THE CORRELATION BETWEEN SMALL VENTILATION RATES AND INDOOR RADON CONCENTRATONS USING A MULTI-ROOM HOUSE MODEL.

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Abstract

One of the most vexing problems radon professionals encounter when testing for indoor radon during a short-term radon test is being able to estimate the effect of accidental or purposeful ventilation on the final average radon measurement result. Passive radon measurement devices, such as activated charcoal, liquid scintillation, electret ion chambers and alpha track detectors are integrating devices and are thus unable to differentiate when, and if, ventilation occurred. Continuous monitors, on the other hand, have the potential of being able to record wholesale ventilation. However, the results from continuous monitors are not always unambiguous since the actual changes in radon during less obvious ventilation (caused, for example, by opening only one window) can be disguised by the typical fluctuations in radon concentration caused by normal variations in weather, temperature and wind. At radon levels around the 4.0 pCi/L EPA action level, the change in radon caused by purposeful ventilation of this more subtle kind can be enough to influence decisions made concerning mitigation. It is precisely the effect of modest ventilation rates on the final radon value that the authors wish to examine by using a model based on a multi-room "house", where the rooms communicate with each other and with the outside using typical air exchange parameters.

Introduction

Previous work by the authors (Burkhart, J. and Camley, R., 2000) focused on modeling the effects of ventilation on the final average radon concentration in a house that was comprised of one large single room. For this simple case, it was found that opening even one window in the model house for a few hours had a measurable effect on the final radon value. For example, the average radon value as measured by a theoretically perfect integrating device was decreased by 11.7% if one window in the model house (ACH = 0.35/hr with no ventilation) was opened for four hours during the 48 hour test, assuming that closed house conditions were employed for 12 hours prior to the opening of the window and the beginning of the radon sampling. Further, the model predicted an astonishing 86.4% drop in average radon for the same house if the window was opened for the full 48 hours of the sampling time.

This earlier work also demonstrated that the error introduced by the open window, whether opened for the full 48 hours or only for four hours, was larger for houses with air changes less than 0.35/hr and smaller for houses with air changes greater than 0.35/hr.

In this present investigation, the authors mathematically designed what they hope is a more realistic model, one that has several rooms. It is intended that the results from this model will be more applicable to real life situations.

Description of Model

Figure 1 shows a house that is made up of 6 rooms that can exchange air with each other and the outside and one room, room 1, that has a window that can be opened.

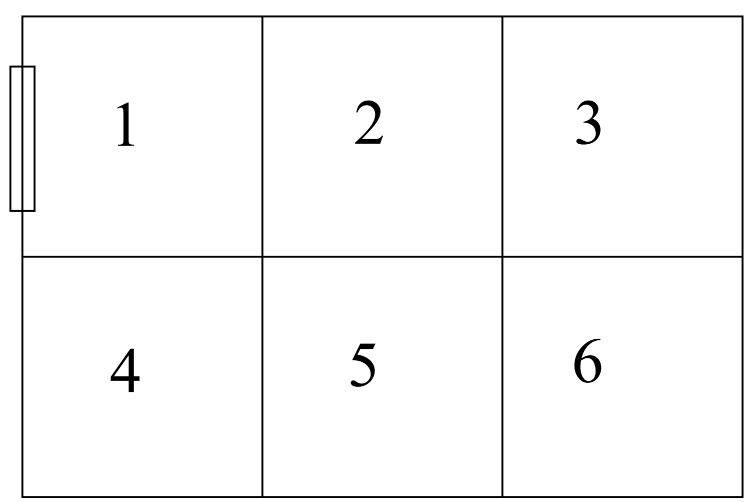

Figure 1: Indicating the window in room 1 and the arrangement of rooms

The equation governing the time dependence of the radon concentration in room 1, N_1, is given by

$$\frac{dN_1}{dt} = R_{12}(N_2 - N_1) + R_{14}(N_4 - N_1) + R_i - R_{out}N_1 \ -N_1\lambda e^{-\lambda t}$$

where

R_{12} is the exchange rate between rooms 1 and 2
R_{14} is the exchange rate between rooms 1 and 4
R_i is the infiltration rate of radon from the ground
λ is the decay rate for radon (.693/91.68 hours)
N_2 is the concentration of radon in room 2, etc.
R_{out} is the exchange rate of the room with the outside

As can be seen in the above equation, room 1 is allowed to communicate with the outside, R_{out}, with the soil, R_i, and with the nearest neighbor rooms (room 2 and room 4).

