RESIDENTIAL AIR QUALITY IN INTERIOR ALASKA

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ABSTRACT
Interior Alaska has indoor air quality issues similar to other far northern communities associated with long cold winters and reduced ventilation rates. Moreover, geological features in the hills around Fairbanks, Alaska increase the likelihood of elevated radon levels. Over thirty percent of the tested homes in the hills around Fairbanks had radon levels > 4 pCi/l compared with a nationwide average of 7%. Active sub-slab depressurization systems tested were very effective in reducing indoor radon concentrations (average reduction of over 90% for 8 homes). For homes with wood stoves, we found the indoor PM_{10} concentrations peaked after the stoves were lit. A model was developed to predict transient concentrations of particulates or gases.

INDEX TERMS
Indoor air quality, Modeling, Ventilation, Radon, Mitigation

INTRODUCTION
An overall study of air quality encompasses emissions, transport/chemistry, effects, regulations, and controls. The sources can be stationary or moving, point or diffuse and the transport can include convective as well as dispersive effects. Allowable levels of critical constituents in the outdoor ambient air in the USA are quantified by the National Ambient Air Quality Standards (NAAQS), but there is no such overall encompassing regulation for indoor air. Major indoor pollutants include radon, formaldehyde, combustion products, biological contaminants, tobacco smoke, organic gases, and asbestos. It was established for the first time in the mid 1960s that air pollutants generated indoors might be responsible for adverse health effects originally attributed to the outdoor air (Namiesnik et al, 1992). Moreover, improved indoor air quality (IAQ) has been shown to increase productivity and decrease sick building syndrome symptoms (Fanger, 2000).

Tiny particles can be harmful to health because they can be deposited in the respiratory tract including the lungs. Those less than 10 microns are particularly troublesome both because of interfering with the mass transfer of oxygen due to physically blocking the mucus membranes in the lungs and because toxic substances can attach to them. In one study (Ott and Roberts, 1998), it was found that indoor exposures were 60% greater than one would infer by collecting air sample from both indoor and outdoor air. These higher exposures were attributed, in part, to people stirring up dust clouds as they move round. The indoor environment may offer protection against outdoor pollutants because of filtration, deposition

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and decay as outdoor air penetrates the building envelope. The protection provided will vary depending on the way the building is ventilated.

Of particular concern in Alaskan homes is the possibility of elevated radon levels. Initiated with the decay of U^{238} and ending with Pb^{206} , the radon decay series leads to a radiation dose from indoor air greater than that from all other radiation sources combined. (Nero, 1989). The average concentration is US homes is ~ 1.4 pCi/l with maybe 100K homes exceeding this by a factor of 10 and 2% of all US homes having a level > 8.

Radon surveys have been done in Alaska as well as many other states. Eight out of the highest ten radon levels measured in Alaska occurred in Fairbanks. In interior Alaska, 17.6 % of the homes surveyed had radon levels exceeding 4 pCi/l, with 30% of the homes in the hills around Fairbanks having elevated concentrations. These high concentrations are likely associated with high fracture permeability of bedrock coupled with high uranium concentrations in the schist comprising the bedrock (Nye and Kline, 1990). These geological factors coupled with the long heating season create conditions conducive to high radon concentrations.

The high concentrations found in many homes is associated more with elevated radon entry rates than low ventilation rates. The former can vary by factors of more than 1000, a variability characteristic of many indoor air pollutants. The key to the problem lies in the combination of tiny openings in the foundation coupled with a stack effect that causes the indoor building pressure to be a few pascals lower than the ambient. This pressure difference causes a convective driven flow of radon gas from the soil into the home. Since the radon concentration in the soil pores can easily be 1000 pCi/l, only 1% of the infiltration air need be from the soil to explain the data.

