A PROPOSED METHOD FOR

ESTIMATING AIR INFILTRATION

IN NEW RESIDENCES

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ABSTRACT

The National Association of Home Builders sponsored a project in 1982 to update its Thermal Performance Guidelines, first published in 1978. The work was performed by the NAHB Research Foundation.

As part of the project, individual state models were developed which were representative of new homes constructed in each state. Using extensive survey data, the Foundation established representative construction characteristics for each model. The models define the number and types of windows and doors, including method of window operation, sash material, layers of glass, presence or absence of storm windows, and a reasonable estimate of window and door fit.

Using the data, a procedure was developed for estimating the winter air infiltration rate for each model. The procedure was applied to all locales in the program. It takes into account winter temperature and wind speed and by using various procedures already in the literature, establishes effective wind speeds which include the effects of temperature differentials. Temperature and wind pressures are converted to air flow rates and combined to allow prediction of air infiltration rates attributable to window and door cracks.

It is felt that the procedure and subsequent investigations may have merit in estimating design heat losses and heating energy consumption for residences while at the planning stage.

Curves and equations are given showing effective wind speeds, pressure differentials, and rates of infiltration air flow for a variety of weather conditions and building designs.

KEY WORDS:

air infiltration, wind speed, pressure difference, stack effect, air flow coefficient, air flow exponent, air flow rate, air changes per hour, window fit, door fit, storm sash

INTRODUCTION

Over the past several years, residential air infiltration prediction and measurement has received a great deal of attention in the building and scientific communities. Numerous models have been developed which employ both theoretical and empirical bases. In addition, literally scores of field measurement projects have been reported, generally involving pressurization and gas decay techniques.

One reason for this research emphasis is that with widespread acceptance of high levels of thermal protection in the opaque portions of the residential building envelope, the development of fully insulated exterior doors and the regular specification of multiple layers of window glazing with improved sash thermal characteristics, the additional energy conservation potential which might result from still lower thermal transmittances is modest.

Many of today's homes are being constructed with envelope insulation systems and glazing layers which approach, or are on the relatively low sloped portion of, the common thermal transmittance versus thermal resistance curve. The thermal design of new homes is often based on one or more of a myriad of economic analysis techniques which have been widely published over the past decade.

With the above in mind, it is only logical that residential heating and cooling energy conservation research efforts have shifted in emphasis to, among other subjects, control of natural and mechanical ventilation.

A second reason for the proliferation of reported air infiltration research is the development of, and common accessibility to, automatic recording and analytic equipment, thus enabling investigators to process, report and analyze large and continuous series of measurements with ease.

While vast amounts of information on the subject are readily available, by the nature of the limited applicability of most and the sophisticated form of much of the work, there is a need for enhanced information transfer from the scientific and research communities to the world of day-by-day decision making which is a hallmark of the home building design and construction process. Very simply, builders and designers need information in a form which lends itself to ready understanding and which can be used at the very local level with relative ease.

As a part of the recent development of the revised National Association of Home Builders Thermal Performance Guidelines *(1)*[2], natural winter air infiltration was examined on a locale-specific basis, as one part of the energy consumption modeling techniques employed. These techniques have been reported elsewhere. *(2)* In that work, local winter weather data for 202 metropolitan areas in the 48 contiguous United States were analyzed and combined with single family detached housing characteristics compiled by the NAHB Research Foundation (Foundation). These characteristics included home size and type (single story, two story, split level and bilevel); number, size and types of windows and doors; number of glazing layers; sash construction; use of storm windows and doors; and the presence or absence of window and door thermal breaks. While siding and wall sheathing data were also included in the characterizing of estimated degrees of air infiltration integrity, no corresponding information on the use of caulks and sealants was available at the time of the analysis. That study was the first part of a multistage investigation of the factors which influence residential air infiltration.

[2]The italic numbers in brackets refer to the list of references appended to this paper.

OBJECTIVE

The work reported in this paper addresses itself to the window and door contributions to natural air infiltration only. It is the intent of the Foundation to evaluate the effect of opaque wall systems and components and sealant and caulking practices as the next phase. Whole-house performance and occupancy patterns will then be examined. Throughout the work, the current "state-of-the-art" methodology developed by the Foundation will be compared to continuing inputs of actual field measurements. It is proposed that a readily understandable infiltration design and selection procedure will be made available to builders and designers at the conclusion of the entire work, in the form of printed manuals, programs and any other formats appropriate to the time.

As this initial analysis is limited in scope, assumptions have been made for inputs which will be subsequently examined in detail as the entire project is developed. These gross assumptions are described below and will be modified and refined as the work proceeds.

Currently available field measurement data are presently being compared to the preliminary models presented here. As the data base increases and modifications in the assumptions are made, improved correlation between predicted and measured values is anticipated.

PROCEDURE

Weather data for the 202 locales were compiled and average winter temperatures and wind velocities were employed to estimate space heating consumption for the models developed for each locale. A portion of this compilation is shown in Fig. 1. The generally random nature of temperature-wind combinations is evident. Thus, the air infiltration contribution of each component has been separately addressed.

