BUILDING VENTILATION STUDIES

FINAL REPORT

by

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January 1987

Prepared for:

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ACKNOWLEDGEMENTS

The writer wishes to acknowledge several of the people who were instrumental in this study. First and foremost is Carol Pederson who did a large majority of the sampling, testing and data handling. Her patience, perseverance and interest is this study contributed greatly to its success. The cover picture shows Ms. Pederson with the tracer gas monitor and a sampling syringe.

Lorena Hegdal did the initial testing of a wide range of buildings and helped develop procedures and equipment for the testing. She remained very supportive of the program and was an encouragement to those who continued to work on it.

Throughout the study, John Rezek assisted with the operational and mechanical problems that seem to be inherent in the operation of a gas chromatograph. Mr. Rezek also edited this report.

John Zarling assisted the writer in two areas: 1) solution of differential equations involved in the study and 2) critical review of the interim report on Andreafski High School at St. Mary's.

Alan Braley set up the computer analysis and plotting of the air exchange test data. He also did the statistical analysis work on the data obtained from the first winter of the testing program.

Lee Leonard recognized the importance of the study as a baseline of information about ventilation rates in Alaskan buildings. He was the driving force behind the program, providing support and encouragement to the researchers.

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1.0 INTRODUCTION

Soon after Facilities Research was incorporated into the Research Section of the Department of Transportation and Public Facilities (DOT&PF) in 1978, building air quality was identified as a research need by Lee Leonard, Chief of Facilities Research. A major effort was already underway in the lower 48 States and other parts of the world to determine building air pollutant levels and building ventilation rates. Very little research in this area had been done in Alaska, even though air quality is suspected to be poor in many Alaskan buildings.

Because of sharply increasing fuel costs, some home builders were taking what appeared to be drastic steps to tighten up their building envelopes. DOT&PF provides homes for a number of employees in remote locations around the State; as a result, that agency has a direct interest in the way energy efficient homes are constructed and well-being of the occupants.

By 1979, a building air quality project had been funded by the DOT&PF Research Advisory Board, and efforts were underway to develop a project plan. It became evident that the highest priority need was for information on ventilation rates of Alaskan buildings.

Direct measurement of air pollutant levels was found to require a number of costly, highly complicated monitoring instruments, and the Research Section did not believe that this type of research should be attempted within the constraints of available manpower and money. Much of the available funding would have been needed to purchase equipment, and a highly trained technician would have had to be added to the Research staff.

The Section opted to purchase a portable gas chromatograph designed for determining air exchange rates by the tracer gas dilution method. It cost about $10,000 complete which was much lower than the price of air pollutant monitoring instruments. The tracer gas dilution method is a relatively simple, direct measuring technique that can be performed by a semi-skilled technician.

By measuring air exchange in a number of Alaskan buildings under various environmental and meteorological conditions, Facilities Research intended to first obtain a data base and then use it to determine whether any relationships existed between air exchange rates and more readily measurable variables. If so, the next step might be to develop a method of monitoring and controlling air exchange in a building.

This report describes the air exchange measuring efforts of the Facilities Research staff over the period 1980 through 1985 and summarizes the results of the work.

2.0 METHODS

Two methods were used to measure air exchange rates during the period of study. The primary one was the gas tracer dilution method wherein sulfur hexafluoride (a colorless, odorless, non toxic gas) is injected in a room or building; mixed with fans, convection currents or a mechanical ventilating system; and then sampled at intervals as the concentration decays (becomes more dilute) with time. This is the ASTM Standard Method specified in The American Society for Testing Materials as Designation E741-83, Standard Test Method for Determining Air Leakage Rate by Tracer Dilution (1983).

The second method was still under development by Brookhaven National Laboratories at the time it was tried by DOT&PF. The researchers recognized the need to improve upon the tracer gas measuring technique and make air exchange testing more readily available to others in Alaska. As a result, DOT&PF tested the Brookhaven National Laboratory AIMS Method in March and April of 1983. Later that year and in early 1984, an attempt was made to reproduce the Brookhaven Method; but this effort did not succeed.

AIMS stands for Air Infiltration Measurement System; it involves use of small, tracer gas sources which a emit a colorless, odorless, non-toxic perfluorocarbon gas at a slow, steady flow rate for long periods of time. The sources are installed one or more to a major room of interest within a building. In the same room go samplers that adsorb the gas in proportion to its concentration in the air, the rate being dependent upon the air exchange rate of the room. By analyzing the samplers for the total mass of perfluorocarbon gas collected in a given time period, the average air exchange rate for that period can be computed.

These two methods are described in detail below. Efforts were made during application of the ASTM Standard Method to make it easy to employ and generally as useful as possible. As a result, there were minor deviations from the procedure given by ASTM.

Another prominent method for determining air infiltration is a building pressurization technique (Sherman and Grimsrud, 1980). It is known as the Blower Door Method because an exterior door in the building to be tested is normally removed and replaced with a "blower door" assembly. This apparatus is capable of pressurizing or depressurizing the building and measuring the rate of air flow required to achieve a given differential pressure. As the blower volume rate increases, this pressure difference is related to leakage crack areas, and ultimately to air infiltration rate.

After evaluating the available methods, the researchers chose to use tracer techniques because they provide the only direct measurement of air infiltration rates in homes under actual living conditions. They are also useful for measurements in large buildings.

The Blower Door Method is more applicable for control of construction quality. Because it induces artificial pressure conditions, the method cannot be expected to accurately predict air infiltration rates - only the effective leakage area in an entire house.

2.1 ASTM Standard Method

2.1.1 M. E. Department Equipment

For an initial series of air exchange tests on area homes and schools, and also for air flow testing at the Fairbanks Memorial Hospital, a portable gas chromatograph was borrowed from the University of Alaska Mechanical Engineering Department. John Zarling of the M. E. Department had realized the energy implications of building air exchange some years previously.

In 1978 and 1979, Dr. Zarling evaluated air exchange rates on three Alaskan military bases in a number of buildings ranging from large hangars to multi-family housing units and two family duplexes. The investigation was done for the U.S. Army Cold Regions Research and Engineering Laboratory (CRREL) using CRREL testing equipment. In order to maintain the capability for air exchange testing, the Mechanical Engineering Department purchased a tracer gas analyzer. It was made by Science, Systems and Software (which later became S-Cubed Company) of La Jolla, California.

The M. E. Department's instrument was a Model 215BGC Bench/Laboratory Tracer Gas Monitor. Like all such instruments, it requires a small continuous flow of carrier gas (highly purified, oxygen free nitrogen) to purge oxygen from the GC column and allow zeroing of the instrument.

This zeroing process is the key to obtaining valid measurements of Sulfur Hexafluoride (SF_6) concentrations in air. If the flow of nitrogen gas is not adjusted properly or is not oxygen free, the instrument will not zero. The standing current produced by ionization of the carrier gas will continue to drift upward or downward, and will never reach the stable condition that allows accurate measurement of SF_6 in air.

If the column in the gas chromatograph has become contaminated from testing too many samples or from from inadvertent introduction of high tracer gas concentrations, zeroing will either take place too slowly or not at all. When this condition occurs, the column must be removed from the gas chromatograph and baked in a small oven while carrier gas purges the impurities. The column would last from a day or two to several weeks, depending on how many samples were being analyzed, how high their concentrations were and other factors that were not determined.

The Model 215BGC gave readings that could be related to true SF_6 concentration by calibration with span gases (gases containing known concentrations of SF_6, preferably at both ends of the span of concentrations to be measured). When there was no doubt about the reliability of the instrument, uncalibrated readings could be plotted against time on semi log graph paper. The slope of the resulting straight line would represent the air exchange rate according to the following equation:

$$I = \frac{(\ln C1 - \ln C2)}{t_1 - t_2} \times 60 = \frac{(\ln C1/C2)}{t_1 - t_2} \times 60$$

Where: I is air changes per hour (ACPH)
C1 = SF_6 concentration at time t_1 (minutes)
C2 = SF_6 concentration at time t_2 (minutes)
ln = natural logarithm

The concentrations of SF_6 do not necessarily have to be actual values. As long as they are relatively correct, the air exchange rate calculated from them will be valid. When one becomes familiar with the gas chromatograph and its idiosyncrasies, there is little doubt when the instrument is working properly and the calibration step can be dispensed with.

2.1.2 Air Exchange Measurement Theory

At this point, it is instructive to examine the source of the above equation. It results from applying the "continuity of mass equation" to a building in which there is assumed to be complete mixing of the inside air. As indicated above, the air exchange rate is determined by releasing a small amount of gaseous tracer, such as sulfur hexafluoride, into a building and measuring the rate of change in tracer concentration (Lagus, 1980). The air exchange rate is determined by the logarithmic decay rate of tracer concentration with respect to time.

The rate of change in the total amount of tracer in the house is

$$\frac{dQ}{dt} = (C_{out} - C_{in})\ L \qquad (1)$$

where: Q = total amount of tracer
C_{out} = concentration of tracer outside
C_{in} = concentration of tracer inside
L = average rate of air leaking into and out of the structure.

If V is the total internal volume and if the outside concentration of tracer is small enough to be neglected, then equation (1) reduces to

$$\frac{dC}{dt} = -C\ (L/V) \qquad (2)$$

where the subscripts have been removed and C is assumed to always refer to the inside concentration, C(t).

Integrating Equation (2) leads to

$$C = C_o\ e^{-(L/V)t} \qquad (3)$$

where C_o is the concentration at t = 0.

Equation 3 may be rewritten to give

$$I = L/V = 1/t\ \ln(C_o/C) = 1/t\ (\ln C_o - \ln C)$$

where I is the air changes per unit of time. Because $\ln C_o$ is a constant, it does not affect the slope of the straight line resulting from a plot of ln C on the Y-axis vs. time, t on the X-axis. It follows that the slope of the line ln C versus t is equal to I.

The assumption regarding perfect mixing is undoubtedly the largest source of error in the application of this method. It is discussed further in 2.1.4 Testing Procedures. Sampling and testing errors can also be substantial, mainly due to the extremely small concentrations of tracer that are employed. The researchers used SF_6 concentrations in the range 50 to 1000 parts per trillion (ppt).

2.1.3 Automated Measuring Equipment

Use of the first generation tracer gas monitor and the manual plotting method for calculation of air exchange rates was time consuming and tedious. The Research Section desired an automated instrument that could take samples, compute SF_6 concentrations, read them directly and record them against time.

S-Cubed Company came out with such an instrument in 1982, and DOT&PF purchased the third one produced. It is a Model 215ACA Automated Tracer Gas Monitor and is capable of sampling and analyzing on a preprogrammed schedule (once every seven minutes or longer). Its most useful feature is readout and recording of actual SF_6 concentration, although calibration with a known concentration of SF_6 is still necessary for absolute accuracy of the readings.

This instrument worked surprisingly well for being one of a very small number made. It was not, however, the portable instrument that Research had expected to get. With this anticipated portability in mind, the Facilities Research staff modified a sturdy utility cart to hold the instrument, its bottle of carrier gas and other equipment needed to make air exchange and environmental tests. The complete setup is shown in Figure 1.

Figure 1 - Portable Air Exchange Testing Set-up

In attempting to use this portable unit, which was designed to fit in the back of a station wagon, the researchers found that the gas chromatograph is too fragile an instrument to be moved in and out of buildings during winter. By the time the GC column could be made to stabilize, there was seldom time left to do any testing. Test work could not be scheduled because it was dependent on the unpredictable condition of the tracer gas monitor.

Early in the program, the researchers abandoned the practice of setting the tracer gas monitor up in buildings and proceeded to bring syringe samples to the instrument. While this method did not provide as many samples as desired, nor give unattended sampling over long time periods, it did have the advantage of greater portability and testing speed. The researchers could perform an air exchange test on a building in little more than an hour using only a single technician. Manual sampling with syringes was the only method that worked well enough to allow collection of a reasonable amount of data on a large number of buildings.

2.1.5 Testing Procedure

The specific procedure was to first make an estimate of the volume of the building to be tested by obtaining square footage and ceiling height. A calculation would then be made to determine the amount of SF_6 that would yield an initial concentration of about 1000 ppt in the building.

The calculated volume of tracer gas would be injected into an unventilated house by adding portions to each room approximately proportional to the volume fraction of the total house that was represented by that room. This was not an exact procedure; it was generally accomplished by walking through the house with a syringe loaded to the correct total volume and releasing a preplanned portion in each room.

Prior to dosing a house with the tracer gas, 12 inch oscillating fans (usually one in each of the two or three largest rooms) would be set up to aid distribution of the gas. These fans were not necessary when the house was heated with a ducted, hot air recirculating system. The furnace blower was made to run continuously during the test, and excellent mixing generally resulted. The required amount of gas was injected on the suction side of the blower fan in the hot air furnace.

Excellent mixing also occurred without use of fans in homes with hot water baseboard heat, but only when the baseboards were delivering heat. The convection currents set up by heated air gave very effective mixing as evidenced by the straight line plots of ln concentration vs. time that usually resulted from tests conducted in this type of home.

Conversely, it was sometimes impossible (even with the use of several fans) to obtain a valid air exchange test when the outside temperature was high enough to eliminate the demand for heat during the mixing period. At such times, a considerably larger dose of SF6 was needed to attain the desired initial concentration in the air. This problem was noted with most homes and even some buildings with mechanical systems.

In a large building with conventional mechanical ventilation systems, the calculated dose of gas was injected ahead of the fan or fans that supplied the system. This was often accomplished by penetrating a flexible fabric connector in the ducting ahead of the fan with the injection needle of a hypodermic syringe. If several fans supplied different sections of the building, an effort was made to obtain even distribution of gas by dividing the total dose into separate portions according to the volume served by each fan system.

Gas tight, plastic or glass syringes were used for SF_6 dosing and air sampling. A central location that appeared to have good air circulation was chosen within the building as the sampling site. Five 10-cubic centimeter samples were generally taken in duplicate 10, 20, 30, 40, and 50 minutes after the building had been dosed. The duplicate sample was available for repeat testing in case there was a problem with the first one analyzed.

The samples were tested as soon as practicable to minimize potential leakage errors. Samples were sometimes held in the syringes for as long as four days without apparent ill effects; but at other times, results from old samples were suspect.

An effort was made to use a method for collection and storage of samples that had been presented in the literature (Tamura and Evans, 1983). It involved transfer of syringe samples to evacuated glass tubes of the type used for blood samples in clinical laboratories. The syringe needle is simply inserted through the rubber septum to collect the sample and the same procedure is used for sample withdrawal for testing. The writers reported successful storage for periods up to 21 days.

The DOT&PF experience was that use of the evacuated glass tubes gave a significant reduction in the linearity of three separate air exchange tests, two of which were performed concurrently with tests using syringe samples. Results of these tests are shown in Table I.

TABLE I - AIR EXCHANGE TEST RESULTS, SYRINGE VS. GLASS TUBE METHODS OF SAMPLING

1/18/84
AIR EXCHANGE RATE (ACPH) IN PEDERSON HOME

	10:00 AM	11:25 AM	12:35 AM	1:40 PM
Glass tube method	0.37	0.44	--	0.40
Syringe method	0.20	--	0.28	0.37

Although the glass tube results appear more consistent, poorer linearity of the plotted data made this this method suspect.

Several syringe tests were run at 2:30 PM the same day on the same home to see how the gas was mixing and decaying in various rooms of the home and to determine the air exchange rate of each room. Results are given in Table II.

TABLE II - AIR EXCHANGE TEST RESULTS, TRACER GAS MIXING AND ROOM UNIFORMITY TRIALS

ROOM	ACPH
Bedroom 1	0.13
Bedroom 2	0.28
Dining room	0.23
Living room	0.22
Average (*)	0.22
Average (**)	0.215

* This is the result of an air exchange rate test plot where the concentrations of the four samples from the rooms were averaged for each sampling time.

** This is an arithmetic average of the four rooms tested.

The data from all the room by room tests had excellent linearity, and SF_6 concentrations for all rooms were within the range 770 to 996 ppt. These results indicated that the syringe method results are more reliable. They also showed very good mixing throughout the baseboard heated house and the expected similarity in air exchange rates of the various rooms. They were a general endorsement of the Research syringe method. Because sample aging was not a serious problem, and Research did not wish to sacrifice accuracy of the test results, the glass tube method was not evaluated further.

The SF_6 concentration of each sample, along with the time after release of the SF_6 dose (sampling time) were entered into a computer that had been programmed to solve the dilution equation in 2.1.1 above. An X-Y plotter was employed to show the linearity of the SF_6 concentration vs. time plot, and to print the air exchange rate, temperatures, relative humidity, building volume and any other desired variables. A visual analysis of each SF_6 vs. time plot was made to determine linearity. Sometimes, one or two out-of-line points were thrown out. On rare occasions the entire test was judged to be bad and the results thrown out; the test was then rerun, if possible.

A typical computer generated plot is given in Figure 2. As shown, the plot contains a summary of all the data collected during each test. Appendix A provides all the available data for homes. Additional data on larger buildings is contained in Appendices C & D. Data from the State

Court and Office Building and Memorial Hospital Intensive Care Unit testing have already been published (Kailing, 1983).

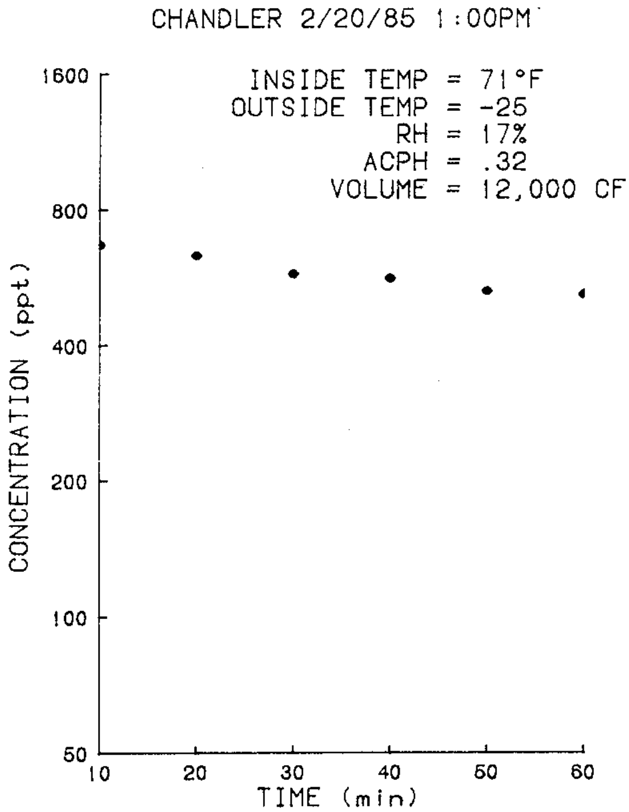


Figure 2 - Typical Plot of Air Exchange Test Data and Results

2.2 Companion Measurements

Several other measurements were taken routinely whenever an air exchange test was made. These were indoor temperature, outdoor temperature and relative humidity of the indoor air. On a few occasions, wind speed was measured. During investigation of several large buildings, air velocities around fans and registers were also taken. These additional measurements were made with the following equipment:

Relative humidity - sling psychrometer for initial measurements; Abbeon certified hygrometer for most of the air exchange tests.

Air temperatures	-	mercury or alcohol filled, glass thermometers that had been verified with distilled icewater.
Wind speed	-	Weather Measure Model W 131 Air Meter .
Air velocity (and temperature)	-	TSI Model 1650 Air Velocity Meter

2.3 Brookhaven AIMS Method

This easy-to-use, continuous method was designed by Brookhaven National Laboratories to provide time integrated measurements of air exchange rates in homes (Dietz and Cote, 1982). A perfluorocarbon tracer (PFT) consisting of perfluorodimethylcyclohexane, perfluoromethylcyclohexane or perfluoro-dimethylcyclohexane is used as a continuous source for AIMS, which is an adaptation of the steady state tracer method (Harrje et al., 1975; Condon et al.,1980). A complete description of the method is given by Dietz and Cote (1982) and a summary is presented in an earlier DOT&PF Research Report (Kailing, 1983).

The AIMS method makes use of passive source and sampling devices that are each about the size and shape of a small cigarette. One PFT source is deployed for each building to be tested. Sources are generally taped to walls and furniture. At least 8 hours after the sources have been exposed, samplers are deployed in a similar manner, usually one to each major room, or 3 to 5 in an average home. Samplers can be collected for analysis and determination of mean air exchange rate (over the time period exposed) after only a few hours or as long as several years of exposure.

It was apparent that unskilled persons could readily master the source and sampler deployment and collection procedures. Sources and samplers also appeared to be very rugged and insensitive to storage time; they could easily be sent through the mail. Only the production of these devices and the analysis of exposed samplers requires a high level of technical expertise and expensive laboratory equipment. Since the latter could all be done in one central location, preferably a private laboratory, the method appeared to have great promise for general application by private individuals and public agencies in Alaska.

Based on the above, DOT&PF Research contracted with Brookhaven National Laboratories for trial of the AIMS method. Facilities Research deployed sources and samplers in several buildings that were already being tested routinely with the ASTM Tracer Dilution Method. Monthly AIMS samples were then sent to Brookhaven for analysis. The results, which are presented in 3.2 below, were quite favorable.

At the time, Brookhaven was over committed on its development program for the AIMS method and was seeking someone in the private sector to develop the capability to run the PFT analysis and manufacture sources and samplers. Brookhaven was unable to complete the contractual scope of services with DOT&PF (only two of three planned monthly tests using 34 samplers in seven buildings were actually carried out). No additional cooperation from Brookhaven could be expected for a period of undetermined length. Therefore, DOT&PF Research made a decision to try and develop the expertise and equipment needed to manufacture and test PFT devices.

The Geophysical Institute at The University of Alaska (UAF) was asked to propose on setting up an analytical facility for perfluorocarbon tracers based on the AIMS methodology. Thomas Gosink of the Geo/Chemistry Section prepared the proposal. He was quite confident that the method could be duplicated using existing Institute equipment for the most part.

Dr. Gosink anticipated that analysis of routine samples would cost about $60 per sample initially, but greater use of the facility would bring the cost down to as low as $15 per sample. Since only about four samples are required for an average size home, the total of $60 plus handling costs appeared to be a reasonable price for a complete, time integrated test. Adoption of the method by private laboratories might lower the price even further.

A Perkin-Elmer 3920 electron capture gas chromatograph, valves, interface and computer integrator were used by the Geophysical Institute for analysis of perfluorodimethylcyclohexane. A 10 port valve with activators was employed to provide for higher potential sampling rates than those achieved by Brookhaven.

Many problems were encountered by the Geo/Chemistry staff in trying to set up the AIMS Method. A viton material with the same permeability as the one used by Brookhaven could not be found. The samplers made were not as rugged a design as those from Brookhaven and they were too large to be readily taped to walls, etc.

The biggest problem was that the Geo/Chemistry section did not have sufficient funding to retain its gas chromatography technician, and adequate calibration of devices and verification of procedures were not completed before he left. There was no way of continuing to develop the AIMS Method without full time funding for the technician by the Research Section alone. This was considered to be prohibitively expensive.

The final report by T.A. Gosink on the above effort is presented as Appendix B. It will be useful if a future effort is made to set up the AIMS Method in Alaska.

3.0 DISCUSSION OF RESULTS

It is difficult to generalize about several years of air exchange testing on various types of buildings, but some results were evident. For homes, air exchange rates were considerably lower than expected based on a literature review covering similar test work done in the Lower 48 States (see 3.3 below).

Many of the older homes tested were as tight as the newest ones, although the tightest home found had been built with extra care to conserve energy. None of the homes had infiltration rates that were below the volume rates of flow recommended by the American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE, 1981) or the Uniform Building Code (1985 Edition).

The anticipated correlation between air exchange rate and inside - outside temperature difference (the stack driven or chimney effect) was extremely poor. Relationships derived by other researchers, along with the correlation coefficients derived from a statistical analysis of the data presented herein, are discussed in 3.2 below.

The correlation with indoor humidity was equally poor. The researchers had envisioned being able to control air exchange in a building by use of a simple humidistat, but there was not sufficient correlation to consider doing this. There was little opportunity to evaluate the correlation with wind, since wind speeds are typically too low to measure during a Fairbanks winter and most of the testing was done in or near the City.

Results obtained for homes, and for mechanically ventilated buildings to a lesser degree, needed to be verified and averaged by making several air exchange tests on each building. Variability in the air exchange rate of the building seemed greater than uncertainty in the test method, but this was not proven conclusively.

There was less variability in replicate tests made on buildings with mechanical ventilation, but at least two measurements made at different times were found to be needed for a fair degree of certainty. This was one of the reasons DOT&PF Research wanted to be able to use the Brookhaven AIMS Method. It promised an integrating capability that would take the place of repeated testing with the ASTM Standard Method.

3.1 Initial Testing Results

An effort was made during the winter of 1980-81 to measure air exchange rates in several homes and small public buildings, primarily schools. The work was done by Lorena Hegdal, an Engineering Assistant in DOT&PF Facilities Research. Ms. Hegdal used the M.E. Department's manual tracer gas monitor and the ASTM Standard Method of testing with sulfur hexafluoride (see 2.0 METHODS).

The buildings were selected for convenient access, interest of the building owner, and Research's interest in the building type. Because no regular program of testing had been set up, the buildings were tested only once or twice.

Some of the values obtained were so low that they must be viewed judiciously. Because limited data was collected on each building, results cannot be considered representative. There is no reason to believe, however, that individual test results are not as accurate as the method allows. The tests were done properly and most of the plots obtained from the data had good linearity.

TABLE III - AIR EXCHANGE TESTING RESULTS, 1980-81 WINTER

Building System	Date	Conditions	ACPH
Rezek house	12/16/80	Outside temp = -42° F, forced air heat	0.62
Rezek house	4/22/81	Outside temp = 44° F (ave)	0.04
Hegdal apartment	12/19/80	Outside temp = -31° F, lower level 624 SF apt. with 4" walls ins. w/ spray urethane	0.03
Leonard house	12/12/80	Superinsulated house w/wood stove operating, Forced air heat, Outside temp = -41° F	0.47
Leonard house	12/12/80	Same as above w/forced air furnace operating, -47° F	0.14
Fox School	2/28/81	3,360 SF, four classroom elementary school, Outside temp = 32° F	0.19
Salcha School	3/14/81	6,400 SF middle school, 5-10 knot winds, 35° F	0.08
Two Rivers School (Old)	3/81	1,104 SF elementary school, Forced air heating system, Outside temp = 32° F	0.32
Manley School	3/28/81	Approx. 1000 SF elementary & middle school, Light breeze, Outside temp = 29° F	0.10
Kotzebue Extension Center	4/27/81	Gusting winds, Outside temp = 29° F	0.93
Al Adams' house in Kotzebue	4/27/81	6" walls, Hot water baseboard heat, Gusting winds, Outside temp = 32° F	0.43

A summary of the results of this testing is presented in Table III. The data represent a wide range of air exchange rates over a large variety of buildings and meteorological conditions. On the basis of the above data alone, one might be led to believe 1) that air exchange rates are highly dependent upon outside temperature (Rezek house data), 2) that they are considerably higher when a wood stove is used for heating (Leonard house data) and 3) that they are dependent on wind (Kotzebue buildings had the highest air exchange rates amoung buildings tested at comparable outside temperatures).

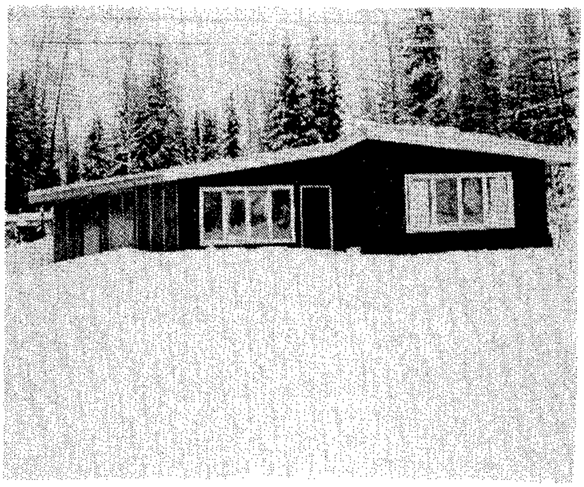
The first one of the above hypotheses was proven false by more extensive testing. The other two weren't tested sufficiently to draw any conclusions.

3.2 Intensified Testing in 1982-83 Winter

To expand upon the results of the initial tests by Ms. Hegdal, Facilities Research carried out a more intensive testing program during the winter of 1982-1983. Carol Pederson, Laboratory Technician, did the bulk of the sampling and testing. The writer managed the project and evaluated the results. During this portion of the project, the Brookhaven AIMS Method was evaluated; a small amount of data on Radon 222 concentration was also collected. A complete report covering this work was published by DOT&PF Research (Kailing, 1983). A technical paper on the project was also presented by the writer at the Third International Cold Regions Engineering Specialty Conference in 1984.

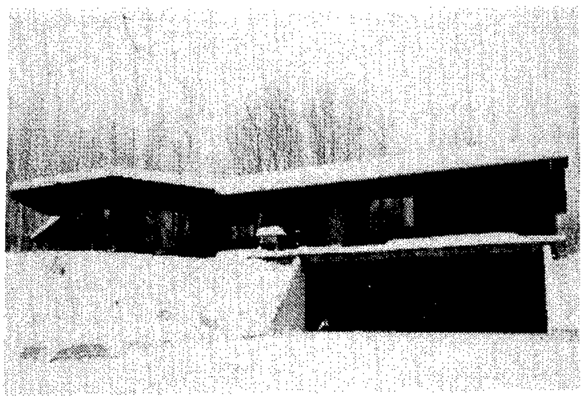
Because it would be necessary for the air sampling technician to spend a good deal of time in each of the buildings selected for testing, private homes were limited to Research Section employees and friends or acquaintances who were interested in the program. Several superinsulated, supertight homes were selected. Three public buildings and one small private office building were also included. Pictures of these homes and other buildings are shown in Figure 3. The buildings are described in Table IV. Both of the two schools tested had separate air handling systems for their main classroom and gymnasium areas. Thus, these areas were treated as two separate buildings for testing purposes.

The results, which are summarized in Table V, showed average values ranging from 0.14 ACPH for the tightest, most carefully constructed home to 0.68 for the Price Associates Office which was an old, converted one story home with a basement. It had been retrofitted with double walls and improved windows, but the insulation improvements did not appear to have had a commensurate effect on building leakage rate. The two older homes tested had about as much leakage as the newer Energy Building, which had been built recently as a showplace for energy conservation in building design. High resistance to conductive heat transfer had obviously been achieved, but the design and construction methods employed did little to reduce heat losses from air infiltration.

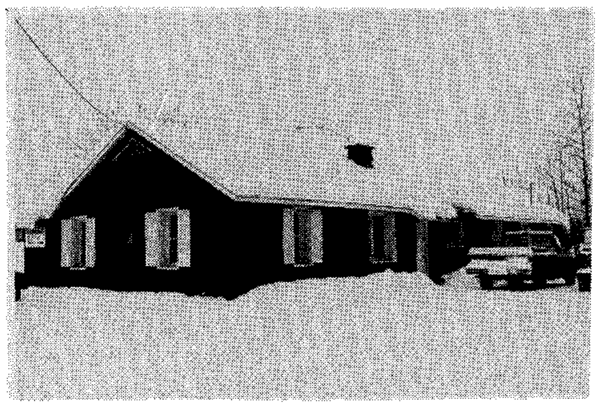


Pederson Residence

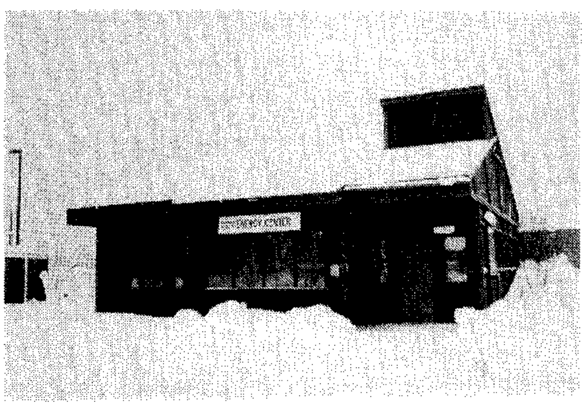
Kailing Residence (old)



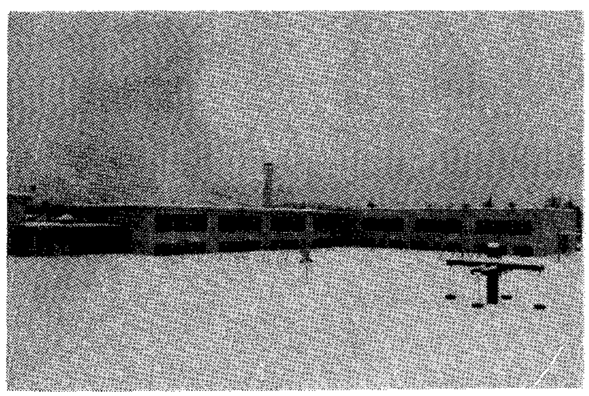
Hegdal Residence



Price Assoc. Office Building

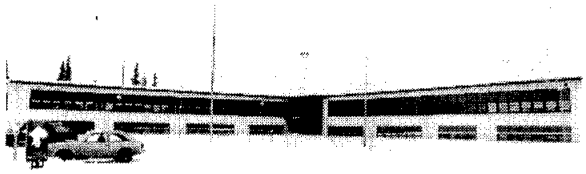


Energy Building



Denali School

Figure 3 - Building Tested Regularly During 1982 - 83 Winter



Nordale School

Figure 3 - (cont.) Buildings Tested Regularly During 1982-83 Winter

TABLE IV

CHARACTERISTICS OF BUILDINGS TESTED

Building	No.	Age 1982	Structure	Sq. Ft. 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 (old)	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 V

AIR EXCHANGE TESTING RESULTS, 1982 - 83 WINTER

			AIR CHANGES PER HOUR		
Building System	Period of Testing	Number of Tests	Mean	Standard Deviation	Standard Deviation as Percent of Mean
Pederson residence	12/05/82-03/15/83	6	0.36	0.21	58
Kailing residence	11/24/82-04/21/83	22	0.40	0.38	95
Hegdal residence	12/14/82-04/11/83	10	0.14	0.09	64
Price Associates Office	12/06/82-04/19/83	15	0.68	0.97	143
Energy Building	11/30/82-04/11/83	14	0.39	0.16	41
Denali School - Main	02/16/83-04/19/83	10	1.71	0.41	24
Denali School - Gym	02/16/83-04/19/83	10	0.78	0.34	44
Nordale School - Main	02/03/83-04/19/83	10	0.96	0.52	54
Nordale School - Gym	02/03/83-04/19/83	10	0.65	0.14	22

The schools, which were the only buildings in the this part of the test program with mechanical ventilation, had considerably higher rates of air exchange; this was expected because they were designed for higher occupancy levels. It should be noted, however, that the main part of Denali School had nearly double the air exchange rate for the classroom section of Nordale School. If this high ventilation rate is a continuing occurrence, it represents a great deal of wasted energy. This energy loss may or may not be easy to correct depending on the design of the ventilation system and other factors that would require investigation by a competent mechanical engineering firm.

A statistical evaluation of the data was performed to determine whether there was any correlation between air exchange rate and the following parameters:

1) Inside - outside temperature difference

2) Relative humidity (indoors)

3) Time of year

Correlation coefficients obtained with all three variables were extremely poor using the following relationships obtained from the literature (Wang and Sepsy, 1980, Sherman, et.al., 1980):

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

2) $Q_{total} = K \quad T$

Where: Q_{total} is the total air infiltration

A,B and K are constants

T is inside minus outside temperature

Several other algebraic equations were also tried using a computer program designed to test such relationships by the method of least squares.

The highest regression coefficient obtained from the best temperature difference equation was 0.601 for the Energy Building. Values obtained from the same test period for the other buildings ranged from 0.003 to 0.499. Correlations for indoor humidity and time of year were equally poor.

One must conclude that the relationships sought in the above work either do not exist or else there are unknown factors that mask them. Efforts to relate air exchange rates to other measurable variables were so fruitless that this was not even attempted in any of the subsequent air exchange testing work.

Results obtained with the Brookhaven AIMS Method appeared to be quite reliable, although this method gave considerably lower exchange rates than those taken during the same period with the SF_6 Method. One must keep in mind, however, that the duration of each Standard Method test is only about one hour whereas the AIMS method samples continuously over the entire monthly test period.

Table VI gives results for each of the methods over the two monthly test periods and allows a limited comparison of the two methods to be made. The standard deviations are not directly comparable because the one given for the SF_6 Method shows variability between repeated tests whereas the standard deviation for the AIMS Method shows variability between the samplers used for a given test. As noted above, the duration of testing is not comparable even though the testing period is the same.

As shown in Table VI, the average mean for each month of testing with the AIMS method was only about half of that obtained from the SF_6 testing. There are at least three possible explanations: 1) Air exchange rates vary appreciably over a 24 hour period and may be considerably lower at night when no SF_6 testing was done, 2) the testing was conducted later in the winter when poorer results were generally obtained with the SF_6 Method due to insufficient mixing of the tracer gas and 3) one of the methods is more accurate (under these particular test conditions) than the other.

A high level of Radon 222 was found in only one of six buildings tested for Radon during the 1982-83 Winter. Results are given in Table VII. Additional data on Radon were collected by Facilities Research during the 1986-87 Winter. A research report on this additional work will be published in the future.

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 PFI 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.

TABLE VII - RADON TESTING RESULTS

Building	Period of Exposure	Radon Exposure Rate (pCi/)*	Std. Dev. (%)	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	----

* pci/ = picocuries per liter of air; EPA limits for indoor air are 4 pci/ average, 6 pci/ maximum.

** March and April, 1983, average value - provided for reference.

3.3 Additional Testing of Homes During 1983-84 and 1984-85 Winters

Several more homes were selected during these two winters for repeated testing, and additional tests were performed on a few of the homes that had been tested previously. Pictures of the homes that were new to the testing program are presented in Figure 4. Some homes that were tested only once as a result of owner request are also included. Characteristics of all additional homes are presented in Table VIII.

Results of this additional testing are given in Table IX. Only the Gerdtsson Home had mechanical ventilation (an air-to-air heat exchanger). Its air exchange rate was relatively high and much more consistent than most of the other homes.

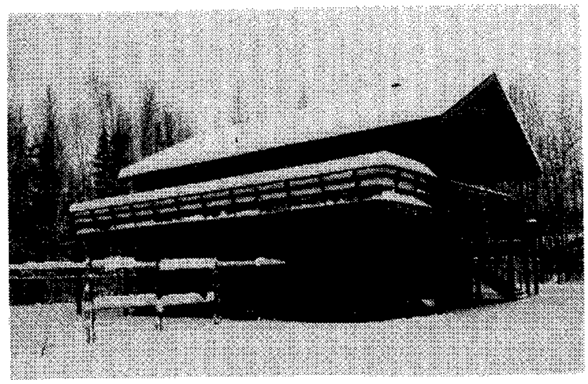
The data obtained from air exchange testing during the 1982-83 Winter is also included in Table IX for comparison. Results from the three winters are quite similar, with the means of all but one of the homes falling in the range 0.23 to 0.69 ACPH. The average air exchange rate for the 17 homes (average of the means) was 0.39 ACPH by the tracer gas dilution method.

The average value of 0.39 ACPH for Fairbanks homes can be compared with 1.25 ACPH reported for ten homes tested similarly in Portland, Maine (Grot, 1980). Harrje and Mills (1980) compared the infiltration rates measured in four Twin Rivers, N.J. townhouses before and after retrofit using the same method. The pre-retrofit houses had an average infiltration rate of 0.65 ACPH. After weatherization, average infiltration dropped to 0.39 ACPH.

Grot and Clarke (1979) presented infiltration rate data for 250 dwellings occupied by low income household in 14 cities. The geometric mean for all dwellings was 1.12 ACPH. Homes in Fargo, ND had the lowest geometric mean, 0.61 ACPH. In descending order were Tacoma, WA, and Colorado Springs, CO, with 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; Easton, PA, 1.24 ACPH; and Chicago, IL, 1.52 ACPH.

Air exchange rates by themselves do not necessarily indicate the adequacy of ventilation in a given building. The Hegdal home had the lowest average rate - only 0.14 ACPH, but it also had the highest occupied volume,

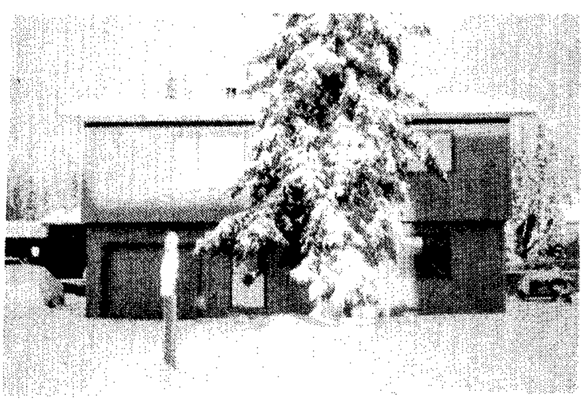
Kelly Home



Gerdtsson Home

Kailing Home (New)

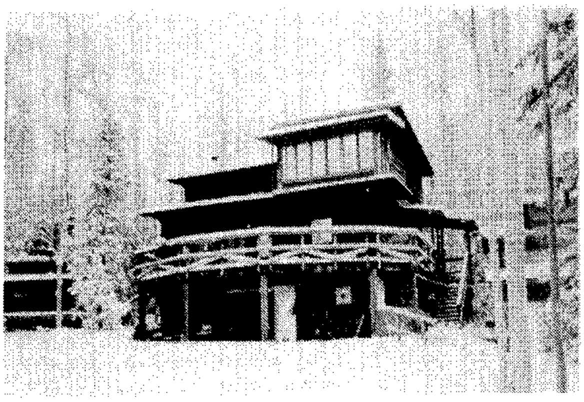
McGee Home



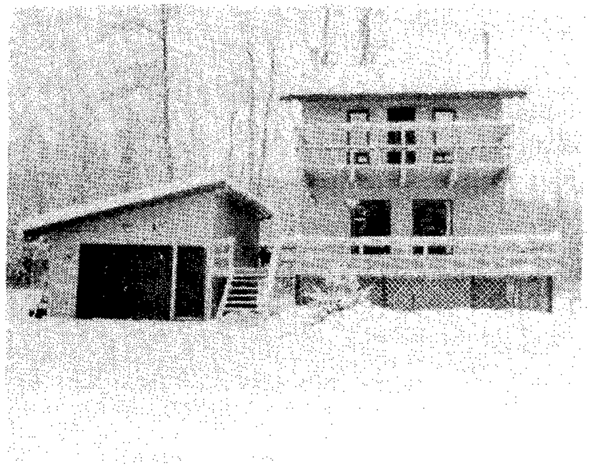
Chandler Home

Sweet Home

Figure 4 - Additional Homes Tested



Braley Home



Braddock Home

Coffer Home

Nielson Home

Figure 4 - (cont.) Additional Homes Tested

TABLE VIII

CHARACTERISTICS OF ADDITIONAL HOMES TESTED

Building	Age 1985	Structure	Square Feet Finished Floor Area	Number of Floors	Garage	Heating	Woodstove/ Fireplace	Basement	Openable Windows	Number of Doors
Kelly	3	18" wall w/3-1/2" air space, wood frame	2100	2	Yes attached	OHWBB	Woodstove	Crawl space	6	3
Gerdtsson	2	6" urethane walls, double radiant heat w/air to air heat exchange, wood frame	1440	1	Yes attached	Oil fired radiant heat in concrete floors (upper & lower)	Fireplace	Partial	8	2
Kailing (new)	2	10" double wall construction, wood frame	2000	2-1/2	Yes attached	OHWBB	Woodstove	Yes	8	3
McGee	20	6" wall, wood frame	3872	3	Yes attached	Coal fired HWBB	Woodstove	Yes	39	5
Chandler	6	6" wall, wood frame	1200	2	Yes attached	OHWBB	Woodstove	Partial/ daylight	8	2
Sweet	1	Wrap & strap construction (unbroken vapor barrier), wood frame	784	1	Yes attached	OHWBB	Woodstove	Partial/ daylight	6	2
Braley	1	10" wall, wood frame	1700	2-1/2	No	Oil fired, forced air	Woodstove	Yes	7	3
Braddock	3	8" double wall construction, wood frame	800	2	Yes attached	Oil fired, forced air	Woodstove	Crawl space	7	2
Coffer	2	6" wall, sprayed urethane on inside of outer wall, wood frame	1092	1	Yes attached	OHWBB	No	Crawl space	6	2
Conn	3	12" double wall, wood frame	1895	2	No	OHWBB	No	Yes daylight	7	3
Nielsen	5	6" wall, wood frame	938	1-1/2	No	Wood	Woodstove	Crawl space	7	2

TABLE IX - AIR EXCHANGE TESTING RESULTS
HOMES TESTED DURING THE PERIOD 1982 - 1985

Building System	Period of Testing	Number of Tests	AIR CHANGES PER HR Mean	AIR CHANGES PER HR Range
1984-85 Winter:				
Kelly home	02/13/85-03/07/85	3	0.32	0.22-0.46
McGee home	02/04/85-03/18/85	6	0.30	0.14-0.36
Chandler home	02/06/85-02/27/85	4	0.38	0.21-0.65
Kailing home	02/04/85-02/19/85	3	0.24	0.15-0.32
Sweet home	02/07/85-03/07/85	4	0.24	0.12-0.32
Braley home	02/17/85-03/10/85	2	0.69	0.67-0.71
Braddock home	02/14/85	1	0.69	
Gerdtsson home	02/11/85-03/04/85	4	0.59	0.53-0.67
1983-1984 Winter:				
Pederson home	01/18/84	3	0.23	0.20-0.28
Coffer home	11/23/83-01/26/84	4	0.34	0.23-0.56
1982-1983 Winter:				
Pederson home	12/05/82-03/15/83	6	0.36	0.07-0.70
Kailing home (old)	11/24/82-04/21/83	21	0.40	0.14-0.68
Hegdal home	12/14/82-04/11/83	10	0.14	0.01-0.29
Price Assoc. Office	12/06/82-04/19/83	13	0.68	0.20-0.79
Energy Building	11/30/82-04/11/83	13	0.39	0.12-0.57
McGee home	02/09/83	1	0.29	
Conn home	02/25/83	1	0.31	
Nielsen home	02/09/83	1	0.43	

34,400 cubic feet. Three persons normally occupy the home, giving the following air flow per person:

$$\frac{.14 \text{ air changes}}{60 \text{ min.}} \times \frac{34{,}400 \text{ cu. ft.}}{\text{air change}} \times \frac{1}{3 \text{ persons}} = 27 \text{ cfm/person}$$

The Uniform Building Code, 1985 Edition, calls for only 5 cfm per person for most occupancies. The lowest air exchange rate found (average value) was, therefore, well within this Code requirement.

