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AIR INFILTRATION REDUCTION IN EXISTING BUILDINGS

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AIR INFILTRATION IN NEW ZEALAND HOUSES

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SUMMARY

The paper reviews air infiltration studies in New Zealand. Tighter houses have evolved over the years through changes in building methods and materials, rather than through a deliberate attempt to reduce air infiltration. We find that some of the tighter houses can be less forgiving of 'windows closed' living styles and dampness problems can develop. At the loose extreme, high heating costs or a reduced standard of thermal comfort are evident.

The air tightness of 40 houses was investigated together with the leakage resistances of a range of building components and bulk sheathing materials. A comparison with houses in other countries shows that comparitively tight houses can arise from simple construction methods not employing vapour barriers.

Air infiltration rates as a function of windspeed are given for a subset of 4 of the 40 houses. Two simplified models were used to calculate infiltration rates that agree with experiment within the limits of our ability to assign wind exposure factors to the building site.

1. INTRODUCTION

There are two important air infiltration related problems in New Zealand houses, these are

1) Control of indoor moisture

2) Winter space heat loss.

The first ranks as the most common reason for unsatisfactory house performance in the country. It is prominent mainly because New Zealand has a warm maritime climate which limits the moisture pick up capacity of ventilation air. During much of the winter, moisture can be controlled adequately by opening windows but in colder periods or for reasons of security when houses are closed up as tight as possible, surface dampness and mildew can develope.

1.1 Control of Indoor Moisture

Dampness problems fall into two classes, those occurring in the living space and those where moisture accumulates within the structure. Both are considered to depend on air leakage to a large extent and both are currently being studied at the Building Research Association.

A survey (1972) of the incidence of dampness in the living spaces of New Zealand houses[3] concluded that:

> "The incidence of mildew growth and surface dampness in New Zealand housing is very high (45%). The most common problem reported is mildew in wardrobes (25%) followed by mildew on bedroom walls (20%), mildew on other walls (11%), visible dampness on bedroom walls (9-10%). In about 20% of all homes dampness problems are serious".

Since this survey result, some measures to control condensation have become more widespread. These include:

1) A uniform standard of insulation in walls, ceilings and foor which helps raise the indoor dew point and wall surface temperatures to discourage condensation.

2) Ventilation in high moisture release areas using fan extraction hoods or window mounted extract fans.

3) Single glass windows with a catch and drain channel to allow condensation to escape outside.

Further measures and more widespread use of 2) and 3) may become necessary to ensure adequate control of moisture. So far no assessment of other options, their suitability and cost has yet been made.

1.2 Winter Space Heat Loss

Standards for thermally insulating walls, ceiling and floors of houses are defined in New Zealand Standard NZS 4218P[1]. With the conductance of walls, ceiling and floor reduced to the extent shown in Fig 1, this leaves heat loss through single glass windows and air infiltration unattended. Until recently, the size of air infiltration in houses with windows and doors closed was unknown. Now that it is believed to lie in the region of 1 ac/h (air change per hour) with wide variation between houses it is evident that air infiltration can be the single largest source of heat loss.

