



# **BUILDING IN ALASKA**

## **Indoor Air Quality and Ventilation Strategies for Cold Climates**

**EEM-00450**

### **INTRODUCTION**

What constitutes the designation cold climate? For the purposes of this informational publication and to emphasize some of the difficulties with mechanical ventilation control strategies, we will use the lower limit of 8000-Fahrenheit heating-degree-days as the level above which we consider the climate cold. The climate of Fairbanks, Alaska, far exceeds this 8000 degree-day lower limit, with an average heating index of 14,300-14,400 Fahrenheit heating-degree-days annually. This designation includes all but the very southernmost portions of Alaska in its definition and much of the northern tier of U.S. states and Canada. This location provides a unique natural laboratory setting in which to not only discover difficulties with ventilation control and the general control of indoor air quality in cold climates, but to also suggest and test new strategies from our research utilizing existing, inhabited homes in our community. This is the source of our most recent research results reported in this paper. The 8000 Fahrenheit-degree-day boundary for classifying cold

climates also provides a large reference zone for most regions of the planet north of 60 degrees latitude.

### **Residential Ventilation—Why Do We Need It?**

With the emphasis in modern cold climate housing on air-tightness and energy efficiency, a house is typically lacking adequate air exchange without the addition of mechanical ventilation. In addition, traffic noise, particulate pollution (such as forest fire smoke in the north during the summer), pollen (a problem for asthmatics and highly allergic people), and the maintenance of a healthy level of relative humidity can be better controlled with mechanical ventilation. A range of humidity considered both achievable and healthful in northern housing is the range from above 30% to 50%. Although relative humidities a bit higher are still considered healthful, our present ability to prevent condensation on colder surfaces is limited by modern window technologies. Keeping windows free of condensation at our most extreme periods of cold is not feasible with windows of R-values of 4 or

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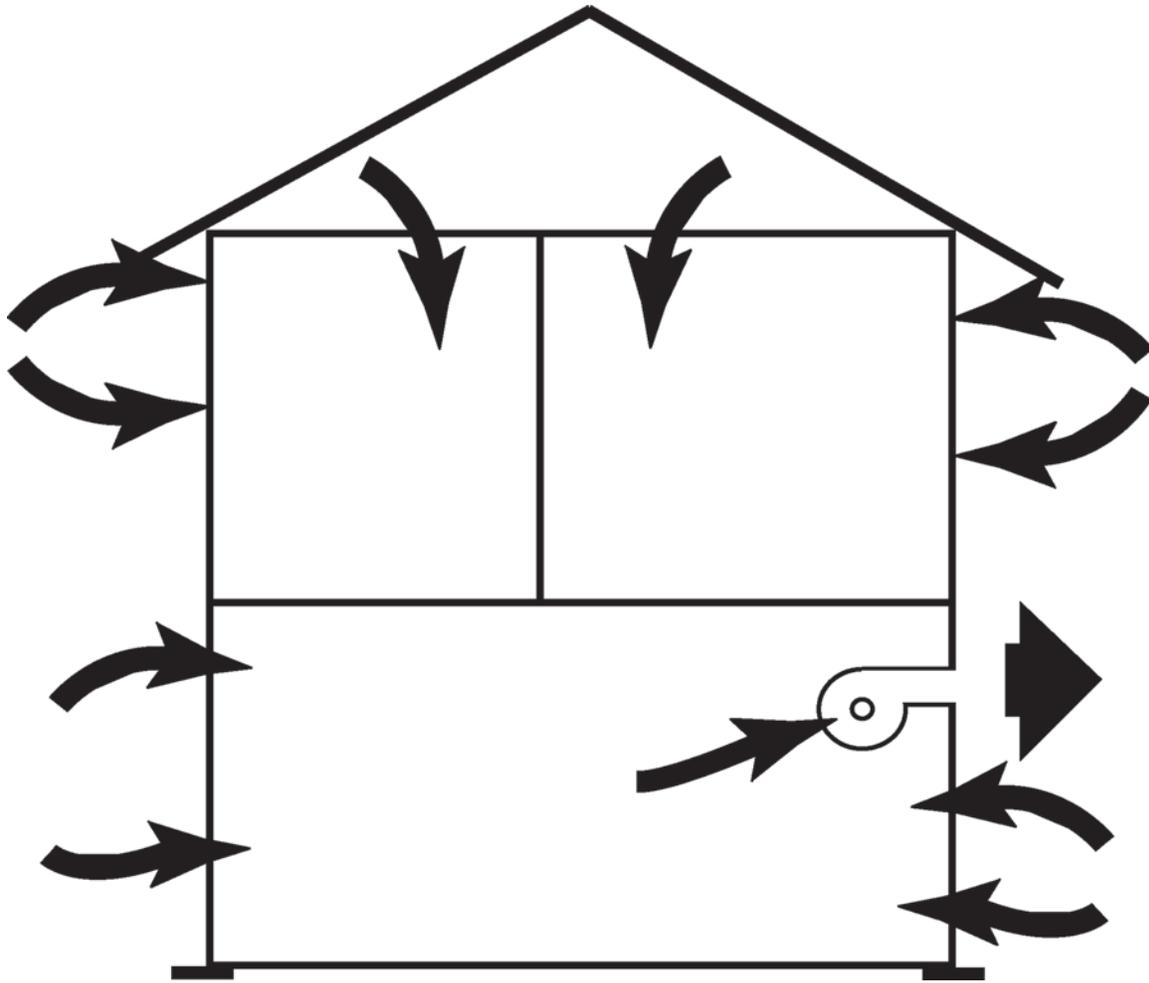