More specifically, the above code requires 2 ACPH of total ventilating air in most rooms of a house, of which one fifth shall be taken from the outside (see Group R Occupancies), when a mechanical ventilating system is used in lieu of openable windows. This amounts to 0.10 ACPH of outside air, which is also met by the Hegdal house average value, but not as easily.

Before drawing any conclusions about the adequacy of ventilation in a given building, the air exchange rate should always be related to volume rate of incoming air flow as shown above. Neither of the above Code provisions actually apply to a house with natural ventilation, but they provide a frame of reference.

ASHRAE (1981) contains outdoor air requirements for ventilation that are given as follows:

Space	cfm/room
General living areas	10
Bedrooms	10
All other rooms	10
Kitchens	100 (*)
Baths, toilets	50 (*)

(*) Installed capacity for intermittent use

The Hegdal house with a total of 81 cfm and seven rooms (including two bathrooms and the kitchen) in the upstairs living space would meet the general requirement of 10 cfm per room. No tests were run while the kitchen fan or bathroom fans were operating.

Because the researchers did not try to evaluate the vapor barrier and tightness of windows and doors in the buildings tested, it is impossible to draw conclusions regarding their absolute or relative impact on air infiltration. One can surmise from the testing results, however, that most Fairbanks area homes built in recent years are not appreciably tighter than homes built 15 or 20 years ago. The reason that older homes in Fairbanks are quite tight is believed to be comfort - a leaky home in a cold environment tends to be quite uncomfortable. The occupant has a strong impetus to plug up the leaks.

3.4 Studies Conducted In Larger Buildings

Through government agency channels and public awareness of Research's capability to evaluate air quality, several studies were requested of the Research Section involving fairly large buildings.

These were opportunities to conduct research in a favorable atmosphere for obtaining access to and information about the buildings. People responsible for building operation were normally quite cooperative once they knew that the results of the research might aid the owner/operator with a maintenance or operating problem.

The type of problem that Research was asked to investigate generally involved complaints by building inhabitants that air quality within a building was poor. As a result, the testing was usually performed in an occupied space that either did have or was perceived to have substandard air quality.

This was an ideal testing ground for the kind of information Research wanted to collect, and the tracer gas dilution method turned out to be very useful for analyzing these situations. In most cases, it provided the only factual information relating to air quality that anyone had been able to obtain.

3.4.1 Air Flow in Fairbanks Memorial Hospital Intensive Care Unit

Figure 5 - Fairbanks Memorial Hospital, 1650 Cowles Street

In late 1982, Facilities Research was asked by Tom Kosatsky of the U.S. Department of Health and Social Services to assist with an investigation of five tuberculosis skin test conversions among nurses in the Intensive Care Unit (ICU) at Fairbanks Memorial Hospital. Dr. Kosatsky wished to evaluate the air flow characteristics of a room where a patient with a case of active tuberculosis was placed prior to being correctly diagnosed and moved to a medical ward. The door to the room was only about 15 feet from the patient room.

The writer borrowed the manual tracer gas monitor from the UAF Mechanical Engineering Department and ran a series of tests that indicated the relative concentrations of SF_6 in the patient room and at the nurses station after a dose of SF_6 had been released in the patient room.

Runs were made with the door to the patient room closed and also, with it open. In the former instance, SF_6 concentrations at the nurses station reached 10% of the in-room concentrations after about 25 minutes. In the latter, nurses station concentrations were as high as 66% of those in the room after 25 minutes, and maximum concentrations at the nurses station were reached much more rapidly (only 5 minutes after the dose).

In order to determine whether other patients in the ICU had been exposed by this incident, the concentration of SF_6 was monitored in an adjacent room while the room that had been occupied by the tuberculosis patient was dosed with SF_6. No cross contamination between patient rooms was indicated with the doors to both rooms kept closed.

Air exchange rates were also measured in the patient room. Results appear in Table X.

TABLE X - AIR EXCHANGE RATE OF A PATIENT ROOM IN THE HOSPITAL INTENSIVE CARE UNIT

Run	Rate (ACPH)	Air Flow (CFM)
1 - Door closed	6.4	126
2 - Door closed	6.3	124
3 - Door open	10.1	199

The study clearly showed the potential for spread of airborne bacteria and demonstrated how the nurses station area became contaminated when the tuberculosis patient was coughing inside the room, particularly during the time that the door was open. It also demonstrated the utility of tracer gas monitoring to show direction and velocity of flow. It established relative concentrations of airborne contaminants in adjacent areas caused by a point discharge of these contaminants in one or more of the areas.

A short technical report on the above work is available from DOT&PF Research in the form of a Technical Note (Kailing, 1983). An epidemiology oriented manuscript may also be available from Tom Kosatsky, M.D. (Kosatsky, et.al., 1984). The paper was submitted to the New England Journal of Medicine, but rejected for publication because it apparently does not add any new information to the Center for Disease Control guidelines for tuberculosis.

3.4.2 Ventilation Study of State Court and Office Building

Figure 6 - State Court & Office Building, 604 Barnette St.

This study, which was performed during the 1982-83 Winter, resulted from the interest of Fred Barrett, then DOT&PF Buildings Manager, Northern Region. Mr. Barrett had been one of the recipients of repeated complaints about heat, cold and stuffiness in the State Court and Office Building in Fairbanks.

Efforts to improve the heating and ventilating system for the building through design and equipment changes had not been very successful. In order to gain more information about the nature of the problem, Fred Barrett asked Facilities Research to determine air exchange rates in high occupancy areas within the building.

When applying the tracer gas dilution method to a single room within a building that has a recirculating air system, one must account for the tracer gas that is recycled to the room during the test period. In anticipation of dealing with this complexity during testing of the Court and Office Building, the researchers proceeded to develop a differential equation that would include this factor. The development is summarized below:

$$\dot{m}_v C_s = \dot{m}_a C + M_z \frac{dc}{dt}$$

Where $\dot{m}_v$ = mass flow of ventilating air into room (lb air/hr.)

C_s = concentration of SF_6 in ventilating air into room (lb SF_6/lb air)

$\dot{m}_a$ = mass flow of ventilating air out of room (lb air/hr.)

C = instantaneous concentration of SF_6 in room air (lb SF_6/lb air)

$M_z = V \times \rho air$ = mass of air in room (lb air)

$ACPH = \frac{\dot{m}_v}{V}$ = air changes per hour (1/hr)

V = Volume of room (ft^3)

ρ = room air density (lb/ft^3)

t = time (hours)

$$\dot{m}_a = \rho(ACPH)V$$

$$\dot{m}_v = \dot{m}_a$$

$$\frac{\dot{m}_v}{V} C_s = (ACPH)C + \frac{dc}{dt}$$

$$e^{\int(ACPH)dt} = e^{(ACPH)t}$$

$$d\left(e^{(ACPH)t} C\right) = \frac{\dot{m}_v}{\rho V} C_s e^{(ACPH)t}$$

$$e^{(ACPH)t} C = \frac{\dot{m}_v}{\rho V} C_s \frac{e^{(ACPH)t}}{ACPH} + D$$

where D is a constant from the integration

$$C = De^{-(ACPH)t} + \frac{\dot{m}_v C_s}{\rho V(ACPH)}$$

at $t = 0$, $C = C_o$ and

$$C_o = D + \frac{\dot{m}_v C_s}{\rho V(ACPH)}$$

where C_o = initial SF_6 concentration in room

$$D = C_o - \frac{\dot{m}_v C_s}{\rho V(ACPH)}$$

substituting for D:

$$C = C_o \, e^{-(ACPH)t} + \frac{\dot{m}_v C_s}{\rho V(ACPH)} \; 1 - e^{(ACPH)t}$$

In order to use this equation, one has to measure the concentration of tracer gas in the supply air coming back from the air fan serving the space being measured. In addition, an iterative computer program is needed to solve for ACPH, the air exchange rate in the space.

Fortunately, the Court and Office Building volume was large enough and the air exchange rate of the entire building high enough so that SF_6 concentration in the supply air was insignificant throughout the tests. Each room that was tested behaved like an isolated building because of the relative volumes involved; this would not have been the case with a smaller, mechanically ventilated building and the above equation would have to be employed for individual room analysis

Results of the study showed that all but one of nine rooms tested had insufficient fresh air supply to allow smoking in them and still meet ventilation rates recommended by the American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE) 62-1981, "Ventilation for Acceptable Air Quality."

The courtrooms tested, which were the primary area of concern due to occupancy rates, were shown to need ventilation rate increases as provided in Table XI.

TABLE XI - COURTROOM VENTILATION NEEDS

Courtroom	Existing Ventilation Rate (ACPH)	Recommended Ventilation Rate (ACPH)
A	2.8	4.5
B	3.1	4.7
C	2.7	4.6
D	4.1	4.8

An air exchange test on the entire building gave a fresh air ventilation rate of 1.0 ACPH. Using a building volume of 700,000 cubic feet this is 700,000 cubic feet per hour. Based on an average Fairbanks winter of 14,344 ^{o}F-Days, the heat load needed to bring this air up to 70 F is calculated as follows:

$$Q = 700{,}000\ ft^3/hr \times 24\ hr/day \times .0184\ Btu/ft^3\text{-}^{o}F \times 14{,}344\ ^{o}F\text{-days}$$

$$= 4.43 \text{ billion Btus per year}$$

At a fuel oil price of $.80/gallon and 80% furnace efficiency, this amount of heat is worth

4.43 EE9 Btu x 1/.80 x 1 gal/135,000 Btu x $.80/gal = $32,800/yr

Obviously, one cannot draw any conclusions about the heating cost of the State Court and Office Building from this exercise. There are a number of other heat losses and substantial heat gains from lights and occupants to be considered, as well as the energy saving operational features that the building has for low occupancy periods. In addition, this particular building uses City steam heat - not fuel oil. But the cost of heating incoming air is shown to be substantial for a building of this size, even at relatively low fuel oil costs.

Since ASHRAE 62-1981 specifies only 7 cfm per person for most nonsmoking occupancies in a building of this type, a flow rate of 700,000 cfh (11,700 cfm) would provide enough fresh air for 1,670 people. It is doubtful that even half this number have ever occupied the building at one time.

The study resulted in recommendations that smoking be banned in all courtrooms and jury rooms and at least one ton of air conditioning capacity be added to the air supply system for the building. A complete report on the project was published by DOT&PF Research (Kailing, 1983). In summary, this work showed that the tracer gas dilution method was quite valuable for troubleshooting ventilation problems in rooms within a large building in addition to the building as a whole.

3.4.3 Energy Analysis of Andreafski High School, St. Mary's, Alaska

In early 1983, Facilities Research was contacted by Fryer-Pressley Engineers about occupant discomfort problems at a new high school in St. Mary's. High air leakage rates were believed to be a cause of the inability to keep the building warm enough during cold windy weather. After receiving a written request for assistance from the St. Mary's School District staff, Facilities Research made plans to do a study at the High School. Figure 6 shows the south side of the school.

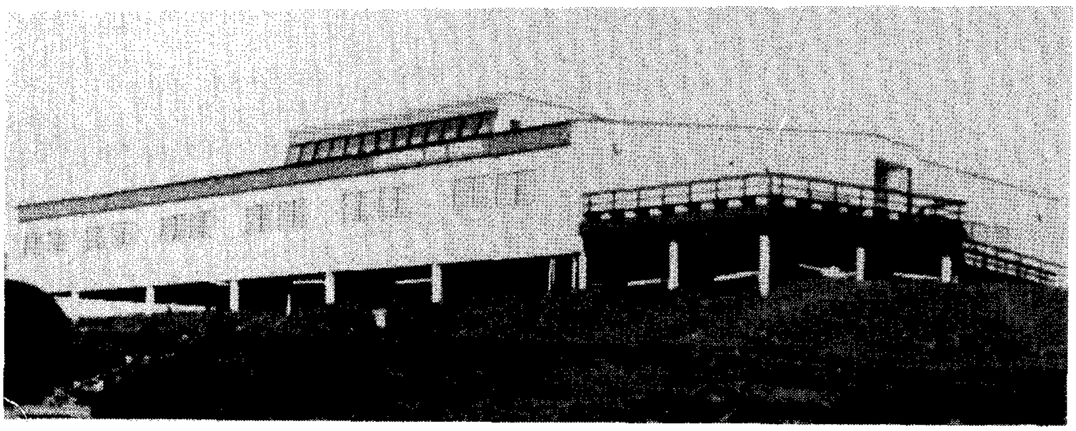


Figure 7 - Andreafski High School, St. Mary's, Alaska

Note the solar chamber on top of the School. It did not function as designed, and will probably never return a significant payback on the State's investment in this "energy saving" feature. The reason was that prevailing winter winds cause a buildup of static pressure on the windward side of the building. Resulting differential pressures cause such high air exchange rates in the solar chamber that most of the heat collected on cold windy days (when it is needed in the building) is simply swept out of the chamber. It ends up being discharged out the leeward side louvers that are part of the cold roof design.

In addition to the fact that assistance was needed by St. Mary's School District, the researchers were in need of data that reflected the effect of wind on air exchange rate of buildings. St. Mary's is known for its windy weather, and this appeared to be an opportunity to collect at least some of the desired data.

A site visit was made in mid-September, 1983, and field data was collected. The energy use characteristics of the School were evaluated using that data, but the researchers were unable to obtain a sufficient amount of additional data to draw any conclusions about the effect of wind.

Field visits to St. Mary's were so expensive in terms of air fares and research time that additional trips could not be justified. There was also a problem with getting the samples back to Fairbanks and analyzing them in time to be sure that sample degradation did not occur.

An interim report on this project was prepared in November, 1983, but no final report was published due to lack of confirming data. The interim report demonstrates how the tracer gas dilution method can be used to help analyze a building's energy use. Because it is an informative case study of a new, bush school building, the interim report is presented in Appendix B.

The air exchange rates found during the one field investigation at Andreafski High School and presented in the interim report were confirmed to some extent by a follow-up investigation by Fryer-Pressley Engineers. Facilities Research had been coordinating with Fryer-Pressley on the investigation and had left a cylinder of SF_6 and sampling equipment at the site.

Fryer-Pressley engineers resampled the building per Research's instructions and sent the samples to Fairbanks for analysis. A comparison of results is given in Table XII. Weather conditions for the 9/14/83 sampling were variable, with winds ranging from 5.9 mph WNW to 12.8 mph E and temperatures varying between 42 and 53 F. During the 2/28/84 sampling, winds ranged from about 10 mph NNW to 20 mph N and temperatures from -9 to 2^oF.

The primary problem at St. Mary's turned out to be a design calculation error in the amount of baseboard heating specified for certain areas of the school. While air exchange rates at Andreafski were shown to be higher than needed, they were not excessive for a school building of this type.

The study was beneficial to St. Mary's School District in getting the problem resolved, and it provided a limited amount of useful information for the research effort.

TABLE XII - AIR EXCHANGE RATES FOR ANDREAFSKI HIGH SCHOOL, ST. MARY'S, ALASKA

	Air Exchange Rate (ACPH)	
Condition	9/14/83 Sampling by Fac. Research	2/28/84 Sampling by Fryer-Pressley
Normal operation (a)	1.5	---
100% recycle of return air w/ 3 exhaust fans operating	1.1	(b)
100% recycle of return air w/all exhaust fans down (c)	---	0.50
All systems off	0.44	(b)
Approx. 50% outside air thru solar chamber, no exhaust fans	---	1.2

(a) Operation with the outside air louvers in the makeup air system set at about 50% open. Only the three air heater/fan units and three exhausters in the main fan room were operating. This was the mode of operation at the time of the field investigation.

(b) Efforts to duplicate earlier conditions run by Research failed due to inconsistency of the measured SF_6 concentrations.

(c) This is the configuration that had been run by School personnel most of the winter because of the problem with insufficient heat in certain areas. The test confirms that it resulted in the lowest air exchange rate for any of the operational modes tested.

3.4.4 Air Exchange Rates in Room 222 of the Federal Building

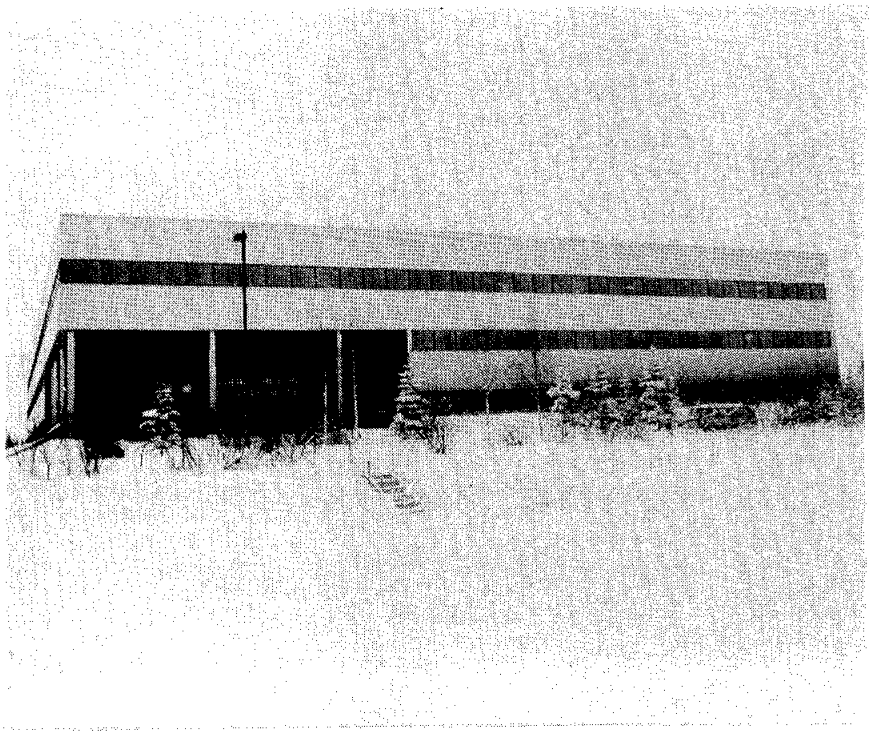


Figure 8 - Federal Building, Fairbanks, Alaska

This study was initiated by the U.S. Fish and Wildlife Service (USF&WLS) after an employee in the Northern Ecological Services Office threatened to sue the U.S. Government because of what was perceived as poor air quality in that Office (Room 222 of the Federal Building). The velocity-area method of air flow measurement was used in this investigation as well as tracer gas because some of the needed flows could not be readily measured by the latter method.

Results showed that air exchange rates in Room 222 were indeed satisfactory for the number of people normally occupying the office. Air quality was marginal, however, for most of the occupants due to uneven distribution of the supply air which contained fresh air. The problem was greatly exacerbated by smoking in an adjacent office because of the pressure differential from the hallway to the USF&WLS Office.

A report on this study entitled TECHNICAL NOTE #2 was prepared, but never published. Therefore, it is included as Appendix C. It contains a discussion on problems due to smoking that helps put that issue in perspective.

3.4.5 Air Exchange Rates at University Plaza, Fairbanks

Figure 9 - University Plaza, 600 University Ave., Fairbanks

In early 1985, Facilities Research was asked to measure air exchange rates in the two connected buildings at 600 University Avenue which were occupied by DOT&PF Planning, Facilities Design and Right of Way. DOT&PF was leasing a large portion of each of these buildings to house the groups mentioned. Employee complaints ranged from headaches to eye strain to rapid fatigue, and many felt that the ventilation system was not providing enough fresh air.

Results of the air testing are presented in TABLE XIII. Ms. Pederson had an unusual amount of difficulty obtaining good, linear air exchange plots from data obtained at University Plaza. The relatively low air exchange rates encountered along with uneven distribution were probably the reasons.

TABLE XIII - AIR TESTING RESULTS OBTAINED AT UNIVERSITY PLAZA, FAIRBANKS

Area Tested	Date	Air Exchange Rate (ACPH)	Bldg. Air Temp. (°F)	Bldg. Air Relative Humidity (%)	Outside Air Temp. (°F)
Inventory and Conditions Office (Front Bldg.)	2/26/85	1.4	76	15	10
Entire Front Bldg.	3/14/85	0.58	78	15	30
	3/19/85	0.83	80	15	33
	3/22/85	1.25	80	12	25
	4/01/85	0.50	76	8	8
	4/03/85	0.35	72	11	4
	4/11/85	0.50	76	11	11
	Averages	0.69	77	12	19
Entire Rear Bldg.	3/14/85	0.43	76	14	30
	3/19/85	0.59	80	15	33
	4/01/85	0.28	80	8	4
	4/03/85	0.48	73	12	4
	4/11/85	0.55	76	11	11
	Averages	0.47	77	12	16

As shown, the buildings had high indoor air temperatures combined with very low humidities. This condition alone would explain much of the discomfort experienced by building occupants.

Unfortunately, high temperature and low humidity are characteristic of most Fairbanks buildings. It costs more to put moisture into incoming air than to maintain the temperature needed to counteract the effect of low humidity on occupant comfort. But low humidity is never completely compensated for by higher temperature, and certain individuals in the population are especially sensitive to the effects of hot, dry air.

3.4.5 Air Exchange Rates at University Plaza, Fairbanks (Cont'd)

The average air exchange rates of 0.69 and 0.47 ACPH were compared with those measured previously in seven other mechanically ventilated buildings. The latter are summarized in Table XIV below:

TABLE XIV - AIR EXCHANGE RATES IN MECHANICALLY VENTILATED BLDGS.

Building System	No. of Tests	Mean ACPH
Denali School - Main	10	1.71
Denali School - Gym	10	0.78
Nordale School - Gym	10	0.96
Nordale School - Gym	10	0.65
Andreafski High School	2	1.3
State Court and Office Building	1	1.0
Fairbanks State Jail - Part served by old vent. sys.	1	1.5
	Average	1.1

Using the lowest air exchange rate measured in the rear building, 0.28 ACPH, the outdoor air supply was computed as shown:

$$\frac{0.28\ \text{AC}}{\text{hr}} \times \frac{130{,}000\ \text{ft}^3}{\text{AC}} \times \frac{1\ \text{hr}}{60\ \text{min}} = 607\ \text{CFM}$$

At the rate of flow specified by the Uniform Building Code, 1985 Edition (5 cfm of outdoor air per person), this is enough ventilating air for 121 people. The Inventory and Conditions Office was where the specific complaints had arisen that led to the testing. It was checked in a similar manner and found to have enough recirculated air for 20 people and enough outside air for 15 people.

Since the actual occupancies were well below those computed above, there were no Building Code violations. ASHRAE 62-1981 recommends 20 cfm of outdoor air per person for office space where smoking is allowed. Using this additional guideline, the Inventory and Conditions Office was shown to have sufficient outside air for just four people. There were five assigned to the office, one of which was a smoker, and visitors were quite frequent.

Although Uniform Building Code requirements were met, lower than normal air exchange rates were part of the problem at University Plaza. They accentuated localized problems due to smoking. It has been shown to be impractical to supply enough outdoor air to completely counteract the effects of smoking as perceived by non-smokers (Repace and Lowrey, 1982; Cain, et al, 1981).

The following recommendations were made to DOT&PF management:

1) Install humidifiers in locations where problems with employee discomfort exists.

2) Work with the manager of the buildings to achieve better temperature control and generally lower building temperatures.

3) Work towards isolation of smokers and elimination of smoking in the two buildings.

3.4.6 Air Exchange Testing at DOT&PF Finance Office

The last study performed by Facilities Research during the time period covered by this report was an investigation of problems with air quality in the Finance Office at the DOT&PF Northern Region Office Complex.

This office was unlike any of those studied previously in that it has no mechanical ventilation system. It is a converted storage area on the second floor of the DOT&PF Equipment Building shown in Figure 10. On the ground floor, vehicle and heavy equipment maintenance is performed on a routine basis.

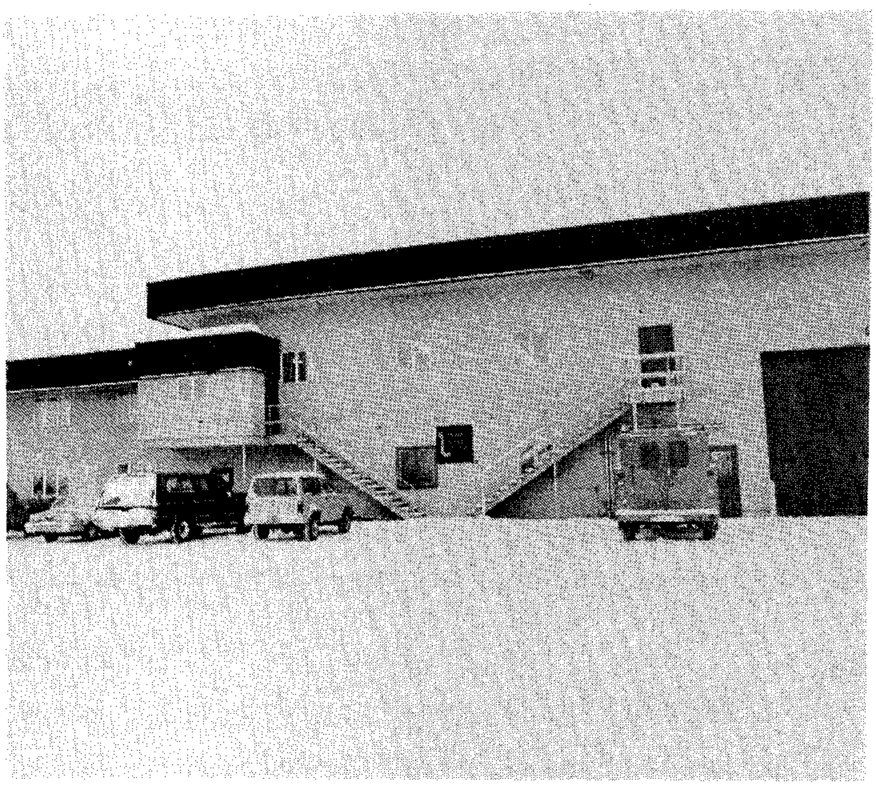


Figure 10 - DOT&PF Finance Office (On Second Floor of Equipment Building), 2301 Peger Road, Fairbanks

Finance Office employees were complaining of stale air, vehicle exhaust odors and many of the physical ailments commonly associated with poor air quality. They felt that they were not getting sufficient fresh air because of the lack of a mechanical ventilating system. After the writer experienced the atmosphere in the Finance Office, his impression was that the employee complaints were justified and he expected that testing would show very low air exchange rates.

Results of the testing are given in Table XV. Air exchange rates were not anything like expected. The Finance Office was shown to have ample air exchange, averaging 1.1 for the test period. Relative humidity was extremely low and temperature unduly high (undoubtedly to try and compensate for the cooling effect of low humidity).

TABLE XV - AIR TESTING RESULTS FROM DOT&PF FINANCE OFFICE

Date		Air Exchange Rate (ACPH)	Relative Humidity (%)	Inside Temp. (^{o}F)	Outside Temp. (^{o}F)
11/15/85		1.2	9.0	75	-6
11/18/85		1.6	9.0	77	10
11/19/85		1.0	9.5	79	3
11/20/85		1.0	9.0	79	8
11/21/85		1.1	9.0	78	2
11/22/85		0.8	9.0	78	6
	Averages	1.1	9.1	78	4

The high air exchange combined with a lack of any means for adding moisture to the incoming air was a significant problem in this space. An even greater one was that the equipment shop downstairs was the source of virtually all the air infiltrating the second story. Since this air was contaminated with vehicle exhaust, vapors from petroleum products, welding fumes, etc. (despite the use of hoods and exhaust fans in the shop), the poor air quality upstairs was the inevitable result.

Natural ventilation rates were shown to be adequate for the DOT&PF Finance Office, but a mechanical ventilation system was recommended unless virtually all the leaks in the ceiling of the Equipment Shop could somehow be sealed. A mechanical system would be designed to pressurize the second story so that the direction of air flow through ceiling leaks would be reversed. Such a system could be designed to take makeup fresh air from the roof of the building where it would be relatively clean in spite of Equipment Shop operations.

3.5 Energy Implications

The cost of energy for heating air in a large building has already been addressed in 3.4.2 Ventilation Study of State Court and Office Building. In a 2000 square foot home that has an average air exchange rate of 0.4 ACPH throughout the heating season, the energy cost for heating this air flow is computed as shown below:

$$q = w\ C_v\ (^{o}\text{F-Days})$$

Where q = heat requirement, Btu/yr.

w = volume flow of air, cu.ft./day.

C_v = volumetric heat capacity of 70 ^{o}F air, 0.0184 Btu/cu.ft.- ^{o}F.

^{o}F-Days = heating index, degree days per year (14,344 for Fairbanks).

$$w = 2000\ ft^2 \times 8\ ft \times 0.4/hr \times 24\ hr/day = 153{,}600\ ft^3/day$$

$$q = 153{,}600\ ft^3/day \times 0.0184\ Btu/ft^3\text{-}^{o}F \times 14{,}344\ ^{o}\text{F-Days}$$

$$= 40{,}540{,}000\ Btu/yr.$$

Using 80% furnace efficiency, a cost of $0.80/gal of fuel oil and a fuel oil heating value of 135,000 Btu/gal, the above heat requirement would cost $300/year to satisfy. The amount of savings from reducing the average air exchange rate of the home to only 0.2 ACPH is then $150/yr. In the same manner, the cost for a home with twice the air exchange rate or 0.8 ACPH would be $300/yr. higher.

Fuel costs of only $0.80 per gallon or less are a recent phenomenon that probably will not last. Any increase in the cost of fuel would increase the costs shown above in direct proportion and make the cost of higher air exchange rates more significant.

4.0 SUMMARY AND CONCLUSIONS

Air exchange rates were measured in a total of 21 homes, eight schools and seven public or private office buildings during the period December, 1980, through March, 1985. The average mean for all the homes was 0.38 ACPH with individual test results ranging from 0.01 ACPH (Hegdal home) to 0.71 ACPH (Braley home). All but one of the homes are in Fairbanks.

The eight schools had an overall average mean air exchange rate of 0.57 ACPH. The four with mechanical ventilation averaged 1.08 ACPH, whereas the other four had an average of only 0.17 ACPH. There appears to be a large difference in the amount of fresh air that occupants receive in power ventilated versus naturally ventilated schools. The values obtained for the latter have a weak statistical base, however, because each was the result of only one air exchange test made during relatively high outdoor temperatures (29 - 35^{o}F).

The seven public or private office buildings had an average mean air exchange rate of 0.81 ACPH. Here again, the three with power ventilation received more than those with natural ventilation only (0.88 ACPH vs. 0.72 ACPH), but the difference was much smaller.

Some conclusions were reached from the study:

1. Homes in Fairbanks have considerably lower air exchange rates than most of the homes that have been studied in the Lower 48.
2. In general, the rates do not appear to be low enough to cause concern about their impact on public health based on national standards for ventilating air. There were some buildings tested during the 1980-81 Winter that appeared to have insufficient ventilation. They would each have to be tested several more times in order to draw firm conclusions.
3. Little correlation between air exchange rate and outdoor temperature, relative humidity or time of year was found by a thorough statistical analysis of the 1982-83 test data. Differences between the means for the various buildings were found to be significant using a paired T-test analysis.
4. Improvements in the design and operation of mechanical ventilating systems could cut energy costs for heating make-up air substantially.

5. Smoking in public buildings is costing the public a great deal in terms of air quality, the need for larger mechanical systems and the energy required to heat additional make-up air. The impact can only be quantified on a building-by-building basis using design parameters established with and without smoking.

6. The tracer gas dilution method works well in most buildings when there is sufficient convection from radiant heat or forced air circulation to adequately mix the tracer gas. Portable fans are not very effective for this purpose.

7. The tracer gas dilution method is primarily a research tool requiring some expertise with gas chromatography. It would be difficult to adopt for general use by the building industry. Private or public laboratories could offer the service, but financial incentives (generally those resulting from State requirements) would have to be considerably greater than they are now. Recently enacted energy conservation standards for new residential construction by the Department of Community and Regional Affairs are moving the State in this direction.

8. The Brookhaven AIMS Method showed promise, even though efforts to set it up at the Geophysical Institute in Fairbanks were not successful. This method, if found to be completely feasible, could provide the information necessary for at least partial implementation of air exchange measurement control in Alaska. Full implementation will only come about when an air exchange measuring device is developed that is suitable for on-line control of a make-up air damper or variable speed fan.

9. The tracer gas dilution method was shown to be a particularly useful tool for analyzing ventilating problems in large buildings. It could be employed to complement the air balancing techniques commonly used to evaluate and improve the operation of building mechanical systems. It is much less applicable for control of building tightness during construction and is not recommended for this application unless there is heat or a power ventilation system in the building when air exchange tests are made.

5.0 IMPLEMENTATION

Implementation of the findings of this study by DOT&PF will depend upon a number of factors. Some of these include the future price of heating fuel, national requirements regarding indoor air pollutant levels and State of Alaska implementation of energy conservation standards.

The State has recently developed energy conservation standards for new residential buildings (Department of Community and Regional Affairs, 1986). These standards are scheduled for implementation on January 1, 1988. They provide for a maximum "seasonal average" air exchange rate of 0.4 ACPH by the tracer dilution method.

As indicated by the data collected for this study, the level of 0.4 ACPH seems reasonable for the winter season; but a seasonal average (with all four seasons weighted equally) is not a good indicator of annual air heating energy consumption and is prohibitively difficult to obtain by the standard tracer gas technique.

The above effort to set a meaningful air infiltration standard emphases the need for a long term, averaging type air exchange rate measuring device. As stated earlier, its development and adoption in Alaska is the only way that major progress will be made toward control of air exchange rates in Alaskan buildings.

The following recommendations for implementation of this study are made:

1) Brookhaven National Laboratory should be contacted by the State to determine recent progress made with the AIMS Method and other techniques for long term air exchange measurements.
2) If feasible, a research implementation program could then be developed for setting up a long term measurement method in Alaska. This program would include a demonstration phase wherein a group of State buildings are studied to show how energy costs can be reduced and utility of the buildings can be improved through changes in the HVAC system and controls.
3) Since the study showed a considerably greater need for ventilation control on existing office buildings than residences, large buildings should be a priority for State implementation activities.

Depending on the results of Recommendation #2 above, the State may wish to develop and maintain its own capability for evaluating building ventilation systems. As a result of this work, the writer feels strongly convinced that the energy cost aspects of properly ventilated buildings are secondary to the morale, sense of well being and overall productivity of people working in a comfortable, healthful working environment. While no data was generated to support this contention, it was evident from observing and communicating with the occupants in each building investigated. In order for the State "to do more with less", greater attention will have to be paid to worker environment.

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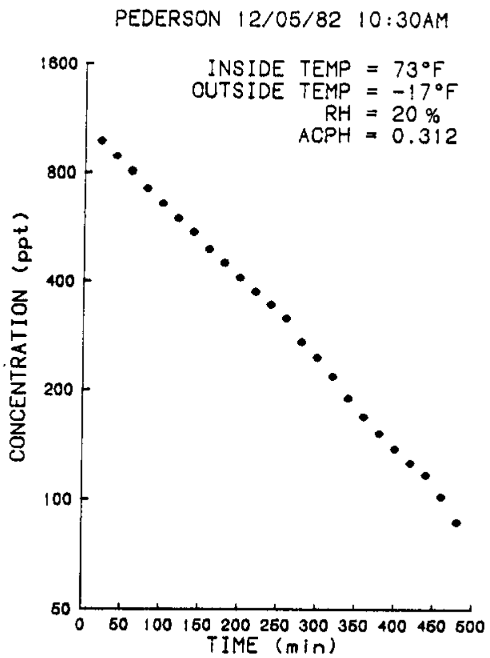
APPENDIX A

AIR EXCHANGE TEST PLOTS AND SITE DATA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OUTSIDE TEMP = -17°F
RH = 20 %
ACPH = 0.312
CONCENTRATION (ppt)
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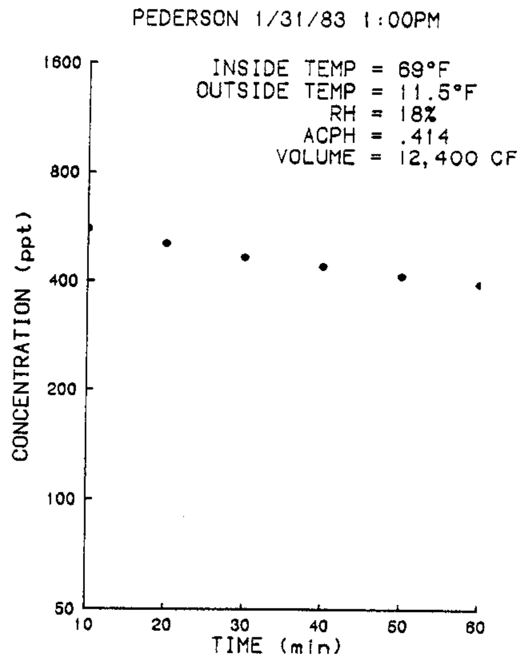
800
400
200
100
50
0 50 100 150 200 250 300 350 400 450 500
TIME (min)


PEDERSON 1/31/83 1:00PM
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OUTSIDE TEMP = 11.5°F
RH = 18%
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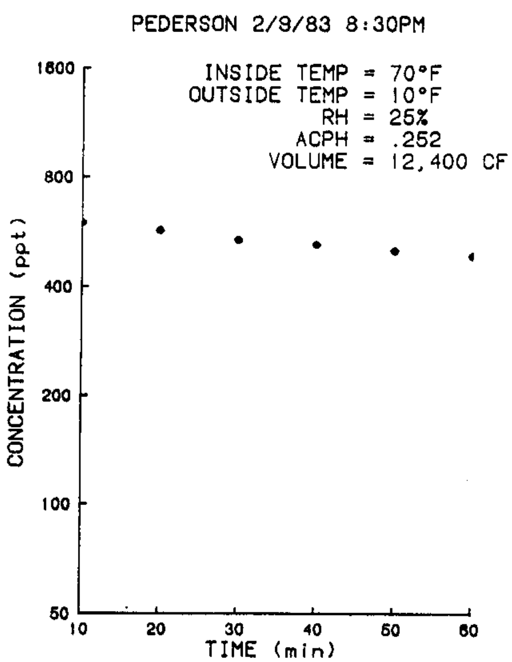
CONCENTRATION (ppt)
1600
800
400
200
100
50
10 20 30 40 50 60
TIME (min)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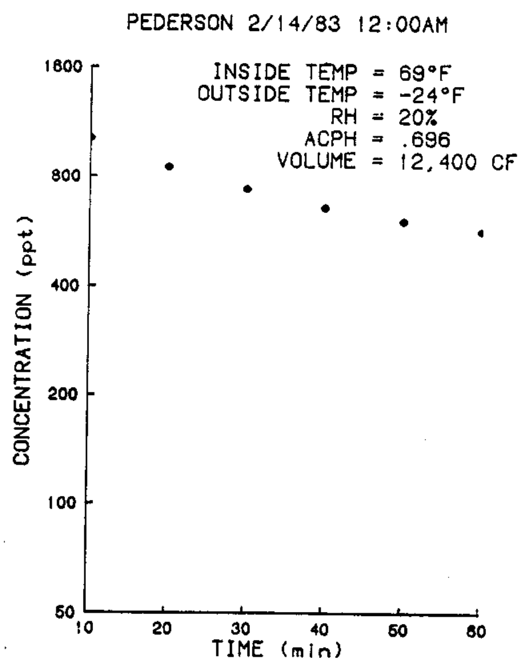
50
10 20 30 40 50 60
TIME (min)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RH = 20%
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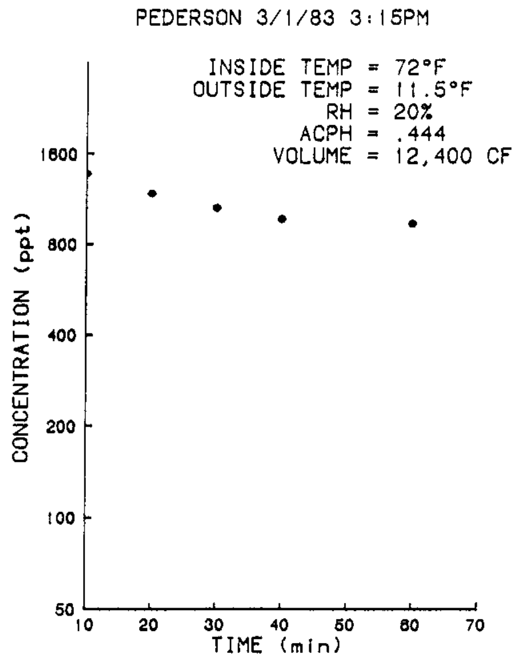
50
10 20 30 40 50 60
TIME (min)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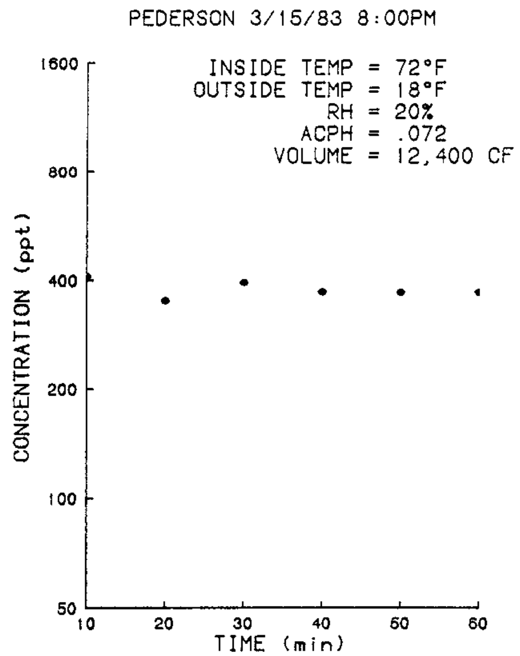
TIME (min)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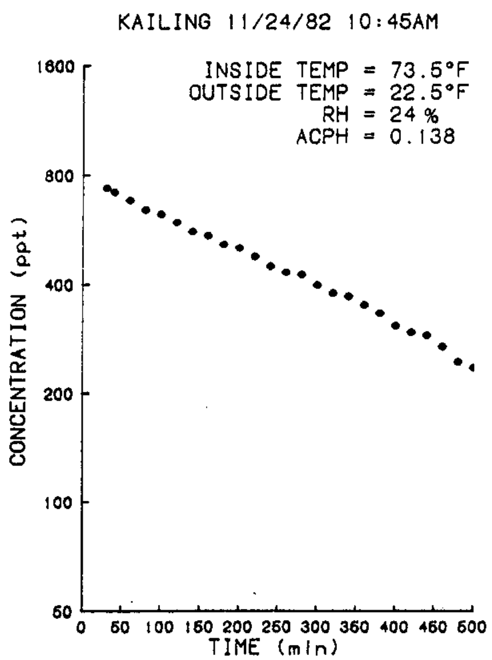
TIME (min)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ACPH = 0.138
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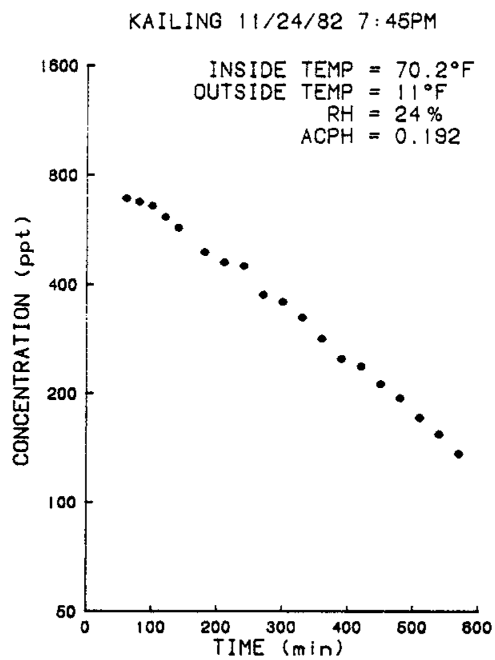
TIME (min)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TIME (min)

