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# SEASONAL VARIATION IN EFFECTIVE LEAKAGE AREA

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## ABSTRACT

Previous research on the seasonal changes in airtightness has been conducted by other researchers on one or two houses in one location. This paper describes air leakage rate measurements using the fan pressurization technique performed monthly over a period of one year in ten occupied houses in three different climates. The purpose of this study is to determine the seasonal variation in effective leakage area in houses in different climates. The three sets of houses included in this study are located in Reno, NV (semi-arid, high desert), Truckee, CA (alpine, mountainous), and the San Francisco Bay Area (temperate, coastal). The houses are all wood-frame construction and range from one year to seventy years in age. Indoor and outdoor air temperatures, wind speed, and the moisture content of wood framing and other building components were measured at the time of each fan pressurization test. Indoor moisture levels were monitored by measuring the moisture content of a reference block of wood that was located indoors at each site. The results indicate a seasonal variation in effective leakage area in some but not all of the houses; the largest variations are seen in the Truckee houses with effective leakage areas up to 45% higher in the summer as compared to those measured in midwinter.

## INTRODUCTION

The fan pressurization technique is used to determine air leakage of residential buildings. This technique uses a large door- or window-mounted fan to blow air into or suck air out of a building to determine the airflow at various pressure differences ($\Delta P$) across the building shell. Energy auditors, contractors, researchers, building officials, and weatherization personnel in many countries are now using the fan pressurization technique to identify air leakage sites and to quantify the air leakage that occurs in a building. With the increase in use of the fan pressurization technique, more questions are being asked about the accuracy of the measurement.

Fan pressurization measurements are influenced by environmental conditions at the time of the test (Persily 1982). The environmental factors influencing the measurement can be grouped into two categories: 1) the effects of air density differences on airflow measurements; and 2) the effects of wind pressures on airflow and inside-outside pressure difference measurements. The air density differences are caused by inside-outside air temperature differences at the time of the test, as well as differences between the air temperature at the time of calibration and the time of the test. Differences in air

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density are also caused by variations in atmospheric pressure from the time of calibration to the time of the test and by changes in elevations. Wind pressures on the surfaces of the building can cause uncertainties in the inside-outside pressure measurement and in the measurement of airflow through leaks and cracks in the building shell.

In studies conducted in the U.S., the U.K. and Canada, researchers have reported another factor influencing fan pressurization measurements: a seasonal variation in air leakage measured at 50 Pa due to seasonal changes in the building characteristics that affect air leakage. In a Canadian study (Kim and Shaw 1984), fan pressurization measurements in two single-family residences showed a 20% higher airflow rate at 50 Pa in winter as compared to the fall. The U.K. study (Warren and Webb 1980) showed a 40% higher airflow at 50 Pa in February as compared to the airflow measured in October. The U.S. study (Persily 1982), conducted by researchers from Princeton University, showed a 22% higher airflow at 50 Pa and a 25% higher airflow at 4 Pa in mid-winter as compared to early summer.

Two residential building standards that have been proposed recently in the U.S.A. would restrict leakage areas in new and existing buildings. The Northwest Power Planning Council's proposed Phase Two Model Conservation Standard (NPPC 1985) would restrict leakage areas in new buildings built after 1988 in the Pacific Northwest, while the proposed ASHRAE Standard 119P (ASHRAE 1985) would provide a maximum normalized leakage area for buildings in different climates. If the seasonal effects on air leakage of residential buildings proves to be important, then organizations that propose building energy efficiency standards that restrict leakage areas may want to consider this effect when setting air leakage standards.

In recent years at least four measurement standards have been introduced to provide a standard method for determining airtightness in buildings. These standards have been introduced in Canada (CGSB 1985), Norway (NBR 1981), Sweden (SIS 021551 1980), and the United States (ASTM 1981). Both the proposed Canadian standard and the ASTM standard incorporate air temperature and atmospheric pressure corrections for airflow measurements, while the Norwegian standard requires only an air temperature correction of airflows. With regard to wind speed at the time of the measurement, the Norwegian standard *requires* that the measurement not be performed when the wind speed is greater than 6.00 m/s. The proposed Canadian standard *recommends* that the measurement not be performed when the wind speed exceeds 5.5 m/s, while the ASTM standard *recommends* that the measurement not be performed when the wind speed exceeds 4.5 m/s. In the *draft* ASTM standard E779-85, the maximum wind speed criteria for calculating the effective leakage area at 4 Pa has been reduced to 2.0 m/s.

In this study, fan pressurization measurements were performed over a one-year period on ten occupied houses in three different climates. Three of the test houses were located in Truckee, CA, three in the San Francisco Bay Area (Oakland and Martinez), and four in Reno, NV, and Sparks. Wood moisture content, wind speed, and inside and outside air temperatures were also measured at the time of each fan pressurization test. The purpose of this investigation was to determine the seasonal variation in leakage area and to study the effect of wood moisture content on leakage area in houses in three different climates.

## BUILDING AND SITE DESCRIPTION

The buildings chosen for this study were selected on the basis that the occupants would not make any changes to the building during the test period that might affect the air leakage characteristics, e.g., install storm windows, seal cracks with caulk, or weatherstrip windows. In addition, if a fireplace or wood-burning stove were present, then it must have an operable flue or fireplace damper. One building in the San Francisco Bay Area was dropped from the study because the fireplace (without a damper) represented a rather high percentage of the total air leakage and was difficult to seal. House R1, in Reno, and house S2, in Oakland, CA, each had a fireplace without a damper which were covered with a piece of wood during the fan pressurization measurements.

Descriptions of the test houses are given in Table 1. The three Truckee houses are all ten years old or less and have exterior wood siding. Houses T1 and T3 have cathedral ceilings with exposed beams and interior walls covered with wood paneling. Two of the four Reno houses are less than 6 years old, while the other two are 20 and 35 years old. The Reno houses all have unfinished attics, and three out of four have wood siding on the exterior wall surface and plaster board on the interior walls. The two Oakland, CA, houses are older construction, with lath and plaster on the interior walls and stucco and wood shingles on the exterior wall surfaces. The house located in Martinez, CA, is a ranch style house built in the mid- 1970s with an unfinished attic, plaster board on the interior walls, and stucco on the exterior wall surfaces.

