

Lawrence Berkeley National Laboratory

LBL Publications

Title

CALCULATING INFILTRATION: IMPLICATIONS FOR A CONSTRUCTION QUALITY STANDARD

Permalink

<https://escholarship.org/uc/item/5211v66c>

Author

Grimsrud, D.T.

Publication Date

1983-04-01

c.2



Lawrence Berkeley Laboratory

UNIVERSITY OF CALIFORNIA

RECEIVED

ENERGY & ENVIRONMENT DIVISION

LAWRENCE
BERKELEY LABORATORY

JUL 5 1983

LIBRARY AND
DOCUMENTS SECTION

Presented at the ASHRAE Conference, Thermal Performance of Exterior Envelopes of Buildings II, Las Vegas, NV, December 6-9, 1982

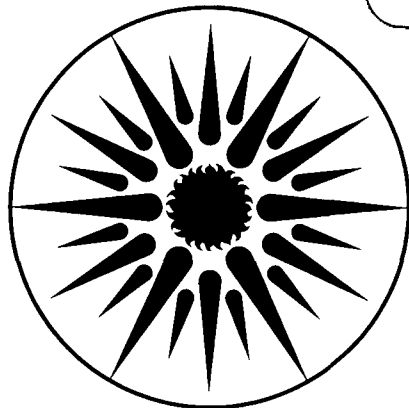
CALCULATING INFILTRATION: IMPLICATIONS FOR A CONSTRUCTION QUALITY STANDARD

D.T. Grimsrud, M.H. Sherman, and R.C. Sonderegger

April 1983

TWO-WEEK LOAN COPY

This is a Library Circulating Copy which may be borrowed for two weeks. For a personal retention copy, call Tech. Info. Division, Ext. 6782.



**ENERGY
AND ENVIRONMENT
DIVISION**

LBL-9416
c.2

DISCLAIMER

This document was prepared as an account of work sponsored by the United States Government. While this document is believed to contain correct information, neither the United States Government nor any agency thereof, nor the Regents of the University of California, nor any of their employees, makes any warranty, express or implied, or assumes any legal responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by its trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof, or the Regents of the University of California. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof or the Regents of the University of California.

Presented at the ASHRAE/DOE
Conference on Thermal Performance of the Exterior Envelopes of Buildings II, Las Vegas NV, December 6-9, 1982.

LBL-9416
EEB-epb 82-1

CALCULATING INFILTRATION: IMPLICATIONS
FOR A CONSTRUCTION QUALITY STANDARD

D.T. Grimsrud, M.H. Sherman, and R.C. Sonderegger

Energy and Environment Division
Lawrence Berkeley Laboratory
University of California
Berkeley, California 94720

April 1983

This work was supported by the Assistant Secretary for Conservation and Renewable Energy, Office of Building Energy Research and Development, Building Systems Division of the U.S. Department of Energy under Contract No. DE-AC03-76SF00098.

Calculating Infiltration: Implications
for a Construction Quality Standard*

D.T. Grimsrud[†] M.H. Sherman[†] R.C. Sonderegger[†]

ABSTRACT

Extensive work in infiltration measurement and modeling has led to a simple method to calculate the leakage area of a house regardless of design or weather conditions. The leakage area, in turn, is used in the LBL infiltration model to calculate infiltration for any weather condition. This method, which uses fan pressurization to measure the leakage area, has been used in a survey of over 300 houses located throughout North America. This paper presents the results of that survey and suggests that the present capability in infiltration modeling offers an excellent framework for an air leakage standard for residential building. Examples of the interpretation of such a standard are described based on the ventilation rates adopted in ASHRAE Standard 62-1981. The results of the interpretations illustrate differences in structural requirements that will occur when such a standard is applied to several ventilation system designs.

Keywords: air infiltration, building standards, ventilation, air leakage, infiltration measurements, infiltration modeling.

INTRODUCTION

Several issues must be considered in setting standards for acceptable building performance. Some are societal and institutional while others are purely technical. This paper focuses on technical issues associated with the development of a standard for air tightness in residential buildings.

Two major technical issues must be addressed in constructing such a standard. The first is the question of measurement and control. If an acceptable level of air tightness is specified, how is this translated to a ventilation rate? How can the air tightness value be measured? How can a designer or builder modify a building design or construction practice to achieve this value?

The second issue is the ventilation specification. Before a ventilation rate can be translated into an air tightness value, the amount of ventilation air required to assure acceptable indoor air quality must be known.

This paper focuses on the former issue. We show that a technique that is currently available to calculate infiltration rates of buildings contains the information required to support a standard. Examples of the calculation procedure are presented for many types of houses found in different areas of the country.

D.T. Grimsrud, M.H. Sherman, and R.C. Sonderegger,
Energy and Environment Division,
Lawrence Berkeley Laboratory,
University of California,
Berkeley, CA 94720.

The research described in this paper was done using SI units; only these units are incorporated in this paper. Table 1 gives conversion factors to convert important quantities in this paper to the inch-pound system of units.

CALCULATING INFILTRATION

Infiltration, the random flow of air through openings in the building shell caused by weather-induced pressures, can be measured using standard tracer gas techniques.¹ The interpretation of the tracer gas measurement is limited to the weather conditions that are present during the measurement. Extrapolation of an individual measurement to predict the infiltration for an entire heating season is not a well-defined procedure.

For this reason an alternative procedure has been developed to find the average infiltration rate of a structure for an arbitrary period of time. The procedure is based upon the observation that infiltration, a flow problem, can be broken into two parts. Pressures caused by local weather conditions cause airflow through openings in the building envelope. Calculating this flow then requires information about (1) the pressures and (2) the openings in the envelope.

Consider the latter problem first. A technique known as fan pressurization can be used to measure the total leakage of the building envelope. This procedure recently was incorporated into ASTM Standard E779.² A fan mounted on an adjustable wooden plate is sealed into a doorway of a house to be tested. The fan speed, which can be adjusted using a DC motor and controller, is varied to produce a pressure drop, ΔP , across the building envelope. The flow through the fan required to produce this pressure difference is measured and the process repeated for fixed pressure increments to produce a curve relating the pressure drop across the envelope to the flow required to produce it. The fan direction is reversed and a corresponding curve of depressurization versus flow is obtained in the same manner. Typical data obtained using this measurement procedure are shown in Fig. 1.

The data contained in Fig. 1 can be interpreted in several ways. Since the pressures that typically drive infiltration most frequently occur in the range of -5 to 5 Pa we use the average flow at 4 Pa Q_4 , to compute a quantity we call the effective leakage area. This is defined by Eq 1.

$$L_o = \frac{Q_4}{\sqrt{2\Delta P/\rho}} \quad (1)$$

where

L_o is the effective leakage area [m^2]
 Q_4 is the flow at 4 Pa [m^3/s]
 ΔP is the pressure causing this flow [4 Pa]
 ρ is the density of air [$1.2 \text{ kg}/m^3$]

The effective leakage area can be interpreted physically as an approximation of the total area of physical openings in the building shell that allows airflow (infiltration) to occur.

A simplified technique to obtain the effective leakage area that is applicable for field use is shown in Fig. 2. Empirically, we find that in almost all cases in which leakage curves are measured, the data are accurately represented by an equation of the form

$$Q = K(\Delta P)^n \quad (2)$$

where

Q is the flow through the fan [m^3/h]
 K and n are empirical constants
 ΔP is the pressure difference across the building shell

Data represented by Eq 2 will fall on a straight line when plotted on graph paper using logarithmic scales on both axes. Extrapolation to find the flow at 4 Pa simply requires extending the line to intersect the 4-Pa pressure line. From this point read directly across the graph to the right-hand axis to find the leakage area in cm^2 . (Leakage areas in this paper are reported consistently in cm^2 . The rationale for this choice is revealed by consulting Table 5. This table gives, in addition to the leakage areas of over 300 houses, a normalized leakage area called the "specific leakage area". We find that dividing the leakage area (expressed in cm^2) by the floor area of the house (in m^2) gives a number between about 1 and 10 (with units of cm^2/m^2) that is a "figure-of-merit" for the leakage of a residence.)

The other half of the infiltration problem, determining the surface pressures that drive airflow through the openings measured by fan pressurization, is somewhat more complicated. The details of the derivation of the expressions used below have been presented elsewhere.³ This problem also has two parts, (1) calculating the pressures caused by indoor-outdoor temperature differences leading to the "stack effect" and (2) the pressures caused by the wind striking the building, the "wind effect."

Infiltration for the two regimes is expressed as

$$Q_{\text{stack}} = L_o f_s (\Delta T)^{1/2} \quad (3)$$

and

$$Q_{\text{wind}} = L_o f_w v \quad (4)$$

where

Q_{stack} and Q_{wind} are stack- and wind-dominated infiltration, respectively [m^3/s]
 L_o is the effective leakage area of the house [m^2]
 ΔT is the indoor-outdoor temperature difference [K]
 v is the measured wind speed [m/s]
 f_s is the stack parameter [$\text{m}/\text{s} \cdot \text{K}^{1/2}$]
 f_w is the wind parameter

These equations display the inherent simplicity of the model. The model predicts that the infiltration separates into the simple product of terms (L_o , f_w , and f_s) that depend on the structure of the house and its surrounding terrain but are independent of the weather and of the terms (ΔT , v) that depend only on the weather.

The terms f_s and f_w are complex expressions, but their interpretations are straightforward. Two additional expressions are introduced. The fraction of the total leakage found on horizontal planes, i.e., the sum of the floor and ceiling leakage areas divided by the total is called R.

$$R = \frac{L_c + L_f}{L_o} \quad (5)$$

The fractional difference between the ceiling leakage area L_c and floor leakage area L_f is called X:

$$X = \frac{L_c - L_f}{L_o} \quad (6)$$

The stack parameter is expressed in terms of R, X, the acceleration of gravity, g , the absolute indoor temperature, T , and the height of the ceiling above grade, H_h , as

$$f_s = \frac{1}{3} \left(1 + \frac{R}{2} \right) \left[1 - \frac{x^2}{(2 - R)^2} \right]^{3/2} \left(\frac{gH_h}{T} \right)^{1/2} \quad (7)$$

The wind pressures on the surface of the house depend upon the terrain class and the shielding class of the structure. The terrain class is affected by the large-scale obstructions in the several-square-km region of the house while the shielding class is determined by the number of trees, fences, and other buildings located in the immediate vicinity of the house.

The wind speed at a measurement site in the region is first corrected to a speed at a standard height using the terrain class at the measurement site, then is adjusted back to the wind speed at the height of the house using the terrain class of the house. Combining all the terms we have

$$f_w = C' (1 - R)^{1/3} \left[\frac{d_h (H_h/10)^{y_h}}{d_m (H_m/10)^{y_m}} \right] \quad (8)$$

where

C' is the shielding coefficient for the house site
 R is the fractional horizontal leakage area
 d_h and y_h are terrain constants for the house
 H_h is the height of the house from grade to the top of the living space [m]
 d_m and y_m are terrain constants for the wind measurement site
 H_m is the height of the wind measurement site [m]

The values of d and y for standard terrain classes are presented in Tab. 2. Most airport wind-speed measurements are made in terrain class II while most houses are located in terrain classes III and IV. The generalized shielding coefficients are presented in Tab. 3.

The total infiltration is obtained by combining the surface pressures point-by-point over the building envelope and calculating the flows that result. We have adopted a model that assumes the flows are proportional to the square root of the pressure difference.⁴ Therefore, we combine the two flows in the same manner:

$$Q = \sqrt{Q_{\text{stack}}^2 + Q_{\text{wind}}^2} \quad (9)$$

or

$$Q = L_o \sqrt{f_s^2 \Delta T + f_w^2 v_m^2} \quad (10)$$

where

Q is the infiltration [m^3/s]
 L_o is the effective leakage area [m^2]
 f_s is the stack parameter [$m/s \cdot K^{1/2}$]
 ΔT is the indoor-outdoor temperature difference [K]
 f_w is the wind parameter
 v_m is the measured wind speed [m/s]

Equation 10 shows the explicit proportionality between the effective leakage area and the infiltration.

The model has been validated in several studies in the United States and Japan.⁵⁻⁷ These field validations allow us to place confidence limits on the ability of the model to predict average infiltration results. Using short term (one hour) averages for ΔT and v_m in Eq 10, the relative standard deviation of the infiltration is approximately 35%. This value decreases as the averaging time increases. When one-week weather averages are used, the

relative standard deviation is approximately 20%.

EXAMPLE CALCULATIONS

Example Calculation: An Individual House

The use of the predictive model of section III is illustrated by computing the infiltration for the heating season (November through March) for a house located in Albany, New York.

1. Find the effective leakage area. Using Fig. 2 we find that the flow at 4 Pa is $620 \text{ m}^3/\text{h}$. This gives an effective leakage area of

$$L_o = \frac{620}{(3600)(2.58)} = 6.7 \times 10^{-2} \text{ m}^2 \quad (11)$$

or 670 cm^2 .

2. Find the stack parameter. Before computing the stack parameter given in Eq 7 we must know the fractional horizontal leakage R (Eq 5), the ceiling-floor leakage difference X (Eq 6), the height of the ceiling above grade, H_h , and the absolute indoor temperature T.

It is difficult to measure either R or X with any precision. Fully 50 to 75% of the leakage area in a house is distributed throughout the structure as background leakage and cannot be localized by any simple measurement.⁸ We therefore recommend that as the leakage characteristics of the house are measured, major leakage sites be identified and their locations (ceiling, walls, or floor) and sizes noted. After the measurements are completed the sum of the leakage areas noted should be subtracted from the total area measured with the aid of the fan. We now assume that the remainder, the background leakage area, is uniformly distributed around the surface of the house, i.e., that the background leakage areas are proportional to the surface areas of their respective components.

