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A Predictive Air Infiltration Model - Field Validation and Sensitivity Analysis

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ABSTRACT

In this paper, we report on a comparative study of residential infiltration as predicted by our computer model and as measured in our Mobile Infiltration Test Unit (MITU) as well as in selected test houses, both occupied and unoccupied. Sensitivity analyses were also conducted on each parameter contained in the model against data obtained from MITU. The predictive model, which projects infiltration rates based on selected building and site parameters and local weather conditions, and the MITU, a portable test structure designed to continuously monitor air infiltration, local weather, and indoor-outdoor pressure differences, are fully described. From these field validation and sensitivity tests, we determined that the most critical parameters for accurate prediction of infiltration in residences in terms of accuracy of prediction are the leakage area of the building shell and the degree to which the structure is shielded from the wind.

INTRODUCTION

Researchers at Lawrence Berkeley Laboratory have developed a model for predicting the air infiltration rate of a residential structure. This model uses wind speed and outdoor temperature data, along with selected building and site parameters, to predict either hour-by-hour or long-term average

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infiltration.

Heretofore, the validity of the model has been tested through short-term survey measurements in occupied houses. Tests in occupied houses are necessarily restricted in terms of the time spent at any given house and the control of the model parameters for each building and site. This report presents long-term field validation results obtained by using a portable test structure, the Mobile Infiltration Test Unit; one week of data from an occupied house in Rochester, New York is used to compare model predictions with measured infiltration data.

INFILTRATION MODEL

The residential infiltration model developed at LBL[1,2] uses the concept of effective leakage area along with building and site parameters to make infiltration predictions from available weather data. The model was specifically designed for simplicity; that is, precise detail was sacrificed for ease of application. The functional form of the model, along with some important assumptions, is expressed as:

$$Q = L \sqrt{f_s^2 \Delta T + f_w^2 v^2} \tag{1}$$

where

Q	is the infiltration [m^3/s],
L	is the effective leakage area [m^2],
ΔT	is the indoor-outdoor temperature difference [K],
f_s	is the stack parameter [$m/s/K^{1/2}$],
v	is the wind speed, and
f_w	is the wind parameter.

The wind and stack parameters, f_w and f_s, convert the wind speed, v, and the indoor-outdoor temperature difference, ΔT, into equivalent pressures across the leakage area of the house; furthermore, they are weather independent quantities which depend upon the distribution of leakage area, the degree to which the house is shielded from the wind, and some geometrical parameters. Refs 1 and 2 give a detailed derivation and description of these two important parameters.

MITU TRAILER

The Mobile Infiltration Test Unit (MITU)[3] is a commercially available construction-site office trailer that was modified and instrumented to permit use for infiltration research. Illustrated in Figure 1, MITU is a portable self-contained test structure that permits complete control of building parameters and site parameters so that infiltration field studies can be conducted in a variety of climates. It is instrumented to validate both long-term average and hour-by-hour infiltration-model predictions. The trailer is also designed to test various components of the model individually (i.e., translation of airport wind data into wind at the structure, reduction of wind-induced pressures due to localized shielding, C′, etc.).

MITU is a wood-frame structure, 4.9 m(16 ft) long, 2.4 m(8 ft) wide, and 2.4 m(8 ft) high. It contains both heating and cooling systems and requires only electrical power at each site. The walls and floor of the trailer contain a total of sixteen window openings that can be fitted with interchangeable calibrated leakage panels for controlling total leakage area, leakage distribution, and leakage type (i.e., narrow cracks, large holes). The trailer shell is sealed with a continuous vapor barrier, and perforations are caulked with silicone sealant to minimize the leakage area. The leakage areas of the panels and the trailer shell are determined with a specially designed fan pressurization system that fits into one of the window openings and measures air flow using an orifice plate.

Air infiltration, weather data, and surface pressures are sampled, reduced, and recorded on floppy disk by a Z-80 microprocessor-based computer. Wind speed and wind direction are measured 10 meters (33 ft) above the ground using sensors on a weather tower mounted on the trailer. Air infiltration is monitored with the Continuous Infiltration Monitoring System (CIMS).[7] This system continuously injects a tracer gas and measures its concentration. The volumetric air infiltration rate is calculated from the equation:

$$C = \frac{F}{Q} + \left(C_o - \frac{F}{Q}\right) e^{\frac{-Qt}{V}} \tag{2}$$

where

Q	is the volumetric air infiltration rate [m^3/hr];
F	is the tracer gas injection rate [m^3/hr];
C	is the tracer-gas concentration [ppm];
C_o	is the tracer-gas concentration at time zero [ppm];
V	is the effective volume of the structure [m^3];
t	is the time elapsed since time zero [hr].