The climates in Reno, Truckee, and the San Francisco Bay Area are each quite different. Reno, NV, is located on a semi-arid plateau at the eastern flank of the Sierra Nevada mountains, at an elevation of 1340 m. The 30-year (1941-1970) annual average degree-days for Reno (National Climatic Center 1980) are 3346 heating degree-days at a base temperature of 18.3 $^{o}$C and 183 cooling degree-days at the same base temperature. The climate is characterized by warm, dry summers and cool winters with moderate amounts of rain and snowfall. Average annual precipitation is 0.2 m, of which more than 50% occurs during the period from December through March, and the average annual snowfall is 0.64 m. Truckee, CA, is located in the Sierra Nevada mountains, at an elevation of 1980 m. It experiences cold winters and mild summers with 4560 heating and 18 cooling degree-days. Average annual snowfall is over 5.1 m, and annual precipitation averages 0.8 m. Located on the eastern edge of the San Francisco Bay, Oakland, CA, has a climate characterized by mild winters and cool summers. Average annual precipitation amounts to 0.5 m. Oakland experiences 1616 heating and 71 cooling degree-days.

## FAN PRESSURIZATION TEST METHOD

Typically, the fan pressurization method is used to measure the airflow rate at one pressure difference across the building shell, commonly at 50 Pa, or at series of pressure differences to provide an airflow vs. pressure signature for a building. The effective leakage area is determined by analyzing the airflow vs. pressure difference data and is a quantity conceptually equivalent to the sum of the areas of all the cracks and holes in the building envelope. This quantity is the scale parameter for estimating natural infiltration in the Lawrence Berkeley Laboratory infiltration model (Sherman and Grimsrud 1980).

Fan pressurization uses a blower door, a door-mounted, variable-speed fan capable of moving large volumes of air (up to 2000 L/s) into or out of a structure and a differential pressure gauge such as an incline manometer or micro-manometer. By supplying a constant airflow with the fan, a pressure difference across the building envelope can be maintained. When the differential pressure is held constant, all airflowing through the fan must also be flowing through the building envelope. The influences of wind and temperature difference on the flow and pressure measurements are diminished somewhat by making the measurements at pressure differences greater than 10 Pa.

In this study, fan pressurization measurements were performed about once per month for up to one year in each house (October 1984 through December 1985). To minimize the effects of errors introduced by changing operators, the same person performed all of the fan pressurization measurements in this study. For each test the blower door was sealed into an exterior doorway, and the pressure gauge was set up with four pressure taps placed outside the building; one tap for each facade with the tap placed facing perpendicular to and away from the building surface. The four outside taps were connected to a pressure averaging box as specified in the proposed Canadian standard (CGSB 1985). The inside pressure tap was placed out of the direct flow path of the fan. All exterior doors and windows were closed, and if a fireplace and/or a wood-burning stove were present, their dampers were closed. All exhaust ventilation systems, e.g., kitchen and bathroom exhaust vents, and dryer vents were sealed. All interior doors, except closet doors, were left open. A calibrated orifice-type blower door was then used to blow air into (pressurize) and to suck air out of (depressurize) the building at a series of fixed pressure differentials from 10 to 60 Pa at 10 Pa intervals. The airflow and the pressure difference across the building shell were measured at each point. The resulting airflow versus pressure curves for both pressurization and depressurization were then used to find the effective leakage area of the building.

For inside-outside temperature differences and for atmospheric pressure differences due to the different elevation, the airflow measurements were corrected by using the algorithms derived from those we found in Appendix D of the proposed Canadian standard (CGSB 1985) for depressurization. In mass flow measuring devices like orifice plates, nozzles, venturis, etc. the airflow is a function of the air density:

$$Q = f\left(\frac{1}{\sqrt{\rho}}\right) \tag{1}$$

Therefore the measured airflow at calibration conditions is:

$$Q_m = constant \frac{1}{\sqrt{\rho_c}} \tag{2}$$

*where*

$Q_m$ = measured airflow, $m^3/s$

$\rho_c$ = density at calibration conditions, $kg/m^3$

The true value of the airflow passing through the blower door therefore can be calculated by using Equation 3:

$$Q_b = Q_m \sqrt{\frac{\rho_c}{\rho_b}} \tag{3}$$

*where*

$Q_b$ = airflow passing through the blower door, $m^3/s$
$\rho_b$ = density of the airflowing through the blower door, $kg/m^3$

The airflow we are interested in is that which flows through the building envelope. As that airflow might have different temperature conditions than the airflow passing the blower door it has to be calculated using the continuity equation of mass for compressible flow means:

$$\rho\, Q = constant \tag{4}$$

and therefore,

$$\rho_b\, Q_b = \rho_{env}\, Q_{env} \tag{5}$$

*where*

$Q_{env}$ = airflow through the building envelope, $m^3/s$
$\rho_{env}$ = density of airflowing through the building envelope, $kg/m^3$

Substituting for $Q_b$ in Equation 5 and solving for $Q_{env}$ we get:

$$Q_{env} = Q_m \frac{\rho_b}{\rho_{env}} \sqrt{\frac{\rho_c}{\rho_b}} \tag{6}$$

The density of air can be calculated from the ideal gas equation:

$$\rho = \frac{p}{R\ T} \tag{7}$$

*where*

$p$ = barometric pressure, $kPa$
$R$ = specific gas constant, $J/g \cdot K$
$T$ = absolute temperature, $K$

and therefore the airflow through the building envelope can be calculated using Eq. 8.

$$Q_{env} = Q_m \frac{T_{env}}{T_b} \sqrt{\frac{p_c}{p_b} \frac{T_b}{T_c}} \tag{8}$$

*where*

$T_{env}$ = temperature of air passing through the envelope, $K$
$T_b$ = temperature of air passing through the blower door, $K$

In order to calculate the leakage area at reference conditions ($p_r = 101.325\ kPa$ ; $T_r = 293.15\ K$) the airflow must be corrected to $Q_{corr}$ according to Equation 9:

$$Q_{corr} = Q_{env} \sqrt{\frac{p_{env}}{p_r} \frac{T_r}{T_{env}}} \tag{9}$$

and given that

$$p_{env} = p_b \tag{10}$$

$$Q_{corr} = Q_m \frac{T_{env}}{T_b} \sqrt{\frac{p_c}{p_b} \frac{T_b}{T_c}} \sqrt{\frac{p_b}{p_r} \frac{T_r}{T_{env}}} \tag{11}$$

$$Q_{corr} = Q_m \sqrt{\frac{T_{env}}{T_b}} \sqrt{\frac{p_c}{p_r} \frac{T_r}{T_c}} \tag{12}$$

$$\sqrt{\frac{p_c}{p_r} \frac{T_r}{T_c}} = constant \tag{13}$$

$$Q_{corr} = Q_m \sqrt{\frac{T_{env}}{T_b}} (constant) \tag{14}$$

This shows that the corrected air leakage is strongly dependent on neither the temperature difference between the flow passing through the blower door and the air leaking through the openings of the building shell nor the elevation differences between different test sites.

