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THE USE OF MECHANICAL VENTILATION WITH HEAT RECOVERY FOR CONTROLLING RADON AND RADON-DAUGHTER CONCENTRATIONS

W.W. Nazaroff, M.L. Boegel, C.D. Hollowell and G.D. Roseme

Energy Efficient Buildings Program
Energy and Environment Division
Lawrence Berkeley Laboratory
University of California
Berkeley, California 94720

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ABSTRACT

An energy research house in Maryland was found to have radon concentrations far in excess of recommended guidelines. A mechanical ventilation system with heat recovery was installed in this house to test its effectiveness as an energy-efficient control technique for indoor radon. Radon concentration was monitored continuously for two weeks under varying ventilation conditions [0.07 to 0.8 air changes per hour (ach)] and radon daughter concentrations were measured by grab-sample techniques about nine times daily during this period. At ventilation rates of 0.6 ach and higher radon and radon daughter levels dropped below guidelines for indoor concentrations. Comparison with other studies indicates that indoor radon buildup may be a problem in a considerable portion of houses characterized by their low infiltration rates. The use of mechanical ventilation systems with air-to-air heat exchangers may offer a practical, cost-effective, and energy-efficient means of alleviating not only the radon problem specifically but also the general deterioration of indoor air quality in houses designed or retrofitted to achieve low infiltration.

Keywords: energy conservation, heat recovery, indoor air quality, mechanical ventilation, radon, residential buildings

features. Three specific energy-conseerving strategies are reducing heat loss through the building envelope, reducing infiltration, and reducing the amount of energy consumed by appliances. For our purposes, measures taken to reduce infiltration are of the greatest importance.

Infiltration Characteristics*

Measured infiltration rates in this house ranged from 0.05 to 0.15 air changes per hour (ach), in contrast to the typical range of 0.5 to 1.5 ach in conventional houses in the U.S.[6] This tenfold reduction was achieved by using a number of relatively inexpensive techniques for blocking air leakage. All cracks around doors, windows, and utility entrances had been sealed with caulking, all doors and windows had been weatherstripped, and a continuous plastic vapor barrier had been placed behind the drywall. All electric outlets and lighting fixtures were surface-mounted (avoiding penetration of the walls and consequent air leakage), and the exhaust fan ducts in the bathroom were dampered.

Other Design Features

The house is a single-story structure with a full basement. The basement walls are about 50% below grade, and are constructed of unfilled concrete block. The floating concrete slab rests on a 4-inch gravel base. The basement drain opens directly to the gravel base which is drained to a sump. The house is heated with a heat pump; air in both the main floor and the basement is conditioned. The air-distribution system takes air from the basement and blows it through registers into the main living space.

Indoor Air Quality

Air-quality problems were observed shortly after construction was completed. Excessive humidity, manifested by mildew and mold on the walls, was corrected by installing a dehumidifier. Spot measurements showed formaldehyde levels to be in excess of indoor formaldehyde standards.[7] The most serious problem we found, however, was the high concentrations of radon and radon daughters within the house. Spot measurements of radon consistently showed concentrations in excess of 20 picocuries per liter (pCi/l). Given typical indoor equilibrium factors** of

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*Infiltration in buildings arises from cracks and holes in the building envelope. The term refers specifically to uncontrolled air leakage, and is typically measured in air changes per hour (ach). One ach means that the amount of air entering the conditioned space of the structure in one hour equals the building volume. Infiltration rates vary with weather conditions: indoor-outdoor temperature differences and wind speed and direction.

**The equilibrium factor is defined as 100 times the radon-daughter working level divided by the radon concentration in pCi/l .

$$n(\text{efficiency}) = 0.75 = \frac{Tsup - 20F}{68F - 20F} \quad (1)$$

Ventilation rates were measured by means of tracer gas decay techniques. A tracer gas is injected into the house where it is mixed to a uniform concentration. The resulting gas concentration is then measured as a function of time and fitted to an exponential decay curve of the form

$$C = C_o e^{-\lambda_v t} \quad (2)$$

where t is time (hours), and λ_v is the air exchange rate (ach). The tracer gas used for this study was sulfur hexaflouride (SF_6), which is chemically inert and nontoxic. It was injected near the basement intake of the air-distribution system; the furnace fan (which operated continuously for all but one day of the experiment) mixed the SF_6 to a uniform concentration throughout the entire house. The SF_6 concentration sampled from the living room was measured with an infrared analyzer and recorded with a strip-chart recorder.

