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APPLICATION OF A GENERALIZED MODEL OF AIR INFILTRATION TO EXISTING HOMES

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ABSTRACT

This paper presents examples of the use of a generalized model of air infiltration, developed earlier, to estimate the air infiltration characteristics of two test homes using data for the structures, weather and furnace installation. One of these is a single-story home with basement, of wood-frame construction, equipped with an oil-fired central space heating furnace. The other is a 2-story interior unit (or a multi-unit low rise structure) with basement, of wood-frame construction, equipped with a gas-fired central space heating furnace. The paper also presents detailed methodologies used with the model to obtain the "total" effective crackage in each test home, the effect of wind-shielding by adjacent structures, and the characteristic permeability of the structure. Reasonable comparisons of the model-estimated air infiltrations to actual measurements for these test homes are also presented over a wide range of conditions affecting infiltration.

INTRODUCTION

Air infiltration in existing (and new) homes is becoming increasingly important and the development of a practical and cost effective means to estimate it through a generalized approach or modeling, not now available, is desirable. This is particularly true for residential structures equipped with fossil-fueled furnaces and boilers and, among these, the storehouse of existing homes is the more challenging. Use of such a generalized model can be made to more properly select and re-size central space conditioning equipment to attain high energy utilization efficiencies (as the infiltration load is becoming a more important factor of the total heating/cooling load because of retrofit insulation, thermostat setback, etc.). Such a practical model (not requiring testing at the site) can also be used to ascertain the energy and cost effectiveness of retrofit approaches to reduce excessive air infiltration, and of means to control the level of contaminants in the indoor environment.

AIR INFILTRATION MODEL DEVELOPMENT

The methodology used in the development of the basic model has been partially presented earlier,[1] together with a state-of-the-art review of ASHRAE[2] and other air infiltration models available in the literature.[3-10] For this reason, only a brief summary of the general approach and governing equations is presented here in order to provide for the necessary linkage to new information presented in this paper.

The most fundamental relationship describing the infiltration of outside air into a structure is the material balance around the envelope of the

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structure. Sinden[5] has described the basic envelope equations and, to some extent, the wind-temperature interaction, but has made no attempt to expand his model to predict infiltration for a wide variety of structures. Likewise, Konrad, et al[10] have described such material balance equations and, in addition, methodologies for determining wind-shielding efforts and oil furnace operation on air infiltration. Although the model was compared to data from one house, no attempt was made to generalize the model to cover other houses.

The Mass Balance Model

The basic driving forces for infiltration are the pressure differentials across the various components of the building envelope generated by the following:

- Wind pressure
- House buoyancy forces due to indoor-outdoor temperature differential
- Fan exhaust or pressurization
- Chimney buoyancy forces generated by chimney temperature and by furnace operation.

These pressure differentials, ΔP, act upon the various orifices and cracks in the building envelope to produce flow according to classical orifice theory –

$$F = \frac{1}{R}\,\Delta P^n = K\Delta P^n \tag{1}$$

where

F = flow rate

R = resistance to flow

K = flow coefficient

ΔP = differential pressure across the orifice

n = power function between 0.5 and 1.0.

The value of the power, n, depends on the relative contribution of kinetic and viscous forces to the energy loss incurred in flow. If the losses are primarily kinetic, n will be close to 0.5 rather than 1.0 which is approached in viscous flow. The literature indicates that flow in the types of orifices found in residential structures will be of the order of 0.5 to 0.65.[2]

The pressure drop across the cracks in the structure is caused by the static pressure arising from the force of wind acting upon a wall, and a buoyant force determined by the indoor and outdoor temperature differential. For a specific condition of outdoor temperature, wind speed, and direction, there is a unique position on each wall where the pressure driving force is zero ($\Delta P = 0$), called the neutral zone. Above this zone, the indoor static pressure is greater than the outdoor pressure and exfiltration occurs; below this point, the outdoor pressure is greater than the indoor pressure and infiltration occurs.