Figure 1: An exhaust-only ventilation system (Alaska Housing Manual, 2000). Although not shown in this figure, exhaust-only systems typically provide for supply air by small inlet vents, such as the Fresh 80, a brand name tubular plastic duct with an external louver to provide inlet air to make up for the air being exhausted. No heat exchange takes place, and the exhaust-only system not only induces air at the outdoor temperature, but also puts a negative pressure on the entire house, possibly leading to induced pollutants, such as radon.

less. Finally, the air quality in homes can often only be ensured by mechanical ventilation, designed for that home.

### COMMON VENTILATION SYSTEMS FOR RESIDENTIAL USE

It is appropriate to review the common technologies in use for residential ventilation to understand the options for control that they afford. These systems include:

#### 1. Unbalanced Mechanical Ventilation Systems—Exhaust-Only

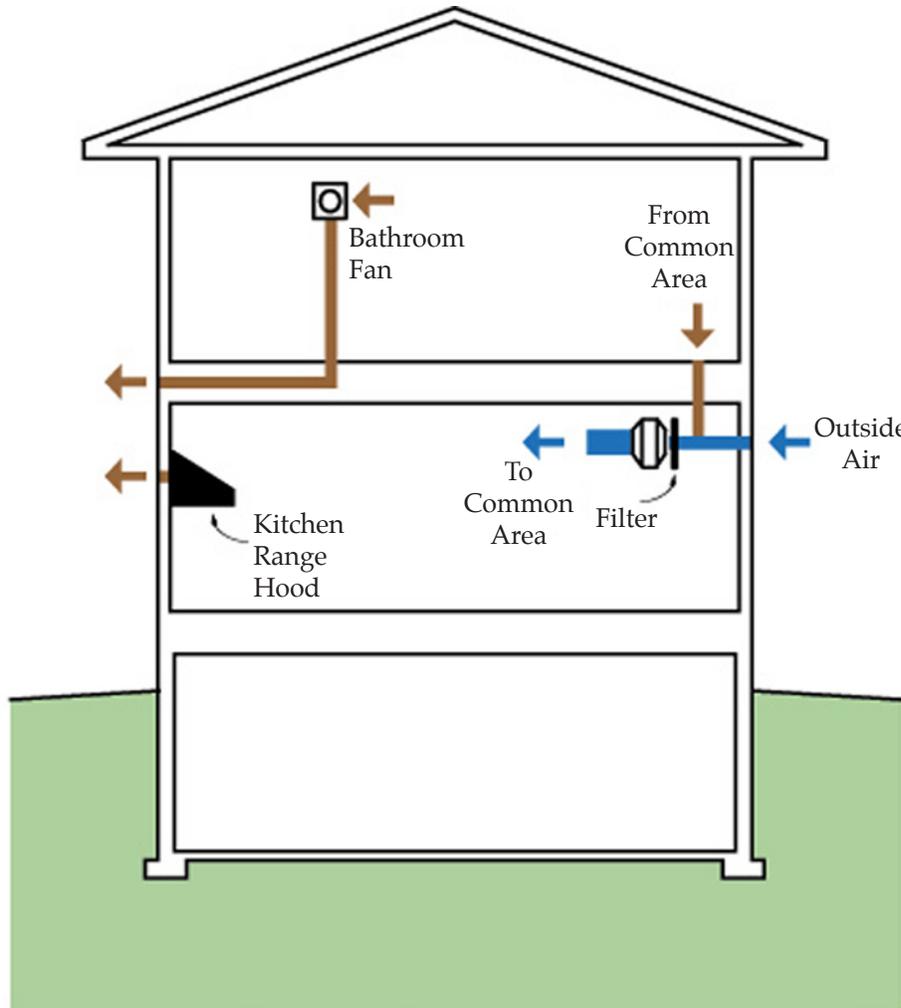
This type of system typically employs a single fan, hopefully strategically placed, to exhaust air from a residence, with air inlets placed in rooms typically requiring supply air, such as bedrooms (Figure 1—supply ducts not shown in figure). Placement of the inlets is crucial because of the pressure dynamics of the building. This is particularly so in cold climates because the temperature differentials are larger and the consequent pressure differentials across