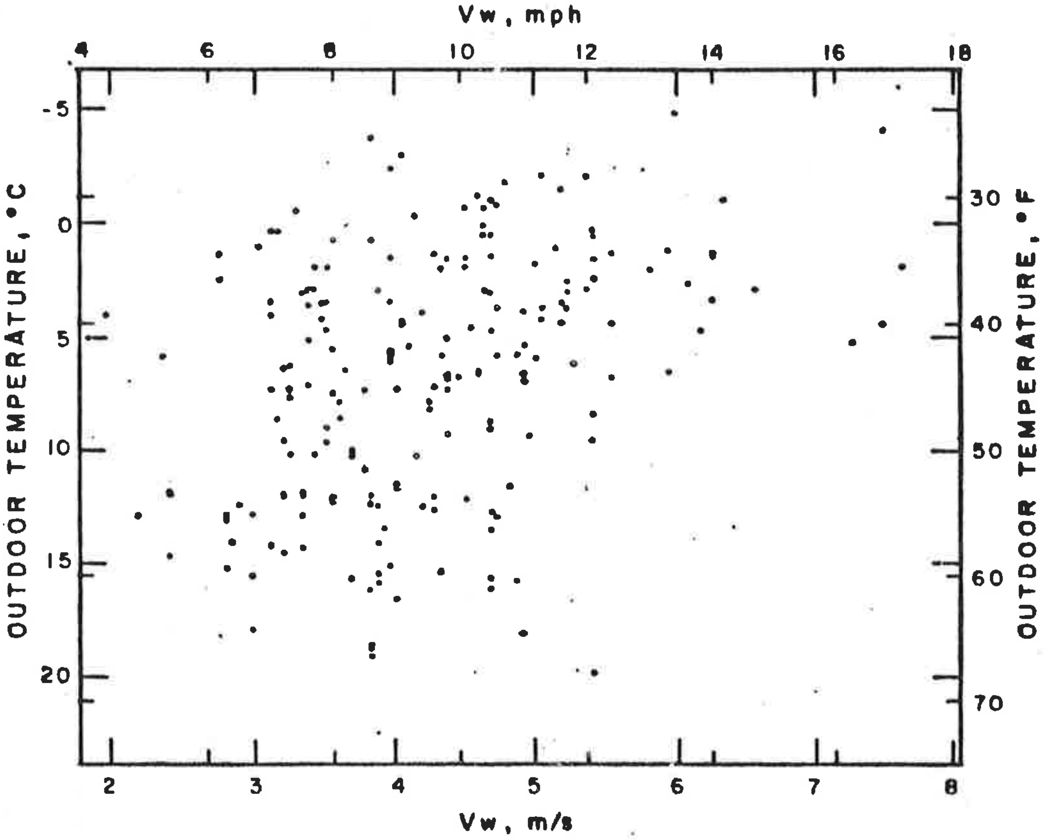

FIG. 1 - Average Outdoor Winter Temperatures and Wind Velocities for Selected U. S. Cities

The widely accepted relationship between wind pressure, air density and wind speed as shown in the ASHRAE Handbooks *(3)* and elsewhere is represented as Fig. 2, and follows the equation:

$$Pv = C(V)^2 \qquad (1)$$

where
- Pv = wind pressure, Pa (in. H_2O)
- C = constant of 0.601 (0.000482) corresponding to a barometric pressure of 101.3 kPa (14.7 psi) and temperature of 20°C (68°F)
- V = wind speed, m/s (mph)

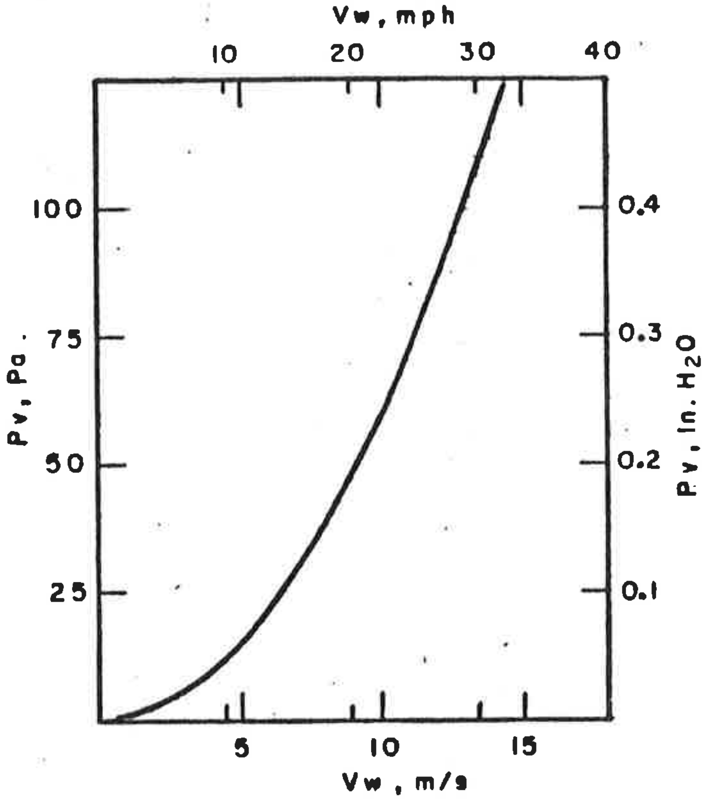

FIG. 2 - Velocity Head versus Wind Velocity

This wind pressure may be converted to a volume flow rate of air *(4)* by the equation:

$$Qw = c(\Delta Pv)^n \qquad (2)$$

where
- Qw = volume flow rate of air due to wind pressure, litres/s (cfm)
- c = flow coefficient, volumetric flow rate per unit length of crack, taken as 0.0131 (1.0)
- ΔPv = pressure difference, Pa (in. H_2O)
- n = flow exponent, taken as 0.65

Infiltration due to temperature difference as a function of building height may then be estimated by first calculating equivalent wind velocity *(5)* as follows:

$$Ve = (\beta)\left[(h)(t_i - t_o)\right]^{0.5} \qquad (3)$$

where

Ve = equivalent wind velocity corresponding to the temperature difference $(t_i - t_o)$, m/s (mph)
β = a constant to take into account floor and ceiling leakage and building height, taken as 0.543 (0.50)
h = height of residence from finish grade to top surface of living area, m (ft)
t_i = indoor temperature, ^oC (^oF)
t_o = outdoor temperature, ^oC (^oF)

Equations (1) and (2) are then employed to calculate the corresponding volume flow rate due to temperature difference and building height. This flow rate is designated as Qs.