The CIMS system measures tracer-gas concentration (C), tracer gas flow rate (F), and elapsed time (t), leaving three unknown parameters: the infiltration rate (Q), the tracer-gas concentration at time zero (C_0), and the effective volume of the structure (V). The unknown parameters are determined by means of a SIMPLEX[4] likelihood maximization algorithm. The control algorithm then adjusts the tracer-gas flow rate to maintain the concentration within a specified range. Tracer concentration and tracer flow are checked every 30 seconds and these data are used by the SIMPLEX algorithm every half-hour. The zero drift of the analyzer is checked every 30 minutes and infiltration rates are stored as half hour averages.

Surface pressures from 82 taps located on the walls, floor and ceiling are measured with differential pressure transducers. Taps are opened and closed by solenoid valves controlled by the computer. During sampling, each tap is kept open for ten seconds. The pressure signal, sampled 40 times per second, is electronically filtered using a one-second time constant in order to eliminate any ringing in the pressure lines due to solenoid operation. The pressures are monitored with pressure transducers on six levels. Four of the transducers are on the walls at 0.23m (0.75 ft), 0.90m (2.95 ft), 1.57m (5.15 ft) and 2.24m (7.35 ft) above the floor of the trailer, while the remaining two transducers are for the ceiling and floor. This system allows for direct measurement of stack-induced pressures and the height of the neutral level. The zero of each transducer is checked every thirty minutes and subtracted from the surface pressures, which are then stored as thirty-minute averages.

INFILTRATION MODEL VALIDATION

MITU Field Trip

The Mobile Infiltration Test Unit was stationed in Reno, Nevada for the winter of 1980 (December, 1980 - March, 1981). The site was chosen for its low temperatures, high winds, and lack of shielding from the wind (see Figure 2). During the four-month period, infiltration and weather data were collected under a variety of conditions. The quantity, shape and distribution of leakage areas were varied, as well as the orientation of the trailer on the site. Half-hour average infiltration predictions were made for 34 days using weather data and appropriate values for each of the model parameters.

A compact method of displaying this type of data is by a histogram showing the ratios of predicted-to-measured infiltration as provided by figure 3 which indicates the distribution of this ratio for half-hour average infiltration rates; the histogram can be represented by a log-normal distribution having a geometric mean ratio of 1.17. The deviation of the (geometric) mean ratio from unity represents the expected systematic error in model predictions, while the width of the curve provides an estimate of the variation of an individual value about the mean. The spread factor, 1.34 in this case, is analogous to the standard deviation of a normal (Gaussian) distribution; the natural log of the spread factor is the standard deviation of the natural log of the ratios. The range corresponding to one standard deviation is determined by multiplying and dividing by the spread factor.

Although a histogram displays systematic errors, it does not provide any information about the tracking ability of the model which is illustrated in figures 4 and 5. Figure 4 is a plot of air infiltration rate vs. time for a three-day period and Figure 5 displays the results of a four-day test in another trailer configuration. Measured infiltration is plotted as a solid line, and predicted infiltration is represented by the dotted line. In both figures, the model predictions track measured infiltration quite well, even when the infiltration rate changed by a factor of ten over the course of the four-day test. These results encourage using the model to provide short-term infiltration predictions in situations that require hour-by-hour infiltration measurements, e.g., measurement of the thermal characteristics of buildings, indoor air quality tests, etc.

The long-term average infiltration rate is an important value for both annual energy use and indoor air quality, since the effects of certain contaminants (such as radon gas) are dependent upon long-term exposure. In many instances, the detailed weather information needed to determine hourly infiltration rates is not available and the long-term infiltration must be determined on the basis of averaged weather data. When long-term weather averages were used to approximate the average infiltration rate of the MITU facility during the 34-day period, the predicted average infiltration rate was 32.9 m^3/hr. The average infiltration rate measured during this time period was 32.5 m^3/hr, and the average of the infiltration predictions from half-hour weather readings was 34.4 m^3/hr.

While the success of the model predictions is encouraging, it is not surprising that structure as simple as MITU can be modelled. A more definitive test of a model is its ability to predict infiltration in a real house.

Occupied Test House

As part of a joint study with the New York State Energy Research and Development Authority and Rochester Gas and Electric Company, researchers at Lawrence Berkeley Laboratory made continuous air infiltration measurements in an occupied house in Rochester, New York. As part of this study, the leakage area of the house was measured, and the local weather conditions were monitored on-site. Our model was then used to make infiltration predictions based on the leakage area and weather measurements.

Figure 6 is a plot of measured and predicted infiltration for 1.5 hour periods over the course of the six-day test. The predictions track the measured infiltration reasonably well, and the average infiltration rates agree better than one would expect.

Using averaged weather data to approximate the average infiltration rate of the house during the six-day period, the model predicted an average infiltration rate of 82.9 m^3/hr. The average infiltration rate measured during this time period was 89.7 m^3/hr, while the average of the individual infiltration predictions was 89.4 m^3/hr.