To continue our example we assume that 100 cm^2 was identified in the ceiling and 60 cm^2 in the walls. The house is a one-story house having 111 m^2 (1200 ft^2) (9.1 m by 12.2 m) of floor and ceiling area. The surface area of the outside walls is 104 m^2 (1120 ft^2). Since there are 670 cm^2 of total leakage, $670 - 160 = 510 \text{ cm}^2$ is background leakage. The total surface area is 326 m^2 so the background leakage is divided into $(510)(111)/326 = 174 \text{ cm}^2$ in the floor and ceiling and 162 cm^2 in the walls. The total effective leakage areas of the walls, floor, and ceiling are therefore 220, 170, and 270 cm^2 , respectively (rounding off to the nearest 10 cm). The values of R and X are therefore 0.66 and 0.15, respectively. The height of the ceiling of the living space above grade is assumed to be 3.0 m (10 ft). The average indoor temperature is $20^\circ\text{C} = 293 \text{ K}$. Gathering these data together

$$f_s = (0.333)(1.33) \left[1 - 0.01 \right]^{3/2} \left[\frac{(9.8)(3.0)}{293} \right]^{1/2} = 0.14 \frac{\text{m}}{\text{s} \cdot \text{K}^{1/2}}$$

3. Find the wind parameter. Descriptions of the local shielding around the house and the value of the shielding class that results are given in Tab. 3. In this case there are several large trees in the yard surrounding the house but no other close buildings. Shielding Class III is chosen where C is given the value of 0.25.

The wind speed is measured at an airport several miles from the house. Airport wind measurement sites are typically terrain class II; the measurement height of the wind speed is 10 m. From Tab. 2 $d_m = 1.00$ and $y_m = 0.15$. The house is located in terrain class III with $d_h = 0.85$ and $y_h = 0.20$. The height of the house, again, is 3.0 m . We have

$$f_w = (0.25)(1 - 0.66)^{1/3} \left[\frac{(0.85)(0.30)^{0.20}}{(1.00)(1.00)^{0.15}} \right]$$

or

$$f_w = 0.12.$$

4. Compute the infiltration. Our basic expression for infiltration is now

$$Q = (0.067) \left[(0.14)^2 \Delta T + (0.12)^2 v_m^2 \right]^{1/2} \quad (12)$$

where

Q is infiltration [m^3/s]

ΔT is indoor-outdoor temperature difference [K]

v_m is measured wind speed [m/s]

To compute the average infiltration for an interval, we must know the average temperature difference and wind speed for that interval. In Albany, for example, the average values of ΔT and v_m for the November-March heating season are 42.5 °F (23.6 °C) and 11.6 mph (5.2 m/s). The average infiltration for this house is thus

$$Q = (0.067) \left[(0.14)^2 (23.6) + (0.12)^2 (5.2)^2 \right]^{1/2}$$

$$Q = 0.062 \text{ m}^3/\text{s} = 223 \text{ m}^3/\text{h}$$

The house has a volume of 9.1 by 12.2 by 2.4 = 266 m^3 (9600 ft^3). Therefore we predict that this house in Albany has an average infiltration for the heating season of 223/266 = 0.84 air changes per hour (ach).

Several comments should be made about the calculation. The calculation assumes that the leakage area of the house is constant through this time period. This is not the case, in fact, since occupants open windows and doors, which adds to the infiltration of the structure. There have been no direct measurements of the influence of occupants on the infiltration of a structure. We estimate, based upon our observations of living habits, that the occupants add 0.10 to 0.20 ach to the infiltration we have predicted.

Our second comment concerns the role of the leakage area in the calculation. It assumes the role of a scale constant and could as well be omitted from the calculation. We would then compute an infiltration per unit leakage area for our house in that environment. An example of this is presented in the next section.

Example Calculation: The Reference House

The same calculation is now repeated for a standard house. However, in this case we specify neither the leakage area nor the location. The house will then be assumed to be moved to each of the 59 U.S. locations that have Test Reference Year weather tapes available. The infiltration of this test house will be computed in each of these cities.

The house is assumed to have an interior temperature of 20°C, a height of 2.5 m, leakage distributions R = 0.5 and X = 0, and to belong to terrain class III and shielding class III. With these assumptions:

$$f_s = 0.120 \text{ m/s} \cdot K^{1/2}$$

$$f_w = 0.128$$

The ratio of infiltration to effective leakage area is then

$$\frac{Q}{L_o} = [(0.120)^2 \Delta T + (0.128) v_m^2]^{1/2}$$

This expression, with average weather data for Albany, New York, for the November-March heating season, gives an infiltration per-unit-leakage area of $0.31 \text{ m}^3/\text{h}\cdot\text{cm}^2$. This is the combination of a stack term ($0.21 \text{ m}^3/\text{h}\cdot\text{cm}^2$) and a wind term ($0.23 \text{ m}^3/\text{h}\cdot\text{cm}^2$). By multiplying the $0.31 \text{ m}^3/\text{h}\cdot\text{cm}^2$ by the specific heat of air per-unit-volume and by the degree-hours using the base temperature of 65°F (18.3°C) for Albany, we obtain a seasonal heating load per-unit-leakage area of $30.7 \text{ MJ}/\text{cm}^2$.

Table 4 shows these figures for Albany, New York and for an additional 58 cities across the United States. Weather tapes for Test Reference Years (TRY tapes) were used to gather the necessary temperature and wind speed data. Based on the same data, infiltration contour maps of the U.S. were constructed. Fig. 3 shows the curves of constant infiltration per-unit-leakage area in $\text{m}^3/\text{h}\cdot\text{cm}^2$. Figure 4 shows similar contours for heating load. As in Tab. 4, all figures are normalized per-unit-leakage area.

It is interesting to note that the variation in infiltration per-unit-leakage area across the United States is relatively small for this reference case. It is typically a factor of two for stack-driven infiltration and a factor of three for wind-driven infiltration. As expected, stack-driven infiltration is highest in New England and the North Central States, where the weather is coldest, and lowest near the Gulf of Mexico and in California. Wind-driven infiltration is highest in Montana and lowest in Southern California and Arizona. The combined infiltration per-unit-leakage area is shown in Fig. 3. The highest values are encountered in Montana, closely followed by those around the Great Lakes. The high infiltration values reach down through the midwest and taper off toward east and west. A similar trend, but more pronounced, is found in Fig. 4, which shows the seasonal infiltration heating load per-unit-leakage area. Here, typical values are $40 \text{ MJ}/\text{cm}^2$ for the northern United States, $15 \text{ MJ}/\text{cm}^2$ for the east coast, and $8 \text{ MJ}/\text{cm}^2$ for the west coast, the Gulf of Mexico, and Florida.

Example Calculation: Survey of Published Data

A third example of the use of the calculation procedure is to examine data in the published literature and determine average infiltration values for the November-March heating season.

Published measurements of infiltration rates in houses go back to the 1957 paper of Bahnfleth, Moseley, and Harris that reported the results of 37 tests in two Illinois residences.⁹ Since the publication of that paper we have identified measurements sets in 312 other houses in Canada and the United States that are suitable for inclusion in this summary. Although other measurement sets exist, at this time the authors have insufficient information about the measurement details to include the results here.

The average infiltration values that are included are those calculated for five winter heating months, November through March. In this season the results are least likely to be affected by occupant behavior such as opening windows. The values were obtained in three ways. The first and most reliable, although possible only in a small number of cases, was to use the values supplied by the authors of the reports directly. These are labeled A in the calculation procedure column of the data table below. For our purposes, the research had to include either sufficient data for computing the average or had to include an empirical fit of the results that related weather conditions and infiltration rates. In the latter case if the weather data used in the empirical fit were weather data that are regularly published, it is possible to use the weather values for the winter heating season to compute the average infiltration. We estimate that in this case, the uncertainty in the average infiltration is about 10%.

In the majority of cases treated in this summary, fan pressurization data are available that allow the effective leakage area of the houses to be calculated. These cases are labeled B in the calculation procedure column of the table. Then, using our model that relates leakage areas and local weather to average infiltration values, the average winter infiltration values are computed. We estimate that the values computed using this procedure have an uncertainty of about 20%.

The third procedure, labeled C below, the least reliable but included to add additional cases to this small sample set, uses results of short-term infiltration measurements combined with the local weather conditions to back-solve for the effective leakage area. This value is then combined with the house characteristics and local weather data to produce an estimate of the average infiltration. We estimate the uncertainty in the averages obtained in this manner to be 30 to 40%.

The individual columns in Tab. 5 are:

1. The reference and its publication date.
2. The state or province in which the house is found.
3. The house code is the code used in the reference.
4. The construction date of the house (if known).
5. The house type: one-story (1), two-story (2), split-level (SL).
6. Floor area of the conditioned space (m^2 , $1 m^2 = 10.8 ft^2$).
7. The volume of the conditioned space (m^3 , $1 m^3 = 35.3 ft^3$).
8. The effective leakage area of the house (cm^2).
9. The ratio of the effective leakage area to the floor area of the house, called the "specific leakage area" (cm^2/m^2).
10. The infiltration averaged over the five-month period from November through March (ach).
11. Calculation procedure A implies long-term infiltration values were available to compute the average infiltration during the heating season. Procedure B uses fan pressurization measurements to determine the leakage area of the house. Procedure C begins with a short-term measurement of infiltration. The leakage area, which yields an equivalent infiltration is found and then serves as the basis for extending the result to the entire heating season.

The average seasonal infiltration values of 312 houses are presented in Tab. 5. The mean of the seasonal infiltration values is 0.63 ach. A better measure of this skewed distribution is the median, 0.50 ach. Fully 50% of the houses in this sample have infiltration values below a value that is frequently used as an acceptable ventilation rate for houses.

A histogram of the infiltration results is presented in Fig. 5. Also shown are results of measurements of 266 houses reported by Grot and Clark.²⁸ While the Grot and Clark results are not seasonal averages but rather individual measurements, the general shapes of the distributions are similar. The broader distribution of the Grot and Clark results is partly the result of inclusion of all individual measurements (averaging all measurements for a single house to give a single number would cause the distribution to be sharper) and partly a difference in the housing stock sampled.

A CONSTRUCTION QUALITY STANDARD FOR AIR TIGHTNESS

The first part of this paper summarized calculation procedures using the LBL infiltration model. Examples were provided showing the infiltration behavior of a reference house in different U.S. locations, using the model to extend information available in the literature. This second section uses the model as the basis for a construction quality standard for air tightness in new residential construction in the United States.

Construction Quality

Construction quality is becoming an increasingly important concept in the building industry. As materials, time, energy, and investment capital become more scarce, steps must be taken to use each more effectively. The particular focus of this paper is increasing the efficiency of energy use in buildings through improved construction quality.

Infiltration accounts for up to 40% of the energy use in small, envelope-dominated buildings such as residences. Reducing this energy use is the goal of a construction quality standard for air tightness in these buildings. In addition to reducing energy use, increasing air tightness also (1) increases thermal comfort, (2) improves the control of moisture migration that results from convective flow of water vapor through openings in the building shell, and (3) reduces noise transmission from the exterior into occupied portions of the building.

The most important benefit of improved air tightness is the control it affords the building designer and operator in supplying the desired amount of ventilation to occupied spaces in the building. With improved air tightness, ventilation can be uniform throughout the building, not randomly dependent on the locations of major leakage sites in the building shell. Furthermore, it can be uniform in time as well, independent of the vagaries of the weather.

A Standard for Air Tightness

We propose that a construction quality standard for air tightness in buildings be developed to provide guidance for designers and builders who wish to improve the performance of their buildings. A standard is but one mechanism to improve construction quality. However, if it also is a voluntary, consensus standard it can be used in several different ways to achieve the desired increase in construction quality.

This is an appropriate time to consider introduction of a standard. Infiltration and air leakage in buildings have been studied extensively for several years. It is now possible to describe a simplified test procedure to measure air leakage; this, in turn, can be related to the average infiltration of the structure. It is essential that such an interpretation of a compliance test be possible.

Ventilation Rate Targets

An air tightness standard must be interpretable in terms of a ventilation rate. Studies of indoor air quality during the past five years have shown that there is no single ventilation rate that will assure adequate air quality in all houses.²⁹ Pollutant concentrations in buildings depend on both the strength of the pollutant sources and on the ventilation rate in the spaces. Specifying only a ventilation rate without knowledge of source strengths cannot assure air quality within a building.

However, ventilation systems are being designed and buildings containing these systems are being built. Since we will never have sufficient information about sources to assure adequate air quality in all buildings we recommend that we proceed with a provisional air tightness standard based on best current information concerning ventilation rates that yield acceptable air quality in most buildings. As additional information is obtained about pollutant concentrations, source strengths, and health effects, these ventilation rates can be modified.

For purposes of this paper, then, we adopt the ventilation rates presented in ASHRAE Standard 62-81 as target ventilation values for new residences.⁹⁰ This standard, as currently understood, will yield ventilation values that will provide adequate air quality in most houses. ASHRAE Standard 62-81 prescribes ventilation values in single-family residences of 10 cfm (18 m³/h) per room independent of room size. In addition, 100 cfm (180 m³/h) ventilation capacity is required in kitchens for intermittent use (as required) while 50 cfm (90 m³/h) ventilation capacity is required in bath and toilet rooms.

These values imply that in a house having a floor area of 139 m² (1500 ft²) with seven rooms, the prescribed ventilation rate is 126 m³/h (70 cfm) without the use of the ventilation fans in the kitchen or bathrooms. If the house has a standard 2.4 m (8 ft) ceiling, this translates to an air change rate of 0.37 ach. Use of the ventilation fans for one hour per day in each of two bathrooms and the kitchen exhaust fan for 2 hr/day adds an average of 0.06 ach to the basic rate. Other occupant activities may add another 0.1 ach yielding a total value slightly larger than 0.50 ach.

Translation of Ventilation Rate Targets to an Air Tightness Standard

Adoption of a ventilation rate target implies an air tightness value for a building. The value depends on (a) the weather conditions for the region in which the building is found, (b) specific building details, and (c) the ventilation system used in the building. The examples that follow will illustrate these ideas.

