AIR EXCHANGE RATE MEASUREMENTS
BASE LINE STUDY OF SEVEN
BUILDINGS IN FAIRBANKS, AK

FINAL REPORT

by

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ABSTRACT

Air exchange rates were measured repeatedly in seven Fairbanks buildings throughout the 1982-1983 winter. These buildings ranged from small private homes to medium sized grade schools. Only the two grade schools had mechanical ventilation systems.

Two air exchange measurement techniques were used, the ASTM Standard Leakage Rate by the Sulfur hexafluoride (SF_6) Tracer Dilution Method and the continuous sampling method developed by Brookhaven National Laboratories (called AIMS). The AIMS method yielded somewhat lower air exchange rates than those measured by the SF_6 method. It gave integrated 22 and 33 day air exchange rates ranging from 0.06 to 0.67 air changes per hour (ACPH).

Average air exchange rates with the SF_6 method ranged from 0.14 to 1.71 ACPH. There was no apparent correlation between air exchange rate and time of year, relative humidity or inside versus outside temperature difference. The effect of wind was not evaluated because wind speed was rarely high enough to be measurable.

Air exchange rates measured in buildings without mechanical ventilation systems were considerably lower than those reported in the literature for buildings elsewhere in the United States.

TABLE OF CONTENTS

Page

LIST OF FIGURES

LIST OF TABLES

INTRODUCTION

Air exchange rates are critical to the quality of the environments within buildings. They also have a large impact on building heating load. For most northern buildings, the heat needed to warm ventilating air is the largest single building energy requirement. Buildings that have unduly low ventilation rates may be economical to operate, but they are often subject to serious indoor air pollution.

In order to better understand the mechanisms for air exchange within buildings, the Alaska Department of Transportation and Public Facilities (DOT&PF) conducted a base line study of several buildings in Fairbanks, Alaska. During the winter of 1982-83, air exchange rates in five private buildings and two public schools were measured repeatedly under varying weather conditions.

The base line study was conducted to gain experience with air exchange measurement techniques and to determine the following:

1) Typical air exchange rates in various Fairbanks buildings during winter.

2) Variability of measured air exchange rates under changing weather and building use conditions.

3) Relationships between air exchange rates and environmental variables.

When air exchange measurement techniques were tested and typical values known, subsequent air exchange measurements in various public facilities could be used to gain better knowledge and control of ventilation rates. If simplified air exchange measurement techniques were developed, more accurate energy audits could be made by incorporating these measurements into the audit procedures. At present, the large energy load required for heating incoming fresh air must essentially be guessed at.

METHODS

Two methods were used to measure air exchange rates in the seven buildings included in this study. A good deal of experience was obtained with these methods and an effort is made to compare results from each.

ASTM Standard Method

The primary method used was the sulfur hexafluoride (SF_6) tracer dilution method. It is specified in the American Society for Testing and Materials as Designation E741-80, Standard Practice for Measuring Air Leakage Rate by the Tracer Dilution Method (1980).

Our air exchange tests used SF_6 tracer gas at concentrations ranging from 50 to 1000 parts per trillion (ppt). First, an estimate was made of the volume of SF_6 gas needed to produce a concentration of about 1000 ppt in the building to be tested. For a 2000 sq. ft. home, the calculation is illustrated below:

Volume of home in cubic centimeters:

$$2000 \text{ ft}^2 \times 8 \text{ ft ceiling ht} \times \frac{2.832 \times 10^4 \text{ cu cms}}{\text{ft}^3} = .453 \times 10^9 \text{ cu cms}$$

Concentration of SF_6:

$$\frac{\chi \text{ cu cms } SF_6}{.457 \times 10^9 \text{ cu cms air}} = \frac{1 \times 10^3}{1 \times 10^{12}}$$

$$\chi = .453 \text{ cu cms } SF_6$$

The calculated volume of SF_6 was then released in the building using a 1 or 10 cu cm hypodermic syringe. Prior to release, two or more portable oscillating fans were placed at strategic locations within the building to mix the air. The release was made so that each room of the building received a quantity of SF_6 gas approximately proportional to its volume.

If there was a mechanical ventilating system or forced air heating system in the building, no portable fans were used and the gas was released into the intake duct work of the ventilating system just ahead of the fan.

The gas was allowed to mix for 10 minutes after release and samples were then taken from a central location in the building. Six samples were usually taken at 10 minute intervals using 10 cu cm plastic syringes.

For the first few tests, the gas chromatograph was physically moved to the building to be tested. The machine used, a Science, Systems & Software (S-cubed) Model 215 ACA gas chromatograph, is capable of sampling, measuring, computing, and printing out the SF_6 concentration at seven minute or longer intervals. Using this feature, we were able to determine how soon after release a uniform mixture of SF_6 in air was obtained. Ten minutes of mixing was shown to be adequate in most situations. The ASTM method calls for use of multiple sample points to obtain an average gas concentration at each point in time. We used only one sample point in each building to expedite the testing, but good straight-line data generally resulted. On two occasions, samples were taken from various locations within a house and found to have little difference in concentration.

Due to serious problems with stability of the gas chromatograph, we soon decided to leave it set up in the laboratory and do the air sampling in buildings with plastic hypodermic syringes. During most of the testing, 10 cu cm syringe samples were transported to the laboratory for analysis. In order to hold the sample in these syringes, the hypodermic needle was closed by inserting it in a soft rubber stopper. The samples were then analyzed as soon as possible, but they could be stored as long as 48 hours without seriously affecting the results. Duplicate samples were taken in order to have a backup in case the gas chromatograph malfunctioned or results from the first sample were questionable.

The SF_6 concentrations measured with the gas chromatograph were read into a computer program that computes the best straight-line relationship between the natural logarithm of SF_6 concentration and time (in hours). The computer finds the slope of this line, which is the number of air changes per hour. An X-Y plotter was then used to produce a graph with test data, test conditions and results as shown in Figure 1.