For the purposes of the model, we assume that the wind acts in a normal direction to only one wall and has no effect on the other three walls. The neutral zone height on the three leeward walls is obtained as the height where the static indoor pressure equals the static outdoor pressure. The difference in height, Z, between the neutral zones on the single windward wall and the other walls is given by Eq 2 below

$$Z = \frac{(ws)^2}{g(\rho_o - \rho_i)} \tag{2}$$

Physically, Z is the height of a column of air that at the given indoor-outdoor temperature differential equals the static pressure developed by the wind force. It is of interest to note that the neutral zones, in fact, may not necessarily fall within the structure (but on imaginary extensions of the walls), indicating the wall is either entirely exfiltrating or infiltrating air.

Given the above definitions and assumptions, material balance equations have been previously developed[1] (by equating infiltration and exfiltration) for four unique conditions dependent on windspeed, wind direction, temperature differential, and the distribution of crackage in the structure.

Analytically, exfiltration and infiltration across the different zones are represented by sets of equations similar to Eq 3 below, for infiltration:

$$\text{Infiltration} = \overbrace{\int_o^Y \Sigma K_x (\rho_o gh - \rho_i gh)}^{\Delta P}{}^n \, dh$$

$$+ \int_o^{Y+Z} K_I (\rho_o gh - \rho_i gh)^n \, dh \tag{3}$$

and Eq 4 below, for exfiltration:

$$\text{Exfiltration} = \int_o^{H-Y-Z} K_I (\rho_o gh - \rho_i gh)^n \, dh$$

$$+ \int_o^{H-Y} \Sigma K_x (\rho_o gh - \rho_i gh)^n \, dh \tag{4}$$

where

ws = wind speed

H = height of structure

Z = distance between windward and leeward wall neutral pressure zones

Y = distance between house floor and lower neutral pressure zone

h = distance from neutral zone

ρ_o = outdoor air density

ρ_i = indoor air density

g = gravitational constant

x, I = exfiltration, infiltration

in consistent units. Eq 3 also shows that the parenthetic terms in these equations are equal to ΔP.

Basic Assumptions

It has been the objective of the modeling effort to provide a tool that allows the determination of the exact locations of the neutral zone in each case (and, therefore, of the rate of air infiltration) by using the basic properties of the structure and weather data. For each case the mass balance formulations around the structure are obtained by equating infiltration and exfiltration above and below the neutral zone. Each such formulation represents a complex nonlinear mass balance equation and the following simplifying assumptions were necessary in order to obtain the required solutions:

- The pattern of crackage is uniform across a wall
- The cracks have a uniform resistance to flow regardless of type or location

- The air flow through a crack is proportional to the 0.50 power of the air pressure differential
- The wind pressure force on the windward walls is positive and does not cause any pressure disturbances on the other walls
- For winds that are not perpendicular to a wall of the house, the wind pressure effect is the cosine of the wind angle (with respect to the wall it acts upon) times the wind speed squared.

A computer program has been developed to facilitate the solution of the mass balance equations mentioned earlier and is also being used to provide a measure of validation of the model.

The data required to perform the mass balance model calculations include the following:

- The height of the house
- The crackage length of the windward wall and of the leeward walls
- The indoor and outdoor temperatures
- The wind speed and direction
- Furnace installation parameters
- Furnace operation data.

The program first computes the magnitude of Z (the difference in the height of the neutral zone) and then compares the magnitude of Y (neutral zone height) for each wall against the structure's height (H), in order to define the appropriate case and respective mass balance equation applicable. This program proceeds to set a value for Y for the leeward wall(s) at its lowest limit possible and to increase this value progressively, in small increments, until the mass balance between infiltration and exfiltration is satisfied. The output, then, of the program is the height of the neutral pressure zone on the leeward wall(s) from ground level. Using this value of Y, effective crack length, shielding, and permeability factors for the entire structure, the air infiltration rate is computed as a function of weather.

Field Test Data and Sources

In parallel to, and in order to aid, the analytical development of the basic air infiltration model, we developed an air infiltration data base consisting of information obtained by IGT in over 20 field test homes (located in the Chicago Metropolitan area) and data of other investigators made available to IGT for this development.

