Recycling and Reuse Technology Transfer Center

Recycling and Reuse Technology Transfer Center

RRTTC
RECYCLING & REUSE
TECHNOLOGY TRANSFER CENTER

http://www.rrttc.uni.ed

Radon Reduction through Solar Ventilation: Design & Evaluation

Publication: 1995 – 040

Heather Rhoads, P Hoekje, Richard Klein, J. Olson

95-040

1

RADON REDUCTION THROUGH SOLAR VENTILATION: DESIGN & EVALUATION

H.E. Rhoads, P.L. Hoekje, R.J. Klein, and J.A. Olson
Environmental Science Program
University of Northern Iowa
Cedar Falls, IA 50614-0421
(608) 273-2645

ABSTRACT

Conventional residential energy conservation measures that limit air exchange rates between the indoors and outdoors have been shown to increase concentrations of radioactive radon decay products as well as other indoor air contaminants such as combustion by-products and off-gases from carpeting, furnishings, appliances, cleaning products, and building materials. The ventilation system under investigation seeks to combine the goals of energy efficiency and conservation with low-cost radon reduction and indoor air quality management. Drawing on established radon mitigation techniques of ventilation, air supply and pressurization, the Solar Radon Reduction System (SRRS) provides radon reduction at low energy costs due solar pre-heating of supply air. Installation costs for the SRRS are also lower than conventional air-to-air heat exchanger and sub-slab suction radon mitigation options. Radon reduction and indoor air quality improvement are accomplished through dilution, reduced infiltration, and slight pressurization of the dwelling through induced-draft solar-heated outdoor air and the supply of combustion appliance make-up air. Installed in six test homes in Waterloo and Cedar Falls, Iowa, the SRRS was found to achieve significant radon reductions in all houses with elevated levels of up to 73% from background levels as high as 20.9 pCi/L.

INTRODUCTION

Increased insulation and weatherization, intended to reduce home energy demands and heating bills, have been found to have detrimental effects on the quality of indoor air due to limiting the frequency of natural air changes. The U.S. Environmental Protection Agency (EPA) now warns that improper ventilation can concentrate contaminants which would otherwise escape through leaks and cracks, and many indoor environments may be dangerously polluted by these toxic chemicals and gases. Tightened to conserve energy, a growing number of homes, buildings and schools are plagued by "sick building syndrome" (Dulley, 1994). The broad array of indoor pollutants includes molds, airborne fungal spores and bacteria, pesticides, solvents, respirable dust, carbon monoxide, nitrogen dioxide, formaldehyde, and other volatile organic compounds (VOCs), but the most insidious may be radon gas and its byproducts. Radon is harder to detect and reduce at the source than other airborne pollutants, and difficult to filter. Still, high levels of radon as well as the many other air pollutants can be prevented from accumulating indoors (Turner and Brennan, 1985). Since U.S. residents spend on average 75-90% of their time indoors, the health of many people may greatly depend on the quality of air in the indoor environment.

An invisible, odorless radioactive gas produced from the natural decay of uranium-238 and radium-226, radon-222 is found in nearly all soils and occurs in low concentrations almost everywhere on earth. High concentrations of radon gas have been traced to large deposits of granite and sillimanite rock, as well as to granitic sand and gravel. Radon is readily soluble in water, so groundwater that has recently reached the surface, including well water, may also carry high levels of radon.

Radon can enter the indoor environment via several paths, including emission from building materials. In both the U.S. and Sweden high radon levels have been attributed to radioactive shales and mine tailings inadvertently used for residential construction (Turner and Brennan, 1985). More typically, radon originates as gas in soil beneath homes and buildings and infiltrates inside through floor drains, hollow-block walls, cracks in concrete walls and floors, gaps and joints in building materials, or direct exposures to soil. It can also outgas from the water supply, when water is exposed to air during showering and other household or industrial uses. Because radon is inert and does not chemically bind or attach to other materials, it can easily pass through all gas-permeable materials including concrete (Renken, 1994). Due to pressure differentials created by the "stack effect" of convection between basements and upper floors, radon is drawn indoors and can accumulate to hazardous levels, particularly in cold seasons or during rainy weather conditions.

The major health concern associated with elevated radon concentrations is an increased risk of contracting lung cancer. Although radon is one of the few *known* (Group A) carcinogens, the level of lung cancer risk associated with residential radon exposure is still controversial. Two short-lived radon decay products, both alpha-emitting polonium isotopes, are solids which can attach to dust particles and, upon inhalation, become lodged in airways near some of the most cancer-sensitive cells in the human body. As the decay process continues, the radioactive particles release bursts of energy that ionize lung tissue. Damaged cells can then multiply rapidly, resulting in lung cancer. Research is currently underway to find out if radon causes other kinds of cancer as well. The EPA reports that drinking water with high radon levels may also pose risks, though hazards from ingesting radon-laden water are believed to be much lower than those from breathing air containing radon. The National Cancer Institute has declared radon exposure the leading cause of cancer among non-smokers, accounting for an estimated 7,000 to 30,000 deaths per year. The EPA has set a recommended "action level" for remediation at the radon concentration of 4 picoCuries per liter of air (pCi/L), which is comparable to having 250 chest x-rays per year. The ubiquitous problem of radon accumulation has prompted senior EPA officials to label radon the "highest cancer risk of any single environmental problem" (Freije, 1990).

A 1988 EPA survey found that nearly one in three homes have elevated radon levels, prompting the Surgeon General to urge testing for all houses and apartments below the third floor. The EPA now estimates that 1 out of every 15 homes throughout the U.S. have radon levels of 4 pCi/L or more (US EPA, 1993). In Iowa, an estimated 70-75% of homes have radon levels above 4 pCi/L (Eckoff, 1990). An EPA survey of 130 schools among 16 states found that 54% of the schools had at least one unsafe room, while 19% of the 3,000 classrooms measured high. It is now believed that the radon danger in schools and most other types of non-residential buildings is at least as severe and widespread as it is in homes

(Freije, 1990). The average indoor radon level is estimated to be about 1.3 pCi/L, compared to an average of 0.4 pCi/L outdoors. The U.S. Congress has set an ambitious long-term goal that indoor radon levels be no more than outdoor levels (US EPA, 1993).