1. The air tightness standard value for an eight-room reference house (ventilation by infiltration). The calculation of infiltration for a reference house having height 2.5 m located in terrain class III and shielding class III is described above. Calculation of the infiltration to leakage area ratio for this house in 59 different U.S. locations led to the results presented in Fig. 3 and Tab. 4. Thus if an eight room house having a description similar to the reference house ($X = 0$, $R = 0.5$, $H_p = 2.5$ m, terrain class III and shielding class III) is found in Salt Lake City, Tab. 4 gives a value of infiltration to leakage area of 0.25 m³/h·cm². From ASHRAE Standard 62-81, an eight-room house requires a ventilation rate of 144 m³/h. Therefore, if infiltration is to supply this ventilation, the builders must adopt a target leakage area of $144/0.25 = 580$ cm². This will yield an average ventilation rate of 144 m³/h over the heating season.

2. Same house, ventilation using exhaust fan or air-to-air heat exchanger. As Tab. 5 shows, houses in the United States can be built with significantly better air tightness than a leakage area of 580 cm². If mechanical ventilation is employed using either an exhaust fan or an air-to-air heat exchanger, significantly lower values of leakage area are desirable. In both cases a leakage area of 200 cm² could be adopted as a target. When using a balanced mechanical ventilation system with an air-to-air heat exchanger, the infiltration that occurs through the 200 cm² leakage area simply adds to the ventilation supplied by the mechanical system. Therefore, in this climate the infiltration will be $(0.25)(200) = 50$ m³/h, so the mechanical system must supply $144 - 50 = 94$ m³/h.

The unbalanced mechanical exhaust system, on the other hand, will reduce the interior pressure in the house, making the ventilation rate almost independent of the outside weather. In this case the exhaust system should have a capacity of the target ventilation rate, or 144 m³/h. The exact choice of the leakage area in this case is not crucial. The choice determines the reduction in interior pressure that occurs when the fan is operating. If the leakage area is 200 cm² the interior pressure will be 2 to 3 Pa below the outside value; if the leakage area were reduced to 100 cm², the interior pressure would be about 10 Pa below the outside reference pressure. In the latter case, the ventilation rate of the house is almost completely isolated from outside weather conditions, but one may begin to experience unpleasant drafts due to jets of outside air entering the living space.

3. Same house, ventilation by infiltration, terrain class IV. As characteristics of the house and its setting are changed from those of the standard reference house, adjustments must be made in the values of Q/A found in Fig. 3 and Tab. 4.

Tables 6 through 9 below give correction factors that are to be applied to the individual Q_{stack} and Q_{wind} terms for other housing configurations.

In the Salt Lake example, a change in terrain class only affects the wind term in the infiltration. From Tab. 4, $Q_{wind}/L_0 = 0.16$ while $Q_{stack}/L_0 = 0.19$. For the house with a height of 2.5 m the wind term in terrain class IV becomes

$$(Q_{wind}/L_0)_{IV} = 0.735(Q_{wind}/L_0)_{III} = 0.13 \text{ m}^3/\text{h} \cdot \text{cm}^2$$

and

$$Q/L_0 = [(0.13)^2 + (0.20)^2]^{1/2} = 0.22 \frac{\text{m}^3}{\text{h} \cdot \text{cm}^2}$$

Therefore the leakage area for a ventilation rate of $144 \text{ m}^3/\text{h}$ using infiltration is 650 cm^2 , up from 580 cm^2 when the house is found in terrain class III.

4. Same house, ventilation by infiltration, height 5.0 m, terrain class III. The height of the house affects both the stack and wind terms. The stack effect operates over a larger distance creating larger pressure differences. The wind speed increases with height, so the house will experience higher wind pressures. From Tab. 9 we have

$$(Q_{wind}/L_0)_5 = 1.149(Q_{wind}/L_0)_{2.5} = 0.21 \text{ m}^3/\text{h} \cdot \text{cm}^2$$

and

$$(Q_{stack}/L_0)_5 = 1.414(Q_{stack}/L_0)_{2.5} = 0.28 \text{ m}^3/\text{h} \cdot \text{cm}^2$$

Therefore

$$(Q/L_0)_5 = [(0.21)^2 + (0.28)^2]^{1/2} = 0.35 \text{ m}^3/\text{h} \cdot \text{cm}^2$$

Consequently, for ventilation by infiltration

$$L_0 = 410 \text{ cm}^2$$

DISCUSSION OF RESULTS

A procedure to calculate infiltration when the leakage area of a house is known has been described. This procedure has been used to compute the average seasonal infiltration of 312 houses located in many different areas of the United States and Canada. The results show that 50% of the houses have infiltration rates less than 0.50 ach. By comparison a sample of 266 houses measured by Grot and Clark show a median infiltration rate of approximately 0.90 ach. These two values probably represent bounds on the median infiltration value of the North American housing stock. The group of houses in Tab. 5 are biased toward new, energy-efficient structures. The houses in the Grot and Clark sample, on the other hand, are houses found in low income neighborhoods.

The calculation procedure is used to illustrate the implementation of an air tightness standard for residences. The examples show the difficulty one encounters if infiltration is to be relied upon for ventilation in new construction. Modern buildings can be built to a tightness level that reduces infiltration considerably below current guidelines for ventilation. Rather than "punching holes" in the modern, tight house, good engineering practice would use a simple mechanical ventilation system to provide the necessary ventilation. As experience with these systems increases (as it is in Canada and

Scandinavian countries) wider use is expected in the United States.

ACKNOWLEDGEMENTS

This work was supported by the Assistant Secretary for Conservation and Renewable Energy, Office of Building Energy Research and Development, Building Systems Division of the U.S. Department of Energy under Contract No. DE-ACO3-76SF00098.

REFERENCES

1. C.M. Hunt, "Air Infiltration: A Review of Some Existing Measurement Techniques and Data," Building Air Change Rate and Infiltration Measurements ASTM STP 719 (Philadelphia: American Society for Testing and Materials, 1980).
2. ASTM Standard E779-81, "Measuring Air Leakage by the Fan Pressurization Method" (Philadelphia: American Society for Testing and Materials, 1981).
3. M.H. Sherman and D.T. Grimsrud, "The Measurement of Infiltration Using Fan Pressurization and Weather Data," Proceedings of the First International Air Infiltration Centre Conference (London: Oscar Faber Partnership, 1980).
4. M.H. Sherman, D.T. Grimsrud, and R.C. Sonderegger, "The Low Pressure Leakage Function of a Building," Proceedings of the ASHRAE/DOE-ORNL Conference Thermal Performance of the Exterior Envelopes of Buildings (New York: ASHRAE, 1981).
5. M.P. Modera, M.H. Sherman, and D.T. Grimsrud, "A Predictive Air Infiltration Model--Long-Term Field Test Validation," ASHRAE Transactions 88 (1982), Part I.
6. M.H. Sherman, M.P. Modera, and D. T. Grimsrud, "A Predictive Air Infiltration Model--Field Validation and Sensitivity Analysis," Proceedings of the Third International Symposium on Energy Conservation in the Built Environment (Dublin: An Foras Forbartha, 1982).
7. Hiroshi Yoshino, Tohoku University, Sendai, Japan, personal communication.
8. M.W. Liddament, "The Role of Mathematical Modeling in the Design of Energy-Efficient Ventilation Systems," Proceedings of the Third International Air Infiltration Centre Conference (London: Oscar Faber Partnership, 1982).
9. D.R. Bahnfleth, T.D. Moseley, and W.S. Harris, "Measurement of Infiltration in Two Residences," ASHRAE Transactions 63 (1957), 439-452.
10. S.D. Veenhuizen and J.T. Lin, "A Study of Infiltration and Air Tightness" (United Industries Corporation, UIC Report No. 7903, Seattle, WA, 1979).
11. M.B. Stewart, T.R. Jacob, and J.G. Winston, "Analysis of Infiltration by Tracer Gas Technique, Pressurization Tests, and Infrared Scans," Proceedings of the ASHRAE/DOE-ORNL Conference Thermal Performance of the Exterior Envelopes of Buildings, (New York: ASHRAE, 1981).
12. D.M. Burch and C.M. Hunt, "Retrofitting an Existing Wood Frame Residence for Energy Conservation--an Experimental Study" (National Bureau of Standards Report No. NBSIR 77-1274, 1977).
13. C.W. Coblentz and P.R. Achenbach, "Field Measurements of Air Infiltration in Ten Electrically-Heated Houses," ASHRAE Transactions 69 (1963), 358-365.

14. J.B. Dickinson, D.T. Grimsrud, D.L. Krinkel, and R.D. Lipschutz, "Results of the Bonneville Power Administration Weatherization and Tightening Projects at the Midway Substation Residential Community" (Lawrence Berkeley Laboratory Report No. LBL-12742, 1982).
15. G. Reeves, M. McBride, and C.F. Sepsy, "Air Infiltration Model for Residences," ASHRAE Transactions 85 (1979).
16. A.K. Blomsterberg and D.T. Harrje, "Approaches to the Evaluation of Air Infiltration Energy Losses in Buildings," ASHRAE Transactions 85 (1979), 1:797-815.
17. G.T. Tamura, "Measurement of Air Leakage Characteristics of House Enclosures," ASHRAE Transactions 81 (1975), 1:202-211.
18. D. Dickerhoff, D.T. Grimsrud, and B. Shohl, "Infiltration and Air Conditioning: A Case Study" (Lawrence Berkeley Laboratory Report No. LBL-11674, 1980).
19. R.K. Beach, "Relative Tightness of New Housing in the Ottawa Area" (National Research Council of Canada, Report No. 149, 1979).
20. F.J. Offermann, J.B. Dickinson, W.J. Fisk, D.T. Grimsrud, C.D. Hollowell, D.L. Krinkel, G.D. Roseme, R.M. Desmond, J.A. DeFrees, and M.C. Lints, "Residential Air-Leakage and Indoor Air Quality in Rochester, NY" (Lawrence Berkeley Laboratory Report No. LBL-13100, 1982).
21. D.L. Krinkel, personal communication.
22. D.T. Grimsrud, M.H. Sherman, A.K. Blomsterberg, and A.H. Rosenfeld, "Infiltration and Air Leakage Comparisons: Conventional and Energy-Efficient Housing Designs," Changing Energy Use Futures (New York: Pergamon Press, 1979).
23. J.O. Collins, P.B. Shepherd, and T.A. Scripps, "Demonstration of Energy Conservation through Reduction of Air Infiltration in Electrically Heated Homes" (Johns Manville Sales Corporation Research and Development Center, Report No. EPRI RP 1351-1, 1981).
24. E. Vine, personal communication.
25. B.C. O'Regan, B.S. Wagner, and J.B. Dickinson, "Preliminary Report of the Walnut Creek House Doctor Project" (Lawrence Berkeley Laboratory Report No. LBL-15083, 1982).
26. R.D. Lipschutz, J.B. Dickinson, and R.C. Diamond, "Infiltration and Leakage Measurements in New Houses Incorporating Energy Efficient Features" (Lawrence Berkeley Laboratory Report No. LBL-14733, 1982).
27. R.D. Lipschutz, J.R. Girman, J.B. Dickinson, J.R. Allen, and G.W. Traynor, "Infiltration and Indoor Air Quality in Energy Efficient Houses in Eugene, Oregon" (Lawrence Berkeley Laboratory Report No. LBL-12924, 1981).
28. "Weatherization Techniques for Low-Income Housing," Proceedings of the ASHRAE/DOE Conference Thermal Performance of Exterior Envelopes of Buildings (New York: ASHRAE, 1981).
29. Indoor Pollutants (Washington: National Academy Press, 1981).
30. ASHRAE Standard 62-1981, "Ventilation for Acceptable Indoor Air Quality" (Atlanta: ASHRAE, 1981).

TABLE 1
Conversion Table

| Item | Units used | IP unit | To convert to IP unit multiply |
|------------------------------------|-------------------------------------|---|--------------------------------|
| Leakage area | cm ² | in. ² | 1.55E - 01 |
| Airflow | m ³ /s | cfm | 2.12E + 03 |
| Pressure | Pa | in. H ₂ O | 4.01E - 03 |
| Density | kg/m ³ | lb/ft ³ | 6.24E - 02 |
| Wind Speed | m/s | mph | 2.24E + 00 |
| Stack parameter | m/s · K ^{1/2} | ft/s · °F ^{1/2} | 2.45E + 00 |
| Height | m | ft | 3.28E + 00 |
| Temperature difference | K | °F | 1.80E + 00 |
| Specific leakage area | cm ² /m ² | in. ² /ft ² | 1.44E - 02 |
| Floor area | m ² | ft ² | 1.08E + 01 |
| Volume | m ³ | ft ³ | 3.53E + 01 |
| Airflow per unit leakage area | m ³ /h · cm ² | ft ³ /min · in. ² | 3.80E + 00 |
| Heating load per unit leakage area | Mjoules/cm ² | kBtu/in. ² | 6.12E + 00 |

TABLE 2
Terrain Parameters for Standard Terrain Classes

| Class | γ | δ | Description |
|-------|------|------|---|
| I | 0.10 | 1.30 | Ocean or other body of water with at least 5 km of unrestricted expanse |
| II | 0.15 | 1.00 | Flat terrain with some isolated obstacles (e.g., buildings or trees well separated from each other) |
| III | 0.20 | 0.85 | Rural areas with low buildings and trees |
| IV | 0.25 | 0.67 | Urban, industrial, or forest areas |
| V | 0.35 | 0.47 | Center of large city (e.g., Manhattan) |

TABLE 3

Generalized Shielding Coefficient vs. Local Shielding

| Shielding Class | C' | Description |
|-----------------|------|---|
| I | 0.34 | No obstructions or local shielding whatsoever |
| II | 0.30 | Light local shielding with few obstructions. Perhaps a few trees or a small shed. |
| III | 0.25 | Moderate local shielding, some obstructions within two house heights. A thick hedge or a solid fence, or one neighboring house. |
| IV | 0.19 | Heavy shielding, obstructions around most of the perimeter. Buildings or trees within 30 ft in most directions. Typical suburban shielding. |
| V | 0.11 | Very heavy shielding, large obstructions surrounding perimeter within two house heights. Typical downtown shielding. |