The two flow rates may then be combined *(6)*:

$$Qws = (Qw^2 + Qs^2)^{0.5} \qquad (4)$$

where

Qws = infiltration from both wind and stack effects, litres/s (cfm)
Qw = infiltration from the wind, litres/s (cfm)
Qs = infiltration from the stack effect, litres/s (cfm)

One graphical representation of the relationship between the two flow components is shown as Fig. 3.

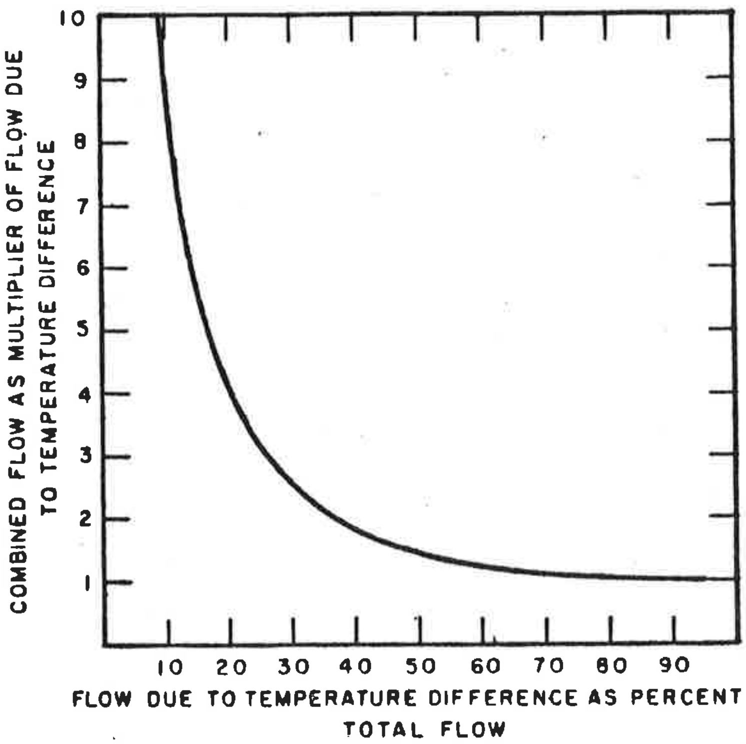

FIG. 3 - Determination of Flow Caused by Combined Forces of Wind and Temperature Difference

Combined crack air flow at various wind velocities, using the preceding equations is shown as Fig. 4, for a one story residence with a height from finish exterior grade to top surface of living area of 3.05 m (10.0 ft). Figs. 5 and 6 show corresponding flow rates for residences of 4.57 m (15.0 ft) height (split level and bilevel) and 6.10 m (20.0 ft) height (two story).

The greater significance of higher temperature differentials for various building heights may be seen by comparing Figs. 4-6. It may be observed that at small temperature differentials, building height is a secondary infiltration influence. Conversely, it may be inferred that infiltration heating requirements at the colder design conditions found in the northern half of the nation are distinctly affected by building heights.

At an average winter temperature differential of 16.7°C (30° F) and a concurrent wind speed of 4.0 m/s (9 mph), calculated air flow of a two story residence is 30 percent greater than that for a one story residence. This temperature-wind combination is representative of a large and populous portion of the nation. Whether equally significant infiltration air flow increases occur in opaque exterior wall assemblies with greater building heights and temperature differentials remains to be determined.