Usual radon mitigation methods attempt to prevent naturally-occurring radon gas from entering a building by keeping the living space at a higher pressure than that of the contiguous soil. The EPA currently recommends the following approaches to reduce radon infiltration and accumulation in existing structures:

- Natural ventilation,
- Forced ventilation,
- Sealing foundation cracks and openings,
- Sub-slab suction,
- Air supply, and
- Heat-recovery ventilation (US EPA, 1986).

Sealing cracks and other openings in the foundation is a basic part of most approaches to radon reduction, although the use of sealing alone is not recommended as it has not been found to lower radon levels significantly or consistently. The most heavily marketed mitigation system at present, sub-slab depressurization (SSD), uses fans oriented upward to apply suction beneath the foundation and vent exhaust air above the roof. Creating a pressure differential large enough to lower radon below the EPA action level often requires drilling several holes into the concrete slab and installing associated piping as well as sealing cracks, holes, and drains (Freije, 1990). This can result in considerable expense to homeowners and may also worsen other common indoor air pollutants, such as carbon monoxide from combustion appliances.

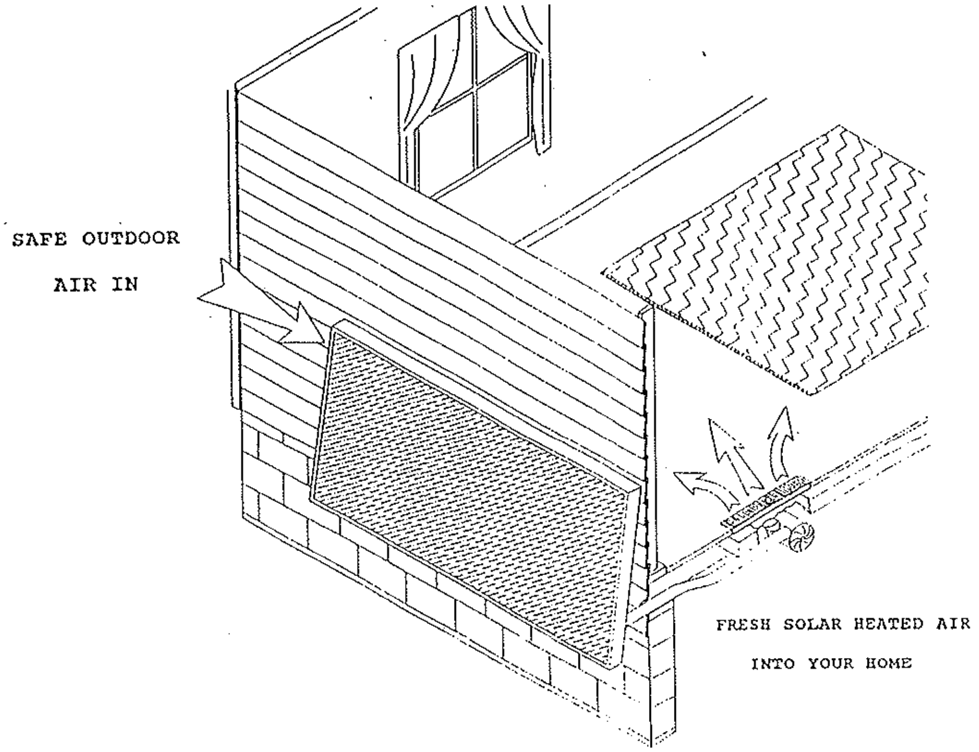
The average charge for a contractor to lower radon levels in a home is about $1,200, although repairs required may range from $500 to $2,500 (US EPA, 1993). Less costly approaches to radon reduction include pressurizing the indoors with supply-air fans and increasing ventilation with air-to-air heat exchangers (AAHX), which help dilute other contaminants as well as radon. However, all commercially available radon mitigation systems, including those equipped with AAHX, operate at a net energy loss in temperate climates through the direct introduction of outdoor-temperature air. Thus these popular air management strategies can be quite energy intensive and counteract steps to increase weatherization and energy conservation.

Controlled evaluation of varied radon mitigation techniques at specific sites is difficult due to the numerous factors that determine indoor radon concentrations, primarily the radon source strength and infiltration rate. Effects of construction factors, such as the integrity of basement slabs and foundation walls, characteristics of sumps and drains, crevices at pipe entry points, unpaved crawl spaces, and the infiltration rate of natural outside air or "tightness" of the dwelling, are often indeterminable before mitigation is attempted. Even a well-ventilated building may have a high radon level due to negative basement pressure and thus an increased gas entry rate. A structure's natural infiltration rate can vary seasonally due to changes in soil moisture and frost level or even hourly based on barometric pressure, convection, and effects of wind direction and velocity (Fleischer, 1988). Given the number of radon mitigation options, the range of factors that affect radon levels in a dwelling, and the fact that no single system can guarantee acceptable indoor radon levels, homeowners and radon mitigation contractors must weigh several variables when developing a mitigation approach. Installation and operating costs associated with each mitigation step often compound the selection of optimum systems.