Whereas the pressure drop along the crack length is expressed in terms of friction and resistance, the airflow through building components is usually described by the empirical power law equation:

$$Q = K\ (\Delta P)^n \tag{15}$$

*where*

$Q$ = airflow, $m^3/s$
$K$ = leakage coefficient, $m^3/s \cdot (Pa)^n$
$n$ = flow exponent, dimensionless
$\Delta P$ = inside-outside pressure difference, $Pa$

The coefficients $K$ and $n$ are obtained using a log-linearized curve-fitting technique. The value of the exponent can be expected to be between its physical limits of n = 1.0 for fully developed laminar flow and n = 0.5 for fully developed turbulent flow. The curves generated by fan pressurization are extrapolated to a reference pressure of 4 Pa (assumed to be representative of natural infiltration) by solving for $Q$ at 4 Pa in Equation 15.

The effective leakage area is defined as the equivalent amount of open area through which would pass the same quantity of air as would pass collectively through the building envelope at the reference pressure of 4 Pa (ASHRAE Standard 119P). This assumes that in the pressure range characteristic of natural infiltration, -10 to +10 Pa, the flow versus pressure behavior of a building more closely resembles square-root (turbulent) than viscous (laminar) flow and can be described by:

$$ELA = \frac{Q_4}{[(2/\rho)\ \Delta P_4]^{0.5}} \tag{16}$$

*where*

$ELA$ = effective leakage area, $m^2$
$Q_4$ = airflow at 4 Pa, $m^3/s$
$\Delta P$ = leakage reference pressure, $4Pa$
$\rho$ = air density, $kg/m^3$

The total leakage area of the envelope, $ELA_o$, is defined as the average of the effective leakage areas from pressurization and depressurization.

## WOOD MOISTURE MEASUREMENT TECHNIQUE

At the time of each fan pressurization measurement, wood moisture and surface temperature measurements were also performed. First, a short piece of 50 mm by 100 mm coastal Douglas Fir was placed in each house as a reference wood block. Each month the moisture content of the wood block was monitored as an indicator of indoor moisture levels. The moisture content and surface temperature of various wood components in the building shell were also measured. Since these buildings were occupied, we could not cut holes into walls to measure the moisture content of wall framing, sheathing, and sill plates. Instead, if the building had an accessible attic space, the wood moisture of the wood members of the roof truss and sheathing were measured. In some cases, the wood moisture content of exterior doors and door frames, window frames and sills, and some interior doors were measured.

The wood moisture content was determined by measuring the electrical resistance between a pair of needle electrodes placed 32 mm apart and 8 mm deep in the wood sample. The electrical resistance was measured with a portable, battery-powered solid-state ohm-meter developed at Lawrence Berkeley Laboratory (Cleary and Sherman 1985). The ohm-meter is based on the ICL8048 monolithic logarithmic amplifier (Intersil). The meter is capable of measuring resistances ranging from $1.5\ 10^{10}$ to $1.5\ 10^{4}$ ohms. The wood moisture content (in % of dry weight) corresponding to the electrical resistance value was obtained from Table 1 in *Electric Moisture Meters for Wood* (USDA 1975). The table value for coastal Douglas Fir was used.

The readings obtained from the resistance meter above $10^{11}$ ohms were somewhat variable, thus they were not used. We experienced some minor difficulties with this instrument during the course of the study due to low battery power, poor electrical contacts within the instrument, and a faulty ground connection. As a result, moisture measurements were not taken at each building every month.

## RESULTS

**Summary results of the monthly measurements of effective leakage area (ELA) and** airflow at 50 Pa ($Q_{50}$) are presented in Table 2 (for detailed results of the fan pressurization measurements see Tables A-1 through A-10 in Appendix A). The range of ELA and $Q_{50}$ measured at each building and the month when the maximum and minimum value were measured are listed in the table. The range of variation in ELA and $Q_{50}$ are calculated using the following equation:

$$ROV = \frac{(max - min)}{(max + min)/2} \cdot 100 \qquad (17)$$

*where*

$ROV$ = range of variation as % of mean, %
max = maximum measured value
min = minimum measured value

The Truckee, CA, houses show the largest variation in both ELA and $Q_{50}$. The largest variation is seen in house T1 with a 45% change in ELA with the maximum occurring in October 1985 and the minimum in February of the same year. The $Q_{50}$ values for pressurization and depressurization vary similarly.

Plots of effective leakage area vs. month of year for the Truckee houses are shown in Figure 1. The effective leakage area drops rapidly during the early winter months and climbs gradually during the spring to a maximum in the summer. The change in the pressurization $Q_{50}$ is less pronounced than that in ELA during the period from November through June, although the maximum and minimum values for each air leakage indicator occur in the same months, October and February, respectively.

Of the ten houses measured, houses T1 and T3 show the largest variation in ELA and are also the only two houses in the sample with exposed beam, cathedral ceilings and extensive wood paneling on the interior walls and ceilings. During the February measurement at house T1, ice was observed inside cracks around the wooden beams that passed through the interior walls to the outside. The source of moisture was melting snow from the roof. At that time a large mantle of snow 0.9 m thick sat on top of the roof, and at least 1.8 m of snow was on the ground around the perimeter of the crawlspace. The effective leakage area measured in house T2 varied the least of all the Truckee houses with a range of 28% over the year.

The results of all but one of the the moisture measurements made in the Truckee houses showed a small variation in wood moisture content. The reference blocks of wood and the inside and outside doors all varied from approximately 7% to 8% wood moisture content as a percent of dry weight with no apparent seasonal trend. In the one house that had an unfinished attic, house T2, the attic wood moisture varied from a high of 12% in February to a low of 8% at the end of August. This was the only house where a significant change in wood moisture content was measured and the peak wood moisture content did coincide with the minimum air leakage measurement. In the two Truckee houses with the large variations in air leakage, houses T1 and T3, we were unable to measure any significant change in wood moisture content.

The variation in effective leakage area in the Reno houses was not as large as that seen in the Truckee houses, and some of the variation observed was probably wind-induced (see changes in exponent for depressurization). The wood moisture content of the reference wood blocks and other building components did not vary significantly during the year. The ELA variation over the year ranged from 18% to 28%, including the 26% measured at house R2 where some of the measurements were conducted under conditions of high wind speeds (see the tables in Appendix A for a listing of wind speeds measured during the fan pressurization tests). One of the factors affecting the fan pressurization measurements in Reno was the occurence of wind during the measurements. Most of the fan pressurization measurements performed in Reno took place in the afternoon, which is normally the period of the day when maximum wind speeds occur. In some cases, the measurement was postponed or halted until the wind speeds decreased.