the building shell are enhanced. Exhaust-only systems also induce a constant negative pressure inside the building—with respect to outdoors—and induce radon from below grade walls along with other soil gasses. For these important reasons, most building scientists in northern regions have rejected exhaust-only technology for cold climate ventilation.

A second type of unbalanced mechanical ventilation—supply ventilation with point source exhaust—is shown and described in Figure 2.

**2. Balanced Heat Recovery Ventilation (HRV)**

For approximately two decades, improvements in balanced heat recovery ventilation have resulted in steadily gaining adoption



**Supply Ventilation System with Point Source Exhaust**

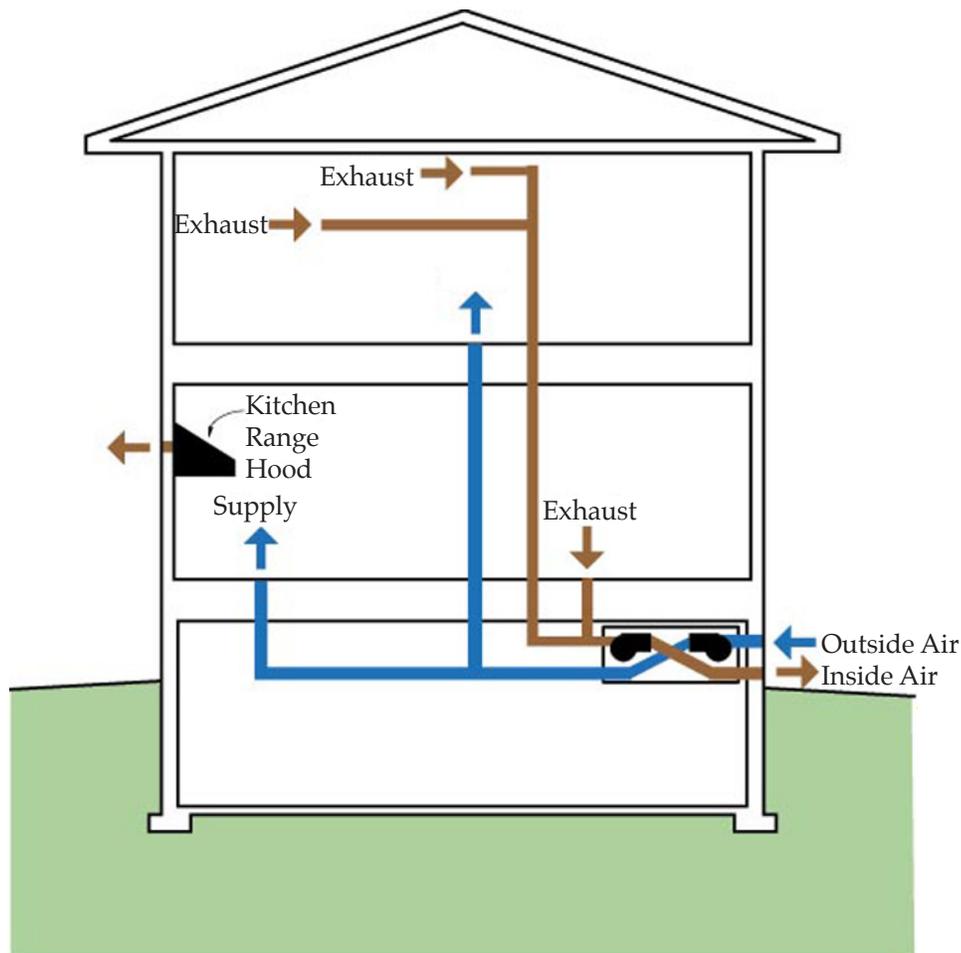
- Supply fan brings in outside air and mixes it with air pulled from a common area (living room, hallway) to provide circulation and tempering prior to supplying to common area.
- Run time is based on time of occupancy.
- In supply ventilation systems, and with heat recovery ventilation, pre-filtration is recommended as debris can affect duct and fan performance reducing air supply.
- Kitchen range hood provides point source exhaust as needed.