The mechanical ventilation system operating at low, medium and high fan speeds yielded air-exchange rates of 0.4, 0.6, and 0.8 ach, respectively. When the mechanical ventilation system was operated at low fan speed, with the intake and exhaust opening almost completely taped over, the air exchange rate was 0.13 ach. The fifth ventilation condition was infiltration with no mechanical ventilation (0.07 ach). The ventilation rate was measured several times under each of these ventilation conditions. Because the range of values obtained for a given condition was small (on the order of 10% or less) we considered the ventilation rate constant for any of the five conditions.

Pitot tubes were used to measure the rate of air flow through the ducts of the mechanical ventilation system. Measurements of total ventilation rate agreed well with the sum of the air flow through the heat exchanger and the natural infiltration rate of 0.07 ach.

RADON AND RADON-DAUGHTER INSTRUMENTATION

Radon concentrations were monitored constantly during the experiment with a continuous radon monitor (CRM), after a design by Thomas.[11] The CRM, designed and built by LBL, is shown in Figure 2. The CRM measurements were supplemented by analyses of approximately 50 grab samples taken at different times during the study. These samples were either counted in the field using the commercially available RDA-200 radon detector*, or sent to LBL for analysis. The grab-sampling apparatus was calibrated using a National Bureau of Standards radium solution. The use of grab sampling techniques provided a secondary standard for calibrating the continuous radon monitor. The uncertainty in this calibration is 10% (one standard deviation of the ratio of radon concentration measured by grab sampling to counts per interval in the CRM).

*EDA Instruments, Toronto, Ontario.

Thus if σ_{Rn} is constant, the plot of $\log(I_{Rn})$ versus $\log(\lambda_V)$ would result in a straight line with a slope of minus one. The data shown in Figure 5 are well fitted by such a line, given a source magnitude of 2.5 pCi/l/hr. The exception is the point corresponding to 0.8 ach. The calculated radon source at this ventilation rate was about half that computed for the rest of the experiment. The reason for this apparent source drop is not known.

As shown in Figure 6, the radon-daughter working level plotted as a function of time, reveals the same general dependence on ventilation as was seen for radon concentration. Within a given ventilation condition, however, the working level shows more variability than the radon concentration and indicates that radon daughter concentrations depend on factors other than radon concentration and ventilation rate. The working level drops below the 0.02 WL value (set as an indoor guideline[9] and adopted as a standard[8] for communities in Florida and Canada, respectively) only when ventilation rates exceeded 0.6 ach.

DISCUSSION

Before the results of this study can be applied on a broad scale, we must address the question of differing radon source magnitudes between this particular energy-efficient house and the general housing stock. The published data on this important question are limited. Histograms of the results of studies in England[13] and in the United States[14] are plotted in Figure 7, and compared with the range of values obtained for the EER in this study. As is evident, the source values span more than two orders of magnitude. The EER values rank from the 60th to the 93rd percentile against the U.S. study and from the 84th to the 95th percentile against the England study, suggesting that while the source magnitude at the EER is high, it is not unique.

Another way of looking at these data is to calculate the fraction of houses that might have radon problems if constructed tightly. Assuming that tight construction could lower infiltration rates to 0.1 ach, that all houses could be constructed this tightly, and that all had source magnitude distributions indicated in Figure 7, then 36% of the homes in England and 75% of the homes in the U.S. would have radon concentrations in excess of 5 pCi/l when closed. Assuming ventilation rates were raised to 0.6 ach, the corresponding percentages would be 5% in England, and 7% in the United States.

Mechanical ventilation systems with heat exchangers, in a size appropriate for residential use, are currently being manufactured in Europe, Japan, Canada and, to a much lesser extent, in the United States. Prices vary widely, from about $200 for a small window unit to $2,500 for a fully installed central mechanical ventilation system that takes exhaust air from the bathrooms and kitchen and supplies fresh air to the living room and bedrooms. The high cost of some units results from the necessity of installing ducts when central forced-air heating and cooling systems are not already in place. In the United States, where forced air-heating systems are the standard in most new housing, the ducts already exist, and the installation cost would be considerably less.