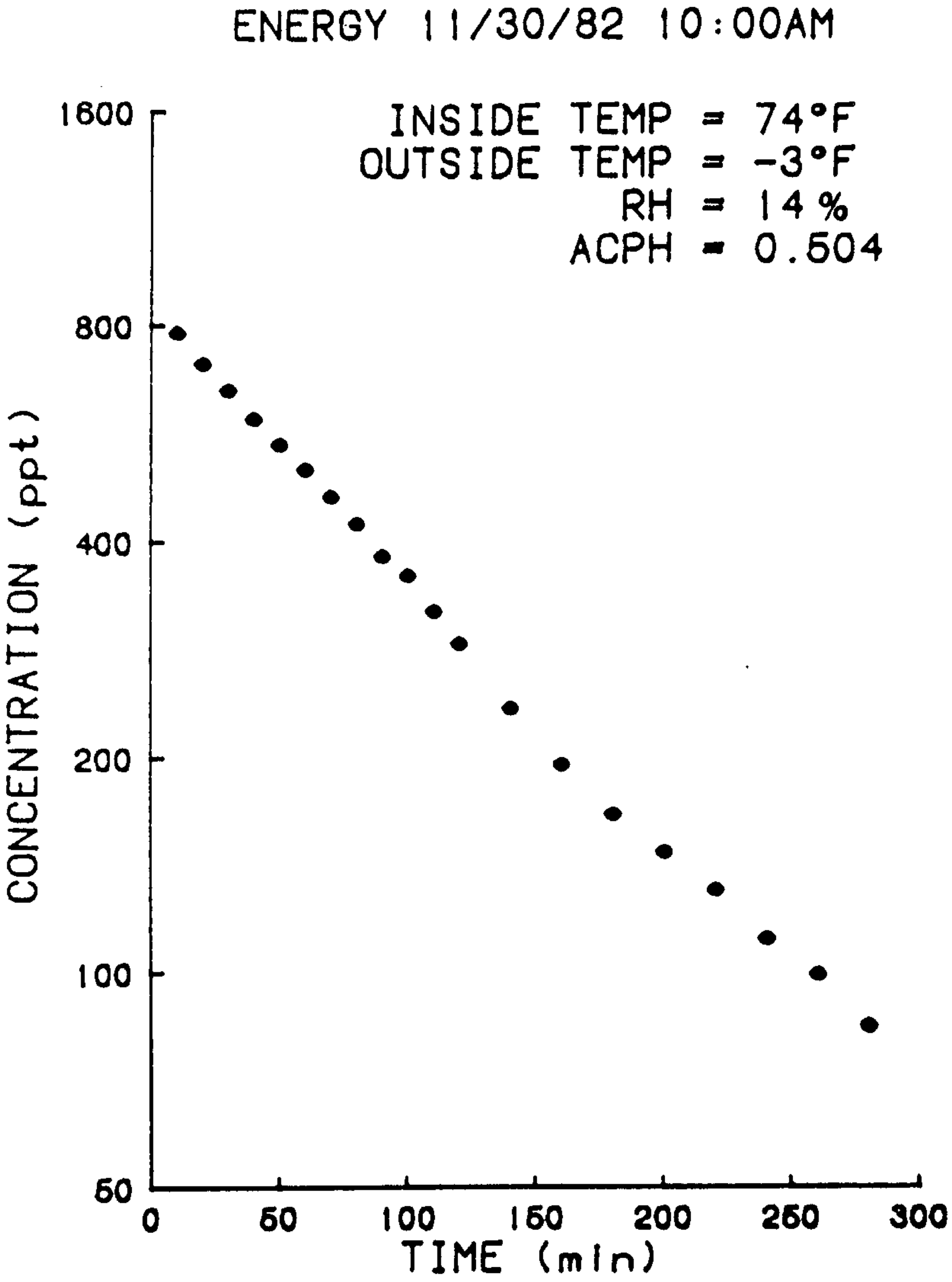

Figure 1 - Typical graph of air exchange rate information.

Brookhaven National Laboratory AIMS Method

An easy to use, continuous method of testing was desired for determining the average air exchange rate in a building over a relatively long period of time. A new method using a perfluorocarbon gas tracer (perfluorodimethylcyclohexane, perfluoromethylcyclohexane or perfluorodimethylcyclobutane) had recently been developed by Brookhaven National Laboratory (BNL) (Dietz and Cote, 1982). It looked promising for the purpose stated above; and in December, 1982, DOT&PF Research contracted with BNL for three months of testing services to evaluate its Air Infiltration Measurement System (AIMS) in the seven buildings under study.

The AIMS method makes use of passive sources and sampling devices that are each about the size and shape of a small cigarette (see Figure 2). The source is a metal shell containing a small quantity of liquid perfluorocarbon tracer (PFT) gas and stoppered by a permeable fluoroelastomer plug. The sampler is a small glass tube containing a quantity of adsorbent in its midsection with a capillary opening at one end. The molecules of a dilute concentration of PFT gas in the air surrounding the sampler diffuse through the capillary end at a rate proportional to the partial pressure driving force. This force results from the relatively high concentration of PFT in the room air at one end and the zero concentration in the adsorbent at the other. Prior to and after the sampling period, both ends of the sampler are capped to prevent adsorption of any PFT gas. When the sampler is exposed, the cap on the capillary end is removed.

Samplers need only be exposed for a long enough time period to provide a measurable quantity of PFT gas in the adsorbent. This interval can be as short as 10 minutes. If desired, it can be as long as several years.

The quantity of PFT adsorbed is measured by driving it out of the sampler with heat and determining the mass of PFT with an integrating gas chromatograph. The air exchange rate is computed by comparing the previously determined emission rates of the sources with the mass of PFT collected in the samplers over time. At relatively constant temperatures, the source emission rate stays the same as long as some liquid PFT still remains in the metal shell. The AIMS method provides an integrated average air exchange rate over the period the samplers were exposed.