FIELD RESULTS

Because of the lack of data regarding IAQ in residences in interior Alaska, our team initiated a data collection program 4 years ago. With our long cold winters and the concomitant time spent indoors, it is especially important here to have acceptable indoor air quality. We have focused on eight homes to gather extensive data on CO, CO_2, relative humidity (RH), and temperature (T) and particulates. We have collected detailed data on radon in 9 homes all of which eventually deployed active sub-slab depressurization mitigation systems. We have focused on three homes to collect detailed data regarding concentrations of particulate matter. We have deployed alpha Trak detectors in 36 homes to gather data regarding average radon levels over a long-term. We have used these data to supplement long-term radon levels measured by others in the past. In all, we have collected firsthand data at 68 homes.

Over an averaging period ranging from 4 to 23 days, the summer PM_{10} averages ranged from 7 to 16 $\mu g/m^3$ and the winter averages ranged from 12 to 30 $\mu g/m^3$ (less than the NAAQS maximum annual average concentration of 50 $\mu g/m^3$). To measure particulate mass concentrations, we used a Dust Trak aerosol monitor made by TSI, Inc. The monitor employs the scattering of laser light to infer aerosol mass concentration.

For homes with wood stoves, we found the indoor concentrations rose after the stoves were lit. As shown in Fig. 1, particulate concentrations, as measured by two different sensors, rose dramatically (by an order of magnitude) after a wood stove was started at about 8 PM one day in a 113 m^3 cabin. The inside $PM_{2.5}$, which was much lower than that outside prior to 8 PM, became much higher inside after starting the stove. The PM_1 (not shown) and PM_{10} also increased after 8 PM and stayed above the pre-8 PM levels for about 3 hours. This is believed to be caused by the particles entrained into the ambient indoor air while the stove door was open during the lighting process. This seems likely rather than a leaky stove since the levels started to drop soon after the stove was lit even though combustion continued for several hours. Other data (not shown here) indicate the fine PM inside to be normally less than that outside.

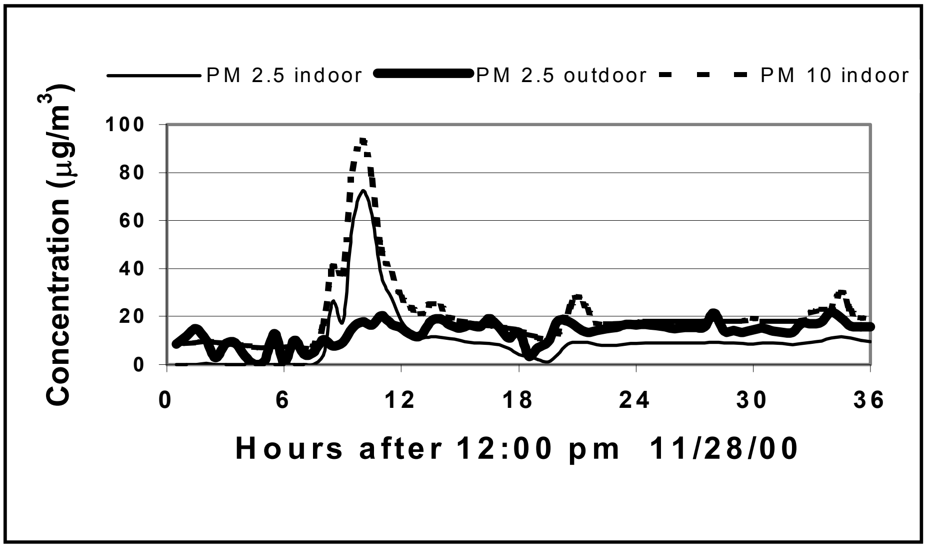

Figure 1. Particulate concentrations vs. time as influenced by a wood stove

On figure (2) are shown results for the rise in indoor PM2.5 following an outdoor fire for the cabin discussed above along with predicted results discussed in the next section.