- IGT Field Test Data. Over a two year period beginning in 1977, as part of A.G.A. project HC-4-33, IGT conducted testing and measurements in a total of 23 homes.[11] These measurements included intensive measurements in three homes, and extensive measurements in the other 20 test homes. One intensive test home was unoccupied while the other two and all of the extensive test homes were occupied. The group included a wide variety of type of construction and house age and all were equipped with central gas-fired furnaces.

- Canton Test Homes. We also utilized data on file at IGT for the Canton Gas and Electric test homes.[12] The data included air infiltration measurements, weather data, and measurements of other house operating parameters obtained over a two year period (furnace and other appliance operation, door openings, vent-fan operation, etc.).

- Princeton Townhouses. We used air infiltration data for two townhouses from the Twin Rivers development supplied to IGT by Nick Malik, presently of the firm of Gamze-Korobkin-Caloger of Chicago.[13] These data were obtained as part of Dr. Malik's Ph.D. dissertation at Princeton University and include continuous measurement of air infiltration rates, door closures, weather data, and gas furnace operation.

- Ohio State University. We also used air infiltration data acquired from Robert Blancett of Owens-Corning Fiberglas. These data were obtained as part of a project conducted by Ohio State University for the Electric Power Research Institute[14] and include air infiltration measurements, weather data, furnace operating characteristics, and door closures. Data from this source are available for six homes and three apartments, with the residences equipped with various heating systems.

- Canadian Test Homes. Detailed air infiltration data, and enclosure permeability data, were reported by Tamura[15] for a single story residence located in Ottawa, Canada. These data cover a one year period of measurements from a house equipped with an oil furnace.

SUPPORT SUB-ROUTINE DEVELOPMENT

The major objective of the air infiltration model development effort is an accurate but practical model and program that can be used with information readily available for the residence (from house blue-prints and spec sheets, furnace installation parameters, and weather), without the need for testing. To accomplish the stated objective, the basic model formulations presented earlier are supported with additional information about the structure in order to account for other real effects and this is done through the development of several support models.

The "Total" Crackage Model

Our objective in the development of the model, as has been stated, is to produce a practical model that would have as inputs easily measured variables such as outdoor temperature, wind speed and direction. The most easily measured house structure characteristics are the observed window, door and sill cracks. If we assume that these cracks are uniformly distributed along the height of the house, solutions to Eq 3 and 4 can easily be obtained, reducing the amount of complex computer programming and the need to input the exact location of the observable cracks. The test of these assumptions comes in the comparison of the model predictions to the measured infiltration data.

To develop a proper accounting for the total crackage, a sequence of 5 crackage levels are used, termed crack inventory levels 1 through 5, and are as follows –

- Door and window perimeters
- Door and window perimeters plus door and window frame perimeters
- Door and window perimeters plus door and window frame perimeters plus sill plate
- Door and window perimeters plus door and window frame perimeters plus twice the sill plate
- Door and window perimeters plus door and window frame perimeters plus four times the sill plate.

To assess the validity of each of the above crack sub-models, on the assumption that a single crack permeability coefficient should describe the house, we use them in sequence to back-calculate the permeability coefficients corresponding to distinct sets of field-test occurrences in each house, using the measured air infiltration data. In each case, wind speed and direction and indoor-outdoor temperatures are known at the sites, for each field test occurrence. A range of typical permeability coefficients, back-calculated by the model from measured infiltration data for one test home (Chicago East-Ranch) and for each crack inventory level, are summarized in Table 1 and illustrated in Fig. 1.

Table 1 shows that a wide range of conditions prevailed during the distinct 20 field testing periods, resulting in the three distinct regimes (wind, or buoyancy dominated and mixed) which usually control air infiltration. Fig. 1 shows that crack inventory level 1 is totally unacceptable, resulting in a permeability coefficient for the house varying by a factor of 2.5 over the test conditions. Inventory level 5, on the other hand, results in an estimated range of permeability coefficient that can be used to adequately represent all the data of the house (mean permeability coefficient of 0.26 with a standard deviation of 0.03).

All the results of similar analyses (with data from several of our field test homes) have pointed to a total crackage sub-model equivalent to that obtained by assuming a crackage level inventory type 5 and single uniform whole house permeability. This conclusion is roughly equivalent to stating that infiltration through the sill plate per foot of crackage is roughly twice that for windows and doors. This result has also been corroborated by Caffey,[16] through air infiltration tests performed by using a blower to induce infiltration.