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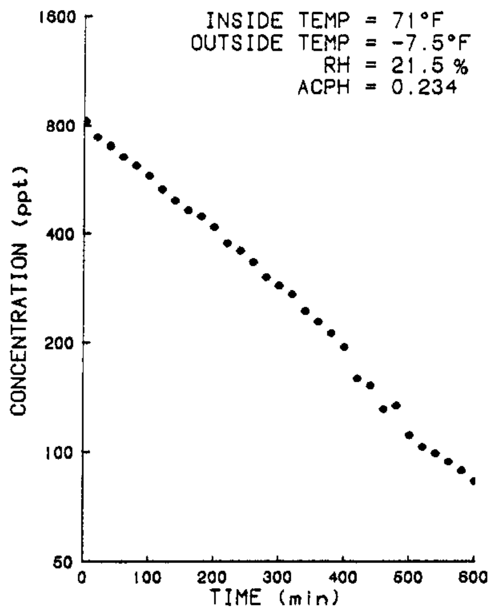

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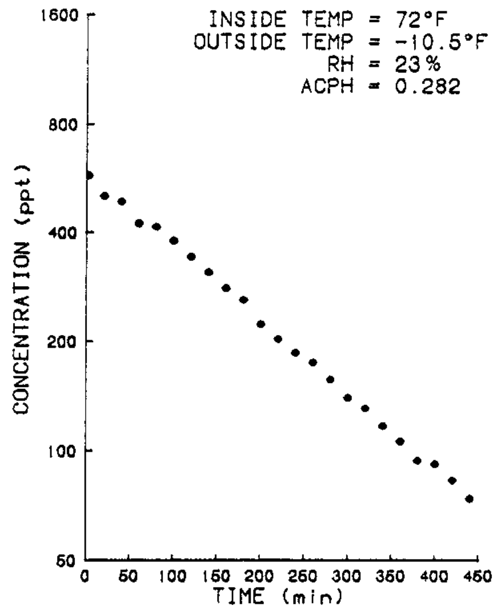

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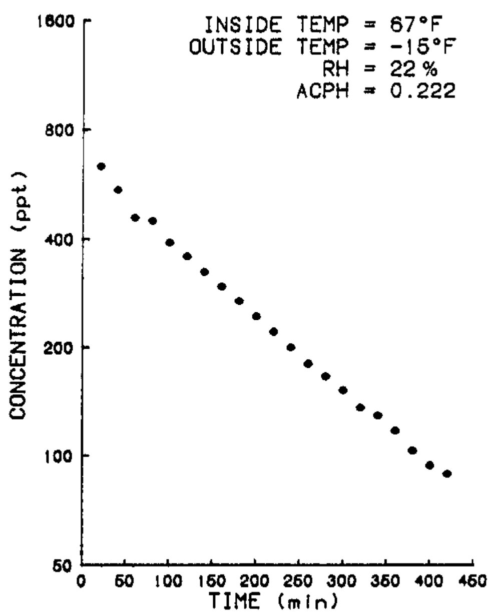
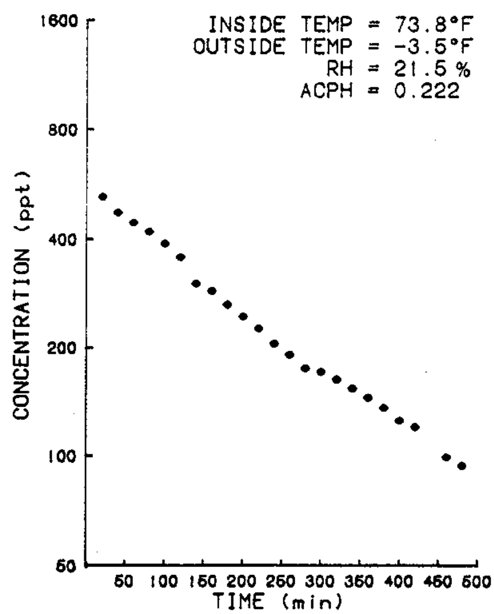
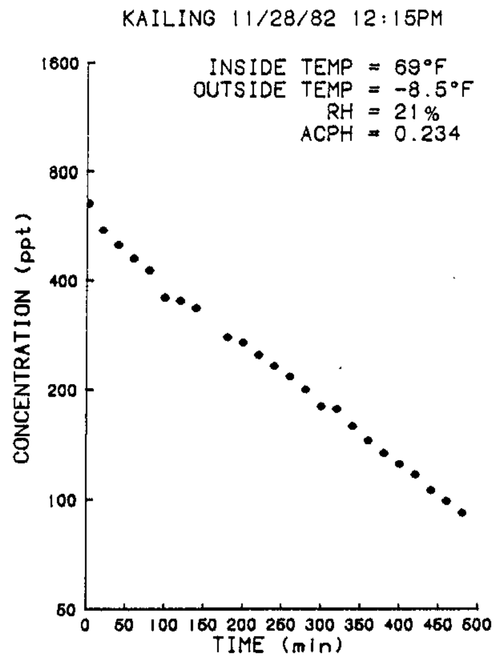
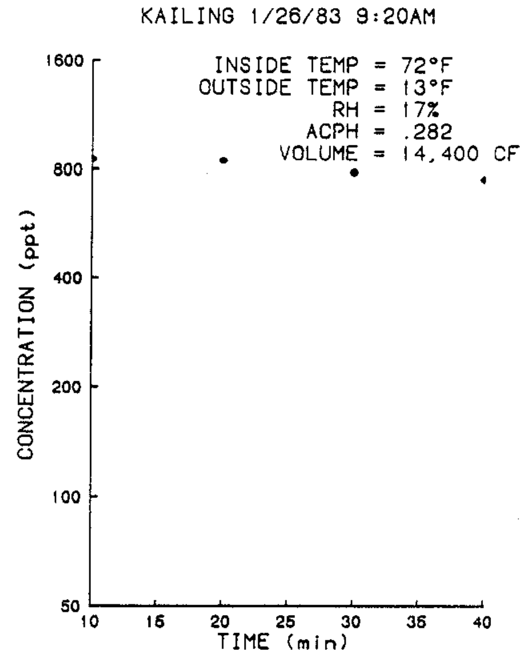
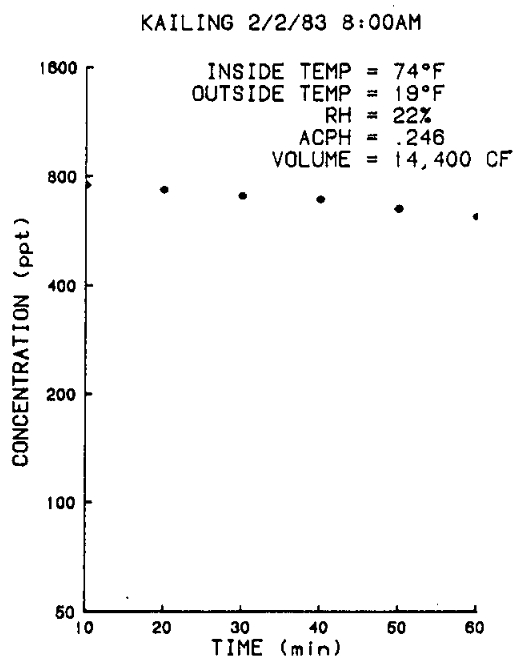


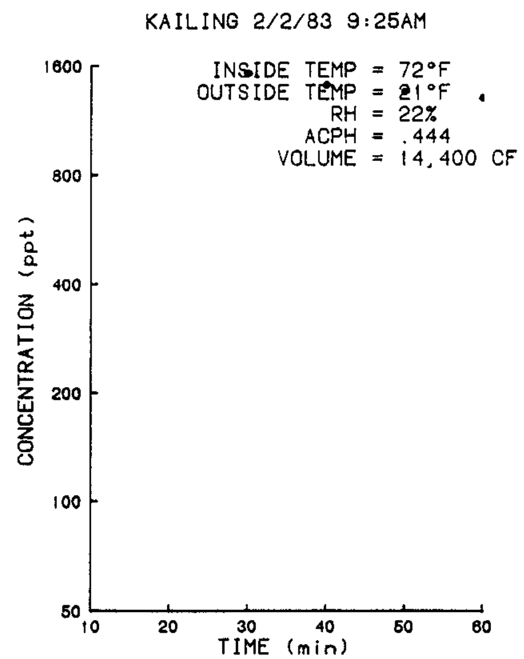
KAILING 11/28/82 10:15PM

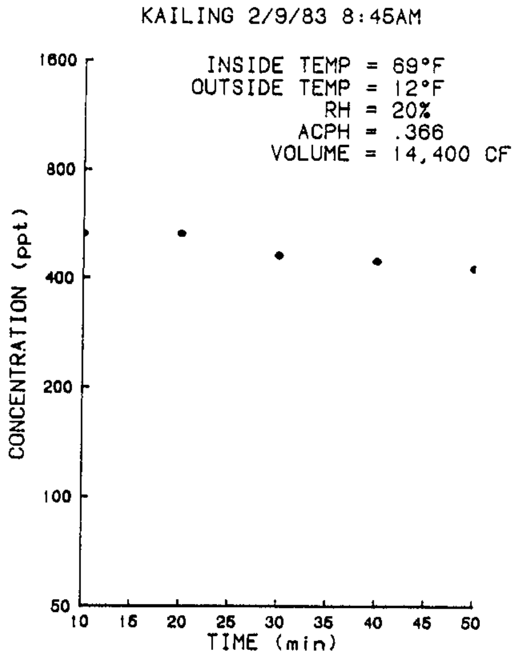


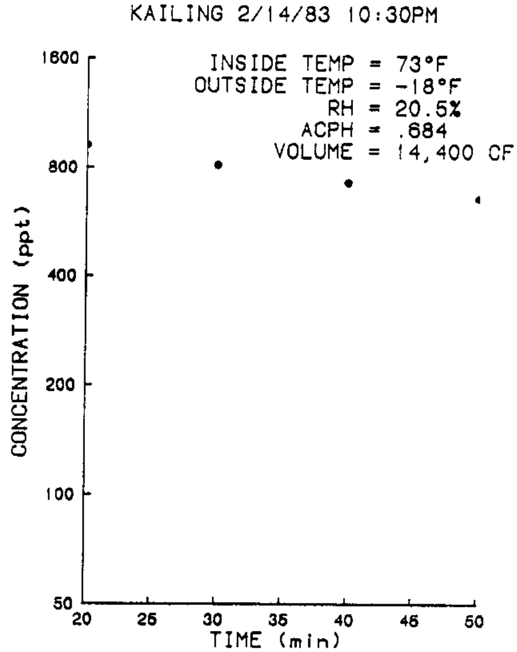

KAILING 11/28/82 12:15PM
INSIDE TEMP = 69°F
OUTSIDE TEMP = -8.5°F
RH = 21%
ACPH = 0.234
CONCENTRATION (ppt)
TIME (min)

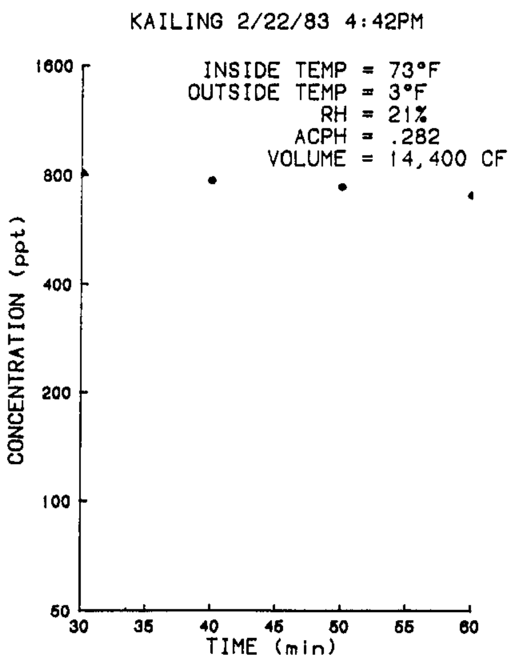

KAILING 1/26/83 9:20AM
INSIDE TEMP = 72°F
OUTSIDE TEMP = 13°F
RH = 17%
ACPH = .282
VOLUME = 14,400 CF
CONCENTRATION (ppt)
TIME (min)

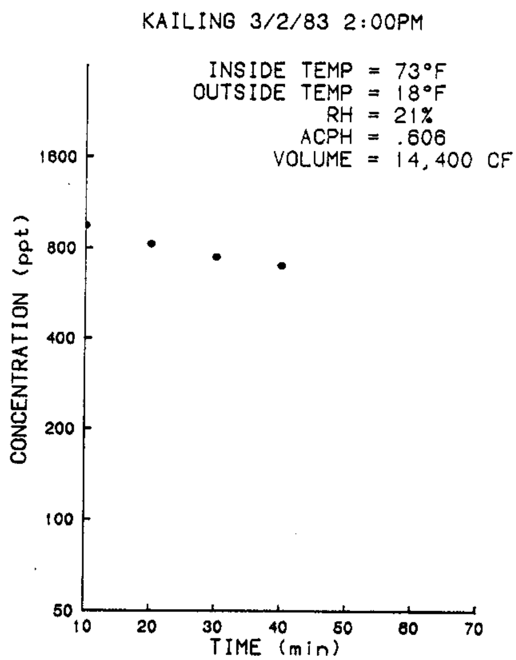

KAILING 2/2/83 8:00AM
INSIDE TEMP = 74°F
OUTSIDE TEMP = 19°F
RH = 22%
ACPH = .246
VOLUME = 14,400 CF
CONCENTRATION (ppt)
TIME (min)


KAILING 2/2/83 9:25AM
INSIDE TEMP = 72°F
OUTSIDE TEMP = 21°F
RH = 22%
ACPH = .444
VOLUME = 14,400 CF
CONCENTRATION (ppt)
TIME (min)

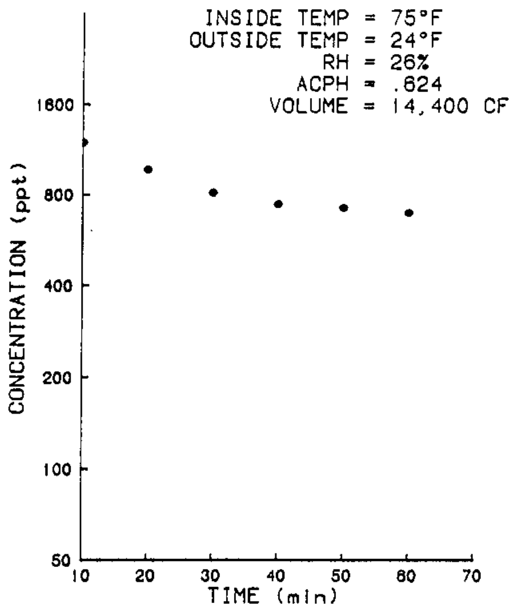

KAILING 2/9/83 8:45AM
INSIDE TEMP = 69°F
OUTSIDE TEMP = 12°F
RH = 20%
ACPH = .366
VOLUME = 14,400 CF
CONCENTRATION (ppt)
1600
800
400
200
100
50
10 15 20 25 30 35 40 45 50
TIME (min)


KAILING 2/14/83 10:30PM
INSIDE TEMP = 73°F
OUTSIDE TEMP = -18°F
RH = 20.5%
ACPH = .684
VOLUME = 14,400 CF
CONCENTRATION (ppt)
1600
800
400
200
100
50
20 25 30 35 40 45 50
TIME (min)

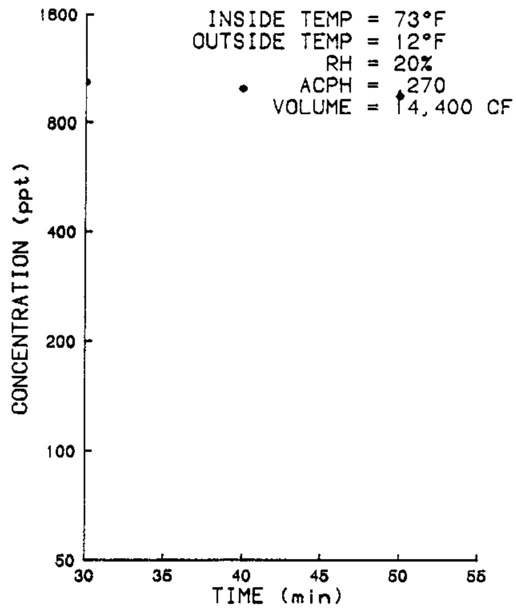

KAILING 2/22/83 4:42PM
INSIDE TEMP = 73°F
OUTSIDE TEMP = 3°F
RH = 21%
ACPH = .282
VOLUME = 14,400 CF
CONCENTRATION (ppt)
1600
800
400
200
100
50
30 35 40 45 50 55 60
TIME (min)


KAILING 3/2/83 2:00PM
INSIDE TEMP = 73°F
OUTSIDE TEMP = 18°F
RH = 21%
ACPH = .606
VOLUME = 14,400 CF
CONCENTRATION (ppt)
1600
800
400
200
100
50
10 20 30 40 50 60 70
TIME (min)

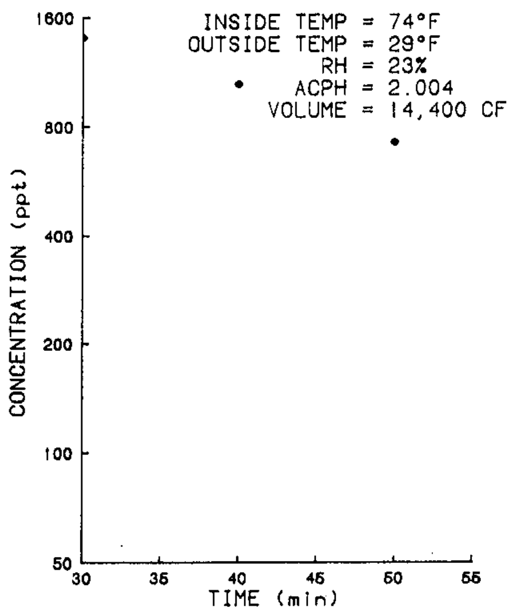
KAILING 3/8/83 10:30AM



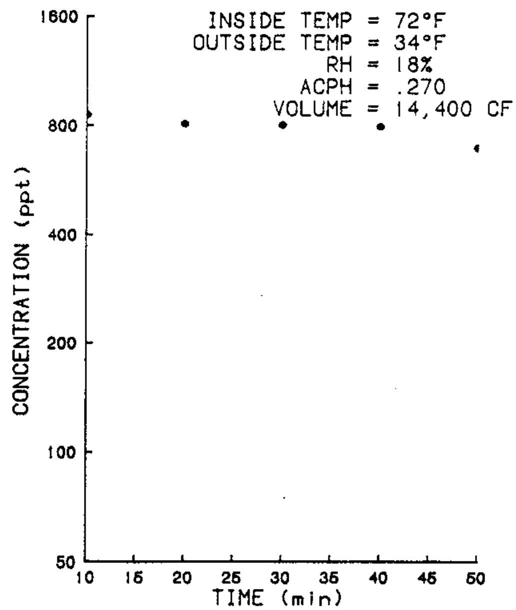
KAILING 3/14/83 1:00PM



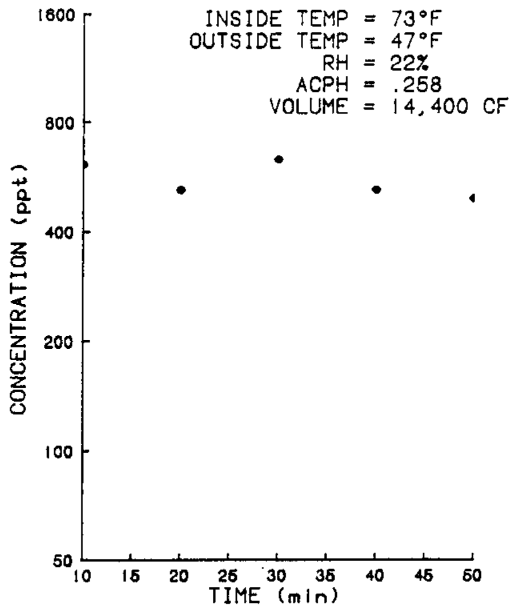
KAILING 3/22/83 9:45AM



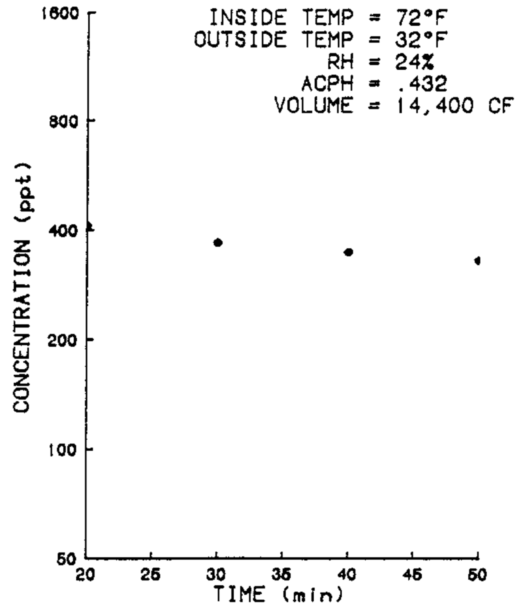
KAILING 3/29/83 9:00AM



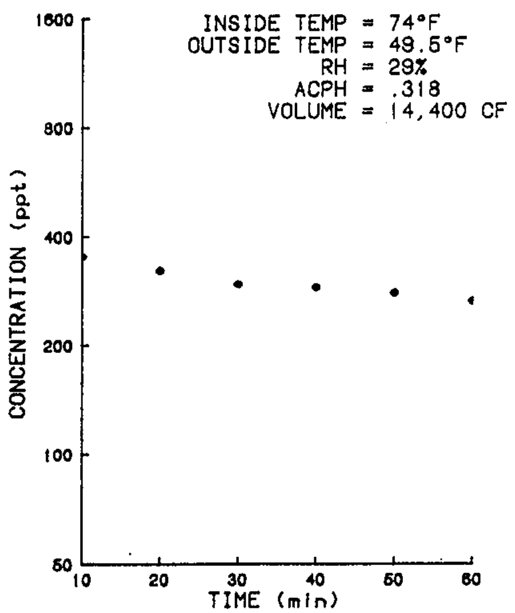
KAILING 4/4/83 10:20AM



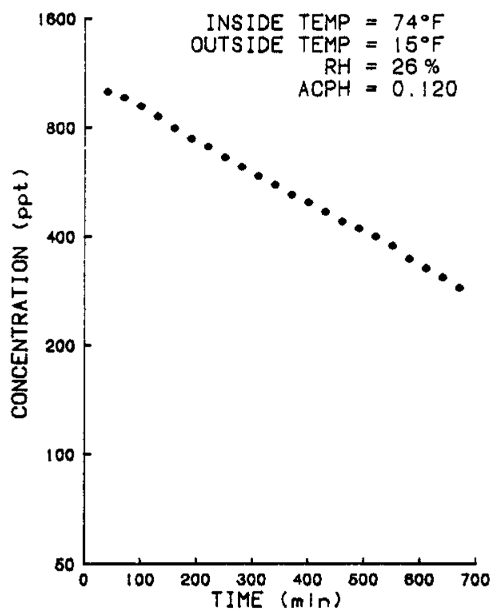
KAILING 4/11/83 2:00PM

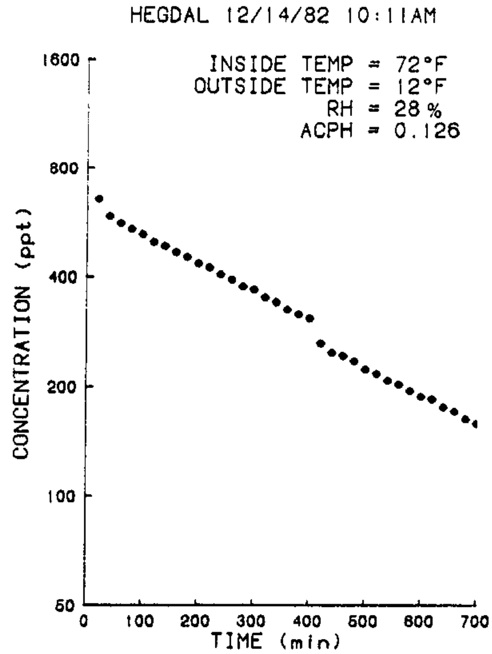


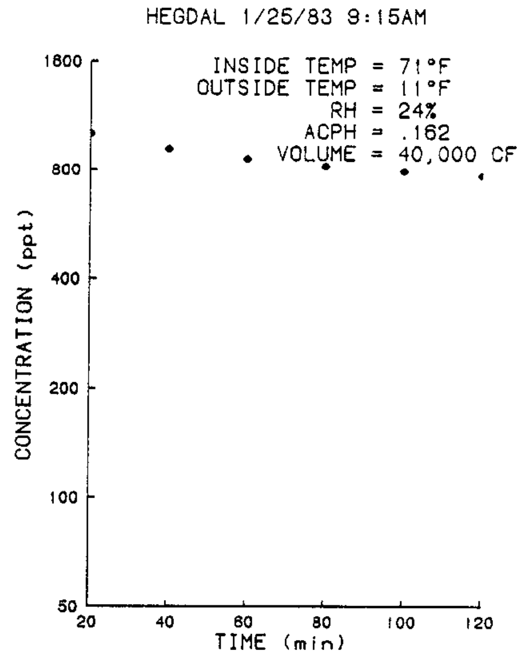
KAILING 4/21/83 10:30AM

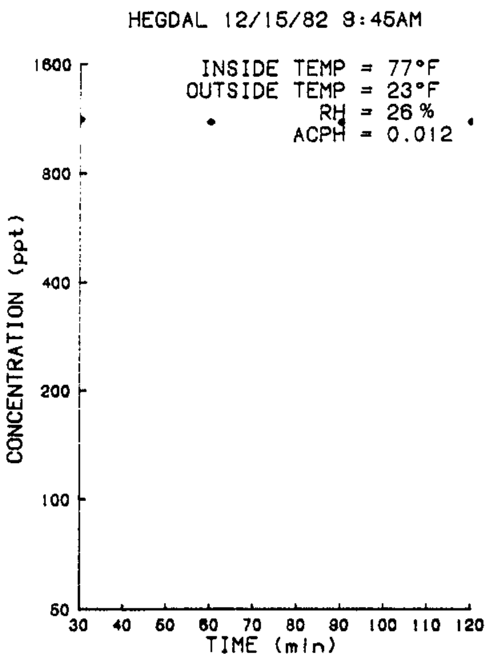


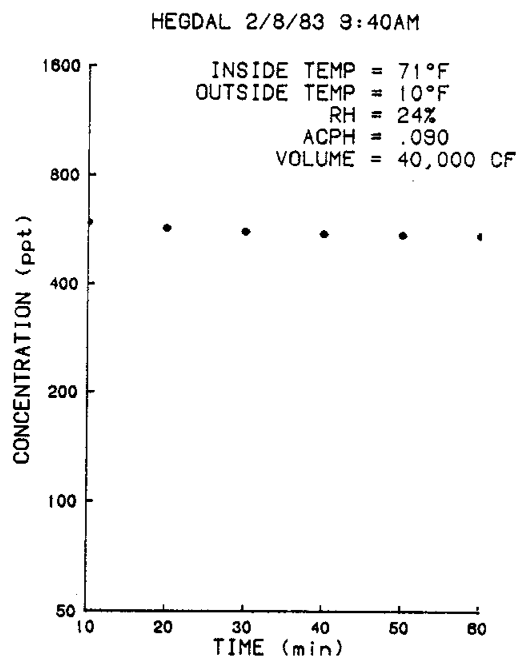
HEGDAL 12/14/82 10:00PM

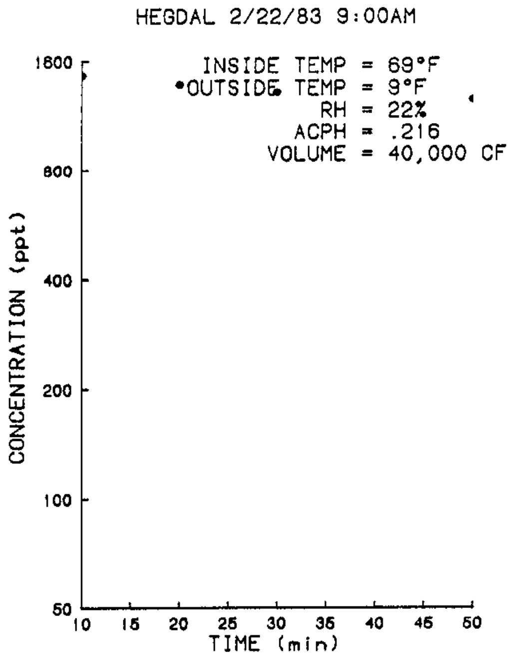


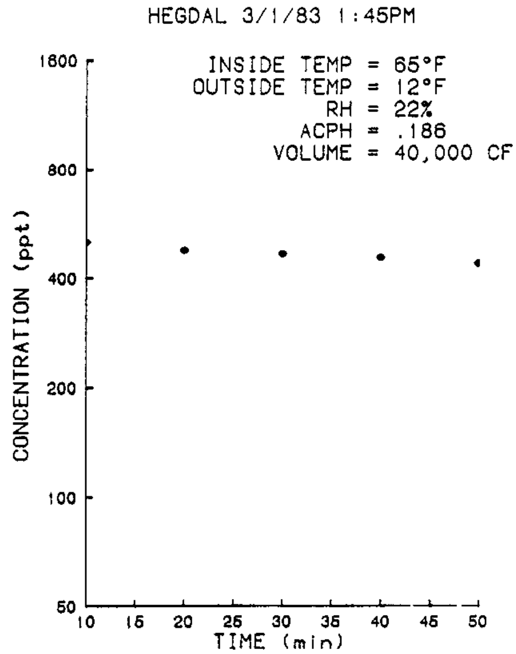

HEGDAL 12/14/82 10:11AM
INSIDE TEMP = 72°F
OUTSIDE TEMP = 12°F
RH = 28 %
ACPH = 0.126
CONCENTRATION (ppt)
TIME (min)

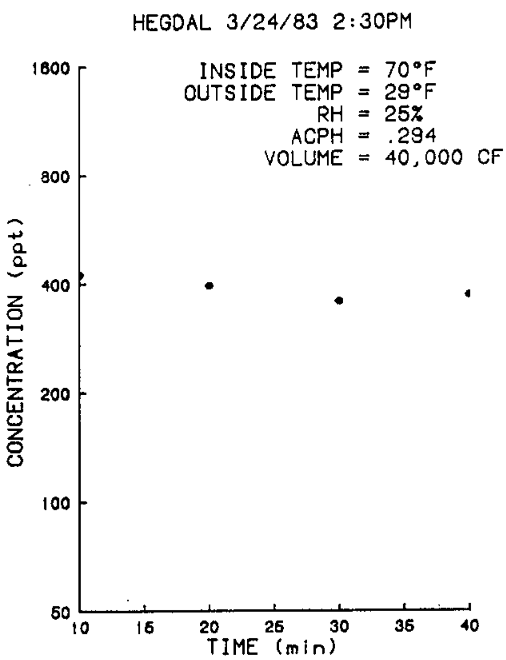

HEGDAL 1/25/83 9:15AM
INSIDE TEMP = 71°F
OUTSIDE TEMP = 11°F
RH = 24%
ACPH = .162
VOLUME = 40,000 CF
CONCENTRATION (ppt)
TIME (min)

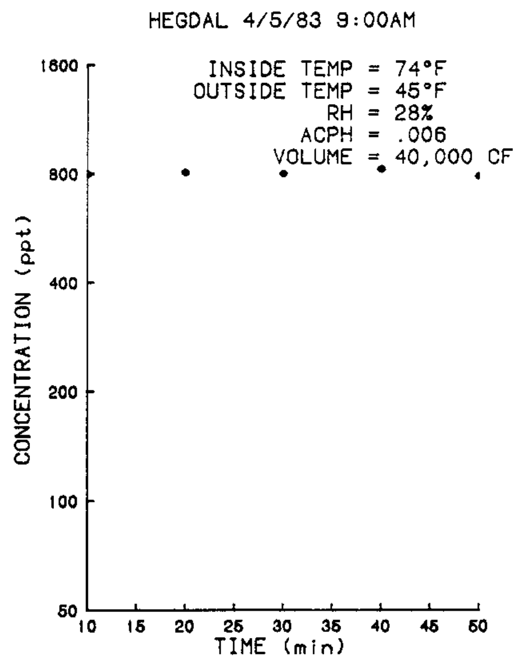

HEGDAL 12/15/82 9:45AM
INSIDE TEMP = 77°F
OUTSIDE TEMP = 23°F
RH = 26 %
ACPH = 0.012
CONCENTRATION (ppt)
TIME (min)

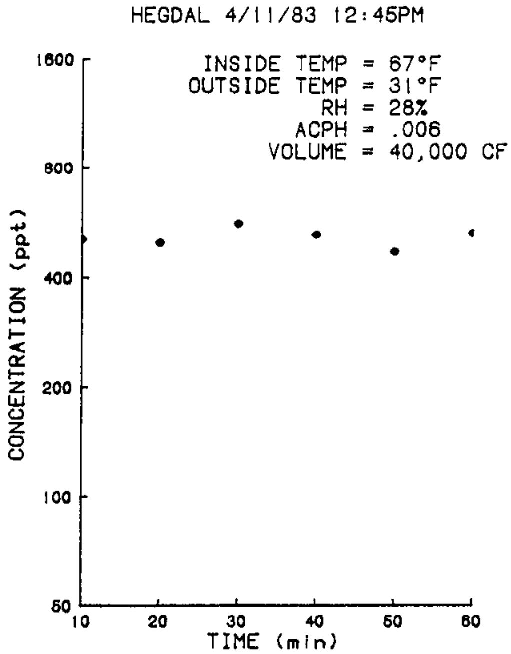

HEGDAL 2/8/83 9:40AM
INSIDE TEMP = 71°F
OUTSIDE TEMP = 10°F
RH = 24%
ACPH = .090
VOLUME = 40,000 CF
CONCENTRATION (ppt)
TIME (min)

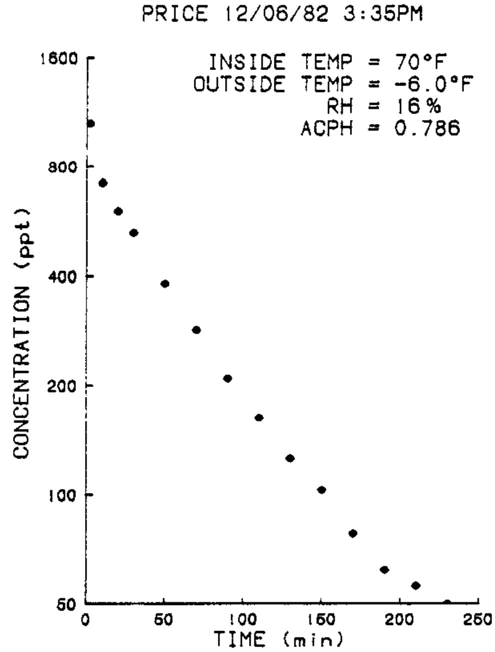

HEGDAL 2/22/83 9:00AM
INSIDE TEMP = 69°F
OUTSIDE TEMP = 9°F
RH = 22%
ACPH = .216
VOLUME = 40,000 CF
CONCENTRATION (ppt)
1600
800
400
200
100
50
10 15 20 25 30 35 40 45 50
TIME (min)

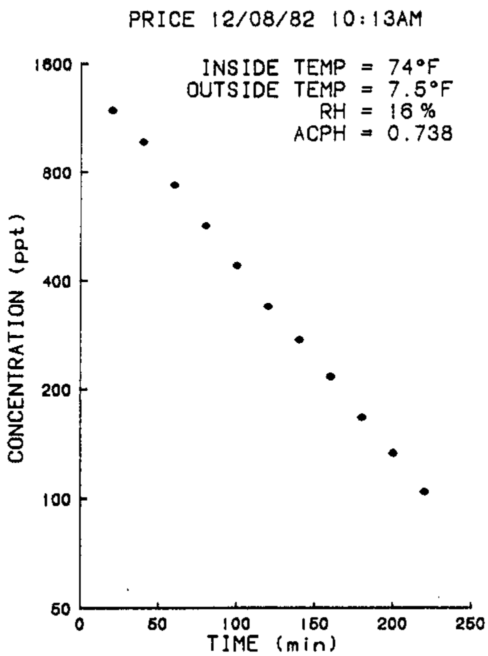

HEGDAL 3/1/83 1:45PM
INSIDE TEMP = 65°F
OUTSIDE TEMP = 12°F
RH = 22%
ACPH = .186
VOLUME = 40,000 CF
CONCENTRATION (ppt)
1600
800
400
200
100
50
10 15 20 25 30 35 40 45 50
TIME (min)

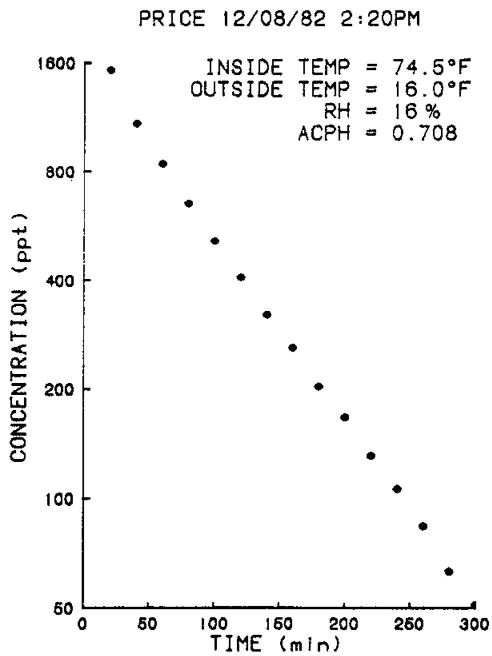

HEGDAL 3/24/83 2:30PM
INSIDE TEMP = 70°F
OUTSIDE TEMP = 29°F
RH = 25%
ACPH = .294
VOLUME = 40,000 CF
CONCENTRATION (ppt)
1600
800
400
200
100
50
10 15 20 25 30 35 40
TIME (min)

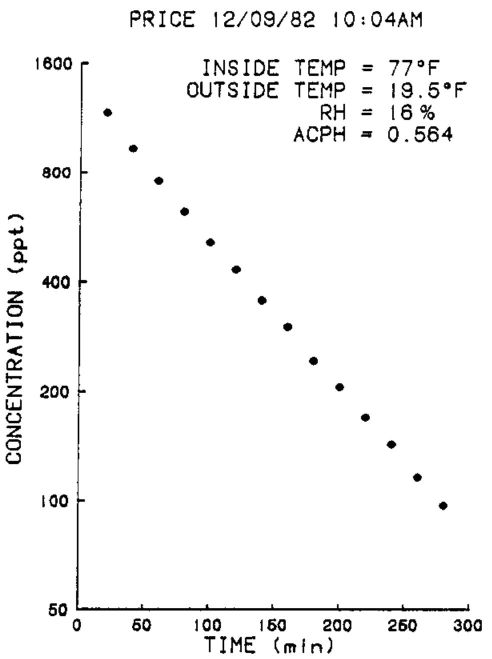

HEGDAL 4/5/83 9:00AM
INSIDE TEMP = 74°F
OUTSIDE TEMP = 45°F
RH = 28%
ACPH = .006
VOLUME = 40,000 CF
CONCENTRATION (ppt)
1600
800
400
200
100
50
10 15 20 25 30 35 40 45 50
TIME (min)

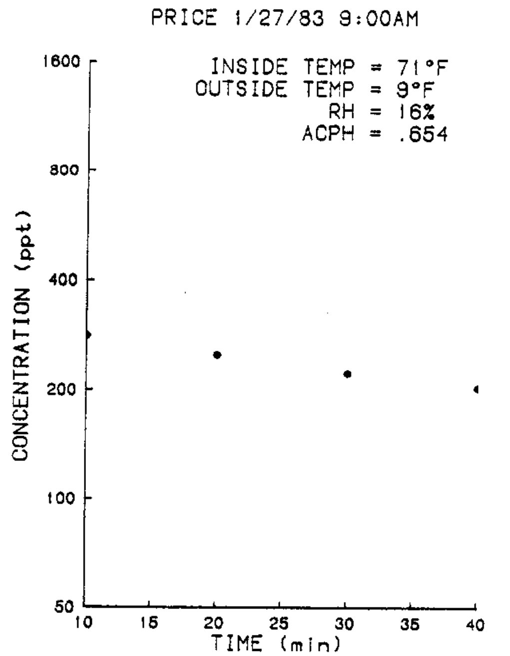

HEGDAL 4/11/83 12:45PM
INSIDE TEMP = 67°F
OUTSIDE TEMP = 31°F
RH = 28%
ACPH = .006
VOLUME = 40,000 CF
CONCENTRATION (ppt)
1600
800
400
200
100
50
10
20
30
40
50
60
TIME (min)

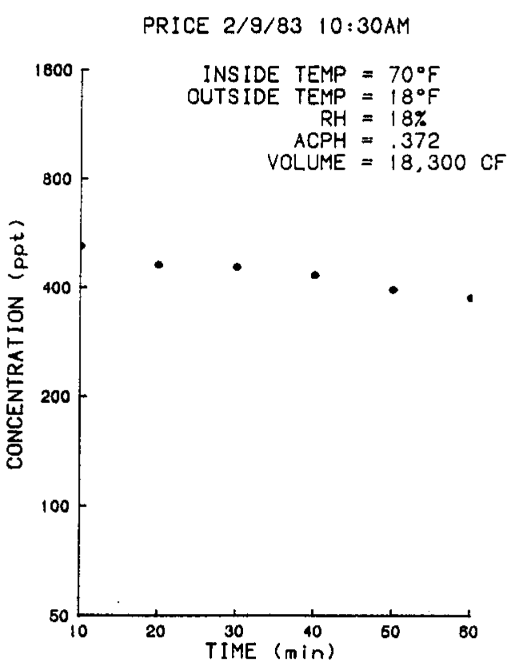

PRICE 12/06/82 3:35PM
INSIDE TEMP = 70°F
OUTSIDE TEMP = -6.0°F
RH = 16 %
ACPH = 0.786
CONCENTRATION (ppt)
1600
800
400
200
100
50
0
50
100
150
200
250
TIME (min)

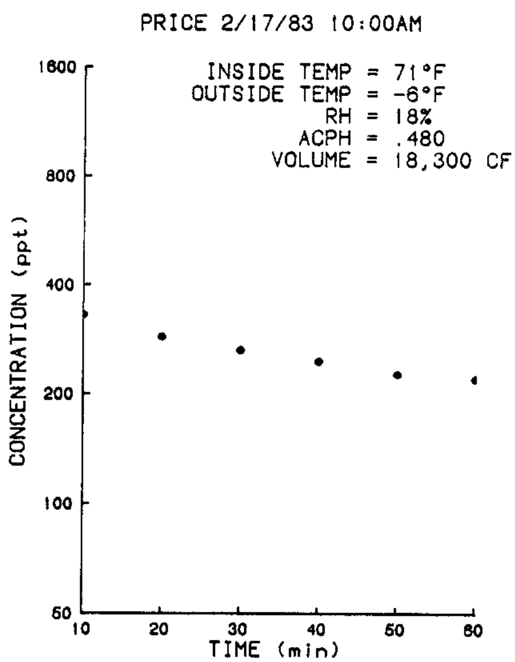

PRICE 12/08/82 10:13AM
INSIDE TEMP = 74°F
OUTSIDE TEMP = 7.5°F
RH = 16 %
ACPH = 0.738
CONCENTRATION (ppt)
1600
800
400
200
100
50
0
50
100
150
200
250
TIME (min)

