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COST-BENEFIT ANALYSIS OF DECREASED VENTILATION RATES AND RADON EXHALATION FROM BUILDING MATERIALS

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Abstract

Decreased ventilation, achieved by weather stripping and other tightening measures, is the most cost effective way to energy conservation. A very low investment can result in a considerable decrease in ventilation rate. For a typical detached house in Sweden this can be equivalent to a decrease in oil consumption of 0.5 m^3. At present price this corresponds to a saving of SEK 1 200, $150 per annum. The contribution of the building materials to the concentration of radon in indoor air is approximately the inverse to air exchange rate. For a small change in ventilation rate and cost, in SEK/man Sv or $/manSv, is a function of ventilation rate, exhalation from building materials, the ratio between surface of walls, floor and ceiling to the volume of air. Thus, it is possible to find the specific ventilation rate where the marginal cost for a small increase in ventilation rate and the marginal reduction in radon concentration will give a specific amount of money for each manSv. Examples are given. Conclusions are that for most building materials in a climate like the Swedish, there are other factors than exhalation of radon from building materials that sets the lower limit of recommendable ventilation rate.

The purpose of cost-benefit analysis can be to verify that a certain action gives a positive result that justifies the costs involved. It can also help in deciding which strategy of several possible, that gives the most benefit from available funds. It is not possible in a short paper to give a generally applicable answer what is worth doing and what is not concerning radon in indoor air. Local conditions vary a lot. Thus most judgements require detailed evaluation of the specific conditions and its implications on the correlation between cost and benefit for the different, possible measures.

The most important sources of radon in indoor air are exhalation from building materials and infiltration of soil gas carrying radon from the soil under the house through any leaks.

In this paper I will discuss some aspects of the exhalation of radon from building materials and the resulting contribution to concentration of radon in indoor air as a function of air exchange rate and low cost remedial actions in situations where soil gas carrying radon infiltrates into a building.

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Ventilation rate and its effect on concentration of radon in indoor air

If the supply of radon to the interior of a building is constant over time the resulting concentration of radon will be inversely related to the air exchange rate. Thus energy conservation in older buildings by means of weather stripping and general tightening of all possible leaks generally result in increased concentration of radon in indoor air. One important component in the design of new energy efficient houses is also to make the structure very tight. If the building is not equipped with mechanical ventilation with recovery of heat (or cold) in the exhaust air by i.e. heat exchanger or heat pumps, the result is a low air exchange rate and a possible build up of radon in the indoor air to an undesirable level.

In many cases an action that has impact on the air exchange rate of a building also has some impact on the supply of radon. If a leaking building is weather stripped any unremedied route of entry for soil gas will provide a greater part of the total untightness of the building and thus a greater part of the air supply will be soil gas. If then the building is supplied with mechanical exhaust ventilation the result will be a stronger negative pressure indoor followed by an increased infiltration of soil gas. The exhalation of radon from building materials can be regarded as constant over a longer period of time although it does vary and is influenced by changes in barometric pressure /1/. The exhalation is also a function of the water content of the material and thus is not constant during the drying out of a new building /2/.

The correlation between air exchange rate and supply of radon is

$$C_{Rn}\,(n) = \frac{E}{n + \lambda} \quad \text{where} \qquad (1)$$

$C_{Rn}\,(n)$ = concentration of radon in indoor air (Bq/m^3) as a function of n
E = supply of air Bq m^{-3}, h^{-1}
n = air exchange rate, h^{-1}
λ = decay constant for radon, $7.55 \cdot 10^{-3}$ h^{-1}

The supply of air E Bq/m^3,h is a function of the specific exhalation from different surfaces and the ratio between exhalating surface and volume of building, thus

$$E = \frac{P \cdot F}{V} \qquad (2)$$

P = specific exhalation Bq/m^2,h
F = exhalating surface, m^2
V = volume of building, m^3

If there are surfaces with different specific exhalation the relation is

$$E = \sum \frac{P_i \cdot F_i}{V} \qquad (3)$$

P_i = specific exhalation $Bq/m^2,h$ from surface i
F_i = area of surface i, m^2

In the following calculation F/V is set equal to 1.8 m^{-1} which represents a room 3 x 4 x 2.5 m with 4 m^2 excluded for door and window.