Wind Shielding Model

In the derivation of the air infiltration model equations, it was pointed out that wind speed is an important driving force in determining infiltration rates and that it is extremely important that wind speed levels at the site be known. Generally however, weather data are available from the nearest official weather station and it is usually assumed that outdoor dry-bulb temperatures, and to a large extent, wind direction data from such nearby sources correspond adequately with similar data at the test site. On the other hand, wind speed, and to a lesser extent wind direction, can be severely altered, due to shielding by surrounding structures and trees with foliage.

There is only minimal information in the literature regarding wind shielding factors. Dagliesh and Boyd[17] have attempted to develop conversion factors for changing weather station wind speed to on-site wind speed and Tamura[15] used their model in two test houses and found that the ratios of on-site wind speed to weather station wind speed were 0.65 and 0.56, respectively. Warren[18] has determined that the wind speed profile, under various types of shielding, could be related by the empirical equation:

$$\frac{V}{V_m} = a\, h^b \qquad (5)$$

where

V = wind speed at height h above ground, mph

V_m = wind speed at 10 metres

h = height, metres.

The coefficients a and b have been related to four types of shielding conditions defined as open, country, urban and city, in order of increasing shielding and their values are summarized in Table 2.

Table 2 Wind Velocity Profiles*

Type of Shielding	Equation Constants a	b
Open	0.68	0.17
Country	0.52	0.20
Urban	0.40 .35	0.25
City	0.31 .21	0.33

* Developed by Warren[18]

The wind speed profiles which represent the extreme (open and city) are illustrated in Fig. 2.

Fig. 2 also shows the agreement between the Warren typical wind profiles and that computed with Eq 5 for IGT's Canton Field Test Homes from detailed on-site and Canton-Akron airport weather station data, available for March and April 1970. The detailed comparison of the actual wind speed data (on-site to airport) is shown in Fig. 3 (3 and 1-hr averages), with the data indicating a shielding factor of about 0.56. It must be noted, however, that the Canton Test Homes were located in an open area (new subdivision) with newly planted trees.

Fig. 4 shows the comparison of the Warren predicted wind profiles with data from 4 additional IGT Field Test Homes (Chicago-East, Chicago-South, Chicago-West and Chicago-North). The actual data from these houses show shielding factors even lower than the lowest estimates of Warren (for city dwellings). Further work is needed in order to expand the Warren modeling to cover shielding arrangements such as encountered in the 4 IGT test homes or to develop other alternative approaches to correlate a structure's surroundings with wind shielding effects.

Permeability, Vent-Fan Use and Door-Window Openings

In addition to modeling of total crackage and of the effect of shielding of the wind force on a house, several other effects and characteristic quantities remain to be developed, before general use of the air infiltration model can be made. Of these, development of characteristic permeability coefficients for various typical structures (from gross structural information) is of prior importance. We have used the detailed air infiltration data available from several test homes, the total crackage sub-model, and the shielding values, estimated for each home through Eq 5 and actual on-site and weather station data, to compute typical permeability coefficients. A summary of these estimates is presented in Table 3.

It is seen in Table 3 that, generally, permeability coefficients with values around 0.35 tend to be typical of single-story with basement or crawlspace and split-level structures, with or without chimneys. Two-story structures with basement (but without chimney) may correspond to coefficients around 0.53, while 2-story structures and higher, with basements and chimneys, may be characterized by permeability coefficients in the range of 0.88 to 1.24.

While the data of Table 3 may be limited, they represent the only information available that begins to provide a systematic, but totally empirical, approach to developing the needed whole-house permeability data. Further work is required to augment the available data with information from other structures or to develop permeability coefficients by totally different approaches.

Ways to include the effect of house vent-fan usage and unscheduled door and window openings on air infiltration represent second order refinements of the model and have not been fully addressed to date. Initial tests (using infiltration data for periods during which scheduled fan-usage and/or door openings were programmed) indicate that proper accounting can be made of these effects, given sufficient data on air flow capacities, and schedule of operation, typical of actual homes and living habits.