PROJECT HISTORY

In attempt to address both elevated radon levels and heating costs, one of the authors (R. J. Klein) devised and installed an original solar ventilation system to introduce fresh, pre-heated air indoors at a test home in Waterloo, Iowa in 1990. The Solar Radon Reduction System (SRRS), initially comprised of a 4' x 8' flat-plate solar air collector, ductwork into the central heating system, and a 0.59 Amp, 75 cfm (cubic feet per minute) mechanical blower, was designed to both pressurize the indoors and improve air quality in an energy-efficient manner (Fig. 1). The supply of outdoor make-up air for combustion appliances and stack effect losses helps to lower indoor radon levels through reduced infiltration and dilution. During cold seasons, the SRRS introduces solar-heated outdoor air into the home, augmenting its existing heating system to produce a net energy gain. In the summer months, the system's blower provides low-energy cooling by ventilating the structure when outdoor air temperatures drop below indoor comfort levels (Klein, 1992; Klein & Olson, 1993).

Fig. 1 Diagram of Solar Radon Reduction System



Based on charcoal canister readings, the initial radon concentration of 8.8 pCi/L in the basement of the first test home was reduced to 2.5 pCi/L, a reduction of more than 70%. Energy costs were reduced and the general indoor comfort level was reported to be improved by the addition of solar heated outside air. In 1991 the system was chosen as an award recipient in the Innovative Radon Mitigation Design Contest sponsored by the U.S. EPA, the Association of Energy Engineers, and Environmental Engineers & Managers Institute. The EPA requested that further research be conducted on the technique according to EPA Protocols for Diagnostic Measurements in Radon Mitigation Demonstration Projects (US EPA, 1986).

An additional solar collector, which heats domestic water in tubes inside the panel as well as vents solar-heated air indoors, was then installed in conjunction with the first SRRS to further extend heat gain and energy savings throughout the year. This homemade panel was constructed from debris recycled from a home improvement project, as the glazing was previously used as sliding glass doors. A second complete SRRS was installed in 1991 at another test home in Cedar Falls, Iowa, which originally exhibited a charcoal canister radon reading of 19.9 pCi/L in the basement. Construction and installation was accomplished at about 10% of the cost of comparable commercially available radon mitigation systems (Klein & Olson, 1993). In 1993, the SRRS design was issued U.S. Patent 5,186,160 and awarded funds by the University of Northern Iowa's Reuse & Recycling Technology Transfer Center to continue research. A detailed instruction manual was developed for homeowners or contractors to build an SRRS — a solar panel installed on a south-facing wall, roof or as free-standing unit together with a fan, wiring, and ductwork into the building's central heating system — for about $200, or even less if constructed with recycled materials (Klein, 1993).

SRRS efficiency evaluations were first conducted in the winter of 1992-93 at test home North, a 960 ft^2, 1½-story wood-frame home equipped with a natural gas water heater, clothes dryer and forced-draft furnace; and test home Lovejoy, a single story, 1270 ft^2 wood-frame home with all-electric appliances including a resistant heat forced-draft furnace. Both houses have partial basements and crawl spaces under the living area. Initial data collection included radon levels, hours of system operation, air flow rates, structure pressure differentials, temperature differentials, and estimated energy used. Radon data were collected in both homes as the mean of 4-hour intervals with two continuous radon data loggers (Honeywell Model 05-418) operated in accordance with EPA protocol (US EPA, 1993).

The duration of SRRS and furnace operation was measured and recorded daily using elapsed time hour meters. The volume of air the SRRS induced-draft fans introduced into the homes was based on manufacturer data confirmed with pitot tube velocity and duct outlet area measurements. The SRRS at North produced an air flow of either 65 or 130 cubic feet per minute (cfm), based on whether one or both of solar panel fans were in operation, resulting in 0.6 or 1.2 air changes per hour (ACH). Single SRRS panel operation at Lovejoy produced an air flow of 75 cfm, adding 0.4 ACH. Dwelling pressures were determined with manometers and blower door tests, and utility meters along with temperature/relative humidity strip charts were used to calculate energy usage (Klein & Olson, 1993).

The two Honeywell radon monitors were initially operated side-by-side simultaneously with a carbon canister test at Lovejoy to evaluate the precision of the instruments. Based on ten day monitor means of 8.4 and 8.3 pCi/L and the canister result of 8.1 pCi/L, the instruments were determined to be statistically calibrated at a 96% confidence interval. The monitors were then installed on the first floors at the test homes, which were maintained in "closed house conditions" with the SRRS deactivated and sealed, to establish background radon levels according to EPA protocol (US EPA, 1993). Data indicated 1st floor background radon concentrations of 4.3 pCi/L for North and 8.0 pCi/L for Lovejoy.

The SRRS was tested in a variety of operational modes to evaluate individual effectiveness of the system as well as when used in conjunction with other EPA-recommended mitigation methods. The initial evaluation was conducted with the SRRS operating in a solar thermostat-driven mode, which achieves maximum energy benefits by introducing solar heated air inside only during times when adequate solar energy is available to heat outdoor air above the ambient indoor temperature, to a minimum of 25°C and often as high as 50°C. The thermostat located on the inside surface of the solar collector typically triggered the induced-draft fan to operate in this mode between 9 am and 3 pm.