Figure 2: Non-integrated supply and multi-point exhaust ventilation system (uncommon in the north, but could be adapted here). Credit: Building Science Corporation, 2004, used with permission.

of this mechanical ventilation option (Figure 3). A generic cross-sectional view of a heat recovery ventilator (also called an air-to-air heat exchanger) is shown in Figure 4. These systems have been particularly useful in Canada, Alaska and the northern United States. The biggest barriers to wide adoption seem to be initial cost and a satisfactory control strategy. Cost of installation is nearly always less for new construction, as the duct

distribution system and design integration into the structure are much simpler to include at the time of construction. But satisfactory performance of these systems is not always certain due to immature control technologies.

**3. Heat Wheel HRV with latent heat recovery.** This third type of heat recovery ventilation system uses a rotating heat transfer surface, which transits between the outgoing exhaust and the



***Balanced Ventilation System with Heat Recovery via an Air-to-Air Heat Exchanger***

- The ventilation system has a separate duct system not integrated with the heating and A/C system.
- Run time based on time of occupancy.
- Exhausts are typically from bathrooms and supplies are typically to bedrooms.
- In supply ventilation system, and with heat recovery ventilation, pre-filtration is recommended as debris can affect duct and fan performance reducing air supply.

Figure 3: A Heat Recovery Ventilation System. Credit: Building Science Corporation, 2004, used with permission.

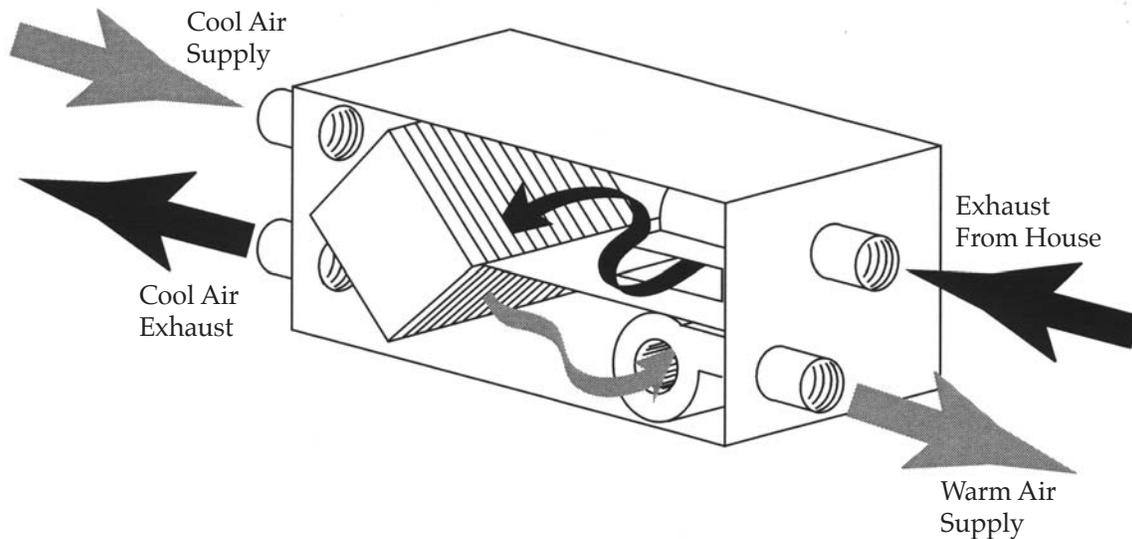


Figure 4: A cut-away view of a typical Heat Recovery Ventilator, single core. Credit: Alaska Housing Manual, 2000.

incoming cooler, dryer air. Consequently there is cross pollution of the air streams. This type of system is not recommended even though it solves the condensation and humidity issues in some instances.