MODEL VERIFICATION

Part of the data base available to IGT consists of very detailed air infiltration, structural, and furnace operation data from two test homes. These are a single story house located in Ottawa, Canada equipped with an oil furnace for space heating, and a 2-story frame housing unit in the Twin Rivers Project of New Jersey equipped with a central gas furnace, similar to house No. 11 shown in Table 3. The Canadian house (Tamura Test Home No. 1) was monitored over 3 distinct seasons (winter, summer and winter-spring period) during 1960-62, and the Twin Rivers housing unit (Malik Test Home No. 2) in 1974, with usable detailed infiltration data covering the October-December 1974 periods.

We have used IGT's air infiltration model, the support subroutine for total crackage estimation, shielding factors available from the investigators of these test homes and the permeability data of Table 3 above, in order to project detailed air infiltration data for these houses for comparison to the actual data. We used an average value of 0.35, as the representative permeability coefficient of the Canadian Test Home, and the permeability coefficient (1.25) from Table 3 for the Malik Test Home No. 2, because of the similarity to its companion unit (TR-1).

The comparisons between measured and model estimated infiltration rates for these two test houses are shown in Fig. 5 and 6. The measured data cover ranges of weather conditions and furnace operation which caused infiltration rates in the Canadian home to vary by a factor of 4 (from 24 m^3/hr to 95 m^3/hr or from 0.06 air changes per hour to 0.24 air changes per hour) and in the Twin Rivers home by a factor of 2.5 to 3 (from 127 m^3/hr to 348 m^3/hr or from 0.25 air changes per hour to 0.68 air changes per hour).

The data in Fig. 5 and 6 show that the model can be used to estimate rates of infiltration in these test homes with reasonable accuracy. Specifically for both test homes, the model predicts the actually measured air infiltration rates within 15% of the actual values at a level of confidence over 70% or at one standard deviation. We believe that for practical applications, this level of accuracy is quite acceptable, given the alternatives, but that more effort is required in order to increase the level of accuracy and to extend the model's applicability to other types of structures, climates and even more to occupants' living styles. At present, the preliminary model and data are being used to develop a dynamic air infiltration load model for general use with residential building energy calculation and load programs.

REFERENCES

1. Macriss, R. A. et al, "An Air Infiltration Model for Modern Single Family Dwellings," Paper No. 79-14.5 presented at the 72nd APCA Annual Meeting, Cincinnati, OH, June 24-29, 1979.

2. American Society of Heating, Refrigerating, and Air-Conditioning Engineers Inc., Handbook of Fundamentals. NY, 1972.

3. Coblentz, C. W., and Achenbach, P. R., "Field Measurements of Air Infiltration in Ten Electrically Heated Houses," ASHRAE Trans. 69, 358-65 (1963).

4. Malik, N., "Field Studies of Dependence of Air Infiltration on Outside Temperature and Wind," Energy & Bldgs. I, 281-292 (1977/78).

5. Sinden, F. W., "Wind Temperature and Natural Ventilation – Theoretical Considerations," Energy & Bldgs. I, 275-280 (1977/78).

6. Harrje, D. T., "Variations in Infiltration in Townhouses Before and After Retrofit." Paper presented at the E-6 Symposium on Air Infiltration and Air Change Rate Measurement, ASTM March Committee Week, Washington, DC, March 13, 1978.

7. Hittman Associates, Inc., "Residential Energy Consumption in Single-Family Housing," Report No. HUD-HAI-2. Columbia, MD., March 1973.

8. Sand~~y~~er, D.M., FORTRAN IV Program to Calculate Air Infiltration in Buildings, National Research Council of Canada, Research Computer Program, No. 38, May 1974.

9. Shaw, C. Y. and Tamura, G. T., "The Calculation of Air Infiltration Rates Caused by Wind and Stack Action for Tall Buildings." ASHRAE Trans. 83, Part 2, Paper No. 2359, 1977.

10. Konrad, A., Larson, B. T., and Shaw, C. Y., "Programmed Computer Model of Air Infiltration in Small Residential Buildings with Oil Furnace," Paper presented for the Third International Symposium on the Use of Computers for Environmental Engineering Related to Building, Banff, Alberta, Canada, May 10-12, 1978.