CONCLUSIONS

Having compared our model predictions with measured infiltration rates obtained in the MITU trailer, one can conclude that the model can be used to predict successfully both long-term and hour-by-hour infiltration rates. For the entire 34-day data set, the half-hour infiltration predictions have an accuracy of 35%, the daily infiltration predictions are within 20%, and the weekly infiltration predictions are within 10%. The comparison of model predictions with the infiltration rates measured in the Rochester test house offers further evidence that the infiltration rates provided by the model correlate well with actual infiltration rates in occupied houses. The results are encouraging and additional tests in occupied houses under different weather and occupant conditions are underway to provide further insight into the strengths and weaknesses of infiltration modelling.

ACKNOWLEDGEMENTS

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REFERENCES

1. Sherman, M.H.. 1981. Air infiltration in buildings. (Lawrence Berkeley Laboratory report, LBL-10712).

2. Sherman, M.H., Grimsrud, D.T.. 1980. The measurement of infiltration using fan pressurization and weather data. Proc. of 1st AIC Conf., London.

3. Blomsterberg, A.K., Modera, M.P., Grimsrud, D.T.. 1981. The mobile infiltration test unit-- Its design and capabilities: Preliminary experimental results. Lawrence Berkeley Laboratory report, LBL-12259.

4. Nelder and Mead, 1967. Computer Journal,7,308.

Figure 1. Exterior view of Mobile Infiltration Test Unit in Blackberry Canyon at Lawrence Berkeley Laboratory.

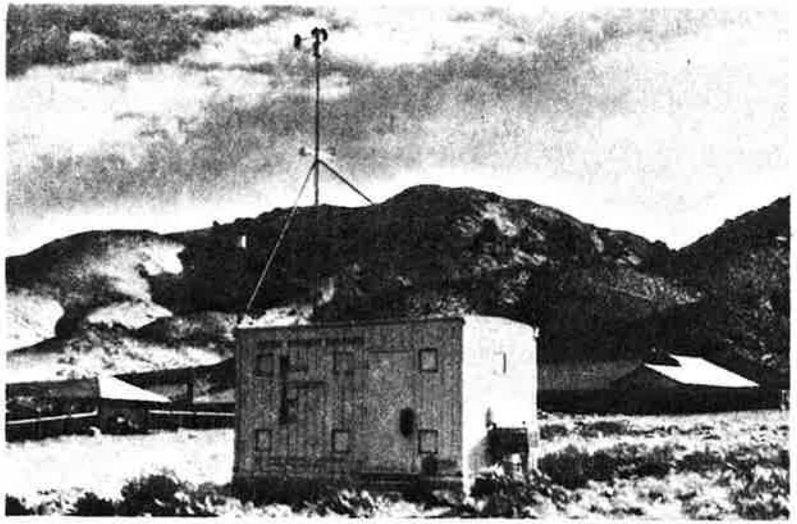

Figure 2. Mobile Infiltration Test Unit in Reno, Nevada test site.

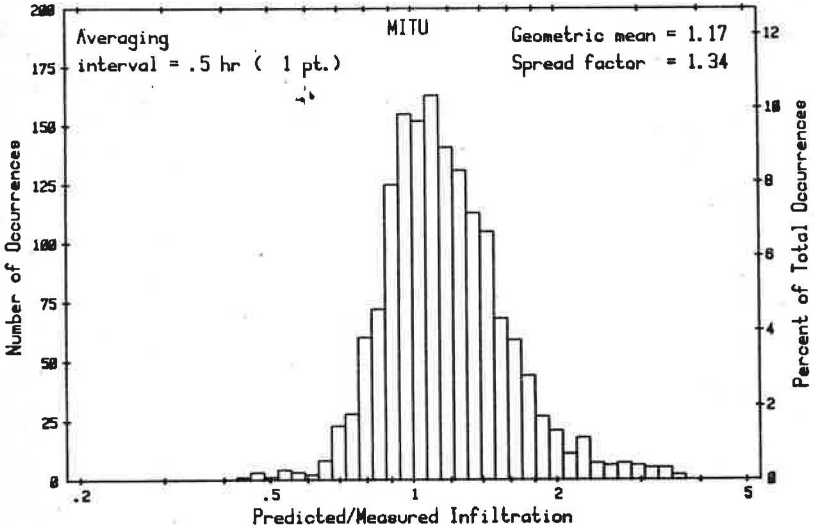

Figure 3. Histogram of predicted infiltration/measured infiltration for 34 days of data from MITU.

