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AIR LEAKAGE, SURFACE PRESSURES AND INFILTRATION RATES IN HOUSES

Author
Grimsrud, D.T.

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

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Lawrence Berkeley Laboratory University of California/Berkeley
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Air leakage, surface pressures and infiltration rates in houses

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

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

Summary

A model is presented whose input is two sets of measurements: 1. air leakage under fan pressurization, and 2. natural pressure differences between indoors and outdoors. The output is the house's natural infiltration rate. The model was tested on six United States houses, three conventional houses located in a region of mild climate and three energy-efficient houses located in a cold winter region of the country. Good agreement was obtained between infiltration rates measured using a tracer gas and rates calculated from the model.

Fuites d'air, pressions de surface et taux de renouvellement d'air dans les maisons

Résumé

Nous présentons un modèle nécessitant deux ensembles de mesures: 1. fuite d'air sous pression par un ventilateur et 2. différences de pression naturelles entre l'intérieur et l'extérieur d'une maison. Le résultat du modèle est le renouvellement naturel d'air. Ce modèle à été vérifié sur six maisons aux Etats-Unis, dont trois maisons conventionnelles situées dans une région de climat tempéré et trois maisons à haute éfficacité énergétique situées dans une région froide du pays et visitées en hiver. Nous avons obtenu un bon accord entre les prédictions du modèle et les taux de renouvellement d'air mesurés avec un gaz traceur.

Introduction

While the importance of reducing air infiltration rates in buildings is widely recognized as an important goal for energy conservation, many problems remain to be solved before acceptable levels for air exchange rates can be incorporated into building codes. One problem is in ensuring adequate indoor air quality in tightened structures with low air exchange rates. Another problem is in developing a measurement procedure that can be used to check that new buildings are meeting the prescribed limit for air leakage. An essential part of this problem is in understanding the mechanisms driving air infiltration. In an attempt to find a simplified method for measuring air infiltration, this paper looks at the correlation between the surface pressures distributed over the exterior surface of the building and the air infiltration rate as measured. As part of this study, six houses were surveyed, three typical houses in the relatively mild climate of the San Francisco Bay area, and three energy-efficient houses, recently built in the northern midwest section of the United States. The survey was designed to see if the minor modifications in the building of the midwest houses showed significant reductions in the air infiltration rates from the California houses. Good agreement is found between predicted and measured infiltration rates considering the simplicity of the model used to calculate the predicted infiltration rates.

Infiltration model

The model we used to describe these results has been discussed in a previous paper [1] and will be summarized but briefly in this report. A model similar to this has also been used in wind tunnel studies by Mattingly and Peters [2] and by Kelnhofer [3].

Measurement of the air leakage of a house using fan pressurization yields an average leakage function for the house. A typical leakage curve is shown in Fig. 1.

Measurements of the mean surface pressures, the driving mechanism for the natural ventilation process, combined with the leakage function predict the response, i.e. the air flow through the structure. This calculated air flow divided by the volume of the house yields the air exchange rate for the house which we compare to air exchange rates measured with a tracer gas.

Many assumptions are contained in that brief summary. Some represent an inherent inability to obtain more information about the process while others will be modified as the model evolves in future work. We assume:

(A) That the leakage function represents a uniform distribution of cracks

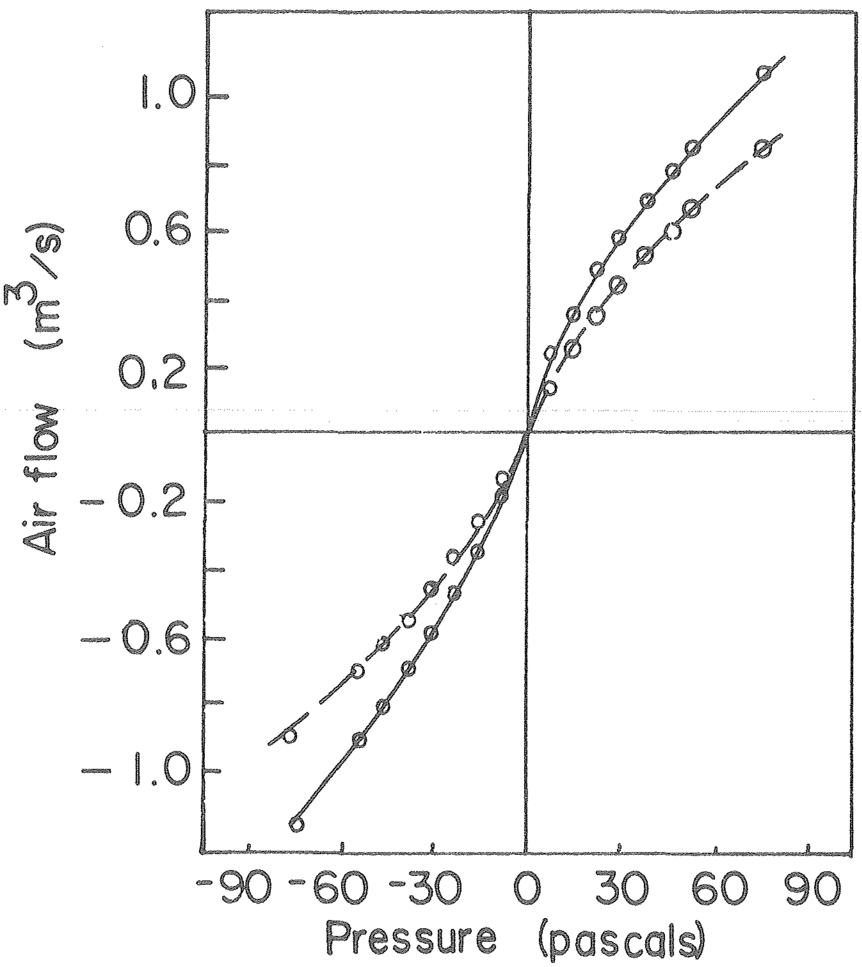

Figure 1. Air leakage vs. pressurization for the Haven house. The solid line refers to normal operating conditions; the ducts were sealed when the measurements described by the dashed line were made.

and openings over the shell of the structure. (This assumption improves as the number of large openings, such as chimneys and vents, goes to zero.)

(B) That the flow into the structure caused by the average positive surface pressure equals the flow out of the structure caused by the average negative surface pressure. (In both cases the reference pressure is the pressure of the interior of the house.)

(C) That at the low surface pressures seen, the flow through the structure is linearly proportional to the average positive (or negative) surface pressure. This, in turn, assumes that the major portion of the air flow comes through cracks. Honma's work [4] shows that for the pressure range similar to the surface pressures observed in this study, the flow through a crack is linearly proportional to the pressure difference across the crack.

(D) That pressure fluctuations with frequencies less than 1 Hz all contribute to the average surface pressure, i.e. that mixing of outdoor and indoor air occurs rapidly compared to a time scale of seconds. The data logging technique for the surface pressure measurements filters out all frequencies higher than 1 Hz. Air movement along the wall of 50mm/s sweeps incoming air emerging from a crack (width of 1 mm) across that crack in 20 msec. Therefore fluctuations of pressure having frequencies greater than about 50 Hz would be required to prevent mixing.

Test procedures

Infiltration rates were measured using a standard tracer gas technique. Ethane was injected into the return duct of a forced air heating system until its concentration reached 80 ppm. At this time the injection was stopped and the concentration monitored as a function of time. If the air exchange rate, A, is constant and if mixing between the inside and outside air is adequate the concentration decreases exponentially in time with a time constant given by the reciprocal of the air exchange rate.

Air leakage values with fan pressurization were obtained by temporarily sealing a tubeaxial fan driven by a variable speed motor into an open doorway (Fig. 2). The fan speed was adjusted to give a predetermined set of pressure differences between the inside and outside of the structure; flow through the fan was measured using a fixed pitot tube array with a flow straightener. At the pressures used, the flow through the fan is equal to the flow through the shell of the house.