The exhalation of radon from building materials is not generally known. The Swedish Building Research Council has funded research to answer this question /2/. The result shows that the exhalation from a surface is depending on the type of material, moisture content, activity of radium in the material, thickness, any impervious surface treatment and cracks and holes in this surface treatment. It was found that many surface treatments can strongly reduce exhalation as long as the opposite side is not sealed. If both sides are treated, however, there still is a significant effect of some paints and plastic wallpapers. However, the effect is sensitive to cracks, holes after nails and electrical installations inside a wall. Because of this it is very hard to quantify the exhalation from building materials to the indoor air of a dwelling by calculations based on laboratory measurements on samples of building materials. In an existing structure the exhalation can be determined by measuring air exchange rate and concentration of radon. It is probably an acceptable compromise to estimate the exhalation from measurements on samples with representative moisture content but without surface treatment.

When the Swedish Radon Commission /3/ estimated the contribution to radon concentration in indoor air resulting from exhalation from building materials they assumed the following specific exhalation figures as being representative for typical Swedish building materials.

Aerated concrete without alumshale,	49	Bq/kg	^{226}Ra	exhalating	1-2	$Bq/m^2,h$
Concrete	20	"	"	"	4	"
"	50	"	"	"	10	"
"	200	"	"	"	40	"
Aerated concrete with alumshale	1460	"	"	"	105	"
	2500	"	"	"	200	"

The correlation between air exchange rates and radon concentration for these materials are illustrated in figure 1.

Any air exchange rate is a compromise between the desire to conserve as much energy as possible and the desire to keep concentration of radon as low as possible.

If only radon is considered and both cost and benefit are described in the same dimension, preferrably monetary, a strict optimization is possible.

The benefit of reducing the concentration of radon in indoor air can be quantified in monetary terms under the following assumptions:
- the equilibrium between radon and radon daughters in the air is 0.5, i.e. 2 Bq/m^3 of radon corresponds to 1 Bq/m^3 radon daughter EEC.
- the exposure to radondaughters in indoor air results in 0.08 mSv/Bq, year,m^3 according to UNSCEAR /4/.
- in optimization of radiation protection the limit of what is considered to be a resonable cost of avoiding one mansievert has in Sweden been specified by the Radiation Protection Board to 100 000 SEK (approx. $12 000, March 1984) /5/.

For each exposed person the value of a reduction in concentration of radon in indoor air of 1 Bq/m^3 under these assumptions can be calculated • to 4 SEK/year
(100 000 SEK/manSv x 0.5 Bq/m^3 RnD per Bq/m^3 Rn x 0.08 mSv per Bq RnD year/m^3)

In Stockholm one exchange of air per hour corresponds to approx. 90 kWh/m^2,year for heating the air from ambient to room temperature. The price of energy is approx. 0.35 SEK/kWh if produced by combustion of fuel oil in detached houses. The cost of electrical heating is approx. 0.25 SEK/kWh. If the house is heated with a heat pump or the energy is recovered from the exhaust air with a heat exchanger the cost for each kWh of heat can be as low as 0.10 SEK/kWh. If each person is assumed to occupy 35 m^2 of heated living space the energy cost for heating the ventilation air is 1100, 800 or 300 SEK/year for each air exchange per hour depending on source of energy.

There is a balance between increased cost of energy and the benefit of reduced concentration of radon in the indoor air when the derivative of eq (1) $\frac{-E}{(n+\lambda)^2}$

i.e. the marginal change in radon concentration as a function of a small change in air exchange rate corresponds to

1100/4 = 277, 800/4 = 200 or 300/4 = 75 Bq m^{-3}/air exchange h^{-1}

The air exchange rate for which this balance occurs increases with increased supply of radon to the indoor air. For a detached house heated by fuel oil the balance is as follows:

Supply of radon $E = P \cdot F/V$ Bqm^3h^{-1}	Balance between cost and air exchange rate, h^{-1}	benefit at Bq/m^3 radon
1x1.8 = 1.8	0.073	22
2x1.8 = 3.6	0.11	32
4x1.8 = 7.2	0.15	45
10x1.8 = 18	0.25	71
40x1.8 = 72	0.50	141
105x1.8 = 189	0.82	229
200x1.8 = 360	1.13	316