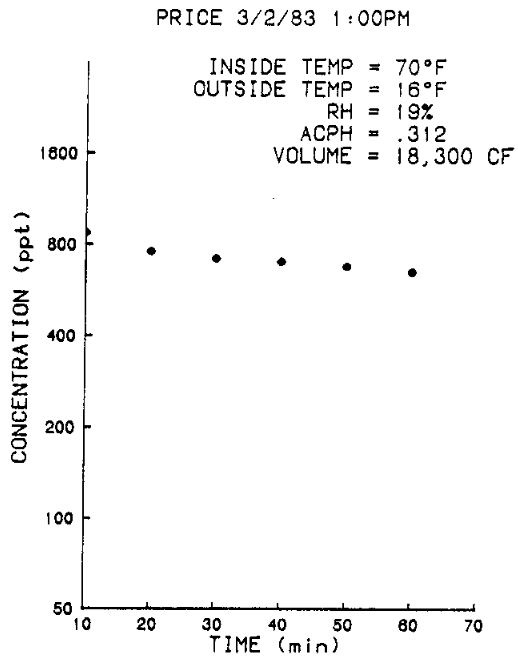

PRICE 12/08/82 2:20PM
INSIDE TEMP = 74.5°F
OUTSIDE TEMP = 16.0°F
RH = 16 %
ACPH = 0.708
CONCENTRATION (ppt)
1600
800
400
200
100
50
0
50
100
150
200
250
300
TIME (min)

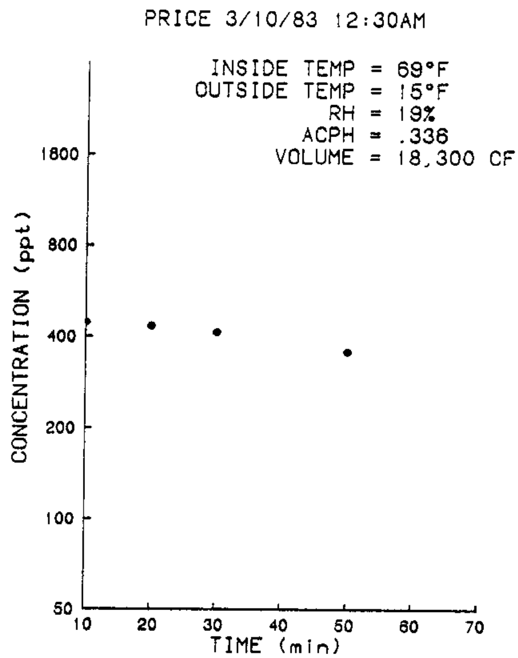

PRICE 12/09/82 10:04AM
INSIDE TEMP = 77°F
OUTSIDE TEMP = 19.5°F
RH = 16 %
ACPH = 0.564
CONCENTRATION (ppt)
TIME (min)

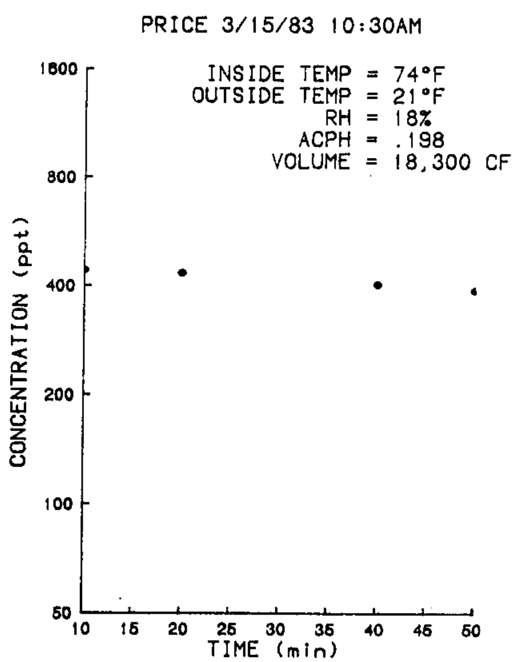

PRICE 1/27/83 9:00AM
INSIDE TEMP = 71°F
OUTSIDE TEMP = 9°F
RH = 16%
ACPH = .654
CONCENTRATION (ppt)
TIME (min)

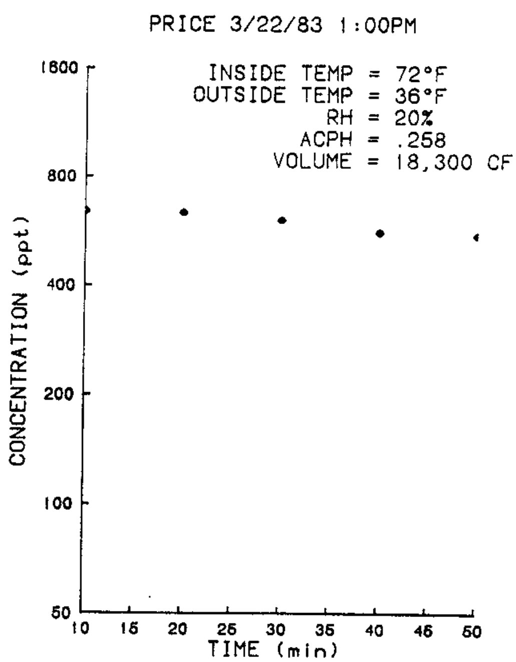

PRICE 2/9/83 10:30AM
INSIDE TEMP = 70°F
OUTSIDE TEMP = 18°F
RH = 18%
ACPH = .372
VOLUME = 18,300 CF
CONCENTRATION (ppt)
TIME (min)

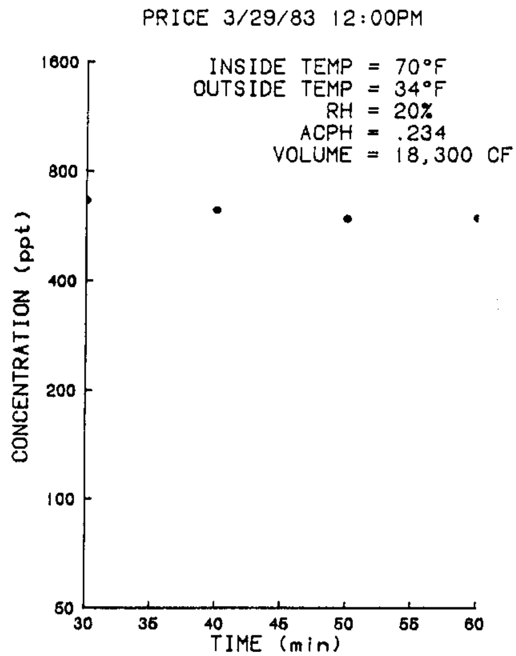

PRICE 2/17/83 10:00AM
INSIDE TEMP = 71°F
OUTSIDE TEMP = -6°F
RH = 18%
ACPH = .480
VOLUME = 18,300 CF
CONCENTRATION (ppt)
TIME (min)

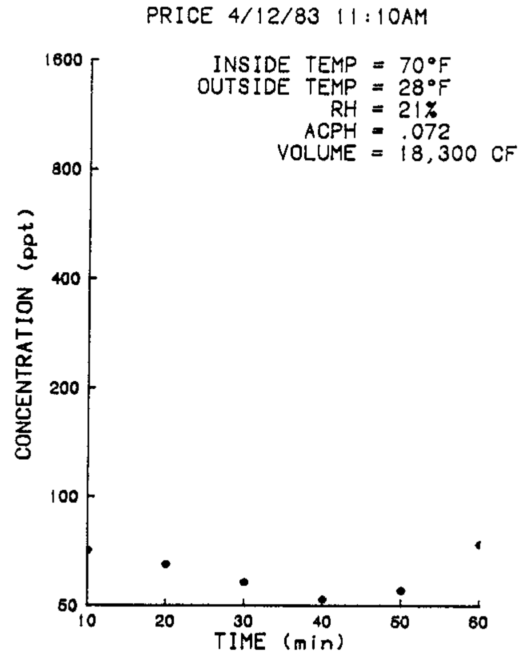

PRICE 3/2/83 1:00PM
INSIDE TEMP = 70°F
OUTSIDE TEMP = 16°F
RH = 19%
ACPH = .312
VOLUME = 18,300 CF
CONCENTRATION (ppt)
1600
800
400
200
100
50
10 20 30 40 50 60 70
TIME (min)

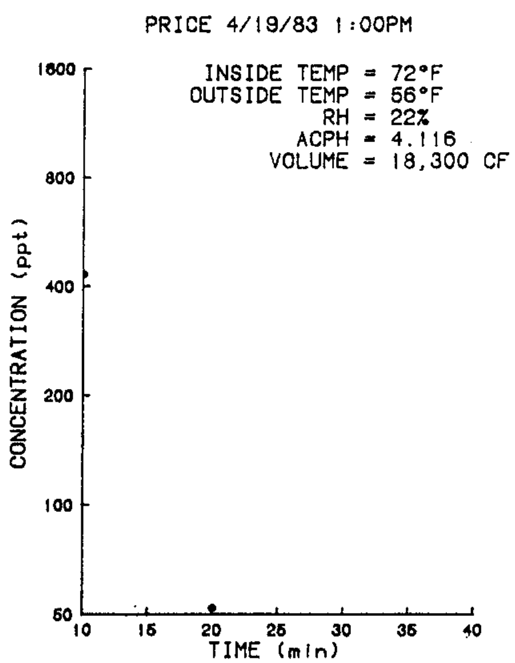

PRICE 3/10/83 12:30AM
INSIDE TEMP = 69°F
OUTSIDE TEMP = 15°F
RH = 19%
ACPH = .336
VOLUME = 18,300 CF
CONCENTRATION (ppt)
1600
800
400
200
100
50
10 20 30 40 50 60 70
TIME (min)

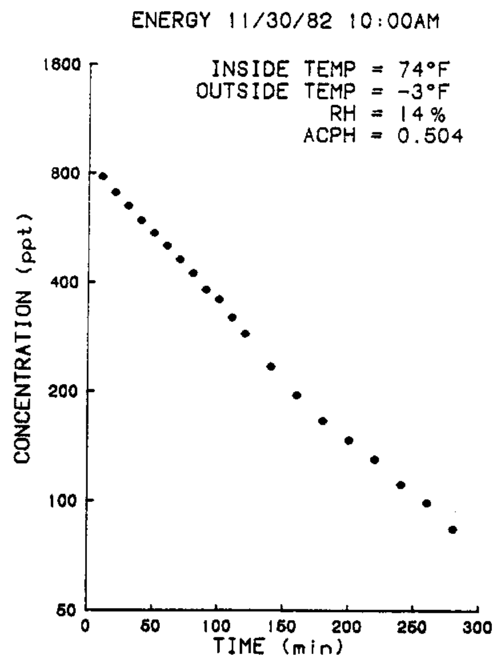

PRICE 3/15/83 10:30AM
INSIDE TEMP = 74°F
OUTSIDE TEMP = 21°F
RH = 18%
ACPH = .198
VOLUME = 18,300 CF
CONCENTRATION (ppt)
1600
800
400
200
100
50
10 15 20 25 30 35 40 45 50
TIME (min)

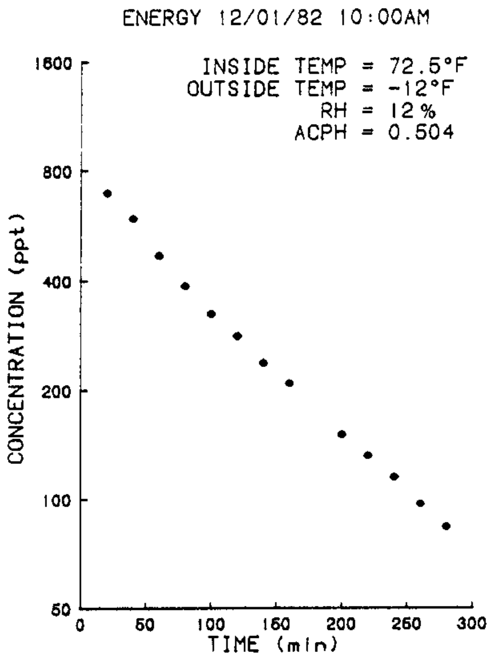

PRICE 3/22/83 1:00PM
INSIDE TEMP = 72°F
OUTSIDE TEMP = 36°F
RH = 20%
ACPH = .258
VOLUME = 18,300 CF
CONCENTRATION (ppt)
1600
800
400
200
100
50
10 15 20 25 30 35 40 45 50
TIME (min)

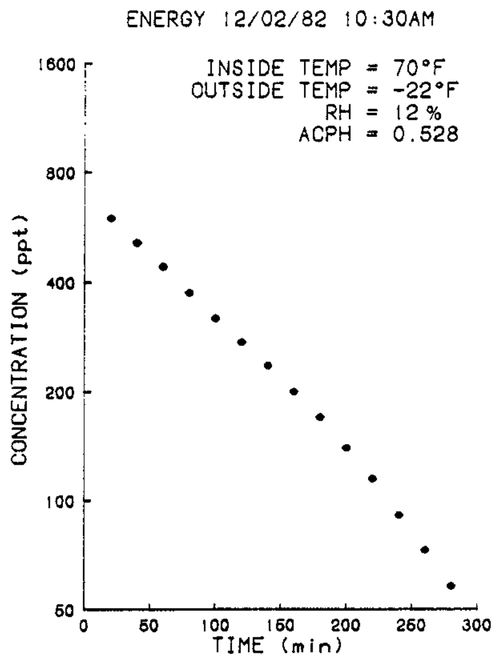

PRICE 3/29/83 12:00PM
INSIDE TEMP = 70°F
OUTSIDE TEMP = 34°F
RH = 20%
ACPH = .234
VOLUME = 18,300 CF
CONCENTRATION (ppt)
TIME (min)

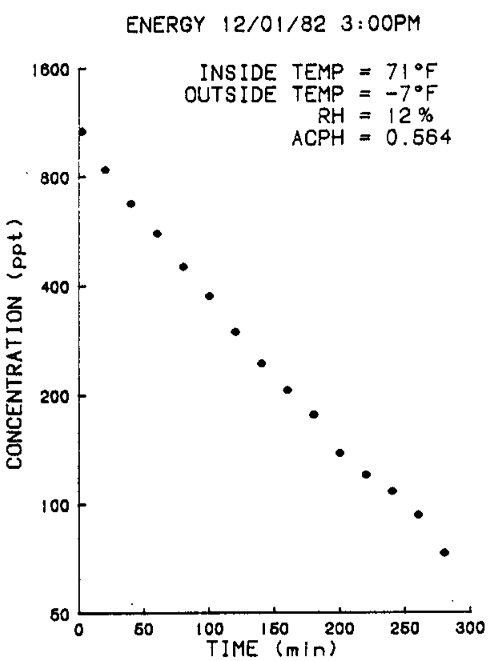

PRICE 4/12/83 11:10AM
INSIDE TEMP = 70°F
OUTSIDE TEMP = 28°F
RH = 21%
ACPH = .072
VOLUME = 18,300 CF
CONCENTRATION (ppt)
TIME (min)

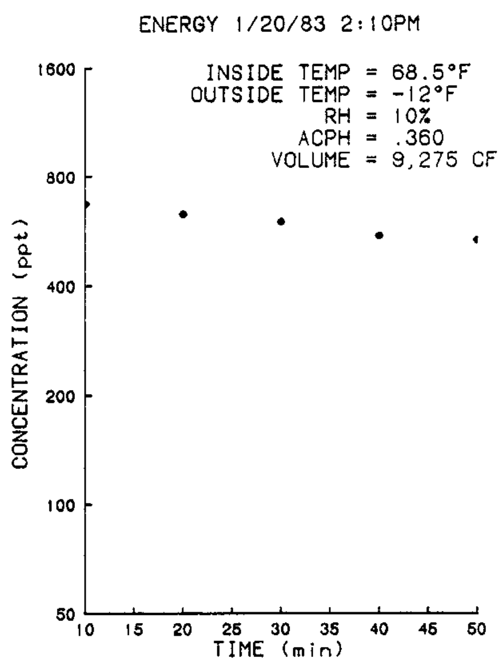

PRICE 4/19/83 1:00PM
INSIDE TEMP = 72°F
OUTSIDE TEMP = 56°F
RH = 22%
ACPH = 4.116
VOLUME = 18,300 CF
CONCENTRATION (ppt)
TIME (min)

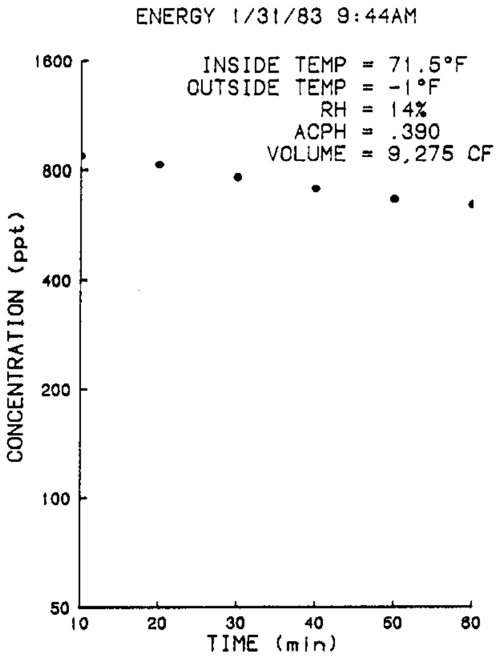

ENERGY 11/30/82 10:00AM
INSIDE TEMP = 74°F
OUTSIDE TEMP = -3°F
RH = 14 %
ACPH = 0.504
CONCENTRATION (ppt)
TIME (min)

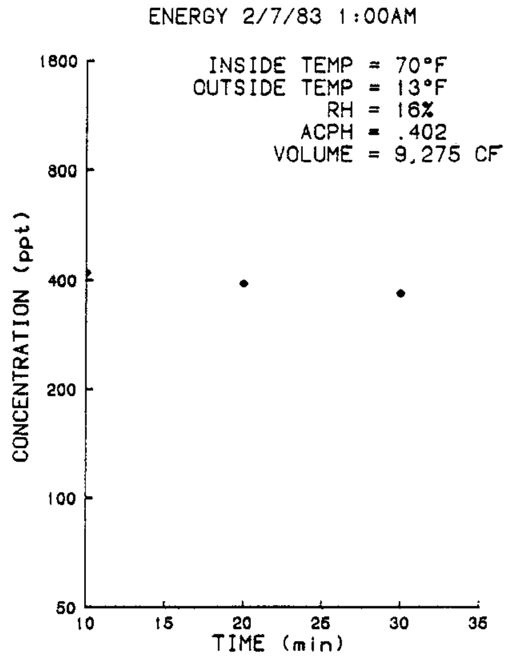

ENERGY 12/01/82 10:00AM
INSIDE TEMP = 72.5°F
OUTSIDE TEMP = -12°F
RH = 12%
ACPH = 0.504
CONCENTRATION (ppt)
1600
800
400
200
100
50
0
50
100
150
200
250
300
TIME (min)

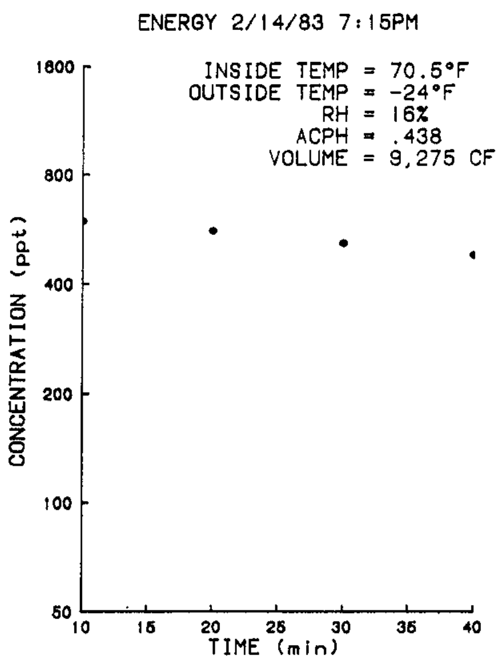

ENERGY 12/02/82 10:30AM
INSIDE TEMP = 70°F
OUTSIDE TEMP = -22°F
RH = 12%
ACPH = 0.528
CONCENTRATION (ppt)
1600
800
400
200
100
50
0
50
100
150
200
250
300
TIME (min)

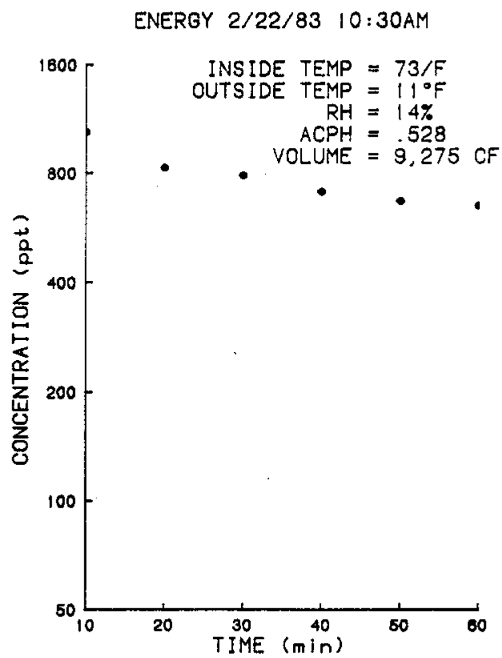

ENERGY 12/01/82 3:00PM
INSIDE TEMP = 71°F
OUTSIDE TEMP = -7°F
RH = 12%
ACPH = 0.564
CONCENTRATION (ppt)
1600
800
400
200
100
50
0
50
100
150
200
250
300
TIME (min)

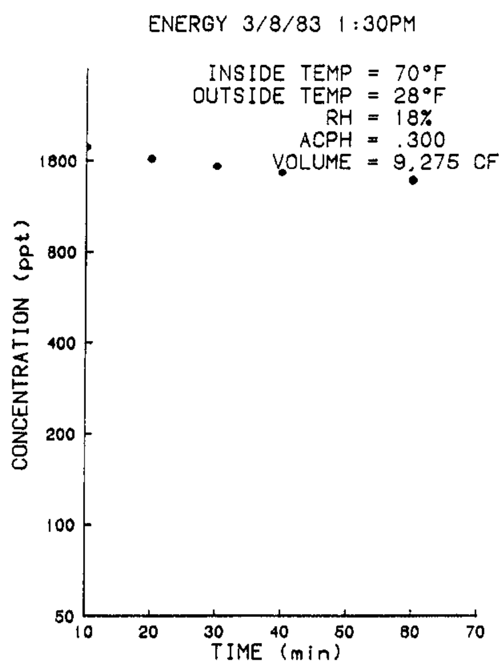

ENERGY 1/20/83 2:10PM
INSIDE TEMP = 68.5°F
OUTSIDE TEMP = -12°F
RH = 10%
ACPH = .360
VOLUME = 9,275 CF
CONCENTRATION (ppt)
1600
800
400
200
100
50
10
15
20
25
30
35
40
45
50
TIME (min)

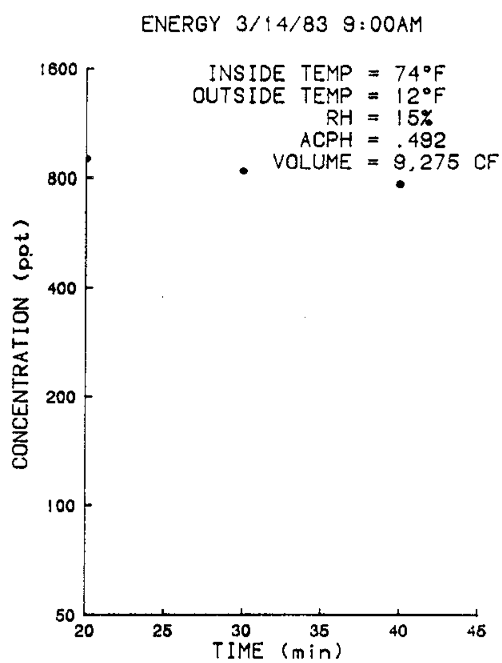

ENERGY 1/31/83 9:44AM
INSIDE TEMP = 71.5°F
OUTSIDE TEMP = -1°F
RH = 14%
ACPH = .390
VOLUME = 9,275 CF
CONCENTRATION (ppt)
TIME (min)

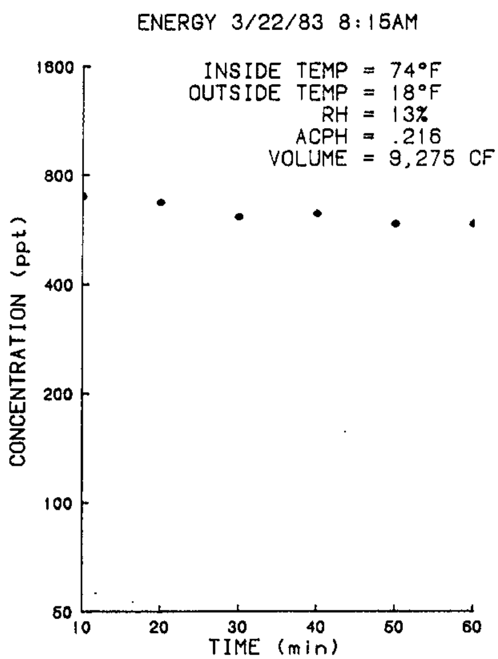

ENERGY 2/7/83 1:00AM
INSIDE TEMP = 70°F
OUTSIDE TEMP = 13°F
RH = 16%
ACPH = .402
VOLUME = 9,275 CF
CONCENTRATION (ppt)
TIME (min)

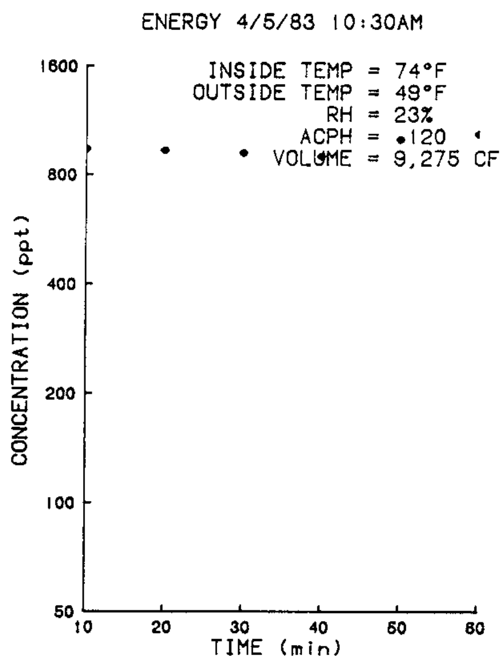

ENERGY 2/14/83 7:15PM
INSIDE TEMP = 70.5°F
OUTSIDE TEMP = -24°F
RH = 16%
ACPH = .438
VOLUME = 9,275 CF
CONCENTRATION (ppt)
TIME (min)

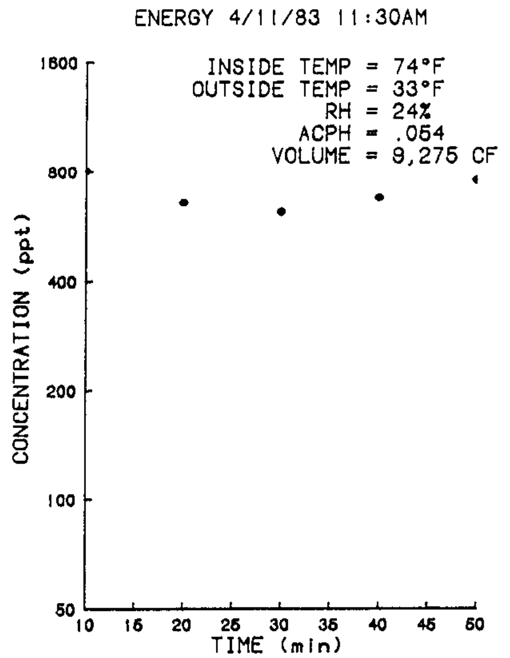

ENERGY 2/22/83 10:30AM
INSIDE TEMP = 73/F
OUTSIDE TEMP = 11°F
RH = 14%
ACPH = .528
VOLUME = 9,275 CF
CONCENTRATION (ppt)
TIME (min)

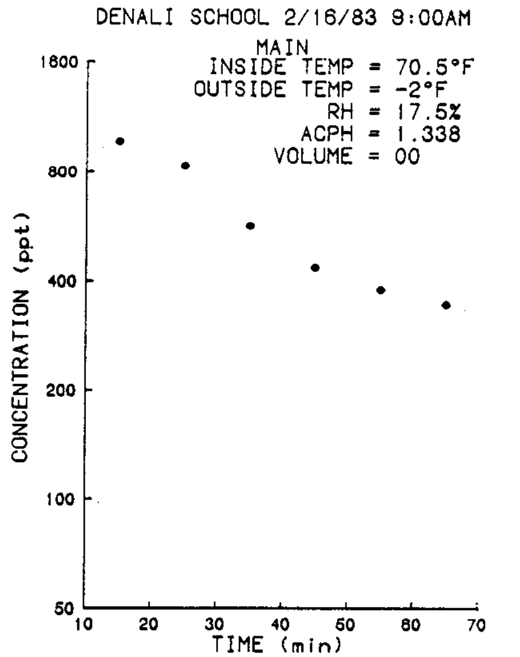

ENERGY 3/8/83 1:30PM
INSIDE TEMP = 70°F
OUTSIDE TEMP = 28°F
RH = 18%
ACPH = .300
VOLUME = 9,275 CF
CONCENTRATION (ppt)
TIME (min)

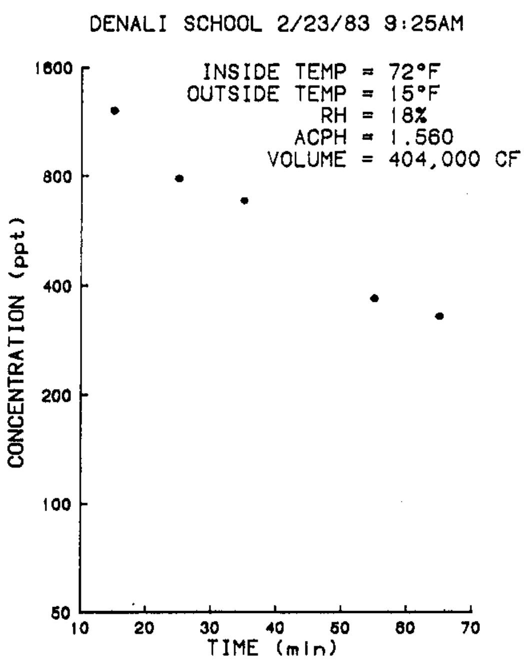

ENERGY 3/14/83 9:00AM
INSIDE TEMP = 74°F
OUTSIDE TEMP = 12°F
RH = 15%
ACPH = .492
VOLUME = 9,275 CF
CONCENTRATION (ppt)
TIME (min)

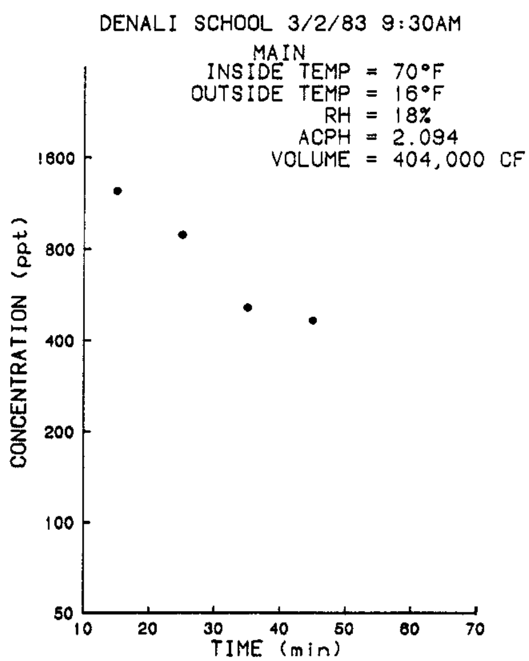

ENERGY 3/22/83 8:15AM
INSIDE TEMP = 74°F
OUTSIDE TEMP = 18°F
RH = 13%
ACPH = .216
VOLUME = 9,275 CF
CONCENTRATION (ppt)
TIME (min)

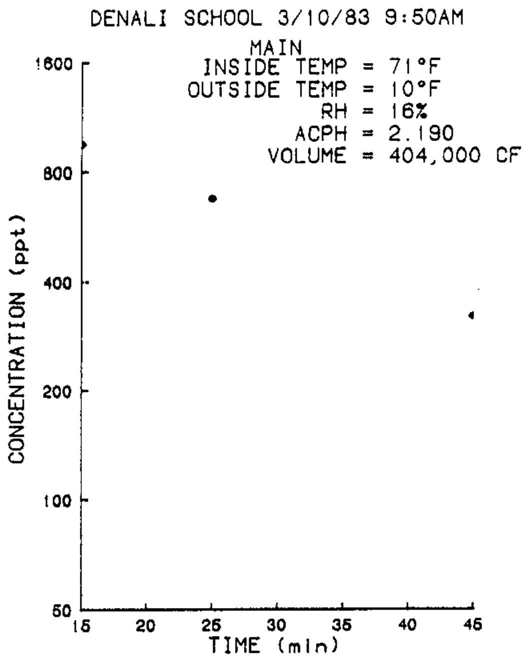

ENERGY 4/5/83 10:30AM
INSIDE TEMP = 74°F
OUTSIDE TEMP = 49°F
RH = 23%
ACPH = .120
VOLUME = 9,275 CF
CONCENTRATION (ppt)
TIME (min)

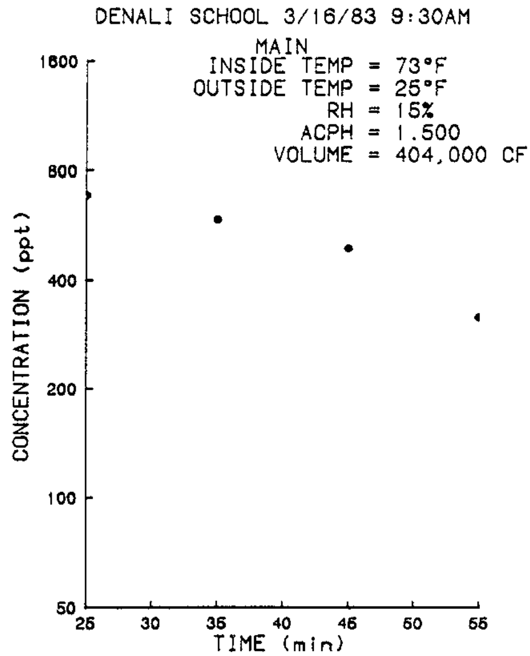

ENERGY 4/11/83 11:30AM
INSIDE TEMP = 74°F
OUTSIDE TEMP = 33°F
RH = 24%
ACPH = .054
VOLUME = 9,275 CF
CONCENTRATION (ppt)
TIME (min)

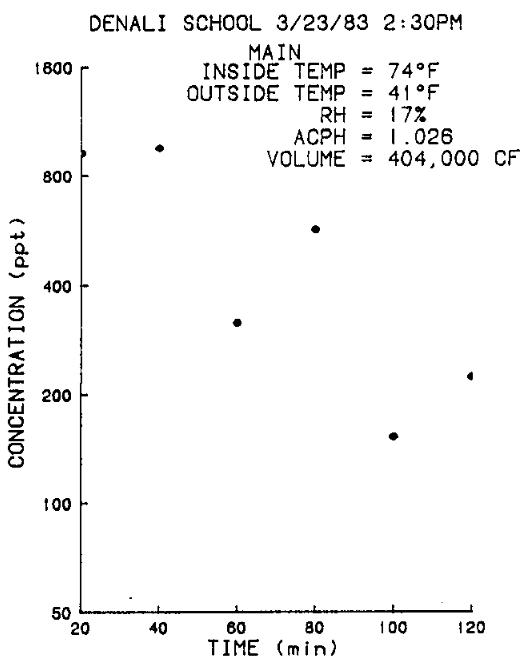

DENALI SCHOOL 2/16/83 9:00AM
MAIN
INSIDE TEMP = 70.5°F
OUTSIDE TEMP = -2°F
RH = 17.5%
ACPH = 1.338
VOLUME = 00
CONCENTRATION (ppt)
TIME (min)

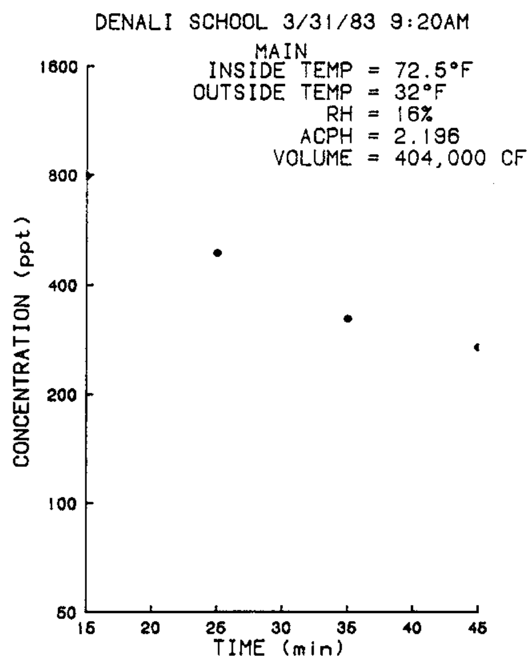

DENALI SCHOOL 2/23/83 9:25AM
INSIDE TEMP = 72°F
OUTSIDE TEMP = 15°F
RH = 18%
ACPH = 1.560
VOLUME = 404,000 CF
CONCENTRATION (ppt)
TIME (min)

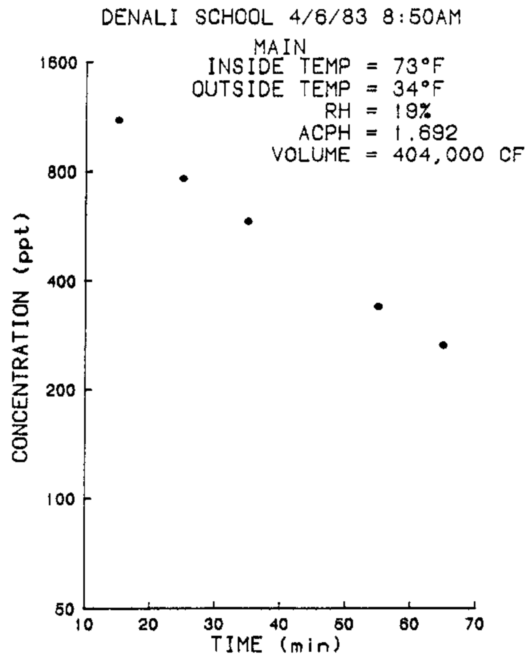

DENALI SCHOOL 3/2/83 9:30AM
MAIN
INSIDE TEMP = 70°F
OUTSIDE TEMP = 16°F
RH = 18%
ACPH = 2.094
VOLUME = 404,000 CF
CONCENTRATION (ppt)
TIME (min)

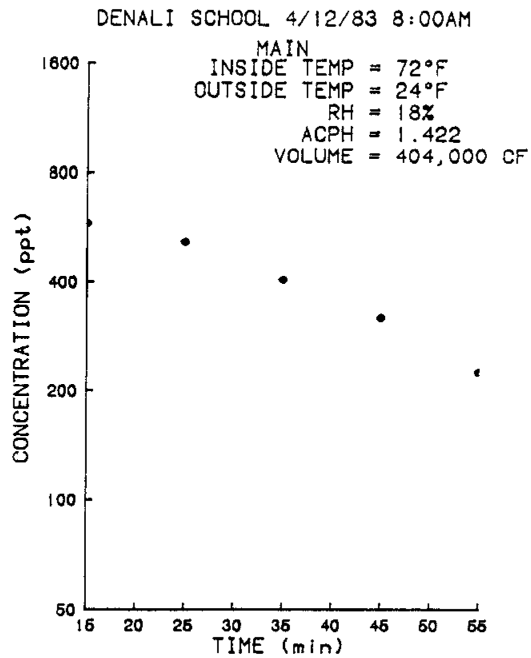

DENALI SCHOOL 3/10/83 9:50AM
MAIN
INSIDE TEMP = 71°F
OUTSIDE TEMP = 10°F
RH = 16%
ACPH = 2.190
VOLUME = 404,000 CF
CONCENTRATION (ppt)
1600
800
400
200
100
50
15
20
25
30
35
40
45
TIME (min)

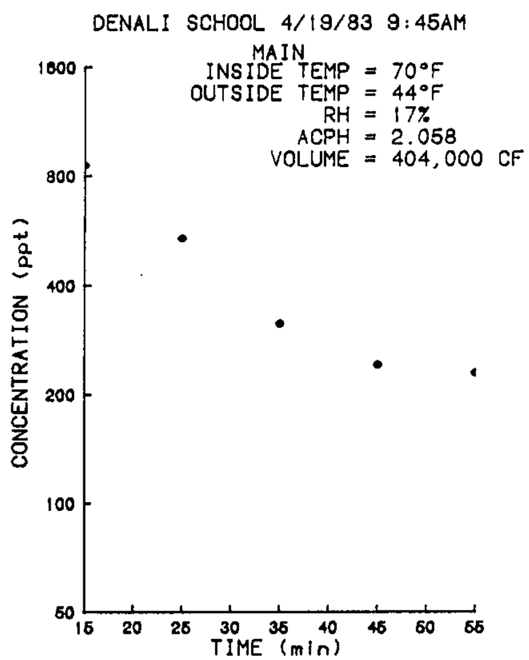

DENALI SCHOOL 3/16/83 9:30AM
MAIN
INSIDE TEMP = 73°F
OUTSIDE TEMP = 25°F
RH = 15%
ACPH = 1.500
VOLUME = 404,000 CF
CONCENTRATION (ppt)
1600
800
400
200
100
50
25
30
35
40
45
50
55
TIME (min)

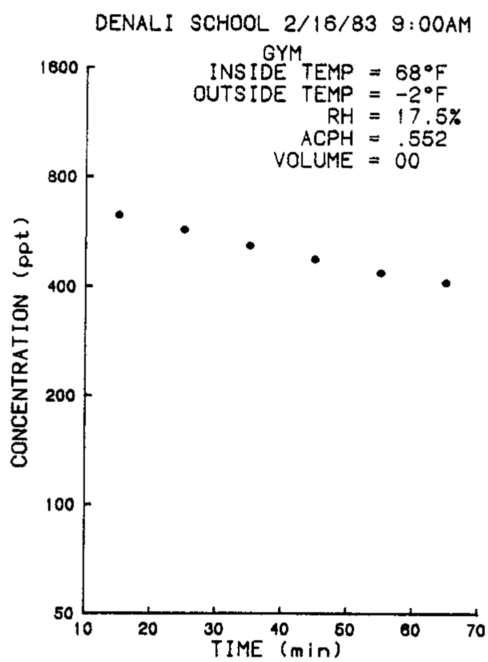

DENALI SCHOOL 3/23/83 2:30PM
MAIN
INSIDE TEMP = 74°F
OUTSIDE TEMP = 41°F
RH = 17%
ACPH = 1.026
VOLUME = 404,000 CF
CONCENTRATION (ppt)
1600
800
400
200
100
50
20
40
60
80
100
120
TIME (min)

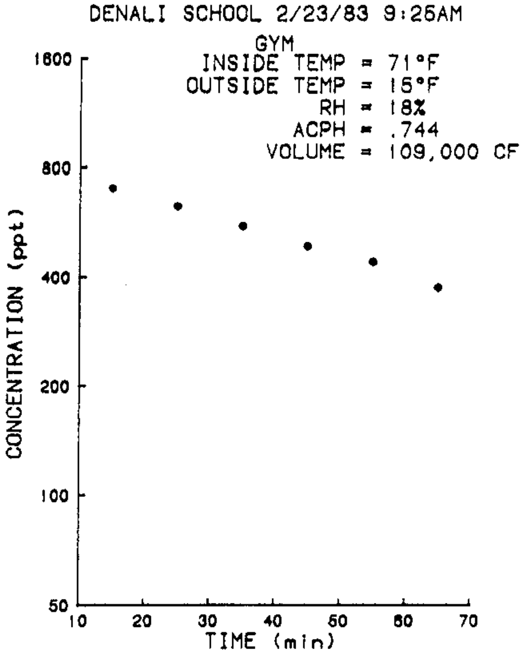

DENALI SCHOOL 3/31/83 9:20AM
MAIN
INSIDE TEMP = 72.5°F
OUTSIDE TEMP = 32°F
RH = 16%
ACPH = 2.196
VOLUME = 404,000 CF
CONCENTRATION (ppt)
1600
800
400
200
100
50
15
20
25
30
35
40
45
TIME (min)