TABLE 4

Infiltration for Reference Case in 59 TRY Cities

| City | Stack-effect infiltration (m ³ /h·cm ²) | Wind-effect infiltration (m ³ /h·cm ²) | Total infiltration (m ³ /h·cm ²) | Total seasonal heating load (MJ/cm ²) |
|--------------------|---|--|--|--|
| Albany, NY | 0.21 | 0.23 | 0.31 | 30.7 |
| Albuquerque, NM | 0.17 | 0.15 | 0.23 | 16.7 |
| Amarillo, TX | 0.17 | 0.30 | 0.35 | 23.6 |
| Atlanta, GA | 0.14 | 0.21 | 0.25 | 13.8 |
| Bismark, ND | 0.23 | 0.21 | 0.31 | 42.0 |
| Boise, ID | 0.18 | 0.18 | 0.25 | 20.7 |
| Boston, MA | 0.19 | 0.30 | 0.36 | 30.4 |
| Brownsville, TX | 0.06 | 0.24 | 0.25 | 4.0 |
| Buffalo, NY | 0.19 | 0.27 | 0.33 | 31.1 |
| Burlington, VT | 0.21 | 0.21 | 0.29 | 30.9 |
| Charleston, SC | 0.12 | 0.20 | 0.23 | 10.0 |
| Cheyenne, W | 0.19 | 0.27 | 0.34 | 31.6 |
| Chicago, IL | 0.19 | 0.21 | 0.28 | 25.2 |
| Cincinnati, OH | 0.17 | 0.19 | 0.26 | 19.6 |
| Cleveland, OH | 0.19 | 0.24 | 0.31 | 29.1 |
| Columbia, SC | 0.18 | 0.22 | 0.29 | 25.2 |
| Detroit, MI | 0.19 | 0.24 | 0.31 | 23.9 |
| Dodge City, KS | 0.18 | 0.28 | 0.33 | 28.1 |
| El Paso, TX | 0.13 | 0.17 | 0.22 | 11.2 |
| Fort Worth, TX | 0.12 | 0.23 | 0.26 | 12.3 |
| Fresno, CA | 0.14 | 0.12 | 0.18 | 9.4 |
| Great Falls, MT | 0.20 | 0.40 | 0.45 | 57.1 |
| Houston, TX | 0.10 | 0.23 | 0.25 | 9.1 |
| Indianapolis, IN | 0.19 | 0.23 | 0.30 | 26.7 |
| Jackson, MS | 0.12 | 0.20 | 0.24 | 10.9 |
| Jacksonville, FL | 0.09 | 0.19 | 0.21 | 6.3 |
| Kansas City, MO | 0.18 | 0.21 | 0.28 | 23.4 |
| Lake Charles, LA | 0.11 | 0.19 | 0.22 | 8.4 |
| Los Angeles, CA | 0.10 | 0.16 | 0.19 | 5.6 |
| Louisville, KY | 0.18 | 0.23 | 0.29 | 20.2 |
| Lubbock, TX | 0.15 | 0.28 | 0.31 | 19.2 |
| Madison, WI | 0.20 | 0.19 | 0.28 | 29.3 |
| Medford, OR | 0.18 | 0.10 | 0.21 | 13.1 |
| Memphis, TN | 0.14 | 0.20 | 0.24 | 14.0 |
| Miami, FL | 0.03 | 0.19 | 0.19 | 1.2 |
| Minneapolis, MN | 0.22 | 0.21 | 0.31 | 38.0 |
| Nashville, TN | 0.15 | 0.21 | 0.26 | 15.6 |
| New Orleans, LA | 0.11 | 0.20 | 0.23 | 9.5 |
| New York, NY | 0.17 | 0.26 | 0.31 | 22.7 |
| Norfolk, VA | 0.15 | 0.26 | 0.31 | 16.7 |
| Oklahoma, OK | 0.16 | 0.30 | 0.34 | 23.3 |
| Omaha, NE | 0.19 | 0.21 | 0.29 | 27.9 |
| Philadelphia, PA | 0.18 | 0.25 | 0.31 | 25.4 |
| Phoenix, AZ | 0.11 | 0.09 | 0.14 | 5.9 |
| Pittsburgh, PA | 0.18 | 0.23 | 0.29 | 21.5 |
| Portland, ME | 0.20 | 0.18 | 0.27 | 27.2 |
| Portland, OR | 0.16 | 0.21 | 0.27 | 15.9 |
| Raleigh, NC | 0.15 | 0.19 | 0.24 | 15.4 |
| Richmond, VA | 0.17 | 0.18 | 0.24 | 18.5 |
| Sacramento, CA | 0.14 | 0.12 | 0.19 | 10.9 |
| Salt Lake City, UT | 0.19 | 0.17 | 0.25 | 23.3 |
| San Antonio, TX | 0.11 | 0.20 | 0.23 | 9.6 |
| San Diego, CA | 0.10 | 0.13 | 0.16 | 4.4 |
| San Francisco, CA | 0.13 | 0.18 | 0.22 | 10.0 |
| Seattle, WA | 0.17 | 0.21 | 0.27 | 18.0 |
| St. Louis, MO | 0.18 | 0.22 | 0.29 | 24.3 |
| Tampa, FL | 0.06 | 0.19 | 0.20 | 3.0 |
| Tulsa, OK | 0.15 | 0.22 | 0.27 | 17.2 |
| Washington, D.C. | 0.16 | 0.16 | 0.23 | 15.6 |

TABLE 5

Data Summary

| Ref | Location | House | Const. date | Type | Floor area (m ²) | Volume (m ³) | Leakage area (cm ²) | Spec. leakage area (cm ² /m ²) | Average infiltration (ach) | Calc. proc. |
|---------|----------|-------|-------------|------|------------------------------|--------------------------|---------------------------------|---|----------------------------|-------------|
| 10-1979 | WA | H 1 | 1949 | 1S | 212 | 447 | 1050 | 5.0 | 0.95 | A |
| 10-1979 | WA | H 2 | 1950 | 1S | 117 | 248 | 814 | 7.0 | 2.45 | A |
| 10-1979 | WA | H 3 | 1899 | 1S | 78 | 190 | | | 0.79 | A |
| 10-1979 | WA | H 4 | 1978 | SL | 164 | 382 | 1370 | 8.4 | 0.84 | A |
| 10-1979 | WA | H 5 | 1923 | 1S | 214 | 465 | 1080 | 5.0 | 0.75 | A |
| 11-1979 | OH | B | 1977 | 1S | 129 | 314 | 441 | 3.4 | 0.33 | A |
| 11-1979 | OH | C | 1977 | 1S | 129 | 314 | 652 | 5.0 | 0.55 | A |
| 12-1977 | MD | B | 195X | 1S | 192 | 495 | | | 0.51 | A |
| 13-1963 | IN | A | 1940 | 1S | 113 | 276 | | | 0.49 | C |
| 13-1963 | IN | B | 1933 | 1S | 114 | 278 | | | 0.90 | C |
| 13-1963 | IN | C | 1963 | 1S | 140 | 342 | | | 0.28 | C |
| 13-1963 | IN | D | 1940 | 2S | 114 | 269 | | | 0.74 | C |
| 13-1963 | IN | E | 1923 | 2S | 140 | 366 | | | 0.81 | C |
| 13-1963 | IN | F | 1963 | 1S | 154 | 375 | | | 0.29 | C |
| 13-1963 | IN | G | 1963 | 1S | 105 | 240 | | | 0.71 | C |
| 13-1963 | IN | H | 1917 | 2S | 158 | 374 | | | 0.86 | C |
| 13-1963 | IN | I | 1963 | 2S | 179 | 410 | | | 0.43 | C |
| 13-1963 | IN | J | 1963 | 1S | 56 | 133 | | | 0.78 | C |
| 9-1957 | IL | RR2 | | 1S | 94 | 229 | | | 0.62 | C |
| 15-1979 | OH | KTSC | | 2S | | 363 | | | 0.73 | C |
| 15-1979 | OH | ETSC | | 2S | | 363 | | | 0.66 | C |
| 15-1979 | OH | HSLG | | SL | | 348 | | | 0.62 | C |
| 15-1979 | OH | CTSE | | 2S | | 363 | | | 0.78 | C |
| 15-1979 | OH | HTSC | | 2S | | 363 | | | 1.53 | C |
| 15-1979 | OH | SRSR | | 1S | | 408 | | | 0.56 | C |
| 14-1982 | WA | 1 | 1943 | 1S | 108 | 247 | 532 | 4.9 | 0.51 | B |
| 14-1982 | WA | 2 | 1943 | 1S | 108 | 247 | 495 | 4.6 | 0.47 | B |
| 14-1982 | WA | 3 | 1943 | 1S | 108 | 247 | 490 | 4.5 | 0.46 | B |
| 14-1982 | WA | 4 | 1943 | 1S | 124 | 283 | 499 | 4.0 | 0.41 | B |
| 14-1982 | WA | 5 | 1943 | 1S | 108 | 247 | 521 | 4.8 | 0.49 | B |
| 14-1982 | WA | 6 | 1943 | 1S | 124 | 283 | 566 | 4.6 | 0.47 | B |
| 14-1982 | WA | 7 | 1943 | 1S | 124 | 283 | 572 | 4.6 | 0.47 | B |
| 14-1982 | WA | 8 | 1951 | 1S | 123 | 281 | 384 | 3.1 | 0.32 | B |
| 14-1982 | WA | 9 | 1951 | 1S | 123 | 281 | 382 | 3.1 | 0.32 | B |
| 14-1982 | WA | 10 | 1951 | 1S | 123 | 281 | 367 | 3.0 | 0.31 | B |
| 14-1982 | WA | 11 | 1951 | 1S | 123 | 281 | 365 | 3.0 | 0.30 | B |
| 14-1982 | WA | 12 | 1951 | 1S | 106 | 242 | 311 | 2.9 | 0.30 | B |
| 14-1982 | WA | 13 | 1951 | 1S | 123 | 281 | 367 | 3.0 | 0.30 | B |
| 14-1982 | WA | 14 | 1951 | 1S | 123 | 281 | 446 | 3.6 | 0.37 | B |
| 14-1982 | WA | 15 | 1951 | 1S | 106 | 242 | 417 | 3.9 | 0.40 | B |

TABLE 5 (continued)

| Ref | Location | House | Const. date | Type | Floor area (m ²) | Volume (m ³) | Leakage area (cm ²) | Spec. leakage area (cm ² /m ²) | Average infiltration (ach) | Calc. proc. |
|---------|----------|----------|-------------|------|------------------------------|--------------------------|---------------------------------|---|----------------------------|-------------|
| 14-1982 | WA | 17 | 1965 | 1S | 103 | 235 | 318 | 3.1 | 0.31 | B |
| 14-1982 | WA | 19 | 1968 | 1S | 103 | 235 | 327 | 3.2 | 0.32 | B |
| 14-1982 | WA | 20 | 1968 | 1S | 206 | 235 | 321 | 1.6 | 0.16 | B |
| 22-1979 | CA | Niel | 1924 | 1S | 96 | 230 | 1280 | 13.3 | 1.38 | B |
| 22-1979 | CA | Purd | 1949 | 1S | 93 | 240 | 855 | 9.2 | 0.88 | B |
| 22-1979 | CA | SCar | 1940 | 1S | 58 | 147 | 845 | 14.6 | 2.09 | B |
| 22-1979 | CA | South | 1929 | 2S | 370 | 1000 | 1640 | 4.4 | 0.71 | B |
| 22-1979 | CA | Haven | 1965 | 1S | 100 | 230 | 750 | 7.5 | 1.13 | B |
| 22-1979 | CA | Val I | 1978 | 1S | 104 | 270 | 560 | 5.4 | 0.55 | B |
| 22-1979 | CA | Val II | 1978 | 1S | 104 | 270 | 670 | 6.4 | 0.61 | B |
| 22-1979 | CA | Nogal | 1977 | 1S | 107 | 292 | 960 | 9.0 | 0.74 | B |
| 22-1979 | MN | Ivanhoe | 1977 | 2S | 174 | 490 | 100 | 0.6 | 0.08 | B |
| 22-1979 | MN | Telemark | 1978 | 2S | 197 | 480 | 140 | 0.7 | 0.12 | B |
| 22-1979 | IA | TP | 1978 | 2S | 220 | 480 | 200 | 0.9 | 0.21 | B |
| 16-1979 | NJ | SO | | SL | 190 | 535 | 1120 | 5.9 | 0.93 | B |
| 17-1975 | ONT | 1 | 195- | 1S | 77 | 379 | 316 | 4.1 | 0.28 | B |
| 17-1975 | ONT | 2 | 195- | 1S | 77 | 379 | 300 | 3.9 | 0.27 | B |
| 17-1975 | ONT | 3 | 195- | 1S | 99 | 487 | 656 | 6.6 | 0.49 | B |
| 17-1975 | ONT | 4 | 195- | 1S | 89 | 436 | 714 | 8.0 | 0.59 | B |
| 17-1975 | ONT | 5 | 195- | 2S | 108 | 410 | 591 | 5.5 | 0.63 | B |
| 17-1975 | ONT | 6 | 195- | 2S | 128 | 471 | 610 | 4.8 | 0.57 | B |
| 18-1980 | GA | KE | 1967 | 1 | 203 | 495 | 2593 | 12.7 | 1.78 | B |
| 18-1980 | GA | NE | 1959 | 2 | 209 | 510 | 2531 | 12.1 | 1.84 | B |
| 18-1980 | GA | BR | 1979 | 2 | 119 | 291 | 2103 | 17.6 | 2.02 | B |
| 18-1980 | GA | KL | 1970 | SL | 130 | 318 | 1775 | 13.6 | 1.43 | B |
| 18-1980 | GA | HA | 1976 | 2 | 205 | 500 | 2062 | 10.1 | 1.37 | B |
| 18-1980 | GA | EW | 1976 | 1 | 173 | 422 | 2573 | 14.9 | 1.91 | B |
| 18-1980 | GA | SD | 1977 | 2 | 197 | 480 | 2342 | 11.9 | 1.47 | B |
| 18-1980 | GA | ST | 1972 | 2 | 190 | 463 | 2690 | 14.2 | 1.73 | B |
| 19-1979 | ONT | 1 | 1978 | SL | 151 | 556 | 570 | 3.8 | 0.45 | B |
| 19-1979 | ONT | 2 | " | 2 | 188 | 765 | 360 | 1.9 | 0.24 | B |
| " | " | 3 | " | 2 | 202 | 805 | 800 | 4.0 | 0.47 | B |
| " | " | 4 | " | SL | 142 | 528 | 300 | 2.1 | 0.27 | B |
| " | " | 5 | " | 2 | 134 | 428 | 390 | 2.9 | 0.45 | B |
| " | " | 6 | 1978 | SL | 122 | 507 | 560 | 4.6 | 0.48 | B |
| 19-1979 | ONT | 7 | " | 2 | 161 | 682 | 830 | 5.1 | 0.57 | B |
| " | " | 8 | " | 2 | 157 | 531 | 550 | 3.5 | 0.51 | B |
| " | " | 9 | " | 2 | 202 | 805 | 610 | 3.3 | 0.37 | B |
| " | " | 10 | " | 2 | 205 | 772 | 490 | 2.4 | 0.38 | B |
| " | " | 11 | 1978 | 2 | 192 | 677 | 610 | 3.2 | 0.43 | B |