### How Much Ventilation Do You Need?

**ASHRAE 62-2** is a residential ventilation standard. This standard recommends 7.5 cubic feet per minute (cfm) of ventilation air per person based on the number of bedrooms in the house plus one. In addition, an ASHRAE compliant design must add .01 cfm for each square foot of floor area. As an example:

A three bedroom 1500 sq. ft. house would take:

$$7.5 \times 4 \text{ plus } 1500 \times .01 = 45 \text{ cfm}$$

This could be supplied in many ways, and we'll talk about the control mechanisms for doing so.

### RESIDENTIAL VENTILATION CONTROL STRATEGIES

Either by inference or by consensus of engineering, we have agreed to reproduce indoors the outdoor climate of the tropical savannah.

These conditions are typified by a relative humidity range from 30 to 60 percent and the temperature between 65° to 70°F (18° to 21°C). There are probably many reasons why this design strategy and set point condition were agreed upon. But it's hard to imagine that our evolutionary emergence from the tropical savannah was not a strong influence in this resulting agreement.

Residential control strategies have consequently been developed to try to keep the relative humidity in the range of 30 to 60 percent. In Alaska we have to slide toward the dry side of this range and not exceed 50 percent relative humidity indoors. Present window technologies do not allow us to tolerate indoor relative humidities higher than 50 percent.

All cold weather ventilation strategies are inherently dehumidification processes. In a heating climate, warm moist air is being exhausted and replaced by cooler drier outside air.

Another aspect of indoor air quality affected by ventilation strategy is radioactive radon gas. When present in the soil gas, radon infiltrates into a house driven by the same mechanisms that cause the infiltration of cool dry

outdoor air into a house. Transport of radon into a house is primarily due to air leakage (air containing radon) caused by differential pressures between the house and soil<sup>5</sup>. Infiltration can take place anywhere there are pressure differences and openings in the building envelope. Houses typically leak air in low and out at the top of the building.

The ventilation rate of a house at any given time is a function of the openings in the structure and the forces causing air to move through the house. The effect of the air buoyancy is often referred to as the stack effect and this effect is significant during the heating season in Fairbanks.

### **First, let's look at some research:**

During the winter of 2000, researchers at the University of Alaska Fairbanks did a series of experiments and research tests to study the results of various ventilation systems and their controlled operation on the indoor air quality of several homes in the Fairbanks area.

They recorded indoor radon concentrations, indoor temperatures, and outdoor temperatures at two Fairbanks homes for the period between the spring of 1999 and the spring of 2000. They also measured differential pressures across the basement slab at one of the houses during the winter months. The purpose was to demonstrate the seasonal variability of indoor radon concentrations, the variation of indoor radon concentrations with outdoor temperature and the effectiveness of subslab depressurization systems in the Fairbanks area. TSI instruments were also used to acquire data consisting of relative humidity, carbon monoxide, carbon dioxide, and indoor temperature measurements in twelve different homes in Interior Alaska. In all but a very few periods of measurement, homes were occupied and in routine use. Houses were measured for two-week intervals for each season, typically rotating through a data collection interval every 10-12 weeks for nearly three years. Radon data was typically gathered simultaneously with a Sun Nuclear radon monitor and supplemented

with various radon test kits for corroboration. Air leakage tests were typically done during the autumn or winter, and a mix of blower door tests and carbon dioxide dilution tests were utilized to measure air leakage under various outdoor conditions.

### **RESEARCH RESULTS**

Figure 5 is a plot of indoor relative humidity and the simultaneous indoor/outdoor temperature differential in two different houses. However, the time periods are contiguous and the contrast in sustained indoor relative humidity levels between the two houses is an important indicator of the importance of air leakage. House R-S has 50% more natural air leakage than House R-A. The temperature differential during the period of measurement for House R-S was markedly greater indicating it was much colder outside during that time period.