By multiplying both sides of the equation by dt, and integrating, the radon at any time, t, can be found for room 1. Similar equations hold for the other rooms. This set of six coupled differential equations is solved numerically, giving the radon in each room at any time, t.

It should be noted that this model does not attempt to quantify any changes in radon concentration that may be caused by weather, temperature or climatic conditions. Also, unlike our previous work, this model does not modify the infiltration rate of radon on the basis of the amount of ventilation. In fact, we are deliberately isolating the effects of an open window on the instantaneous and average radon concentration while holding all of these other variables constant.

Results

The above set of equations is first solved for the simple case of the window being continuously closed. It is assumed that the house is in closed house conditions for 12 hours prior to the initiation of the radon test and for the full 48 hours of the test. The house was further assumed to have an air exchange with the outside of 0.35/hr, which has been shown to be characteristic of the typical home (ASHRAE Standard 62, 1989; Wallace, L.A. and Ott, W.R., 1996). Figure 2, below, shows that the radon builds up in the home for all rooms identically. This occurs over a 12-hour period and then levels off at an equilibrium radon value that is dependent, in this model, on the radon influx term $R_{i,}$ and the air exchange of each room with the outside, R_{out} . This graph, along with all other graphs in this paper, use arbitrary units for the radon since it has been previously shown (Burkhart, J. and Camley, R., 1999) that the results given simply scale proportionately with the radon influx term. The arbitrary value of 1 given to the final radon concentration will thus allow us to easily compare later graphs (which include ventilation) with this graph (which has no ventilation).

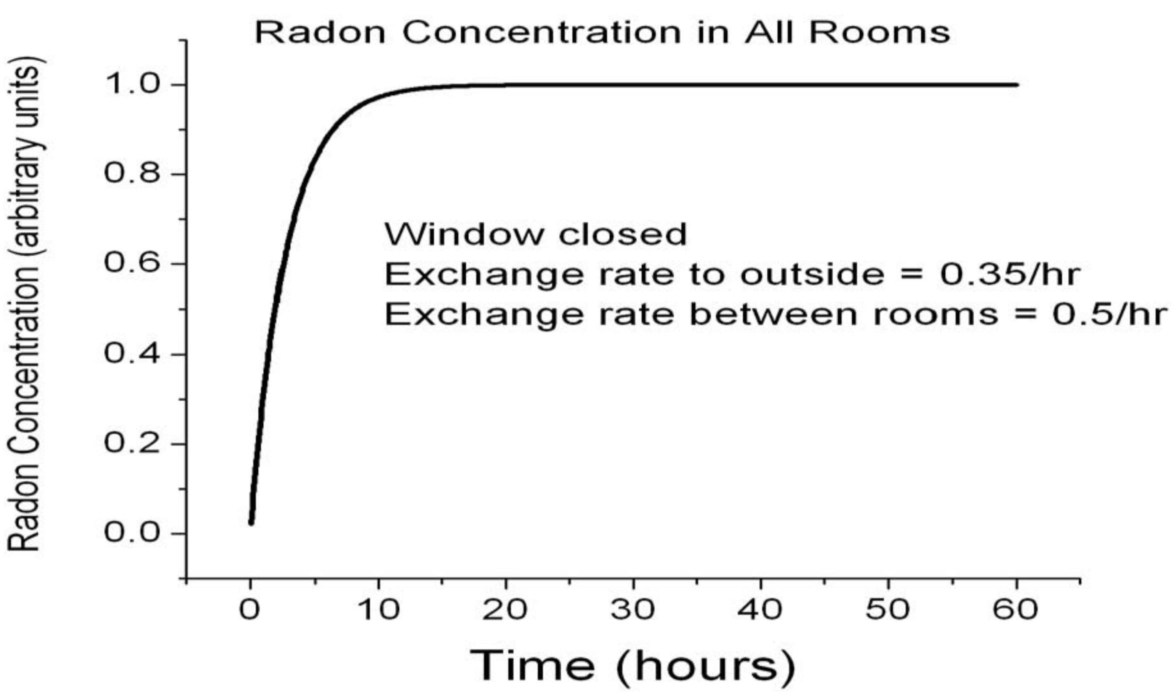

Figure 2: Radon concentration in a house with no window open (window in room 1 is closed) and air exchange between all rooms is equal to 0.5/hr