CONCLUSIONS

We have demonstrated the effectiveness of mechanical ventilation with heat recovery in reducing the concentrations of radon and radon daughters in a low-infiltration house. By a simple analysis, we were able to show that the strategy of building tight houses and installing mechanical ventilation systems with air-to-air heat exchangers may satisfy energy-conservation goals in a cost-effective manner without compromising indoor air quality.

This approach cannot, by itself, eliminate indoor air-quality problems in situations where source levels of pollutants are high. In the case of radon, for example, the ventilation rate in houses built on land where the radon source is characteristically high cannot be increased to the magnitude that would be necessary for effectively controlling indoor radon concentrations. In such cases, methods of eliminating or blocking the source must be adopted; however, mechanical ventilation with heat recovery may still be desirable to maintain low concentrations of other indoor air contaminants.

As more experience with air-to-air heat exchangers is gained, other important issues must be resolved--among them, the long-term reliability and efficiency of heat exchangers and public acceptance of maintaining an additional home appliance.

ACKNOWLEDGEMENTS

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Table 2. Annual Energy Cost Savings* (in Dollars).

	Mode #2			Mode #3		
	0.5 ach			0.75 ach		
City	Oil	Gas	Electricity	Oil	Gas	Electricity
Atlanta, Georgia	---	24.71	72.05	---	10.90	47.72
Washington, D.C.	79.34	52.04	158.86	56.50	32.93	125.18
Chicago, Illinois	113.18	72.64	283.28	82.33	47.14	230.02
Minneapolis, Minn.	166.26	109.80	332.36	130.82	81.82	275.10

*Savings of Modes #2 and #3 when compared to base case (Mode #1). [Fuel prices taken from "Consumer Price: Energy," Press Release, U.S. Department of Labor, Bureau of Labor Statistics, USDL-79-679 (August 1979)].