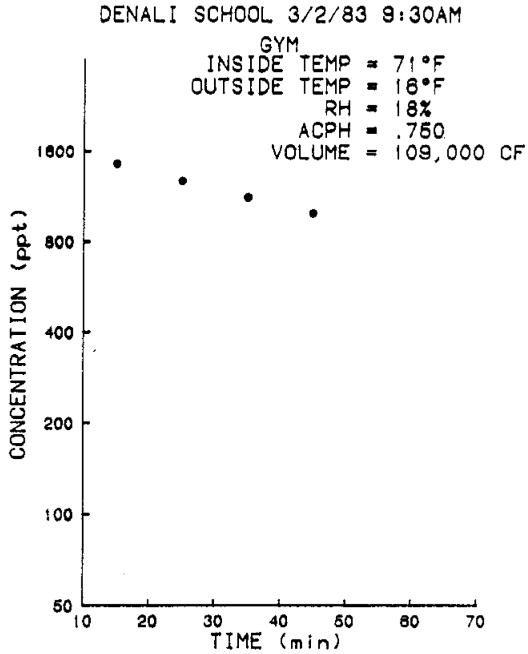

DENALI SCHOOL 4/6/83 8:50AM
MAIN
INSIDE TEMP = 73°F
OUTSIDE TEMP = 34°F
RH = 19%
ACPH = 1.692
VOLUME = 404,000 CF
CONCENTRATION (ppt)
TIME (min)

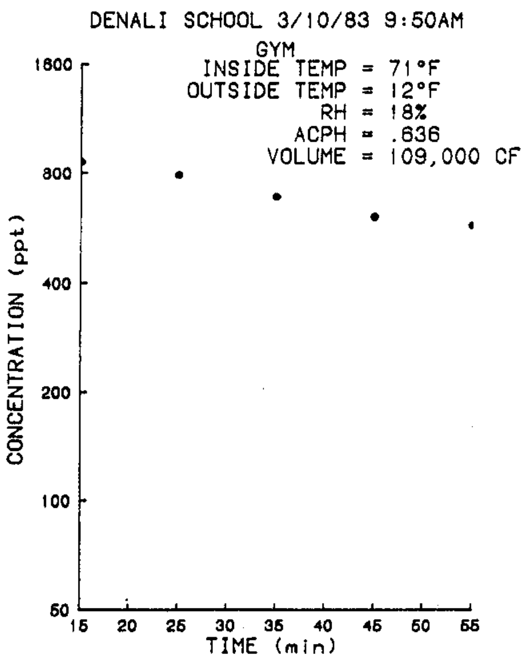

DENALI SCHOOL 4/12/83 8:00AM
MAIN
INSIDE TEMP = 72°F
OUTSIDE TEMP = 24°F
RH = 18%
ACPH = 1.422
VOLUME = 404,000 CF
CONCENTRATION (ppt)
TIME (min)

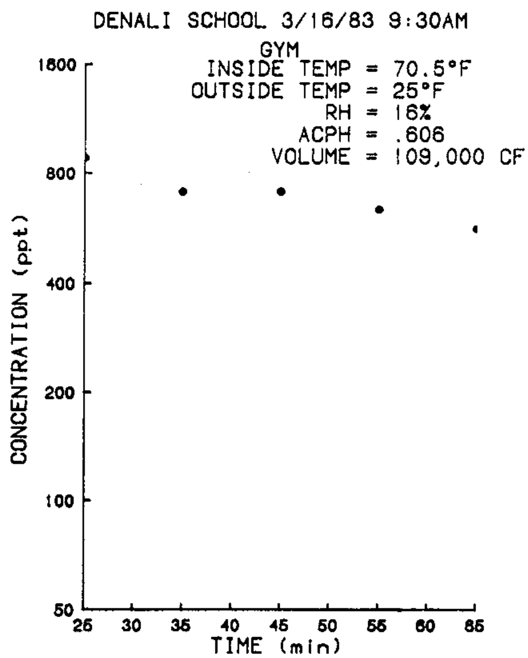

DENALI SCHOOL 4/19/83 9:45AM
MAIN
INSIDE TEMP = 70°F
OUTSIDE TEMP = 44°F
RH = 17%
ACPH = 2.058
VOLUME = 404,000 CF
CONCENTRATION (ppt)
TIME (min)

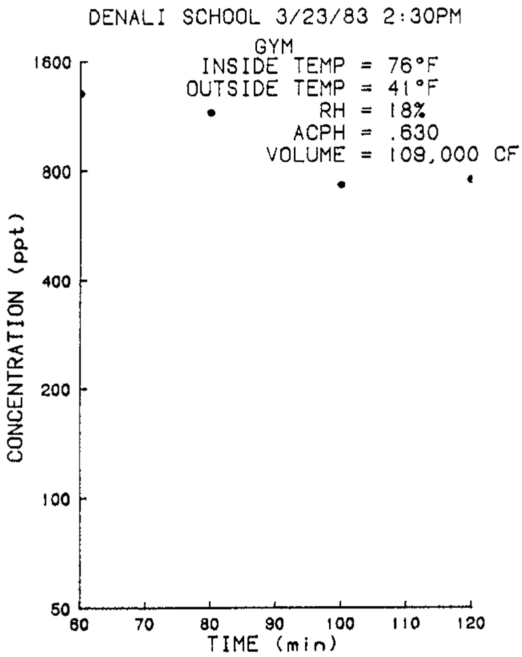

DENALI SCHOOL 2/16/83 9:00AM
GYM
INSIDE TEMP = 68°F
OUTSIDE TEMP = -2°F
RH = 17.5%
ACPH = .552
VOLUME = 00
CONCENTRATION (ppt)
TIME (min)

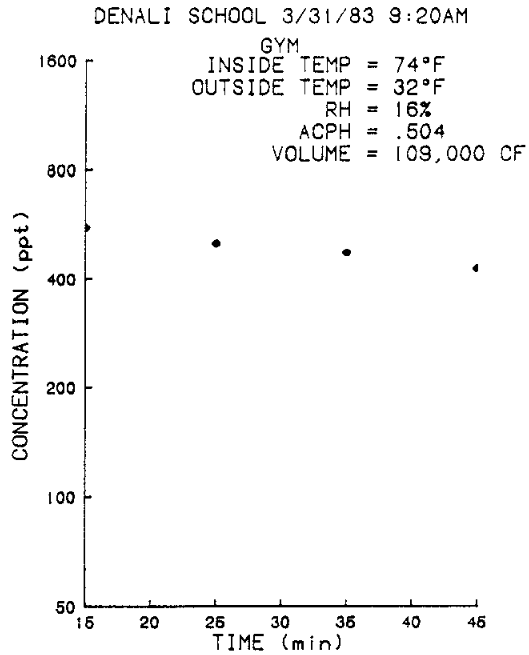

DENALI SCHOOL 2/23/83 9:25AM
GYM
INSIDE TEMP = 71°F
OUTSIDE TEMP = 15°F
RH = 18%
ACPH = .744
VOLUME = 109,000 CF
CONCENTRATION (ppt)
TIME (min)

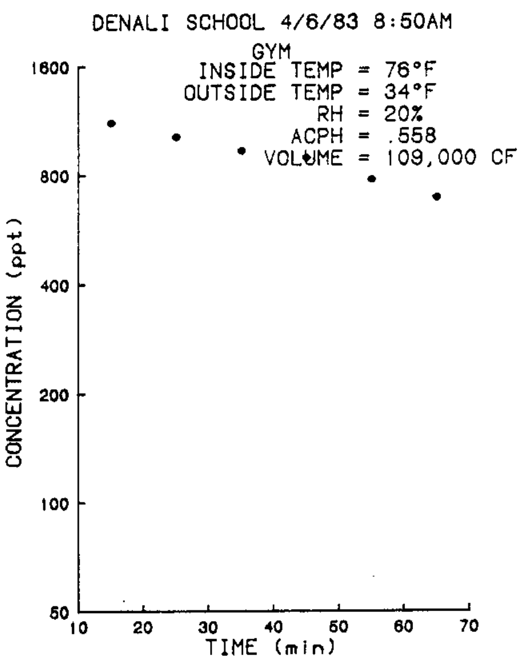

DENALI SCHOOL 3/2/83 9:30AM
GYM
INSIDE TEMP = 71°F
OUTSIDE TEMP = 16°F
RH = 18%
ACPH = .750
VOLUME = 109,000 CF
CONCENTRATION (ppt)
TIME (min)

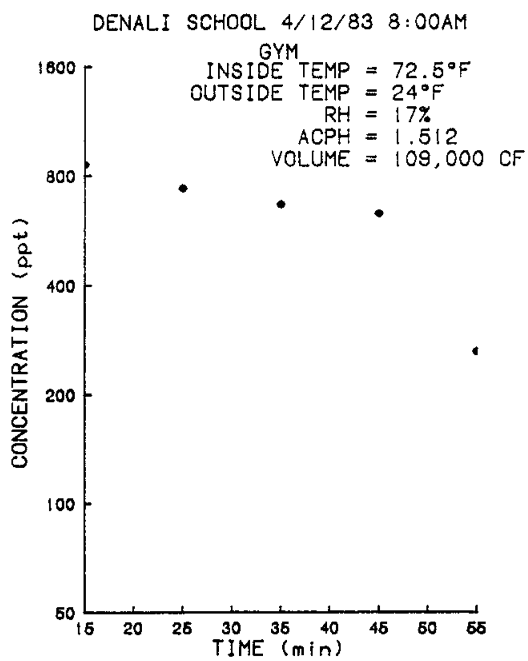

DENALI SCHOOL 3/10/83 9:50AM
GYM
INSIDE TEMP = 71°F
OUTSIDE TEMP = 12°F
RH = 18%
ACPH = .636
VOLUME = 109,000 CF
CONCENTRATION (ppt)
TIME (min)

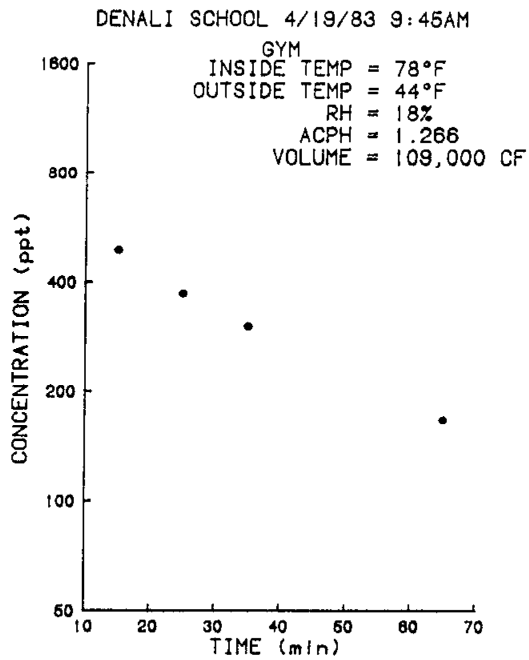

DENALI SCHOOL 3/16/83 9:30AM
GYM
INSIDE TEMP = 70.5°F
OUTSIDE TEMP = 25°F
RH = 16%
ACPH = .606
VOLUME = 109,000 CF
CONCENTRATION (ppt)
TIME (min)

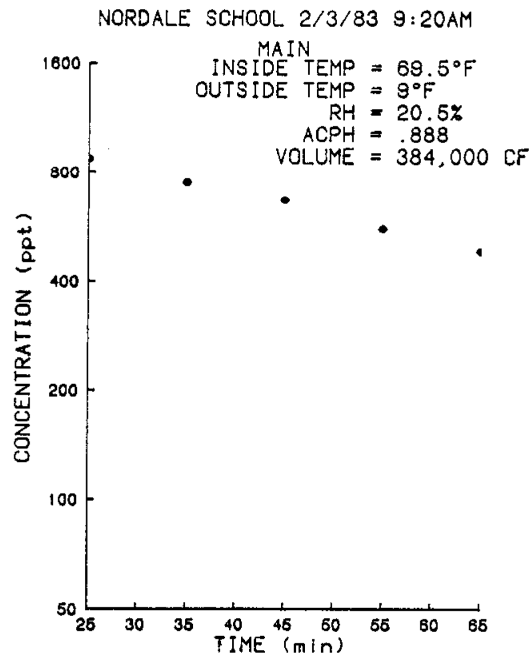

DENALI SCHOOL 3/23/83 2:30PM
GYM
INSIDE TEMP = 76°F
OUTSIDE TEMP = 41°F
RH = 18%
ACPH = .630
VOLUME = 109,000 CF
CONCENTRATION (ppt)
TIME (min)

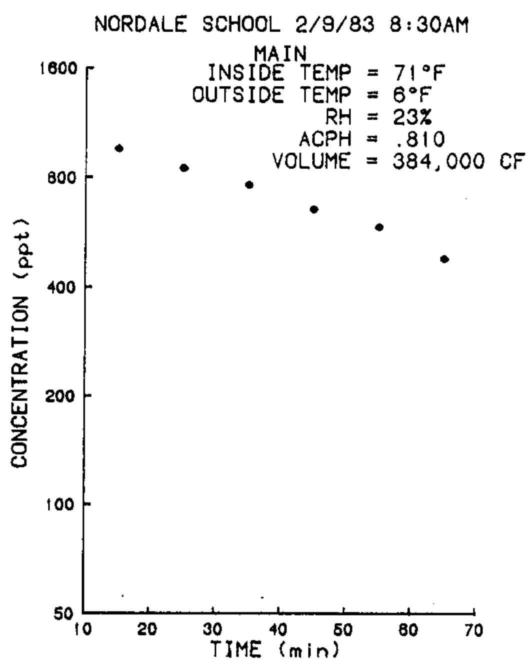

DENALI SCHOOL 3/31/83 9:20AM
GYM
INSIDE TEMP = 74°F
OUTSIDE TEMP = 32°F
RH = 16%
ACPH = .504
VOLUME = 109,000 CF
CONCENTRATION (ppt)
TIME (min)

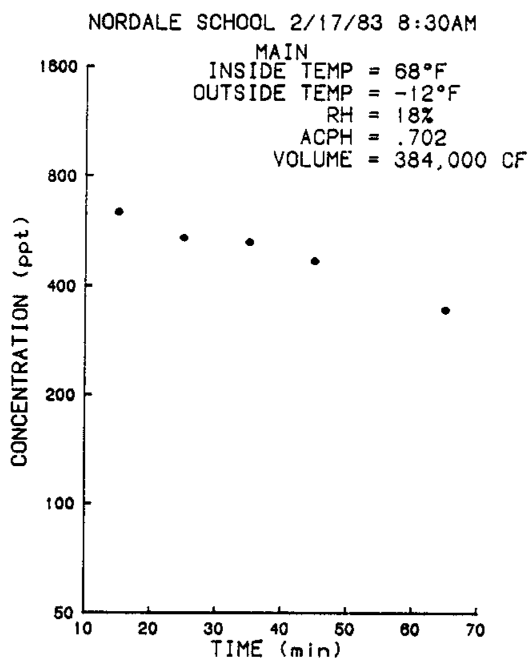

DENALI SCHOOL 4/6/83 8:50AM
GYM
INSIDE TEMP = 76°F
OUTSIDE TEMP = 34°F
RH = 20%
ACPH = .558
VOLUME = 109,000 CF
CONCENTRATION (ppt)
TIME (min)

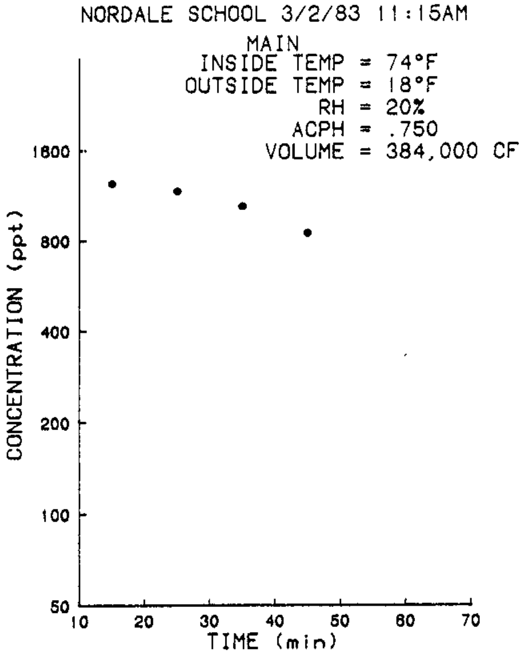

DENALI SCHOOL 4/12/83 8:00AM
GYM
INSIDE TEMP = 72.5°F
OUTSIDE TEMP = 24°F
RH = 17%
ACPH = 1.512
VOLUME = 109,000 CF
CONCENTRATION (ppt)
TIME (min)

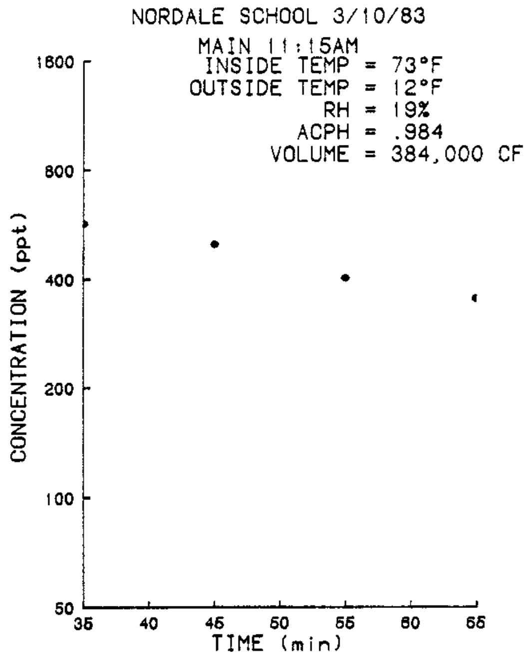

DENALI SCHOOL 4/19/83 9:45AM
GYM
INSIDE TEMP = 78°F
OUTSIDE TEMP = 44°F
RH = 18%
ACPH = 1.266
VOLUME = 109,000 CF
CONCENTRATION (ppt)
TIME (min)

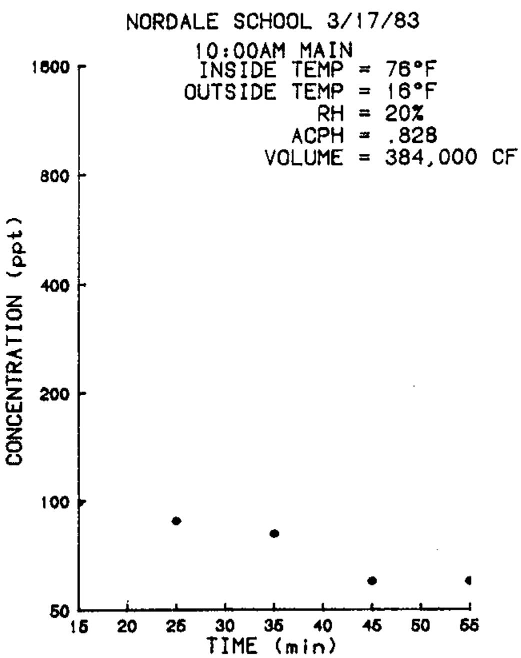

NORDALE SCHOOL 2/3/83 9:20AM
MAIN
INSIDE TEMP = 69.5°F
OUTSIDE TEMP = 9°F
RH = 20.5%
ACPH = .888
VOLUME = 384,000 CF
CONCENTRATION (ppt)
TIME (min)

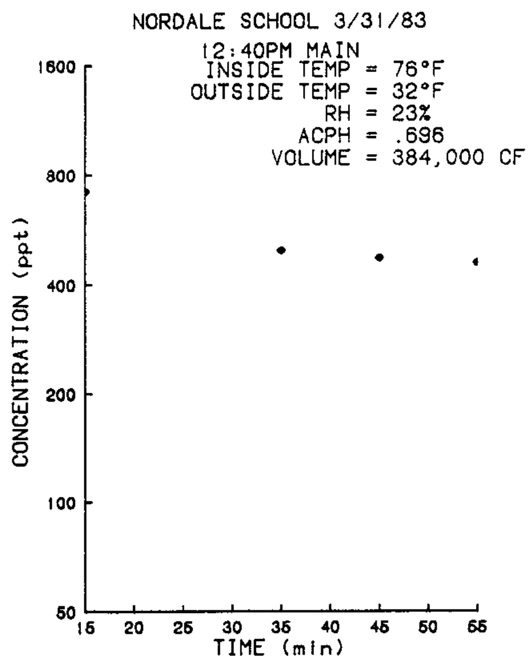

NORDALE SCHOOL 2/9/83 8:30AM
MAIN
INSIDE TEMP = 71°F
OUTSIDE TEMP = 6°F
RH = 23%
ACPH = .810
VOLUME = 384,000 CF
CONCENTRATION (ppt)
TIME (min)

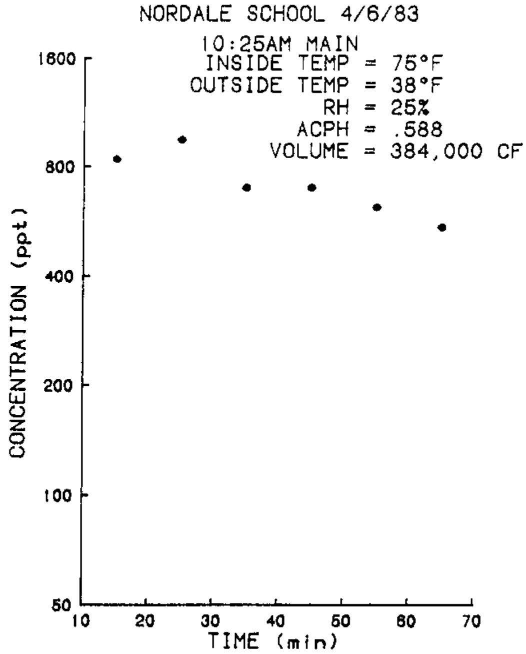

NORDALE SCHOOL 2/17/83 8:30AM
MAIN
INSIDE TEMP = 68°F
OUTSIDE TEMP = -12°F
RH = 18%
ACPH = .702
VOLUME = 384,000 CF
CONCENTRATION (ppt)
TIME (min)

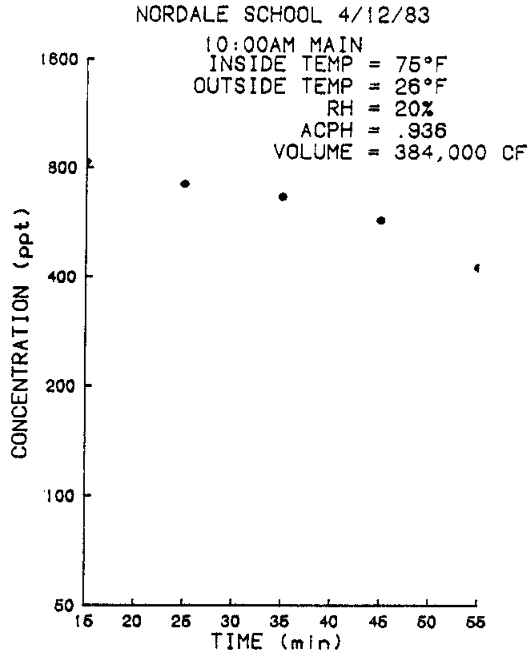

NORDALE SCHOOL 3/2/83 11:15AM
MAIN
INSIDE TEMP = 74°F
OUTSIDE TEMP = 18°F
RH = 20%
ACPH = .750
VOLUME = 384,000 CF
CONCENTRATION (ppt)
TIME (min)

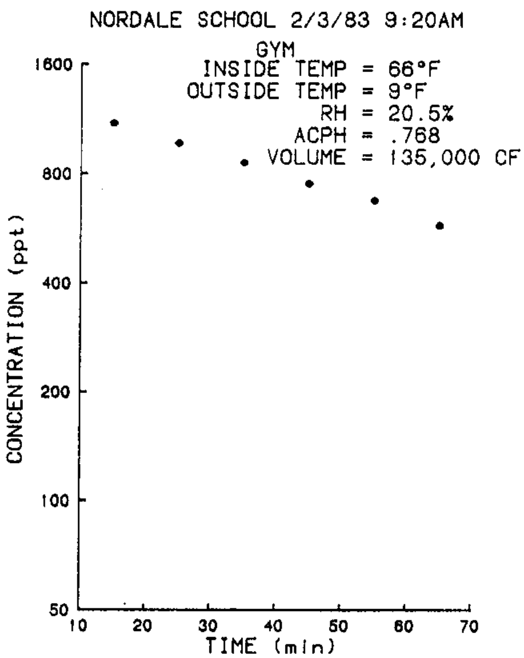

NORDALE SCHOOL 3/10/83
MAIN 11:15AM
INSIDE TEMP = 73°F
OUTSIDE TEMP = 12°F
RH = 19%
ACPH = .984
VOLUME = 384,000 CF
CONCENTRATION (ppt)
TIME (min)

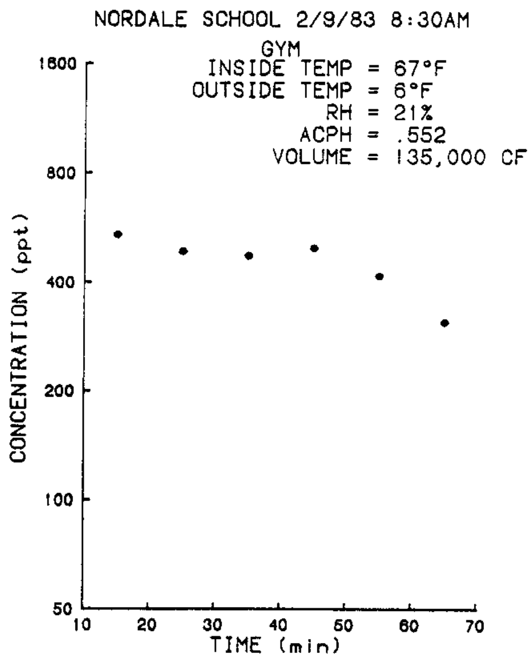

NORDALE SCHOOL 3/17/83
10:00AM MAIN
INSIDE TEMP = 76°F
OUTSIDE TEMP = 16°F
RH = 20%
ACPH = .828
VOLUME = 384,000 CF
CONCENTRATION (ppt)
TIME (min)

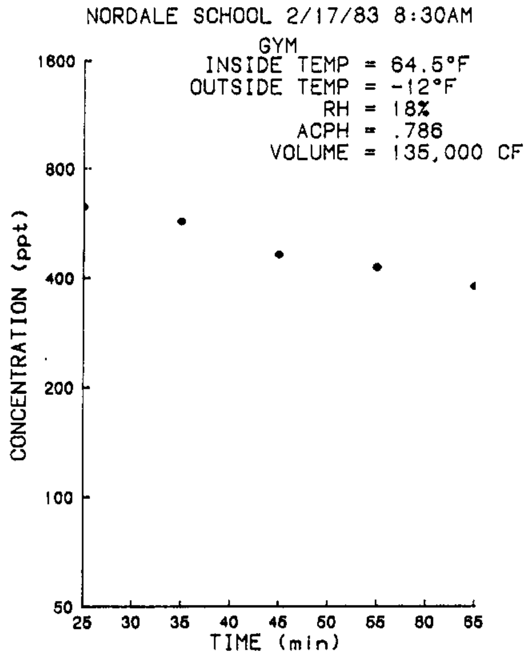

NORDALE SCHOOL 3/31/83
12:40PM MAIN
INSIDE TEMP = 76°F
OUTSIDE TEMP = 32°F
RH = 23%
ACPH = .696
VOLUME = 384,000 CF
CONCENTRATION (ppt)
TIME (min)


NORDALE SCHOOL 4/6/83
10:25AM MAIN
INSIDE TEMP = 75°F
OUTSIDE TEMP = 38°F
RH = 25%
ACPH = .588
VOLUME = 384,000 CF
CONCENTRATION (ppt)
1600
800
400
200
100
50
10
20
30
40
50
60
70
TIME (min)

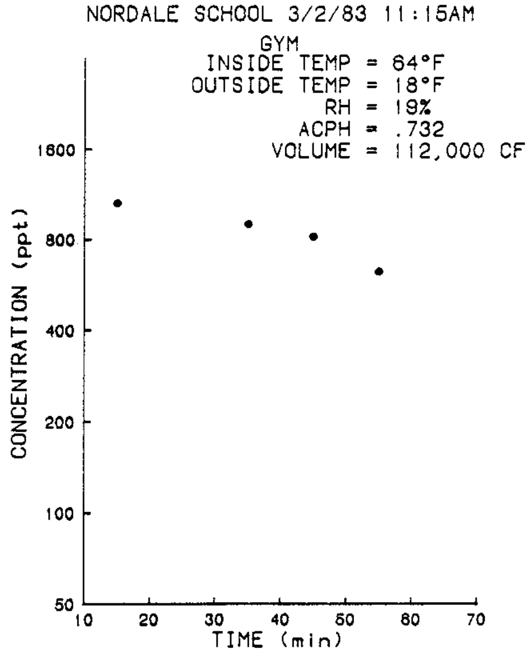

NORDALE SCHOOL 4/12/83
10:00AM MAIN
INSIDE TEMP = 75°F
OUTSIDE TEMP = 26°F
RH = 20%
ACPH = .936
VOLUME = 384,000 CF
CONCENTRATION (ppt)
1600
800
400
200
100
50
15
20
25
30
35
40
45
50
55
TIME (min)


NORDALE SCHOOL 2/3/83 9:20AM
GYM
INSIDE TEMP = 66°F
OUTSIDE TEMP = 9°F
RH = 20.5%
ACPH = .768
VOLUME = 135,000 CF
CONCENTRATION (ppt)
1600
800
400
200
100
50
10
20
30
40
50
60
70
TIME (min)

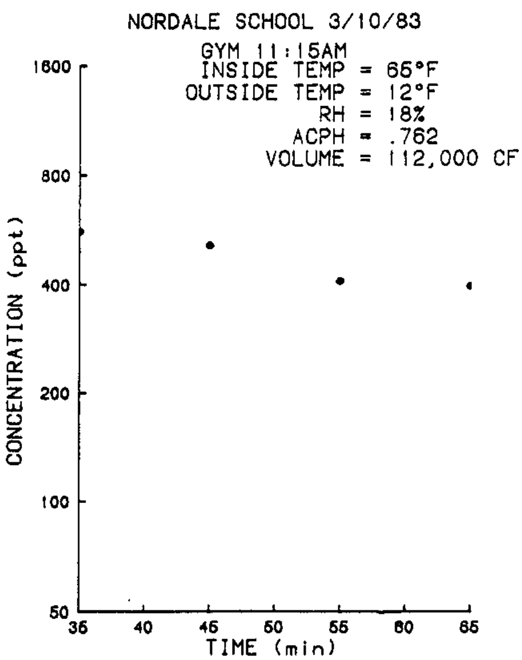

NORDALE SCHOOL 2/9/83 8:30AM
GYM
INSIDE TEMP = 67°F
OUTSIDE TEMP = 6°F
RH = 21%
ACPH = .552
VOLUME = 135,000 CF
CONCENTRATION (ppt)
1600
800
400
200
100
50
10
20
30
40
50
60
70
TIME (min)



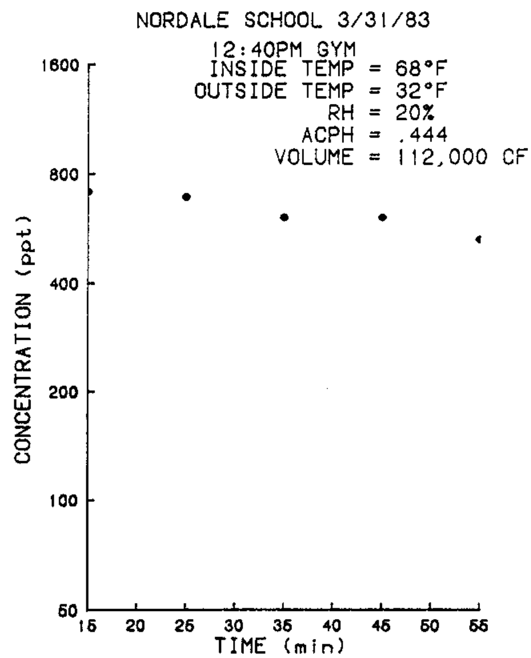
NORDALE SCHOOL 2/17/83 8:30AM
GYM
INSIDE TEMP = 64.5°F
OUTSIDE TEMP = -12°F
RH = 18%
ACPH = .786
VOLUME = 135,000 CF
CONCENTRATION (ppt)
1600
800
400
200
100
50
25 30 35 40 45 50 55 60 65
TIME (min)



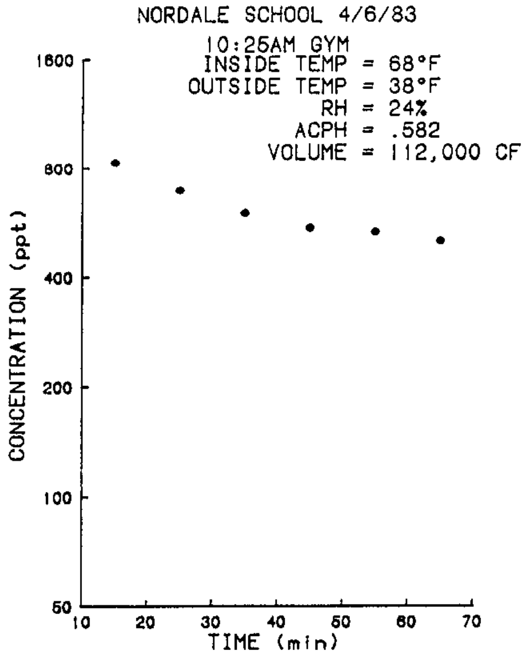
NORDALE SCHOOL 3/2/83 11:15AM
GYM
INSIDE TEMP = 64°F
OUTSIDE TEMP = 18°F
RH = 19%
ACPH = .732
VOLUME = 112,000 CF
CONCENTRATION (ppt)
1600
800
400
200
100
50
10 20 30 40 50 60 70
TIME (min)

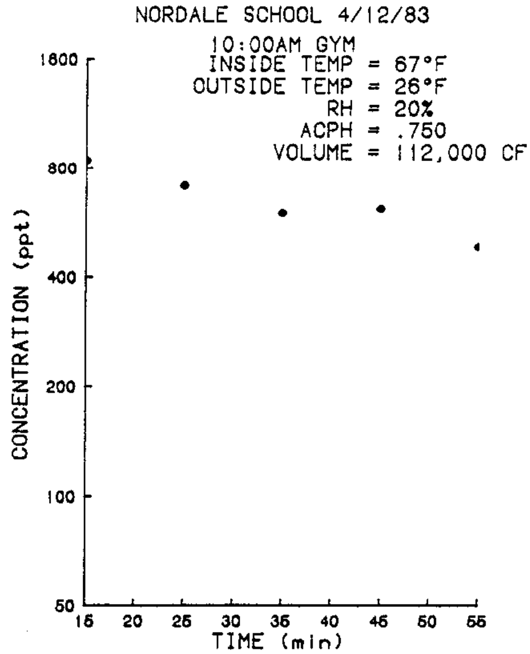


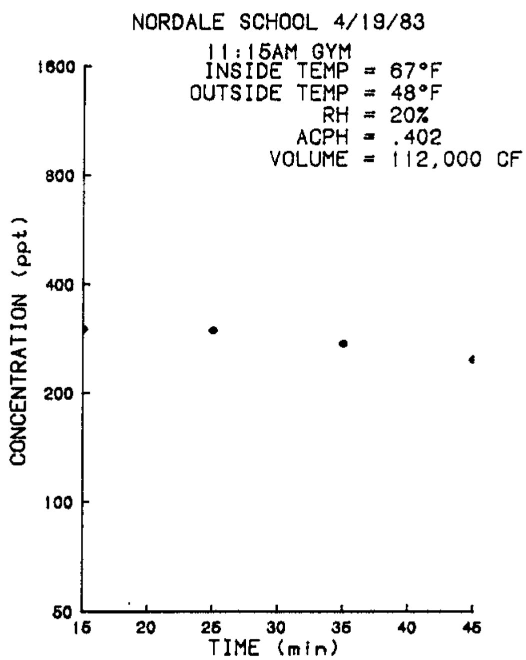
NORDALE SCHOOL 3/10/83
GYM 11:15AM
INSIDE TEMP = 65°F
OUTSIDE TEMP = 12°F
RH = 18%
ACPH = .762
VOLUME = 112,000 CF
CONCENTRATION (ppt)
1600
800
400
200
100
50
35 40 45 50 55 60 65
TIME (min)

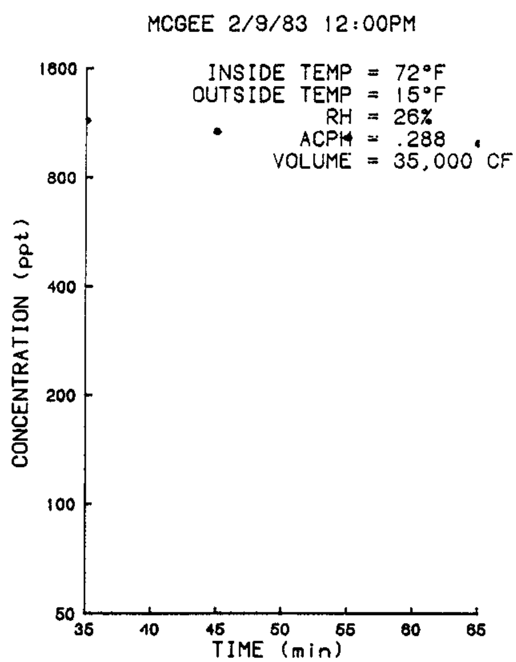


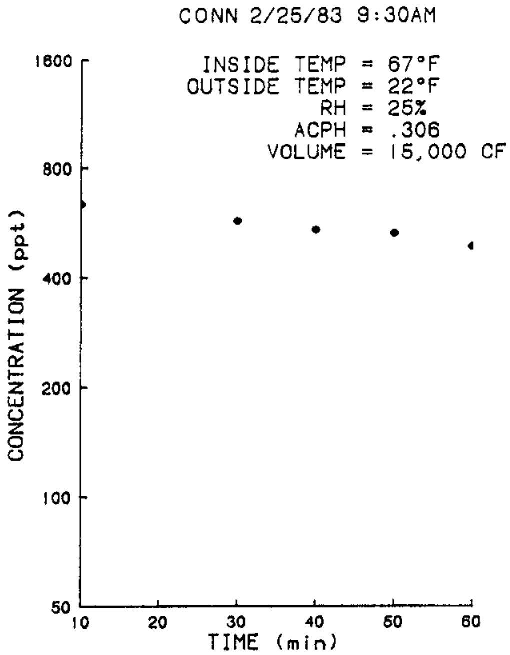
NORDALE SCHOOL 3/31/83
12:40PM GYM
INSIDE TEMP = 68°F
OUTSIDE TEMP = 32°F
RH = 20%
ACPH = .444
VOLUME = 112,000 CF
CONCENTRATION (ppt)
1600
800
400
200
100
50
15 20 25 30 35 40 45 50 55
TIME (min)

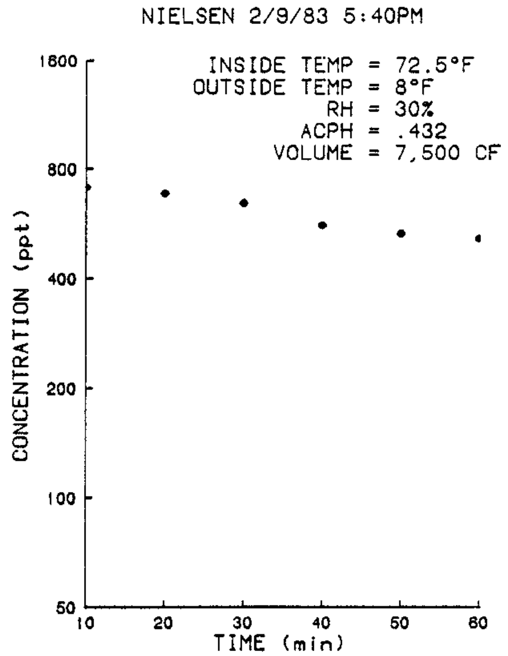

NORDALE SCHOOL 4/6/83
10:25AM GYM
INSIDE TEMP = 68°F
OUTSIDE TEMP = 38°F
RH = 24%
ACPH = .582
VOLUME = 112,000 CF
CONCENTRATION (ppt)
TIME (min)

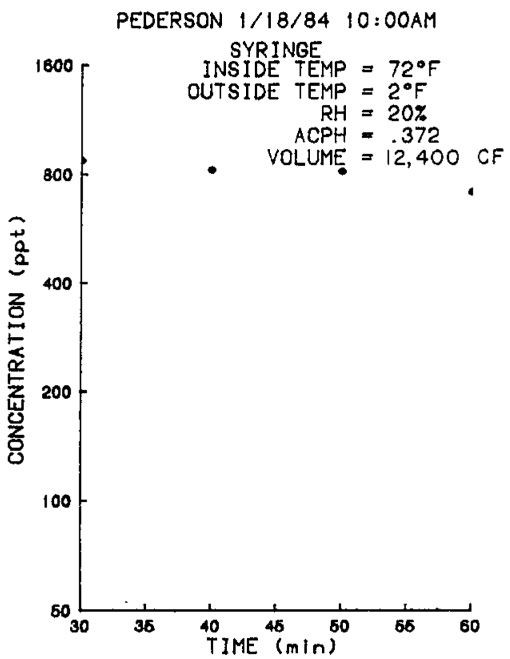

NORDALE SCHOOL 4/12/83
10:00AM GYM
INSIDE TEMP = 67°F
OUTSIDE TEMP = 26°F
RH = 20%
ACPH = .750
VOLUME = 112,000 CF
CONCENTRATION (ppt)
TIME (min)

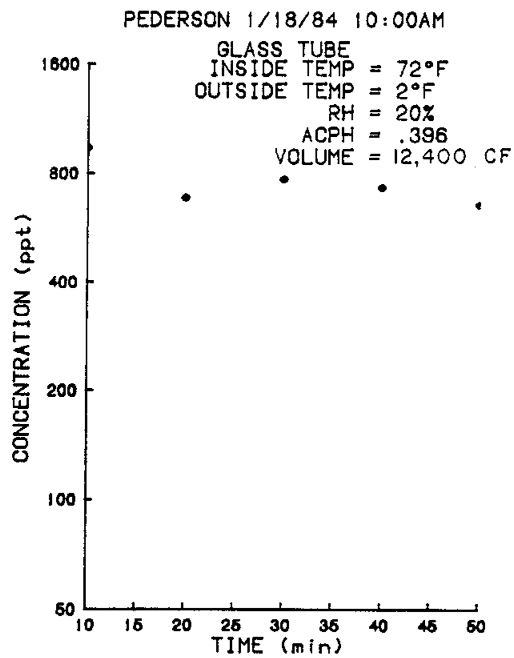

NORDALE SCHOOL 4/19/83
11:15AM GYM
INSIDE TEMP = 67°F
OUTSIDE TEMP = 48°F
RH = 20%
ACPH = .402
VOLUME = 112,000 CF
CONCENTRATION (ppt)
TIME (min)

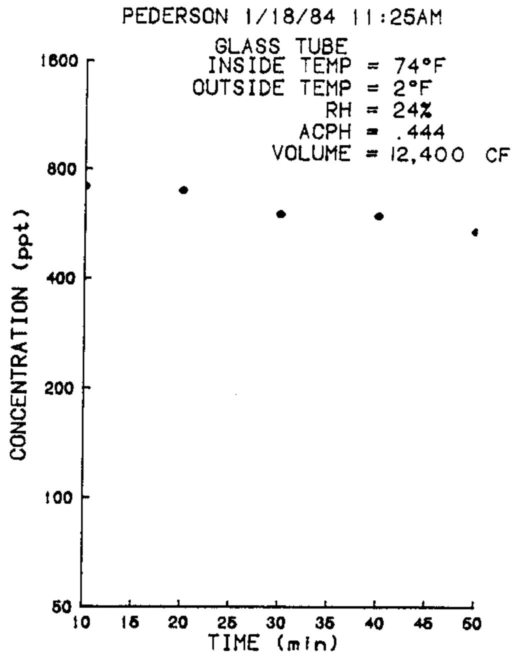

MCGEE 2/9/83 12:00PM
INSIDE TEMP = 72°F
OUTSIDE TEMP = 15°F
RH = 26%
ACPH = .288
VOLUME = 35,000 CF
CONCENTRATION (ppt)
TIME (min)

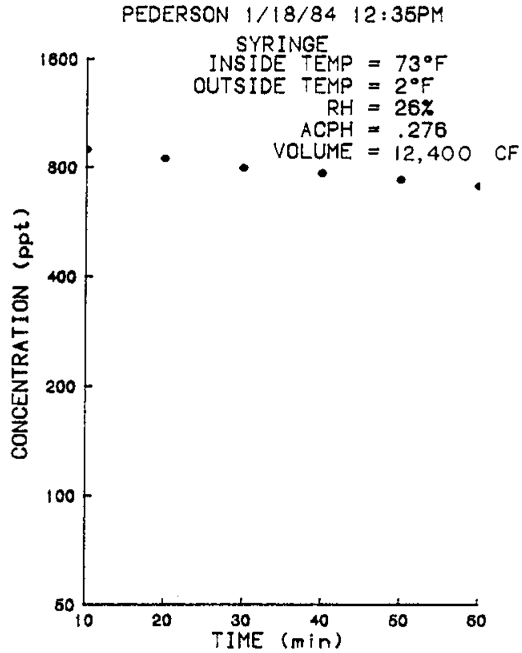

CONN 2/25/83 9:30AM
INSIDE TEMP = 67°F
OUTSIDE TEMP = 22°F
RH = 25%
ACPH = .306
VOLUME = 15,000 CF
CONCENTRATION (ppt)
TIME (min)