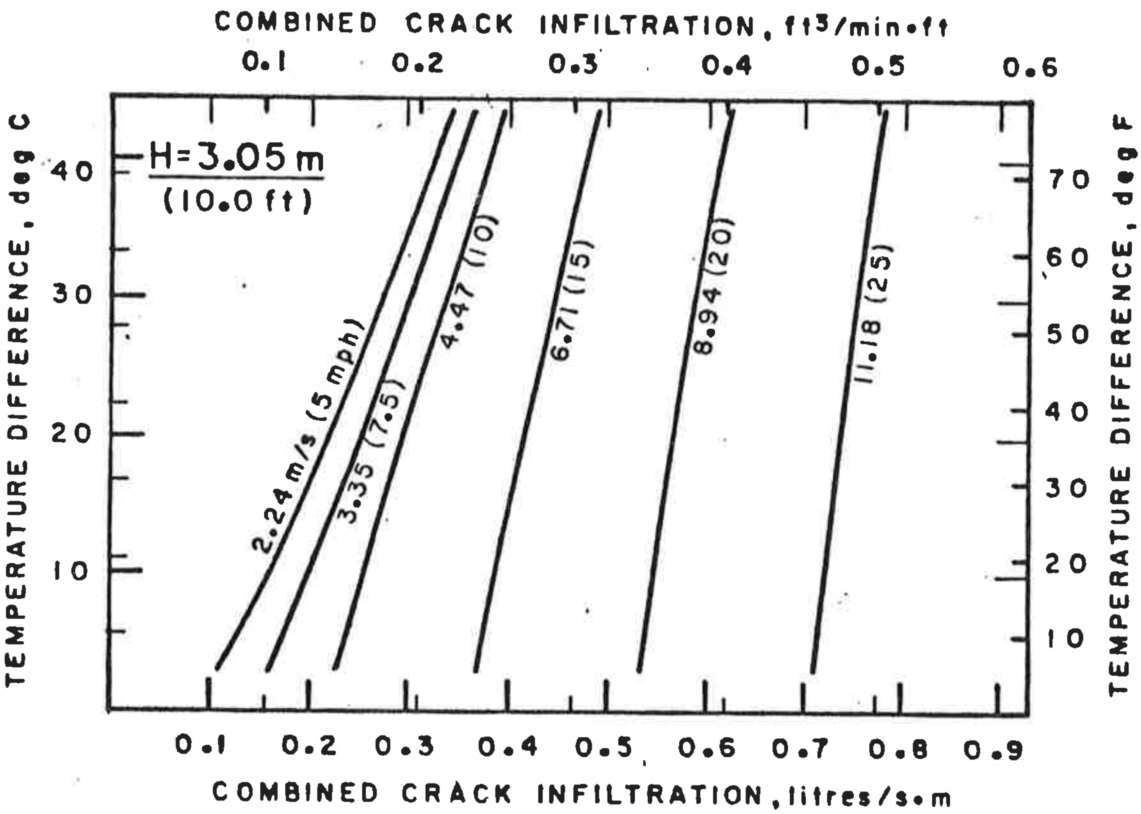

FIG. 4 - Combined Crack Infiltration for a One Story Residence

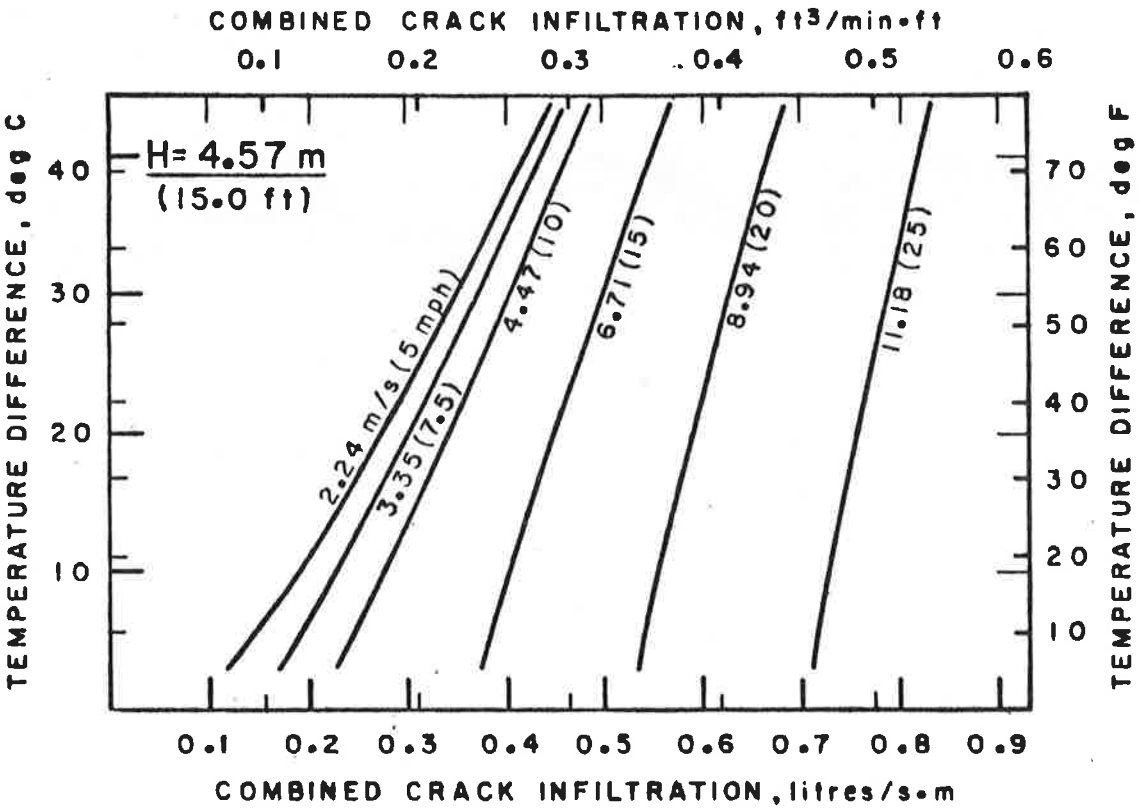

FIG. 5 - Combined Crack Infiltration for a Split Level or Bilevel Residence

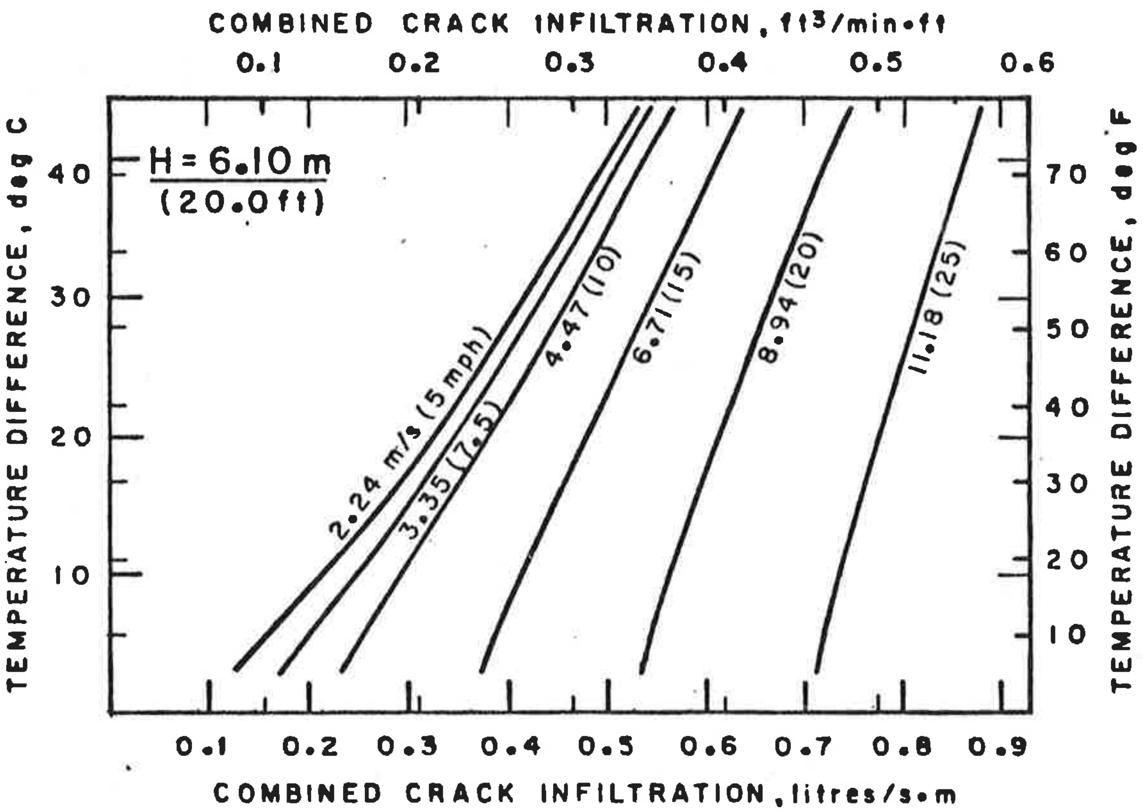

FIG. 6 - Combined Crack Infiltration for a Two Story Residence

The quantitative effects of window and door fit and the application of storm windows and doors were next examined. The ASHRAE Cooling and Heating Load Calculation Manual assigns arbitrary "K" value classifications representing "tight", "average" and "loose" fitting windows and doors as K-1.0, K-2.0 and K-6.0 respectively *(7)*. See Fig. 7. As this paper addresses new residences only, the categories presented are limited to the K-1.0 and K-2.0 classifications.

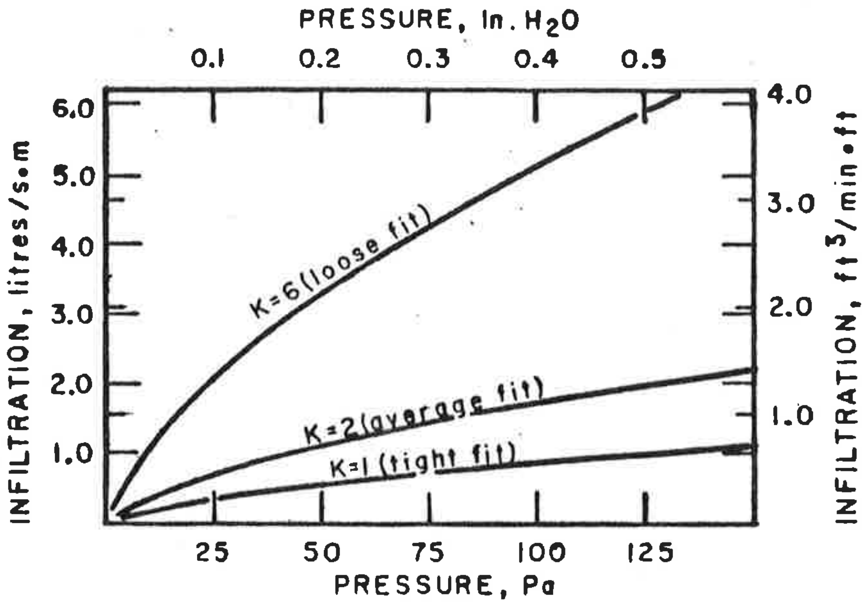

FIG. 7 - Window and Residential Type Door Infiltration Characteristics

Air flow reduction due to the addition of storm sash is shown in equation form by ASHRAE *(8)* as:

$$Qc = Qp\left[\frac{1}{(Cp/Cs^{1/n} + 1}\right]^{n} \qquad (5)$$

where

- Qc = flow rate for combined prime and storm window
- Qp = flow rate for prime window
- Cp = proportionality constant for prime window
- Cs = proportionality constant for storm window
- n = flow exponent, taken as 0.65

This equation is graphically shown as Fig. 8. Values for Ks of 0.5, 3, 4, 5 and 8 have been included for information and as an additional frame of reference. Examination of Fig. 8 reveals the possibility of condensation on the interior surface of tightly fitting windows and glazed storm doors fitted over relatively poorer fitting prime windows and doors.