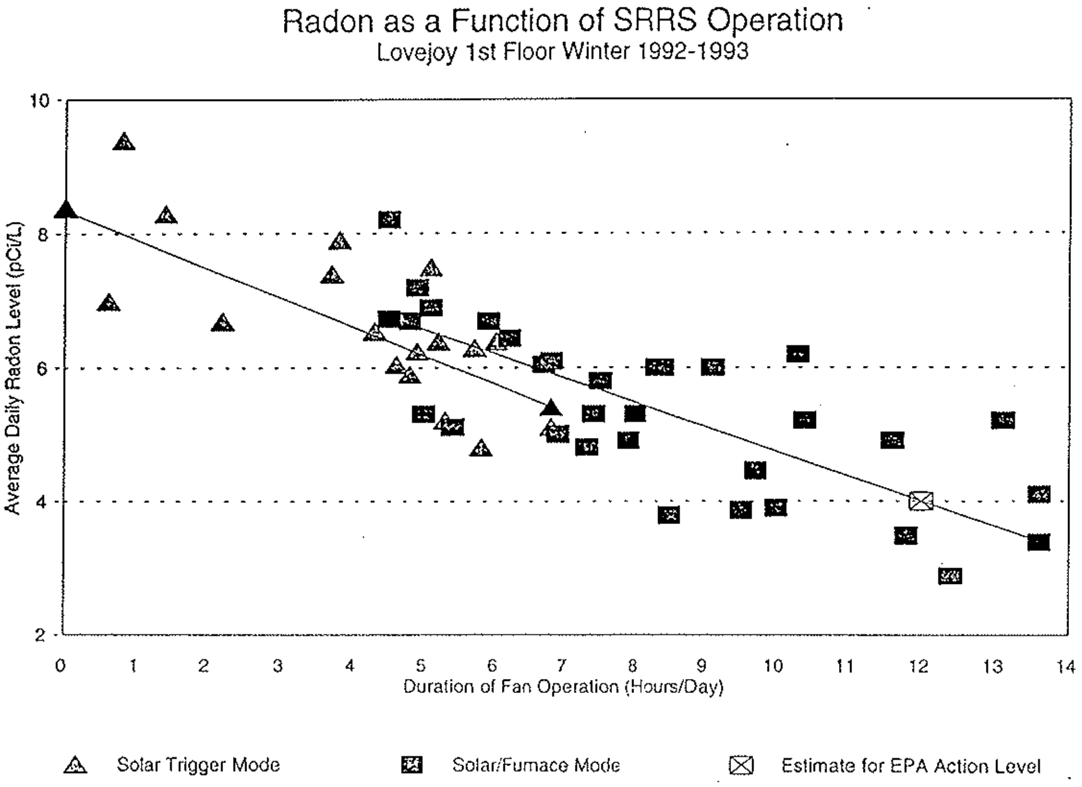
Compared to background radon concentrations, SRRS solar thermostat-driven operation was found to lower mid-day radon levels by an average of 29% at North and by 24% at Lovejoy (Klein & Olson, 1993). This initial research revealed that over the 6-week test period, cloudiness and adverse weather conditions limited SRRS operation to less than 1 hour for about 15 days. Due to continued radon infiltration when the mitigation fans were off, night-time and early morning radon levels returned to near background levels.

The second operational mode evaluated the effect of the SRRS when the fans were allowed to operate for additional periods of time than could be achieved in the solar thermostat-driven mode, when home heating demands required furnace operation. A "solar/furnace-driven mode" was achieved by wiring the SRRS to trigger its induced-draft fan both by the solar thermostat and an electrical relay circuit from the central furnace fan. In addition to providing longer SRRS operation, this mode allowed operation of the system at intervals throughout the day and night as well as during times of solar insolation.

As would be expected for a ventilation/pressurization mitigation system, SRRS radon reduction effectiveness was found to be related to the duration and volume of air introduced into the dwelling. Data collected during the extended furnace-driven mode showed mixed results: North showed little correlation between radon concentration and hours of SRRS operation, which may be attributed to the rate in which radon resumed infiltration during non-operational periods; yet Lovejoy showed a direct correlation between reduced radon and hours of system operation (Fig. 2). Extended solar/furnace-driven SRRS operation accomplished maximum radon reductions of 53% at North and 56% at Lovejoy compared to background levels.

Through graphical interpolation of the data obtained with both test modes, SRRS operation (with a 75 cfm flow rate) for 12 hours per day was predicted to keep first floor radon levels below EPA's action level of 4.0 pCi/L at Lovejoy. Even with extended operation, the solar heating aspect of the SRRS still provided a net conventional energy gain by introducing pre-heated air indoors several hours per day. Based on BTU heat gain and loss calculations, energy savings for the 6-week period were estimated to be 1.1 MBTU at North and 0.2 MBTU at Lovejoy, verifying that the SRRS yielded a net, albeit small, energy savings in both test homes (Klein & Olson, 1993). Long-term energy savings were predicted to be greater, as solar insolation received during the test period was approximately half the average available in the region for January through March.

Fig 2. Effect of thermostat-driven and increased hours solar/furnace-trigger SRRS operation on radon concentration for test home Lovejoy



MODIFICATION & EVALUATION

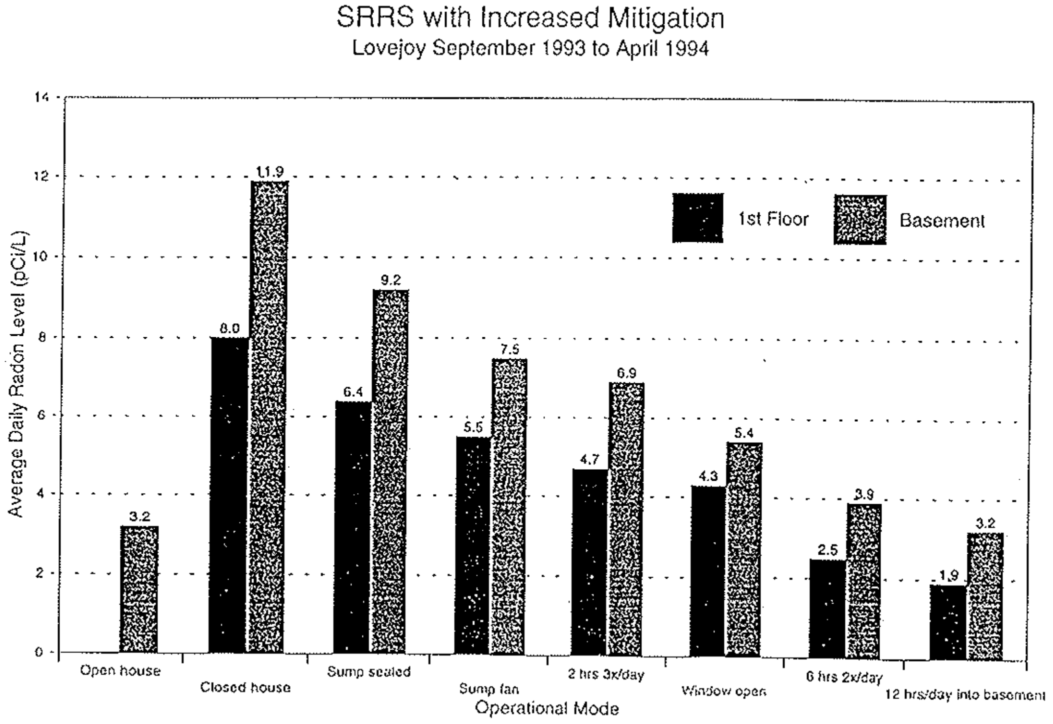
Further testing continued in 1993 and 1994 to evaluate the flexibility of the SRRS in additional modes of operation as well as to determine the optimum operational mode and resulting radon reduction efficiencies. Test home Lovejoy, equipped with the two continuous radon monitors in both the basement and first floor living areas, was monitored over seven months with increasing levels of mitigation as shown in Table 1, selected to coincide with EPA's radon mitigation action steps (US EPA, 1986).