No significant seasonal trend can be seen in the variation of effective leakage area and $Q_{50}$ measurements in the Reno houses due to noise in the measurements caused by wind. One observation that can be made about the fan pressurization tests performed in Reno is that a variation in effective leakage area did occur, though we cannot explain how much of that variation was due to seasonal changes in the building leakage characteristics or how much was due to the wind effects on the measurement.

The San Francisco Bay Area houses (see Fig. 3) show almost no change in air leakage over the period that they were measured (November-May). The range of variation (ROV) in effective leakage area for the three houses is 7% to 18%, while the $Q_{50}$ values vary by 8% to 12% for pressurization and 6% to 17% for depressurization. This result is not too surprising, as the climate of the Bay Area is significantly milder than the climate in either Reno or Truckee.

## CONCLUSIONS

Seasonal variations in effective leakage area of 28% to 45% and airflow at 50 Pa of 12% to 34% were seen in buildings in Truckee, CA, with the maximum air leakage occurring in the summer and the minimum air leakage occurring in winter. This result is just opposite the effect seen in studies conducted by other researchers. Since almost all of the measurements at the Truckee houses were made when wind speeds were 1.0 m/s or lower, the large seasonal variation cannot be explained by wind-induced errors in the fan pressurization measurement. The moisture measurements of wood components on the exterior and interior of the building did not reveal any significant correlation to the seasonal swing in airtightness, although the locations we chose to measure probably were not representative of the wood moisture conditions of the entire building.

The variations in effective leakage area and airflow at 50 Pa of the houses in the San Francisco Bay Area were on the order of 10%. This is within the range of error that one would expect from fan pressurization measurements conducted on the same building under different wind conditions. In Reno, NV, variations in effective leakage area of about 20% were measured.

## RECOMMENDATIONS AND FUTURE WORK

The measurements do not give a clear answer whether or not seasonal variations of the effective leakage area should be expected for a given building. The study does point out, however the problems of determining the existance of such an effect without doing long term measurements. The small sample of houses does not give a clear indication of the dependency of seasonal effects on building design, climate or age. To determine the variables causing the described effect, a study that covers a much larger sample of houses and climates should be done. This is a particularly urgent issue because of several upcoming standards that restrict the leakage of new houses.

## ACKNOWLEDGMENTS

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**TABLE 1:** Description of Test Houses

| House ID | City | Year of Construction | Floor Area ($m^2$) | Volume ($m^3$) | Window Type | Exterior Wall Finish | Interior Wall Finish |
|---|---|---|---|---|---|---|---|
| T1 | Truckee,CA | 1975 | 175 | 516 | F/HS | WS | PB |
| T2 | Truckee,CA | 1979 | 71 | 172 | HS | WS | PB |
| T3 | Truckee,CA | 1984 | 179 | 518 | F/HS | WS | PB/WP |
| S1 | Martinez,CA | 1974 | 171 | 450 | HS | S | PB |
| S2 | Oakland,CA | 1920 | 134 | 360 | DH | WS | P |
| S3 | Oakland,CA | 1915 | 128 | 320 | DH | WS | P |
| R1 | Reno,NV | 1940 | 75 | 188 | DH | S | P |
| R2 | Reno,NV | 1977 | 211 | 552 | HS | WS | PB |
| R3 | Reno,NV | 1965 | 117 | 283 | HS | WS | PB/WP |
| R4 | Sparks,NV | 1984 | 128 | 311 | HS | WS | PB |

WS = Wood Siding; S = Stucco; PB = Plaster Board;
P = Plaster; WP = Wood Paneling; DH = Wood Frame, Double-Hung;
HS = Metal Frame, Horizontal Sliding; F = Wood Frame, Fixed

**TABLE 2:** Summary of Variations in Effective Leakage Area and Air Flow at 50 Pa in Ten Houses in Three Climates

| House ID | ELA Range (%) | Month | | Pressurization | | | Depressurization | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | $Q_{50}$ Range (%) | Month | | $Q_{50}$ Range (%) | Month | |
| | | High | Low | | High | Low | | High | Low |
| T1 | 45 | Oct | Feb | 34 | Aug | Feb | 32 | Aug | Apr |
| T2 | 28 | Oct | Feb | 12 | Aug | Dec | 14 | Oct | Jan |
| T3 | 36 | Oct | Feb | 19 | Oct | Feb | 23 | Aug | Jan |
| S1 | 13 | Feb | May | 8 | Dec | Apr | 6 | Feb | Nov |
| S2 | 7 | Nov | Dec | 8 | Apr | Nov | 8 | Apr | Nov |
| S3 | 18 | Apr | Nov | 12 | Apr | Nov | 17 | May | Dec |
| R1 | 28 | Apr | Jan | 19 | Apr | Oct | 8 | Apr | Jan |
| R2 | 26 | Aug | Apr | 17 | Aug | Dec | 20 | Aug | Dec |
| R3 | 18 | Apr | Oct | 30 | Apr | Oct | 12 | Apr | Oct |
| R4 | 24 | May | Oct | 28 | Feb | Oct | 12 | Apr | Oct |

