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VENTILATION RESEARCH AND CHARACTERIZATION IN THREE TYPES OF RESIDENCES

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VENTILATION RESEARCH AND CHARACTERIZATION IN THREE TYPES OF RESIDENCES

SYNOPSIS

Pacific Power and Light Company and Battelle PNW Laboratories have completed a project which investigated residential ventilation rates. The results presented in the report discuss evaluation of methods used to measure ventilation rates, the behavior of ventilation rates in residences and the comparison of ventilation rates among home construction types.

The perfluorocarbon tracer gas decay technique for measuring ventilation rates was concluded to be the best method used during the testing. This technique was easy to perform and resulted in highly accurate data when compared to a recognized standard. It was also found that fan depressurization results overpredicted air exchange rates in all three homes. The ventilation rate results of the three homes indicated the energy-saver home had the lowest rate, followed by the unoccupied home with the next higher, and the pre-weatherized home with the highest rate.

1.0 INTRODUCTION

Air exchange between a home and the surroundings has come under increasing scrutiny. This is a direct result of the interest in reducing space heating consumption by weatherization and infiltration reduction efforts. Up until recently, little attention was given to quantifying the existing ventilation rate in the home or, what the resultant ventilation rate was after energy conservation measures were applied. There is a greater concern now about the ventilation rates of homes and the impact of conservation measures and efficient building design on those ventilation rates. However, the task of determining the ventilation rate of the home exists. And, even if a ventilation rate for the home was measureable given codes or standards are not in place which specify a target ventilation rate. Understanding ventilation rates remains a problem of measurement technique, evaluating what ventilation rate (minimum) is needed and, obtaining the correlation that relates the two variables.

This paper describes a research project undertaken in 1982 by the Pacific Power & Light Company and its Contractor, Battelle Northwest Laboratories to investigate residential ventilation rates. The primary objective of the study is to evaluate the impact upon ventilation rates resulting from:

(a) infiltration weatherization measures,

(b) operation of an air-to-air heat exchanger, and

(c) occupancy

A second objective of the study is to evaluate present techniques for determining or monitoring ventilation rates in homes.

2.0 PROJECT PLAN

The test plan developed for this project investigates ventilation rates of three different homes for a period of two years. Selected homes were chosen which would satisfy the primary study objective. One home is a standard construction home which would receive weatherization. A second home is an energy efficient home and would have an air-to-air heat exchanger installed. The third home is a vacant home which would be occupied in the second year of monitoring. The results available from the first year's data would provide an evaluation of methods used for determining ventilation rates, an analysis of the dynamic behavior of ventilation rates in residences and comparison of ventilation rates among residential construction types.

The first year of monitoring gathered data in the "before" condition, i.e., pre-weatherization, pre-air-to-air heat exchanger and, unoccupied. The second year of monitoring recorded data after the modifications to the homes had been made. The focus of the monitoring period falls during the time of year when residents are indoors the most often and when the house is sealed off from the outdoors.

Data collected at all three homes is identical in format and can be categorized into three areas: electrical end-use, meteorological and environmental and, ventilation data. The ventilation data consists of tracer gas monitoring using SF_6 and perfluorocarbon in parallel. Fan pressurization tests were run for comparison to the tracer data and to evaluate modifications made to the weatherized home. Hourly meteorological and environmental data consisting of outdoor temperature, windspeed, wind direction, horizontal radiation, indoor air temperature and indoor relative humidity were monitored in all homes. Electrical end-use data was recorded for various circuits and major appliances in the home as well as the total electrical.

3.0 DESCRIPTION OF TEST HOUSES

The test houses were chosen to represent the specific construction conditions affected by infiltration reducing weatherization measures, energy efficient construction techniques, and occupancy. The three homes in this project are an existing pre-weatherized home ("weatherized home"), an energy efficient new home ("energy saver home"), and an unoccupied home ("control home"). A description of each home and its characteristics is given in the following sections.

3.1. WEATHERIZED HOME

The weatherized home is a wood frame type residence built in 1974. The home is approximately 920 square feet (85.47 $meters^2$) of heated floor area constructed on a crawlspace with a pitched roof enclosing an attic space. The home design is three bedrooms, two baths, kitchen, and adjoining living room/eating area. There is an attached garage as well. This home is typical of the construction quality during the time it was being built. There are minimum insulation levels in the ceiling and walls and the windows are single-pane, aluminum casing.

A distributed electric baseboard heating system and living room fireplace provides space heating in the home. The home is equipped with exhaust fans in the bathrooms and above the kitchen electric range. There is no air conditioning system in the home.

A young family of three occupies the home which is located in Portland, Oregon, USA in a large residential area.

3.2 ENERGY SAVER HOME

This passive solar home was built in 1982 and incorporates energy efficient design features to reduce its space heating needs. The home is a ranch style design with wood frame construction including additional amounts of thermal storage mass. The wall construction is 2 X 8 framing with an R-30 insulation batting, one inch styrofoam insulating board, one inch sprayed foam and a 6-mil infiltration barrier. The heated floor area of the home is about 1,370 square feet(127.27 $meters^2$), excluding an attached garage and solarium air lock entry. The ceiling is a vaulted design with an R-38 insulation level. The floor is built on a crawlspace with R-30 insulation under the floor.

This home is two bedrooms and two baths and has electric forced-air heating. The home is equipped with exhaust fans in the two bathrooms. A young couple occupies the home which is located in Bend, Oregon in a high desert, open residential area.