Data collected reveals incremental reductions for each of the test configurations (Fig. 3). The first mode, with the SRRS deactivated and basement and upstairs windows open a majority of the time to accommodate relatively mild fall weather, resulted in an average basement radon concentration of 3.2 pCi/L, which represents the minimum radon level expected utilizing natural ventilation as the sole form of mitigation. While this most simple method achieved a radon concentration below the EPA action level, such open house conditions are impractical in Iowa and most temperate climates during several months of the year.

Table 1. Increased radon mitigation steps with Lovejoy SRRS

Time Interval	SRRS/Dwelling Conditions
9/10/93-10/7/93	SRRS deactivated; periodic open house conditions including basement windows open.
10/8/93-11/8/93	SRRS deactivated; closed house conditions.
11/9/93-11/26/93	SRRS 75 CFM fan discharging through central heating system to 1st floor during adequate solar insolation (solar thermostat-trigger mode); foundation sump pump pit sealed and passively vented outdoors.
11/27/93-12/29/93	SRRS discharging upstairs during adequate solar insolation; sump pit vented outdoors with 45 CFM fan.
1/1/94-1/9/94	SRRS discharging upstairs triggered by timer set for 2 hours, 3 times per day; continued sump pit forced venting.
1/10/94-2/6/94	SRRS discharging upstairs during times of adequate solar insolation; one basement window slightly opened; continued sump pit forced venting.
2/7/94-2/22/94	SRRS discharging upstairs with timer trigger set for 6 hours, 2 times per day; one basement window slightly opened; continued sump pit forced venting.
3/25/94-4/17/94	SRRS discharging directly into basement with timer trigger set 6 hours, 2 times per day; basement window closed; continued sump pit forced venting.

Fig. 3 Incremental radon reduction at Lovejoy



The second test period determined closed house background radon concentration levels of 8.0 pCi/L upstairs and 11.9 pCi/l downstairs, used as baselines to establish radon reduction efficiencies for subsequent SRRS test modes. Lovejoy had visually sound basement concrete slab and foundation walls, but an open foundation drain tile sump pit was identified as a possible direct radon entry point. During the third test period, the SRRS was activated to discharge air through the home's ductwork into the 1st floor living area with solar thermostat-driven operation. In addition, the foundation drain tile sump pump pit was sealed and passively vented to the outdoors. The combined SRRS solar thermostat operational mode in conjunction with basement sealing lowered radon levels an average 20% upstairs and 23% downstairs. These values are consistent with first year solar-thermostat mode testing results of a 24% reduction, suggesting the mitigation achieved during this test mode was primarily due to the operation of the SRRS. Therefore in this case basement sealing and sump pit venting appeared to be negligibly effective in improving the mitigation.

In the fourth test mode, the SRRS remained in solar-thermostat operation while the sump pit ventilation system was modified to include a 45 cfm forced-draft exhaust fan, a variation of the popular subslab depressurization mitigation technique. Given constant SRRS operation, this more aggressive radon mitigation technique resulted in radon reduction improvements of 11% upstairs and 14% downstairs as compared to natural sump pit ventilation, yet EPA action levels were still not obtained.