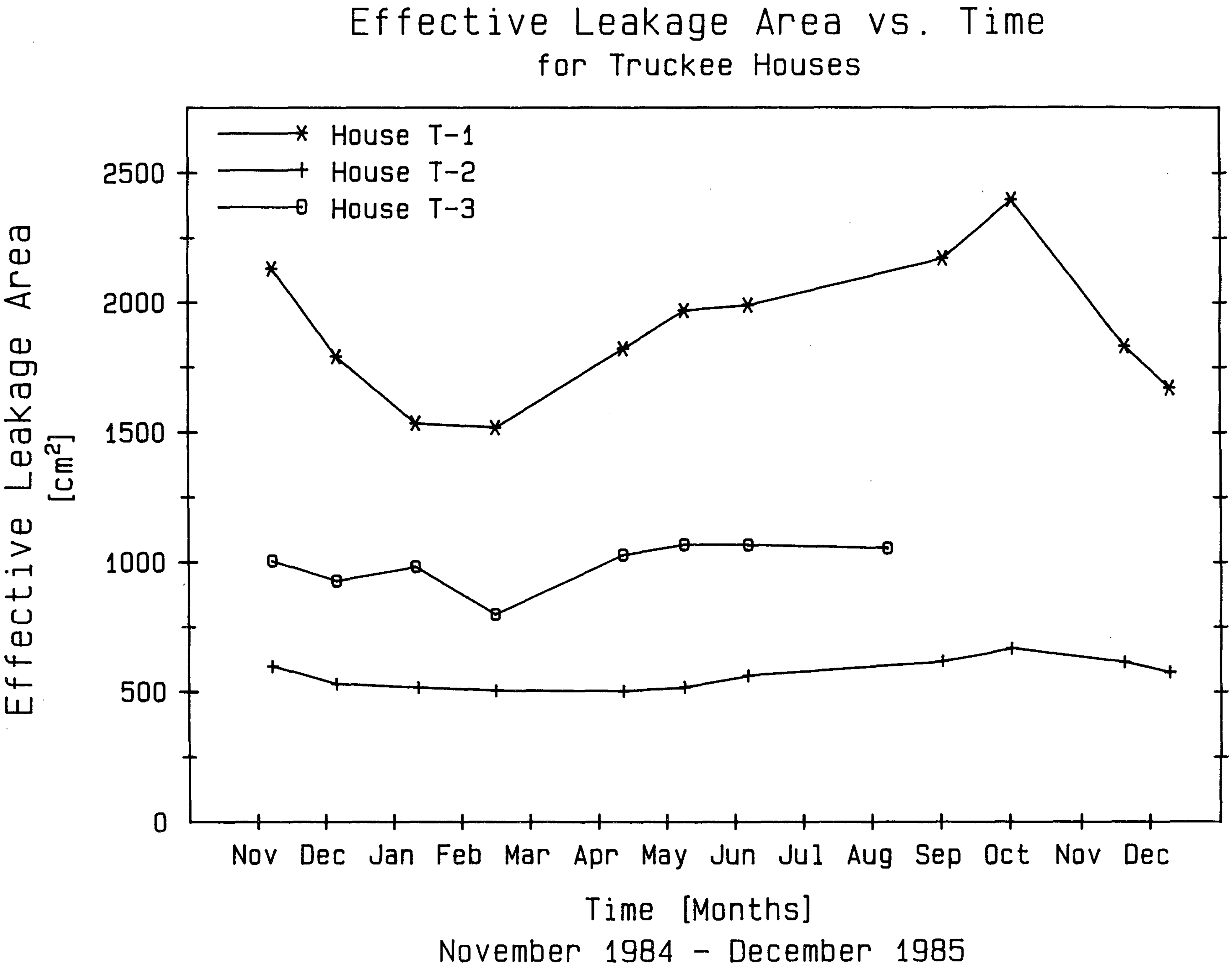

Fig. 1: Effective Leakage Area vs. Time for Truckee Houses

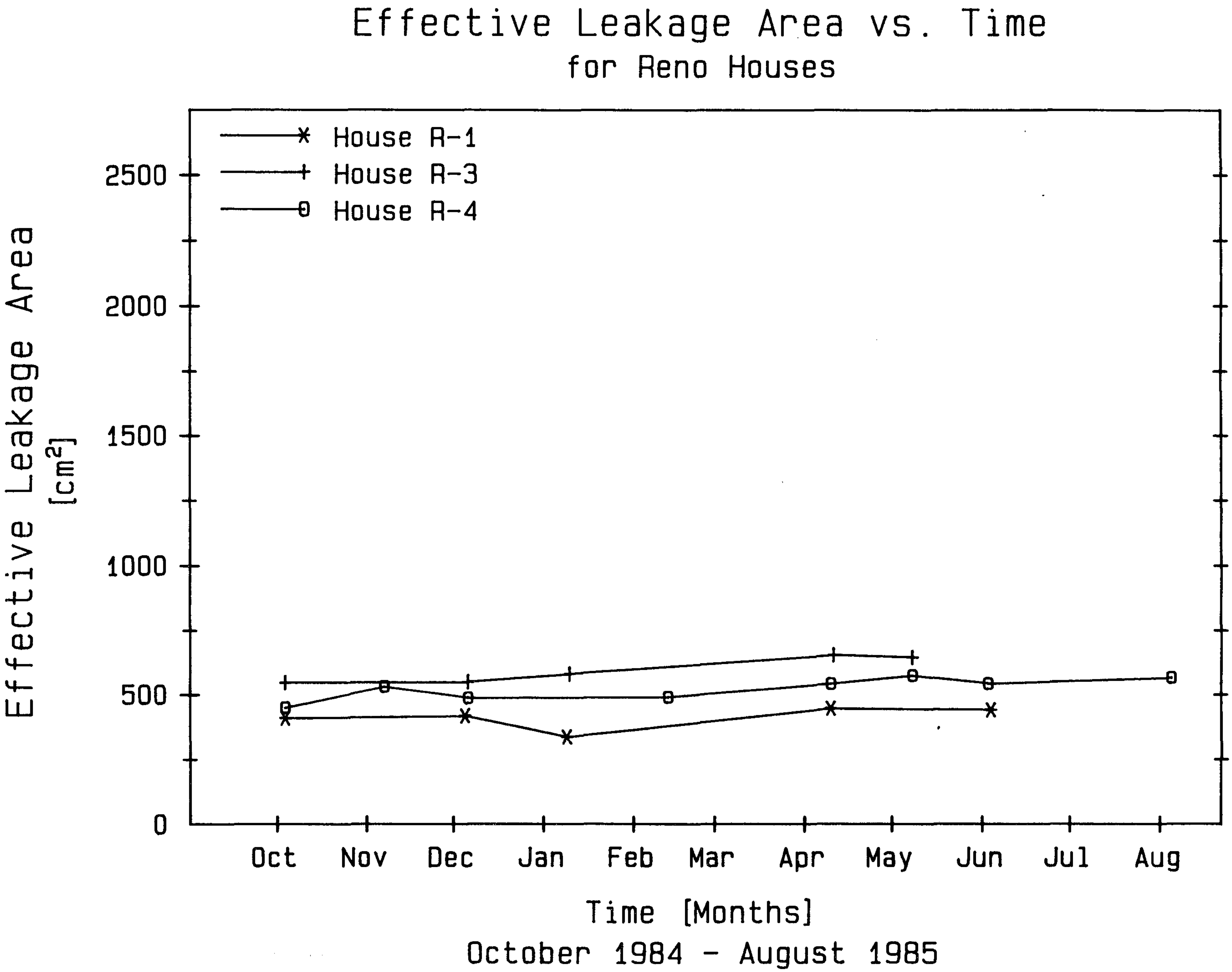

Fig. 2: Effective Leakage Area vs. Time for Reno Houses

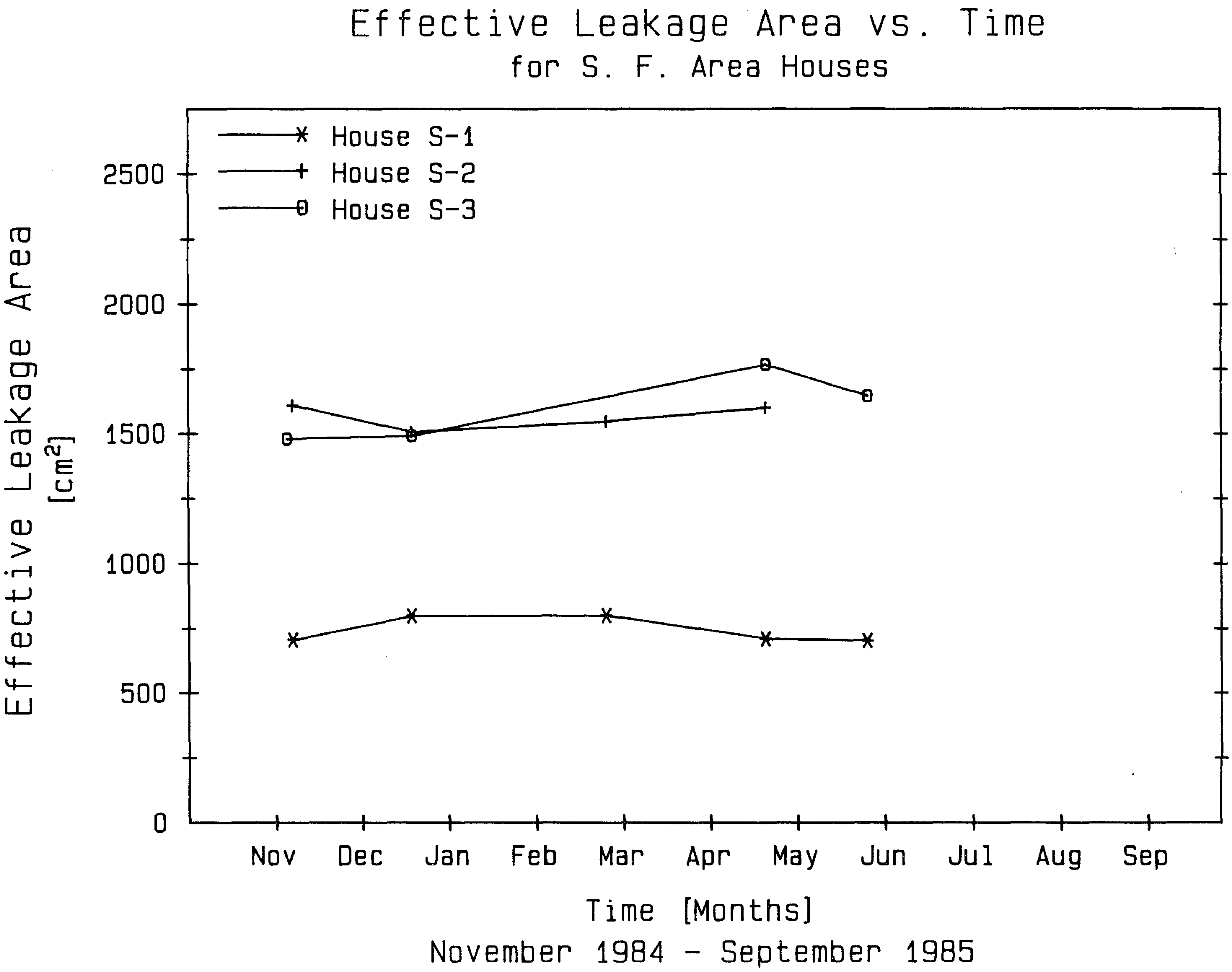

Fig. 3: Effective Leakage Area vs. Time for S.F. Bay Area Houses

## APPENDIX A

Table A-1: House T-1 in Truckee, CA

| | | | Pressurize | | | | | Depressurize | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Date | Average ELA ($m^2$) | Wind Speed (m/s) | K (L/s-$Pa^n$) | n | $R^2$ | ELA ($m^2$) | $Q_{50}$ (L/s) | K (L/s-$Pa^n$) | n | $R^2$ | ELA ($m^2$) | $Q_{50}$ (L/s) |
| 11/7/84 | .2131 | 1 | 222.8 | .65 | .9927 | .2130 | 2833 | 228.7 | .63 | .9956 | .2132 | 2689 |
| 12/5/84 | .1791 | 0-1 | 199.7 | .64 | .9981 | .1894 | 2442 | 166.8 | .69 | .9986 | .1688 | 2480 |