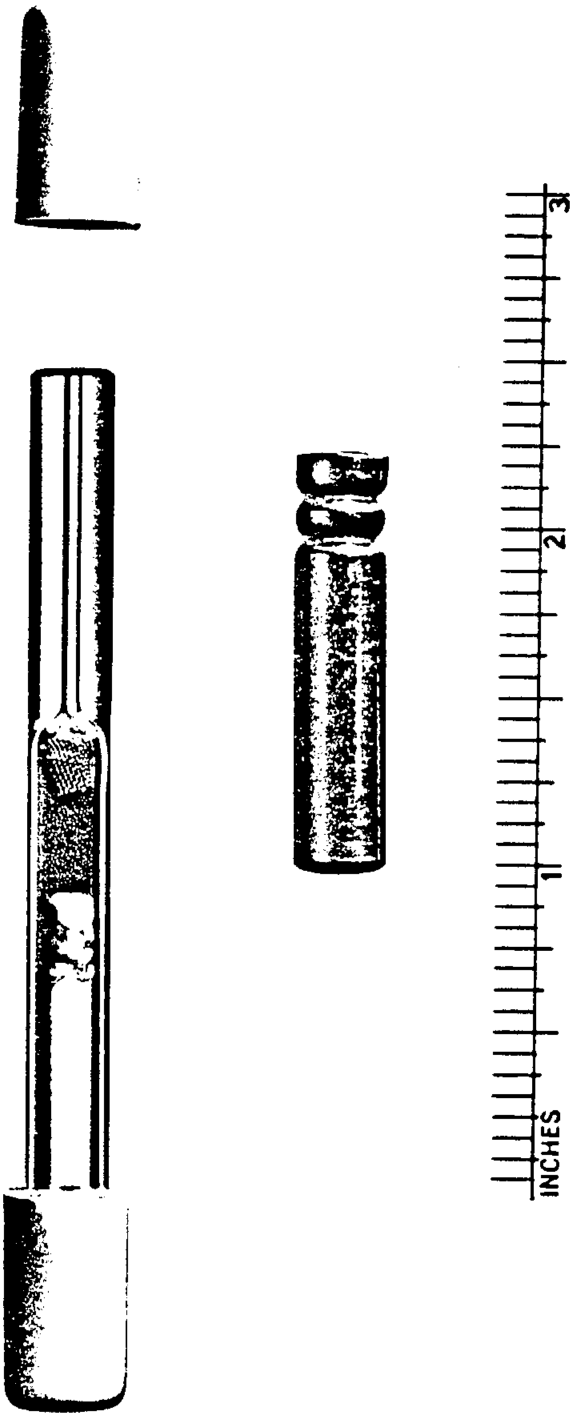

Figure 2 - AIMS measuring devices; capillary absorbtion tube sampler (CATS) on left, PFT diffusion source on right.

BNL has also developed a programmable sampler that is capable of making many measurements over a given time period. The programmable Brookhaven Atmospheric Tracer Sampler is a portable, battery operated unit containing 23 sampling tubes for collecting PFTs in air with an internal pump. It can be programmed to expose each of the sampling tubes for a certain length of time with a specific time interval between each exposure. The automatic sampler was not evaluated in our study, but it is mentioned here because of the potential for use by a facility that acquires the AIMS testing capability.

Our measurements with the AIMS method were made using BNL services to provide the samplers and sources, analyze the exposed samplers and compute the air exchange rates. In order to use the AIMS method on a regular basis, a facility would have to develop its own capability to produce the samplers and sources and to analyze the exposed samplers. The costs involved and expertise needed to do this are discussed under the IMPLEMENTATION section of this report.

Use of the AIMS method in a small building is quite simple once samplers and calibrated sources are available and there is an adequate means of analyzing the samplers after exposure.

Deployment of Sources

One PFT source is deployed for each 4000 cu ft of space to be tested. In a large building, 20 or more sources may be needed. It may be possible to reduce this number to one or two by designing larger sources, installing them in the mechanical ventilating system, and then running this system continuously during the test period. Each source is generally taped to a piece of furniture, a door jam, or some other structure in the room so that the permeable end extends out into natural or forced convection air currents. For a room with baseboard heating, a location well above the heater and near the outside wall is preferred. The source should not be allowed to touch an outside wall nor should it be placed near the heater since the rate of PFT emission by the source is somewhat temperature dependent. Rising air currents from a baseboard heater will keep the PFT emissions well mixed within the room air. For mechanical air systems, installation of sources in supply air ducts is recommended if there is good air temperature control and the mechanical system runs continuously. Otherwise, locations within the room should be chosen.

Deployment of Samplers

At least 8 hours after the sources are in place, the samplers are set out. Each sampler is taped to furniture, door jams, or walls at least 6 feet from the nearest source and preferably across the room from it. Enough samplers are used to get a representative set of measurements for the building involved. Normally there would be a minimum of two in a one room building, one in each main room for a total of 3 to 5 in an average size home, and 10 to 20 or more in a medium to large size building.

Sampling rate is not temperature dependent, but it appears to be affected (increased) by high air velocities. Thus, samplers should not be placed in ventilating ducts or within fan units. Samplers are normally exposed for a period of one week to one month and an integrated average air exchange rate is obtained over the exposure period.

As mentioned previously, samplers could be exposed for as little as 10 minutes once an equilibrium concentration of PFT had been allowed to develop within the building. Thus, the method could be used for short term testing of mechanical systems, but a minimum of several hours would be needed between tests in order for a new equilibrium concentration to be reached.

Other Measurements

Relative humidity was taken with a sling psychrometer for some of the initial readings. A direct reading, Abbeon certified hygrometer was later used to facilitate measurements. Temperatures were measured with mercury or liquid filled thermometers.

BUILDINGS STUDIED

Seven buildings were selected to provide a diverse group of typical northern buildings. Three were private residences ranging from 1,550 to 4,300 of floor space, excluding attached or enclosed garage areas. The largest of these, the Hegdal residence, was still under construction although the building shell was complete. It is a superinsulated, very tight home where extreme care was taken to provide a continuous vapor barrier and to seal all joints around windows and doors. The other two residences are more conventional homes with four inch walls that were built before energy costs became such a large factor in the cost of owning a home.

One private office building was included in the study. This is a 2,300 sq. ft. office building owned by a real estate appraisal firm, Price Associates. This building was formerly a single story home. Recently, it received major energy conserving building improvements. These included triple pane windows (one with a movable outside shutter), a new exterior and insulation of ceiling and added wall space. Part of the improvements were paid for by a $35,000 grant from the State of Alaska Division of Energy and Power Development.

The smallest building in the study was the 1,100 sq. ft. Energy Center at the Tanana Valley Fairgrounds. This building was constructed in 1978 by the Tanana Valley Fair Association to demonstrate advanced energy conservation features and construction methods. It has an attached sunspace, triple pane windows, several types of insulated shutters and super insulated walls and ceiling. It is heated by a hydronic floor slab and an oil fired hot water boiler.

The two largest buildings in the study were Nordale and Denali Schools, both of which are public grade schools. Each school was treated as two buildings because the gyms and main schools have separate heating and ventilating systems. There is no interchange of air between each gym and main school building except for a small amount caused by opening and closing doors in the passageways. The two main schools and gyms are of about equal size and age. Nordale School has undergone a fairly extensive weatherization program to reduce air leakage; Denali School has not been tightened up at all.

Characteristics of the seven buildings are summarized in Table I.

DISCUSSION OF RESULTS

SF_6 Testing

The SF_6 tracer dilution method generally gave reasonable results, but there were some problems. The gas chromatograph was not reliable when it was transported from place to place, particularly when disconnected from its nitrogen gas supply and subjected to temperature shocks.

A special cart was built to carry the gas chromatograph (GC) and a small nitrogen bottle so that the nitrogen flow through the GC column did not have to be interrupted during transport. Even so, problems with stability of the detector continued to occur and the unit had to be left in the new location at least overnight to become stable. After experiencing repeated stability problems and a very severe contamination problem when pure SF_6 was inadvertently introduced into the sampling chamber, we decided to leave the GC in the laboratory and bring air samples to it as explained in the METHODS section. This procedure worked quite well and gave the results shown in Table II.