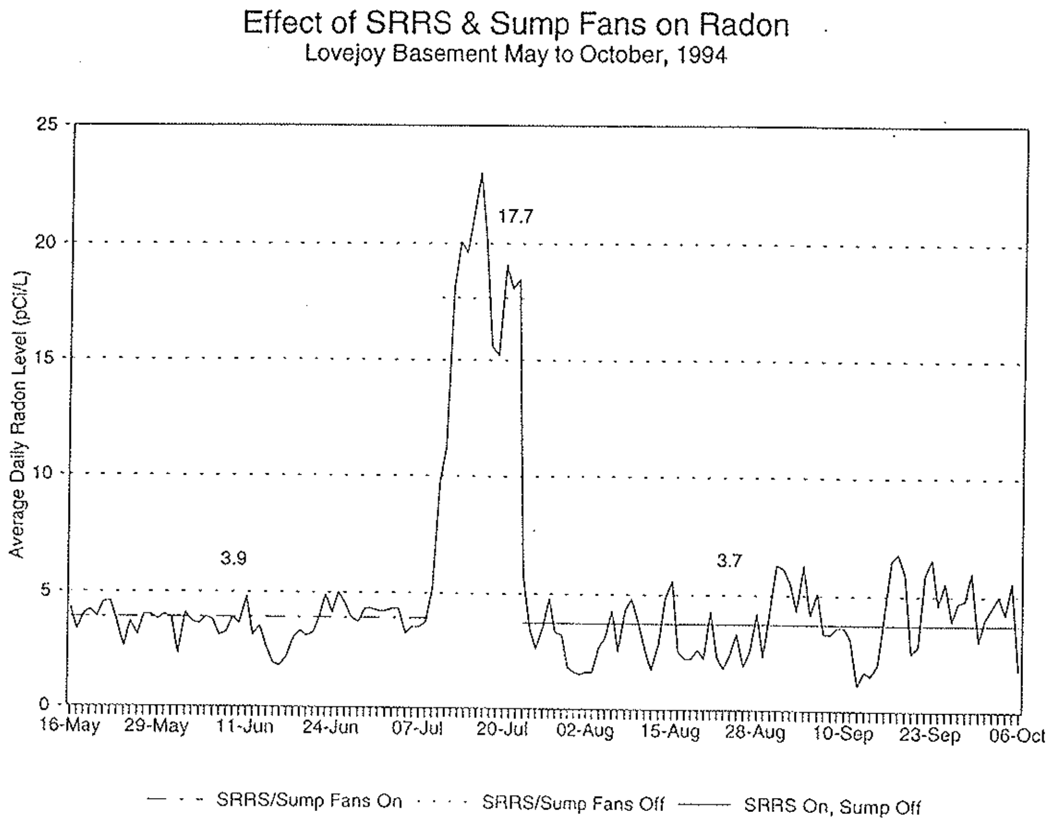
During optimum solar insolation conditions (i.e. non-cloudy days), the SRRS operates for approximately 6 hours, typically between 9 am and 3 pm. To evaluate the effect of the SRRS during ideal weather conditions as compared to actual weather-related operation, the SRRS was wired to a timer set to operate the system for two-hour intervals evenly spaced three times throughout the day. From the data obtained during this fifth test mode, actual SRRS radon reduction performance during actual solar-driven operation was estimated to be an impressive 85% to 92% of what was measured under simulated ideal conditions. This relatively high actual to ideal efficiency may be related to the system's ability to reduce infiltration by supplying low impedance appliance makeup air throughout the day regardless of fan operation (Klein & Olson, 1994).

Since downstairs radon levels remained consistently higher than first floor levels, increased air supply directly to the basement was predicted to aid the mitigation. Thus test period 6 incorporated natural basement ventilation with SRRS operation, accomplished by returning to solar thermostat-driven operation and opening one basement window. Lower radon levels were again obtained and the relative difference between the basement and 1st floor levels was reduced.

In consideration of results from first year testing which indicated that 12 hours of SRRS operation could achieve an average upstairs radon level of 4.0 pCi/L, a timer was set to trigger the fan to operate 6 hours two times per day for test mode 7. This timer-based operation coincided with the optimum solar insolation period to obtain maximum energy gain (9 am to 3 pm), and an additional 6-hour period provided evenly-spaced mitigation during the night. This mode of operation resulted in an first floor radon concentration of 2.5 pCi/L (69% reduction) and a basement level of 3.9 pCi/L (67% reduction). The SRRS was next modified to discharge fresh air directly into the downstairs area of the dwelling rather than through the home's central heating system, and the basement window was closed. With the fan still timer-operated for 12 hours per day, this approach achieved a maximum reduction of 76% upstairs and 73% downstairs (Klein & Olson, 1994).

Longer-term evaluations of the 12-hour timer-based SRRS operational mode were continued at Lovejoy over the summer of 1994 to evaluate the effect of both the SRRS intake fan and the sump pit exhaust fan (Fig. 4). The three-month basement radon concentrations from May to July during operation with both fans running averaged 3.9 pCi/L. A two-week period in July when both fans were deactivated and the house was maintained in closed house conditions while the homeowners were on vacation graphically illustrates how quickly the basement returns to high background radon levels of 17.7 pCi/L without mitigation, which is even higher than the winter-time baseline obtained the previous year (11.9 pCi/L). The following three-month test was conducted with only the SRRS fan in operation and revealed larger daily average radon ranges but a long-term average almost equivalent to the test with both the SRRS and sump fans, 3.7 pCi/L. This demonstration documents the stronger mitigation influence of SRRS ventilation and positive pressurization relative to the sub-slab suction achieved by the sump fan in this case. It also indicates that the lowest expected long-term basement radon levels at Lovejoy even with combined mitigation methods are in the 4 pCi/L range.

Fig. 4. Relative importance of SRRS and sump pit fan operation on radon mitigation



The improvements developed and successful results obtained during the second year of research established that the SRRS is a promising radon reduction technique, but additional evaluations on a larger number of test houses were desired to more fully document the effectiveness of the system. While radon reduction effectiveness and energy efficiency will undoubtedly vary from installation to installation, improved indoor air quality and energy benefits are expected in all cases.

ENERGY CONSIDERATIONS

A major advantage of the Solar Radon Reduction System over other radon mitigation methods is its ability to introduce solar-heated air into the home during cold weather as well as to provide low-energy summertime cooling. This energy gain is optimized when system operation is limited to periods of adequate solar isolation during the heating season and when outdoor temperatures drop below ambient indoor levels in the summer. The net energy efficiency of the SRRS can be contrasted to sub-slab depressurization systems, which introduce no external air into the house. A drawback of SRRS operation in other modes is the introduction of wintertime cold outside air during cloudy days and nighttime operation as well as overly warm and humid outdoor air during the cooling season.

Such heat gains and losses can be calculated for Lovejoy for the 12-hour timer-based operational mode (6 hours twice a day) for the month of March, 1994, which included 10 clear days, 11 partly cloudy days, and 10 cloudy days; an average outside temperature of 2°C; and an estimated average relative humidity of 50%. Fan temperature monitoring indicates that average SRRS outlet air can be assumed to be:

- 38°C for 4 hours and 20°C for 2 hours on clear days;
- 20°C for 6 hours on partly cloudy days;
- 2°C for 6 hours on cloudy days; and
- 2°C for all 6 hour nighttime operation intervals.