3.3 CONTROL HOME

This is a three bedroom, two bath home with 2 X 4 wood frame construction over a full crawlspace. This ranch style design was built in 1974 and has about 1,470 square feet (136.56 meters^2) of heated floor area and an attached garage. It is located in a residential area northeast of Vancouver, Washington, USA. Minimum levels of insulation were installed during original construction. Floor insulation and storm windows were added several years before the testing at this home.

The heating system in the home is principally an overhead electric radiant system. A woodstove is used in the family room as a space heating device and a fireplace is located in the living room but does not receive any use. Exhaust fans are located in both bathrooms and above the kitchen stove. The home has not been occupied at any time during the first phase of monitoring.

4.0 METEOROLOGICAL, ENVIRONMENTAL AND ELECTRICAL DATA

All of the test homes were instrumented to gather data on outdoor and indoor conditions as well as energy use. This was desirable because infiltration is directly related to space heating load in the home. Outdoor measurements of air temperature, wind speed, wind direction and horizontal insolation were taken using a 10-meter weather station. These data were summarized and stored as hourly data.

Indoor air temperature and relative humidity data were recorded on an hourly basis. Electrical energy use in each home was recorded using sub-metering and summarized into hourly data. All of the above measurements were recorded using a programmable data logger. This data logger gathered data for the entire year.

5.0 AIR EXCHANGE RATE MEASUREMENTS

The air exchange rate in each of the three residences was measured during the heating season months of 1983-1984 using tracer gas. Both sulfur hexafluoride (SF_6) and perfluorocarbon (PFT) tracer gas were used and the air exchange rate was determined by measuring the decay of the tracer gas released in the residence. The decay of sulfur hexafluoride was measured using a Systems Science and Software portable gas chromatograph with an electron capture detector which is sensitive to sulfur hexafluoride at concentrations as low as 1 part per billion. Periodic samples of the inside air produced a plot of SF_6 concentration versus time over several hours. The slope of the line for this plot is the air exchange rate in the residence during the time of the measurement.

The principle and techniques of measuring air exchange rate using perfluorocarbon tracer are described elsewhere 1,2. The perfluorocarbon is released from source capsules at a constant rate at a given temperature and the air-borne perfluorocarbon is captured using small capture tubes (capillary-type tubes) filled with a solid sorbent.

Perfluorocarbon was also captured using a Gillian[1] Programmable Atmospheric Tracer sampler (PATS) deployed in each residence. The PATS can be programmed to measure infiltration in a residence from 1-hour to several hundred hour periods for each of its 23 tubes.

Several time periods were chosen for measuring air infiltration that were designed to take advantage of potential large inside outside temperature difference or high windspeed or both. This is why periods during the middle of winter (where high inside-outside temperature differences would be expected) and during the beginning of the spring season (where high winds would be expected) were chosen.

6.0 FAN DEPRESSURIZATION TESTS

Fan depressurization tests were performed on each of the three homes. The tests collect data on the induced ventilation of the residence. The fan depressurization is performed by forcing a flow of air out of the home through an orifice. The exiting air volume results in a pressure gradient which causes air to enter the home through leakage paths in the home's envelope. A series of pressure gradient data points are generated by varying the fan speed across the orifice. An air density normalizing technique is employed during the analysis of this fan depressurization data to allow a better comparison of the results. A summary of the fan pressurization tests are presented in Table 1.

It is important to note that using this methodology to induce a ventilation is extremely useful for identifying leakage paths within homes. It does not, however, represent real conditions imposed upon a home. A wind induced ventilation rate in a home causes a pressure gradient between the windward side(s) of a home and the leeward sides of the home.[2] Wind-induced infiltration is a dynamic variable and involves complex analysis.

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1 Gillian Instrument Corp, Wayne, New Jersey.

2 It is noted here that a thermal stack component for natural ventilation exists in the overall ventilation rate.

TABLE 1. Summary of Fan Depressurization Testing

	Test Homes		
	Weatherized	Control	Energy Saver
Floor Area m^2 (sq ft)	85(917)	129(1387)	142(1528)
Volume m^3 (cu ft)	200(7059)	295(10415)	406(14340)
Pressurization ELA* cm^2 (sq in)			
Trial #1	265.0(41.08)	415.0(64.33)	350.0(54.25)
Trial #2	265.0(41.08)	415.0(64.33)	350.0(54.25)
Trial #3	285.0(44.18)	390.0(60.45)	350.0(54.25)
Trial #4	285.0(44.18)	390.0(60.45)	350.0(54.25)
Depressurization ELA cm^2 (sq in)			
Trial #1	385.0(59.68)	405.0(62.78)	455.0(70.53)
Trial #2	385.0(59.68)	405.0(62.78)	455.0(70.53)
Trial #3	410.0(63.55)	425.0(65.88)	455.0(70.53)
Trial #4	410.0(63.55)	425.0(65.88)	455.0(70.53)
Average Depressurization Air Change per Hour (ACH)**	0.50	0.42	0.31

*ELA is Equivalent Leakage Area.

** Depressurization ACH is defined here as the air flow (cubic feet per minute) divided by the interior house volume.

6.1 FAN DEPRESSURIZATION ANALYSIS

Results from the fan depressurization data provide a "snap-shot" picture of the leakage potential of each home. The fan depressurization analysis looks at the artificially induced leakage conditions at 0.016 inches of water (4 Pa) pressure drop between the inside and outside of the house. The selection of 0.016 inches of water (4 Pa) corresponds to conditions that represent average outdoor wind effects.