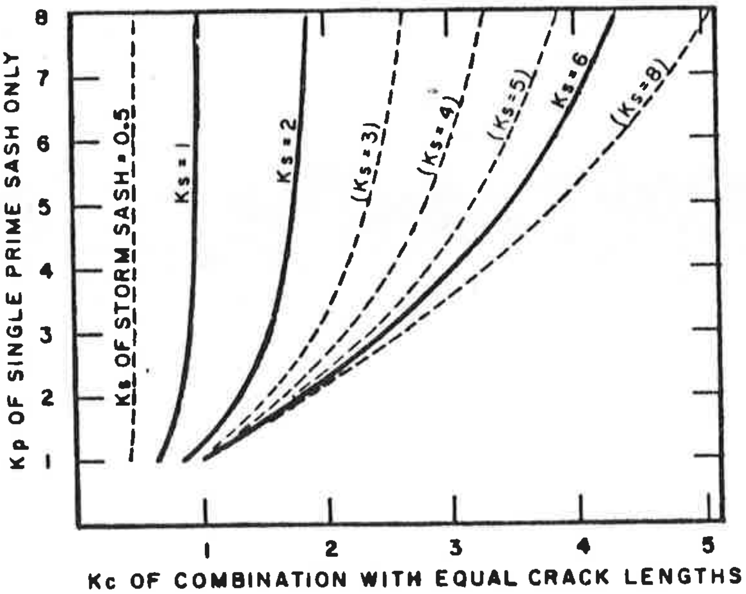

FIG. 8 - Kc Multiplier for Prime Sash with Storm Sash Over

The above procedures were then used to derive predicted air infiltration as a function of wind speed, temperature difference, building height and building "tightness". In addition, ratios of window crack length to window area have been investigated, to differentiate between fixed, single-hung, double-hung and casement window sash constructions.

The predicted air change rates have been compared to other empirical models *(9-10)*. Four curves from the sources cited are shown as Fig. 9.

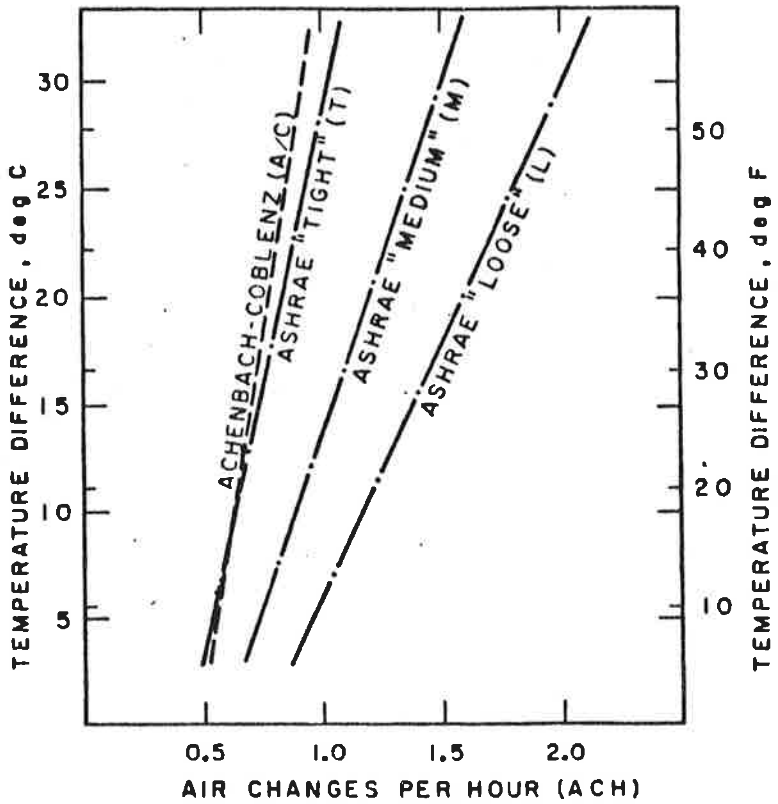

FIG. 9 - Calculated Air Changes from Referenced Empirical Models

RESULTS

Predicted air change rates were calculated for a residence of 140 m^2 (1 500 ft^2) of living area with two exterior doors and a window area equal to ten percent of floor area. Fig. 10 applies to a one story home with an exterior wind speed of 4.5 m/s (10 mph). The empirical models shown in Fig. 9 are included for comparison. The K-1 and K-2 curves are shown with single-hung (ratio of crack length to window area of 1.0) and double-hung (ratio of 1.4) windows. Corresponding curves for split level and bilevel homes are shown as Fig. 11, and for two story homes as Fig. 12. K-1 windows and doors have been assumed to constitute 40 percent of the total wall infiltration, while K-2 windows and doors have been assumed to constitute 50 percent of the higher K-2 home infiltration values. Occupancy contribution has been arbitrarily assigned as an additional 0.2 air changes per hour (ach). This is in contrast to the assumptions of 0.10 ach in *(9)* and 0.252 ach in *(10)*.

These and similar curves are currently being compared to field measurements for both occupied and unoccupied conditions. As more data are received and evaluated, the curves will be continuously adjusted. Additional modifications will be made as the effects of wall assemblies, caulks and sealants, HVAC equipment, fireplace installation and usage, and most importantly, occupancies are evaluated and better understood in relation to the air infiltration integrity of new homes.