| 1/9/85 | .1535 | 0 | 160.8 | .69 | .9979 | .1639 | 2391 | 130.9 | .75 | .9921 | .1430 | 2461 |
| 2/13/85 | .1514 | 0-.5 | 130.0 | .73 | .9954 | .1399 | 2260 | 159.7 | .70 | .9880 | .1628 | 2469 |
| 4/10/85 | .1824 | 0-1 | 224.9 | .60 | .9951 | .2020 | 2352 | 162.3 | .68 | .9963 | .1627 | 2321 |
| 5/7/85 | .1969 | .5-1 | 229.7 | .62 | .9815 | .2113 | 2597 | 180.7 | .69 | .9961 | .1825 | 2687 |
| 6/4/85 | .1990 | 0-.5 | 250.2 | .58 | .9718 | .2187 | 2419 | 179.8 | .68 | .9809 | .1792 | 2571 |
| 8/29/85 | .2171 | .5-2 | 251.6 | .65 | .9945 | .2402 | 3199 | 177.5 | .74 | .9957 | .1939 | 3210 |
| 10/2/85 | .2396 | 0 | 266.2 | .62 | .9984 | .2444 | 3010 | 246.8 | .65 | .9981 | .2347 | 3138 |
| 11/20/85 | .1830 | 0-2 | 163.6 | .73 | .9708 | .1741 | 2845 | 199.6 | .65 | .9801 | .1919 | 2538 |
| 12/10/85 | .1669 | 1-2 | 164.7 | .69 | .9921 | .1663 | 2449 | 172.1 | .66 | .9897 | .1675 | 2276 |