This result is identical to the result that was found from our earlier model in which the whole house was modeled as one large room and the air exchanged between each adjacent room has no effect on the final radon concentration.

In Figure 3 below, the window in room 1 is opened at hour 6 and kept open for the balance of the radon test. The incremental increase in ventilation that occurs in room 1, as a result, is calculated to be approximately 1.0/hr for a window opened 10 inches and was determined from:

$$N_v = 0.12/hr/in,$$

where the linear length (in inches) of the window opening is used (Wallace, L.A. and Ott, W.R., 1966).

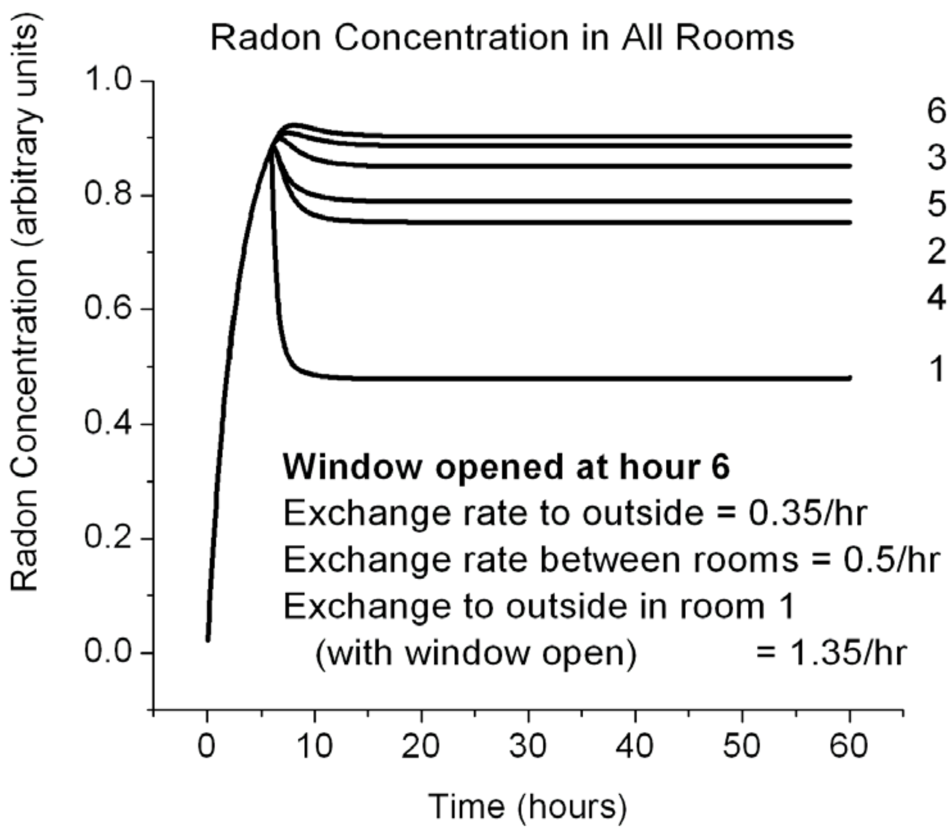

Figure 3: Radon concentration in a house with window in room 1 opened 10 inches and air exchange between all rooms equal to 0.5/hr. Each room number is shown next to the appropriate curve in the upper right hand side of the graph

The radon concentration in room 1 is, of course, lowered the most. Its final radon concentration is about 50 % of its normal equilibrium value. What is more telling, however, is that the radon concentration in the room farthest from room 1, which is room 6, is also modified (by lowering about 10 %). An inter-room air exchange rate of 0.5/hr was used, mimicking the condition when the doors are closed between each room. Thus, one can immediately see that a recording test device placed in any room is going to show some error ranging from 50% below to 10% below the “true” hourly radon value. Since 10% precision is a typical performance characteristic for a continuous monitor, this drop in radon will not be picked up by the test device when it is placed in the room farthest from the open window.