The buildings with mechanical ventilation systems (the schools) generally had the highest air exchange rates and the lowest variability in air exchange rate. Only one other building, the Price Associates office, had the same level of air exchange, but it had the most variability. As shown in Figure 3, this building had an appreciable reduction in air exchange rate during the testing period (excluding the last two data points where some windows may have been open). This probably resulted from efforts made by Price Associates to reduce infiltration. A basement air vent was blocked and a fireplace opening closed as a result of the initial measurements. James Price reported that his heating bills have been significantly lower since these changes were made.

As expected, the Hegdal residence had the lowest average air exchange rate. The two older residences had nearly as low a level of air exchange as the Energy Building which was built with much thicker walls and tighter windows to minimize heat loss.

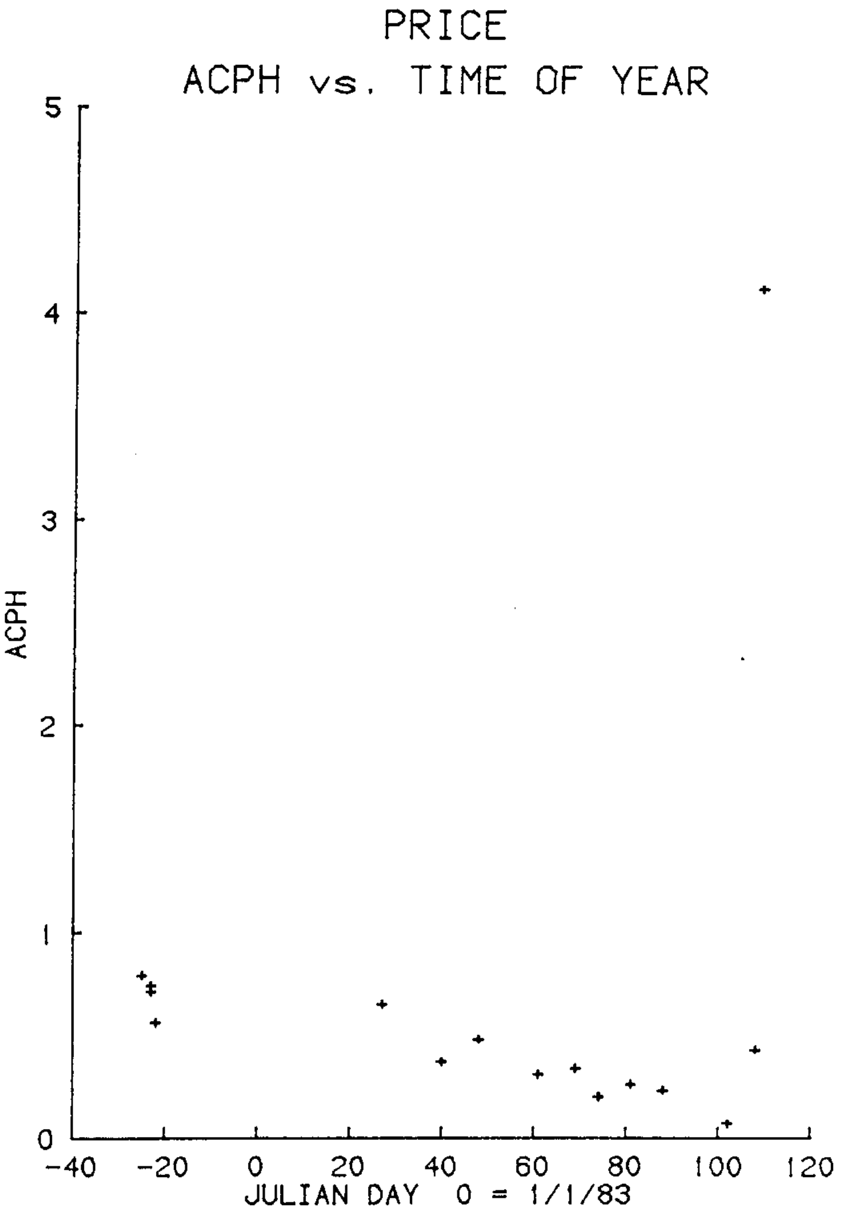

Figure 3 – Air exchange rate vs. time for Price Associates office building.

TABLE I

CHARACTERISTICS OF BUILDINGS TESTED

Building	No.	Age 1982	Structure	Square Feet Finished Floor Area	Number of Floors	Basement	Heating	Woodstove or Fireplace	Orientation	Garage	Number of Openable Windows	Number of Doors
Pederson Residence	1	25	wood frame	1,550	1	no	oil HWBB	woodstove	E-W	attached	18	2
Kailing Residence	2	15	wood frame	1,800	1	yes daylight (finished)	oil HWBB	fireplace and woodstove	E-W	attached	15	3
Hegdal Residence	3	0-5	wood frame	4,300	1	yes	oil pot burner stove	none	E-W	attached	12	3 regular doors 2 garage doors*
Price Assoc. Office Bldg	4	24	wood frame	2,300	1	yes	forced air (oil)	fireplace	N-S	none	18	2
Energy Building	5	2	wood frame	1,100	1	no	hydronic slab (oil)	none	E-W	none	5	2
Denali School Main	6	32	concrete wood	39,400	2	2 small boiler rooms	oil HWBB	none	E-W	none	72	7
Denali School Gym	7	32	concrete	4,400	1	no	oil HWBB	none	N-S	none	none	2
Nordale School Main	8	31	concrete steel, wood	42,680	2	1 small boiler room	coal/steam	none	NA	none	66	6
Nordale School Gym	9	28	concrete steel, wood	4,900	1	no	coal/steam	none	NA	none	none	1

* Garage doors opened into space that was continuous with living space, since house was unfinished when tests were conducted.

TABLE II

AIR EXCHANGE TESTING RESULTS

				AIR CHANGES PER HOUR	
Building System	Period of Testing	Number of Tests	Mean	Standard Deviation	Standard Deviation as Percent of Mean
Pederson residence	12/5/82 - 3/15/83	6	0.36	0.21	58
Kailing residence	11/24/82 - 4/21/83	22	0.40	0.38	95
Hegdal residence	12/14/82 - 4/11/83	10	0.14	0.09	64
Price Associates Office	12/6/82 - 4/19/83	15	0.68	0.97	143
Energy Building	11/30/82 - 4/11/83	14	0.39	0.16	41
Denali School - Main	2/16/83 - 4/19/83	10	1.71	0.41	24
Denali School - Gym	2/16/83 - 4/19/83	10	0.78	0.34	44
Nordale School - Main	2/3/83 - 4/19/83	10	0.96	0.52	54
Nordale School - Gym	2/3/83 - 4/19/83	10	0.65	0.14	22

Air Exchange Relationships

As a result of testing various buildings over different temperatures and times of the year, we had hoped to develop relationships that would explain the large amount of variability that was encountered with building air exchange. Several researchers in the energy and buildings field have used their data to develop relationships that are of the form:

$$I = A + B(\Delta T) + C(\nu)^2$$

Where I = air changes per hour
A = intercept (at $\Delta T = 0$ and $\nu = 0$)
B = temperature coefficient
C = velocity coefficient
ΔT = inside-outside temperature difference $(T_i - T_o)$
ν = wind speed

The term $B(\Delta T)$ is the infiltration caused by inside-outside temperature difference. This is called the stack effect because it is caused by the lighter, warmer air in the house rising and being displaced by the heavier, colder outside air. The term $C(\nu)^2$ is the infiltration caused by pressure differences due to wind. Wang and Sepsy (1980) proposed the above equation. It was also used by Bryant, et. al. (1981), to relate infiltration rates measured on 10 Pullman, Washington, homes to inside-outside temperature differences and wind speeds.