Table A-2: House T-2 in Truckee, CA

| | | | Pressurize | | | | | Depressurize | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Date | Average ELA ($m^2$) | Wind Speed (m/s) | K (L/s-$Pa^n$) | n | $R^2$ | ELA ($m^2$) | $Q_{50}$ (L/s) | K (L/s-$Pa^n$) | n | $R^2$ | ELA ($m^2$) | $Q_{50}$ (L/s) |
| 11/7/84 | .0598 | 0-1 | 64.5 | .64 | .9938 | .0607 | 776.7 | 60.7 | .66 | .9981 | .0589 | 802.8 |
| 12/5/84 | .0529 | 0 | 53.0 | .68 | .9929 | .0528 | 724.7 | 53.4 | .68 | .9968 | .0529 | 741.4 |
| 1/10/85 | .0516 | 0 | 54.2 | .68 | .9984 | .0543 | 777.5 | 48.0 | .69 | .9952 | .0488 | 715.0 |
| 2/13/85 | .0503 | 0 | 45.6 | .71 | .9950 | .0478 | 733.6 | 53.0 | .68 | .9925 | .0527 | 732.8 |
| 4/10/85 | .0591 | .5-1.5 | 62.8 | .63 | .9975 | .0588 | 738.3 | 64.4 | .62 | .9987 | .0594 | 728.1 |
| 5/7/84 | .0516 | .5-1 | 53.1 | .68 | .9951 | .0529 | 758.9 | 49.1 | .70 | 1.0000 | .0502 | 750.3 |
| 6/4/85 | .0560 | 0-1 | 60.6 | .64 | .9934 | .0574 | 744.2 | 55.5 | .67 | .9944 | .0545 | 752.8 |
| 8/29/85 | .0616 | 1-1.5 | 61.1 | .67 | .9950 | .0599 | 818.3 | 66.7 | .64 | .9949 | .0633 | 818.3 |
| 10/2/85 | .0666 | 0-.5 | 71.8 | .62 | .9934 | .0660 | 810.0 | 73.2 | .62 | .9980 | .0672 | 821.4 |
| 11/20/85 | .0612 | 0-1 | 63.8 | .66 | .9937 | .0615 | 816.9 | 64.4 | .64 | .9947 | .0609 | 780.6 |
| 12/10/85 | .0573 | 0.5 | 53.2 | .69 | .9984 | .0536 | 772.5 | 64.6 | .64 | .9871 | .0610 | 782.5 |

Table A-3: House T-3 in Truckee, CA

| | | | Pressurize | | | | | Depressurize | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Date | Average ELA ($m^2$) | Wind Speed (m/s) | K ($L/s\text{-}Pa^n$) | n | $R^2$ | ELA ($m^2$) | $Q_{50}$ (L/s) | K ($L/s\text{-}Pa^n$) | n | $R^2$ | ELA ($m^2$) | $Q_{50}$ (L/s) |
| 11/7/84 | .1007 | 1-2 | 108.9 | .66 | 1.0000 | .1052 | 1421 | 98.5 | .66 | 1.0000 | .0961 | 1313 |
| 12/5/84 | .0929 | 0-1 | 100.5 | .67 | .9886 | .0986 | 1429 | 87.1 | .68 | .9993 | .0872 | 1257 |
| 1/9/85 | .0984 | 0 | 111.0 | .64 | .9975 | .1047 | 1344 | 95.1 | .66 | 1.0000 | .0921 | 1236 |
| 2/13/85 | .0798 | 0-1 | 76.3 | .73 | .9953 | .0813 | 1277 | 72.8 | .73 | .9994 | .0782 | 1261 |
| 4/10/85 | .1028 | 0-1 | 112.6 | .65 | 1.0000 | .1076 | 1408 | 100.3 | .66 | 1.0000 | .0980 | 1350 |
| 5/7/85 | .1068 | .5-1 | 107.5 | .68 | .9979 | .1070 | 1496 | 109.2 | .66 | .9982 | .1065 | 1454 |
| 6/4/85 | .1066 | 0-.5 | 110.9 | .66 | .9991 | .1078 | 1447 | 108.7 | .66 | 1.0000 | .1054 | 1420 |
| 8/5/85 | .1054 | 0-1 | 98.2 | .71 | 1.0000 | .1015 | 1537 | 110.1 | .68 | 1.0000 | .1092 | 1539 |
| 8/29/85 | .0986 | 0-1.5 | 102.4 | .69 | .9965 | .1039 | 1507 | 85.4 | .74 | .9965 | .0932 | 1558 |
| 10/2/85 | .1147 | 0-1 | 125.1 | .65 | 1.0000 | .1192 | 1543 | 111.8 | .67 | 1.0000 | .1101 | 1522 |

Table A-4: House S-1 in Martinez, CA

| | | | Pressurize | | | | | Depressurize | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Date | Average ELA ($m^2$) | Wind Speed (m/s) | K (L/s-$Pa^n$) | n | $R^2$ | ELA ($m^2$) | $Q_{50}$ (L/s) | K (L/s-$Pa^n$) | n | $R^2$ | ELA ($m^2$) | $Q_{50}$ (L/s) |
| 11/6/84 | .0705 | - | 58.0 | .74 | .9649 | .0629 | 976.7 | 86.4 | .61 | .9927 | .0780 | 924.2 |
| 12/19/84 | .0799 | 0-1 | 97.3 | .60 | .9976 | .0874 | 1056 | 75.1 | .65 | .9955 | .0723 | 964.7 |
| 2/22/85 | .0800 | .8-1 | 92.2 | .61 | 1.0000 | .0837 | 1008 | 80.9 | .64 | .9954 | .0763 | 978.9 |
| 4/18/85 | .0709 | 1-3 | 73.1 | .66 | .9914 | .0712 | 973.3 | 74.1 | .65 | 1.0000 | .0705 | 927.2 |
| 5/23/85 | .0701 | 2-3 | 74.4 | .66 | .9993 | .0725 | 1007 | 70.1 | .66 | 1.0000 | .0677 | 927.5 |

Table A-5: House S-2 in Oakland, CA

| | | | Pressurize | | | | | Depressurize | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Date | Average ELA ($m^2$) | Wind Speed (m/s) | K ($L/s\text{-}Pa^n$) | n | $R^2$ | ELA ($m^2$) | $Q_{50}$ (L/s) | K ($L/s\text{-}Pa^n$) | n | $R^2$ | ELA ($m^2$) | $Q_{50}$ (L/s) |
| 11/6/84 | .1607 | - | 179.7 | .61 | .9970 | .1621 | 1908 | 179.1 | .60 | 1.0000 | .1592 | 1852 |
| 12/19/84 | .1504 | 2 | 162.3 | .64 | .9895 | .1526 | 1948 | 159.0 | .63 | .9971 | .1482 | 1888 |
| 2/22/85 | .1546 | 2-4 | 184.0 | .61 | .9680 | .1678 | 2016 | 144.2 | .67 | .9960 | .1413 | 1991 |
| 4/18/85 | .1599 | .5-2.5 | 173.4 | .64 | 1.0000 | .1627 | 2072 | 168.1 | .63 | 1.0000 | .1571 | 2004 |