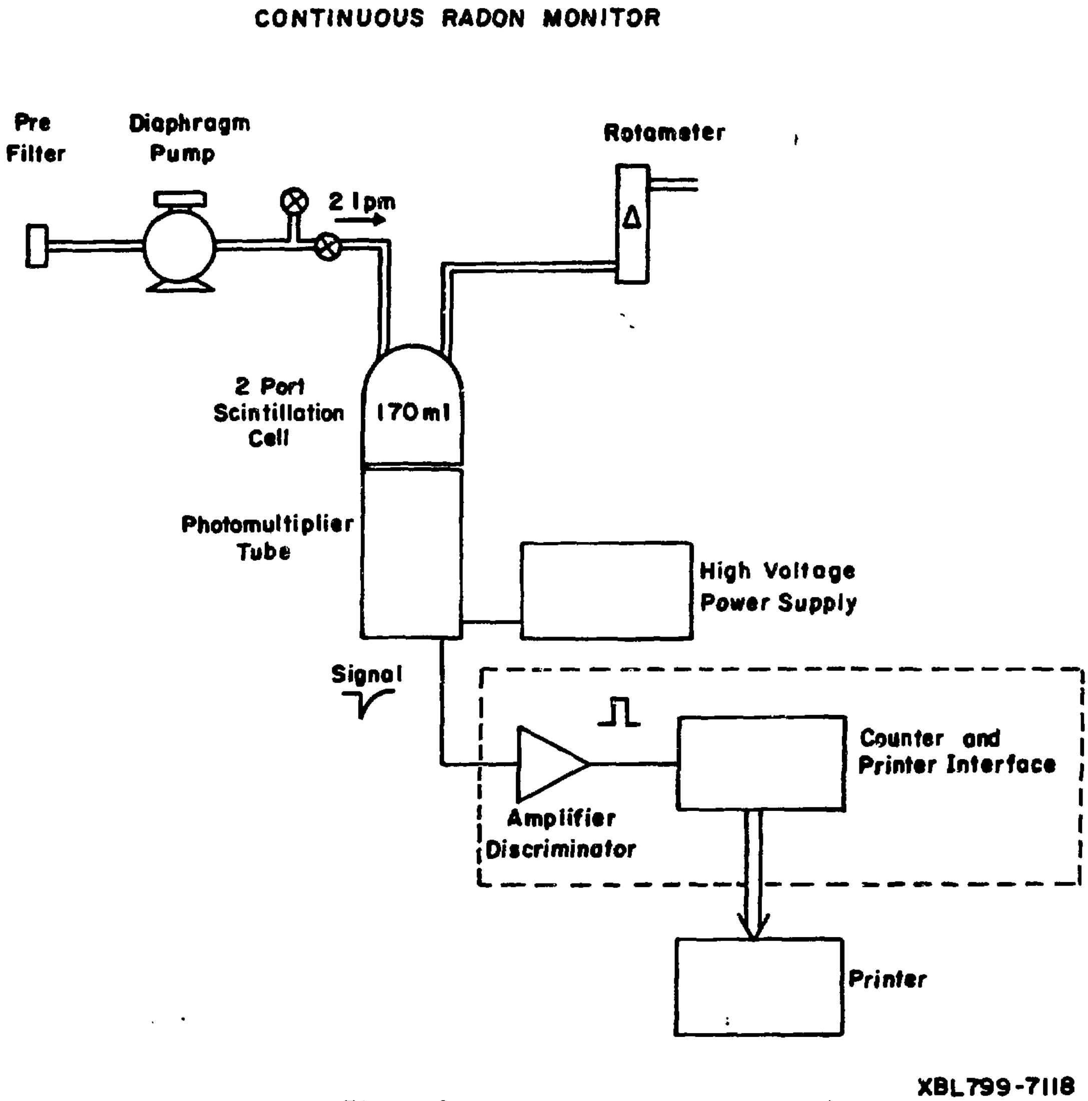
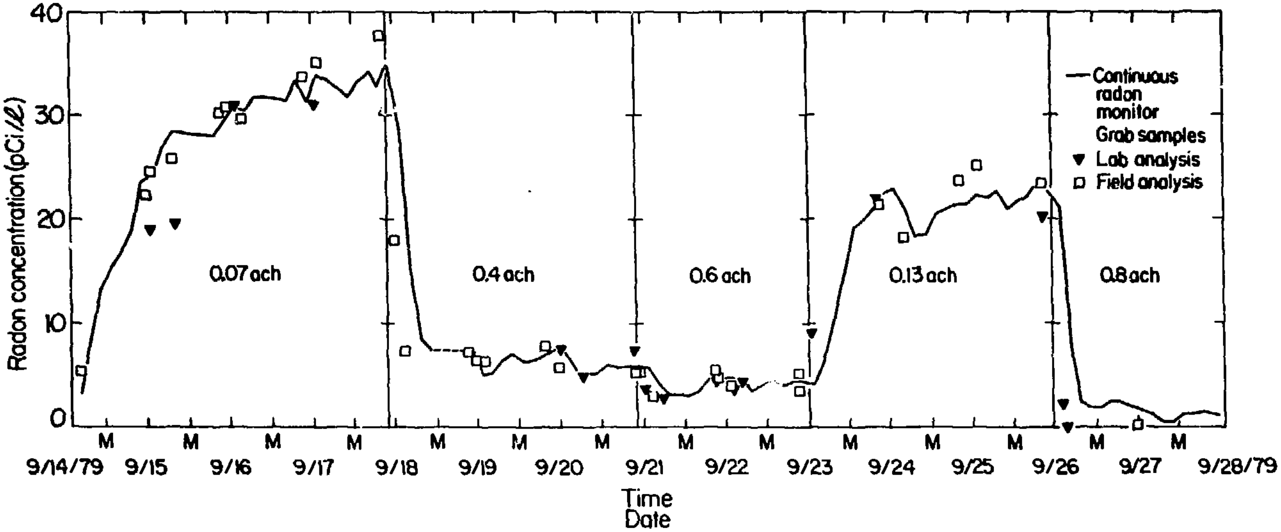

CONTINUOUS RADON MONITOR
Pre
Filter
Diaphragm
Pump
2 lpm
Rotameter
2 Port
Scintillation
Cell
170 ml
Photomultiplier
Tube
High Voltage
Power Supply
Signal
Counter and
Printer Interface
Amplifier
Discriminator
Printer
XBL799-7118