In Figure 4, below, the air exchange between rooms has been increased to an inter-room air exchange of 2/hr, which is assumed to be more representative of the air movement when room doors are opened to each other.

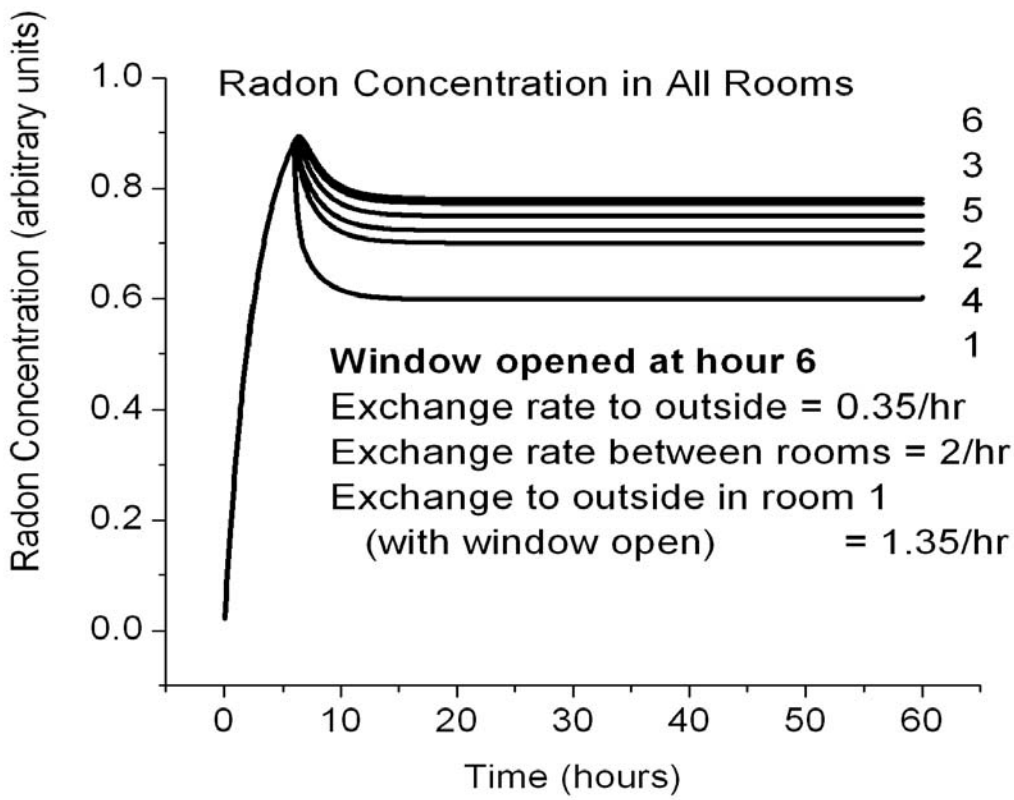

Figure 4: Radon concentration in a house with window in room 1 opened 10 inches and air exchange between all rooms equal to 2 /hr. Each room number is shown next to the appropriate curve in the upper right hand side of the graph

Not surprisingly, the radon in room 1 is actually increased so that the net drop in radon concentration in room 1 as a result of a window being open starting at hour 6 is 40% instead of the previous 50%. This is because the increase in air exchanges between rooms has brought more radon into room 1 from adjacent rooms, slightly offsetting the radon loss out of the window. All of the other rooms show a drop in radon, however. Even room 6, the farthest room from 1, now shows a 20% drop in reported radon.

Figure 5, below, has been generated for a "tight" house with an air exchange of 0.1/hr to the outside. Such homes are not uncommon (Nazaroff and Nero, 1984, for example). Once again, the inter-communication between rooms has been set to imitate open doors (between rooms) and is 2/hr.