Table A-6: House S-3 in Oakland, CA

| | | | Pressurize | | | | | Depressurize | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Date | Average ELA $(m^2)$ | Wind Speed (m/s) | K $(L/s\text{-}Pa^n)$ | n | $R^2$ | ELA $(m^2)$ | $Q_{50}$ (L/s) | K $(L/s\text{-}Pa^n)$ | n | $R^2$ | ELA $(m^2)$ | $Q_{50}$ (L/s) |
| 11/4/84 | .1479 | - | 159.5 | .62 | 1.0000 | .1468 | 1784 | 162.8 | .62 | 1.0000 | .1490 | 1814 |
| 12/19/84 | .1492 | 1-3 | 187.9 | .60 | .9948 | .1669 | 1904 | 134.3 | .67 | 1.0000 | .1315 | 1811 |
| 4/18/85 | .1766 | .5-1.5 | 187.3 | .61 | 1.0000 | .1689 | 2018 | 211.5 | .58 | .9999 | .1843 | 2058 |
| 5/23/85 | .1644 | 0-1 | - | - | - | - | - | 173.0 | .64 | .9996 | .1644 | 2144 |

Table A-7: House R-1 in Reno, NV

| | | | Pressurize | | | | | Depressurize | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Date | Average ELA ($m^2$) | Wind Speed (m/s) | K (L/s-$Pa^n$) | n | $R^2$ | ELA ($m^2$) | $Q_{50}$ (L/s) | K (L/s-$Pa^n$) | n | $R^2$ | ELA ($m^2$) | $Q_{50}$ (L/s) |
| 10/3/84 | .0409 | - | 38.6 | .67 | .9953 | .0381 | 532.2 | 45.7 | .65 | .9948 | .0437 | 577.5 |
| 12/5/84 | .0417 | 0-.5 | 41.5 | .68 | .9983 | .0416 | 606.4 | 42.7 | .66 | .9987 | .0417 | 575.3 |
| 1/9/85 | .0337 | 1-3 | 39.1 | .69 | .9934 | .0396 | 583.6 | 22.9 | .82 | .9995 | .0278 | 567.2 |
| 4/10/85 | .0446 | 2-3 | 45.4 | .68 | .9972 | .0452 | 645.8 | 44.3 | .68 | .9981 | .0439 | 615.8 |
| 6/4/85 | .0440 | 2-4 | 46.1 | .63 | .9867 | .0431 | 541.9 | 47.9 | .63 | .9966 | .0449 | 569.4 |

Table A-8: House R-2 in Reno, NV

| | | | Pressurize | | | | | Depressurize | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Date | Average ELA ($m^2$) | Wind Speed (m/s) | K (L/s-Pa$^n$) | n | $R^2$ | ELA ($m^2$) | $Q_{50}$ (L/s) | K (L/s-Pa$^n$) | n | $R^2$ | ELA ($m^2$) | $Q_{50}$ (L/s) |
| 11/8/84 | .2459 | 3-10 | 325.7 | .50 | .9629 | .2533 | 2303 | - | - | - | - | - |
| 12/6/84 | .1993 | 0-.5 | 249.2 | .56 | .9965 | .2103 | 2194 | 211.6 | .60 | .9946 | .1882 | 2213 |
| 4/10/85 | .1897 | 1-2 | 218.9 | .61 | .9779 | .1975 | 2380 | 185.3 | .67 | .9846 | .1818 | 2548 |
| 8/5/85 | .2465 | 0-4 | 303.4 | .55 | .9809 | .2543 | 2609 | 269.9 | .59 | .9620 | .2387 | 2714 |

Table A-9: House R-3 in Reno, NV

| | | | Pressurize | | | | | Depressurize | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Date | Average ELA $(m^2)$ | Wind Speed (m/s) | K $(L/s\text{-}Pa^n)$ | n | $R^2$ | ELA $(m^2)$ | $Q_{50}$ (L/s) | K $(L/s\text{-}Pa^n)$ | n | $R^2$ | ELA $(m^2)$ | $Q_{50}$ (L/s) |
| 10/3/84 | .0546 | - | 59.8 | .63 | .9943 | .0558 | 703.2 | 51.9 | .70 | .9964 | .0533 | 791.1 |
| 12/6/84 | .0547 | 0-.5 | 53.0 | .70 | .9975 | .0543 | 803.9 | 54.4 | .69 | .9952 | .0551 | 793.1 |
| 1/10/85 | .0580 | 0-1 | 56.2 | .73 | .9799 | .0602 | 925.0 | 53.0 | .72 | .9955 | .0557 | 856.7 |
| 4/11/85 | .0654 | 0-1 | 76.2 | .64 | .9999 | .0724 | 946.9 | 56.5 | .70 | .9939 | .0583 | 890.6 |
| 5/8/85 | .0644 | 3-5 | 69.3 | .63 | .9655 | .0649 | 805.6 | - | - | - | - | - |

Table A-10: House R-4 in Sparks, NV

| | | | Pressurize | | | | | Depressurize | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Date | Average ELA ($m^2$) | Wind Speed (m/s) | K ($L/s\text{-}Pa^n$) | n | $R^2$ | ELA ($m^2$) | $Q_{50}$ (L/s) | K ($L/s\text{-}Pa^n$) | n | $R^2$ | ELA ($m^2$) | $Q_{50}$ (L/s) |
| 10/4/84 | .0450 | - | 44.7 | .66 | .9901 | .0437 | 591.1 | 44.5 | .71 | .9962 | .0462 | 706.1 |
| 11/7/84 | .0530 | 3-4 | 52.1 | .67 | .9958 | .0513 | 719.2 | 56.7 | .66 | .9999 | .0547 | 733.3 |
| 12/6/84 | .0488 | 2-5 | 52.7 | .68 | .9950 | .0528 | 738.6 | 41.9 | .73 | .9940 | .0447 | 715.6 |
| 2/13/85 | .0489 | 1-2 | 35.5 | .79 | .9959 | .0414 | 785.0 | 57.8 | .66 | .9983 | .0563 | 771.7 |
| 4/10/85 | .0542 | 2-3 | 48.6 | .70 | .9906 | .0496 | 730.8 | 61.7 | .65 | .9963 | .0588 | 794.4 |
| 5/8/85 | .0574 | 0-1 | 60.6 | .64 | .9964 | .0576 | 745.8 | 59.8 | .65 | .9968 | .0572 | 763.1 |
| 6/3/85 | .0543 | 2 | 50.1 | .67 | .9949 | .0492 | 673.3 | 62.9 | .64 | .9981 | .0594 | 772.2 |
| 8/5/85 | .0567 | 0-.5 | 57.0 | .65 | .9954 | .0546 | 712.2 | 63.4 | .63 | .9987 | .0587 | 723.1 |

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