The equivalent leakage area (ELA) results of each home would seem to suggest that the energy saver home has the greatest amount of leakage associated with it. However, this result is misleading since the volume of the energy saver home is also the greatest and, therefore, it has more wall surface area involved and a lower house air change per hour (ACH) value. This later result is borne out by the value under depressurization ACH. The depressurization ACH represents a uniform leakage across all walls at the induced pressure gradient. Therefore, by evaluating ACH with only depressurization data, you may be masking any opposite or neutral effects encountered under actual conditions where the windward walls contribute to infiltration and leeward walls contribute to exfiltration. The variation of ELA results between pressurization and depressurization in Table 1 suggests that the leakage paths behave differently under the two induced conditions. Therefore, the results obtained from pressurization and the results obtained from depressurization should not be combined in a simple fashion.

The repeatability of the measurements is examined by looking at the individual trials (one set of four measurements either pressurization or depressurization). In each of the homes, measurements #1 and #2 didn't vary from #3 and #4 by more than 7.5 percent. Measurements #1 and #2 were performed in the morning hours, while #3 and #4 were collected in the afternoon. Considering the percent error attributable to the various instrumentations, this data would suggest a good degree of repeatability in measurements of pressurization or depressurization for a specific home.

The fan depressurization does permit location of gross leakage paths of the home. This procedure, using smoke sticks, was used to identify leakage sources to be sealed in the weatherized home at the end of the first year's testing. The same procedure was used in all the homes.

7.0 RESULTS

The data presented in Table 2 was taken when the houses were in the "before" condition as discussed earlier. This data is referred to in the ANALYSIS AND DISCUSSION OF

RESULTS which focuses on the correlation of measured air exchange rates with the meteorological factors of temperature and windspeed at each residence.

The air exchange rates measured in the three residences using the various measurement techniques are summarized in Table 2. Average values are given for the air exchange rates. In addition, the average values of wind speed and inside and outside temperature difference for the time periods indicated are given in the table as taken by the meteorological sensors at each residence.

8.0 AIR EXCHANGE RATE CORRELATIONS WITH WIND SPEED AND TEMPERATURE

The nonlinear dependence of air exchange on temperature difference and wind is usually modeled as a linear relation in the equation:

$$I(\text{air exchange}) = A(\text{constant}) + B(\text{constant})\,\Delta T + C(\text{constant})V^2$$

where ΔT = inside-outside temperature, V = wind speed

Other equations have been used to fit or predict air exchange rate data, all of which are derivatives of this basic equation. Because the relation of infiltration rate and the wind and temperature is nonlinear, the constants A, B, and C will vary among houses due to the weather conditions during the infiltration measurements as well as because of variations in the structures themselves (including shielding). In order to obtain estimates of A, B, and C for any given house under any given tightness, many infiltration measurements over a large range of wind and temperature difference need to be taken. This was done for the three homes in this study. A linear regression analysis to find a fit to the equation and to determine the variable A, B, and C was performed for each house for the measurements of air exchange and windspeed and inside-outside temperature difference during the air exchange measurements. A "goodness of fit" or r^2 value was computed for each regression to see how well the equation could determine the variables and thus be able to yield air exchange values for the homes based upon these variables for each home.

This regression analysis was performed for the short term PATS measurements in each home as well as for the longer term CATS measurements combined with the average air exchange, average wind speed and average temperature difference values over the time period of the PATS analysis.

TABLE 2. Air Exchange Rates and Ventilation Rates in the Three Residences

Residence	Time Period	Measurement Method	Wind Speed, V M/S	Inside-Outside Temperature (C)	Air Exchange Rate (ACH)
Vancouver					
	1/30-2/6	PFT-PATS	0.85 ± 1.5	18.5 ± 2.3	0.27 ± 0.1
	1/29-2/7	PFT-CATS	0.43 ± 1.3	18.4 ± 2.2	0.29 ± 0.03
	1/29-2/13	PFT-CATS	1.05 ± 0.8	17.5 ± 2.2	0.27 ± 0.03
	2/26-3/5	PFT-CATS	0.93 ± 1.1	16.3 ± 1.9	0.20 ± 0.02
	2/7	SF6	0.0 ± 0.0	16.7 ± 1.5	0.29 ± 0.04
	3/5	SF6	0.25 ± 0.5	19.75 ± 2.36	0.35 ± 0.05
Portland					
	1/31-2/7	PFT-PATS	1.1 ± 1.4	13.5 ± 3.6	0.45 ± 0.17
	2/27-3/3	PFT-PATS	0.9 ± 1.0	12.9 ± 1.4	0.29 ± 0.03
	1/30-3/18	PFT-CATS	1.3 ± 1.1	13.0 ± 3.3	0.34 ± 0.01
	1/30-3/5	PFT-CATS	1.2 ± 1.1	12.0 ± 3.1	0.28 ± 0.01
	1/30-2/8	PFT-CATS	1.8 ± 1.6	13.4 ± 3.6	0.38 ± 0.04
Bend					
	11/22		2.8 ± 0.4	21.5 ± 1.9	0.31
	12/5-12/10	PFT-PATS	2.3 ± 1.1	18.8 ± 2.5	0.18 ± 0.14
	3/18-3/23	PFT-PATS	2.2 ± 0.6	17.7 ± 3.9	0.22 ± 0.1