TABLE 5 (continued)

| Ref | Location | House | Const. date | Type | Floor area (m ²) | Volume (m ³) | Leakage area (cm ²) | Spec. leakage area (cm ² /m ²) | Average infiltration (ach) | Calc. proc. |
|---------|----------|-------|-------------|------|------------------------------|--------------------------|---------------------------------|---|----------------------------|-------------|
| 19-1979 | ONT | 12 | 1978 | 2 | 158 | 664 | 400 | 2.6 | 0.30 | B |
| " | " | 13 | " | 2 | 141 | 505 | 630 | 4.5 | 0.61 | B |
| " | " | 14 | " | 2 | 147 | 564 | 600 | 4.1 | 0.51 | B |
| " | " | 15 | " | 2 | 177 | 611 | 610 | 3.4 | 0.48 | B |
| " | " | 16 | " | 2 | 137 | 466 | 570 | 4.3 | 0.60 | B |
| 19-1979 | ONT | 17 | 1978 | 2 | 185 | 773 | 700 | 3.8 | 0.43 | B |
| " | " | 18 | " | SL | 170 | 606 | 430 | 2.5 | 0.32 | B |
| " | " | 19 | " | 1 | 131 | 458 | 300 | 2.3 | 0.26 | B |
| " | " | 20 | " | 2 | 118 | 426 | 440 | 3.7 | 0.51 | B |
| " | " | 21 | " | SL | 175 | 589 | 690 | 3.9 | 0.50 | B |
| 19-1979 | ONT | 22 | 1978 | 2 | 139 | 574 | 640 | 4.6 | 0.53 | B |
| " | " | 23 | " | 2 | 151 | 591 | 480 | 3.2 | 0.40 | B |
| " | " | 24 | " | 2 | 170 | 659 | 560 | 3.3 | 0.41 | B |
| " | " | 25 | " | 2 | 190 | 582 | 500 | 2.6 | 0.42 | B |
| " | " | 26 | " | 2 | 177 | 603 | 350 | 2.0 | 0.29 | B |
| 19-1979 | ONT | 27 | 1978 | 1 | 157 | 380 | 400 | 2.5 | 0.40 | B |
| " | " | 28 | " | 1 | 107 | 429 | 430 | 4.0 | 0.36 | B |
| " | " | 29 | " | SL | 162 | 525 | 630 | 3.9 | 0.51 | B |
| " | " | 30 | " | 2 | 117 | 391 | 390 | 3.3 | 0.50 | B |
| " | " | 31 | " | SL | 117 | 453 | 520 | 4.5 | 0.51 | B |
| 19-1979 | ONT | 32 | 1978 | 2 | 153 | 533 | 500 | 3.3 | 0.47 | B |
| " | " | 33 | " | 2 | 183 | 658 | 500 | 2.7 | 0.37 | B |
| " | " | 34 | " | 2 | 137 | 403 | 340 | 2.4 | 0.42 | B |
| " | " | 35 | " | 2 | 163 | 576 | 540 | 3.3 | 0.46 | B |
| " | " | 36 | " | 2 | 149 | 530 | 500 | 3.3 | 0.46 | B |
| 19-1979 | ONT | 37 | 1978 | 1 | 99 | 461 | 300 | 3.0 | 0.23 | B |
| " | " | 38 | " | 2 | 150 | 486 | 470 | 3.1 | 0.48 | B |
| " | " | 39 | " | 2 | 135 | 451 | 360 | 2.7 | 0.41 | B |
| " | " | 40 | " | 1 | 142 | 522 | 540 | 3.8 | 0.38 | B |
| " | " | 41 | " | 1 | 125 | 354 | 250 | 2.0 | 0.26 | B |
| 19-1979 | ONT | 42 | 1978 | 1 | 91 | 440 | 390 | 4.3 | 0.32 | B |
| " | " | 43 | " | SL | 161 | 644 | 520 | 3.2 | 0.35 | B |
| " | " | 44 | " | 2 | 143 | 496 | 490 | 3.5 | 0.49 | B |
| " | " | 45 | " | 2 | 133 | 470 | 480 | 3.6 | 0.50 | B |
| " | " | 46 | " | 2 | 121 | 395 | 330 | 2.7 | 0.42 | B |
| 19-1979 | ONT | 47 | 1978 | SL | 148 | 549 | 630 | 4.2 | 0.50 | B |
| " | " | 48 | " | 1 | 131 | 363 | 270 | 2.1 | 0.27 | B |
| " | " | 49 | " | 1 | 101 | 476 | 690 | 6.8 | 0.50 | B |
| " | " | 50 | " | SL | 150 | 602 | 350 | 2.3 | 0.27 | B |
| " | " | 51 | " | SL | 175 | 680 | 710 | 4.0 | 0.45 | B |

TABLE 5 (continued)

| Ref | Location | House | Const. date | Type | Floor area (m ²) | Volume (m ³) | Leakage area (cm ²) | Spec. leakage area (cm ² /m ²) | Average infiltration (ach) | Calc. proc. |
|---------|----------|-------|-------------|------|------------------------------|--------------------------|---------------------------------|---|----------------------------|-------------|
| 19-1979 | ONT | 52 | 1978 | 2 | 182 | 642 | 260 | 1.4 | 0.22 | B |
| " | " | 53 | " | 2 | 127 | 487 | 400 | 3.2 | 0.41 | B |
| " | " | 54 | " | 2 | 195 | 751 | 910 | 4.7 | 0.57 | B |
| " | " | 55 | " | 1 | 105 | 579 | 310 | 3.0 | 0.21 | B |
| " | " | 56 | " | 2 | 191 | 709 | 370 | 2.0 | 0.27 | B |
| 19-1979 | ONT | 57 | 1978 | 1 | 120 | 514 | 680 | 5.6 | 0.46 | B |
| " | " | 58 | " | SL | 181 | 643 | 690 | 3.8 | 0.47 | B |
| " | " | 59 | " | 2 | 166 | 587 | 310 | 1.8 | 0.27 | B |
| " | " | 60 | " | 2 | 118 | 392 | 330 | 2.8 | 0.43 | B |
| " | " | 61 | " | 2 | 131 | 504 | 490 | 3.7 | 0.48 | B |
| 19-1979 | ONT | 62 | 1978 | 2 | 157 | 583 | 530 | 3.4 | 0.45 | B |
| " | " | 63 | " | 1 | 104 | 440 | 380 | 3.7 | 0.30 | B |
| " | " | I | " | 2 | 109 | 399 | 340 | 3.1 | 0.40 | B |
| " | " | II | " | 2 | 109 | 399 | 270 | 2.5 | 0.33 | B |
| " | " | III | " | 2 | 109 | 399 | 290 | 2.6 | 0.35 | B |
| 19-1979 | ONT | IV | 1978 | 2 | 109 | 399 | 270 | 2.5 | 0.33 | B |
| 23-1981 | CO | C2 | | SL | 128 | 312 | 460 | 3.6 | 0.61 | B |
| " | " | C3 | | 2 | 130 | 353 | 800 | 6.1 | 0.94 | B |
| " | " | C4 | | 1 | 91 | 221 | 520 | 5.7 | 0.81 | B |
| " | " | C7 | | 1 | 91 | 221 | 830 | 9.1 | 1.29 | B |
| 23-1981 | CO | C8 | | 2 | 111 | 272 | 940 | 8.4 | 1.44 | B |
| " | " | C10 | | SL | 157 | 383 | 1220 | 7.7 | 1.32 | B |
| " | " | C11 | | SL | 157 | 383 | 1120 | 7.1 | 1.22 | B |
| " | " | C13 | | 2 | 180 | 438 | 920 | 5.1 | 0.88 | B |
| " | " | C19 | | SL | 159 | 388 | 810 | 5.1 | 0.87 | B |
| 23-1981 | CO | C20 | | 1 | 128 | 312 | 530 | 4.1 | 0.59 | B |
| " | " | C21 | | 2 | 244 | 594 | 990 | 4.1 | 0.69 | B |
| " | " | C22 | | 1 | 133 | 324 | 960 | 7.2 | 1.01 | B |
| " | " | C23 | | 1 | 250 | 611 | 320 | 1.3 | 0.18 | B |
| " | " | C24 | | SL | 86 | 210 | 1160 | 13.5 | 2.31 | B |
| 23-1981 | CO | C27 | | 1 | 119 | 289 | 1000 | 8.4 | 1.19 | B |
| " | " | C28 | | SL | 111 | 270 | 980 | 8.8 | 1.52 | B |
| " | " | C29 | | SL | 181 | 441 | 950 | 5.2 | 0.90 | B |
| " | " | C30 | | SL | 190 | 463 | 920 | 4.8 | 0.83 | B |
| " | " | R1 | | SL | 94 | 228 | 1770 | 19.0 | 3.24 | B |
| 23-1981 | CO | R2 | | SL | 124 | 303 | 990 | 8.0 | 1.37 | B |
| " | " | R3 | | SL | 158 | 387 | 760 | 4.8 | 0.82 | B |
| " | " | R4 | | SL | 169 | 413 | 680 | 4.0 | 0.68 | B |
| " | " | R7 | | 1 | 91 | 221 | 830 | 9.1 | 1.26 | B |
| " | " | R8 | | 1 | 91 | 221 | 900 | 9.9 | 1.37 | B |

TABLE 5 (continued)

| Ref | Location | House | Const. date | Type | Floor area (m ²) | Volume (m ³) | Leakage area (cm ²) | Spec. leakage area (cm ² /m ²) | Average infiltration (ach) | Calc. proc. |
|---------|----------|-------|-------------|------|------------------------------|--------------------------|---------------------------------|---|----------------------------|-------------|
| 23-1981 | CO | R9 | | SL | 152 | 371 | 1180 | 7.8 | 1.33 | B |
| " | " | R10 | | 1 | 97 | 235 | 660 | 6.8 | 0.93 | B |
| " | " | R11 | | 1 | 178 | 435 | 670 | 3.7 | 0.52 | B |
| " | " | R15 | | 1 | 87 | 212 | 930 | 10.7 | 1.48 | B |
| " | " | R19 | | 1 | 146 | 356 | 540 | 3.7 | 0.51 | B |
| 23-1981 | CO | R22 | | 1 | 117 | 317 | 800 | 6.1 | 0.84 | B |
| " | " | R25 | | 2 | 174 | 303 | 1340 | 7.7 | 1.85 | B |
| " | " | R28 | | SL | 147 | 358 | 450 | 3.1 | 0.53 | B |
| 20-1982 | NY | 1 | 1977 | 1 | 210 | 445 | 500 | 2.4 | 0.37 | B |
| " | " | 2 | 1977 | 1 | 190 | 445 | 390 | 2.1 | 0.30 | B |
| 20-1982 | NY | 3 | 1976 | 1 | 190 | 425 | 450 | 2.4 | 0.36 | B |
| " | " | 4 | 1976 | 2 | 210 | 466 | 470 | 2.2 | 0.42 | B |
| " | " | 5 | 1977 | SL | 200 | 456 | 520 | 2.6 | 0.44 | B |
| " | " | 6 | 1977 | SL | 180 | 450 | 490 | 2.8 | 0.42 | B |
| " | " | 7 | 1976 | 1 | 180 | 396 | 600 | 3.4 | 0.58 | B |
| 20-1982 | NY | 8 | 1977 | 1 | 190 | 426 | 480 | 2.5 | 0.41 | B |
| " | " | 9 | 1977 | 2 | 270 | 623 | 680 | 2.5 | 0.44 | B |
| " | " | 10 | 1976 | 1 | 160 | 378 | 220 | 1.4 | 0.23 | B |
| " | " | 11 | 1977 | 1 | 190 | 418 | 520 | 2.8 | 0.43 | B |
| " | " | 12 | 1976 | 2 | 250 | 561 | 740 | 3.0 | 0.56 | B |
| 20-1982 | NY | 13 | 1976 | SL | 180 | 418 | 350 | 1.9 | 0.29 | B |
| " | " | 14 | 1977 | 2 | 260 | 571 | 440 | 1.7 | 0.33 | B |
| " | " | 15 | 1975 | 2 | 190 | 419 | 250 | 1.3 | 0.22 | B |
| " | " | 16 | 1978 | 2 | 260 | 575 | 650 | 2.5 | 0.43 | B |
| " | " | 17 | 1979 | 2 | 300 | 665 | 700 | 2.3 | 0.41 | B |
| 20-1982 | NY | 18 | 1979 | 1 | 240 | 552 | 700 | 2.9 | 0.42 | B |
| " | " | 19 | 1980 | 2 | 240 | 552 | 860 | 3.6 | 0.61 | B |
| " | " | 20 | 1979 | 2 | 210 | 566 | 640 | 3.0 | 0.45 | B |
| " | " | 21 | 1978 | 2 | 290 | 642 | 840 | 2.9 | 0.50 | B |
| " | " | 22 | 1979 | 2 | 260 | 592 | 740 | 2.8 | 0.53 | B |
| 20-1980 | NY | 23 | 1979 | 1 | 220 | 509 | 370 | 1.7 | 0.26 | B |
| " | " | 24 | 1980 | SL | 170 | 379 | 630 | 3.7 | 0.65 | B |
| " | " | 25 | 1980 | SL | 190 | 466 | 770 | 4.0 | 0.70 | B |
| " | " | 26 | 1980 | SL | 190 | 466 | 540 | 2.8 | 0.49 | B |
| " | " | 27 | 1978 | 2 | 260 | 694 | 1000 | 3.8 | 0.57 | B |
| 20-1982 | NY | 28 | 1979 | 2 | 200 | 455 | 610 | 3.0 | 0.55 | B |
| " | " | 29 | 1980 | SL | 190 | 420 | 670 | 3.5 | 0.61 | B |
| " | " | 30 | 1980 | SL | 200 | 452 | 530 | 2.6 | 0.45 | B |
| " | " | 31 | 1980 | 1 | 180 | 417 | 510 | 2.8 | 0.47 | B |
| " | " | 32 | 1980 | 1 | 190 | 411 | 450 | 2.4 | 0.42 | B |