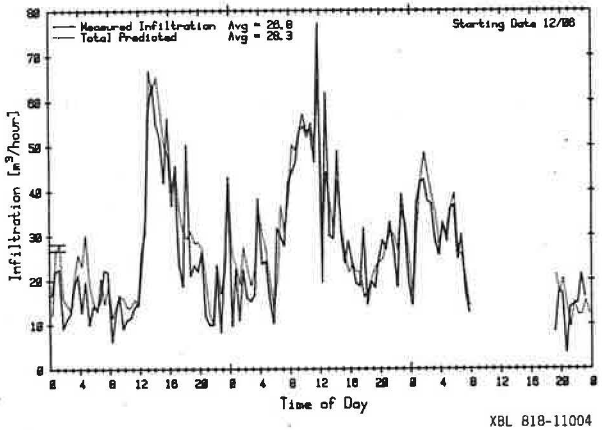

Figure 4. Plot of measured infiltration and infiltration model predictions vs. time: Three-day test in MITU.

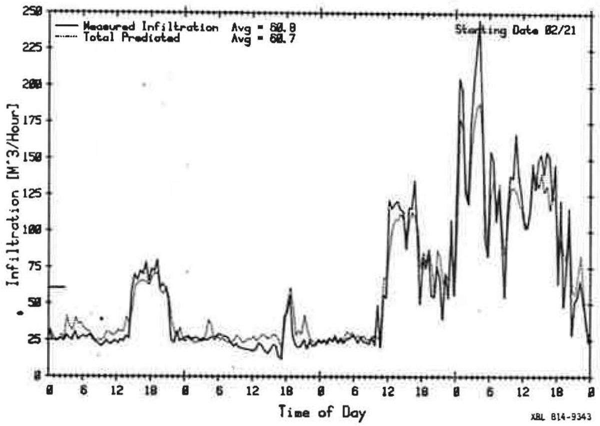

Figure 5. Plot of measured infiltration and infiltration model prediction vs. time: Four-day test in MITU.

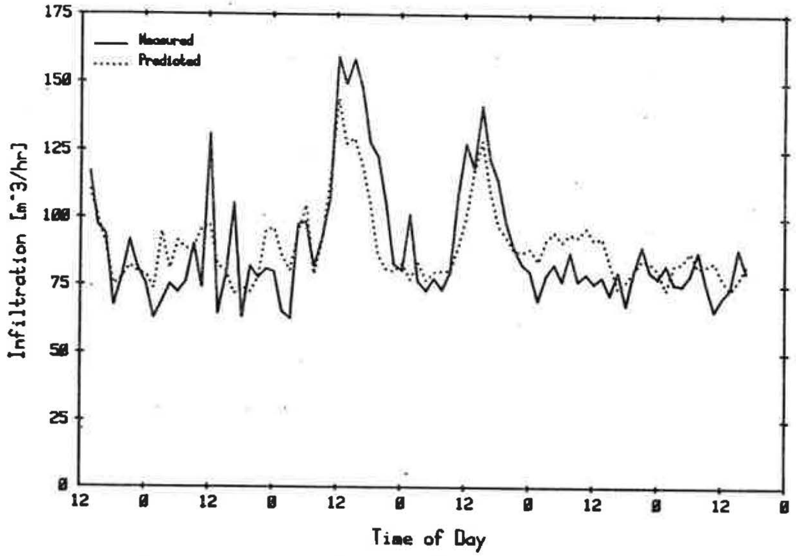

Figure 6. Measured and Predicted infiltration vs. time in Rochester Test House.

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Air Tightness vs. Air Infiltration for Swedish Homes - Measurements and Modelling

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ABSTRACT

Air infiltration, an important energy loss mechanism in buildings, has been studied in a number of homes in Sweden. Two methods for measurement have been utilized: the fan pressurization technique and the tracer gas technique. The pressurization technique is used to measure the air tightness of the building envelope, while the tracer gas technique is used to measure the air infiltration. Pressurization is used routinely for checking dwellings in Sweden. This technique does not give the air infiltration as a direct result.

A previously developed model correlating air tightness and air infiltration was used for evaluating the performance of Swedish homes. The results show that it is difficult to achieve the recommended minimum ventilation rate according to the Swedish Building Code only relying on natural air infiltration. It may work for a house with little shielding located in a windy area. Most new Swedish homes do, however, meet the stringent air tightness requirement of the Swedish Building Code. A comparison with American houses show that Swedish homes are very tight.

INTRODUCTION

Air infiltration typically accounts for a third of the energy loss in a heated building. The driving forces for natural air infiltration are weather i.e. wind and temperature. For a given combination of weather conditions the size of the air infiltration is determined by the character of the building envelope. The main property being the air tightness of the shell.

A promising technique to characterize this housing quality is air leakage measurements. An air leakage standard for new construction exists since 1975 in Sweden. Pressurization i.e. measurement of the air leakage is performed