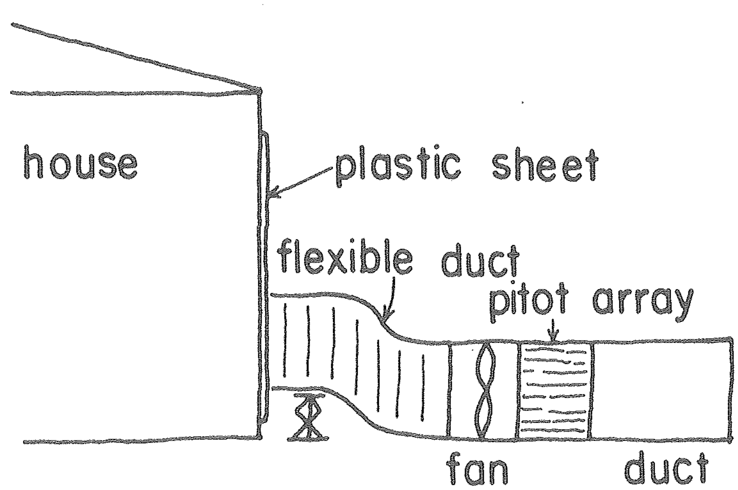

Figure 2. A sketch of the blower door assembly.

Measurements of air leakage using both pressurization and depressurization were made. In addition, measurements with the houses in their normal operating condition were followed by measurements obtained when major vent openings were covered by plastic and taped. Fig. 1, above, shows a typical leakage curve.

Surface pressures were measured using a capacitance differential pressure sensor attached to a manifold (Fig. 3). Seven pressure taps were connected to the manifold using 6 mm i.d. plastic tubing. Each tap was sampled in sequence for ten seconds at 40 Hz by opening and closing solenoid valves on the manifold under the control of a microprocessor. The microprocessor processed the pressure data, and stored the results on a floppy disk.

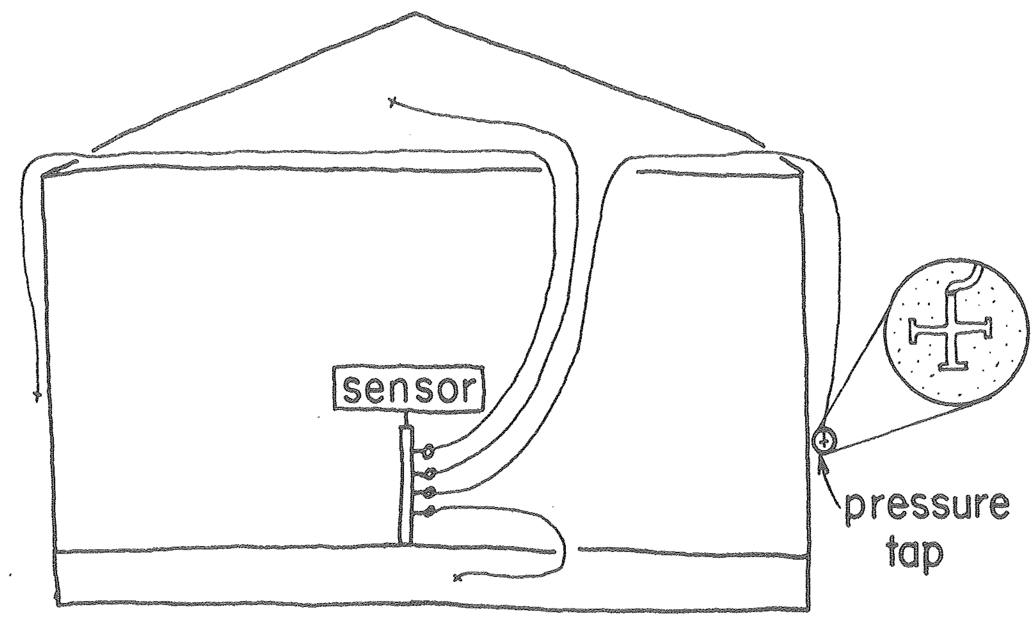

Figure 3. Sketch of pressure tap and sensor configuration used in measuring surface pressures.