The latter half of the measurement period for House R-A (1/28 to 2/8) compares somewhat closely to the period (1/13 to 1/28) for House R-S. The relative humidity in house R-A is consistently 15-20% higher, and in a healthful range (ca. 45%). Air leakage is an important controlling factor in this difference. The blower door leakage rates for the two houses were 2.5 ACH<sub>50</sub> for House R-A and 3.7 ACH<sub>50</sub> for House R-S (ACH<sub>50</sub> means the Air Changes per Hour at 50 Pascals pressure difference. 50 Pascals is a common test pressure for blower door tests). This 50% greater air leakage appears to exceed a crucial boundary since House R-A is able to sustain healthful humidity levels, and House R-S is not able to do so.

A strong correlation was found between the indoor radon concentrations and differential pressures across the slab at House R-A (Figure 6). It is generally accepted that pressure driven flow dominates as a radon entry mechanism. This demonstrates the correspondence between the pressure differences across the building envelope and the entry of radon bearing soil gas assuming that the soil gas radon concentrations remained stable. In House R-A



Figure 5: Relative Humidity (%) indoors is directly related to the outdoor-indoor temperature difference and the "leakiness" of the house. A leaky house, such as house R-S here, cannot maintain a healthful level of relative humidity at low outdoor temperatures. "Dt" here means temperature difference.

there was no positive correlation between indoor-outdoor temperature differences and the radon concentrations. This was unexpected. In work with other homes, strong correlations were observed between the indoor-outdoor temperature differences and indoor radon concentrations. In a study of passive ventilation in a house in Sapporo, Japan, Fukushima noted that the leakage rate of an average size airtight house increases with indoor-outdoor temperature difference<sup>7</sup>. It was expected that the temperature differences would be a good indicator for the pressure differences across the basement slab and also an indicator of soil gas infiltration.

The infiltration rates of the other houses tested in this study were between 0.3 to 0.6 air changes per hour (ACH) as measured by tracer gas measurements at temperatures less than 19.4°F (-7°C) and blower door measurements. Tracer gas measurements indicated the infiltration

rate of House R-A to be between 0.1 and 0.2 ACH at 19.4°F (-7°C). The range of differential pressures across the slab was from 0 to 18 Pa with only 2% of the data points greater than 10 Pa. In this house the operation of the kitchen fan, 2 bathroom fans, clothes dryer, and oil-fired boiler in various combinations could reduce the pressure in the house by as much as 11 Pa. Other confounding factors would be the opening of the garage door on the ground level and the occasional wind.

## CONCLUSIONS

There are several fundamental conclusions one can draw from our results. First, the greater the temperature difference (i.e., the lower the outdoor temperature is), the greater the air leakage (infiltration) rate is likely to be, and a fraction of that infiltration will be soil gas that possibly contains radon or other pollutants. Second, the concentration resulting from radon bearing soil gas induction is very strongly