As can be seen from figure 1 radon only cannot justify more than 0.25-0.30 air exchanges h^{-1} in buildings of ordinary concrete and only approx. 0,1 air exchange h^{-1} in buildings of aerated concrete without alumshale. In structures built of the strongly exhalating aerated concrete based on alumshale the possible reduction in radon concentration can justify 0.8-1.2 air exchange h^{-1} even without recovery of heat. However, it is hard to establish >0.5 air exchange h^{-1} under maintenance of comfortable indoor climate without a mechanical ventilation system. Once there is a mechanical ventilation system installed the added cost for heat recovery is justified by the energy conserved when the air exchange rate is $\geq$0.5 h^{-1}. When the equipment for recovery of heat is installed and thereby the energy cost reduced, very high air exchange rates are justified from a radiation protection point of view. In the extreme case where all walls, floor and ceiling are made of the most strongly exhalating material it is practical design criteria and not cost benefit relations that determine the air exchange rate. In Sweden ordinary concrete is the most widely used building material. It is a coincidence that, for this material the 0.5 air exchange h^{-1} required in the building code, corresponds with the ambition in radiation protection, when the ventilation system is equipped with recovery of heat.

Cost benefit evaluation of sub-floor depression system

In 39 dwellings a sub-floor depression system has been installed as a remedial action against infiltration of soil gas carrying radon /6/. The mean reduction of radon concentration achieved was 2 600 Bq/m^3, corresponding to 1 300 Bq/m^3 of radon daughters EEC with an assumed equilibrium factor of 0.5. If each dwelling is occupied by 3 persons the yearly reduction in effective dose equivalent is (39 dwellings x 3 persons/dwelling x 0.8 x 10^{-3} Sv/Bq year person m^{-3}) = 12 manSv. If the relationship between effective dose equivalent and fatal cancer is assumed in accordance with ICRP /7/, to be 0.02 fatal cancers for each manSv, the lung cancer risk in this group of inhabitants was reduced by 0.24 hypothetical case per year. For each dwelling the installation cost for this system is 5000 to 10 000 SEK ($650-$1 300) and the yearly running cost 100 SEK ($12). The annual cost including capital charges, based on annuity over 25 years and 4 % real insterest, then follows to be not more than 800 SEK ($100). This indicates that the costs for preventing one case of lung cancer in this program have been 130 000 SEK ($10 000), which corresponds to 2 600 SEK ($300) per manSv.

Cost benefit evaluation of sealing obvious routes of entry for infiltrating soil gas

In 18 dwellings the entrance of the water pipe was sealed as an attempt to stop infiltration of radon from the soil /6/. The average concentration was reduced by 400 Bq/m^3 from 500 to 100 Bq/m^3. The costs involved were 100 SEK and a couple of hours work by the owner of the house.