11. Institute of Gas Technology, "Field Verification of the Gas Furnace-Water Heater-Chimney-Home Flue Loss Model," Final Report, A.G.A. Project HC-4-33, January 1978.

12. R. H. Elkins, C. E. Wensman, "Natural Ventilation of Modern Tightly Constructed Homes." Paper presented at the American Gas Association-Institute of Gas Technology, Conference on Natural Gas Research and Technology, Chicago, IL, February 28-March 3, 1971.

13. Malik, N., "Field Studies of Dependence of Air Infiltration on Outside Temperature and Wind," Energy & Bldgs. I, No. 3, April 1978.

14. Jones, C. et al, "Data Acquisition and Instrumentation for Energy Studies of Remote Sites," ASHRAE Trans. Vol. 85, Part 1, 1979.

15. Tamura, G. T., "The Calculation of House Infiltration Rates, Paper No. 2513 presented at the ASHRAE Semiannual meeting, Philadelphia, PA, January 28-March 1, 1979.

16. Caffey, G. E., "Residential Infiltration," ASHRAE Trans. Vol 85, Part 1, 1979.

17. Dagliesh, W. A. and Boyd, D. W., "Wind on Buildings," Division of Building Research, National Research Council of Canada, 1962.

18. Warren, P. R., "Principles of Natural Ventilation," BRE Digest, February, 1978.

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Table 1 Calculated Permeability Coefficients for the Intensive Ranch Home (Chicago-East)

Run No.	Wind Speed, m/s	Wind Direction	T °C	Regime	Infiltration Rate m^3/hr	Permeability Coefficient CIL* 1	2	3	4	5
						<——	m^3/hr-m-$P_a^{1/2}$			——>
1	0	-	19	Buoyancy	46	NA	1.7	1.3	1.1	0.1
2	2.2	SE	26	Wind	12	NA	0.1	0.1	0.1	0.1
3	0.9	S	19	Mixed	24	2.3	0.8	0.6	0.5	0.3
4	0.9	SW	23	Mixed	29	2.4	0.9	0.6	0.5	0.4
5	0.9	S	16	Mixed	19	1.4	0.5	0.4	0.3	0.2
6	2.2	NE	14	Wind	41	NA	NA	NA	NA	NA
7	1.3	S	8	Mixed	32	1.6	0.6	0.4	0.4	0.2
8	1.3	N	14	Mixed	29	1.2	0.4	0.4	0.3	0.2
9	3.6	S	19	Mixed	29	2.5	0.9	0.5	0.4	0.2
10	2.7	W	4	Mixed	37	1.0	0.4	0.3	0.2	0.2
11	0.9	S	1	Buoyancy	46	1.5	0.6	0.4	0.4	0.2
12	1.8	S	-1	Mixed	49	1.8	0.7	0.5	0.4	0.3
13	4.5	S	4	Mixed	46	2.1	0.8	0.5	0.4	0.2
14	2.7	S	4	Mixed	56	2.2	0.6	0.6	0.4	0.3
15	4.9	W	1	Wind	48	0.7	0.3	0.2	0.2	0.1
16	2.2	S	1	Mixed	32	1.2	0.4	0.3	0.2	0.2
17	3.1	S	6	Mixed	32	1.4	0.5	0.4	0.3	0.2
18	1.8	SE	-13	Buoyancy	70	1.9	0.7	0.5	0.4	0.3
19	1.3	S	-13	Buoyancy	70	2.0	0.7	0.5	0.5	0.3
20	3.6	N	-1	Wind	54	0.8	0.3	0.3	0.2	0.2
					Average	1.66	0.63	0.46	0.36	0.26
					S. Dev.	0.14	0.08	0.06	0.05	0.03

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* CIL - Crack Inventory Level

1 Window and door perimeters only
2 Window and door perimeters and framing
3 Window and door perimeters and framing plus sill plate
4 Window and door perimeters and framing plus two times sill plate
5 Window and door perimeters and framing plus four times sill plate.