Local weather conditions (wind speed and direction, dry bulb temperature) were measured at each site using equipment mounted on a 10 meter weather tower. Indoor temperature and relative humidity were measured using a hygrothermograph located in the living room of each house. As with surface pressures, weather data was processed and logged by the microprocessor.

<u>House descriptions</u>

A. Haven: Located in Walnut Creek, California. Mild climate {1760 heating (18.3^{o}C base) degree days}. One story wood frame construction. Built in 1965. Gas forced air heating system. 100 m^2 floor area, 230 m^3 volume. Single glazed sliding glass windows, fireplace, leaky heating ducts. Well shielded from all directions by trees, fences and other buildings.

B. Neilson: Located in Berkeley, California. Mild climate (1780 heating degree days). One story wood frame construction. Built in 1924. Gas floor furnace heating. 96 m^2 floor area, 249 m^3 volume. Single glazed windows, fireplace with no damper. Unshielded on two sides.

C. Purdue: Located in Kensington, California. Mild climate (1780 heating degree days). One story wood frame construction. Built in 1949. Gas forced air heating system. 93 m^2 floor area, 240 m^3 volume. Single glazed windows. Leaky duct system, fireplace, well shielded on three of four sides.

D. Ivanhoe: Located in Northfield, Minnesota. Severe climate (4380 heating degree days). Two story wood frame (2 x 8") construction. Built in 1977. Well insulated walls and ceiling. Double and triple glazed casement windows. 0.10 mm polyethelene vapor barrier. Active solar heating system with electric back-up. Sealed combustion wood stove. 174 m^2 floor area, 490 m^3 volume. Owner-built air-to-air heat exchanger installed. Shielding provided by building design, little natural shielding.

E. Telemark: Located in Northfield, Minnesota. Severe climate (4380 heating degree days). Two story wood frame (2 x 4") construction. Built in 1978. Well insulated walls and ceiling. Triple glazed casement windows. 0.15 mm polyethelene vapor barrier. Oil fired hot water radiant heating system; sealed combustion wood stove back-up. 197 m^2 floor area, 480 m^3 volume. Good shielding provided by trees and terrain.

F. Torey Pines: Located in Ames, Iowa. Cold winter climate (3580 heating degree days.) Three story wood frame (2 x 6") construction. Built in 1978. Several different insulation designs in different walls. Double glazed sliding glass windows. 0.10 mm polyethelene vapor barrier. Many heating systems possible including active solar. 220 m^2 floor area, 480 m^3 volume. Unshielded building site: earth berms and fences reduce wind exposure.

Results

Results of this study are presented in tabular form and as Figures 4-6. Table 1 gives air leakage measured at 50 Pascals for each house in its normal operating condition, the range of natural infiltration rates measured for the house and the low pressure leakage function applicable to the +/- five Pascal pressure range.

Table 1

House	Air Leakage[a] (hr^{-1})	Infiltration Rates (hr^{-1})	Leakage Function[b] ($m^3 \cdot hr^{-1} \cdot Pa^{-1}$)
Haven	14	0.15-0.61	135
Purdue	13	0.50-0.69	144
Neilson	18	0.64-1.36	215
Telemark	2.5	0.08-0.13	24
Ivanhoe	1.8	0.10-0.12	15
Torey Pines	3.2	0.31-0.42	47

a. At 50 Pa.
b. Between -5 and +5 Pa.

Fig. 4 summarizes the air leakage values (air changes per hour) at 50 Pascals.