The net energy content or enthalpy of SRRS outlet air was therefore estimated to be 1.7 MBTU for the month of March, and the enthalpy of indoor air at an average 22°C and 25% relative humidity replaced by SRRS air was about 2.7 MBTU (Klein & Olson, 1994). Thus approximately 1.0 MBTU of extra heating energy (300 KWH with an electric furnace) was required to accommodate SRRS outlet air to indoor ambient levels. Additionally, operating the 115 Volt, 0.59 Amp induced-draft fan for 12 hours per day for 31 days required 25 KWH of electricity. At the volume-discounted rate of $0.03/KWH in Cedar Falls, IA, the energy expense attributable to SRRS operation for March 1994 was about $9.75. The solar collector's heat input saved 510 KWH or $15.30.

If each month of operation resulted a similar net expense due to a heavier demand on either heating or air conditioning, the annual SRRS operating bill would be around $117. Complete installation of the SRRS was estimated to be $500 versus a typical $2,500 for sub-slab mitigation, which operating 24 hours per day with the same type of fan would cost 50 KWH/month or $42/year. Negating the time value of money, the energy payback of the SRRS toward the sub-slab system would be about 27 years, most likely beyond the working life of the system and the time most people reside in a home (Klein & Olson, 1994).

CURRENT RESEARCH

Initial SRRS evaluation involved progressively more aggressive system operation and intervention to obtain below action-level radon concentrations. In other dwellings, similar trials and radon recording instrumentation was anticipated to be necessary to determine optimal system operation. In order to simplify subsequent SRRS installations, newly available and affordable continuous radon alarms equipped with start/stop electrical relays (EnvirAlert Model MTL-102 with MTL-106 mitigation controllers), which trigger fans to operate above pre-programmable radon levels, have been incorporated into the SRRS strategy.

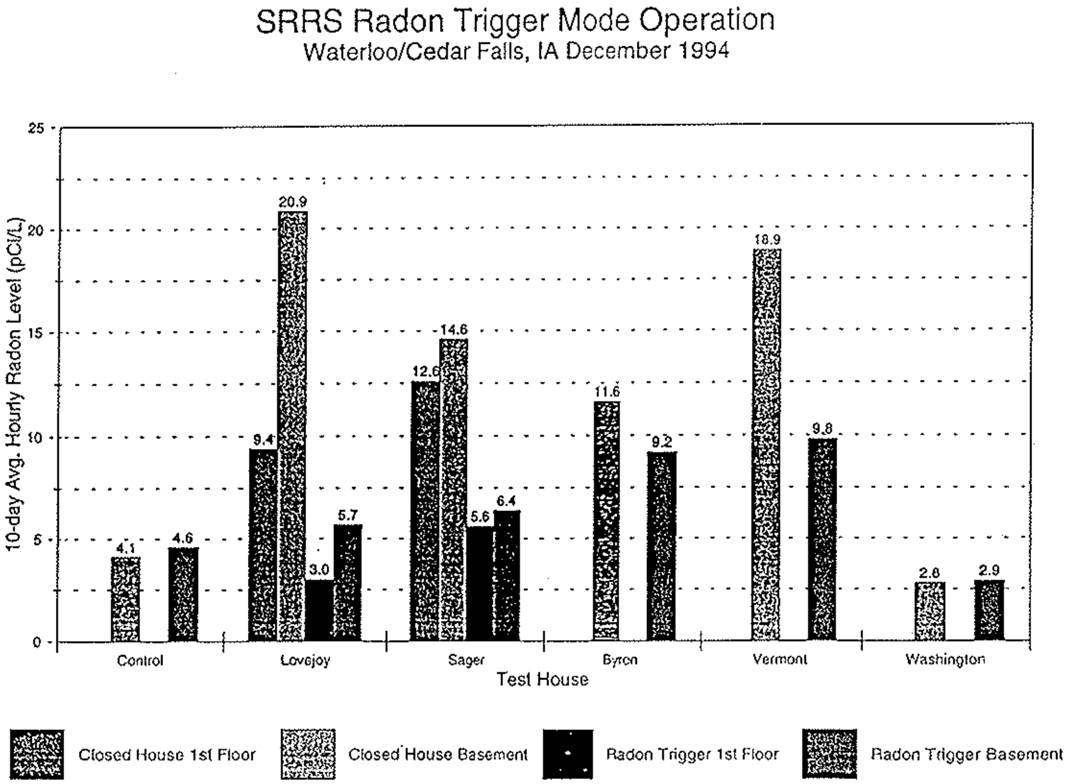
In the summer and fall of 1994, modified SRRS systems were installed at four additional test sites with elevated radon levels. Each house was equipped with EnvirAlert radon-trigger mitigation control devices as well as computer data acquisition systems for continuous datalogging. These "radon-stats" activate the SRRS when radon levels reach 3.0 pCi/L, and to maximize energy benefits, are wired in conjunction with electronic temperature sensors that additionally activate the fan either above (heating mode) or below (cooling mode) a preset intake temperature. The sites were monitored to determine the most suitable operational mode at each to maximize energy savings for desired radon reduction levels. Data collected include radon levels, solar radiation, inlet and outlet temperatures and humidity, air speed, and indoor/outdoor pressure differentials at hourly intervals to assess radon infiltration and energy gains under varying conditions.

Based on initial side-by-side operation for several days, the six EnvirAlert radon monitors were determined to be calibrated at a 90% confidence interval. Preliminary data was collected in December 1994 for closed house conditions and radon-trigger operation (at 3.0 pCi/L mitigation level) at the four new sites Sager, Byron, Vermont, and Washington as well as Lovejoy and a "control" house which had no radon mitigation installed. The two Honeywell monitors were used to record 1st floor radon levels at Lovejoy and Sager, and Air Chek mail-in charcoal radon testers were used to determine 1st floor levels at Byron, Vermont, Washington, and the control.