Other researchers (Sherman, et.al., 1980) have given somewhat different relationships for stack driven and wind driven effects:

$$Q_{stack} = f_{s*}A_o\Delta T$$
$$Q_{wind} = f_{w*}A_o\nu$$

Where Q_{stack} is stack driven infiltration
Q_{wind} is wind driven infiltration
f_{s*} is the reduced stack parameter

f_{w*} is the reduced wind parameter
A_0 is the total leakage area
ΔT and ν are as previously defined

Q_{wind} and Q_{stack} are not added arithmetically to give total infiltration. It is given by:

$$Q_{total} = \sqrt{Q_{wind}^2 + Q_{stack}^2}$$

Thus Q_{total} is the vectorial sum of the two separate effects; it is considerably less than their arithmetic sum.

The ASHRAE Handbook, 1981 Fundamentals, gives a more complicated expression for air exchange due to stack and wind effects where there is no significant resistance to air flow within the building:

$$Q_{stack} = CA\sqrt{h(T_i - T_o)/T_i}$$

Where C is a constant of proportionality that depends upon effectiveness of the openings.
A is free area of outlets or inlets (assumed equal)
h is height from inlets to outlets
T_i is average temperature of indoor air at height h
T_o is temperature of outdoor air

Since T_i is relatively constant at about 70°F and h can be averaged for a given building, the above equation has the simplified form:

$$Q_{stack} = K_2 (T_i - T_o) = K_1 - K_2 T_o$$

Where K_1 and K_2 are constants containing T_i, C, A and average h.

For the wind effect, ASHRAE gives $Q_{wind} = C_v A \nu$ where C_v is the effectiveness of openings (dependent on orientation with respect to wind direction) and A is free area of inlet openings. ASHRAE uses the same vector addition for adding the two effects:

$$Q_{total} = \sqrt{Q_{stack}^2 + Q_{wind}^2}$$

DeWalle and Heivler (1983) show five similiar relationships that have been developed by other researchers in the field of energy and buildings. They all include ΔT to the 1/2 or 1st power and ν to the 1st or 2nd power; but two have an additional term involving ΔT times ν^2.

Since there was no measurable wind during the air exchange measurements made in Fairbanks, the expressions for total infiltration can be simplified. According to the equations given above, they would be:

1) $Q_{total} = A + B\Delta T$

or 2) $Q_{total} = f^*A_0\Delta T = K_1\Delta T$

(This is the same as the equation above with A = 0)

or 3) $Q_{total} = K_2 \; \Delta T$

Where $\Delta T = T_i - T_o$

The above relationships and others were explored using a statistical computer program which finds the constants of best fit and gives the regression coefficients for the data. A regression coefficient above 0.9 generally indicates a good fit, i. e. good correlation. A perfect fit would yield a regression coefficient of 1.0.

Several other equations were also tried:

$$Q = Ae^{B(\Delta T)}$$

$$Q = A(\Delta T)^B$$

$$Q = 1/[A + B(\Delta T)]$$

$$Q = \Delta T/[A + B(\Delta T)]$$

These equations fit about as poorly as those shown in Table III. For most buildings, the equation $Q = A + B/\Delta T$ gave the best regression coefficients, but they were not nearly good enough to make this a valid relationship. There are two possibilities: 1) building air exchange rate is not strongly related to temperature differences or 2) the SF_6 tracer method used was not accurate enough to show the relationship.

Similar relationships were tested to see if there is any correlation between air exchange rate and relative humidity or time of year. Correlation coefficients were very poor. For all buildings combined, the best equations were as follows:

Equation	r^2	A	B
$Q = Ae^{B(RH)}$	0.209	4.36	-0.116
$Q = Ae^{Bt}$	0.024	0.52	-0.001

Where RH = Relative Humidity (%)
t = day of year (Julian calendar)

With r^2 values this low, there is essentially no correlation between air exchange rate and relative humidity or time of year.

We can perform a statistical test to show whether the SF_6 tracer method gave meaningful results. This is the paired t-test; it is used for finding whether two means are statistically different based on the values of these means and their standard deviations. If the SF_6 tracer gas decay method did not give representative results (or all buildings had similiar air exchange rates), results of measurements on the seven buildings would have a random distribution and the mean for any one of them would not be statistically different from the mean for any other.

The following formula can be used to calculate t-scores for evaluating the difference between two means when the standard deviations of each mean may not be assumed equal:

$$t \cong (x_1 - x_2)/[(s_1/n_1)^2 + (s_2/n_2)^2]$$

TABLE III

RESULTS OF CURVE FITTING

	$Q = A + B\Delta T$			$Q = A + B\sqrt{\Delta T}$			$Q = A + B/\Delta T$		
Building System	r^{2*}	A	B	r^{2*}	A	B	r^{2*}	A	B
Pederson residence	0.071	0.855	-0.024	0.36	-0.657	0.124	0.378	0.947	-38.3
Kailing residence	0.0134	0.534	-0.002	0.010	0.613	-0.028	0.0006	0.382	1.051
Hegdal residence	0.156	0.002	0.073	0.177	-0.170	0.044	0.243	0.295	-7.28
Price Association Office	0.155	1.73	-0.021	0.206	2.80	-0.304	0.350	-0.210	36.1
Energy Building	0.574	-0.004	0.006	0.601	-0.35	0.091	0.581	0.651	-15.5
Denali School - Main	0.0032	1.78	-0.002	0.003	1.85	-0.021	0.004	1.631	3.37
Denali School - Gym	0.057	1.122	-0.007	0.056	1.46	-0.099	0.053	0.437	15.73
Nordale School - Main	0.284	1.968	-0.019	0.329	3.30	-0.286	0.480	-0.137	54.8
Nordale School - Gym	0.456	0.371	0.006	0.499	0.098	0.082	0.551	0.881	-9.4
All building systems	0.047	1.054	-0.008	0.054	1.48	-0.115	0.081	0.260	18.4

* r^2 is the regression coefficient obtained from a least squares data fit.

