TEMPTS TO DETERMINE RADON ENTRY RATE AND AIR EXCHANGE RATE VARIABLE IN TIME FROM THE TIME COURSE OF INDOOR RADON CONCENTRATION

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INTRODUCTION

For the study and explanation of the diurnal variability of the indoor radon concentration $a(t)$ [Bq/m^3], which is proportional to the ratio of the radon entry rate A [Bq/h] and the air exchange rate k [1/h], it would be of advantage to know separatetely the diurnal variability of both determining quantities $A(t)$ and $k(t)$. To measure directly and continuously the radon entry rate $A(t)$ is possible only in special studies (mostly in experimental rooms) and also continuous measuring of the air exchange rate $k(t)$ is possible also only in special studies for a short time. But continuously measuring radon meters are now common, do not trouble people in normal living regime during day and night. The goal of this endeavour would be the evaluation of the time courses of both determining quantities from the time courses of the indoor radon concentration directly without additional experimental work and so a better utilisation of such measurements.

APPROACHES TO THE TIME ANALYSIS OF THE RADON CONCENTRATION

The variation in time of the radon concentration $a(t)$ in a room with volume V (m^3), radon entry rate $A(t)$ and air exchange rate $k(t)$ is studied here using the linear (compartmental) model

$$a(t)' = - k(t)\, a(t) + A(t)/V , \qquad (1)$$

expressing the balance of removal and entry of radon by the differentiate a' [Bq/(h m^3)] and assuming that the air exchange rate is much more quicker than the decay constant of radon. This differential equation has for the initial condition $a(t_0)$ a general analytical solution which could be used in principal for the determination of the unknown functions $A(t)$ and $k(t)$ by numerical methods. This approach seems to be very complicated and unrealistic. The other way is to use the differential equation itself.

Mostly the entry and air exchange rates are evaluated with the assumption of their constancy in time during the measuring period. The solution is in this case simple

$$a(t) = A(1-e^{-kt})/kV + a_0 e^{-kt} \quad \text{for } t>0=t_0 \qquad (2)$$

and the three unknown values a_0, k, and A can be obtained by numerical methods from three concentrations a_1, a_2, a_3 measured in times t_1, t_2, t_3 (at least two of them not in steady-state). The insufficiency of this approach is in the unability to assure the constancy of k and A for a longer time than several hours.

DETERMINISTIC SOLUTION OF AN EQUIVALENT DIFFERENCE EQUATION

Measurements result in average concentrations a_i during the i-th time interval $\{t_i, t_i+d\}$ of duration d [h], therefore also average values A_i and k_i can be only obtained from difference equations equivalent to the differential equation:

$$a_i' = - k_i\, a_i + A_i/V \qquad (3)$$

where the average differences a_i' have to be calculated by a numerical calcul from the measured, or better from smoothed values a_i. To calculate the two unknown values k_i and A_i one needs to evaluate at least two adjacent intervals,i.e. two difference equations. Assuming

the same values k and A for both intervals of a concavely increasing course or a convexly decreasing course of experimental values gives good results but fails for convexly increasing and concavely decreasing courses of the radon concentration resulting in meaningless negative air exchange rates. The reason can be understood from the concavely increasing or convexly decreasing time courses of the exact solution (2) of the differential equation assuming constant k and A.

One possibility to extend the applicability of this approach is to assume linear changes for both quantities $k_i = k + \kappa\ t_i$ and $A_i = A + \alpha t_i$ - decreasing or increasing in accordance to the sign of κ and α. Then four equations for four adjacent intervals have to be used for a general deterministic evaluation. Three equations can be used if the change in time of one of the quantity can be neglected and two equations are enough, if A and k are nearly the same for two adjacent intervals and the courses are properly concavely increasing or convexly decreasing.

STATISTICAL SOLUTION OF THE EQUIVALENT DIFFERENCE EQUATION
The deterministic approach has two important disadvantages. First the "uncompromising" fit of the deterministic solution to the uncertain input data a_i and a_i' gives manytimes completly meaningless results, second it does not give uncertainties for the calculated results. This can be overwhelmed by a linear regression analysis using the difference equation as the statistical model with index i as the independant variable. This approach gives beside of the four mutually interdependant results A, k , α and κ also their covariance matrix, of course the price for this is a larger number of intervals used for the evaluation with the same tendency of linear change assumed for the entry rate and air exchange rate. The optimal number of intervals suitable for evaluation can be determined by computer using the covariance matrix. Setting the difference equations symetrically over the used intervals and shifting automatically the evaluation to the next interval the evaluation should give reasonable results, but only for properly monotonically increasing or decreasing radon concentrations.

Unfortunately the statistical approach results sometimes in multifolds of the real values k and A, of course with the right ratio for the steady state radon concentration. The reason for this is that the minimalisation process finds the lowest minimum but off the real region. Overwhelming of this disadvantage needs to use constraints, but the evaluation gets more and more complicated. Another disadvantage of the approaches is that it cannot be applied around maximal and minimal radon concentrations because a monotonic tendency of the radon entry rate or the air exchange rate is not justified.

STOCHASTIC APPROACH
A promising approach to evaluate the time courses of the radon entry rate and of the air exchange rate from the whole time course of the measured radon concentration is hoped to be the stochastic approach used for simulation of sequences of data , the theory of which is described e.g. in (1). The equation (3) is the generic model for the evaluation and unrealistic solutions are avoided by limits for the air exchange rate and by realistic estimated starting values.

COMMENT TO THE APPLICABILITY OF THE COMPARTMENTAL MODEL
The compartmental or linear kinetic model used for the description of the indoor radon concentration assumes a perfect and immediate mixing of the entered radon in the whole

volume of the room. This is of course not true and it has to be considered if this is not the reason for failures in the above described evaluation. It seems so that normal circulation of the indoor air in occupied rooms produced by heating systems during heating seasons but even by the entry of daylight through windows or by the inhomogeneity of insulation and temparatures of walls, floors and ceilings leads to quick and homogeneous enough mixing of radon entering mostly at the floor level. At least their may be a delay between the real entry time of radon and the calculated "effective" entry time of radon which could be corrected for.

CONCLUSION

Two approaches are given for the determination of variable in time radon entry rates and air exchange rates from continuously measured indoor radon concentrations by numerical solution of the equivalent difference equations in deterministic or statistic form. Unfortunately these approaches are not always successful. But the analysis of the reasons for the failures leeds to a better understanding of the problem. It is hoped that the more sophisticated simulation approach shall solve the problem.

REFERENCES
1. L.Ljung, System Identification - Theory for Users, Prentice - Hall, Inc., 1987