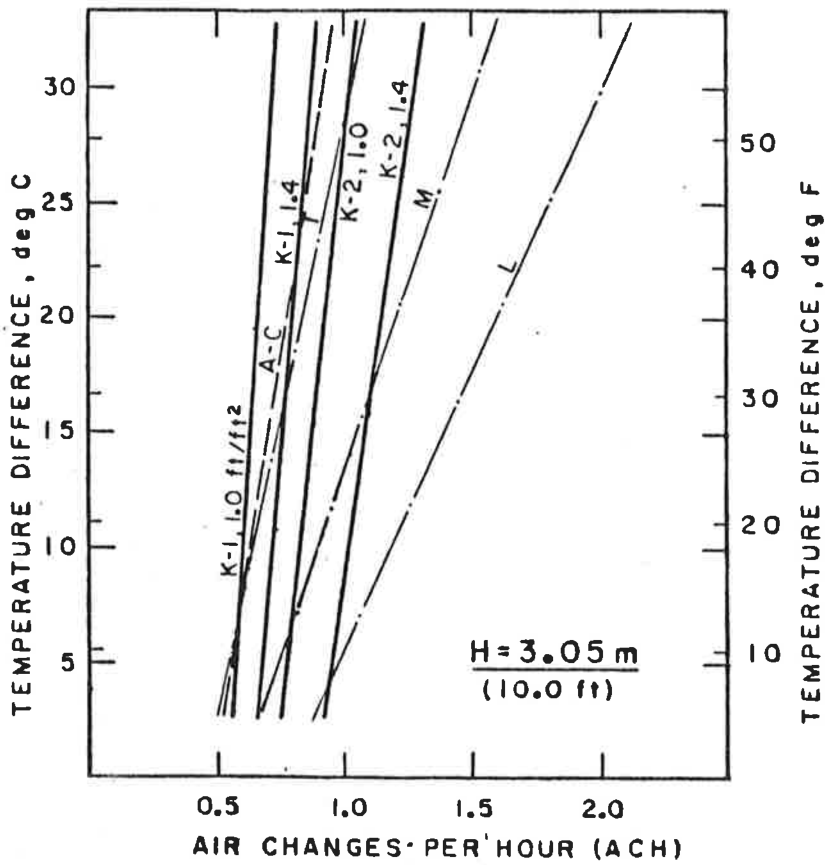

FIG. 10 - Calculated Air Changes for One Story Model

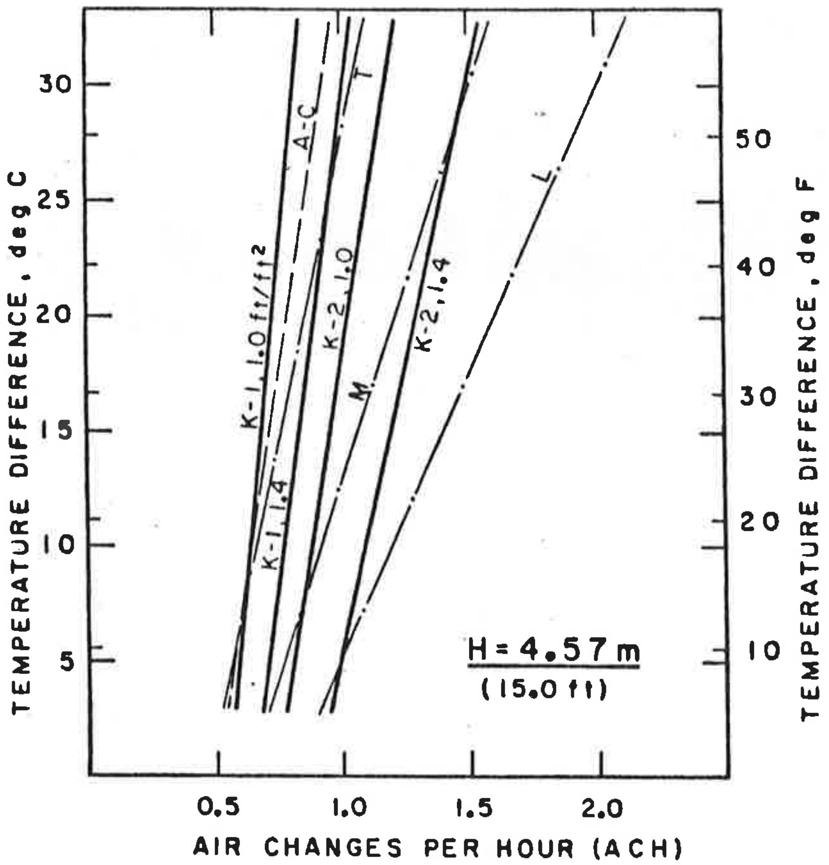

FIG. 11 - Calculated Air Changes for Split Level or Bilevel Model

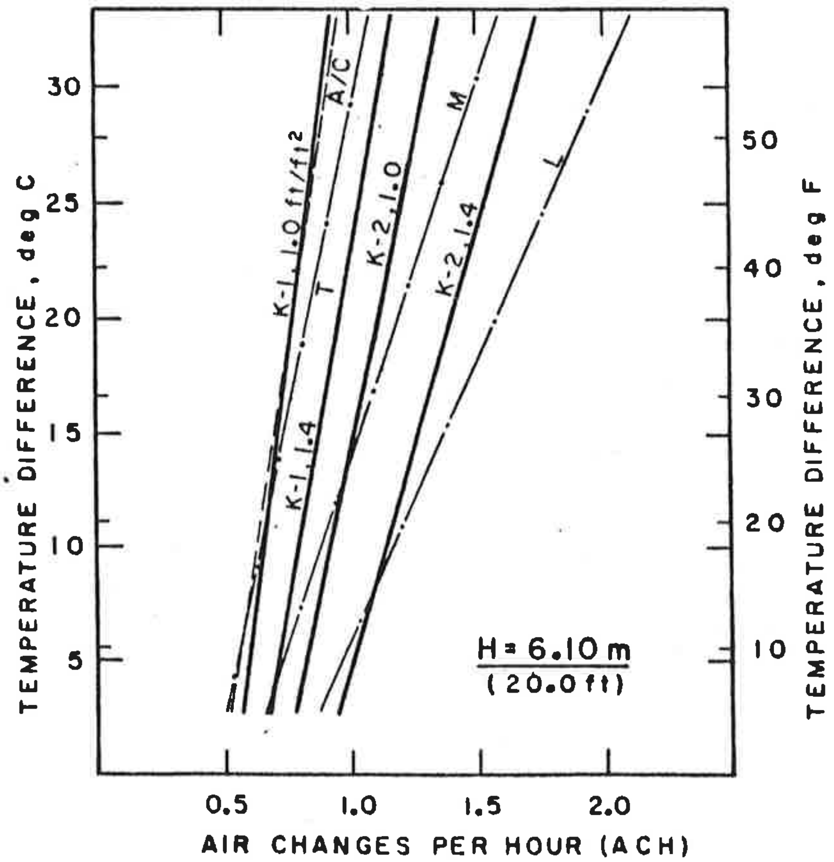

FIG. 12 - Calculated Air Changes for Two Story Model

As a concluding sidelight, Fig. 13 shows curves of equal crack air flow leakages superimposed over the 202 scattered points shown in Fig. 1. The curves were constructed using the Foundation methodology described above and represent a one story residence. It may be noted that such apparently divergent winter climes as Concord, NH and Wilmington, NC, as well as Bangor, ME and Norfolk, VA, are paired in relation to the curves. If the methodology proves to be valid, it follows that from a winter heating consumption viewpoint, the paired locales justify equal attention regarding natural winter air infiltration through window and door cracks.

Future work may show the feasibility of developing a "window-chill" (perhaps similar to a "wind-chill") index or factor, in recognition of the combined air flow leakage associated with winter temperatures and concurrent wind speeds.

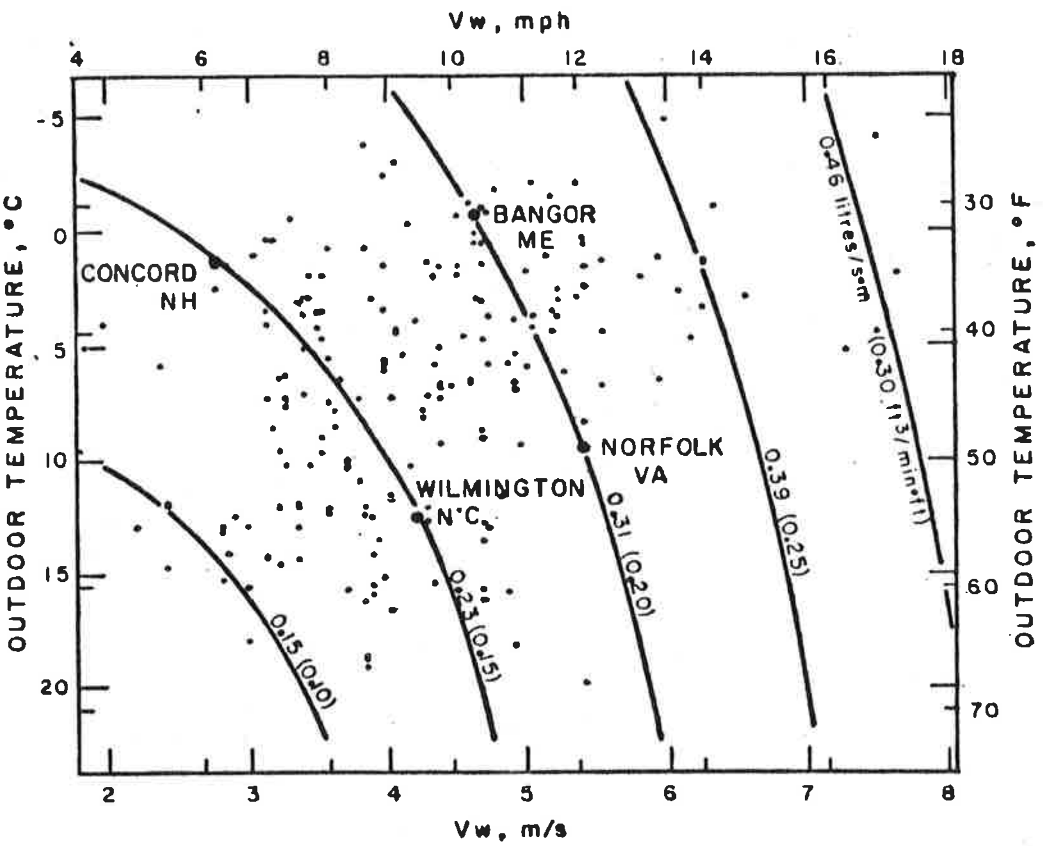

FIG. 13 - Curves of Equal Air Flow Crack Leakage with Comparison

REFERENCES