For the 10-day test periods, the SRRS was found to significantly reduce the average basement radon concentrations at every house with elevated radon levels during radon-trigger operation compared to closed house conditions (Fig. 5). The maximum response was seen at Lovejoy, which was the only mitigation which included sump pump pit and foundation sealing, from a background level of 9.4 pCi/L to 3.0 pCi/L on the first floor (a 68% reduction) and from 20.9 pCi/L to 5.7 in the basement (a 73% reduction). Since the EnvirAlert monitors output a radon value which is an average of the previous 22 hours, the lag time between the start of an upward radon trend and the electrical activation of the SRRS fan may be a limiting factor; additional testing during combined radon-trigger and solar temperature-trigger operation has shown improved reductions.

Based on mail-in testers, below-EPA action level results were also achieved on the first floor at both Byron (3.9 pCi/L) and Washington (3.5 pCi/L) during this winter-temperature/radon-trigger operational mode. Foundation sealing and improved weatherization as well as higher capacity fans may likely achieve greater reductions at these new houses, which were all shown to be more "leaky" than Lovejoy with blower-door tests. A further modification of activating the SRRS from RadonAlarms located on the first floor is also under evaluation to provide a tighter control on living space radon levels, which may be required for houses such as Washington that appear to have higher radon levels upstairs than in the basement.

Fig. 5 Preliminary results of expanded SRRS testing with fans activated when radon levels reach 3.0 pCi/L



CONCLUSIONS

This research has shown that the Solar Radon Reduction System is effective in reducing indoor radon concentrations with energy savings. Due to the ventilation, air supply, and pressurization principles incorporated in SRRS operation, radon reduction efficiency was found to be related to the duration the system and the volume of fresh air introduced into the dwelling.

In order to meet the EPA action level of 4.0 pCi/L, modified modes of SRRS operation were tested in conjunction other radon mitigation techniques including natural ventilation, sealing foundation cracks and openings, and a variation of sub-slab suction. Compared to SRRS operation before sump sealing at Lovejoy, only a 4% greater radon reduction was achieved, indicating that in this case, the sealing effort had little effect on living space radon concentrations. Installing a forced-draft exhaust fan to the sump pit, a low-cost type of sub-slab suction, produced an additional 11% to 14% radon reduction compared to sump sealing alone. However, later research showed the sump fan had little additional effect with the SRRS operating for a timer-based 12 hours per day. Increased natural basement ventilation with an open basement window had drawbacks in reducing control over ambient basement temperature, and evaluation of SRRS direct basement discharge found that this tactic was not necessary to achieve low radon levels.

Operation of the SRRS system at Lovejoy for two 6-hour periods per day exceeded the prediction based on interpolation of first year data with an average living space radon yield of 2.5 pCi/L. The modification to discharge SRRS outlet air directly into the basement air was a significant improvement in terms of radon reduction, energy efficiency, and indoor comfort levels. This configuration achieved a reduction efficiency of 76%, and it rendered fan operation during less than ideal temperature conditions less noticeable to homeowners. In addition, basement walls, usually well-insulated by surrounding earth, may provide a heat sink to prolong energy benefits and buffer losses.

The SRRS shows promise as a radon mitigation technique that can reduce radon in almost all cases and can obtain concentrations below the EPA action levels in existing dwellings with elevated background radon levels. While this study was limited in the number of dwellings evaluated, the proven and referenced mitigation techniques incorporated into the SRRS project satisfactory radon reduction results in other "problem" dwellings.

Compared to other radon mitigation options, the SRRS offers control over system operation to balance energy demands, improvement in overall indoor air quality and comfort, low installation costs and the lowest annual operating costs. These advantages suggest more home owners may be likely to install a mitigation system and, once installed, be less likely to discontinue its operation.

REFERENCES

Eckoff, Ronald D., M.D., M.P.H., 1990. Radon Report. Des Moines, IA: Iowa Department of Public Health.

Fleischer, Robert L., 1988. "Basement Ventilation Needed to Lower Indoor Radon to Acceptable Levels," JAPCA 38:914-916.

Freije, Matthew R., 1990. How to handle radon, Professional Safety November: 36-39.

Klein, Richard J., 1992. Solar Radon Reduction System Proposal to Recycling & Reuse Technology Transfer Center. Cedar Falls, IA: University of Northern Iowa.

Klein, Richard J., 1993. Solar Radon Reduction System Do-It-Yourself Guide. Waterloo, IA: Enviromiser Co.

Klein, Richard J., and James A. Olson, 1993. Solar Radon Reduction System Demonstration Project Final Report. Cedar Falls, IA: University of Northern Iowa Recycling & Reuse Technology Transfer Center.

Klein, Richard J., and James A. Olson, 1994. Solar Radon Reduction System Demonstration Project: Radon Mitigation in Existing Dwellings. (Year 2 Final Report.) Cedar Falls, IA: University of Northern Iowa Recycling & Reuse Technology Transfer Center.

Renken, Kevin and Steven Konopacki, 1993. An Innovative Radon Mitigation-Energy Conservation Retrofit System for Residential Buildings, Journal of Air & Waste Management Association 43: 310-315.

Turner, William, and Terry Brennan, 1985. Radon's Threat Can Be Subdued, Solar Age May: 19-22.

U.S. Environmental Protection Agency, 1986. "Radon Reduction Methods: A Homeowner's Guide," OPA-86-0005.

U.S. Environmental Protection Agency, 1993. Home Buyer's and Seller's Guide to Radon, 402-R-93-003. Washington, DC: U.S. Government Printing Office.