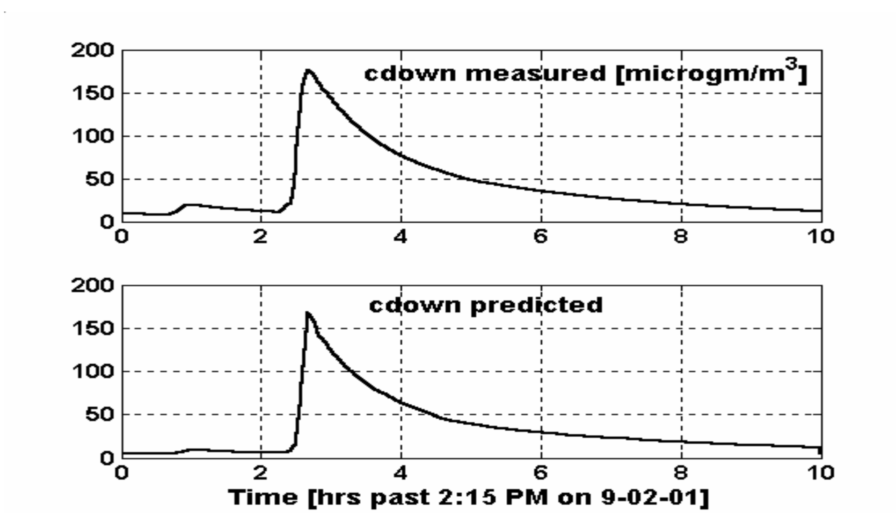

Figure 2. Modeling results for indoor PM2.5 with outdoor PM source

Continuous radon monitor (CRM) results demonstrated the effectiveness of mitigation systems. Such systems utilized induced draft fans to decrease the pressure beneath basement slabs and thus reduce the driving force for radon to enter houses from subsurface soil. This driving force (ΔP) tends to be larger with colder ambient temperatures because of the stack effect. Observing the results of an existing mitigation system required monitoring the system in the operating and non-operating conditions. The CRM's recorded average radon concentrations at intervals of 1, 8, or 24 hours depending on the frequency of scheduled site visits. Typically indoor and outdoor temperatures were recorded at hourly intervals where the CRM's were deployed in order to monitor changes that would affect the stack effect of the house. As can be seen from Table I, for 8/9 homes, use of a mitigation system reduced the radon concentration by more than 89%. Houses with successful retrofitted mitigation systems had a negative ΔP over a large fraction of the house footprint, and a moderate (approximately > 1 m^3/ min) flow rate in the mitigation duct. The home with the poorly performing system was the only one that had neither. Each data point represents at least one days worth of data for 18/20 values shown with CRMs being deployed for about a month for each of the first two homes.

Table I. Radon concentrations [pCi/l] for Fairbanks homes

Home #	1	2	3	4	5	6	7	8	9
fan off	14.4	9.8	32.3	61.1	9.7	509	61	26	27
fan on	14.3	1.1	0.0	4.6	0.3	4.6	1.7	1.3	0.8

Figure (3) reveals the pronounced influence of the mitigation system for house no.6 [volume = 365 m^2 with a daylight basement] with levels in excess of 400 pCi/l frequently occurring when the mitigation system was inoperative.

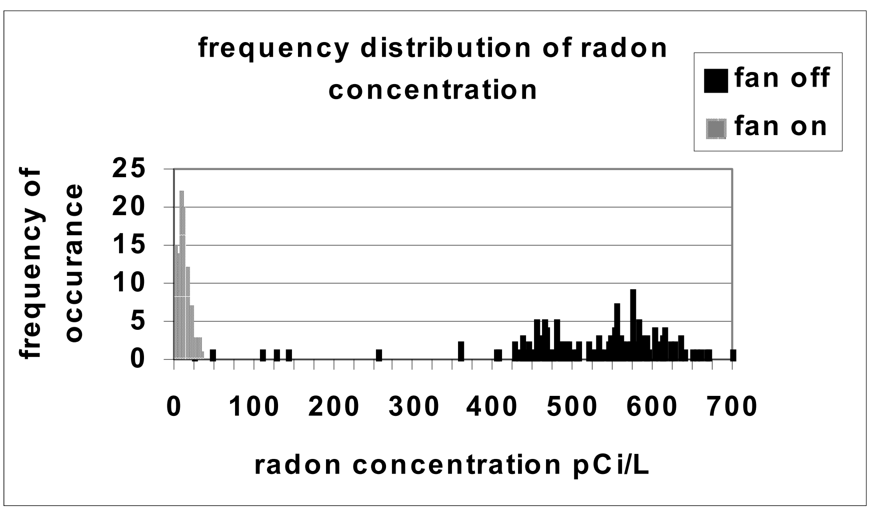

Figure 3. Frequency distribution of radon concentrations at house # 6

MODELING

We employed both steady state and transient mass conservation models to help quantify the relationships between critical variables for our studies involving both radon and particulates. To estimate ventilation rates, we used data from the natural decay of CO_2 after it appeared the inhabitants had left the house. The conservation of mass relation for a given zone may be expressed as:

$$\mathbf{V dc/dt = Q(}p\mathbf{c}_a \mathbf{- c) - (}k + k_d\mathbf{)Vc} + \dot{S} \qquad (1)$$

where V is the zone volume, c concentration, $\dot{S}$ source strength, Q convective flow through the zone, p penetration from outside the zone, c_a concentration of air entering the zone, k_d deposition rate coefficient, and k decay rate coefficient. We utilized integration blocks within Simulink to integrate Eqn. (1) and march downstream with time for each of two zones within a 113 m^3 cabin. Results shown on Fig. 2 reveal the penetration of fine particulate matter into a dwelling following a sudden rise in ambient concentration associated with outdoor burning.

If we neglect decay and assume steady state, the equilibrium indoor air radon concentration for one zone and negligible ambient radon concentration is:

$$c = \dot{S}/\dot{V} \qquad (2)$$

where $\dot{S}$ is the source strength and $\dot{V}$ is the ventilation rate. If the dominant resistance to the flow of radon is the soil resistance, then we may express the source strength (Scott, 1992)

$$\dot{S} = c_s \Delta P / I_s \qquad (3)$$

where c_s is the radon concentration in the soil, ΔP the pressure difference between the ambient and indoor air, and I_s the soil resistance to the flow of air. For rectangular basements, we may approximate I_s with:

$$\mathbf{I_s = (7 \times 10^{-7}/k)\ Pa\text{-}s/m^3} \qquad (4)$$

where k is the soil permeability. For house no. 6, we used January data for CO_2 plus mass conservation to infer the soil gas to basement ventilation rate and CO_2 source strength $\dot{S}$. Then, with a measured ΔP, we calculated $I_s = 1652$ Pa-s/m^2 via Eqn. (3) [corresponding to $k = 3 \times 10^{-10}$ m^2; the value for clean sand/gravel = 10^{-11} m^2]. We then used this I_s together with measured values for radon in the soil c_s and ΔP to predict the source strength $\dot{S}$ for radon. Using this in Eqn. (2) gives a predicted radon concentration c = 527 pCi/l. This is close to the measured values between 550 and 600 pCi/l on that day. Our data and this model predict dramatic effects on radon concentration resulting from reductions in ΔP.

CONCLUSIONS AND IMPLICATIONS

(1) The PM_{10} multi-day averages ranged from a low of 7 in the summer to 30 μg/m^3 during the winter, each less than the NAAQS maximum annual concentration of 50 μg/m3. One house (with a woodstove) exceeded the 24 - hour PM_{10} of 150 μg/m^3 for 14% of the time during a 2-week period in the spring.

(2) A transient mass conservation model was able to predict indoor $PM_{2.5}$ concentration changes in response to changes in outdoor concentration with ventilation rates inferred from CO_2 decay data.

(3) By combining information obtained by measured CO_2 levels within dwellings as well as in the ground underneath together with simple mass conservation models, one can make baseline predictions for both concentrations of gases such as radon and particulates. Such predictions can be useful for those interested in achieving suitable IAQ in both new and existing homes.

(4) Thirty percent of the tested homes in the hills around Fairbanks had radon levels > 4 pCi/l compared with a nationwide average of 7%.

(5) Active sub-slab depressurization [ASD] systems tested were very effective in reducing indoor radon concentrations (average reduction of over 90% for 8 homes).

(6) Even though certain geologic and topographic features may predispose certain homeowners in Alaska to increased risk of elevated radon levels, ASD technologies can be very effective even with very low ambient temperatures.

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