TABLE 5 (continued)

| Ref | Location | House | Const. date | Type | Floor area (m ²) | Volume (m ³) | Leakage area (cm ²) | Spec. leakage area (cm ² /m ²) | Average infiltration (ach) | Calc. proc. |
|---------|----------|-------|-------------|------|------------------------------|--------------------------|---------------------------------|---|----------------------------|-------------|
| 20-1982 | NY | 33 | 1979 | 2 | 220 | 527 | 550 | 2.5 | 0.42 | B |
| " | " | 34 | 1978 | SL | 160 | 377 | 410 | 2.5 | 0.46 | B |
| " | " | 35 | 1980 | SL | 180 | 396 | 1110 | 6.3 | 1.21 | B |
| " | " | 36 | 1980 | 1 | 140 | 319 | 760 | 5.5 | 1.00 | B |
| " | " | 37 | 1974 | 2 | 180 | 413 | 980 | 5.4 | 0.92 | B |
| 20-1982 | NY | 38 | 1973 | 2 | 250 | 561 | 1010 | 4.0 | 0.71 | B |
| " | " | 39 | 1973 | SL | 280 | 632 | 730 | 2.6 | 0.47 | B |
| " | " | 40 | 1980 | SL | 170 | 388 | 590 | 3.4 | 0.61 | B |
| " | " | 41 | 1979 | 1 | 200 | 427 | 530 | 2.7 | 0.42 | B |
| " | " | 42 | 1973 | SL | 340 | 760 | 1030 | 3.0 | 0.51 | B |
| 20-1982 | NY | 43 | 1974 | 2 | 180 | 398 | 1600 | 9.0 | 1.71 | B |
| " | " | 44 | 1978 | 2 | 280 | 620 | 640 | 2.3 | 0.41 | B |
| " | " | 45 | 1979 | 2 | 310 | 705 | 610 | 2.0 | 0.38 | B |
| " | " | 46 | 1979 | SL | 190 | 466 | 540 | 2.8 | 0.45 | B |
| " | " | 47 | 1980 | SL | 150 | 343 | 580 | 3.8 | 0.60 | B |
| 20-1982 | NY | 48 | 1973 | SL | 260 | 597 | 950 | 3.6 | 0.63 | B |
| " | " | 49 | 1973 | 2 | 250 | 561 | 650 | 3.5 | 0.42 | B |
| " | " | 50 | 1973 | 2 | 250 | 562 | 1030 | 4.1 | 0.71 | B |
| 21-1980 | CA | TUN | 1980 | 2 | 214 | 679 | 1710 | 8.0 | 0.59 | B |
| 21-1980 | NY | BAS | 1978 | | 167 | 495 | 500 | 3.0 | 0.43 | B |
| 21-1980 | CA | SCH | 1930 | 2 | 139 | 404 | 1190 | 8.5 | 0.82 | B |
| 21-1980 | CA | GIR | 1955 | 1 | 95 | 246 | 920 | 9.7 | 0.73 | B |
| 21-1980 | NM | BAL | 1975 | 2 | 214 | 577 | 1020 | 4.8 | 0.54 | B |
| 24-1980 | CA | 511 | 1976 | 1S | 104 | 255 | 930 | 8.9 | 0.63 | B |
| 24-1980 | CA | 506 | 1976 | 1S | 149 | 363 | 1410 | 9.5 | 0.64 | B |
| 24-1980 | CA | 491B | | 1S | 208 | 508 | 2240 | 10.8 | 0.72 | B |
| 24-1980 | CA | 489 | 1964 | 1S | 175 | 426 | 1320 | 7.5 | 0.50 | B |
| 24-1980 | CA | 468 | 1972 | 2S | 202 | 493 | 1460 | 7.2 | 0.64 | B |
| 24-1980 | CA | 467 | 1976 | 1S | 154 | 376 | 1100 | 7.1 | 0.46 | B |
| 24-1980 | CA | 455 | 1972 | 1S | 107 | 261 | 770 | 7.2 | 0.46 | B |
| 24-1980 | CA | 448 | 1972 | 1S | 130 | 316 | 770 | 5.9 | 0.38 | B |
| 24-1980 | CA | 346 | 1972 | 1S | 97 | 237 | 600 | 6.2 | 0.39 | B |
| 24-1980 | CA | 344 | 1964 | 1S | 203 | 496 | 1680 | 8.3 | 0.61 | B |
| 24-1980 | CA | 326 | 1972 | 1S | 249 | 607 | 1970 | 7.9 | 0.53 | B |
| 24-1980 | CA | 325 | 1972 | 1S | 98 | 238 | 1040 | 10.6 | 0.68 | B |
| 24-1980 | CA | 314 | 1972 | 1S | 194 | 473 | 1150 | 5.9 | 0.38 | B |
| 24-1980 | CA | 312 | 1972 | 1S | 159 | 387 | 1290 | 8.1 | 0.52 | B |
| 24-1980 | CA | 310 | 1964 | 1S | 242 | 589 | 1500 | 6.2 | 0.46 | B |
| 24-1980 | CA | 241 | 1973 | 2S | 321 | 782 | 1580 | 4.9 | 0.43 | B |
| 24-1980 | CA | 225 | 1976 | 1S | 122 | 298 | 1230 | 10.1 | 0.64 | B |

TABLE 5 (continued)

| Ref | Location | House | Const. date | Type | Floor area (m ²) | Volume (m ³) | Leakage area (cm ²) | Spec. leakage area (cm ² /m ²) | Average infiltration (ach) | Calc. proc. |
|---------|----------|-------|-------------|------|------------------------------|--------------------------|---------------------------------|---|----------------------------|-------------|
| 25-1982 | CA | A2 | 1969 | 1 | 177 | 431 | 1420 | 8.0 | 0.62 | B |
| 25-1982 | CA | A3 | 1955 | 1 | 146 | 355 | 1500 | 10.3 | 0.78 | B |
| 25-1982 | CA | A5 | 1965 | 1 | 152 | 370 | 1320 | 8.7 | 0.68 | B |
| 25-1982 | CA | A6 | 1956 | 1 | 142 | 346 | 1130 | 7.9 | 0.62 | B |
| 25-1982 | CA | A7 | 1968 | 1 | 245 | 597 | 1640 | 6.7 | 0.52 | B |
| 25-1982 | CA | A9 | 1966 | 2 | 172 | 418 | 1150 | 6.7 | 0.68 | B |
| 25-1982 | CA | A10 | 1960 | 1 | 136 | 331 | 2010 | 14.8 | 1.15 | B |
| 25-1982 | CA | B1 | 1965 | 2 | 202 | 491 | 2090 | 10.4 | 1.06 | B |
| 25-1982 | CA | B2 | 1970 | 1 | 213 | 518 | 1920 | 9.0 | 0.70 | B |
| 25-1982 | CA | B4 | 1969 | 2 | 261 | 637 | 2710 | 10.4 | 1.06 | B |
| 25-1982 | CA | B5 | 1970 | 1 | 204 | 507 | 1760 | 8.6 | 0.67 | B |
| 25-1982 | CA | B6 | 1960 | 1 | 179 | 436 | 1440 | 8.0 | 0.62 | B |
| 25-1982 | CA | B7 | 1969 | 2 | 263 | 642 | 1460 | 5.6 | 0.57 | B |
| 25-1982 | CA | B8 | 1969 | 1 | 248 | 604 | 3160 | 12.8 | 0.99 | B |
| 25-1982 | CA | B9 | 1965 | 1 | 196 | 477 | 2150 | 11.0 | 0.85 | B |
| 25-1982 | CA | B10 | 1969 | 2 | 317 | 773 | 1230 | 3.9 | 0.40 | B |
| 25-1982 | CA | C1 | 1964 | 1 | 201 | 496 | 1650 | 8.2 | 0.63 | B |
| 25-1982 | CA | C2 | 1970 | 1 | 220 | 536 | 1090 | 5.0 | 0.38 | B |
| 25-1982 | CA | C4 | 1965 | 1 | 179 | 437 | 1680 | 9.4 | 0.72 | B |
| 25-1982 | CA | C6 | 1972 | 1 | 243 | 592 | 1060 | 4.3 | 0.34 | B |
| 25-1982 | CA | C7 | 1970 | 1 | 251 | 614 | 1500 | 6.0 | 0.46 | B |
| 25-1982 | CA | C8 | 1970 | 1 | 219 | 533 | 1910 | 8.7 | 0.67 | B |
| 25-1982 | CA | C9 | 1968 | 2 | 259 | 682 | 2030 | 7.9 | 0.56 | B |
| 25-1982 | CA | C10 | 1972 | 1 | 261 | 635 | 1490 | 5.7 | 0.44 | B |
| 26-1982 | CA | 1 | 1980 | 1 | 150 | 350 | 790 | 5.4 | 0.44 | B |
| 26-1982 | CA | 2 | 1980 | 1 | 150 | 350 | 860 | 5.9 | 0.48 | B |
| 26-1982 | CA | 3 | 1980 | 1 | 150 | 350 | 940 | 6.4 | 0.52 | B |
| 26-1982 | CA | 4 | 1980 | 1 | 120 | 290 | 560 | 4.6 | 0.38 | B |
| 26-1982 | CA | 5 | 1980 | 1 | 150 | 350 | 900 | 6.1 | 0.50 | B |
| 26-1982 | CA | 6 | 1980 | 1 | 120 | 290 | 770 | 6.4 | 0.52 | B |
| 26-1982 | CA | 7 | 1980 | 1 | 150 | 350 | 770 | 5.2 | 0.43 | B |
| 26-1982 | CA | 8 | 1980 | 1 | 150 | 350 | 400 | 2.7 | 0.22 | B |
| 26-1982 | CA | 9 | 1980 | 1 | 150 | 350 | 570 | 3.7 | 0.35 | B |
| 26-1982 | CA | 10 | 1980 | 1 | 250 | 610 | 1550 | 6.1 | 0.62 | B |
| 26-1982 | CA | 11 | 1980 | 1 | 230 | 560 | 1290 | 5.5 | 0.60 | B |
| 26-1982 | CA | 12 | 1980 | 1 | 200 | 480 | 1010 | 5.1 | 0.57 | B |
| 26-1982 | CA | 13 | 1980 | 1 | 210 | 500 | 1030 | 4.9 | 0.51 | B |
| 26-1982 | CA | 14 | 1980 | 1 | 160 | 390 | 820 | 5.0 | 0.41 | B |
| 26-1982 | CA | 15 | 1980 | 1 | 130 | 310 | 570 | 4.4 | 0.36 | B |
| 26-1982 | CA | 16 | 1980 | 1 | 160 | 380 | 850 | 5.4 | 0.44 | B |