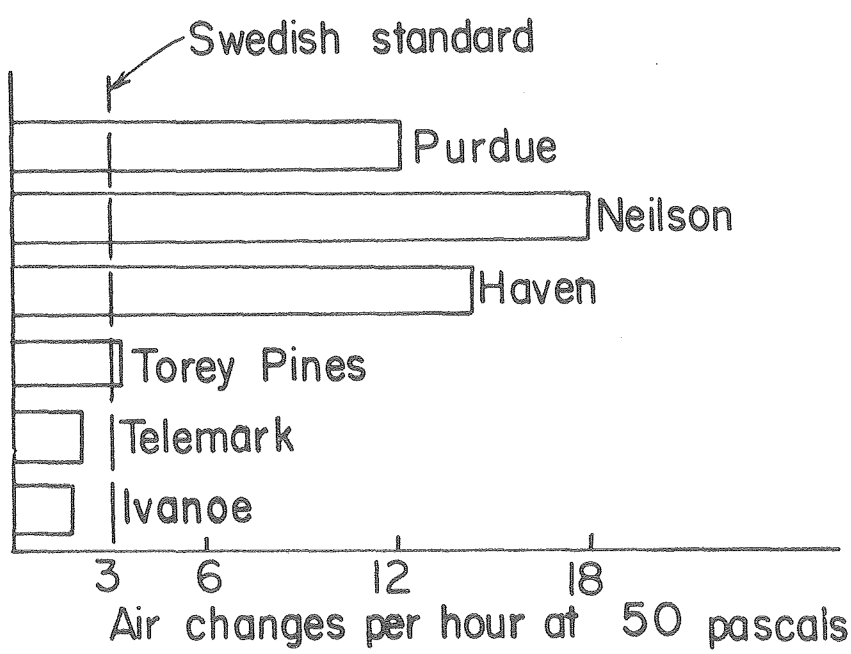

Figure 4. Air leakage values measured for the survey houses. (The values are the average of pressurization and depressurization results and are normalized by dividing the flow values by the house volume.)

Table 2 and Fig. 5 present a comparison of measured and predicted infiltration results for the six houses. Average weather conditions during the measurements are given in Table 2.

Table 2

House	Measured Infiltration (hr^{-1})	Wind Speed (m/s)	Temperature Difference (deg C)	Predicted Infiltration (hr^{-1})
Haven	0.26	5	6	0.23
	0.33	2	8	0.22
	0.23	3	10	0.18
	0.25	3	10	0.62
	0.28	2	5	0.29
	0.15	2	5	0.17
	0.61	3	9	0.40
	0.54	4	7	0.39
	0.54	4	7	0.44
	0.31	1	11	0.28
	0.29	3	12	0.21
	0.42	4	13	0.19
	0.36	4	14	0.28
	0.35	3	14	0.21
	0.47	4	15	0.20
Ivanhoe	0.12	4	22	0.14
	0.12	8	22	0.29
	0.10	6	22	0.19
Neilson	0.70	2	5	0.34
	0.64	2	6	0.33
	0.74	1	4	0.26
	1.36	1	5	0.52
Purdue	0.50	2	9	0.37
	0.52	2	9	0.43
	0.64	4	9	0.57
	0.69	5	10	0.72
Telemark	0.13	5	26	0.15
	0.10	4	25	0.12
	0.08	3	25	0.12
Torey Pines	0.35	7	18	0.27
	0.31	6	19	0.27
	0.42	7	19	0.28
	0.42	8	19	0.25
	0.38	8	20	0.25

Discussion

The agreement between predicted and measured infiltration rates is good considering the simplicity of the model used for the predictions. The average of the ratio of measured and predicted infiltration rates for all the points is 1.35 +/- 0.58. The uncertainty listed is the standard deviation of all the points. While some of the differences between measured and predicted values for a particular house will be the result of systematic errors, the variations over the six houses will tend to be more random. Therefore we feel that the use of the standard deviation to represent the spread of values in the model is appropriate