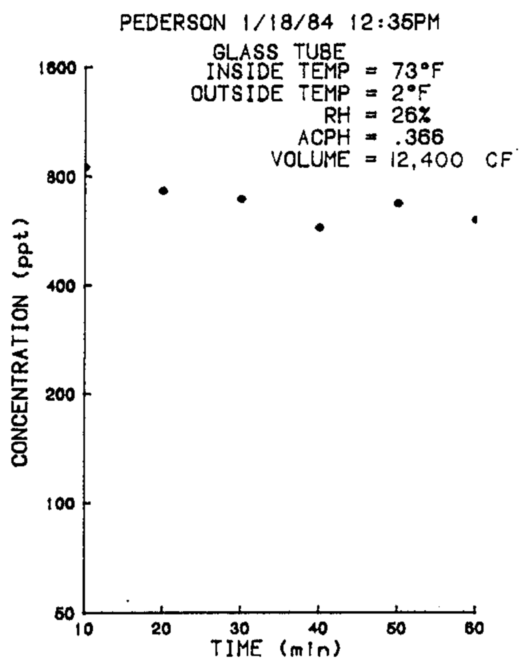

NIELSEN 2/9/83 5:40PM
INSIDE TEMP = 72.5°F
OUTSIDE TEMP = 8°F
RH = 30%
ACPH = .432
VOLUME = 7,500 CF
CONCENTRATION (ppt)
TIME (min)

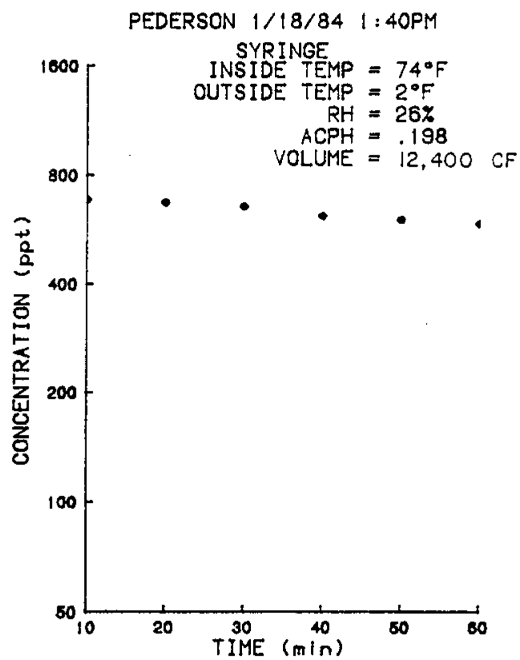

PEDERSON 1/18/84 10:00AM
SYRINGE
INSIDE TEMP = 72°F
OUTSIDE TEMP = 2°F
RH = 20%
ACPH = .372
VOLUME = 12,400 CF
CONCENTRATION (ppt)
TIME (min)

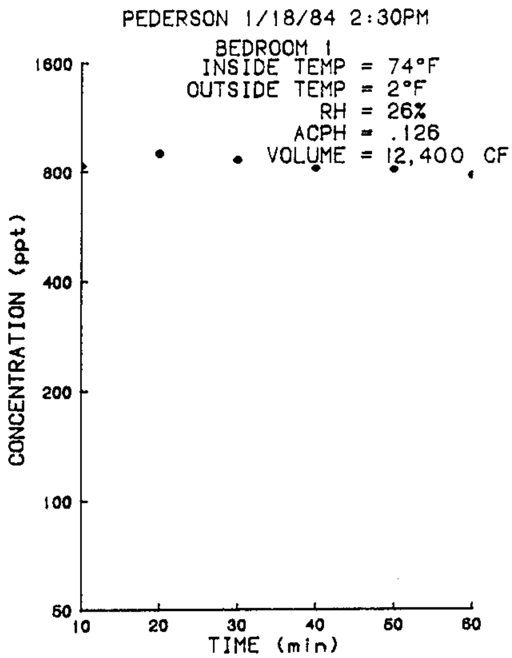

PEDERSON 1/18/84 10:00AM
GLASS TUBE
INSIDE TEMP = 72°F
OUTSIDE TEMP = 2°F
RH = 20%
ACPH = .396
VOLUME = 12,400 CF
CONCENTRATION (ppt)
TIME (min)


PEDERSON 1/18/84 11:25AM
GLASS TUBE
INSIDE TEMP = 74°F
OUTSIDE TEMP = 2°F
RH = 24%
ACPH = .444
VOLUME = 12,400 CF
CONCENTRATION (ppt)
1600
800
400
200
100
50
10
15
20
25
30
35
40
45
50
TIME (min)

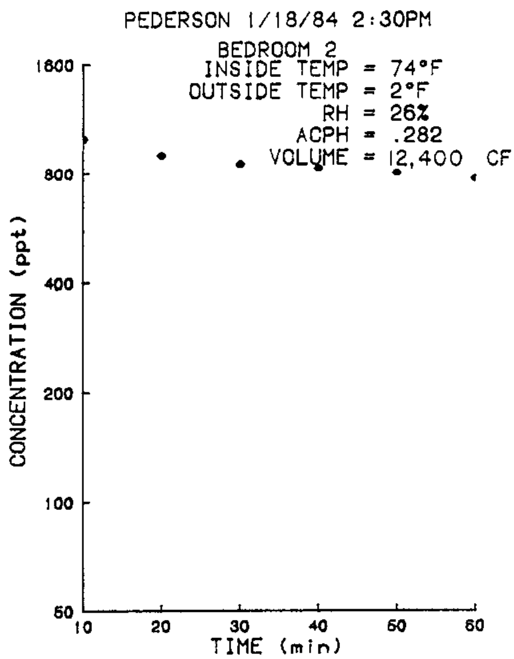

PEDERSON 1/18/84 12:35PM
SYRINGE
INSIDE TEMP = 73°F
OUTSIDE TEMP = 2°F
RH = 26%
ACPH = .276
VOLUME = 12,400 CF
CONCENTRATION (ppt)
1600
800
400
200
100
50
10
20
30
40
50
60
TIME (min)


PEDERSON 1/18/84 12:35PM
GLASS TUBE
INSIDE TEMP = 73°F
OUTSIDE TEMP = 2°F
RH = 26%
ACPH = .366
VOLUME = 12,400 CF
CONCENTRATION (ppt)
1600
800
400
200
100
50
10
20
30
40
50
60
TIME (min)

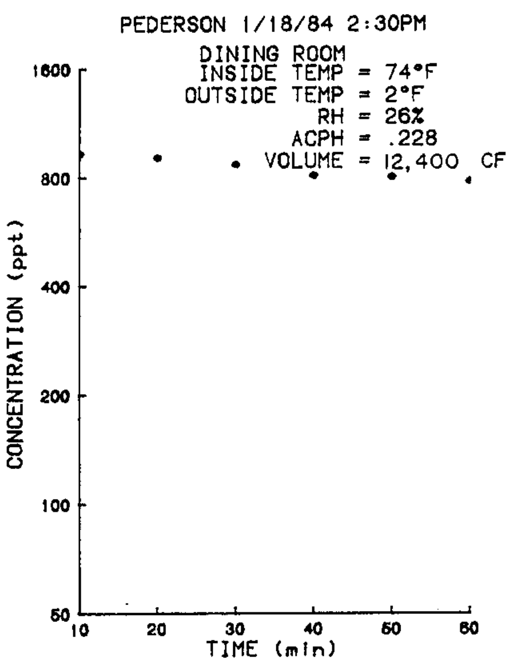

PEDERSON 1/18/84 1:40PM
SYRINGE
INSIDE TEMP = 74°F
OUTSIDE TEMP = 2°F
RH = 26%
ACPH = .198
VOLUME = 12,400 CF
CONCENTRATION (ppt)
1600
800
400
200
100
50
10
20
30
40
50
60
TIME (min)



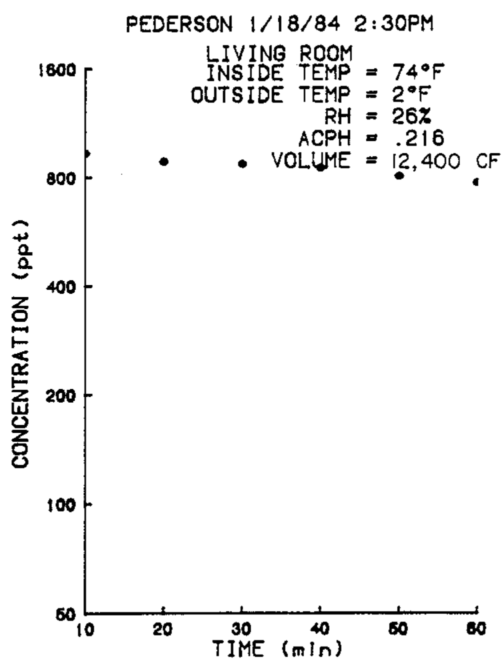
PEDERSON 1/18/84 2:30PM
BEDROOM 1
INSIDE TEMP = 74°F
OUTSIDE TEMP = 2°F
RH = 26%
ACPH = .126
VOLUME = 12,400 CF
CONCENTRATION (ppt)
1600
800
400
200
100
50
10
20
30
40
50
60
TIME (min)



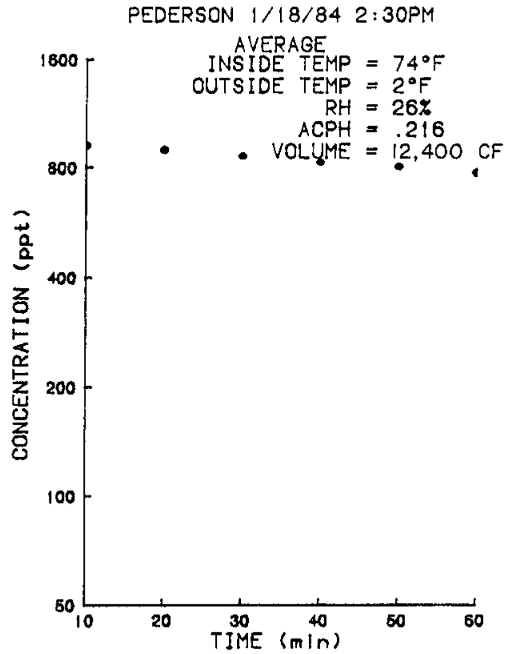
PEDERSON 1/18/84 2:30PM
BEDROOM 2
INSIDE TEMP = 74°F
OUTSIDE TEMP = 2°F
RH = 26%
ACPH = .282
VOLUME = 12,400 CF
CONCENTRATION (ppt)
1600
800
400
200
100
50
10
20
30
40
50
60
TIME (min)

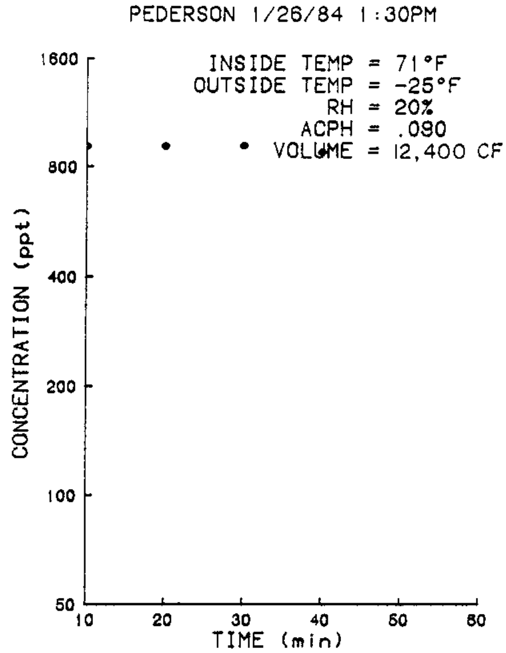


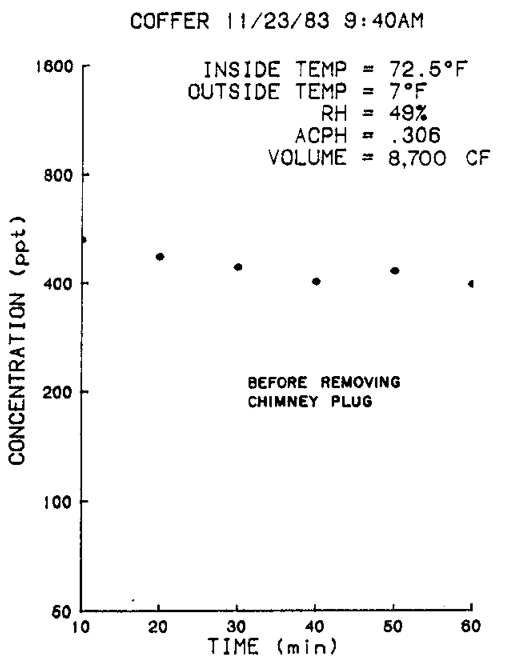
PEDERSON 1/18/84 2:30PM
DINING ROOM
INSIDE TEMP = 74°F
OUTSIDE TEMP = 2°F
RH = 26%
ACPH = .228
VOLUME = 12,400 CF
CONCENTRATION (ppt)
1600
800
400
200
100
50
10
20
30
40
50
60
TIME (min)

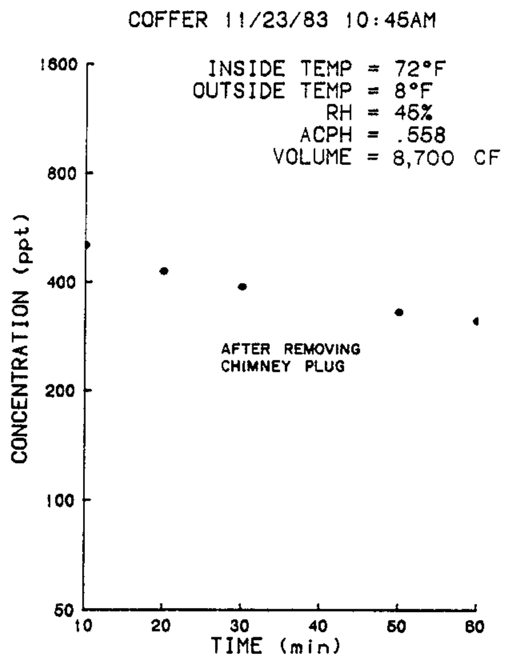


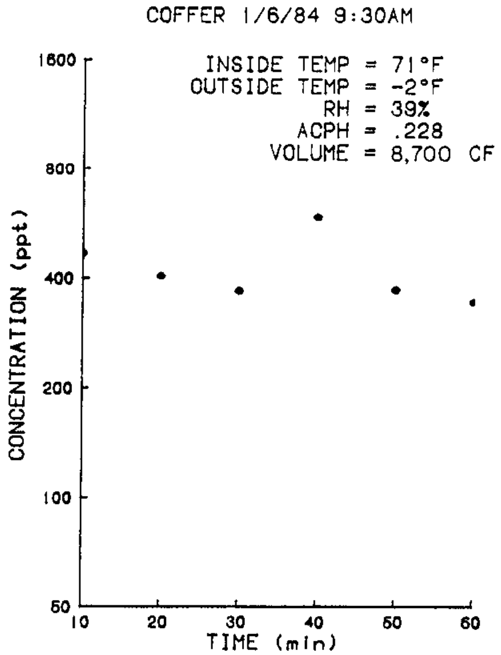
PEDERSON 1/18/84 2:30PM
LIVING ROOM
INSIDE TEMP = 74°F
OUTSIDE TEMP = 2°F
RH = 26%
ACPH = .216
VOLUME = 12,400 CF
CONCENTRATION (ppt)
1600
800
400
200
100
50
10
20
30
40
50
60
TIME (min)

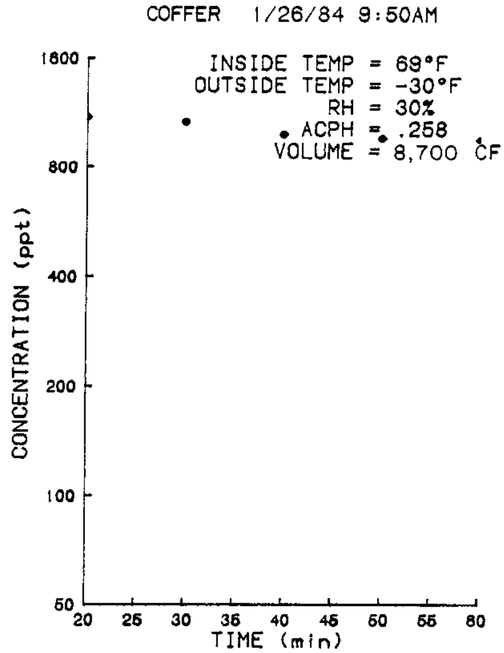

PEDERSON 1/18/84 2:30PM
AVERAGE
INSIDE TEMP = 74°F
OUTSIDE TEMP = 2°F
RH = 26%
ACPH = .216
VOLUME = 12,400 CF
CONCENTRATION (ppt)
TIME (min)

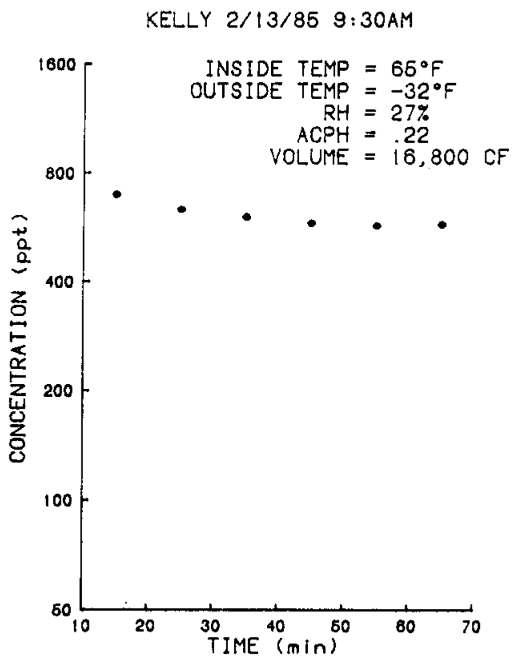

PEDERSON 1/26/84 1:30PM
INSIDE TEMP = 71°F
OUTSIDE TEMP = -25°F
RH = 20%
ACPH = .080
VOLUME = 12,400 CF
CONCENTRATION (ppt)
TIME (min)

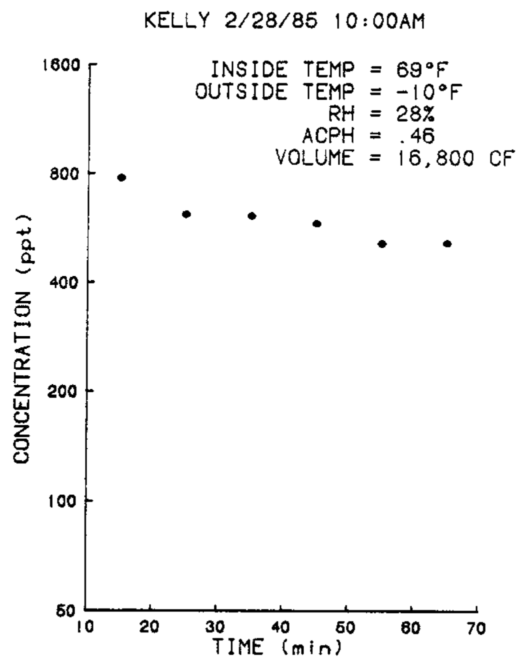

COFFER 11/23/83 9:40AM
INSIDE TEMP = 72.5°F
OUTSIDE TEMP = 7°F
RH = 49%
ACPH = .306
VOLUME = 8,700 CF
BEFORE REMOVING CHIMNEY PLUG
CONCENTRATION (ppt)
TIME (min)

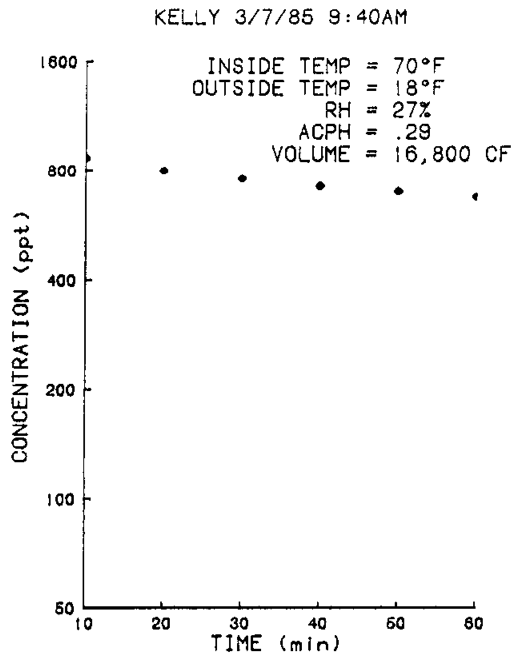

COFFER 11/23/83 10:45AM
INSIDE TEMP = 72°F
OUTSIDE TEMP = 8°F
RH = 45%
ACPH = .558
VOLUME = 8,700 CF
AFTER REMOVING CHIMNEY PLUG
CONCENTRATION (ppt)
TIME (min)

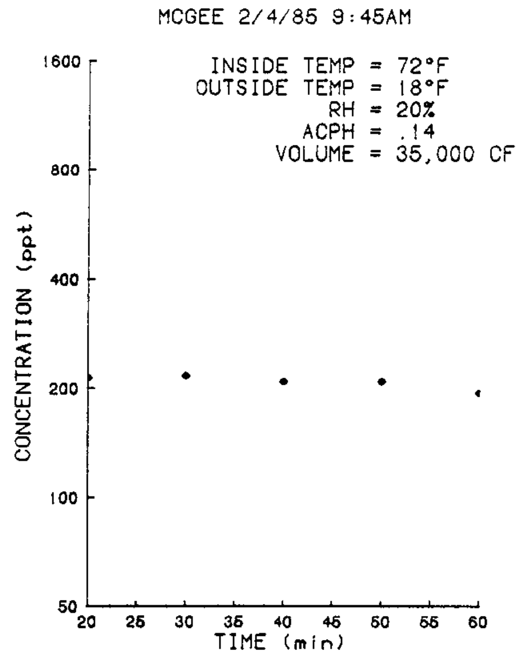

COFFER 1/6/84 9:30AM
INSIDE TEMP = 71°F
OUTSIDE TEMP = -2°F
RH = 39%
ACPH = .228
VOLUME = 8,700 CF
CONCENTRATION (ppt)
1600
800
400
200
100
50
10
20
30
40
50
60
TIME (min)

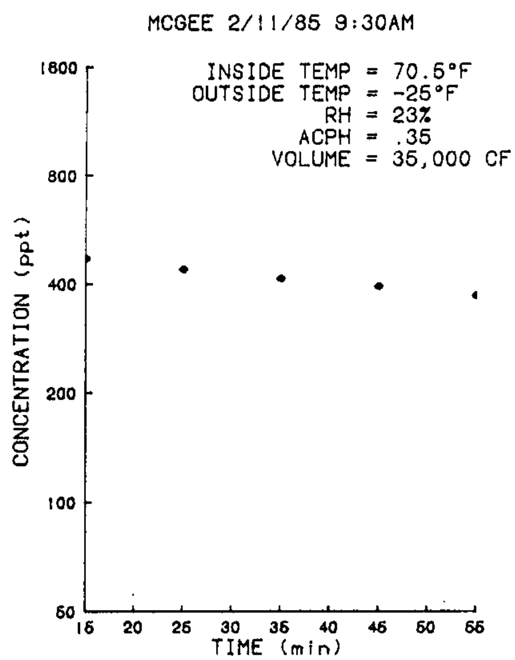

COFFER 1/26/84 9:50AM
INSIDE TEMP = 69°F
OUTSIDE TEMP = -30°F
RH = 30%
ACPH = .258
VOLUME = 8,700 CF
CONCENTRATION (ppt)
1600
800
400
200
100
50
20
25
30
35
40
45
50
55
60
TIME (min)

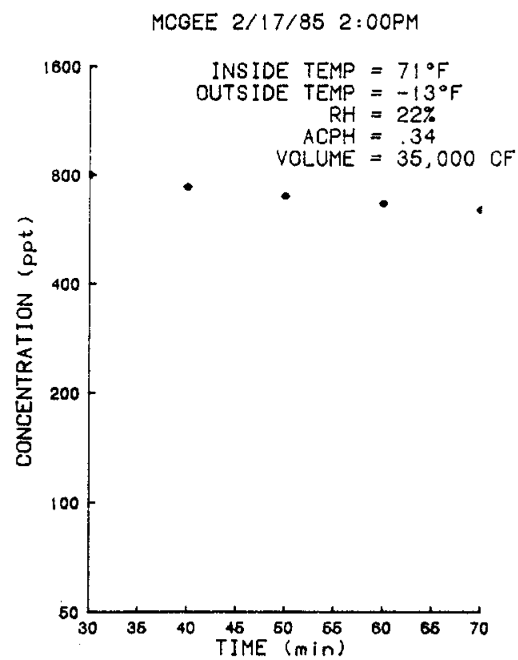

KELLY 2/13/85 9:30AM
INSIDE TEMP = 65°F
OUTSIDE TEMP = -32°F
RH = 27%
ACPH = .22
VOLUME = 16,800 CF
CONCENTRATION (ppt)
1600
800
400
200
100
50
10
20
30
40
50
60
70
TIME (min)

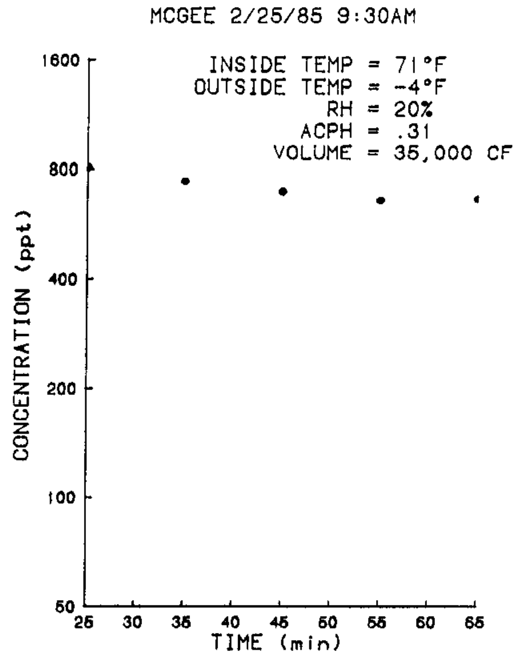

KELLY 2/28/85 10:00AM
INSIDE TEMP = 69°F
OUTSIDE TEMP = -10°F
RH = 28%
ACPH = .46
VOLUME = 16,800 CF
CONCENTRATION (ppt)
1600
800
400
200
100
50
10
20
30
40
50
60
70
TIME (min)

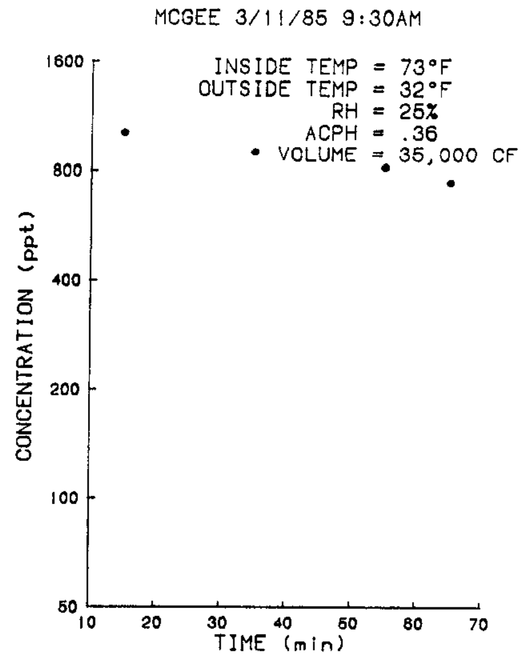

KELLY 3/7/85 9:40AM
INSIDE TEMP = 70°F
OUTSIDE TEMP = 18°F
RH = 27%
ACPH = .29
VOLUME = 16,800 CF
CONCENTRATION (ppt)
TIME (min)

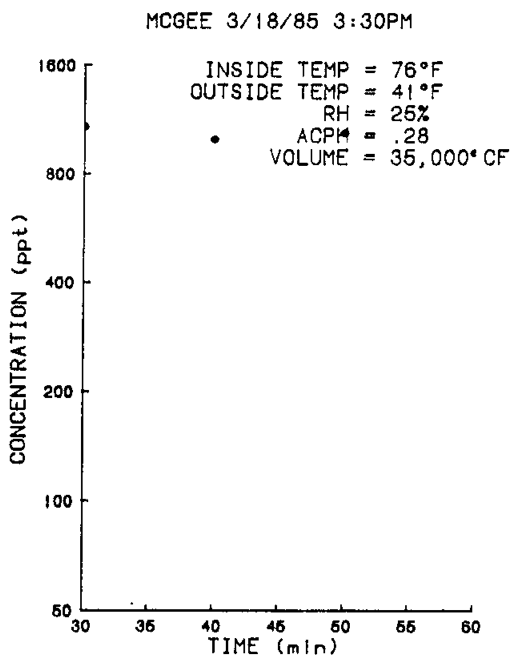

MCGEE 2/4/85 9:45AM
INSIDE TEMP = 72°F
OUTSIDE TEMP = 18°F
RH = 20%
ACPH = .14
VOLUME = 35,000 CF
CONCENTRATION (ppt)
TIME (min)

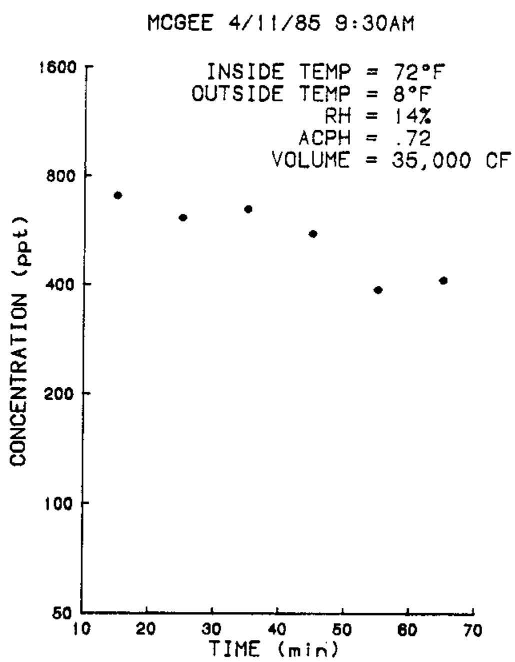

MCGEE 2/11/85 9:30AM
INSIDE TEMP = 70.5°F
OUTSIDE TEMP = -25°F
RH = 23%
ACPH = .35
VOLUME = 35,000 CF
CONCENTRATION (ppt)
TIME (min)


MCGEE 2/17/85 2:00PM
INSIDE TEMP = 71°F
OUTSIDE TEMP = -13°F
RH = 22%
ACPH = .34
VOLUME = 35,000 CF
CONCENTRATION (ppt)
TIME (min)

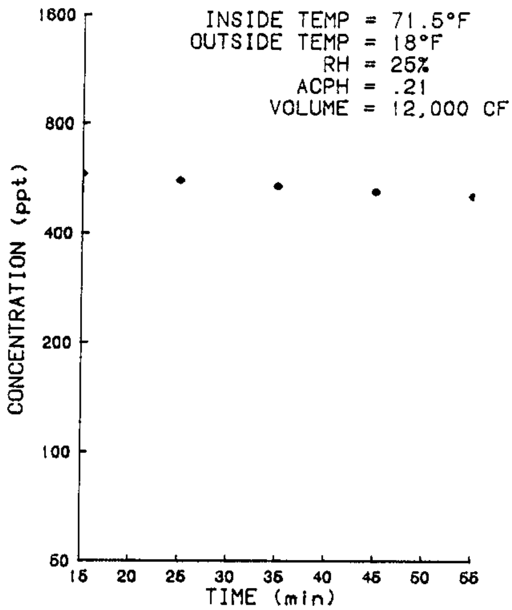

MCGEE 2/25/85 9:30AM
INSIDE TEMP = 71°F
OUTSIDE TEMP = -4°F
RH = 20%
ACPH = .31
VOLUME = 35,000 CF
CONCENTRATION (ppt)
1600
800
400
200
100
50
25
30
35
40
45
50
55
60
65
TIME (min)


MCGEE 3/11/85 9:30AM
INSIDE TEMP = 73°F
OUTSIDE TEMP = 32°F
RH = 25%
ACPH = .36
VOLUME = 35,000 CF
CONCENTRATION (ppt)
1600
800
400
200
100
50
10
20
30
40
50
60
70
TIME (min)

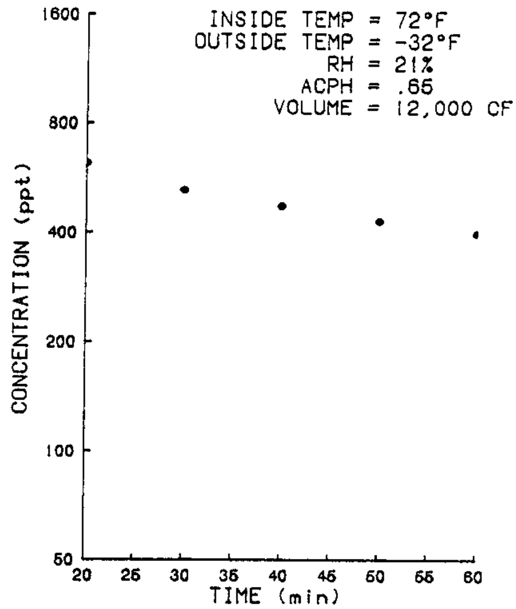

MCGEE 3/18/85 3:30PM
INSIDE TEMP = 76°F
OUTSIDE TEMP = 41°F
RH = 25%
ACPH = .28
VOLUME = 35,000 CF
CONCENTRATION (ppt)
1600
800
400
200
100
50
30
35
40
45
50
55
60
TIME (min)


MCGEE 4/11/85 9:30AM
INSIDE TEMP = 72°F
OUTSIDE TEMP = 8°F
RH = 14%
ACPH = .72
VOLUME = 35,000 CF
CONCENTRATION (ppt)
1600
800
400
200
100
50
10
20
30
40
50
60
70
TIME (min)

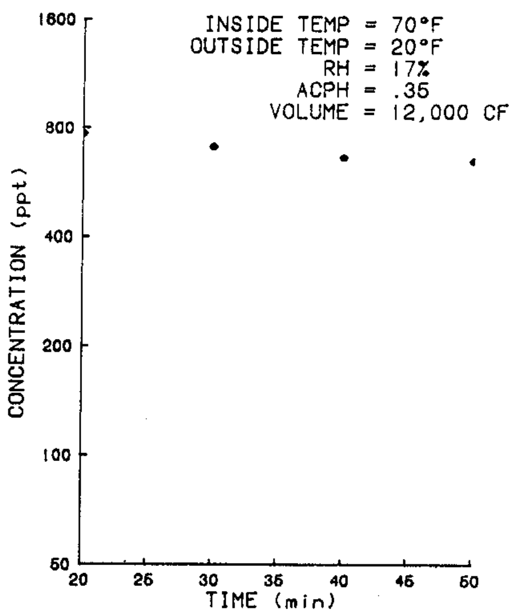
CHANDLER 2/6/85 9:25AM



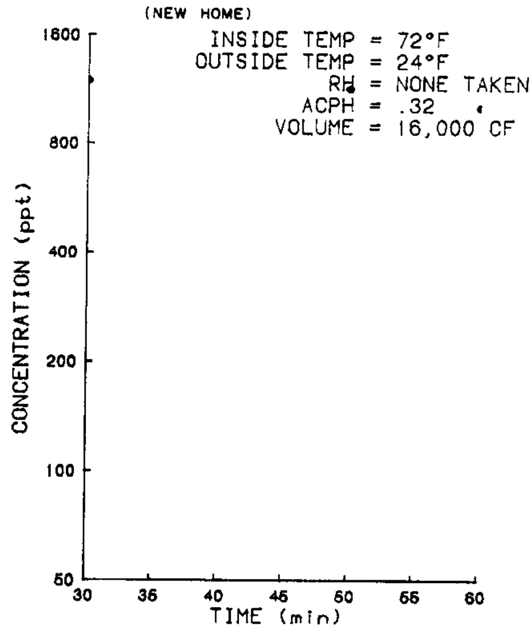
CHANDLER 2/13/85 4:55PM

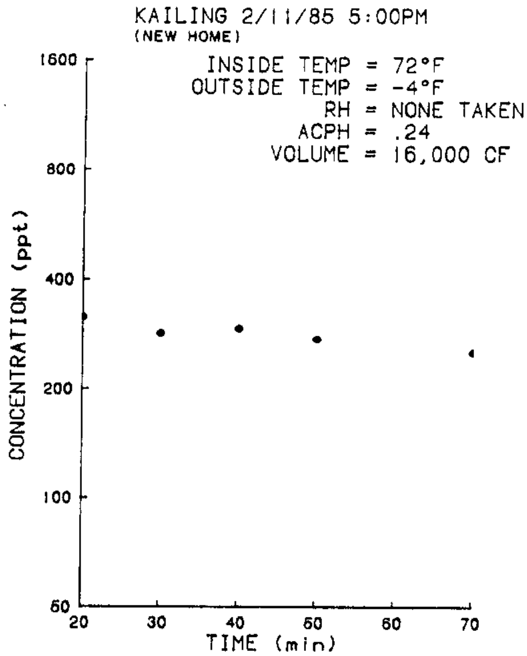


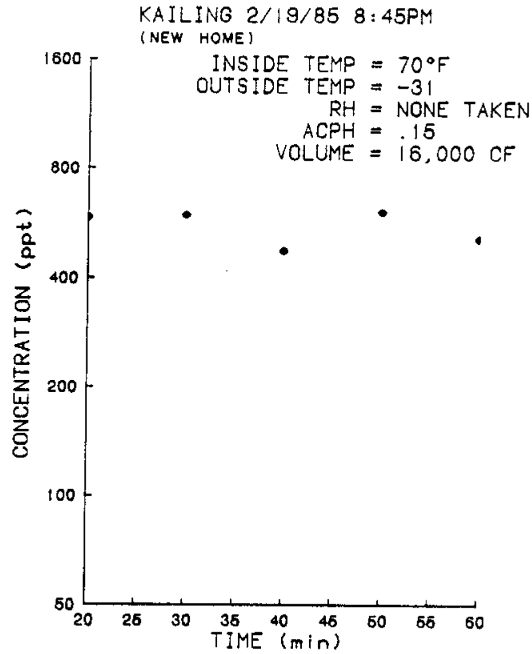
CHANDLER 2/27/85 12:30PM

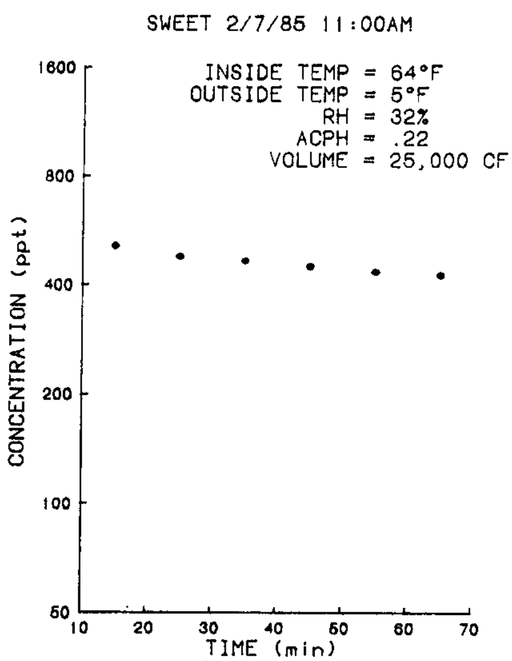


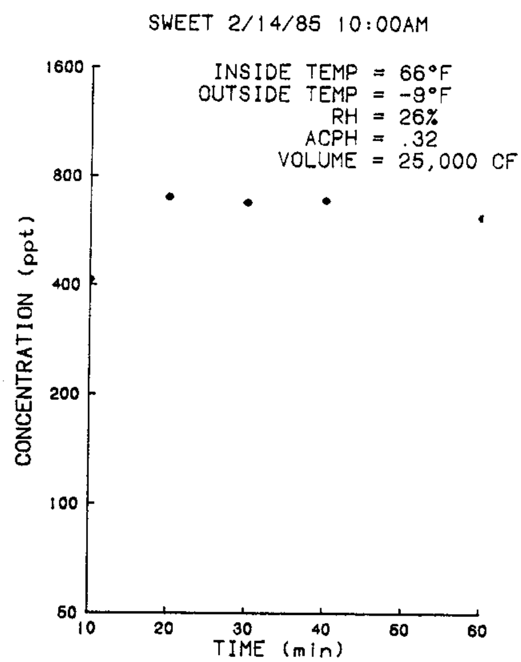
KAILING 2/4/85 8:40PM
(NEW HOME)

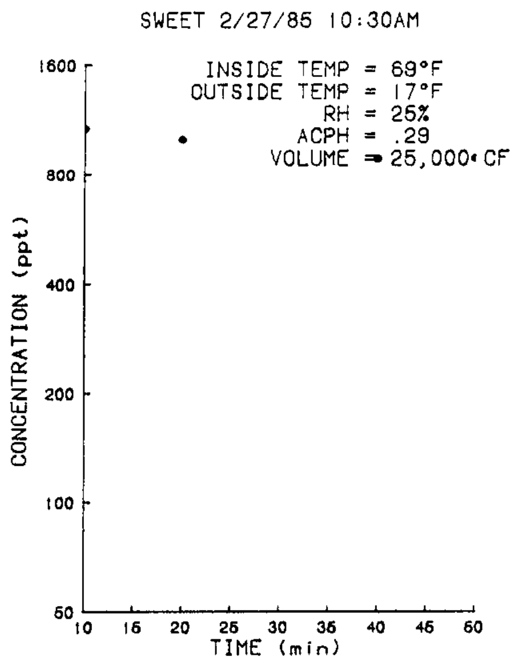


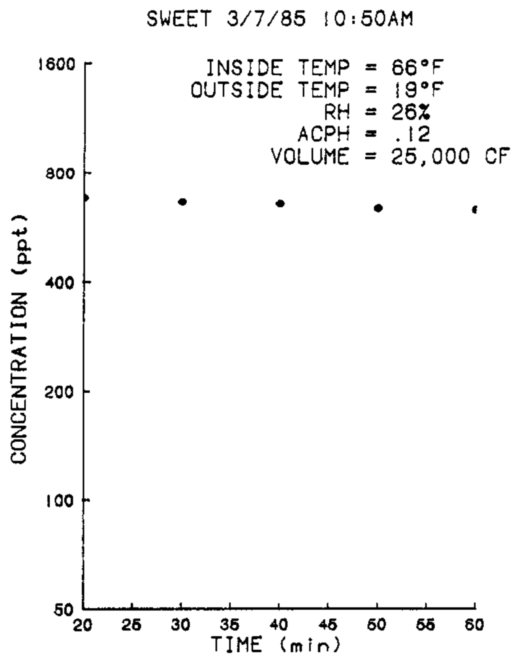

KAILING 2/11/85 5:00PM
(NEW HOME)
INSIDE TEMP = 72°F
OUTSIDE TEMP = -4°F
RH = NONE TAKEN
ACPH = .24
VOLUME = 16,000 CF
CONCENTRATION (ppt)
1600
800
400
200
100
50
20 30 40 50 60 70
TIME (min)

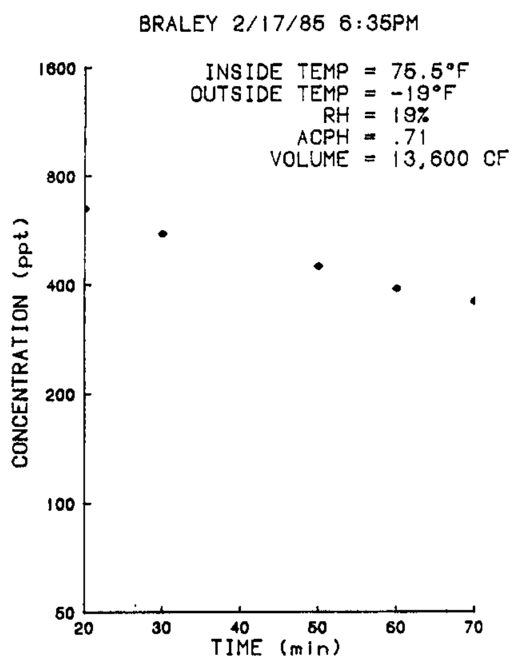

KAILING 2/19/85 8:45PM
(NEW HOME)
INSIDE TEMP = 70°F
OUTSIDE TEMP = -31
RH = NONE TAKEN
ACPH = .15
VOLUME = 16,000 CF
CONCENTRATION (ppt)
1600
800
400
200
100
50
20 25 30 35 40 45 50 55 60
TIME (min)