The regression coefficients are all different for each set of regression analyses. The fit of the curve (r^2) for all three homes using the PATS data is very poor ranging from 0.01 in the Vancouver home to 0.36 in the Portland home. Taking the PATS exchange data for the Portland and Bend homes for only the quiescent periods of the day (2400hrs-0800hrs) and performing a linear regression analysis did not yield any better fit to the curve. The r^2 values were 0.01 and 0.00 for the Portland and Bend homes respectively. The fit of the curve using the average of the PATS data combined with the CATS data, which are both longer term measurement data (greater than 5 days average) yields a much better curve fit in the Vancouver and Portland homes. The r^2 value for these data are 0.84 in the Vancouver home and 0.69 in the Portland home. No long term CATS measurements were taken in the Bend home and not enough CATS data was taken to average for the long-term regression analyses.

The empirical equation for infiltration that gives the best fit for the regression analysis (largest r^2 value) can be used to predict infiltration given the temperature and windspeed parameters. This was done for the Vancouver home for the days in which SF_6 decay analyses was performed to measure the infiltration. The observed infiltration on 2/7 from SF_6 decay analysis was 0.31 ACH; the predicted infiltration using the empirical equation is 0.29 ACH. The average relative error is 6%. The observed infiltration on 3/5 from SF_6 decay analyses was 0.23; the predicted infiltration using the empirical equation is 0.35 ACH. The average relative error is 52%.

Air infiltration was also predicted for the Bend home for the period when the blower door measurements were made by using the best-fit empirical equation. The Bend home is chosen for this analysis because it is the only home for which temperature and windspeed data are available on the same day that the blower door test was performed. For the Bend home, the measured air exchange from the blower door measurements on 11/22 was 0.31 ACH; the predicted air exchange for that day is .23 ACH. The average relative error is 26%.

9.0 OBSERVATIONS AND CONCLUSIONS

The experiences in measuring air exchange rates in these three residences led to the following observations and conclusions about the use of the different tracer gases and measurement techniques.

The use of SF_6 as a tracer gas combined with onsite analysis is a sensible approach to measuring air exchange rates in unoccupied structures or in occupied structures where there is freedom to move about and disperse and collect the tracer sample. Access to the residence must be gained several hours prior to the measurement of SF_6 decay so that the gas can be released and to allow time for complete mixing in the structure. Although not done in this study, fans or the HVAC system of the residence can be used to mix the gas. The equipment used in this study to perform the SF_6 tracer analysis onsite is somewhat large and would need to be set up in an unused space in the residence. In the case of the Vancouver house, the kitchen was used for the analysis equipment since the house was unoccupied.

The use of SF_6 decay for air exchange rate determination is a time-tested and highly accurate method. It will yield results that are accurate within $\pm 10\%$ of the true air exchange in the structure over short (hours) or long (several hours) time periods. However, a trained technician must be present to perform the analysis and interpret the results. The air exchange rate determination is available almost instantaneously using SF_6 tracer and this method can provide a valuable and valid check on the results of other techniques used to determine air exchange rate. This was the case for the Vancouver residence where the SF_6 decay data was used as a check on the accuracy of the PFT decay analysis data.

The use of PFT tracer gas and PATS seems particularly well-suited for measuring short term (<24 hours) air exchange in all of these residences. The PFT gas was easily deployed and analysis was fairly inexpensive. The deployment of the tracer gas is unobtrusive and was not noticed by any of the residents. The only difficulties experienced during the measurements in the three residences were malfunction of the printing of the time and pump stroke information on the paper tape of the PATS units. If this information is missing or not readable, the air exchange rates are difficult to analyze. Because only two places in the country presently have the equipment to perform low-level PFT analyses, it can take several months to receive results.

Using the CATS in combination with PFT was most helpful in determining long-term (>24 hours) average air exchange rates in the residences. (The CATS can also be used to determine short-term (<24 hours) air exchange rates.) The CATS require no attention or moving parts and can be left in a residence for weeks or months with little notice from the residents. These can be recovered by the resident and mailed to the investigator if necessary. As with the PATS, the temperature of the PFT sources must be known to determine the airborne concentration of the PFT during the measurements. Analyses of CATS measurements also take several weeks to months.

The regression analysis of the air exchange rate data and for each residence and a discussion of the results is present in the following sections.

9.1 OBSERVATIONS IN THE VANCOUVER HOME

Short term infiltration measurements (8-hour) from 1/30 - 2/6 using the PATS yield infiltration data gave a poor linear regression correlation (curve fit). This may be due to the poor mixing in this residence which was unoccupied during these tests. This is especially evident when examining Figure 1. Figure 1 is a plot of the air exchange rate, ΔT and V^2 for the time period 1/30 - 2/6. Figure 1 shows the large increase in air exchange between 2/5 and 2/6 lagging by several hours a significant increase in wind between the same days. The wind may be incident on one side of the house (which may be on the other side of the house from the PATS measuring instrument) and dramatically affect the infiltration in that portion of the house nearly instantaneously; but the actual air exchange rate measured in another part of the house where the measurement equipment is placed, may not change as dramatically or as suddenly. Eventually this change in air exchange will be measured, but will be lagging the actual event that caused the change (increase in windspeed in this case) by several hours or more.