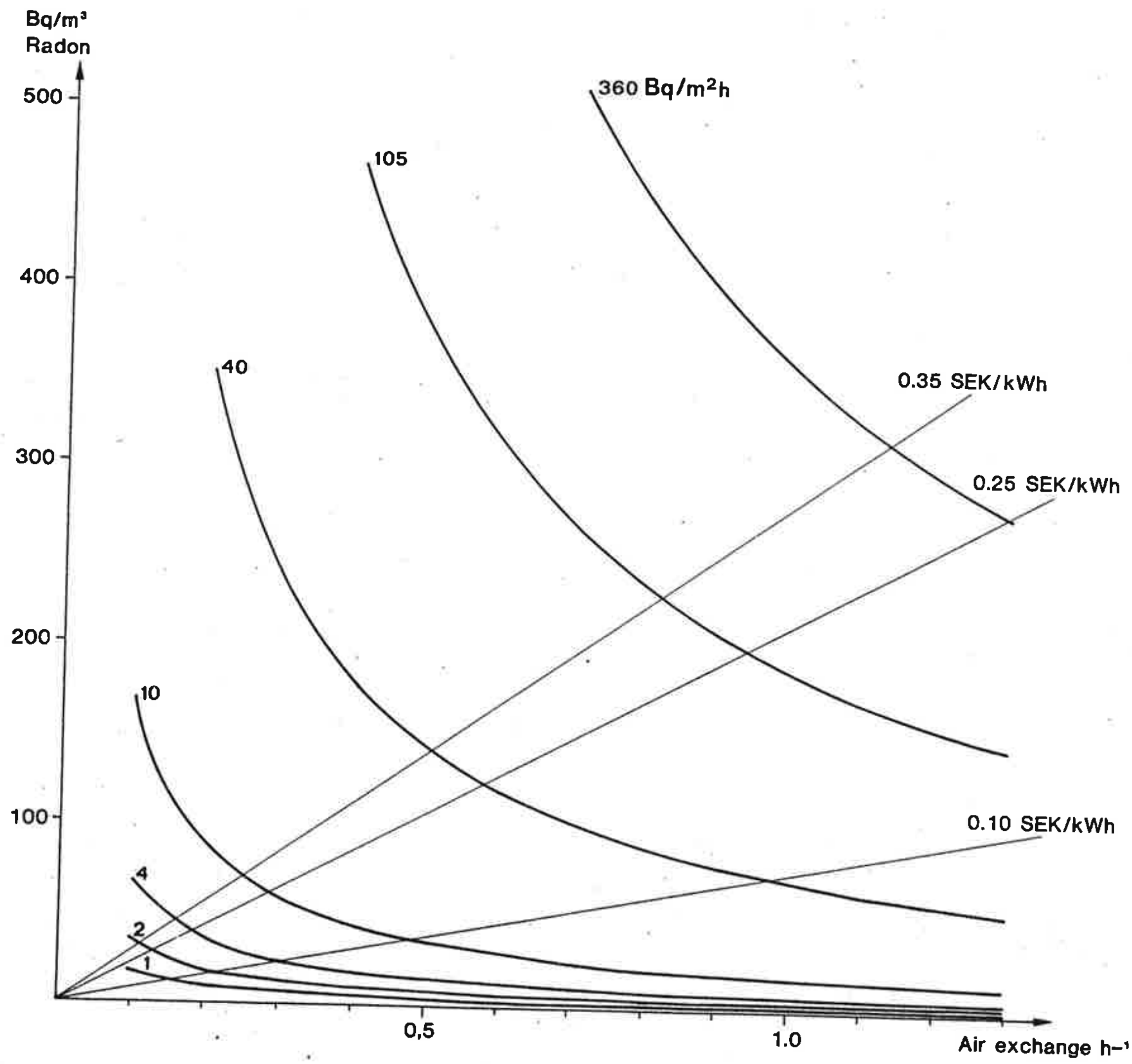
The yearly reduction in effective dose equivalent in this group of dwellings can be estimated to be 0.9 manSv. If the durability of the sealing is assumed to be 5 years the cost would be 800 SEK/manSv ($100 manSv) corresponding to 40 000 SEK ($5 000) for each avoided fatal lung cancer.

Conclusions

The exhalation of radon from normal building materials does not under present price of energy and principles of optimization of radiation protection alone justify the minimal ventilation rate 0.5 air exchange h^{-1} recommended in the Building Code. Other fators thus limit the possibility of energy conservation through weather stripping and other tightening measures. In older houses built with aerated concrete based on alumshale the exhalation from the structure can alone justify a ventilation rate significantly above 0.5 air exchange $^{-1}$. Remedial actions in buildings where soil gas has infiltrated and carried signigificant amounts of radon from the soil into the house have in general been very cost effective.

REFERENCES

1. Jonassen N: On the Effect of Atmospheric Pressure Variations on the Radon-222 Concentration in Unventilated Rooms, Health Physics, Vol 29, 1975, p 216-220
2. Pettersson H et al: Radonexhalation från Byggnadsmaterial, Swedish Testing Institute, Technical Report SP-RAPP 1982:32, ISSN 0280-2503, Borås 1982 (in Swedish)
3. Radon i Bostäder, betänkande av Radonutredningen, SOU 1983:6 (in Swedish)
4. Ionizing Radiation: Sources and Biological Effects. UNSCEAR 1982, UN
5. Lindell Bo: Riskfilosofi inom strålskyddsverksamheten. SSI: 1980-38 (in Swedish)
6. Ericson S-O et al: Modified technology in new constructions and cost effective remedial action in existing structures, to prevent infiltration of soil gas carrying radon, presented at 'Indoor Air 84'
7. Limits for Inhalation of Radon Daughters by Workers. Publ 32. Annuals of ICRP, vol 6, No 1, 1981



Relation between air exchange rate and contribution to concentration of radon exhalation from building materials. Straight lines illustrate points where there is a balance between cost (energy for heating the ventilation air) and benefit (reduced concentration of radon) for the energy price of 0.10, 0.25 and 0.35 SEK/kWh.