TABLE 5 (continued)

| Ref | Location | House | Const. date | Type | Floor area (m ²) | Volume (m ³) | Leakage area (cm ²) | Spec. leakage area (cm ² /m ²) | Average infiltration (ach) | Calc. proc. |
|---------|----------|-------|-------------|------|------------------------------|--------------------------|---------------------------------|---|----------------------------|-------------|
| 26-1982 | CA | 17 | 1980 | 1 | 160 | 380 | 440 | 2.8 | 0.23 | B |
| 26-1982 | CA | 18 | 1980 | 1 | 160 | 380 | 700 | 4.5 | 0.36 | B |
| 26-1982 | CA | 19 | 1980 | 1 | 160 | 380 | 550 | 3.5 | 0.29 | B |
| 26-1982 | CA | 20 | 1980 | 1 | 160 | 380 | 500 | 3.2 | 0.26 | B |
| 26-1982 | CA | 21 | 1980 | 1 | 160 | 380 | 440 | 2.8 | 0.23 | B |
| 26-1982 | CA | 22 | 1980 | 1 | 180 | 420 | 760 | 4.3 | 0.40 | B |
| 26-1982 | CA | 23 | 1980 | 1 | 160 | 380 | 1010 | 6.5 | 0.62 | B |
| 26-1982 | CA | 24 | 1980 | 1 | 240 | 570 | 1030 | 4.3 | 0.59 | B |
| 26-1982 | CA | 25 | 1980 | 1 | 230 | 560 | 1290 | 5.5 | 0.57 | B |
| 26-1982 | CA | 26 | 1980 | 1 | 210 | 490 | 1210 | 5.9 | 0.65 | B |
| 27-1981 | OR | A | 1977 | 1 | 107 | 260 | 410 | 3.8 | 0.46 | B |
| 27-1981 | OR | B | 1977 | 1 | 107 | 262 | 340 | 3.2 | 0.39 | B |
| 27-1981 | OR | C | 1976 | 1 | 102 | 249 | 260 | 2.5 | 0.32 | B |
| 27-1981 | OR | D | 1976 | 1 | 102 | 249 | 230 | 2.2 | 0.28 | B |
| 27-1981 | OR | E | 1977 | 1 | 108 | 264 | 220 | 2.0 | 0.24 | B |
| 27-1981 | OR | F | 1977 | 1 | 102 | 249 | 130 | 1.3 | 0.17 | B |
| 27-1981 | OR | H | 1979 | 1 | 81 | 197 | 350 | 4.3 | 0.49 | B |
| 27-1981 | OR | I | 1979 | 1 | 81 | 197 | 280 | 3.5 | 0.40 | B |
| 27-1981 | OR | J | 1979 | 1 | 134 | 326 | 310 | 2.3 | 0.29 | B |
| 27-1981 | OR | S1 | 1979 | 1 | 140 | 390 | 480 | 3.4 | 0.37 | B |
| 27-1981 | OR | S2 | 1979 | 1 | 116 | 293 | 340 | 2.9 | 0.35 | B |
| 27-1981 | OR | S3 | 1980 | 2 | 147 | 368 | 340 | 2.4 | 0.34 | B |
| 20-1982 | NY | 51 | 1973 | 2 | 130 | 310 | 1540 | 11.8 | 2.18 | B |
| " | NY | 52 | 1980 | 2 | 160 | 380 | 220 | 1.4 | 0.22 | B |
| " | NY | 53 | 1977 | 2 | 200 | 490 | 590 | 2.9 | 0.47 | B |
| 20-1982 | NY | 54 | 1973 | 2 | 140 | 350 | 980 | 6.8 | 1.16 | B |
| " | NY | 55 | 1980 | 2 | 100 | 240 | 510 | 5.0 | 0.87 | B |
| " | NY | 56 | 1980 | 2 | 160 | 380 | 500 | 3.2 | 0.56 | B |
| " | NY | 57 | 1974 | 2 | 150 | 360 | 910 | 6.1 | 1.14 | B |
| " | NY | 58 | 1974 | 2 | 130 | 310 | 780 | 6.0 | 1.04 | B |
| 20-1982 | NY | 59 | 1967 | SL | 190 | 440 | 870 | 4.7 | 0.82 | B |
| " | NY | 60 | 1978 | 2 | 210 | 520 | 580 | 2.7 | 0.47 | B |

TABLE 6

Correction Factors for $X \neq 0$

| X | Q_s/L_0 factor |
|-----|------------------|
| 0.0 | 1.000 |
| 0.1 | 0.993 |
| 0.2 | 0.973 |
| 0.3 | 0.941 |
| 0.4 | 0.895 |
| 0.5 | 0.838 |

TABLE 7

Correction Factors for $R \neq 0.5$

| R | Q_{wind}/L_0 factors | Q_{stack}/L_0 factors |
|-----|---------------------------|----------------------------|
| 0.0 | 1.260 | 0.80 |
| 0.1 | 1.216 | 0.840 |
| 0.2 | 1.170 | 0.880 |
| 0.3 | 1.119 | 0.920 |
| 0.4 | 1.063 | 0.960 |
| 0.5 | 1.000 | 1.000 |
| 0.6 | 0.928 | 1.040 |
| 0.7 | 0.843 | 1.080 |
| 0.8 | 0.737 | 1.120 |
| 0.9 | 0.585 | 1.160 |
| 1.0 | | 1.200 |

TABLE 8

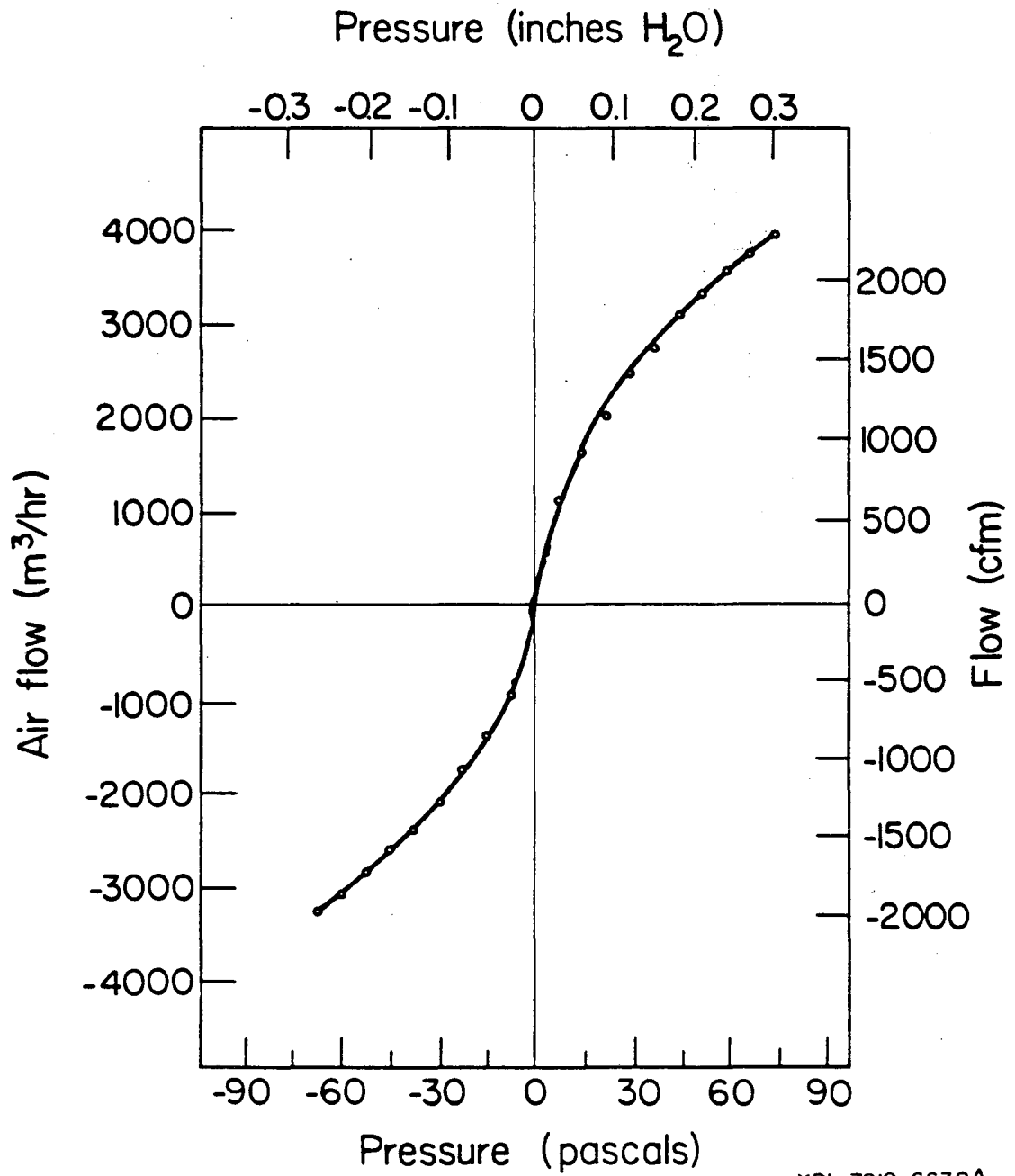
Correction Factors for Shielding Coefficients $\neq 0.25$

| Shielding Class | C' | Q_{wind}/L_0 Factors |
|-----------------|------|------------------------|
| 1 | 0.34 | 1.360 |
| 2 | 0.30 | 1.200 |
| 3 | 0.25 | 1.000 |
| 4 | 0.19 | 0.760 |
| 5 | 0.11 | 0.440 |

TABLE 9

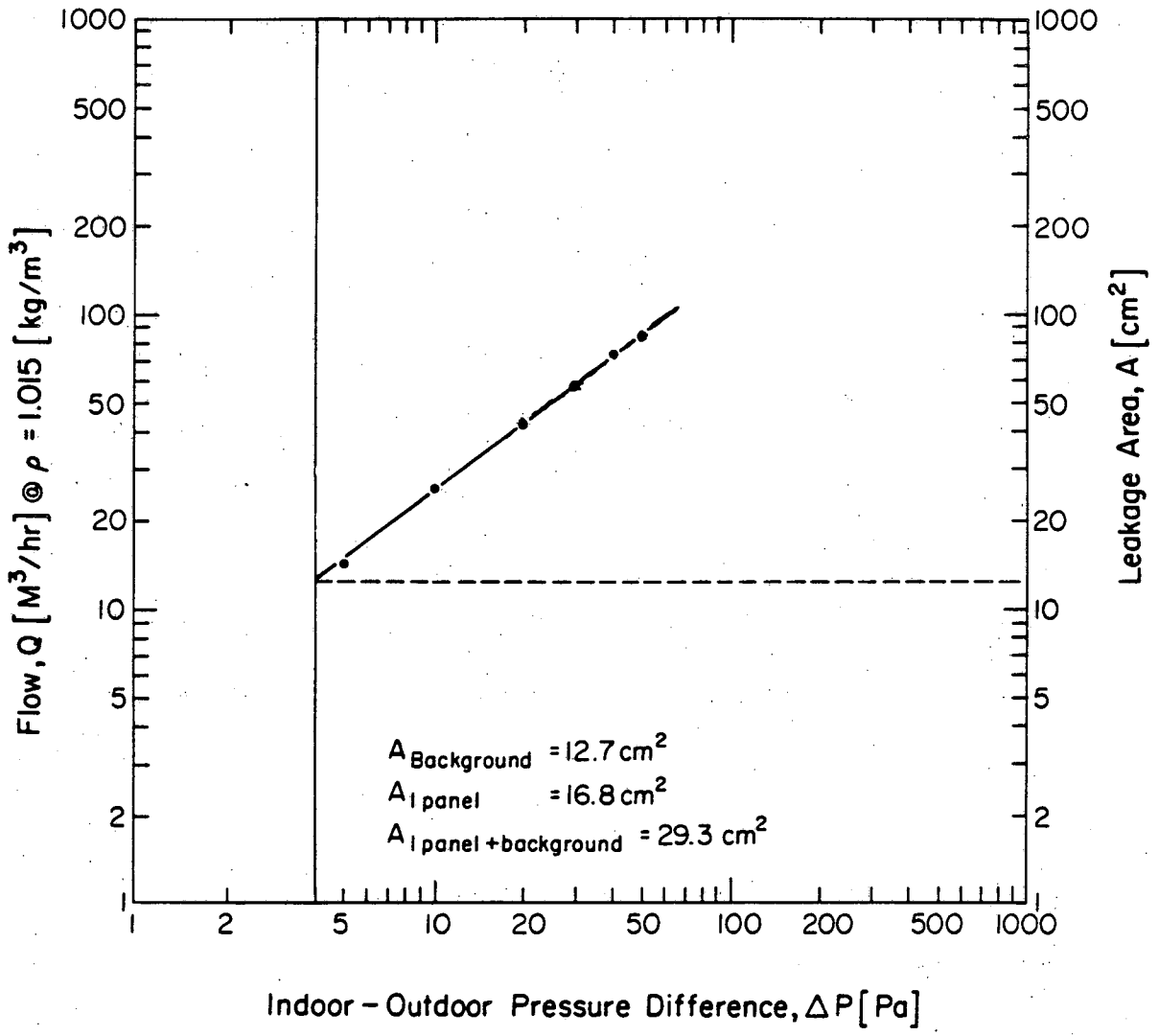
Correction Factors for Height $\neq 2.5$ m and Terrain Class \neq III Q_{wind}/L_0 factors for terrain classes

| Height (m) | I | II | III | IV | V | $Q_{stack}L_0$ factors |
|------------|-------|--------|-------|-------|-------|------------------------|
| 2.0 | 1.718 | 1.219 | 0.956 | 0.696 | 0.415 | 0.894 |
| 2.5 | 1.757 | 1.261 | 1.000 | 0.735 | 0.449 | 1.000 |
| 3.0 | 1.789 | 1.296 | 1.037 | 0.770 | 0.479 | 1.095 |
| 3.5 | 1.817 | 1.326 | 1.070 | 0.800 | 0.505 | 1.183 |
| 4.0 | 1.841 | 1.353 | 1.099 | 0.827 | 0.529 | 1.265 |
| 4.5 | 1.863 | 1.377 | 1.125 | 0.852 | 0.552 | 1.342 |
| 5.0 | 1.883 | 1.399 | 1.149 | 0.875 | 0.572 | 1.414 |
| 5.5 | 1.901 | 1.1419 | 1.171 | 0.896 | 0.592 | 1.483 |
| 6.0 | 1.918 | 1.438 | 1.191 | 0.915 | 0.610 | 1.549 |
| 6.5 | 1.933 | 1.455 | 1.211 | 0.934 | 0.627 | 1.612 |
| 7.0 | 1.947 | 1.471 | 1.229 | 0.951 | 0.644 | 1.673 |
| 7.5 | 1.961 | 1.487 | 1.246 | 0.968 | 0.660 | 1.732 |
| 8.0 | 1.974 | 1.501 | 1.262 | 0.984 | 0.675 | 1.789 |