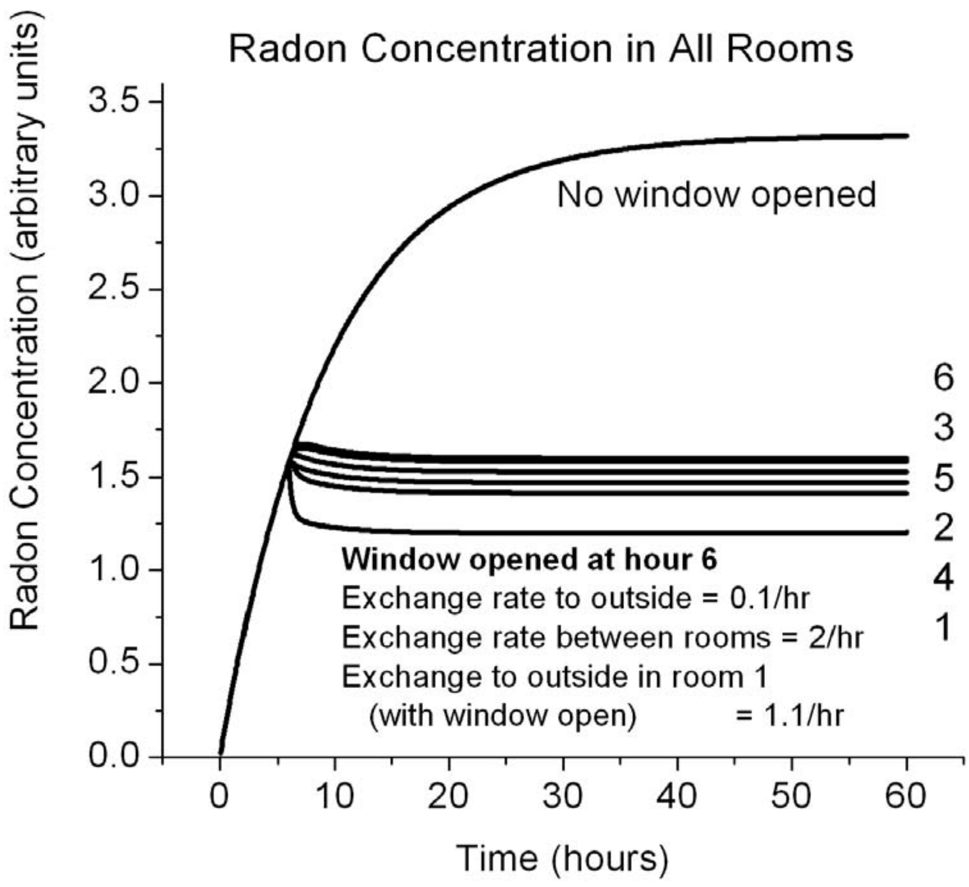

Figure 5: Radon concentration in a house with window in room 1 opened 10 inches and air exchange between all rooms equal to 2 /hr. This represents a tight home with an air exchange to the outside of only 0.1/hr. Each room number is shown next to the appropriate curve in the upper right hand side of the graph

Clearly, the instantaneous radon levels in all room are being seriously affected by the open window in room 1. It can be shown that room 1 has a final radon concentration that is more than 60 % below the value it would have had without this constant ventilation. Moreover, even room 6 is at half of its "true" radon value. Thus, a radon-testing device of any type would record a false negative result (either hourly or a 48-hour average).

In the final example below, Figure 6, the window in room 1 is open for 24 hours during the test. We arbitrarily chose to have the window opened at hour 6 and closed at hour 30. This ventilation period might be, for example, the result of a less flagrant violation of the closed house protocols.