Figure 2

INDOOR RADON CONCENTRATION

Energy Research House
With Mechanical Ventilation
Carroll County, Maryland

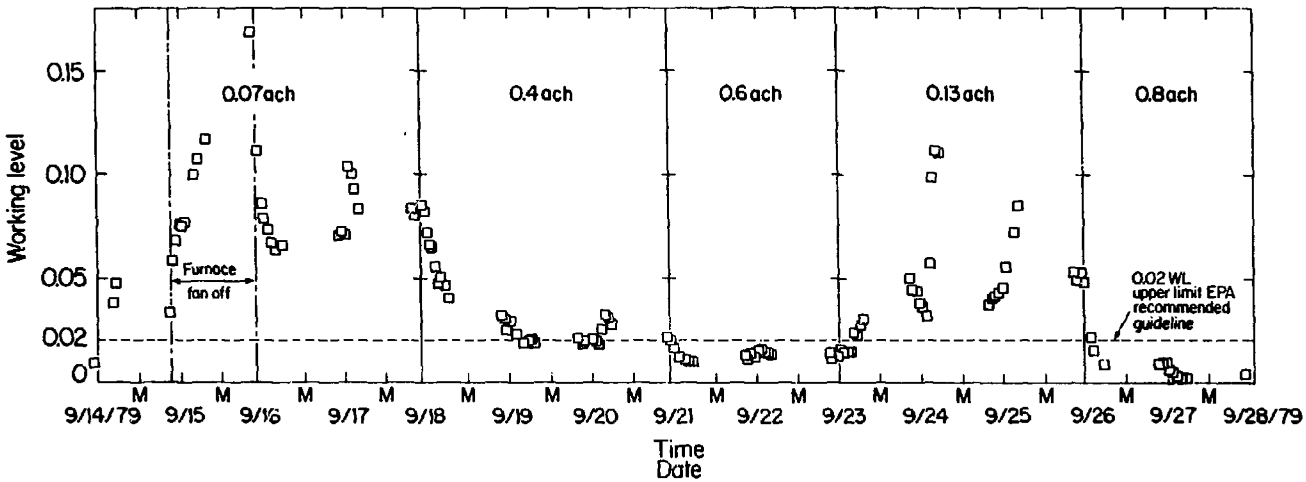


XBL 790-4440

Figure 4

RADON DAUGHTER WORKING LEVEL

Energy Research House
With Mechanical Ventilation
Carroll County, Maryland



XBL 7910-4484

Figure 6

The Use of Mechanical Ventilation With Heat Recovery For Controlling Radon and Radon Daughter Concentrations

Questions/Comments

E. Haubrich : What is the floor area of the homes in which the heat exchanger has been used.

W. Nazaroff : These homes were approximately 2,000 $ft.^2$ with 7.5 ft. ceilings, and we provided up to .75 of an air change per hour.

E. Haubrich : Are you assuming that provided the full air exchange?

W. Nazaroff : We measured the air-flow through the heat exchanger itself and it agreed closely with the k method that is adding .07 to the infiltration rate. We concluded that we didn't affect the natural infiltration rate significantly by using mechanical ventilation. We were providing approx. .73 air changes/hr. through the heat exchanger itself as verified by air-flow measurements.

L. Haywood : Has a cost/benefit analysis been done in this case?

W. Nazaroff : The energy load savings has been calculated which includes the operating cost.

C. Winzer : It appears from the figures given that the exchanger would pay for itself in about 2.5 years. Why has the concept not been adopted?

W. Nazaroff : What has happened to date is that many builders have gone only as far as the first stage - building more airtight structures.

A. Booth : You said that $450 was the cost of the heat exchanger?

W. Nazaroff : That is the cost that Besant has projected to install these units in homes. That cost would apply to new tightly sealed homes rather than existing, older housing.

Existing houses are very difficult to deal with because they cannot be more tightly sealed without a great deal of additional expense.

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R. Eaton : A possible remedial technique for some of the difficult houses we are dealing with would be to seal up the homes tightly and install controlled ventilation, utilizing air to air heat exchangers. The fan size used would be optimized to effect appropriate reductions in radon and toxic chemical levels as well as achieve certain energy savings. The tight seal of the home would ensure that the occupants would maintain the fan in operational mode to protect their own comfort. That way, you could ensure the remedial work, ventilation, is maintained.

A. Scott : Existing techniques for tightening up old houses are reasonably standard in Canadian construction practice. There are new homes currently being built using these techniques which are electrically heated, have continuous vapor barriers and have the juncture of the wood frame and the concrete foundation walls sealed. These homes, when unoccupied, have ventilation periods exceeding 10 hours.

W. Nazaroff : Do you know of any people complaining about air quality problem in such homes?

A. Scott : I haven't heard of any.

A. Vivyurka : We are having moisture problems with those homes.

R. Eaton : Are the houses occupied?

A. Vivyurka : Yes.