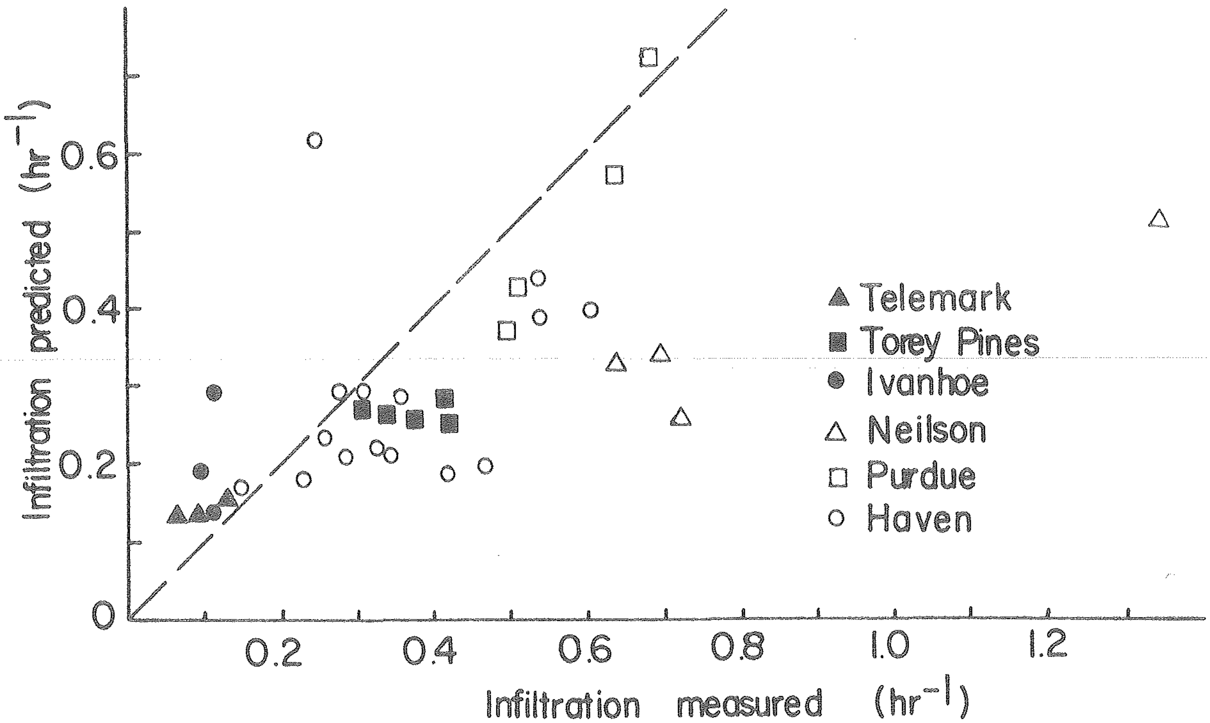

Figure 5. Infiltration rates predicted for each house from air leakage and surface pressure measurements plotted versus infiltration rates measured with a tracer gas. The dashed line is the locus of points for which measured and predicted values agree. It is not a fit of the observations.

for the data.

Systematic errors which are present include:

(a) inadequate ability to account for the leakage behavior of large openings (such as a fireplace without a damper) in the building shell. In a previous publication [1], these openings were taped closed; in this work, houses were measured in their normal condition. The effect of a large opening will depend upon the pressure distribution over the shell This in turn will depend upon the weather conditions at the house during the measurements.

(b) Pressures caused by the stack effect are not well treated by the measurement procedure as it currently exists. A far better procedure would be to use individual pressure sensors mounted adjacent to horizontal pressure taps passing through the walls. This eliminates the uncertainty due to unknown temperature distributions in the vertical runs of tubing connecting the pressure tap to the pressure sensor. However, our procedure was designed to be a portable technique to be used in occupied houses. Therefore penetrations of the building shell were to be minimized. This led to our present procedure.

The differences seen between the mild climate and severe climate houses is striking. Admittedly the selection is biased since the midwest houses are new and were designed to be energy-efficient. Both Minnesota houses have such a low natural ventilation rate that indoor air quality problems could occur. It is worth noting that the two Minnesota houses, built by a private contractor and completely financed by their owners, comply to the strict 1978 Swedish air leakage standard.

Future directions for this work include: 1. Studying the effects of the terrain upon surface pressures of a house. 2. Developing measurement techniques which can be used to study the gross distribution of leakage sites in the shell of a house. 3. Extending the study to other housing styles in other climate zones in the United States.

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