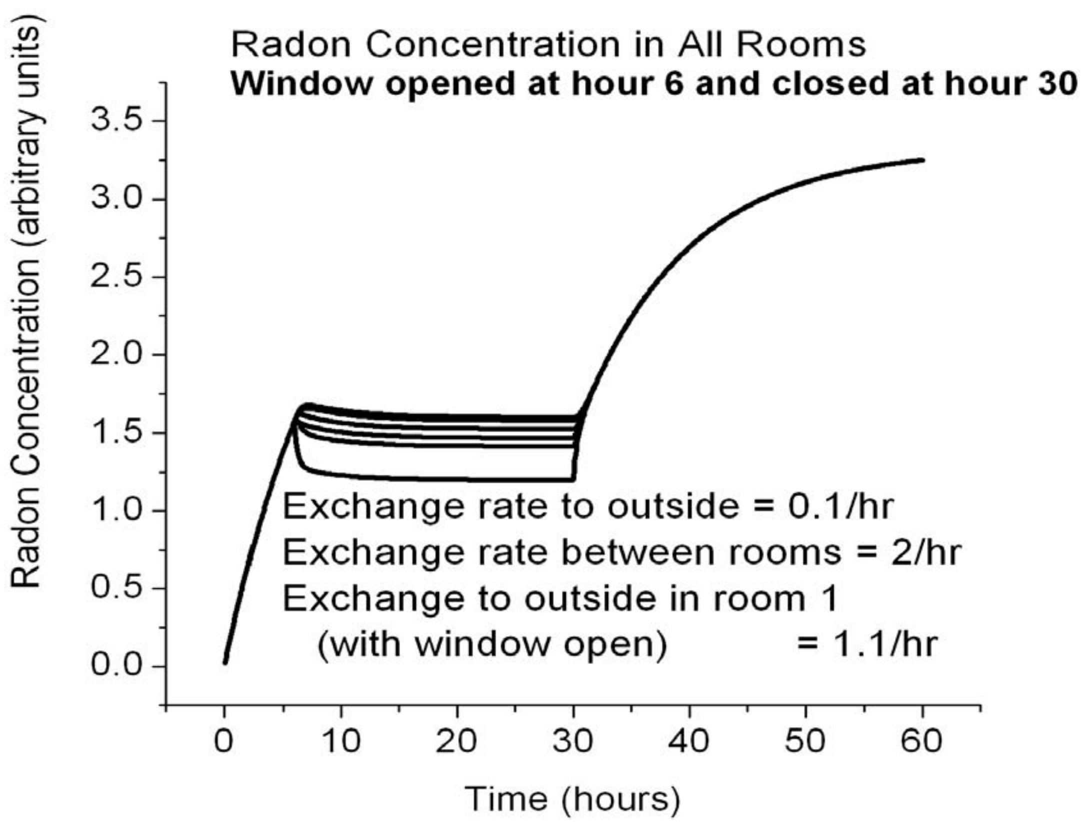

Figure 6: Radon concentration in a house with window in room 1 opened 10 inches for 24 hours and air exchange between all rooms equal to 2 /hr. This represents a tight home with an air exchange to the outside of only 0.1/hr. Each room number is shown next to the appropriate curve in the upper right hand side of the graph

As can be seen, the open window results in a decreased radon value in every room for the duration of the ventilation. However, the deleterious effect on the radon concentration continues well after the window in room 1 is closed. In particular, the instantaneous radon value only achieves its final equilibrium value at hour 60, instead of at hour 12 (which would be the case if there were no ventilation). As a result, the final average radon concentration (over a 48-hour test) is decreased by 30.5 % in room 1 and 26% in the farthest room, room 6.

Conclusions

This paper presents a mathematical model that can be used to predict indoor radon concentrations as a function of time for a house comprised of six rooms, where air exchange is allowed between each room and between the rooms and the outside. When a window is opened in this model house, the effect on the resulting radon concentration for each room has been determined. It has been found that the predicted radon in the room farthest from the ventilation is at a minimum of 10% below (the value the house would have without ventilation) and that obtains when all doors between rooms are closed. For a tighter house and, for the case when the doors between the rooms are opened, the radon in the farthest room is dropped by 50 % below its normal, unventilated, value.

Since the model used here has no unusual assumptions built into it, it is suspected that ventilation, whether purposeful or accidental, by the opening of even one window in a house can indeed lower the measured radon value enough to give a false positive result. If this model is on the right track, radon testers will have to remain very vigilant regarding ventilation during a (closed house) radon test even when the ventilation is so subtle as to involve only one window in the house for only a portion of the testing period.

References

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