(1) NAHB Thermal Performance Guidelines, National Association of Home Builders, Washington, D.C., 1983

(2) Johnson, R. J. and Johnson, A. W., "NAHB Thermal Performance Guidelines: 1982 Methodology Update", Proceedings, Thermal Performance of the Exterior Envelopes of Buildings II, Las Vegas, NE, December 1982.

(3) American Society of Heating, Refrigerating and Air-Conditioning Engineers, ASHRAE Handbook Fundamentals, 1981, p. 22.3

(4) Ibid., p. 22.8

(5) American Society of Heating and Air-Conditioning Engineers, Heating Ventilating Air Conditioning Guide, 1959, p. 143

(6) ASHRAE Handbook Fundamentals, 1981, p. 22.5

(7) Cooling and Heating Load Calculation Manual, ASHRAE GRP 158, p. 5.7

(8) ASHRAE Handbook Fundamentals, 1981, p. 22.10

(9) Ibid., p. 22.13

(10) Affordable Housing Through Energy Conservation, Applied Science Division, Lawrence Berkeley Laboratory, University of California, Berkeley, CA, 1983, p. 27

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AUTHOR'S NOTE

This work could not have been accomplished without the commitment to the updating of the NAHB Thermal Performance Guidelines and other related Foundation investigations by the Energy Committee of the National Association of Home Builders. The authors herewith express their appreciation to that Committee.