACT

$$p = -\tfrac{1}{2}\,\rho\left(\frac{Q_{sf}}{A_1 C_d}\right)^2 \qquad (1)$$

$$q_{rsf} = \frac{-pA_{sc}}{R_s}\cdot c_{soil} \quad \text{pressure driven flow from soil to underfloor space} \qquad (2)$$

assuming flow is laminar i.e. Darcy

substituting equation (1) in (2)

$$q_{rsf} = \tfrac{1}{2}\rho \left(\frac{Q_{sf}}{A_1 C_d}\right)^2 \frac{A_{sc}}{R_s} \cdot c_{soil} \qquad (3)$$

By definition

$$c_{rsf} = \frac{q_{rsf}}{Q_{sf}} \qquad (4)$$

assuming that the ambient radon level C_o is relatively small and that $q_{rsf} << Q_{sf}$ i.e. the flow of radon gas is much less than the underfloor ventilation rate.

Substituting equation (3) in (4)

$$c_{rsf} = \tfrac{1}{2}\rho \; \frac{Q_{sf}}{A_1^2 C_d^2} \cdot \frac{A_{sc}}{R_s} \cdot c_{soil} \qquad (5)$$

Diffusion across the floor (It is assumed that flow of radon across the floor in the extract case is by diffusion only because the pressure gradient is negative)

$$q_{rr} = K_f A_{fd} \; (c_{rsf} - c_{rr}) \qquad (6)$$

By definition

$$c_{rr} = \frac{q_{rr}}{Q_r} \qquad (7)$$

again assuming that the ambient radon level C_o is relatively small

eliminating q_{rr} between equations (6) and (7)

$$Q_r \; c_{rr} = K_f A_{fd} (c_{rsf} - c_{rr}) \qquad (8)$$

hence

$$c_{rr} = \frac{K_f \; A_{fd} \; c_{rsf}}{Q_r + K_f \; A_{fd}} \qquad (9)$$

substituting for c_{rsf} from equation (5)

$$\underset{extract}{c_{rr}} = \frac{K_f A_{fd} \; \tfrac{1}{2}\rho \frac{Q_{sf}}{A_1^2 C_d^2} \cdot \frac{A_{sc}}{R_s} \cdot c_{soil}}{Q_r + K_f A_{fd}} \qquad (10)$$

SUPPLY

Flow into underfloor space by diffusion

$$q_{rsf} = K_s A_{sd} \, (c_{soil} - c_{rsf}) \tag{11}$$

By definition

$$c_{rsf} = \frac{q_{rsf}}{Q_{sf}} \tag{12}$$

substituting (12) in (11)

$$q_{rsf} = K_s A_{sd} (c_{soil} - \frac{q_{rsf}}{Q_{sf}}) \tag{13}$$

rearranging

$$q_{rsf} \, (\frac{1}{K_s A_{sd}} + \frac{1}{Q_{sf}}) = c_{soil} \tag{14}$$

$$\therefore \; q_{rsf} = c_{soil} \, (\frac{K_s A_{sd} \, Q_{sf}}{K_s A_{sd} + Q_{sf}}) \tag{15}$$

substitute (15) in (12)

$$c_{rsf} = \frac{c_{soil} \, \frac{K_s A_{sd} \, Q_{sf}}{K_s A_{sd} + Q_{sf}}}{Q_{sf}} \tag{16}$$

$$= c_{soil} (\frac{K_s A_{sd}}{K_s A_{sd} + Q_{sf}}) \tag{17}$$

Flow into room by pressure

$$p = ½\rho \, (\frac{Q_{sf}}{A_1 C_D})^2 \tag{18}$$

The pressure is assumed uniform throughout the underfloor space.