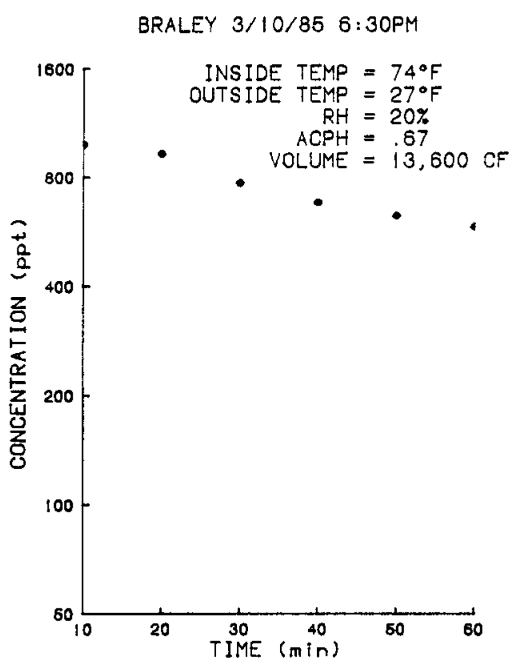

SWEET 2/7/85 11:00AM
INSIDE TEMP = 64°F
OUTSIDE TEMP = 5°F
RH = 32%
ACPH = .22
VOLUME = 25,000 CF
CONCENTRATION (ppt)
1600
800
400
200
100
50
10 20 30 40 50 60 70
TIME (min)

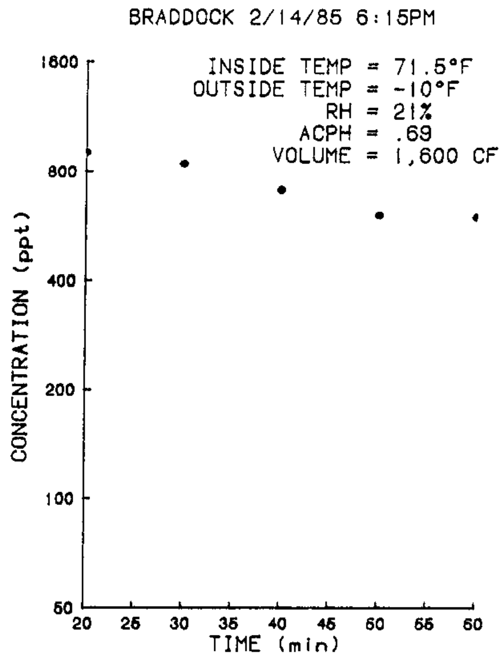

SWEET 2/14/85 10:00AM
INSIDE TEMP = 66°F
OUTSIDE TEMP = -9°F
RH = 26%
ACPH = .32
VOLUME = 25,000 CF
CONCENTRATION (ppt)
1600
800
400
200
100
50
10 20 30 40 50 60
TIME (min)

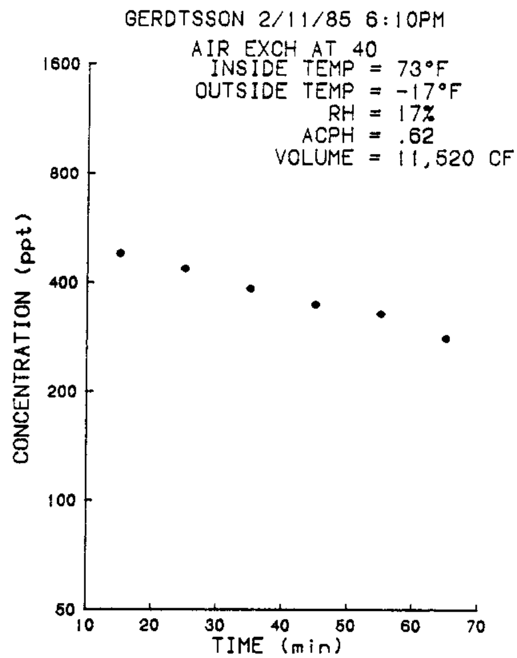

SWEET 2/27/85 10:30AM
INSIDE TEMP = 69°F
OUTSIDE TEMP = 17°F
RH = 25%
ACPH = .29
VOLUME = 25,000 CF
CONCENTRATION (ppt)
TIME (min)

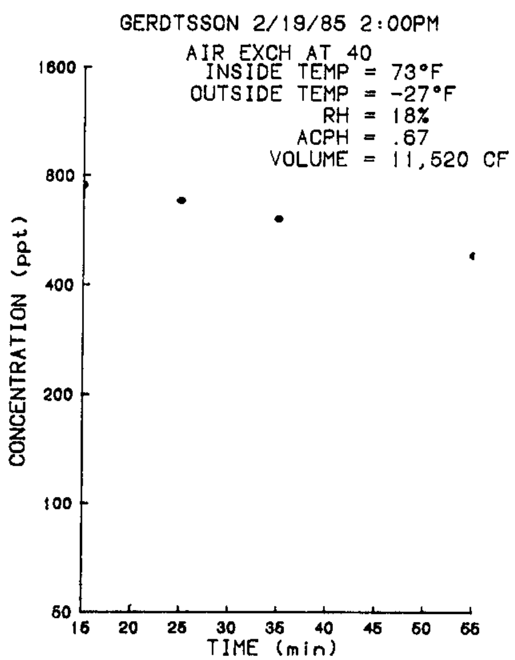

SWEET 3/7/85 10:50AM
INSIDE TEMP = 66°F
OUTSIDE TEMP = 19°F
RH = 26%
ACPH = .12
VOLUME = 25,000 CF
CONCENTRATION (ppt)
TIME (min)

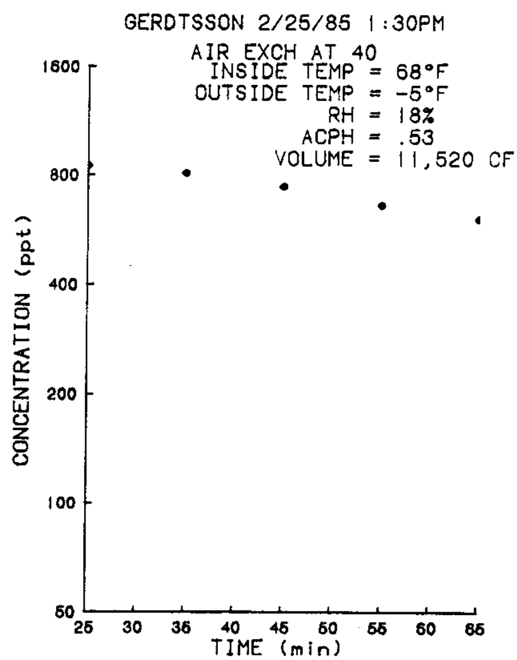

BRALEY 2/17/85 6:35PM
INSIDE TEMP = 75.5°F
OUTSIDE TEMP = -19°F
RH = 19%
ACPH = .71
VOLUME = 13,600 CF
CONCENTRATION (ppt)
TIME (min)

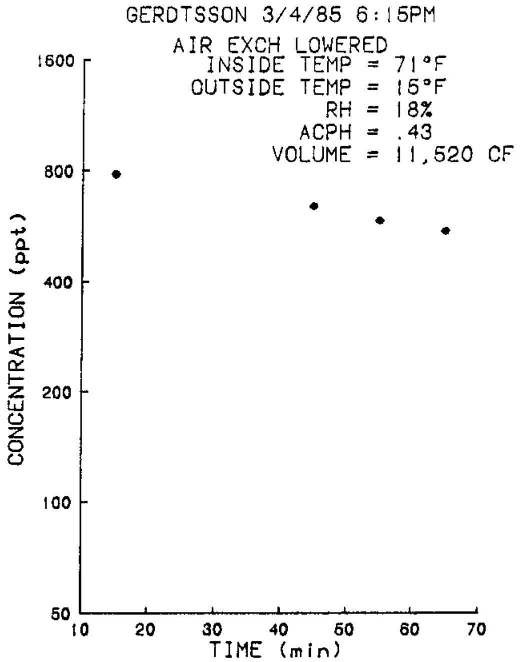

BRALEY 3/10/85 6:30PM
INSIDE TEMP = 74°F
OUTSIDE TEMP = 27°F
RH = 20%
ACPH = .67
VOLUME = 13,600 CF
CONCENTRATION (ppt)
TIME (min)

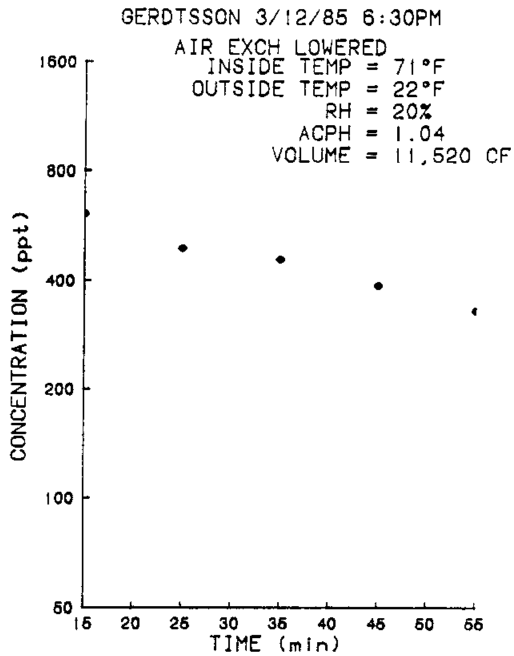

BRADDOCK 2/14/85 6:15PM
INSIDE TEMP = 71.5°F
OUTSIDE TEMP = -10°F
RH = 21%
ACPH = .69
VOLUME = 1,600 CF
CONCENTRATION (ppt)
1600
800
400
200
100
50
20 25 30 35 40 45 50 55 60
TIME (min)

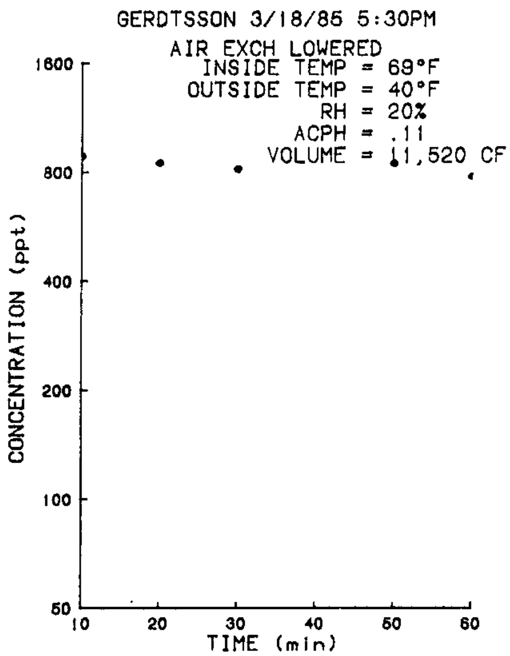

GERDTSSON 2/11/85 6:10PM
AIR EXCH AT 40
INSIDE TEMP = 73°F
OUTSIDE TEMP = -17°F
RH = 17%
ACPH = .62
VOLUME = 11,520 CF
CONCENTRATION (ppt)
1600
800
400
200
100
50
10 20 30 40 50 60 70
TIME (min)

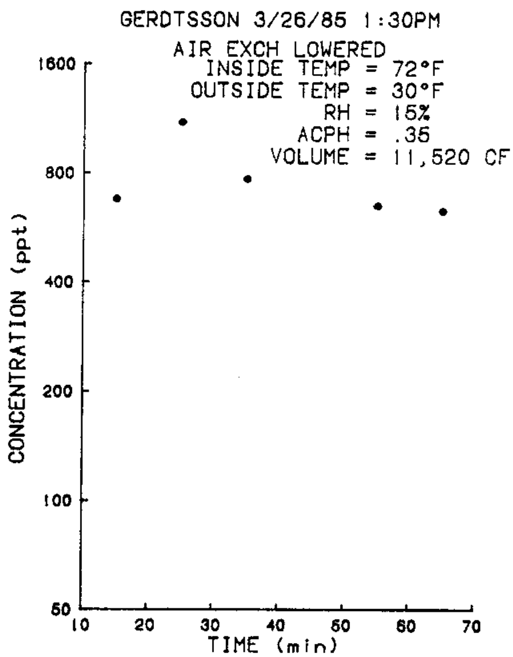

GERDTSSON 2/19/85 2:00PM
AIR EXCH AT 40
INSIDE TEMP = 73°F
OUTSIDE TEMP = -27°F
RH = 18%
ACPH = .67
VOLUME = 11,520 CF
CONCENTRATION (ppt)
1600
800
400
200
100
50
15 20 25 30 35 40 45 50 55
TIME (min)

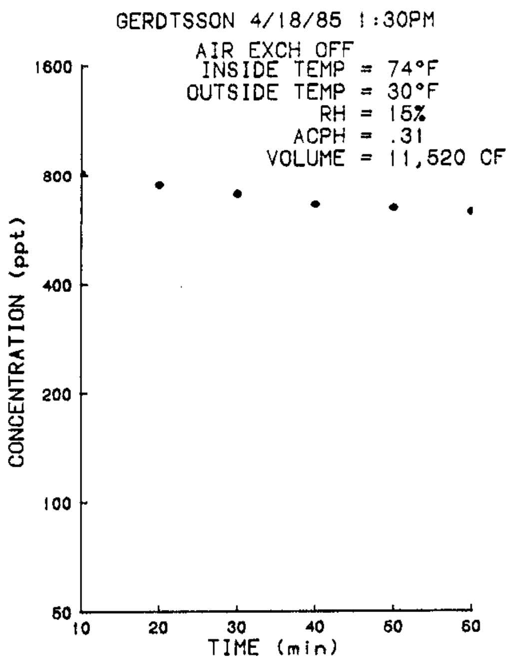

GERDTSSON 2/25/85 1:30PM
AIR EXCH AT 40
INSIDE TEMP = 68°F
OUTSIDE TEMP = -5°F
RH = 18%
ACPH = .53
VOLUME = 11,520 CF
CONCENTRATION (ppt)
1600
800
400
200
100
50
25 30 35 40 45 50 55 60 65
TIME (min)

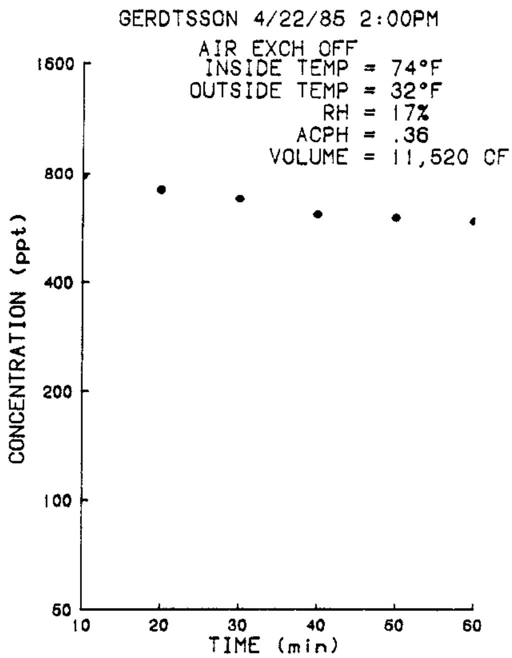

GERDTSSON 3/4/85 6:15PM
AIR EXCH LOWERED
INSIDE TEMP = 71°F
OUTSIDE TEMP = 15°F
RH = 18%
ACPH = .43
VOLUME = 11,520 CF
CONCENTRATION (ppt)
TIME (min)

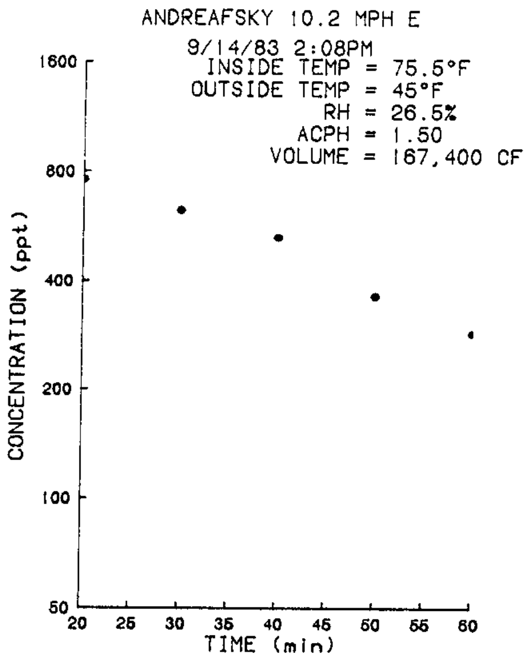

GERDTSSON 3/12/85 6:30PM
AIR EXCH LOWERED
INSIDE TEMP = 71°F
OUTSIDE TEMP = 22°F
RH = 20%
ACPH = 1.04
VOLUME = 11,520 CF
CONCENTRATION (ppt)
TIME (min)


GERDTSSON 3/18/85 5:30PM
AIR EXCH LOWERED
INSIDE TEMP = 69°F
OUTSIDE TEMP = 40°F
RH = 20%
ACPH = .11
VOLUME = 11,520 CF
CONCENTRATION (ppt)
TIME (min)

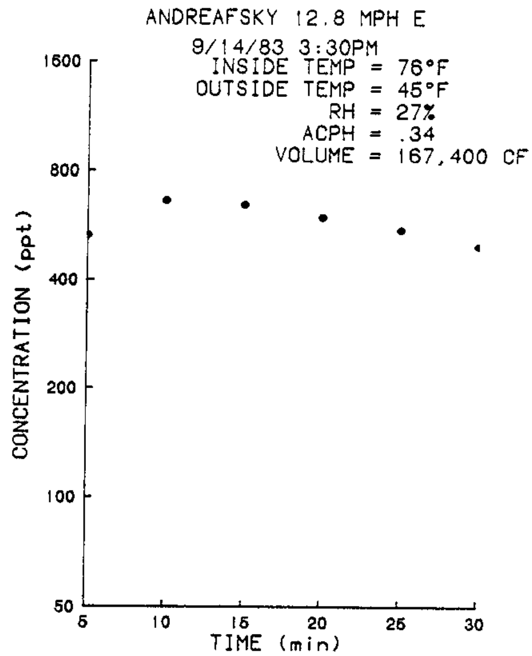

GERDTSSON 3/26/85 1:30PM
AIR EXCH LOWERED
INSIDE TEMP = 72°F
OUTSIDE TEMP = 30°F
RH = 15%
ACPH = .35
VOLUME = 11,520 CF
CONCENTRATION (ppt)
TIME (min)


GERDTSSON 4/18/85 1:30PM
AIR EXCH OFF
INSIDE TEMP = 74°F
OUTSIDE TEMP = 30°F
RH = 15%
ACPH = .31
VOLUME = 11,520 CF
CONCENTRATION (ppt)
1600
800
400
200
100
50
10
20
30
40
50
60
TIME (min)

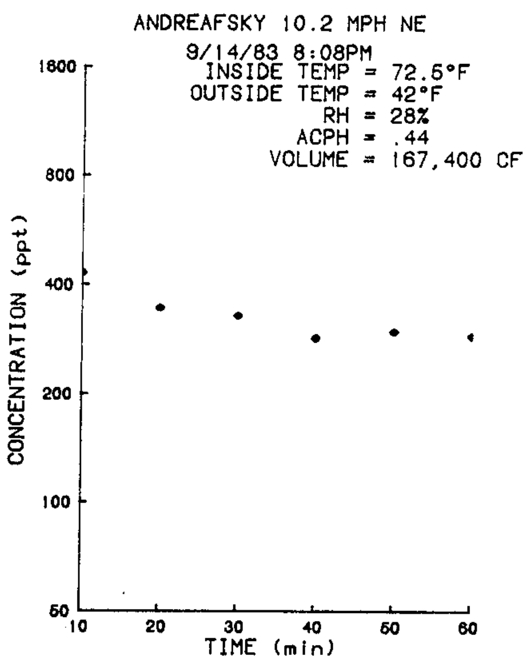

GERDTSSON 4/22/85 2:00PM
AIR EXCH OFF
INSIDE TEMP = 74°F
OUTSIDE TEMP = 32°F
RH = 17%
ACPH = .36
VOLUME = 11,520 CF
CONCENTRATION (ppt)
1600
800
400
200
100
50
10
20
30
40
50
60
TIME (min)



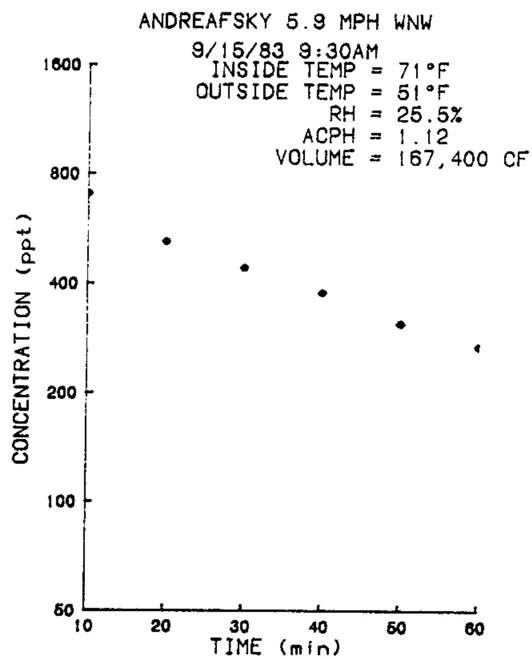
Run #1: Condition 1 - Normal Operation



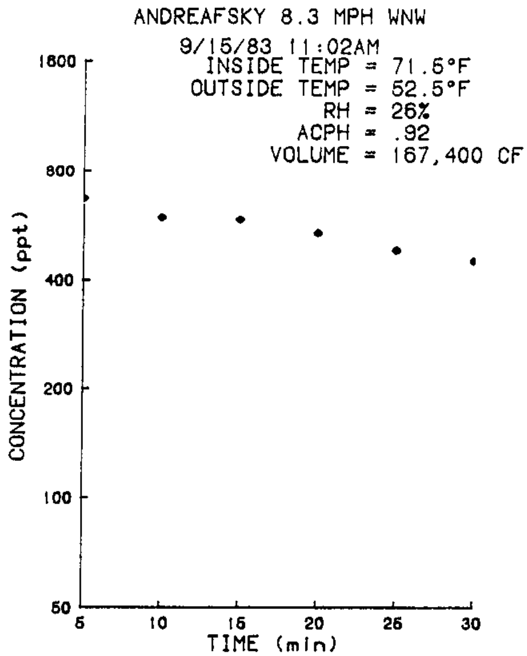
Run #1A: Condition 1 - Normal Operation



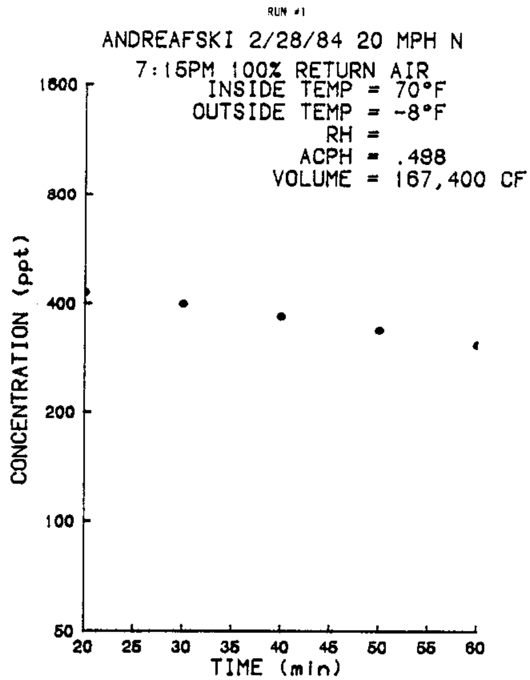
Run #2: Condition 2 - Systems Off

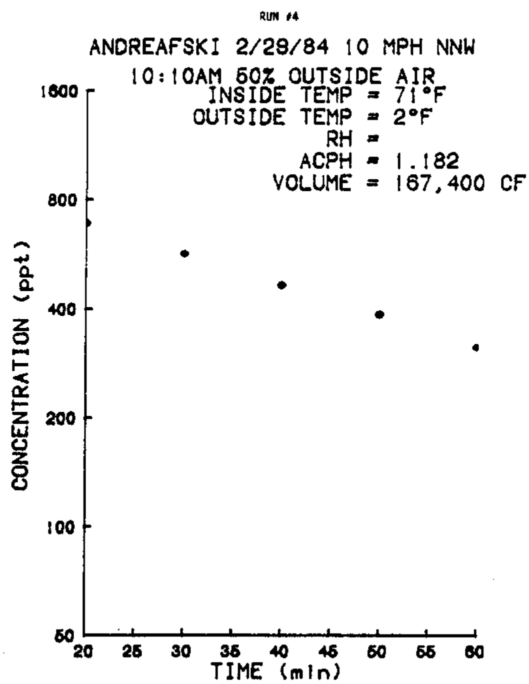


Run #3: Condition 3 - 100% Recycle



Run #3A: Condition 3 - 100% Recycle





APPENDIX B

FINAL REPORT

to the

Research Section

of the

Department of Transportation and Public Facilities

from the

Geophysical Institute

Analytical System
For the Perfluoro Tracer Technique
Used in Air Infiltration Measurements

T. A. Gosink

August, 1984

(Proposal G184-58)

General Comments

Air infiltration data permit engineers to calculate actual air exchange rates, heat loss and the potential for indoor air pollution. Dietz and Cote (1982) demonstrated a miniaturized perfluorocarbon tracer (PFT) technique for this purpose. The specifications of Dietze and Cote (1982) were generally followed in setting up a system in one of the Geophysical Institute Laboratories for the purpose of analyzing perfluorocarbons. Modifications were necessary because of the discontinued manufacture of several of the components.

The figure at the end of the report shows how a Valco 10-port valve has been plumbed to perform the same operation as the two six-port values used by the Brookhaven group.

Poracil is no longer available on the market. We substituted pherosil XOB-015 (80-100 mesh) for the "heavy" trap and analytical column shown in the diagram.

"Viton" types and availability have also changed over the years. Our only current source of viton for the source devices turns out to be nearly impermeable to perfluorocarbons. A different viton in our laboratory from a project of about 2 years ago is only slightly better. Yet another type of viton from a project of 4 years ago is equal to or of greater permeability than that in the source devices already in existence in the Alaska State Department of Transportation and Public Facilities.

Your original sources are basically still good (a few apparently depleted in perfluorocarbon) with concentrations ranging from 15 to 45 ppb (parts per billion 10^{-9}) in a 50 ml/min gas stream (1.3-4.0 x 10^{-8} g/min) (based on molecular weight of 400 for PDCH-perfluorodimethylcyclohexane C_8F_{16}. We can supply two (2) very large sources made from the 4 year old viton described above. The source strength currently is about 1000 times larger than the standard sources. (All sources should be calibrated seasonally before use. This requires about 5-7 minutes per source after the system is set up).

The response of the gas chromatographic detector as set up according to the operation instructions (this report) with the standing current (SC) set at 1.0 is better for stability, linearity and accuracy than for a SC of 2.0 which appears to be more sensitive, but lacking in the above characteristics.

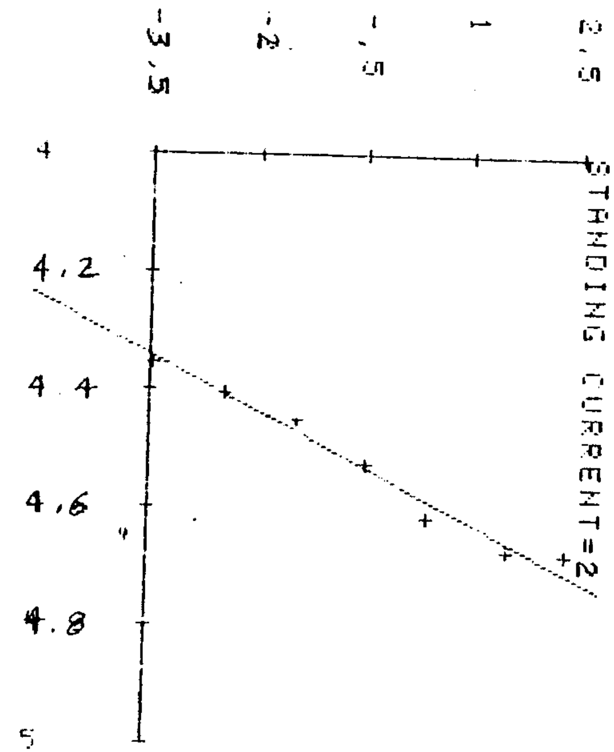
I	X(I)	Y(I)
1	4.6767	2.3367
2	4.6716	1.5366
3	4.6142	0.4362
4	4.5235	-0.4634
5	4.4495	-1.4634
6	4.4052	-2.4634
7	4.3568	-3.4634

AOV: LINEAR REG CODE 1

SOURCE	DF	SS	MS	F
TOTAL	6	26.6		
REG	1	26.0	26.0	207.7
RESID	5	0.6	0.1	

R SQUARE = 0.976

YHAT = -73.312 + 16.078 X



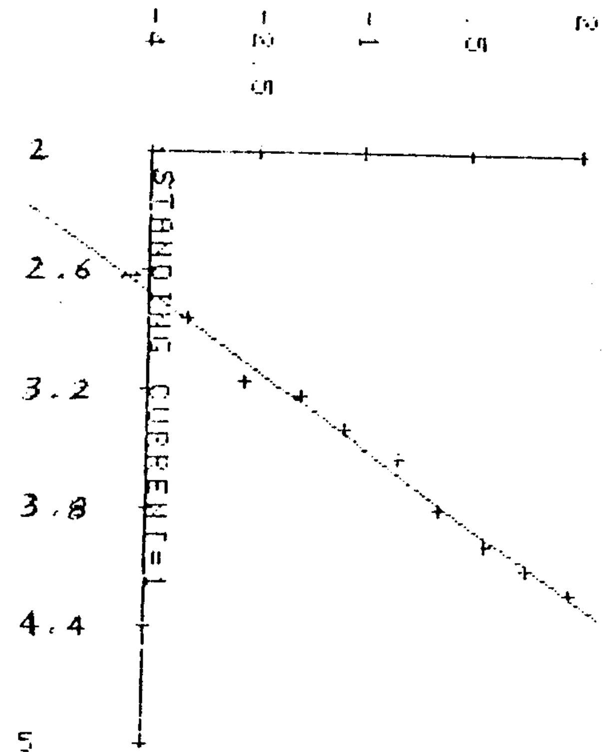
I	X(I)	Y(I)
1	4.3272	1.9365
2	4.0984	1.3765
3	3.9727	0.7372
4	3.8037	0.1367
5	3.5411	-0.4634
6	3.3985	-1.2628
7	3.2257	-1.8633
8	3.1477	-2.6633
9	2.8414	-3.4634

AOV: LINEAR REG CODE 1

SOURCE	DF	SS	MS	F
TOTAL	8	27.0		
REG	1	26.7	26.7	637.2
RESID	7	0.3	0.0	

R SQUARE = 0.989

YHAT = -14.490 + 3.870 X



The detection limit (SC = 1.0) is on the order of 20 parts per trillion (20×10^{-12}).

A six decade exponential dilution calibration for the system is shown in the figure on the next page.

for SC = 1.0:

$$\log PPM = -14.49 + 3.87 \log Pk.Ht.$$

where PPM is the parts per million concentration (in an arbitrary 2.0 ul sample) of the perfluorocarbon in air, and Pk.Ht. is the peak height as measured by the Nelson/HP readout system. (1 ppm = 1.79×10^{-8} g/ml of PDCH).

Several passive samplers have been prepared. The passive sampler capillary length is 25 mm long by 1 mm diameter for use in calculations as specified in Dietz and Cote (1982).

There is about 5 ml of redistilled PDCH in the laboratory. The commercially available material roughly distilled into 3 fractions, which also show up in the chromatogram. These are probably a mixture of the 3 possible positional isomers and some cis-trans isomers as well.

Reference

Dietz, R. N. and E. A. Cote, 1982. Air infiltration measurements in a home using a convenient perfluorocarbon tracer technique. Environ. Intern., 8, 419-433.

Experiment Operation Instructions

Setup Conditions for Perkin-Elmer 3920 Gas Chromatograph

Detector - 200°C
Standing Current - 1.0 or 2.0 (recommend 1)
Column temp - 110°
Interface - 100°
Injector - 100°
Flow = 25 ml/min @ 50 psi

Orange Variac - Controls temperature of the palladium catalysts - normally 38 volts or 200°C on meter
Green Variac - Controls temperature of the external Porapak QS trapping column-normally 18-20 volts
Blue Variac - Controls voltage to the filament transformer during direct ohmic heating only - normally 50 volts
Temperature Controller - Direct ohmic heating only - temperature to 370° Attenuation 4.

Computer Conditions -
1) Full scale = 100 millivolts
2) Channel Ø
3) Method name - tracer
4) Blank disc in drive Ø
5) Nelson software in drive 1
6) Program Mass

Storage device = Disk 1

7) HP-1B Select code = 7
8) Disk/device address = 3
9) Data/methods mass storage device = DISK Ø

Normal Startup

1) Turn G.C. and column heater on. (2 red lights should come on)
2) Turn orange variac (Pd catalysts) on.
3) Set pressure regulator on carrier gas to 50 psi. If this is the 1st startup in a few weeks or longer, the G.C. will have to run approximately 1 day before continuing. (Overnight or over weekend, leave system on, just turn carrier flow down to about 10-15 psi).
4) Turn HP 85 on.
5) Turn disc drive on.
6) Turn Nelson interface on.
7) Type on HP 85: LOAD "Autost:D731" Press ENDLINE
After red light on drive 1 goes out press RUN
7a) Enter time of day (comma between hour and minutes)
8) "Program mass storage device" prompt type 1 ENDLINE
9) "HP-IB select code" prompt press ENDLINE
10) "Disk device address code" prompt press 3 ENDLINE

11) "Data/methods mass storage device" prompt press Ø ENDLINE
12) "HP-IB select code" prompt press ENDLINE
13) Enter # of minutes you want to monitor the baseline (suggest 2 ENDLINE)
14) "Full scale" enter 100 ENDLINE
15) "Channel" enter Ø ENDLINE
Monitor the baseline to make sure it is on scale. If not adjust with coarse and fine control knots on amplifier.
Menu reappears.
16) Enter appropriate # for Method Area % and ENDLINE
It takes approximately 1 minute for program to be loaded.
17) "Print catalog" prompt either ENDLINE if don't want a printout or type Y ENDLINE if you do want a printout of disc in drive Ø.
18) "File name" prompt enter TRACER ENDLINE. The method will be entered into the program and a series of prompts will be displayed. Type in the appropriate answers to the questions. After the last prompt, in the upper left hand corner of the screen, ready will appear and the lower half of the screen will have a dashed line going across the screen and ABORT/START in bottom left hand corner. The computer is now locked into the ready mode and sample analysis can be done.

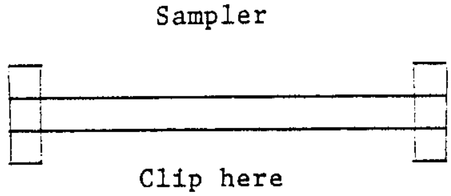
<u>If using syringe and septum for samples</u>

1) Make sure valve actuator is <u>ON</u> and in <u>LOAD</u> position.
2) Make sure green variac (Porapak QS column) is OFF and cool.
3) Toggle valve (carrier gas) is OFF.
4) Inject sample (2 ml)
   a) Push button computer - K1
   b) Start timer
   c) Open toggle valve (carrier gas)
5) Wait 45 seconds then quickly:
   a) Turn off toggle valve (carrier gas)
   b) Switch valve actuator into RUN position
   c) Turn on green variac
6) At the end of the run:
   a) Turn green variac OFF
   b) Switch valve actuator to LOAD
7) The next sample can be injected when the
   a) computer is reset to the READY mode
   b) Porapak column is cool to the touch

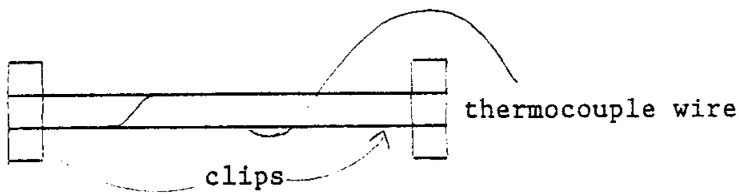
<u>If using direct ohmic heating</u>

1) Turn toggle valve OFF (carrier gas)
2) Set valve actuator to LOAD position
3) Make sure green variac is OFF and column cool
4) Make sure temperature controller is OFF
Note: The blue variac should be turned ON and left ON
5) Connect the passive sampling tube with the capillary end [numbered end] nearest to the G.C. The other end is connected to the tubing from the toggle valve. Make sure the fittings are tight.

6) Connect the clips from the filament transformer to tube between the connecting nuts. Make sure they are secure.



7) Wrap thermocouple wire (from the back of the temperature controller) around the middle of the sampling tube and cover with a piece of glass wool.



Make sure the thermocouple wire is securely attached. If the wire comes loose and falls off the tube, the tube, transformer, and temperature controller will be destroyed when heat is applied.

8) Set up computer to READY mode.

Sample run

9) Quickly:
   a) Turn toggle valve ON
   b) Turn temperature controller ON
   c) Turn timer ON
10) After 1 minute, push start (K-1) on computer
11) At 1 minute 30 seconds, quickly
   a) Turn temperature controller OFF
   b) Turn toggle valve OFF
   c) Switch valve actuator to RUN
   d) Turn green variac ON
12) After the run, return switches to load position (directions 1-4). The sampling tube can be disconnected and a new tube inserted.

APPENDIX C

ENERGY ANALYSIS

OF

ANDREAFSKI HIGH SCHOOL

AT

ST. MARY'S, ALASKA

INTERIM REPORT

by

Stephen H. Kailing
Senior Research Engineer

November 1983

STATE OF ALASKA
DEPARTMENT OF TRANSPORTATION AND PUBLIC FACILITIES
DIVISION OF PLANNING AND PROGRAMMING
RESEARCH SECTION
2301 Peger Road
Fairbanks, Alaska 99701-6394

BACKGROUND

In April 1983, the Research Section of the Alaska Department of Transportation and Public Facilities (DOTPF) was contacted by Walt Kallenberg of Fryer-Pressley Engineers about our ability to do the air exchange testing needed to properly evaluate energy loads at Andreafski High School in St. Mary's, Alaska. Fryer-Pressley has been retained by St. Mary's School District to determine why parts of this new (in 1982) school building are uncomfortably cold during extreme winter weather and to make recommendations for improving the situation.

In May 1983, we received a written request from Charley Chaney, Facilities Coordinator, St. Mary's School District, to assist with "analyzing the high school building in terms of insulation efficiency, building envelope performance during high wind conditions, performance efficiency of the heating-ventilating system in general and the solar heating system in particular." We replied that the DOTPF Research Section would be wiliing to assist with those parts of the investigation that we had a unique capability to perform. These include air exchange testing and use of the F-LOAD computer program for building energy loads.

DESCRIPTION OF HIGH SCHOOL

Andreafski High School is a 14,000 square foot, single story building supported by refrigerated piles. It is "state-of-the-art" wood frame construction with six inch insulated walls, aluminium siding, a ventilated metal roof, 12 inches of fiberglass insulation above the ceiling, and a two foot sub-floor space containing much of the ventilating air ductwork and insulated with six inches of fiberglass. Double pane windows are used throughout and they are primarily located on the south side of the building. The front and rear entrances have an airlock between duplicate sets of well fitting glass and metal doors.

The most distinctive feature of the high school is a large, south facing; solar chamber that is designed to warm the make-up air to the building's mechanical ventilation system. A rather unique and very aesthetic feature is the placement of a set of windows in an interior wall to provide daylighting patterns on a curved wall section above the library.

In general, the high school is an attractive, functional building. It appears to be well designed and constructed. There have been problems, however, with building energy use and maintenance of a comfortable environment within parts of the building during winter. Charley Chaney reported that approximately 18,000 gallons of No. 1 fuel oil had been used during the 1982-1983 school year and very little of this went for domestic water heating. (The school contains no kitchen facilities and the showers were not used during this period.) Mr. Chaney's understanding from the building architect was that the high school would use 10,000 gallons of fuel oil per year, or less.

Colin Baxter, District Superintendent, and other members of the administrative staff reported having to wear heavy sweaters or coats during much of January 1983 and whenever low temperatures and high winds occur simultaneously. Charley Chaney said that during last winter, the mechanical ventilating system had to be operated with 100% return air by blocking off all outside air louvers to maintain reasonably warm temperatures throughout the building. Mr. Chaney also reported that there have been problems with the two hot water boilers, requiring that the mechanical contractor be contacted about check valves, firing rates, combustion efficiencies, etc. These problems have not been completely resolved.

EXPERIMENTAL WORK

Due to difficulties in getting all three parties involved to St. Mary's at the same time, we were not able to visit the school until September 14, 1983. At that time Charley Chaney, Walt Kallenberg, Carol Pederson of the DOTPF Research Section and the writer were present. After familiarizing ourselves with the building design and general characteristics of the ventilation system, we ran air exchange tests by using sulfur hexafluoride tracer gas and collecting samples in 10 cc plastic syringes to be transported back to Fairbanks.

Three conditions were selected for air exchange testing:

1. Normal operation with about 50% outside air being drawn in by the mechanical system at the time of testing. (This system, which is located on a mezzanine floor adjacent to the multi-purpose room,

consists of three air heater/fan units and three exhausters.) All six fan units were operated during this test;

2. All mechanical systems off;

3. No outside air, i.e. 100% recycle, with all six fan units running.

Test data for these runs are given in Appendix C-I.

The 10cc air samples were transported back to Fairbanks by commercial aircraft and analyzed on the Research Section's S-cubed gas chromatograph. The resulting SF_6 concentrations were used to compute the following air exchange rates:

Condition	Air changes per Hour (ACPH)
1-Normal	1.5
2-Systems off	0.44
3-100% Recycle	1.1

The computer plots of log concentration versus time for all runs are included in Appendix C-II for reference.

Conditions 1 and 3 were run over both one hour and half hour test periods. In the one hour tests, duplicate air samples were taken every ten minutes. The results for the half hour tests (wherein samples were taken every five minutes) did not look realistic. Thirty minutes may be too short a time period to get a suitable decrease in concentration of SF_6. Another possibility is that gas concentration differences resulted from adding more SF_6 gas for the half hour run before the gas from the one hour run had dissipated (due to incomplete mixing). In any event, the results from the half hour runs were thrown out.

F-LOAD COMPUTER RUNS (WITHOUT SOLAR CHAMBER)

F-LOAD is an interactive computer program that is capable of calculating monthly heating loads of buildings and the lifecycle cost of heating. It is designed for residential and light commercial buildings. It incorporates passive heating features as well as conventional heating systems. The program can be purchased from Beckman, Duffie and Associates, Madison, Winsonsin 53562. It was bought by the Mechanical Engineering Department of the University of Alaska - Fairbanks and implemented onto the University of Alaska's Honeywell Computer in 1981 using DOT&PF support.

The program allows detailed specification of building shape, construction, orientation and location. Most of the input values were determined from inspection of a set of blueprints of the school. Others, such as annual electrical consumption, were obtained from information provided by Charley Chaney. It was necessary to use Bethel as the location, since this was the closest place for which F-LOAD programs contained weather and insolation data.

An initial estimate of the average air exchange rate was made by weighting the measured valves for condition 1 (normal operation) and condition 2 (systems off) over the time periods they are expected to exist. The mechanical systems are normally operated in the condition 1 mode eleven (11) hours of the day, five (5) days per week. An automatic timelock mechanism switches to condition 2 for thirteen (13) hours per day and all day on Saturday and Sunday. The weighted average is then obtained as shown:

1.5	ACPH	11 hr/day	5/7 of the time
0.44	ACPH	13 hr/day	5/7 of the time
0.44	ACPH	--	2/7 of the time

$$[(1.5)(11/24) + (0.44)(13/24)] \times 5/7 = 0.66$$

$$0.44 \times 2/7 = \underline{0.13}$$

$$0.79$$

used 0.8 ACPH

The results of an F-LOAD run using the 0.8 ACPH exchange rate are shown in Table 1. Appendix C-III includes copies of all the F-LOAD input and output info. The 0.8 ACPH run gives a total heating load of 1141×10^6 Btu/yr. The equivalent fuel oil consumption is computed as follows:

$$\frac{1141 \times 10^6 \text{ Btu}}{\text{year}} \quad \text{X} \quad \frac{1 \text{ gal \#1 fuel oil}}{132{,}000 \text{ Btu}} \quad \text{X} \quad \frac{1}{.60} \text{ eff.} = \begin{array}{c}14{,}000 \text{ gal \#1} \\ \text{fuel oil/year}\end{array}$$

We know that the school used about 18,000 gallons of fuel oil during the first year of operation. If we assume that the R-values, areas, the 60% overall furnace efficiency and other inputs are reasonably accurate, the air exchange rate can be varied to find the point where total computed heating load is equivalent to 18,000 gallons of fuel oil (1426×10^6 Btu/year heating load).