The long term (greater than several days) air exchange measurements tend to reduce the effects of this lagging phenomenon. This is borne out by the fact that the regression analysis of the long term (CATS and average PATS) data yielded a better curve fit. The number of data points are fewer for the long-term analysis which will also contribute to a better curve fit.

9.2 OBSERVATIONS IN THE PORTLAND HOME

The regression analysis of the short term PATS data yielded a very poor curve fit. This poor curve fit is most likely due to a the fact that the house is not only occupied, but the fireplace was used during the air exchange measurements. Use of fireplace and to a lesser degree occupancy, will dramatically affect the air exchange rate in relatively short time periods (the fireplace uses combustion air drawn from the outside through cracks and openings in the house). The effect of fireplace use will overshadow the effects of windspeed and ΔT making it difficult to establish any correlation for the variables of windspeed and ΔT.

Figure 3 is a plot of air exchange, ΔT and V^2 for the time period 1/31 - 2/7. As noted in Figure 3, the air exchange seems to be more dependent upon the ΔT than upon the windspeed. As the ΔT increases (decreasing outdoor temperature), the likelihood of wood consumption increases with a corresponding increase in the air exchange. This air exchange rate increase however, is not just due to the temperature difference because of the poor correlation seen in Figure 2, indicating that the fireplace use was a major contributor to the infiltration. The one day of high windspeed on 2/4 was not reflected in a corresponding increase in the air exchange rate. This increase corresponded with a decrease in the ΔT and probably a decrease in fireplace use. This again points out that the fireplace use may have the most pronounced effect on air exchange.

An attempt was made to factor out the occupancy and perhaps the fireplace use by using only the infiltration data during the quiescent periods of the day (2400hrs-0800hrs) from 1/31 - 2/7 and performing a linear regression analysis. The analysis indicated a very poor correlation. This was perhaps due to either poor mixing (as in the Vancouver home) or due to the fireplace damper being open as the fire died down which would create air leakage into the house which may overshadow the infiltration due to either the windspeed or the ΔT. As in the Vancouver home, the best correlation of the linear regression analysis occurred by taking the longer terms infiltration data (CATS and average PATS) which would tend to reduce the occupancy and fireplace use effects.

9.3 OBSERVATIONS IN THE BEND HOME

Like the other two homes, the regression analysis of the short term PATS data yielded a poor curve fit. This is the only home of the three with forced air heat which may have a greater influence on the air exchange than does the windspeed and ΔT. In addition, this house is very "tight" with the lowest overall air exchange rate compared to the other two houses.

As in the Vancouver home, there appears to be a lag in the response of infiltration to the changes in ΔT and windspeed (see Figures 4, and 5). This may be due to the fact that for long periods of time during the day, the house is unoccupied and therefore, there is poor mixing. This especially may be the case in this home because it is a very energy efficient structure, and it may be less responsive to changes in wind and temperature. Unlike the Vancouver and Portland homes, no long-term CATS data was taken to examine the regression of long term air exchange measurements to see if better correlations can be found for this house. It is expected that a better correlation would be found using long term data.

REFERENCES

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2. Dietz, R. N. 1983. Brookhaven Air Infiltration Measurement System (BNL/AIMS) Description and Application. Prepared for the Office of Building and Community Systems and the Office of Health and Environmental Research of the United States Department of Energy.