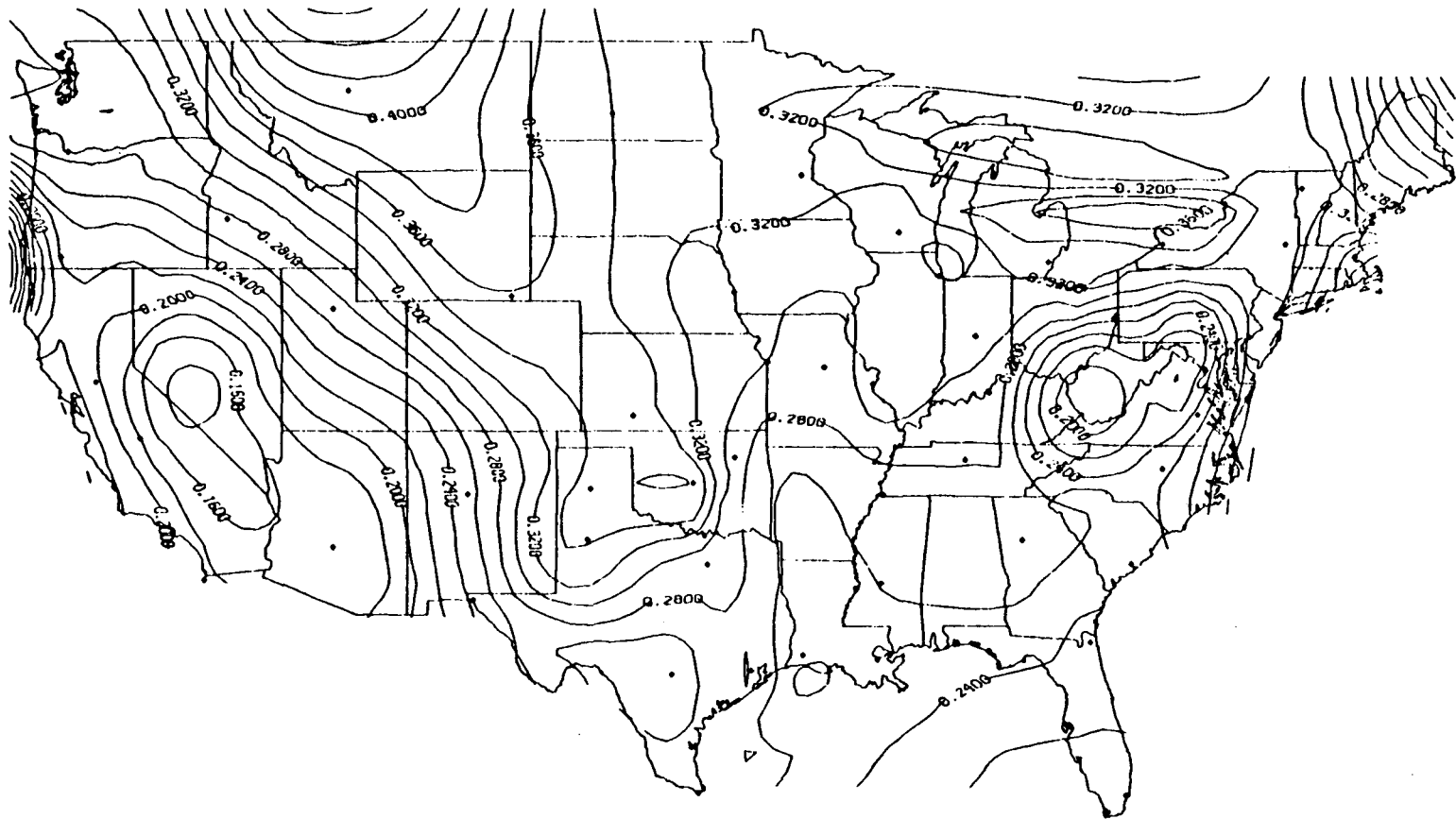
XBL 7810-6630A

Figure 1 Typical flow versus pressure characteristic obtained using fan pressurization.



XBL 811-2109

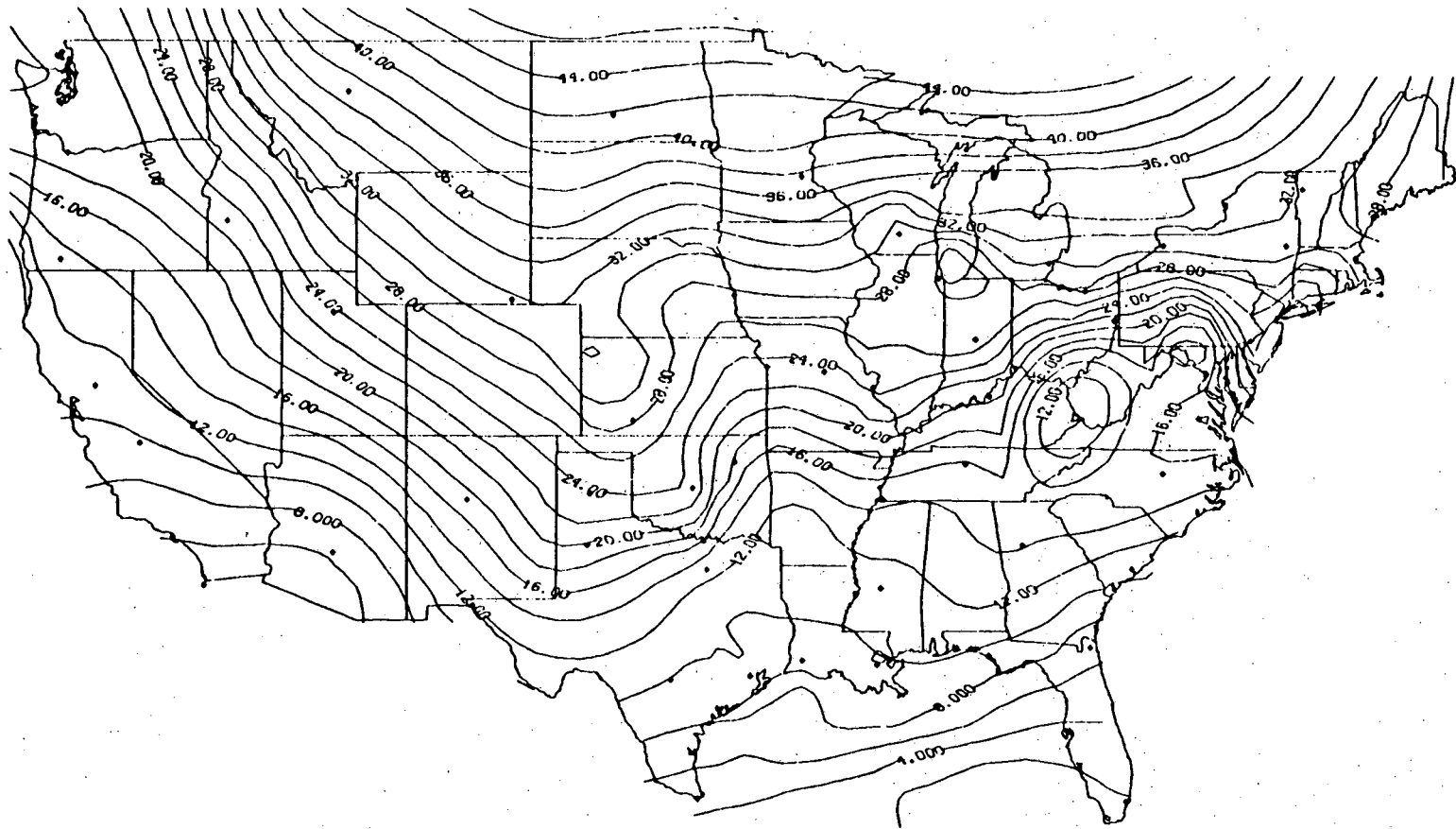
Figure 2 Pressure versus flow monograph that can be used to obtain the leakage area. Extrapolate to find the flow at 4 Pa; follow the dashed line to the right scale to read the leakage area.



Heating Season Infiltration ($\text{m}^3/\text{hr}\cdot\text{cm}^2$)

XBL 8212-12076

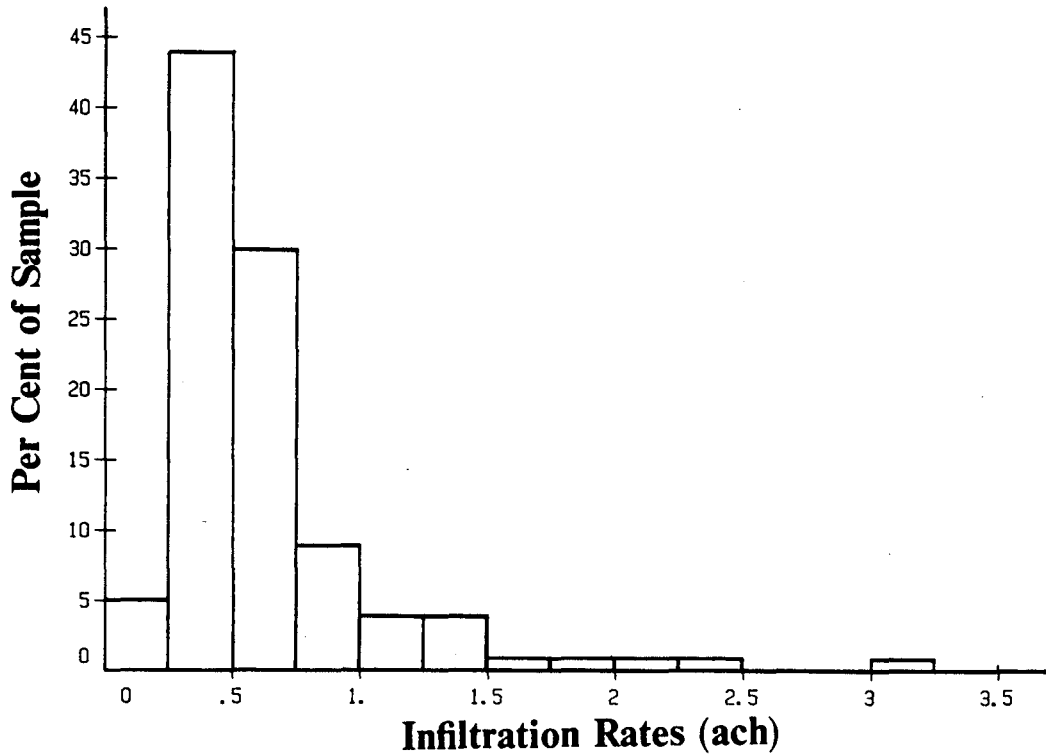
Figure 3 Heating season average infiltration [$\text{m}^3/\text{h}\cdot\text{cm}^2$]. The contour interval is $0.02 \text{ m}^3/\text{h}\cdot\text{cm}^2$ ($0.076 \text{ ft}^3/\text{min}\cdot\text{in.}^2$).



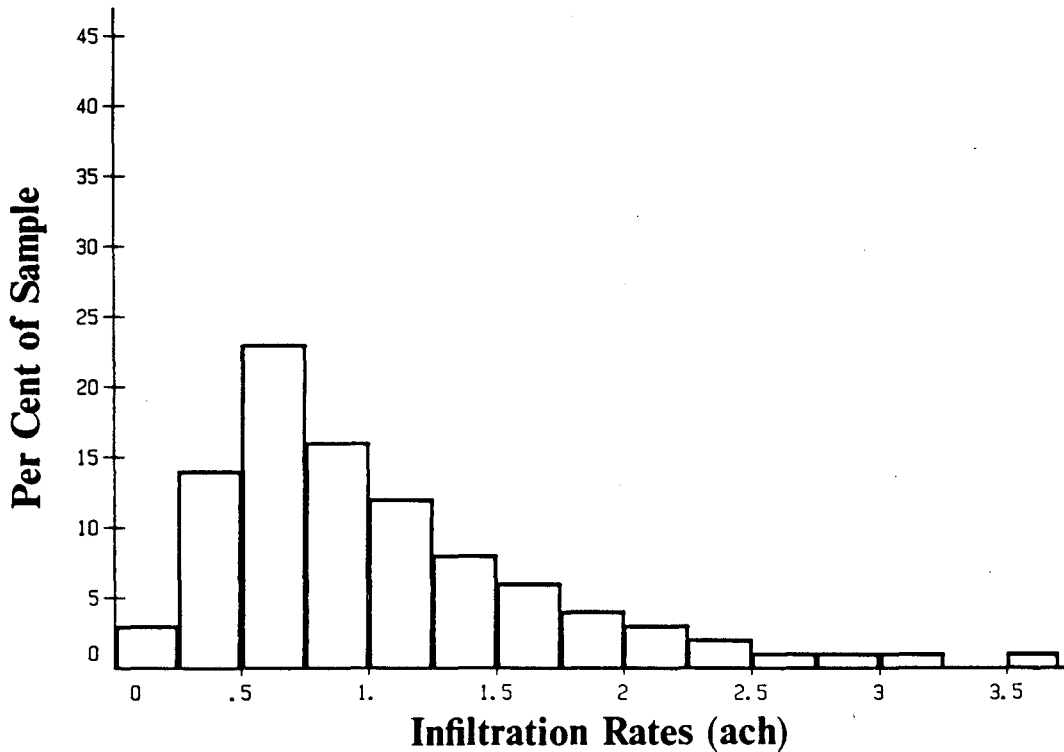
Heating Season Infiltration Load (MJoules/cm²)

XBL 8212-12077

Figure 4 Heating season infiltration load [MJoules/cm²]. The contour interval is 2.0 MJoules/cm² (12.24 kBtu/in.²).



XBL 8212-12078



XBL 8212-12079

Figure 5

Histogram of infiltration values from the data sample contained in Tab. 5. The lower histogram is another sample reported by Grot and Clark (Ref 28). The two sample distributions represent the difference that may be observed among new construction (top) and low income housing (bottom).

This report was done with support from the Department of Energy. Any conclusions or opinions expressed in this report represent solely those of the author(s) and not necessarily those of The Regents of the University of California, the Lawrence Berkeley Laboratory or the Department of Energy.

Reference to a company or product name does not imply approval or recommendation of the product by the University of California or the U.S. Department of Energy to the exclusion of others that may be suitable.

TECHNICAL INFORMATION DEPARTMENT
LAWRENCE BERKELEY LABORATORY
UNIVERSITY OF CALIFORNIA
BERKELEY, CALIFORNIA 94720