The house will generally be at a pressure lower than atmospheric. Therefore the pressure difference between the underfloor space and the house will be greater than p say γp where $\gamma \geq 1$

assume flow is laminar

$$\text{then } q_{fr} = \gamma \frac{p \cdot A_{fc}}{R_f} \qquad (19)$$

substituting equation (18) into (19)

$$\text{then } q_{fr} = \gamma \tfrac{1}{2} \rho \left(\frac{Q_{sf}}{A_1 C_d}\right)^2 \cdot \frac{A_{fc}}{R_f} \qquad (20)$$

Flow of radon is airflow x concentration

$$\therefore \; q_{rr} = q_{fr} \cdot c_{rsf} \qquad (21)$$

substituting (20) in (21)

$$q_{rr} = \gamma \tfrac{1}{2} \rho \left(\frac{Q_{sf}}{A_1 C_d}\right)^2 \cdot \frac{A_{fc}}{R_f} \, c_{rsf} \qquad (22)$$

substituting for c_{rsf} from equation (17)

$$q_{rr} = \gamma \tfrac{1}{2} \rho \left(\frac{Q_{sf}}{A_1 C_d}\right)^2 \cdot \frac{A_{fc}}{R_f} \, c_{soil} \left(\frac{K_s A_{sd}}{K_s A_{sd} + Q_{sf}}\right) \qquad (23)$$

$$\text{By definition } C_{rr} = \frac{q_{rr}}{Q_r} \text{ again assuming } q_{rr} << Q_r$$

$$\therefore C_{rr\,supply} = \gamma \tfrac{1}{2} \rho \left(\frac{Q_{sf}}{A_1 C_d}\right)^2 \cdot \frac{A_{fc}}{R_f} \, \frac{C_{soil}}{Q_r} \left(\frac{K_s A_{sd}}{K_s A_{sd} + Q_{sf}}\right) \qquad (24)$$

Let us now look at the ratio of the room radon concentration for supply compared with that for extract.

$$\frac{C_{rr}\ supply}{C_{rr}\ extract} = \frac{\gamma \frac{1}{2}\rho \left(\frac{Q_{sf}}{A_1 C_d}\right)^2 . \frac{A_{fc}}{R_f} . \frac{C_{soil}}{Qr} \left(\frac{K_s A_{sd}}{K_s A_{sd} + Q_{sf}}\right)}{K_f A_{fd}\ \frac{1}{2}\rho \frac{Q_{sf}}{A_1^2 C_d^2} . \frac{A_{sc}}{R_s} . \frac{1}{Q_r + K_f A_{fd}} . C_{soil}} \tag{25}$$

Now pressure driven flows are >> diffusion flow thus $Q_{sf} >> K_s A_{sd}$., $Q_r >> K_f A_{fd}$.

$$\therefore \frac{C_{rr}\ supply}{C_{rr}\ extract} = \frac{\gamma \left(\frac{Q_{sf}}{A_1 C_d}\right)^2 . \frac{A_{fc}}{R_f} . \frac{K_s A_{sd}}{Q_r . Q_{sf}}}{K_f A_{fd} \frac{Q_{sf}}{A_1^2 C_D^2} . \frac{A_{sc}}{R_s} . \frac{1}{Q_r}} \tag{26}$$

$$= \gamma \frac{K_s}{K_f} \frac{R_s}{R_f} . \frac{A_{fc}}{A_{fd}} \frac{A_{sd}}{A_{sc}} \tag{27}$$

Let us assume for the moment that $A_{fc} = A_{fd}$ and $A_{sd} = A_{sc}$. Now $K \propto \frac{1}{L}$ and $R \propto L$, which will be true for a given crack width

Thus

$$K \propto \frac{1}{R} \tag{28}$$

$$Thus \quad \frac{K_s}{K_f} = \frac{R_f}{R_s} \tag{29}$$

$$thus\ \frac{C_{rr}\ supply}{C_{rr}\ extract} = \gamma \geq 1 \tag{30}$$

Thus we might expect extract ventilation of subfloor spaces to be more effective than supply. This agrees with the generally accepted wisdom, Henschel (Ref 1). However we have had practical cases where supply ventilation is more effective than extract. Diffusion flow of radon is not overwhelmingly through the same cracks as convective flow; diffusion through concrete for example can be significant, Rogers and Nielson (Ref 2). Rogers and Nielson also state that for concrete, diffusion flow through the slab is much greater than advection through the slab. The same may be true for timber. Thus it is entirely possible that $A_{fd} > A_{fc}$.