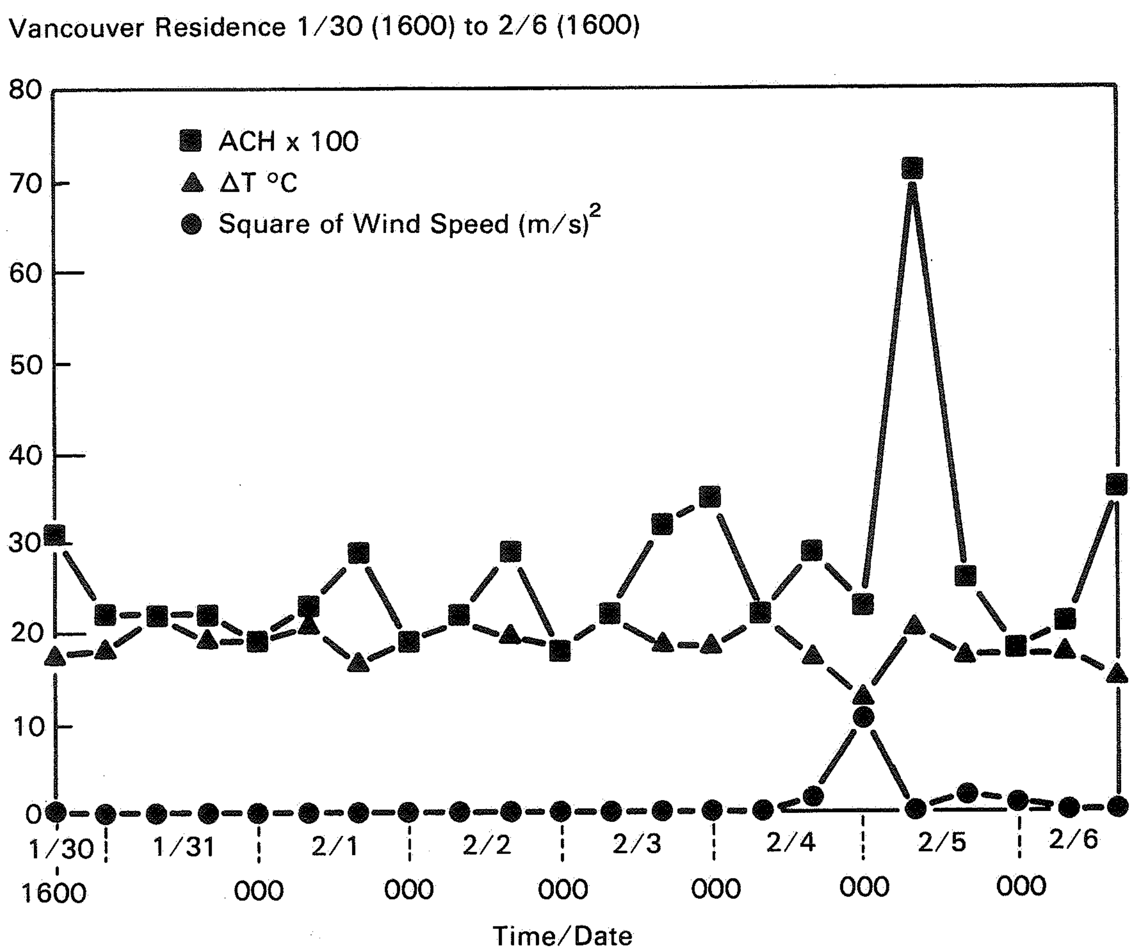

Figure 1. Measured Air Exchange Rate, Windspeed and Inside–Outside Temperature in the Vancouver Residence 1/30–2/6.

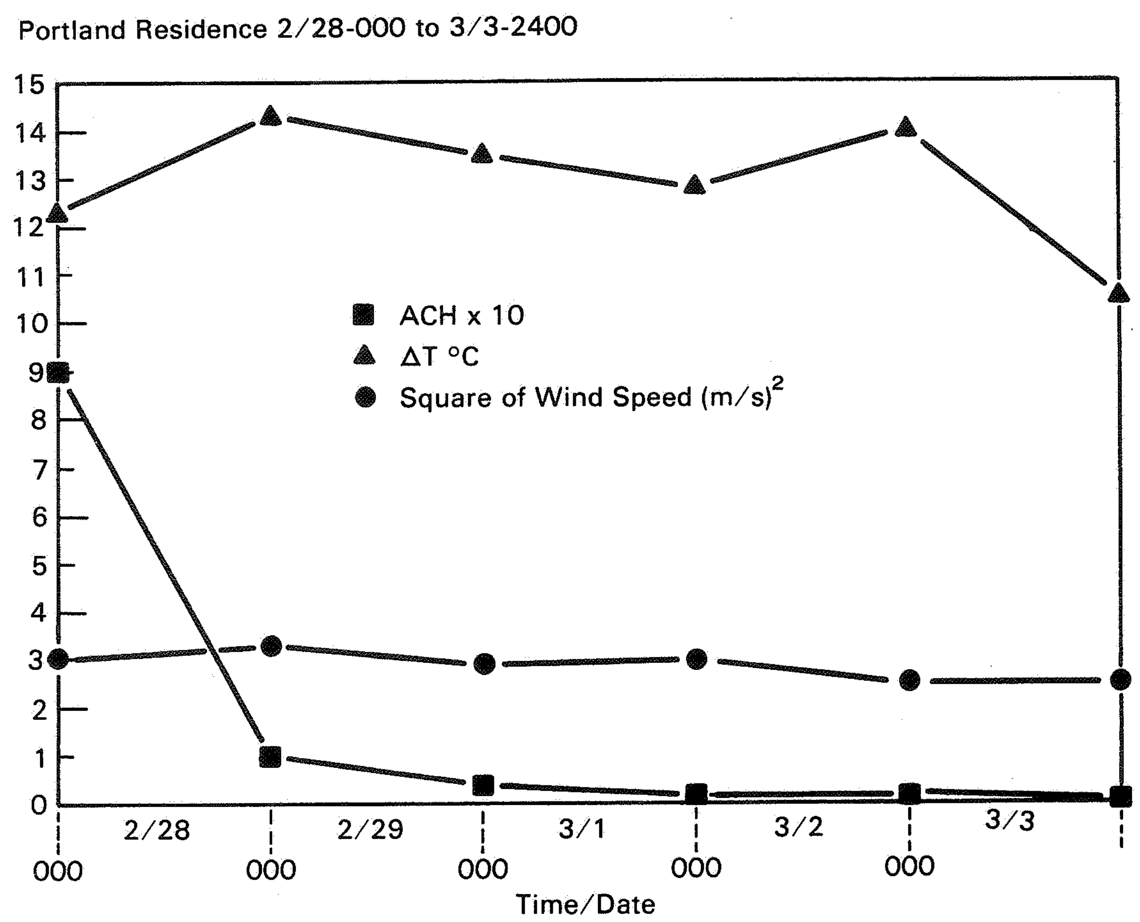

Figure 2. Measured Air Exchange Rate, Windspeed and Inside–Outside Temperature in the Portland Residence 2/28–3/3.