Where x_1, x_2 = the two means
s_1, s_2 = the corresponding standard deviations
n_1, n_2 = the number of samples comprising each mean

A computer program was used to calculate the "t" scores for each pair of means. These t scores were tested at the 95% confidence interval. The underlined "t" values in Table IV are for pairs of means that cannot be shown to be statistically different at 95% confidence.

Twenty-four of the 36 comparisons were shown to be statistically different at the 95% confidence interval. Six of the twelve that were not shown significantly different involved Price Associates which had extreme variability. Based on this analysis, differences in mean air exchange rates found for the various buildings with the SF_6 method are believed to be significant, despite the variability encountered.

One final method was used to evaluate the SF_6 test data. The straight line relationship between logarithmic SF_6 concentration and time can be extrapolated to time zero. The resulting SF_6 concentration (Co) can then be compared with the calculated concentration (C). C is simply the SF_6 volume released in the building divided by the total volume of air in the building. The difference between these two concentrations can be expressed as follows:

$$\text{Percent difference} = [(Co - C)/C] \times 100\%$$

This expression gives an indication of the accuracy of the air exchange test, although the test results can be accurate even when the percent difference is large. The reason for this is explained later. Errors in building volume calculation and analysis of air samples for SF_6 content both contribute to percent difference. Incomplete mixing of SF_6 in building air is probably the largest source of error.

Analysis of the air exchange rate data for percent difference gave the results shown in Table V. No definite conclusions can be drawn from this analysis, but it does provide a benchmark for comparisons. Denali School - Main shows particularly high percent differences and they are all positive,

TABLE IV

t SCORE FOR EACH PAIR OF MEANS

	Denali Main	Energy Building	Hegdal Residence	Kailing Residence	Nordale Gym	Nordale Main	Pederson Residence	Price Associates
Denali Gym	5.58	3.40	5.71	2.71	1.09	0.93	3.01	0.34
Denali Main		9.77	11.87	8.56	7.76	3.61	8.69	3.62
Energy Building			4.68	0.20	4.22	3.39	0.23	1.17
Hegdal Residence				2.98	9.33	4.90	2.41	2.13
Kailing Residence					2.62	3.03	0.33	1.06
Nordale Gym						1.82	2.93	0.14
Nordale Main							3.22	0.91
Pederson Residence								1.21

TABLE V

DIFFERENCES BETWEEN CALCULATED AND EXTRAPOLATED AIR EXCHANGE RATE VALUES

	Percent of Air Exchange Rate Values Within:		
Building	±10% Difference	±20% Difference	±50% Difference
Pederson Residence	17	17	67
Kailing Residence	23	36	68
Hegdal Residence	10	50	70
Price Associates Office	23	46	85
Energy Building	14	29	50
Denali School - Main	0	0	10
Denali School - Gym	10	33	80
Nordale School - Main	0	50	70
Nordale School - Gym	40	50	80

i.e. the concentration obtained by extrapolating the test data was always higher than the concentration calculated from the tracer gas release. The ventilating air systems in the two schools and the forced air heating system in the Price Associates building were expected to provided very good mixing conditions, but apparently this did not happen at Denali School - Main.

It should be noted that a calibration error in the gas chromatograph will cause error in the SF_6 concentrations measured, but consistent errors do not affect the slope of the concentration versus time curve. They do, however, affect the percent difference calculation. Thus, a large percent difference does not usually mean that the test result has the same amount of error.

Experimental Design - AIMS Air Exchange and Radon Testing

During the last two months of the winter testing period, the Brookhaven National Laboratories (BNL) Air Infiltration Measurement System (AIMS) method was used in the same seven buildings while concurrent SF_6 testing was done periodically. Weekly SF_6 tests were planned, but could not be accomplished in all buildings for various reasons.

The number of AIMS sources and samplers used in each building is given below:

Building System	Number Sources	Number Samplers
Pederson residence	3	3
Kailing residence	4	4
Hegdal residence	5	4
Price Associates office	4	4
Energy Building	2	2
Denali School - Gym	15	8
Nordale School - Gym	17	10

The AIMS method was not tried in the main sections of Denali and Nordale schools because the number of sources needed in those locations was too large. At least 80 would have had to be deployed in each building to achieve the recommended emission level.

Radon samplers from Terradex Corporation (Type SF detectors) were exposed in six of the same seven buildings toward the end of the testing period. The one placed in Nordale School was lost -- it was probably taken by a curious or mischievous student.

An additional radon sampler was exposed in the basement of the Duckering Building at the University of Alaska, Fairbanks. This area is part of the DOT&PF Research facilities. It was suspected to have a relatively high radon gas concentration due to concrete walls, floor and ceiling, and because a soils laboratory is located there.

AIMS vs SF_6 TESTING RESULTS

A summary of the comparative AIMS and SF_6 testing results is given in Table IV. The standard deviations shown for the AIMS and SF_6 testing methods are not comparable. With the AIMS method, standard deviation is a measure of the variation in measured air exchange from sampler to sampler over each of the exposure periods (22 and 33 days). Standard deviation for the SF_6 method indicates the variability between the results of two or more one hour tests made at different times during one of the above periods. It is primarily a measure of changes in air exchange rate within a building due to differences in weather conditions, building operation, and testing uncertainty.

As shown in Figure 4, there was little correlation between air exchange rates measured with the AIMS method and those obtained by SF_6 testing. This was expected, however, since the SF_6 method gives the average air exchange during the one hour test period, whereas the AIMS method gives an integrated average over a sampling period of many days. The standard deviation between samplers during a given period of measurement appeared to result primarily from variations in air exchange rate and degree of tracer gas mixing within different parts of the building. Standard deviation between the two AIMS samplers in the Energy Building, which is essentially a single, large room, was only 1.0% in March and 3.6% in April.

The AIMS method was found to be convenient and easy to use. It's use resulted in integrated air exchange values over 22 days in March and 33 days in April. The values for these two periods agreed quite closely for all buildings except the two school gymnasiums and the Hegdal residence.