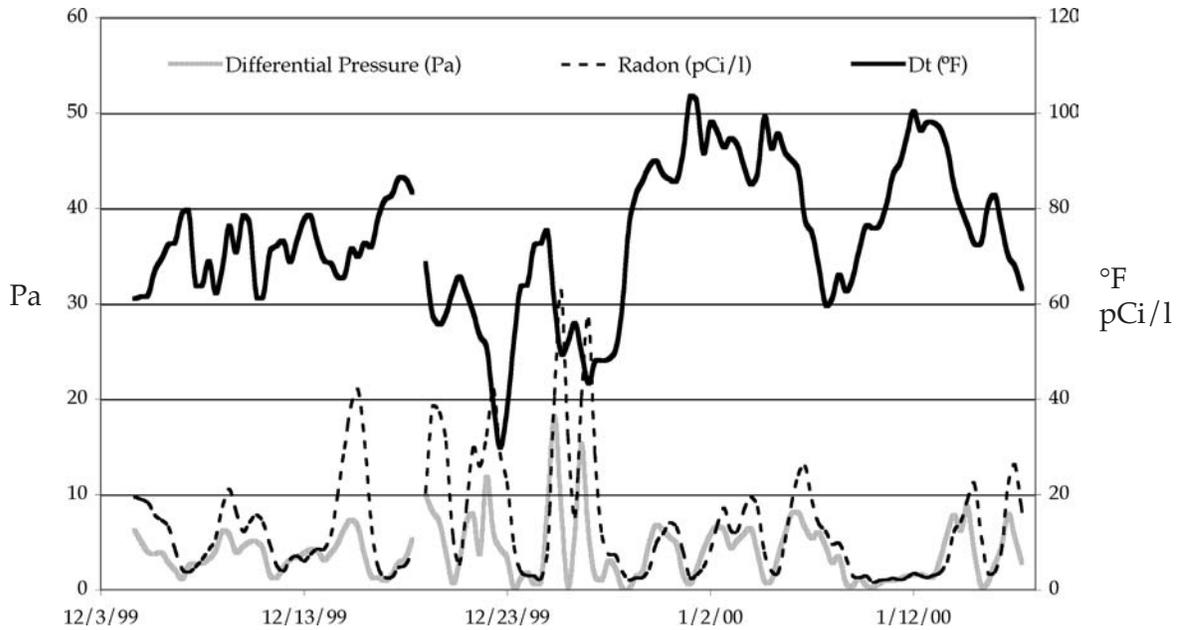


Figure 6: Radon Concentration & Pressure Differential Across Basement Slab vs Time in House R-A.

correlated to the pressure difference across the slab (Figure 6). This clearly indicates that air leakage resulting from the pressure difference is a crucial factor in radon induction. Blocking air and soil gas entry by limiting leakage from the building can go a long way toward controlling radon induction and other soil gas pollutants from entering the home.

Houses with exhaust-only ventilation show a clear tendency to induce radon. So exhaust-only ventilation is workable, but has the added risk of possibly inducing radon in dangerous amounts into the home if it is on a radon risk site. For this important reason, we urge caution in using exhaust-only ventilation systems in Alaska.

The results of this research corroborate that we have made progress toward a control strategy for ventilation systems. Very good control of air leakage, and consequent control of indoor relative humidity is important. This control of leakage makes the house less responsive to differential pressures across the building envelope. **That is what air sealing accomplishes!** Large pressure differences should not be in-

duced on the shell of a building by ventilation systems, as this will induct soil gas, outdoor air pollutants, and would generally limit the ability to control the air flow and pressure difference across the shell. This is another major reason why most building scientists reject the concept of exhaust-only ventilation in very cold climates.

House R-A is an example of a house in which the natural infiltration is well controlled. The lack of a positive correlation between the indoor-outdoor temperature difference and the pressures across the envelope indicates that—in this house—the ventilation is driven less by natural infiltration and predominantly by operation of the various appliances in the house, and the openings of doors and windows. Ideally a house would have provisions to replace air removed by appliances to minimize the depressurization of the house. It is simply a **tight house**. Operation of appliances can cause substantial depressurization, and this has a more significant impact on this house than houses with greater air leakage rates. In interior Alaska, the predominant natural force driving air infiltration is buoyancy resulting

from temperature differences. The average outdoor temperature is less than 19.4°F (-7°C) for approximately five months out of the year<sup>1</sup>.

So what can we conclude about ventilation for Alaskan homes and how to control it? Here are some concise statements about ventilation and its control:

- Controlled ventilation REQUIRES an airtight building envelope and ducts.
- Exhaust ventilation can work, but it is difficult to control and has serious liabilities for inducting pollutants and bad outdoor air into the house.
- Balanced ventilation, which can be single point, multi-point (i.e. fans at locations where exhaust is commonly necessary), integrated with a central fan system or forced air heating system, or with Heat Recovery Ventilation (HRV) is the preferred approach. Control based on maintaining relative humidity above 25% is recommended.

**Installation and selection of a ventilation system for your house is not considered expendable, and should be done by a competent ventilation contractor who is capable of designing the ductwork and certifying the system with tests. Although these services are available in Alaska, there is no certification of ventilation installers. This is regrettable, and Extension, Alaska Building Science Network, and others are working to remedy this situation. For the present, seek experienced installers and consult with your contractor, the ABSN ([www.absn.com](http://www.absn.com)) or local homebuilders association at the time of construction.**

#### **Ventilation system cost estimates**

These estimates are from Building Science Corporation for national labor rates for 2003:

- Central-integrated-fan system \$320 total: \$65 fan recycling control, \$65 motorized damper, \$30 duct parts, \$160 labor.
- Multi-point supply \$800 total: \$250 supply fan with filter and two inlet ports (outside air and recirculation air) and one outlet port, \$150 ducts and grilles, \$400 labor.
- HRV, approximately \$1.25 per square foot of building floor area, installed at the time of construction. Perhaps 20% more in retrofit.

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