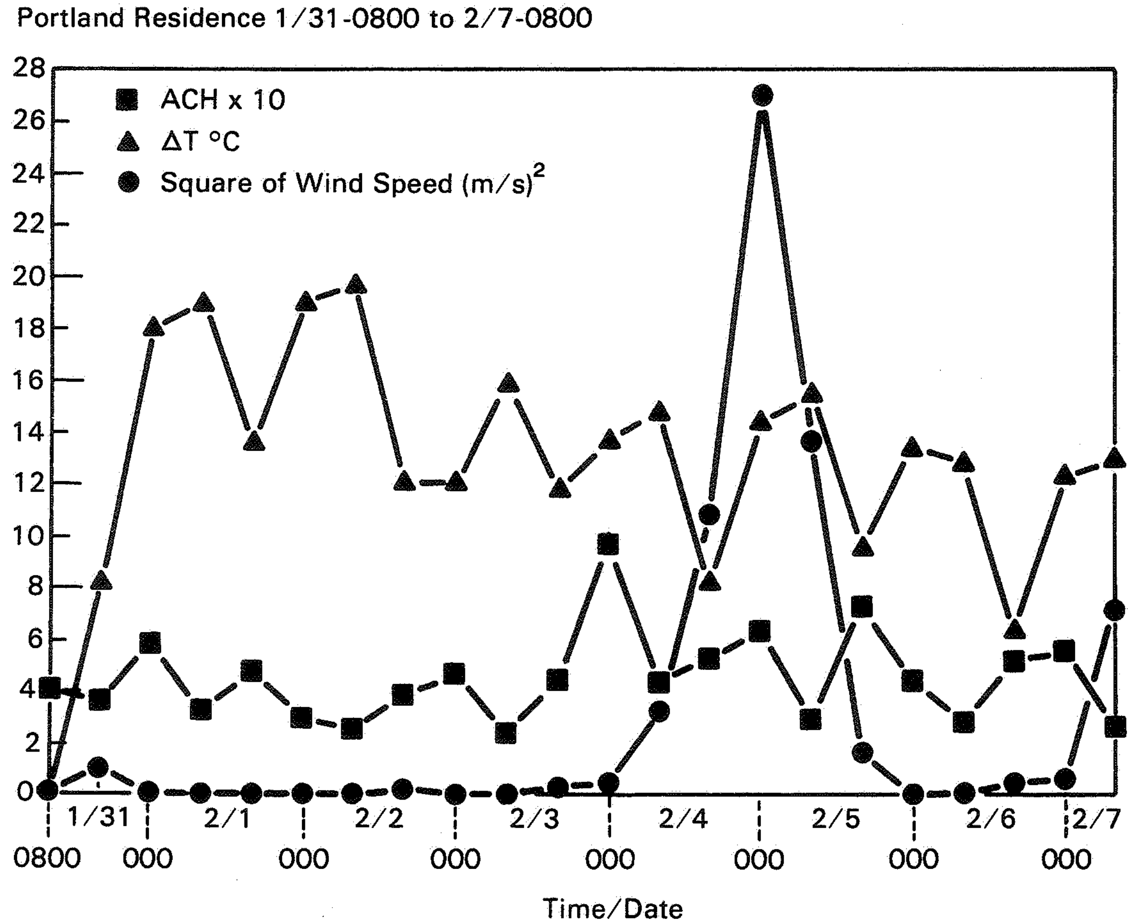

Figure 3. Measured Air Exchange Rate, Windspeed and Inside–Outside Temperature in the Portland Residence 1/31–2/7.