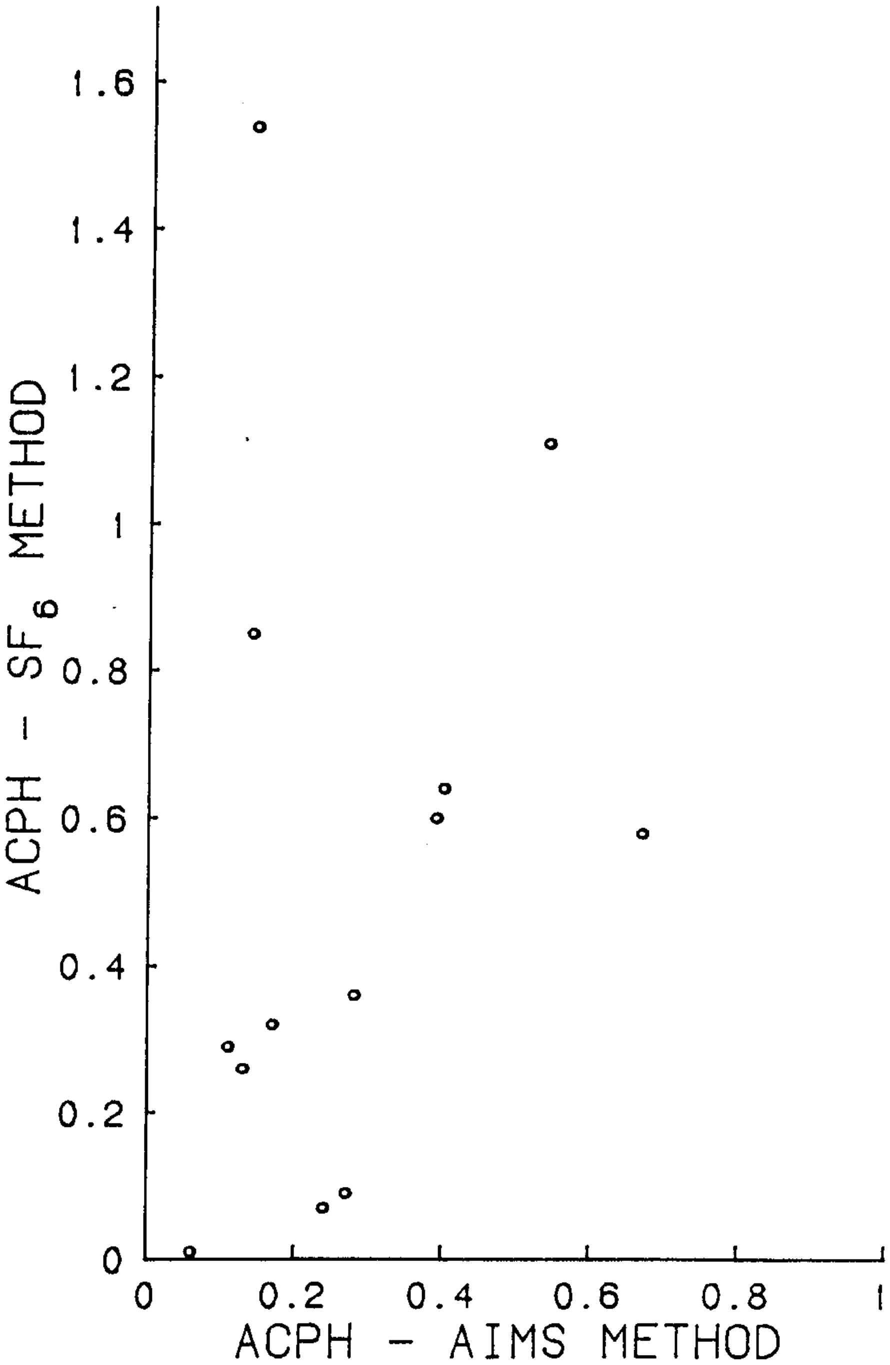

Figure 4 — Comparison of air exchange testing methods (AIMS results vs. mean monthly SF_6 results).

TABLE VI

SUMMARY OF RESULTS: AIMS TESTS VERSUS SF_6 TESTS ON SEVEN BUILDINGS

	PERIOD: March 9 - March 31, 1983						PERIOD: March 31 - May 3, 1983					
	SF_6 Method			AIMS Method			SF_6 Method			AIMS Method		
Building	N	MEAN ACPH	SD(%)	n	MEAN ACPH	SD(%)	N	MEAN ACPH	SD(%)	n	MEAN ACPH	SD(%)
Pederson	1	0.07	--	3	0.24	3.0	0	--	--	3	0.26	2.9
Kailing	3	0.85	118.0	4	0.14	25.0	4	0.32	24.0	4	0.17	23.0
Hegdal	1	0.29	--	4	0.11	43.0	1	0.01	--	4	0.06	8.8
Price	4	0.26	0.2	4	0.13	4.0	3	1.54	145.0	4	0.14	2.0
Energy	2	0.36	53.0	2	0.28	1.0	2	0.09	55.0	2	0.27	3.6
Denali Gym	4	0.60	11.0	7	0.39	14.0	3	1.11	44.0	5	0.54	6.0
Nordale Gym	3	0.64	27.0	10	0.40	14.0	3	0.58	31.0	10	0.67	68.0
Average Mean		0.44			0.24			0.61			0.30	

Where N = Number of SF_6 tests made during the period in that building.
n = Number of PFT samplers deployed during the period in that building.
SD = Standard deviation for the N test results or n sampler results.
ACPH = Air changes per hour.

Percentage of outside air in the gymnasium mechanical ventilation systems was probably increased in April. The low level of air exchange found in the Hegdal residence could have been lower in April due to a minor change in the way the home was operated or by reduced stack effect from warmer average ambient temperatures. The AIMS method appeared to give more reliable, useful information than the SF_6 method. In general, AIMS results were considerably lower than those obtained with SF_6.

Average values for the two testing periods are given in Table VII.

TABLE VII - AVERAGE AIMS TEST RESULTS

Building	March & April 1983 AIMS Method Average Air Exchange (ACPH)
Pederson residence	0.25
Kailing residence	0.16
Hegdal residence	0.08
Price Associates office	0.14
Energy Building	0.28
Denali Gym	0.47
Nordale Gym	0.54
Overall Average	0.27

As shown, the AIMS method gave an average air exchange of 0.27 air changes per hour for all seven buildings. The average for the five buildings having non mechanical ventilation was only 0.18 ACPH.

Comparisons With Other Data

To gain perspective, the air exchange values obtained above were compared with others from the literature. R.A. Grot (1980) reported air exchange test results on ten homes in Portland, Maine. The overall average was 1.25 ACPH, with values ranging from 0.84 to 1.87 ACPH. This is almost seven times higher than those measured with the AIMS method in five Fairbanks buildings of similiar design. It is over three times as high as the average of 0.40 ACPH obtained with SF_6 testing.

Harrje and Mills (1980) compared the infiltration rates experienced in four Twin Rivers, N.J., townhouses before and after retrofit. The SF_6 tracer gas decay method was used. The pre-retrofit houses had an average infiltration rate of 0.65 ACPH. After being retrofit with various weatherization techniques, average infiltration was only 0.39 ACPH. The post-retrofit value is still more than twice as high as the BNL-AIMS average of 0.18 for the five Fairbanks buildings noted earlier, but it is nearly the same as the average value obtained by the SF_6 method.