Table 3 Permeabilities of Various Structures

Test House	Type of Structure	Heating System	Permeability Coefficient $m^3/hr\text{-}m\text{-}Pa^{\frac{1}{2}}$
1. IGT - CHIE	1-Story Frame with Crawlspace	Gas	0.26
2. OSU - SRSG	1-Story Brick (and Stucco) with Basement	Gas	0.40
3. OSU - HSLG	Split Level Frame and Stucco	Gas	0.40
4. Canton Test Home	1-Story Frame with Basement	Electric	0.42
5. OSU - KTSC	2-Story Frame with Basement	Electric	0.55
6. OSU - CTSE	2-Story Frame with Basement	Electric	0.56
7. IGT - CHIC	2-Story Brick with Basement	Gas	0.81
8. IGT - CHIW	Split Level Frame with Crawlspace	Gas	0.89
9. IGT - CHIS	Raised Ranch Frame with Basement	Gas	0.94
10. OSU - HTSG	2-Story Frame with Basement	Gas	1.29*
11. TR#1	2-Story Frame with Basement	Gas	1.29

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* The infiltration rate in this house was very high even when there were no apparent driving forces (i.e., wind, buoyancy).

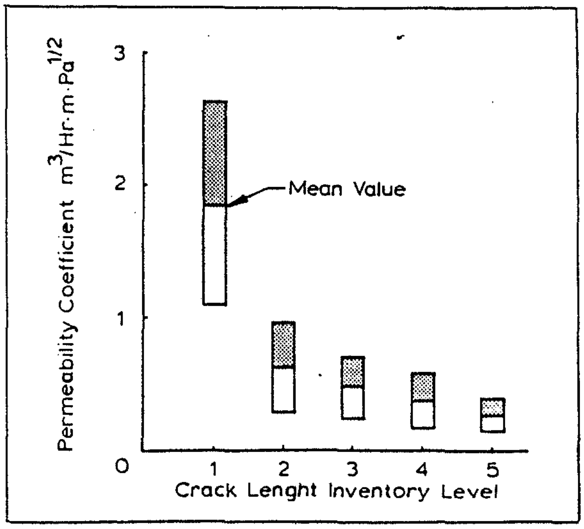

Fig. 1 Assessment of model for"total" crack length estimation

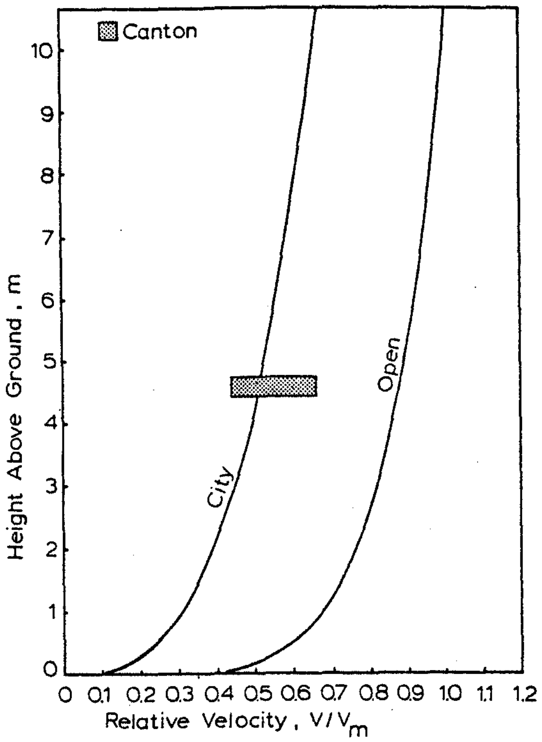

Fig. 2 Wind speed profiles and shieding data for the Canton Field Test Homes

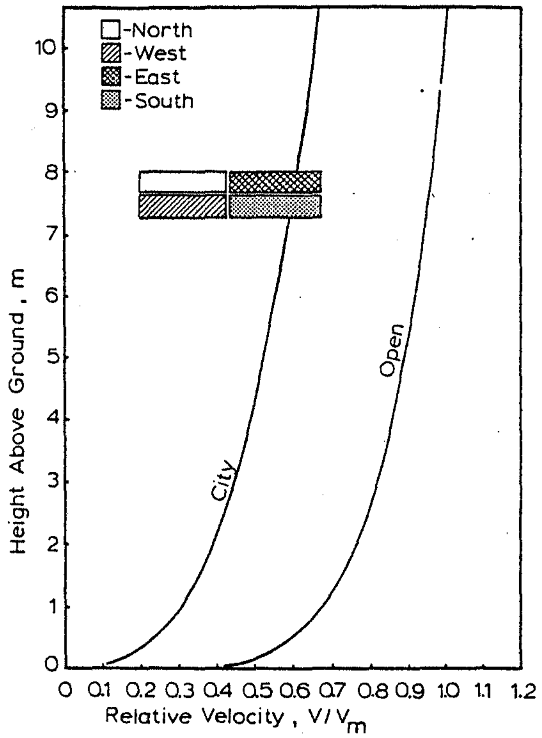

Fig. 4 Wind speed profiles and shielding data for 4 Chicago Field Test Homes

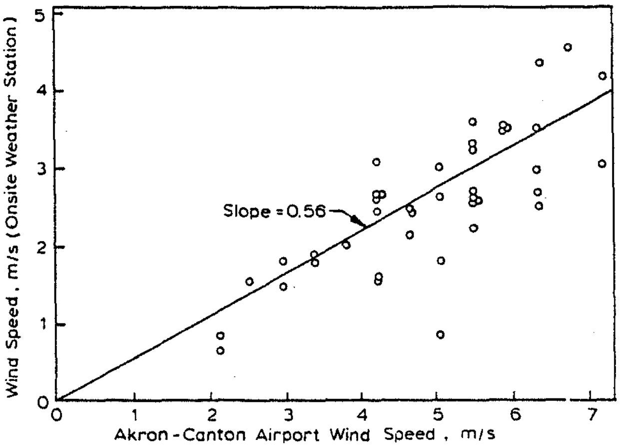

Fig. 3 Comparison of airport weather data (Canton Test Homes)

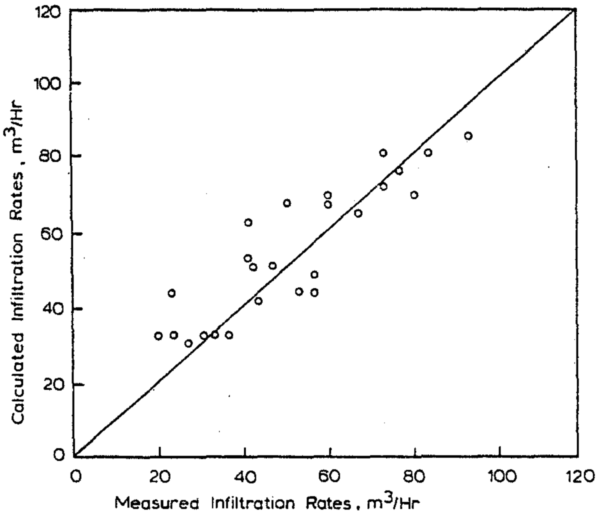

Fig. 5 Comparison of measured infiltration rates in Canadian Test Home and model projections

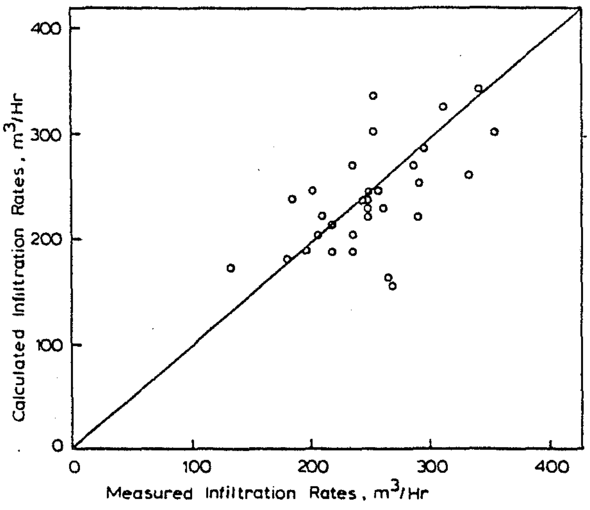

Fig. 6 Comparison of measured infiltration rates in Princeton Townhouse No. 2 and IGT model projections