Bend Residence 12/5-2000 to 12/10-0600

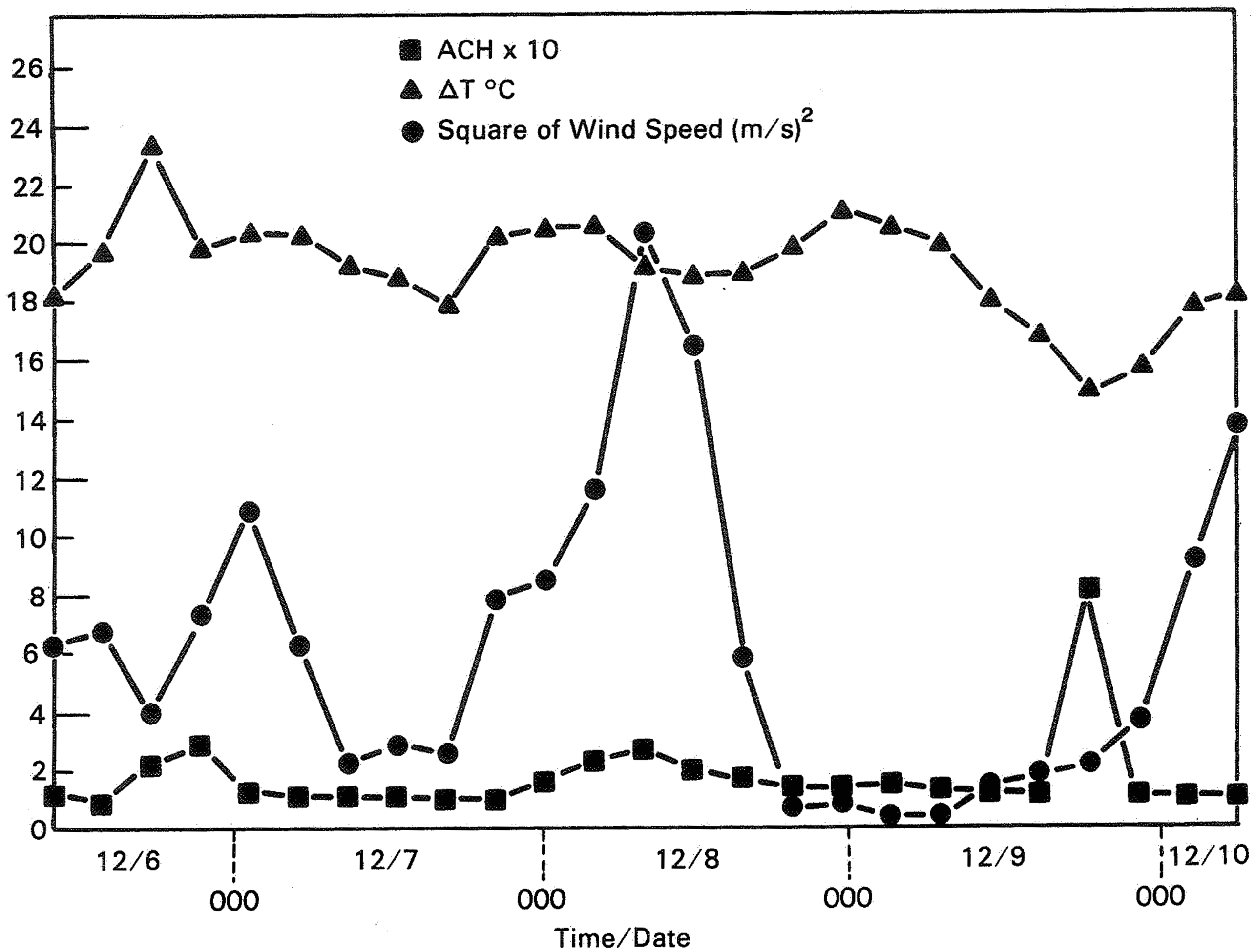

Figure 4. Measured Air Exchenge Rate, Windspeed and Inside–Outside Temperature in the Bend Residence 12/5–12/10.

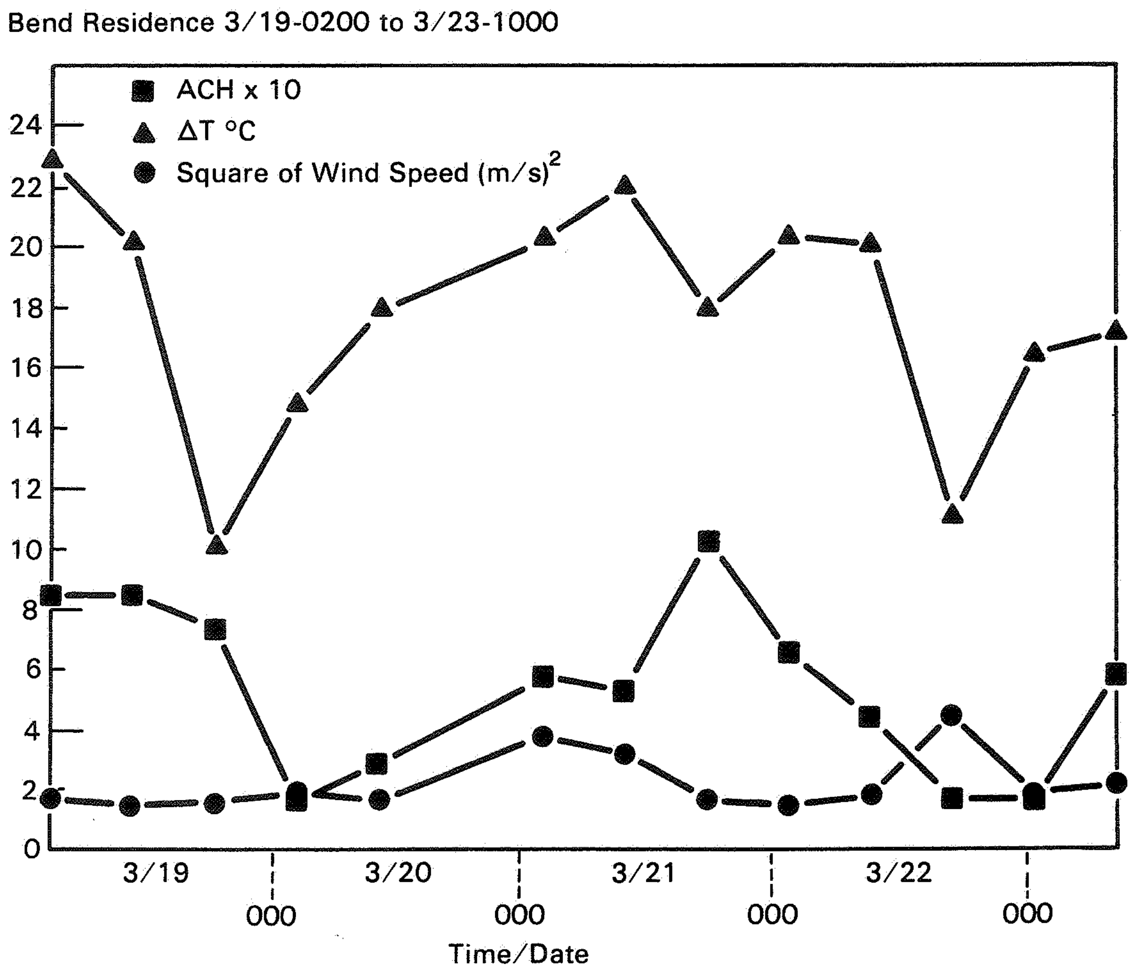

Figure 5. Measured Air Exchange Rate, Windspeed and Inside–Outside Temperature in the Bend Residence 3/19–3/23.