Grot and Clark (1979) presented data on air leakage characteristics of 250 dwellings occupied by low income households in 14 cities, in all major climatic zones of the United States. The tracer gas decay method was used, injecting a 30 ml sample of SF_6 into the dwelling, allowing it to mix for about 30 minutes and then filling an air sample bag from each floor of the dwelling. The tracer gas concentration was then allowed to decay for a period of one to two hours and another air sample bag was filled from each floor. Air samples were sent to the National Bureau of Standards for analysis.

The geometric mean air infiltration rate for all dwellings was 0.86 ACPH, whereas the arithmetic mean was 1.12 ACPH. Homes in Fargo, ND, had the lowest geometric mean, 0.61 ACPH. Next were Tacoma, WA, and Colorado Springs, CO, with geometric means 0.81 ACPH, Atlanta, GA, 0.73 ACPH, Charleston, SC, 1.00 ACPH, St. Louis, MO, 1.06 ACPH, New Orleans, LA, 1.11 ACPH, and Easton, PA, 1.24 ACPH. The leakiest homes were in Chicago, 1.52 ACPH. Arithmetic means were larger than geometric means in all cases, although extremely high infiltration rates (above 2.0 ACPH) occurred only 10% of the time.

As shown above, average air exchange rates measured by other researchers are quite variable, but most are considerably higher than what we measured on similiar buildings in Fairbanks. The significance of this is that many private Fairbanks buildings may already be close to or beyond the minimum air exchange rates that are healthy for their occupants. On the other hand, the two public buildings analyzed had ample outside air volumes that are probably consuming more energy than required. Their mechanical systems are not designed to minimize outside air, except as required to keep the building at a comfortable temperature. Lack of a continuous minute by minute measuring system will hamper any efforts made to improve this situation.

Radon Testing Results

The radon samplers gave the results listed in Table VIII. For comparison, the average air exchange rate by the AIMS method is shown (for March and April only).

TABLE VIII - RADON TESTING RESULTS

Building	Period of Exposure	Radon Exposure Rate (pCi/ℓ)	Std. Dev. (%)	Mar - Apr Average Air Exchange Rate (ACPH)
Kailing residence	Mar 9 - Jun 7	1.00	26.4	0.16
Hegdal residence	Mar 8 - Jun 7	5.59	11.0	0.08
Price Assoc. office	Mar 8 - Jun 7	0.52	36.8	0.14
Energy Building	Mar 8 - Jun 7	0.32	47.8	0.28
Denali School Gym	Mar 8 - Jun 7	0.25	54.4	0.47
Duckering Bldg. Basement	Mar 8 - Jun 7	0.32	47.8	----

Except for the Hegdal residence, in which some sheet rock was installed during the sampling period, none of the radon levels are particularly high. This conclusion is drawn by comparing the test results to those given from Terradex Corporation experience:

Radon Concentration (pCi/ℓ)

	Indoor	Outdoor
Low	< 0.5	< 0.3
Medium	0.5 - 4.0	0.3 - 1.0
High	> 4.0	> 1.0

A study on Radon 222 and its daughters in 9999 Canadian homes found that about 64% had radon concentrations of 1 pCi/ℓ or less (McGregor et. al., 1980). The highest concentration found was 75 pCi/ℓ in St. Lawrence, Newfoundland. Our test results may also be compared to current EPA indoor standards which correspond to limits of 4 pCi/ℓ with a maximum of 6 pCi/ℓ. The results do not correlate well with air exchange rate, but it may be significant that the residence with the lowest air exchange had the highest radon concentration. Much of the radon in this home probably came from installation of sheet rock, and this source combined with the low air exchange rate is believed to have resulted in the high concentration measured.

SUMMARY AND CONCLUSIONS

Air exchange rates in seven Fairbanks buildings were tested by the SF_6 tracer decay method during the 1982-1983 winter. They were quite variable and lower than expected, particularly in the older residences tested. During late winter, the same buildings were tested by the Brookhaven AIMS method with similar, but generally lower, results.

Statistical analyses of the test data revealed no correlation with outdoor temperature, relative humidity or time of year. Because of the high standard deviations encountered, the test data was subjected to a paired T-test. It showed that average differences were significant.

A comparison of calculated versus extrapolated SF_6 concentrations at time zero showed generally poor agreement. This indicates mixing, SF_6 analysis, sampling and/or volume estimation errors, but it does not necessarily mean that measured air exchange rates had the same degree of uncertainty.

The results of radon sampling in six buildings gave radon exposure rates ranging from 0.25 to 5.59 pCi/ℓ. All but the highest value are in the low and medium ranges of recommended exposures. The radon levels did not have a direct correlation with air exchange rate, although the highest level was measured on the building that had the lowest air exchange rate.

The range of air exchange rates measured on all seven buildings (mean values for the testing periods) was 0.14 to 1.71 ACPH using the SF_6 tracer decay method and 0.08 to 0.54 ACPH with the AIMS method. For residences only, the corresponding ranges were .14 to .40 ACPH (SF_6) and .08 to .25 ACPH (AIMS). These values are considerably lower than most of the values for residences that have been reported in the literature. This implies that Fairbanks residents are likely to encounter more serious indoor air pollution in their homes than their counterparts in other states. Efforts to tighten Fairbanks homes to reduce heating energy requirements have apparently been quite successful, even with older homes. A means of ventilation may be needed for many Fairbanks homes to insure the health and well being of the occupants, but ventilation rates should be carefully controlled to avoid energy waste.

RECOMMENDATIONS

This base line study has shown the limitations of the SF_6 tracer decay method. The Brookhaven method appears to have greater potential and we recommend that it be further evaluated. We further recommend that the capability for preparing AIMS sources and samplers and analyzing the samplers be attained in Alaska, preferably in Fairbanks.

IMPLEMENTATION

The research accomplished to date on air exchange rate testing has shown that a more precise, more reliable method is needed if significant progress is to be made in controlling ventilation rates. A continuous air exchange rate measuring device that provides a signal for automatic control of fans, dampers, etc., would be ideal. The state of the art for measuring air exchange is far from this point, however, and the most current advance in this field appears to be the development of the Brookhaven AIMS method.

DOT&PF Research has contracted with the University of Alaska Geophysical Institute to provide us with the capability for using the AIMS method. The project has an estimated cost of $22,378. This figure includes no major equipment purchases and makes use of existing gas chromatography instruments at the University. The costs cover setting up the system and doing initial tests with it. Results will be compared with duplicates obtained by using Brookhaven services.

The AIMS method will be thoroughly evaluated in the Fairbanks area and possibly at some other locations within the State. If results of the evaluation are satisfactory, plans will be made to use the AIMS system in various applications involving control of building ventilation rates. The AIMS system may also be made available to other researchers and to the general public if warranted by demand.

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