$$\text{thus } \frac{C_{rr} \text{ supply}}{C_{rr} \text{ extract}} = \gamma \frac{A_{fc}}{A_{fd}} \text{ assuming } \frac{A_{sd}}{A_{sc}} = 1 \tag{31}$$

$$\text{If } \frac{A_{fd}}{A_{fc}} > \gamma \text{ then } C_{rr} \text{ supply} < C_{rr} \text{ extract.}$$

Such a situation might arise with a fairly tight timber boarded floor with no floor covering. Such a case arose in a school with a polished floor. Supply ventilation to the underfloor space proved much more effective than extract.

$$\text{The ratio } \frac{A_{sd}}{A_{sc}}$$

is likely to be affected by the presence or otherwise of concrete oversite. If there is oversite then it is is likely that $A_{sd} > A_{sc}$ thus it is more likely that C_{rr} supply > C_{rr} extract.

PRACTICAL IMPLICATIONS

It is unlikely that in any particular case one is going to be able to measure the relative tightness or flow resistance of the floor on the one hand or the ground, soil or oversite on the other or the diffusion coefficient of the floor. This analysis does however suggest that where there is a tight bare floor perhaps a tongued and grooved floor and simply bare earth below then supply ventilation will be more effective. In perhaps the majority of cases however one might expect extract ventilation from the underfloor space to be more effective, particularly where there is concrete oversite. In most practical situations the case for supply or extract will not be clear cut and it would seem advisable to choose fans where the flow can easily be reversed.

Looking directly at the equation for extract ventilation equation (11) and supply ventilation equation (25) some hypotheses are suggested for the level of extract and supply. Looking first at extract equation (11) it would appear that the radon level is minimised by reducing Q_{sf} the underfloor ventilation rate and maximising the room ventilation rate Q_r. However if we substitute

$$p = \tfrac{1}{2}\rho \frac{Q_{sf}^{2}}{A_1^2 C_d^2} \tag{32}$$

in equation (11) we get:

$$\underset{\text{extract}}{C_{r_r}} = \frac{K_1 A_{fd} \frac{p}{Q_{s_f}} \cdot \frac{A_2}{R_s} \cdot C_{soil}}{Q_r + K_1 A_{fd}} \tag{33}$$

Thus it can be seen that the room radon concentration is reduced by; low pressure, high subfloor ventilation rate and high room ventilation rate. This agrees with the analysis of Hartless and Gardiner (Ref 3). Thus the right approach would seem to be to have a high subfloor ventilation rate at lower pressure which means a large area of ventilation openings to the underfloor space.

Similarly for supply ventilation to the underfloor space equation (24).
we get

$$\underset{supply}{C_{rr}} = \gamma p \frac{A_{fc}}{R_f} \frac{C_{soil}}{Q_r} \left(\frac{K_s A_{sc}}{K_s \, A_{sc} + Q_{ss}} \right) \tag{34}$$

Again this suggests minimising p and maximising Q_{sf} and Q_r

There is probably a limit to the reduction of the underfloor pressure however whether suction or positive. If this pressure is made too small then there will in the case of extract be areas of positive pressure driving radon into the room and in the case of supply, areas of negative pressure sucking up radon from the ground, due to wind effects. This suggests that the pressure generated under the floor should probably be about the same as that which would occur due to wind. Thus when fitting a fan to an underfloor space it may be advisable to increase the number of airbricks. The requirement in both supply and extract for a high flow rate at low pressure suggests the use of axial flow fans where practicable.

CONCLUSION

A simple analysis has been presented of mechanical ventilation under a suspended timber floor which suggests that the relative efficacy of supply and extract ventilation depends on the relative airtightness of the floor and the ground underneath and the permeability of the floor. The relatively tighter the floor the more effective supply ventilation as against extract. This is in accordance with some limited practical experience but the hypothesis needs systematic experimental verification. In both cases it is suggested that a high flow rate at low pressure will give the best results.

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