Another F-LOAD run was made at 1.5 ACPH to bracket the 18,000 gallon heating load (1663×10^6 Btu/year). It gave a heating load of 1952×10^6 Btu/year. Plotting these points on Figure 1, we can read off an average air exchange rate of 1.05 ACPH at 1426×10^6 Btu/year. Using the measured 0.44 to 1.5 relationship, we can estimate the Condition 1 and Condition 2 air exchange rates as follows:

$x/y = 1.5/0.44 = 3.41, \; x = 3.41y$

$(11x/24 + 13y/24)\; 5/7 + 2/7\; y = 1.05$

$y = 0.59$ ACPH (Condition 1)

$x = 2.0$ ACPH (Condition 2)

In retrospect, the measured value of 1.1 ACPH for 100% recycle should have somehow been averaged in with the value of 1.5 ACPH for the normal condition to reflect operation on 100% recycle in winter. This would result in a lower heat load for the building, but the difference would not be large.

TABLE 1

HEAT LOAD FOR ENTIRE YEAR

(Energy Quantities in million Btus)

Walls	102
Windows	133
Doors	6
Roof	138
Sub-floor space	234
Infiltration & Ventilation Air*	930
Interior Gains	(442)
Excess	42
TOTAL	1,143

* For 0.8 ACPH air exchange rate.

Note: Monthly breakdown of energy quantities included in Appendix C-III.

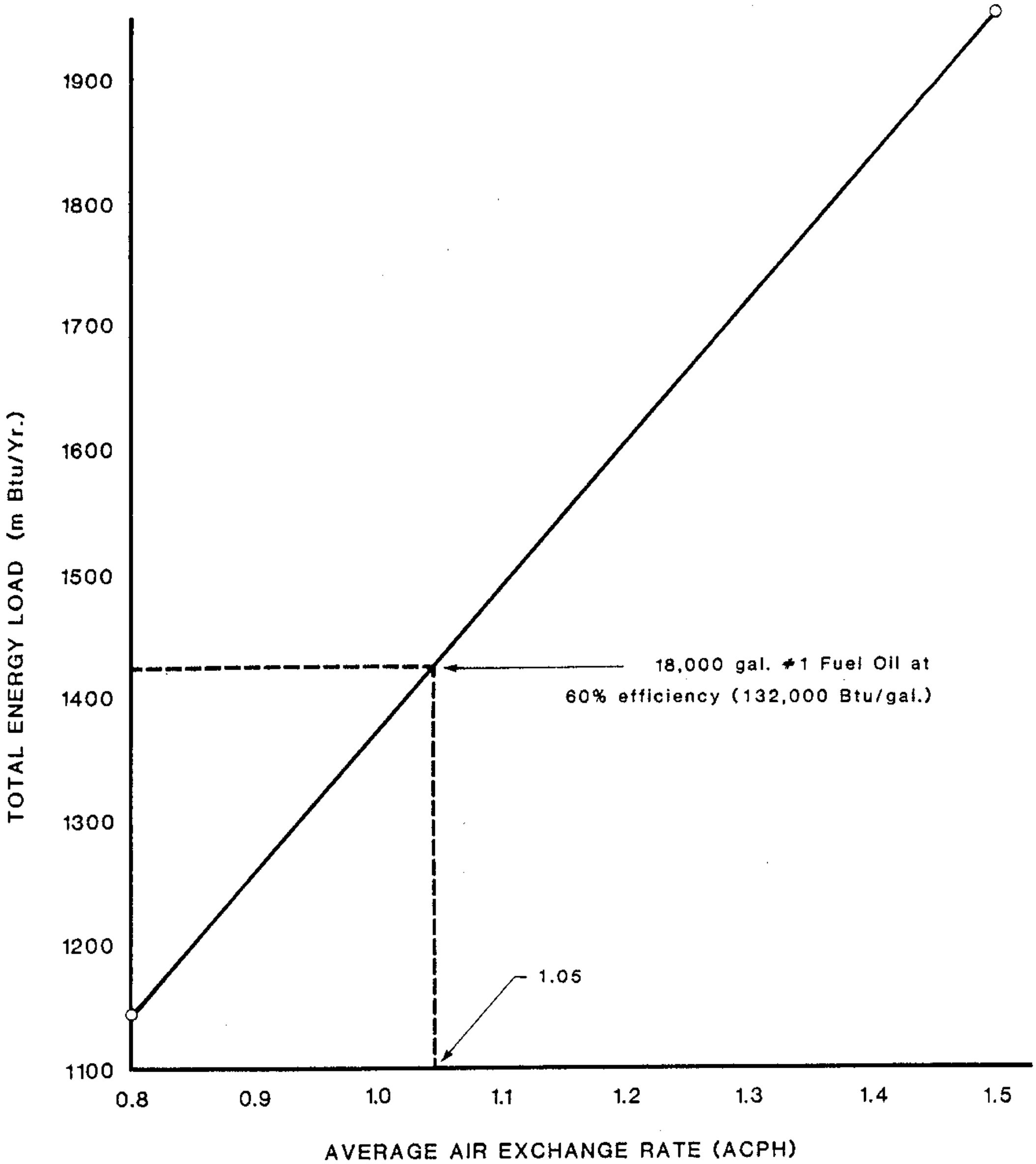


Figure 1 - Graphical method of estimating building air exchange rate (average for entire year)

DISCUSSION OF BUILDING PERFORMANCE RESULTS

The above values for conditions 1 and 2 are not too far from what was measured. The measured values were obtained with a 10 mile per hour (mph) wind speed. The outside temperatures during these runs were 45^{o} F (condition 1) and 42^{o} F (condition 2).

There have been several relationships proposed for air exchange rate versus inside-outside temperature difference (T) and wind velocity (V). Wang and Sepsy (1980) proposed the following equation:

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

Where A = intercept (at T and V = 0)
B = temperature coefficient
C = velocity coefficient
I = air exchanges per hour
ΔT = inside-outside temperature difference (degree F)
V = wind speed in miles per hour

The ASHRAE Handbook, 1981 Fundamentals, gives a more complicated expression for air exchange due to wind and temperature effects. Wind caused infiltration, Q_{wind}, is proportional to wind speed raised to a power that varies from 1 to 2 (usually near 1.30 for leakage openings). Temperature or stack effect driven infiltration, Q_{stack}, is proportional to $[(T_i - T_o)/T_o]^n$ where the exponent n ranges from 0.5 to 1.0 and is usually near 0.65 for leakage openings. T_o is outside temperature and T_i is temperature within the building.

ASHRAE also points out that the effective wind speed is not the value measured at airports or other wind gauging stations. Wind speed at a given building site is usually considerably less due to shielding from vegetation, terrain features and other buildings. The airport value must be reduced according to ASHRAE guidelines in order to be used in the Q_{wind} equation.

Other researchers (Sherman, Grimsrud, Condon and Smith, 1980) give somewhat different relationships for stack driven and wind driven effects:

$$Q_{stack} = f_s^* A_o \quad \Delta T$$

$$Q_{wind} = f_w^* A_o$$

Where Q_{stack} is stack driven infiltration

Q_{wind} is wind driven infiltration

f_s^* is the reduced stack parameter (a constant for the building involved)

f_w^* is the reduced wind parameter

A_o is the total leakage area

ΔT is the inside-outside temperature difference

is the measured wind speed

Here, Q_{wind} is proportioned to velocity to the first power and 0_{stack} is proportional to the square root (or 0.5 power) of the inside-outside temperature difference.

These researchers do agree with ASHRAE in their expression for total weather driven infiltration:

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

When three groups of expert researchers in the field come up with such different relationships for the effects of wind and temperature on air infiltration rates, one has to assume that these rates are nearly impossible to predict with reasonable accuracy. Continued measurements on the Andreafski High School are the only way to be certain that most of the disparity in F-LOAD run results is due to underestimating the effective air exchange rate.

Weather information for St. Mary's, particularly wind data, would be useful in analyzing the energy loads on the building. Some unreduced data does exist for the St. Mary's airport. It consists of six temperature and wind speed observations per day. The records are stored at the Arctic Environmental Information and Data Center at 707 A Street in Anchorage.

Information on furnace efficiency is another missing link in the analysis. According to the name plate data, the two Weil-McLain boilers are each rated at 5.55 gallons per hour or 732,600 Btu/hr for No. 1 fuel oil (input). Their outputs are rated at 542,600 Btu/hr. Output divided by input gives the following steady state efficiency rating:

$$(542{,}600 - 732{,}600) \times 100\% = 74\%$$

The boilers have reportedly been derated to 3 gal/hr and 3.5 gal/hr, respectively, which might make them more efficient. There have been problems with these units, however, and we do not know how well they are functioning at this point. A seasonal efficiency of 60% was assumed for computing fuel oil requirements, but this figure could be as much as 15% high or 10% low. A seasonal efficiency of 48% would result in 18,000 gallons of fuel oil being consumed at the 0.8 ACPH rate. Thus the seeming disparity in actual versus calculated fuel oil use would no longer exist.

The measured value of 0.44 ACPH due to natural infiltration is well within the range predicted by researchers who have examined performance of small rural schools. Zarling and Strandberg (1983) give a ventilation schedule of 0.75 ACPH due to natural wind/stack effects for Climate Region 5 (Western Alaska). Strandberg (1983) gives the following ventilation guidelines:

$\Delta T_{measured} = 35^{o}$ F

Natural ventilation rate:

Tight construction - 0.23 ACPH

Medium construction - 0.60 ACPH

According to our measurements, the incremental air exchange rates due to operation of the mechanical ventilation system ranged from 0.66 at 100% recycle (condition 3 - condition 2) to 1.1 at normal operation (condition 1 - condition 2). These additional volumes are considerably larger than needed as indicated by the following analysis.

Using the estimated building volume of 167,400 cubic feet, the air exchange rates listed above translate to the following air flows and occupancy rates at 5 CFM/person*:

Condition	Air Exchange Rate	Air Flow (cfm)	Number of People
2-systems off	0.44	1230	246
3 (increment)	0.66	1840	368
1 (increment)	1.1	3070	614
3-100% recycle	1.1	3070	614
1-normal	1.5	4190	838

We can compare the increments in air exchange rate caused by the mechanical system with the rated capacity of the three exhausters as follows:

Exhaust Fan		Capacity (SCFM)
EF-1		1100
EF-2		1325
EF-3		180
	TOTAL	2605

As shown, the total capacity of these three exhaust systems at standard temperature and pressure is between the incremental air exchange rates measured for conditions 3 and 1. If there was no restriction to air flow into the building during condition 3, we would expect the incremental air

*5 cfm/person is the minimum fresh air ventilation rate specified by ASHRAE 62-1981, Ventilation for Acceptable Indoor Air Quality.

flow for that condition to equal the rated capacity of the three exhaust fans.

The greater portion of the air exchange apparently results from operation of the mechanical system, even at the 100% recycle condition. We question the need for so much exhaust air. Apparently, the exhausters remove air from the multipurpose room and the four bathrooms in the building. ASHRAE 62-1981 calls for 200 cfm per person on playing floors (gymnasiums, ice arenas, etc.). It specifies 50 cfm per stall or urinal in public restrooms where smoking is permitted, but does not give a lesser figure where smoking is prohibited. If we choose a maximum capacity of 50 people for the multipurpose room and consider the seven toilet stalls and two urinals in the four bathrooms, the following exhaust air should be ample:

50 people x 20 cfm/person	=	1000 cfm
9 stalls & urinals x 50 cfm/each	=	450 cfm
Total	=	1450 cfm

Because smoking is not allowed in the school, the toilet exhaust requirement could be reduced to about 35 cfm per stall or urinal, giving a flow of 315 cfm.

There appears to be a requirement for only about 50% of the installed fan capacity, and the bulk of it (1000 cfm) is only needed while the multipurpose room is being heavily used. If natural air exchange is considered and there is ample recirculated air, the only function of the exhausters would be to remove odors from these areas. There appears to be no reason why the exhauster flow rates could not be reduced considerably. This can be easily accomplished by changing sheave sizes on the exhauster belt drives.

SOLAR CHAMBER ANALYSIS

The solar chamber is located at the confluence of the upper and lower roofs of the building such that it connects these roof sections. These roofs are both well ventilated, and wind pressure on one side of the building drives air up into the roof vents on that side, through the open space between the ceiling insulation and roof boards, then through the solar chamber and out the other roof. Whenever there is any wind at all, this roof ventilating air sweeps the heat from the solar chamber almost as fast as it is collected there. The design was intended to capture any heat coming through the ceiling and recycle it back into the building with outside air to the mechanical system. It might have worked in a wind-free area like Fairbanks, but it does not have a chance in St. Mary's.

In order to see how much heat could be gained by redesign of the solar chamber (isolating it from the roof sections), F-LOAD was run with a simulated fifth wall that was entered as a passive solar well. This wall had the area, "R" values and glass sizing of the solar chamber. The results are given in Table 2. As shown, a total of 52.5×10^6 Btu/yr is the maximum potential solar heat available. During November, December, and January a total of only 6.9×10^6 Btu is available. Obviously, the available insolation could not all be captured with the best system, and there is not a great deal to begin with. Fifty-two and a half (52.5) million Btus is only about 3.7% of the total heating load encountered during the first year of operation.

For the readers' general information, Table 2 also shows the heat loss associated with the wall if it were actually a fifth wall of the building. Due to the fact that the solar windows are single glazed, the total heat loss would be more than twice the gain. This is only an academic exercise because the solar chamber is not an exterior wall, but it shows the danger in trying to use a poorly insulated wall for solar gain.

CONCLUSIONS AND RECOMMENDATIONS

It would be premature to draw final conclusions without additional information on the following:

1. Air exchange rates during periods of high wind and low temperature.

2. Wind speed and prevailing wind directions, i.e. monthly wind rose data.

3. Furnace and baseboard heating system efficiency.

4. Integrity of wall, floor, ceiling insulation.

We can conclude, however, that air exchange by natural ventilation measured at about 10 mph wind speed and 35° F inside-outside temperature difference is reasonable for a new building in this climate region. The increment of air exchange resulting from operation of the mechanical system, even at 100% recycle (no outside air) is much larger than needed and may be one of the main reasons why there are heating problems with the school.

TABLE 2

RESULTS OF F-LOAD RUN ON SOLAR CHAMBER

Energy Quantities in Million Btu's

	Solar Insolation (Heat Gain)	Heat Loss*
Entire Year	52.5	112.4
January	2.6	15.0
February	4.4	12.7
March	6.7	10.0
April	6.3	10.0
May	5.7	7.2
June	5.1	4.3
July	4.8	3.7
August	4.0	4.5
September	4.4	5.8
October	4.2	9.3
November	2.9	11.8
December	1.4	15.1

* Assumes that the solar chamber forms part of a building exterior wall. This is not the case for the solar chamber at Andreafski High School; it is located outside an insulated building wall.

While the solar chamber is not performing according to expectations, this analysis shows that its potential is very limited in any case. Therefore, to spend a good deal of time and money trying to improve its performance is probably not warranted. Because it essentially forms part of the ventilated roof space, the degree of over-ventilation of this roof type in a windy area is readily apparent.

Our interim recommendations for improving the situation are as follows:

1. Caulk the underside of the sub-floor to reduce heat loss in this area. Inspection of this area showed that caulking has never been done and convection through this space can readily remove heat from the ductwork contained therein. Openings in the bottom skin of the building also form an exit for air entering at the roof and finding its way through interior walls to the sub-floor space. This could be a source of heat loss, but it is not expected to be large compared with infiltration.

2. Investigate the feasibility of reducing the high roof ventilation rate. Vents that are automatically closed by wind pressure would minimize heat loss through the roof during windy weather and allow the solar chamber to function as designed without making any modifications to it. It would also help to cut down on the air infiltration rate since there is some communication between interior walls and the roof space.

3. Reduce the speed of the exhaust fans and run the multipurpose room exhauster only as needed. A more detailed investigation of the areas served by each fan needs to be made before deciding how much to slow the fans.

None of the above changes are major ones, and they would undoubtedly alleviate the situation. Our recommendations for further study include the following:

a. Conduct an investigation of furnace efficiency to determine steady state combustion conditions and percent on-time for each furnace.

Investigate the capacity and functioning of the baseboard heating system. These two areas may be the key to high fuel consumption and cold spots in the building.

b. Reduce the available wind data and try to extrapolate existing air exchange rates to the average and maximum conditions. Using this information, it may be possible to make more than just a rough guess as to how much additional baseboard needs to be added to areas that cannot be adequately heated now.

c. Obtain additional air exchange rates under more severe weather conditions. Concurrently, PFT air exchange measurements devices from Brookhaven National Laboratories should be installed to get a 30 day average air exchange value during the windiest month. Correlate this value with wind and temperature data. Use the furnace efficiency and air testing results to adjust the F-LOAD program output. In this manner, we could be certain whether air exchange is the major problem with the building.

Of the above recommendations, DOTPF Research will be able to do item c only. The remainder will have to be accomplished by St. Mary's School District and its consultants.

REFERENCES

ASHRAE 62-1981, Ventilation for Acceptable Indoor Air Quality, by the American Society of Heating, Refrigerating and Air Conditioning Engineers, Inc., 1981.

Bryant, P., B. Lamb and H. Westberg, Air infiltration rates and air quality in residential homes., Air Pollution Research Section, Washington State University, 1981.

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APPENDIX C - I

AIR EXCHANGE TEST DATA

APPENDIX I - AIR EXCHANGE TEST DATA

Run #1 - Normal operation (outside air, louvers about 50% open)

Date: September 14, 1983

Time	Wind	T_o	T_i	Relative Humidity
2:00 pm	10.2 mph E	45^oF	75.5^oF	26.5%

SF_6 released: main school - 3.7 cc
activity room - 0.8 cc
admin area - 0.4 cc

Released SF_6 in suction side of the three heater/fan units and took 6 duplicate 10cc samples at 10 minute intervals from the suction side of the main school (largest) unit.

Run #1A - Normal operation

Date: September 14, 1983

Time	Wind	T_o	T_i	Relative Humidity
3:30 pm	12.8 mph E	45^oF	76^oF	27%

Release same quantities SF_6 as in Run #1 in same manner. Took 6 duplicate samples at 5 minute intervals.

Run #2 - Systems off (tested in the evening with all heater/fan and exhaust fan systems shut down)

Date: September 14, 1983

Time	Wind	TF_o	T_i	Relative Humidity
8:08 pm	10.2 mph NNE	42^oF	72.5^oF	28%

Released the following quantities of SF_6:

main school	-	2.5 cc
activity room	-	0.9 cc
admin area	-	0.3 cc

Let gas mix for 10 minutes with all heater fans (3) and exhausters (2) running, then shut down all at once. Took 6 duplicate samples from hallway intersection next to boys bathroom at 10 minute intervals.

Run #3 - 100% Recycle (outside louvers closed, return air louvers wide open)

Date: September 15, 1983

Time	Wind	T_o	T_i	Relative Humidity
9:30 am	5.9 mph WHW	51°F	71°F	25.5%

Dosed and sampled as per Run #1.

Run #3A - 100% Recycle

Date: September 15, 1983

Time	Wind	TF_o	T_i	Relative Humidity
11:02 am	8.3 mph WNW	52.5°F	71.5°F	26%

Dosed and sampled as per Run #1A

APPENDIX C - II

AIR EXCHANGE RATES/COMPUTER PLOTS

APPENDIX C - III

F - LOAD PRINTOUTS

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***** BASIC BUILDING *****

1.	CITY LOCATION......................................	3.	
2.	REFERENCE ANGLE WRT SOUTH..........................	0.	
3.	HEATED AIR VOLUME..................................	167400.0	FT3
4.	CONSTRUCTION QUALITY (1=VERY TIGHT,5=VERY LOOSE)..	-0.8	
5.	NUMBER OF EXTERIOR WALLS...........................	4.	
6.	EXTERIOR WALL R-VALUE..............................	20.3	FT2-HR-F/BTU
7.	WINDOW R-VALUE - DAYTIME...........................	1.70	FT2-HR-F/BTU
8.	WINDOW R-VALUE - NIGHTTIME.........................	1.70	FT2-HR-F/BTU
9.	INTERNAL STORAGE CAPACITY(1=LIGHT,2=MEDIUM,3=HEAVY)	2.	
10.	OUTPUT PRINT DETAIL (1 TO 4) 1=SUMMARY, 4=DETAILED.	3.	
11.	GRAPHIC OUTPUT? 1=YES, 2=NO........................	2.	

***** WALLS *****			1	2	3	4
1.	ORIENTATION WRT REFERENCE.		0.	90.00	180.00	270.00
2.	GROSS WALL AREA...........	FT2	1946.00	1248.00	1750.00	1104.00
3.	EXTERIOR WALL - R-VALUE...	FT2-HR-F/BTU	20.30	20.30	20.30	20.30
4.	WINDOW - AREA.............	FT2	450.00	40.00	54.00	82.00
5.	WINDOW - DAYTIME R-VALUE..	FT2-HR-F/BTU	1.70	3.40	1.70	2.30
6.	WINDOW - NIGHTTIME R-VALUE	FT2-HR-F/BTU	1.70	3.40	1.70	2.30
7.	WINDOW - % OF TIME SHADED.		0.	0.	0.	0.
8.	DOOR - AREA...............	FT2	0.	11.00	56.00	11.00
9.	DOOR - R-VALUE............	FT2-HR-F/BTU	0.	4.40	6.00	4.40
10.	WINDOW - TILT FROM HORIZ..	DEG	90.00	90.00	90.00	90.00

***** ROOF-FLOOR-BASEMENT-GARAGE *****

1.	TOTAL CEILING AREA.....................................	13916.0	FT2
2.	CEILING R-VALUE..	39.00	FT2-HR-F/BTU
3.	BASEMENT TYPE (1=SLAB,2=CRAWLSPACE,3=FULL,4=COMB.).	2.	
4.	(TYPE 1) HEATING DUCTS IN SLAB? (1=YES,2=NO).......	0.	
5.	(TYPE 1) PERIMETER OF SLAB.........................	0.	FT
6.	(TYPE 1:TYPE2 IF #13<3) R-VALUE EDGE INSULATION 0-5	0.	FT2-HR-F/BTU
7.	(TYPE 2) GROUND FLOOR AREA OVER CRAWLSPACE.........	13916.00	FT2
8.	(TYPE 2) FLOOR R-VALUE.............................	23.00	FT2-HR-F/BTU
9.	(TYPE 2) CRAWLSPACE HEATED? (1=YES,2=NO)...........	2.	
10.	(TYPE 3) BASEMENT HEATED? (1=YES,2=NO).............	0.	
11.	(TYPE 3) GROUND FLOOR AREA OVER BASEMENT...........	0.	FT2
12.	(TYPE 3) FLOOR R-VALUE.............................	0.	FT2-HR-F/BTU
13.	(TYPE2-3) BASEMENT/CRWLSP. DEPTH BELOW GRADE(0-8FT).	0.	FT
14.	(TYPE2-3) BASEMENT/CRWLSP. WIDTH...................	0.	FT
15.	(TYPE2-3) AREA BASEMENT/CRWLSP. WALL ABOVE GRADE....	0.	FT2
16.	(TYPE2-3) BASEMENT/CRWLSP. WALL R-VALUE ABOVE GRADE.	0.	FT2-HR-F/BTU
17.	(TYPE 2-3) BASEMENT/CRWLSP. WALL AREA BELOW GRADE..	0.	FT2
18.	(TYPE 2-3) BASEMENT/CRWLSP WALL R-VALUE BELOW GRADE	0.	FT2-HR-F/BTU
19.	ATTACHED GARAGE (0=NONE,1=1 CAR,2=2 CAR,3=3 CAR)...	0.	
20.	HOUSE WALL AREA COMMON TO GARAGE...................	0.	FT2
21.	R-VALUE OF WALLS COMMON TO GARAGE..................	0.	FT2-HR-F/BTU
22.	HOUSE FLOOR AREA COMMON TO GARAGE..................	0.	FT2
23.	R-VALUE OF FLOOR AREA COMMON TO GARAGE.............	0.	FT2-HR-F/BTU
24.	R-VALUE OF GARAGE EXTERIOR WALLS...................	0.	FT2-HR-F/BTU
25.	HEATING DUCTS IN UNHEATED SPACE (1=YES,2=NO).......	2.	

***** BASIC BUILDING *****

5. NUMBER OF EXTERIOR WALLS............................ 5.

***** WALL 5 (DIRECT GAIN - PASSIVE) *****

1. ORIENTATION WRT REFERENCE............................ 0.
2. DIRECT GAIN WINDOW AREA.............................. 233.00 FT2
3. NUMBER OF GLAZINGS (1 TO 5).......................... 1.
4. DAYTIME GLAZING SYSTEM R-VALUE....................... 0.80 FT2-HR-F/BTU
5. NIGHTTIME GLAZING SYSTEM R-VALUE..................... 0.80 FT2-HR-F/BTU
6. OVERHANG SHADING? (1=YES,2=NO)....................... 2.
7. WIDTH OF WINDOW.................................. 0. FT
8. PROJECTION OF OVERHANG........................... 0. FT
9. GAP BETWEEN OVERHANG AND WINDOW.................. 0. FT

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BETHEL AK
ENERGY QUANTITIES IN MMBTU

	YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
PASS. 5													
(SOLAR IN)	52.5	2.6	4.4	6.7	6.3	5.7	5.1	4.8	4.0	4.4	4.2	2.9	1.4
HEAT LOSS	112.4	15.0	12.7	13.1	10.0	7.2	4.3	3.7	4.5	5.8	9.3	11.8	15.1
WALLS	101.6	13.6	11.5	11.8	9.0	6.5	3.9	3.3	4.0	5.3	8.4	10.7	13.6
WINDOWS	132.7	17.7	15.0	15.4	11.8	8.5	5.1	4.4	5.3	6.9	10.9	13.9	17.8
DOORS	5.5	0.7	0.6	0.6	0.5	0.4	0.2	0.2	0.2	0.3	0.5	0.6	0.7
ROOF	137.7	18.4	15.5	16.0	12.2	8.8	5.3	4.5	5.5	7.2	11.4	14.5	18.5
BASEMENT	233.5	31.2	26.3	27.2	20.7	14.9	9.0	7.7	9.3	12.1	19.3	24.5	31.3
INFIL.	1744.1	233.0	196.8	203.0	154.6	111.1	67.0	57.4	69.5	90.7	143.9	183.2	234.0
GARAGE	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
(INT GAINS)	442.4	33.2	34.0	41.6	40.6	40.9	39.0	38.9	37.1	36.6	36.7	32.8	31.0
EXCESS	41.2	1.7	1.6	1.9	2.4	3.7	5.1	7.2	6.4	4.5	2.8	2.1	1.7
TOTAL	2013.7	295.5	241.7	240.8	174.2	114.3	55.8	44.7	63.5	91.9	165.5	225.5	300.3

DESIGN HEATING LOAD = 684711. BTU/HR

***** INTERNAL SPACE *****

1.	THERMOSTAT SETTING - DAYTIME......................	75.0	F
2.	THERMOSTAT SETTING - NIGHT TIME....................	70.0	F
3.	HOURS FOR NIGHT SETBACK............................	13.0	HR
4.	ALLOWABLE TEMPERATURE SWING (PASSIVE SYSTEMS)......	0.	F
5.	ANNUAL ELECTRICAL CONSUMPTION......................	91000.0	KWH
6.	AVERAGE NUMBER OF OCCUPANTS........................	12.	
7.	CONVENTIONAL FUEL TYPE (1=ELEC,2=NG,3=OIL,4=LPG)...	3.	
8.	SEASONAL EFFICIENCY OF CONVENTIONAL FURNACE........	60.0	%
9.	HOT WATER FUEL (1=ELEC,2=NG,3=OIL,4=LPG)...........	3.0	
10.	HOT WATER TANK SEASONAL EFFICIENCY.................	60.00	%
11.	AVERAGE DAILY HOT WATER USAGE......................	50.0	GAL
12.	HOT WATER SET TEMPERATURE..........................	135.0	F
13.	R-VALUE OF TANK INSULATION.........................	6.00	FT2-HR-F/BTU
14.	HOT WATER TANK VOLUME..............................	500.0	GAL
15.	VENTILATION HX EFFECTIVENESS.......................	0.	
16.	HEAT EXCHANGER FLOWRATE FRACTION...................	0.	
17.	HOT WATER IN HEATED SPACE 1=YES,2=NO...............	2.	

***** ECONOMICS *****

1. ECONOMIC ANALYSIS DETAIL (0 TO 3)0=NONE,3=DETAILED.   0.

?
=K 13
*** BUILDING PARAMETERS HAVE BEEN WRITTEN ON TO FILE 13 ***
?
=C

ASHRAE HOUSE   SEE ASHRAE GRP 158   PAGE 7.8
BETHEL   AK
ENERGY QUANTITIES IN MMBTU

	YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
WALLS	101.6	13.6	11.5	11.8	9.0	6.5	3.9	3.3	4.0	5.3	8.4	10.7	13.6
WINDOWS	132.7	17.7	15.0	15.4	11.8	8.5	5.1	4.4	5.3	6.9	10.9	13.9	17.8
DOORS	5.5	0.7	0.6	0.6	0.5	0.4	0.2	0.2	0.2	0.3	0.5	0.6	0.7
ROOF	137.7	18.4	15.5	16.0	12.2	8.8	5.3	4.5	5.5	7.2	11.4	14.5	18.5
BASEMENT	233.5	31.2	26.3	27.2	20.7	14.9	9.0	7.7	9.3	12.1	19.3	24.5	31.3
INFIL.	930.2	124.3	105.0	108.2	82.5	59.3	35.7	30.6	37.0	48.4	76.7	97.7	124.8
GARAGE	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
(INT GAINS)	442.4	33.2	34.0	41.6	40.6	40.9	39.0	38.9	37.1	36.6	36.7	32.8	31.0
EXCESS	41.9	1.8	1.7	2.1	2.6	3.3	4.9	7.5	6.0	4.8	3.1	2.2	1.8
TOTAL	1140.6	174.5	141.6	139.8	98.6	60.6	25.1	19.3	30.2	48.5	93.6	131.2	177.5

DESIGN HEATING LOAD =   427666. BTU/HR

APPENDIX D

TECHNICAL NOTE #2

Background. On November 21, 1984, the Research Section received a letter from Jerald Stroebele, Field Supervisor of Northern Alaska Ecological Services, U. S. Department of the Interior, Fish and Wildlife Service. Mr. Stroebele reported unusually numerous cases of respiratory problems among employees in Room 222, the Northern Alaska Ecological Services office. Subsequent to his letter, one of the other employees in the Ecological Services office wrote a letter to the General Services Administration (GSA) threatening to sue one or more of the following about poor air quality: (1) the Federal Government, (2) the building maintenance manager, (3) a pipe smoking employee in an adjacent office.

In his November 21 letter, Mr. Stroebele requested that DOT&PF Research Section do whatever air testing we could to determine the validity and extent of the air quality problem in Room 222 of the Federal Building. We agreed to evaluate air circulation rates in the room and try to determine fresh air supply to the room by testing the air exchange rate of the entire building.

Testing Program and Results. Several times in December 1984, Room 222 was tested using the sulfur hexafluoride (SF_6) tracer dilution method[1]. Problems with adjustment of the carrier gas on the gas chromatograph ruined some of the initial test data points, but enough valid data were left to give reasonably good air exchange rates. Tests made after December 12 were not affected by this problem. Results of all tests are shown below:

Date	Time	Air Exchange Rate (ACPH)	Relative Humidity (%)	Room Temp. (°F)	Outside Temp. (°F)	Remarks
12/11/84	12:45 p	2.2	11	72.5	-25	Max variable air
12/12/84	11:00 a	3.0	10	69	-30	Stroebele's office only
12/12/84	11:00 a	1.4	10	71	-30	Min variable air
12/13/84	12:15 a	2.8	10	72.5	-26	Max variable air
12/19/84	10:30 a	1.2	16	74	6	Min variable air
02/11/85	1:30 p	1.1	17	73	-5	Min variable air
02/11/85	3:30 p	0.82	15	70	1	entire building

On 2/11/85 the entire building air exchange rate was determined along with that of Room 222. Air flow was also estimated in ceiling registers using the velocity-area technique.

Discussion of Ventilating System. There are two ventilating air systems serving Room 222. The perimeter air system, which was reported to contain a minimum of 30% outdoor air, supplies the room through six 3/4" by 48" ceiling air registers located next to the outside wall of the room. The interior air system recirculated building air that has been drawn through dust filters. It supplies the interior portion of the room through fifteen 1/4" by 23" ceiling supply air registers.

Air leaves the room through fifteen ceiling return air registers of similar size and design. All the supply and return air registers contain a baffle arrangement for air balancing and diffusing purposes.

During our initial test, we learned that temperature control is done by modulating the ventilating air flow rate into Room 222. If the room temperature is above the thermostat setpoint, a recycling air system damper is automatically opened to increase the flow of relatively cool supply air into the room. If the room temperature is at or below setpoint, the variable ventilating air automatically decreases to a minimum volume. Since the room occupants tend to increase the setpoint temperature for comfort whenever the room feels cool, they sometimes deprive themselves of some ventilating air and make air quality in Room 222 somewhat worse.

This situation is apparently compounded by efforts to reduce building energy use. The temperature of the building is lowered during weekends and at night when the building is not occupied. Because of the high building mass, there is significant radiant heat loss from occupants to the cool building surfaces, particularly during the first part of each week. Occupants of Room 222 report feeling cold during this time and attempt to warm the room by raising the temperature setpoint.

One factor which reduces the outdoor air to most occupants of Room 222 is that outdoor air is being supplied through the perimeter system. Since two of the four supply ducts are in Jerald Stroebele's office, some of this air finds its way back into the return systems before being circulated about the open portion of the room. When Mr. Stroebel's door is closed, this problem is more severe.

If we examine the SF_6 air exchange test results for Room 222, a range of values is apparent:

worst case: 1.1 ACPH

best case : 2.8 ACPH

Taking the worst case, which was measured when the thermostat setpoint temperature had been intentionally increased to give minimum ventilating air, we can estimate the fresh air supply to the room as follows:

Total volume of Room 222:

$$30 \text{ ft.} \times 50 \text{ ft.} \times 8.417 \text{ ft.} = 12{,}625 \text{ ft}^3$$

Flow at worse case:

$$1.1 \text{ AC/hr} \times 12{,}600 \text{ ft}^3\text{/AC} \times 1 \text{ hr/60 min} = 231 \text{ ft}^3\text{/min}$$

Air Flow Measurements. A series of air velocity and ceiling register area measurements were made on 12/13/84. The fifteen supply air registers in the recirculating system had an estimated total flow of 68 CFM. The six perimeter air system registers delivered about 138 CFM before adjustment by a maintenance man and 215 CFM afterward. For comparison purposes, these two conditions give the following air exchange rates:

Before adjustment:

$$\frac{(68 + 138)\text{ft}^3}{\text{min}} \times \frac{1 \text{ AC}}{12{,}600 \text{ ft}^3} \times \frac{60 \text{ min}}{\text{hr}} = 0.98 \text{ ACPH}$$

After adjustment: $(68 + 215) \times (60/12{,}600) = 1.35$ ACPH

These figures are within or close to the range measured for the throttled recirculating air condition using the SF_6 method.

Taking the lower perimeter air flow rate measured (prior to adjustment of one of the supply air registers) and assuming that the perimeter air system delivers a minimum of 30% outside air(2), the minimum outdoor air being supplied to Room 222 can be estimated as follows:

$$138 \text{ ft}^3\text{/min total air} \times .30 \text{ fresh air/total air} = 41 \text{ CFM fresh air}$$

Assuming that the total of this 41 CFM is available for all occupants of Room 222, there is enough air according to the Uniform Building Code, 1979 Edition, for the following number of people:

1 person/ 5 cfm outdoor air x 41 cfm = 8 persons

1 person/15 cfm total recirculated air x 231 cfm = 15 persons

In reality the recirculated air also contains outside air that has been only slightly contaminated because of the relatively low occupancy in the building. Looking at the total air exchange rate measured for the building (which is outdoor air flow only), we get:

$$543{,}000\ ft^3/AC \times 0.82\ AC/hr \times 1\ hr/60\ min = 7{,}420\ cfm$$

At 5 cfm per person, this is enough for 1484 people whereas the normal building occupancy is only about 170. This recirculated air cannot be used to satisfy the outdoor air provision of the Uniform Building Code, however.

A portion of this air is delivered directly to the furnace room for use as combustion air; but even so, the building as a whole appears to be getting an ample supply of outdoor air. Our measurements were made under the minimum outdoor air damper position. According to George Acosta, this setting is supposed to occur at $20^{o}F$ and outdoor air temperature was $-25^{o}F$ at the time of our tests.

To check on the air exchange rate measured by the SF_6 method, we measured air velocities in the two exhausters located on the third floor. The average velocity measured at 7 points on the 35.5 inch round intake opening to the large exhauster was 1613 feet per minute. The flow is then:

$$\frac{1613\ ft}{min} \times \frac{(35.5)^2 in^2}{(4)(144)\ in^2/ft^2} = 11{,}090\ cfm$$

A smaller exhaust system takes building air from the third floor fan room and uses it to give a venturi assist to stack gases from the furnace room in the basement. This air is then ejected from the building along with the stack gases, which contain a relatively small additional volume of outdoor air. The eductor air flow was measured at the rectangular intake with a velocity meter. Twelve velocity measurements over the 12' x 15± opening averaged 921 fpm. This gives a flow of:

$$\frac{921 \text{ ft}}{\text{min}} \times \frac{(12)(15) \text{ in}^2}{144 \text{ in}^2/\text{ft}^2} = 1{,}150 \text{ cfm}$$

The total flow measured by the velocity-area method is 11,090 = 1,150 = 12,240 cfm. This is much higher than the 7,420 cfm measured by the SF_6 tracer decay method.

The Federal Building has a complex mechanical system with a recirculating system on each major floor plus an outdoor air supply system serving all four floors. SF_6 was injected into the outdoor air system ahead of the fan, but we suspect that it did not get evenly mixed throughout the building. Therefore, the estimate made by measuring air velocities at the exhausters is probably the more accurate of the two.

If we use the higher outdoor air estimate of 12,240 cfm coming into the building and assume that 10% is used as combustion air, that leaves (0.9)(12,240) = 11,000 cfm for use by building occupants. We know from our previous analysis that Room 222 with a volume of 12,625 cu. ft. is getting as little as 41 cfm of fresh air. This is:

$$\frac{41 \text{ cfm}}{12{,}625 \text{ cu. ft.}} = \frac{.0032 \text{ cfm}}{\text{cu. ft.}}$$

Under the minimum outdoor air condition, the entire building averaged:

$$\frac{11{,}000 \text{ cfm}}{543{,}000 \text{ cu. ft.}} = \frac{.0200 \text{ cfm}}{\text{cu. ft.}}$$

The ventilation rate of the building as a whole is much better than that of Room 222. To provide a good working environment and conserve energy, areas of low occupancy within a building should be designed to received less outdoor air than office and other high occupancy areas. Not enough testing was done in the Federal Building to determine whether Room 222 is typical, but there is a good possibility that the air system is either not well designed or improperly balanced.

Problems Due to Smoking. The largest air quality problem indicated by employees in Room 222 was reportedly caused by frequent pipe smoking in an adjacent office. This smoking normally occurs with the door to this office open and the Room 222 door closed.

By measuring the direction and velocity of air flow in the 1/2 inch x 36 inch crack underneath the closed door to Room 222, we found that considerable inward air flow was occurring. Since the hallway outside Room 222 has a positive pressure with respect to the room, any contaminants in the hallway tend to enter the room.

The air flow underneath the door was measured at:

$$\frac{80\ \text{ft}}{\text{min}} \times \frac{(1/2 \times 36)\ \text{inch}^2}{144\ \text{in}^2/\text{ft}^2} = 10\ \text{cfm}$$

Because of the pressure difference, a momentary surge much greater than 10 cfm undoubtedly occurs whenever the door is opened.

Even though there is enough outdoor air and recycled air in Room 222 to conform with applicable provision of the Uniform Building Code (for the current number of employees), the smoking versus nonsmoking question raises some real difficulties. ASHRAE(3) recommends 20 cfm of outside air per person where smoking is allowed versus 5 cfm per person in nonsmoking areas. Repace and Lowrey(4) state that higher quantities of outdoor air may not make smoke contaminated air safe for building inhabitants. Close proximity to smokers can still result in very high concentrations of smoke being breathed by other persons in the vicinity. A study by Cain et al(5) showed that control of tobacco odor (as assessed by nonsmokers) was unachievable even at ventilation rates of nearly 70 cfm/person.

Obviously, the best course of action from air quality and energy conservation standpoints is to ban smoking in all buildings. If this cannot be done, the next best solution is to set aside separate smoking areas within a building and install exhaust systems for these areas so that the smoky air is not recycled throughout the building. Because this can be an expensive proposition in an existing building, what is usually done is to seek some compromise between smokers and nonsmokers with regard to designation of smoking and nonsmoking areas. This generally lessens problems caused by close proximity between smokers and nonsmokers and lessens both the objectionable odor problem and the health risk for the latter group.

The issue regarding "passive smoking" by nonsmokers can be a very sensitive one for both sides and it will become more highly charged as evidence continues to mount regarding the health risks of passive smoking. It is one thing to tolerate objectionable odors which affect individuals to greater or lesser degrees. It is a much greater sacrifice to tolerate this unpleasantness when you assume part of the smoker's increased health risk, but none of his pleasure.

Conclusions:

1. The quantity of outdoor air in Room 222 has been sufficient for eight occupants. After some adjustment of one register in Jerald Stroebele's office on 12/13/84, the outdoor air supply increased to a point where it is now adequate for twelve occupants.
2. The configuration of the perimeter air system does not make the best use of the outdoor air being supplied to Room 222. This is particularly true with respect to the office that encloses two of the perimeter air system registers.
3. The higher air pressure in the hallway outside Room 222 causes air pollutants in the hallway to flow directly into the room. This occurs continually through a large crack underneath the door and intermittently whenever the door is opened.
4. The Federal Building itself is well ventilated. Air exchange rates of 0.82 ACPH and 1.2 ACPH were measured by the SF_6 tracer gas decay method and velocity-area method, respectively. If outdoor air could be better distributed, there appears to be potential for cutting down on building ventilation rate and corresponding energy use.
5. The problem with air pollution caused by smoking cannot be resolved by improved ventilation. Smoking would have to be eliminated to completely eliminate the problem. Improvements are possible through designation of smoking areas (particularly if these areas are vented to the outside), installation of an exhauster to make the air pressure in the hallway outside Room 222 negative with respect to the room, and possibly by installation of air cleaning devices in Room 222. The

effectiveness of this last method depends on the capacity and efficiency of the equipment available for this purpose. It must be capable of removing a high percentage of respirable particulates at a flow rate that is at least as high as the air change rate in the room. It is doubtful that any air cleaner except one containing activated carbon or some other highly effective adsorbent could remove the aromatic compounds associated with tobacco smoke odor.

Recommendations. The air quality problem in Room 222 is not a simple problem and does not have any simple solutions. It is caused by a combination of factors, at least one of which is not technical. Our recommendations are given in the order that we feel will do the most good for the least expenditure of money.

1. Deal with the tobacco smoke problem as indicated in our conclusions. If this problem can be resolved, recommendations 3 and 4 may not have to be carried out.

2. Investigate ways of getting more air from the perimeter air system into Room 222 and distributing this air near the entrance end of Room 222. Portable fans may be an interim solution, but they will make the room feel colder.

3. Investigate ways of reducing air pressure in the hallway outside Room 222.

4. Evaluate the effectiveness of the two air cleaning devices recently installed in Room 222. This should include an engineering analysis of the equipment and a survey of the occupants regarding any improvements in air quality noticed.

References

(1) American Society of Testing and Materials, Designation E741-80, _Standard Practice for Measuring Air Leakage Rate by the Tracer Dilution Method (1980)_.

(2) Oral communication with George Acosta, Building Maintenance Chief.

(3) American Society of Heating, Refrigerating and Air-Conditioning Engineers, ASHRAE 62-1981, _Ventilation for Acceptable Indoor Air Quality_.

(4) Repace, J.L., and A.H. Lowrey, _Tobacco Smoke, Ventilation, and Indoor Air Quality_, ASHRAE Transactions 1982, V. 88, Pt. 1.

(5) Cain, W.S., et al, _Ventilation Requirements for Control of Occupancy Odor and Tobacco Smoke Odor_, Laboratory Studies LBL-12589, NTIS, Springfield, VA (1981).