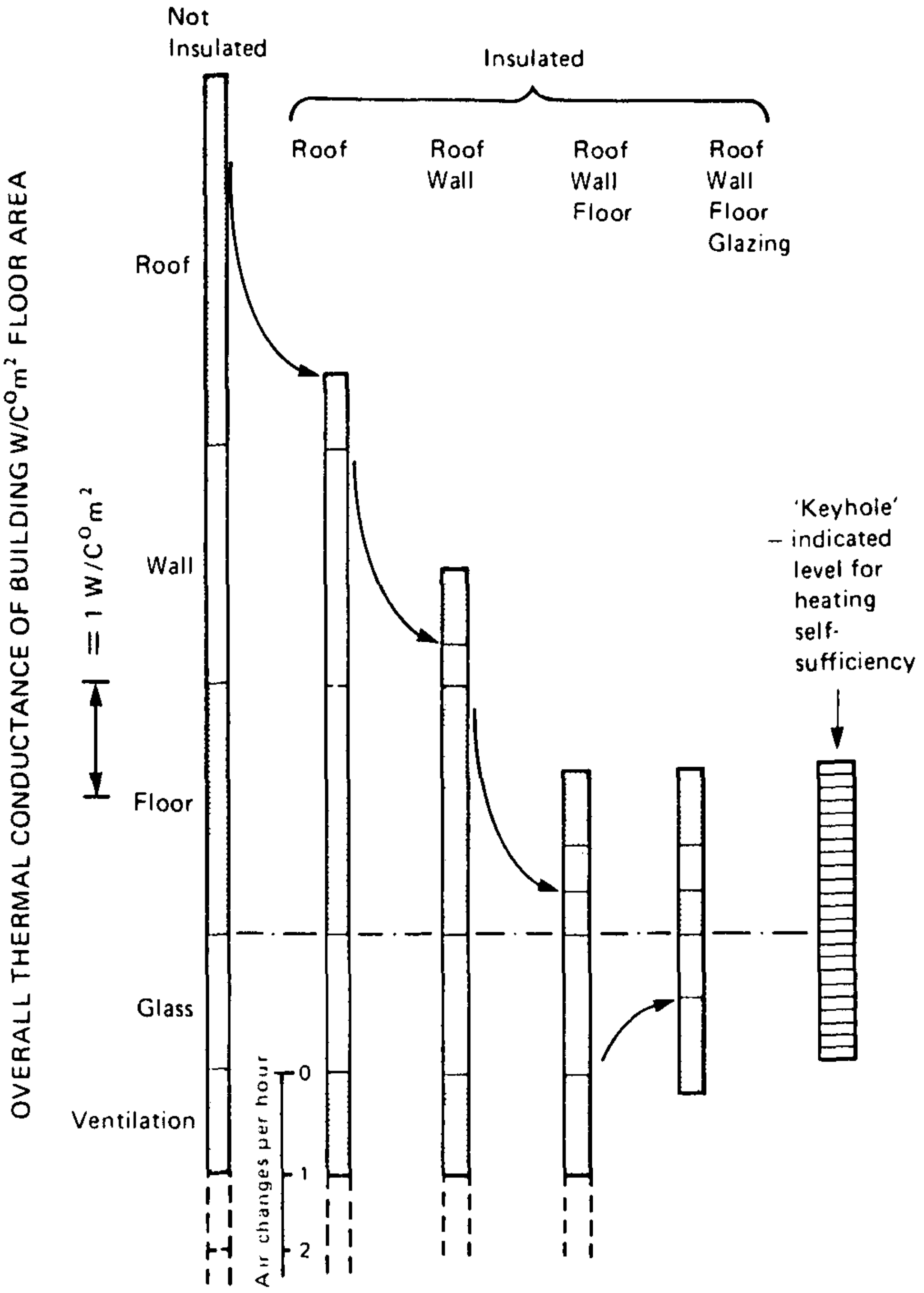

FIG. 1 ILLUSTRATING THE 'KEYHOLE' EFFECT AND THE EFFECT OF A PROGRESSIVE INSULATION PROGRAM

Guidance on low energy house design Trethowen and Bassett[2] has shown that space heating needs could be satisfied by solar heat gains and heat released by appliances and occupants. The size of this incidental heat is represented approximately in Fig 1 as a 'keyhole' through which the building conductance would have to fit in order to be self-sufficient of space heat much of the time. A general tightening of houses may save energy but the dangers of moisture condensation and surface mildew problems mean that ventilation would have to be more tightly controlled, either by the home occupier or by a ventilation system.

2. HOUSE AIRTIGHTNESS

2.1 A Survey of 40 Houses

A survey of house air tightness was completed in 1982 by Bassett[7]. It used the fan pressurization method to measure the air leakage characteristics of 40 houses of different age and construction type in Wellington city.

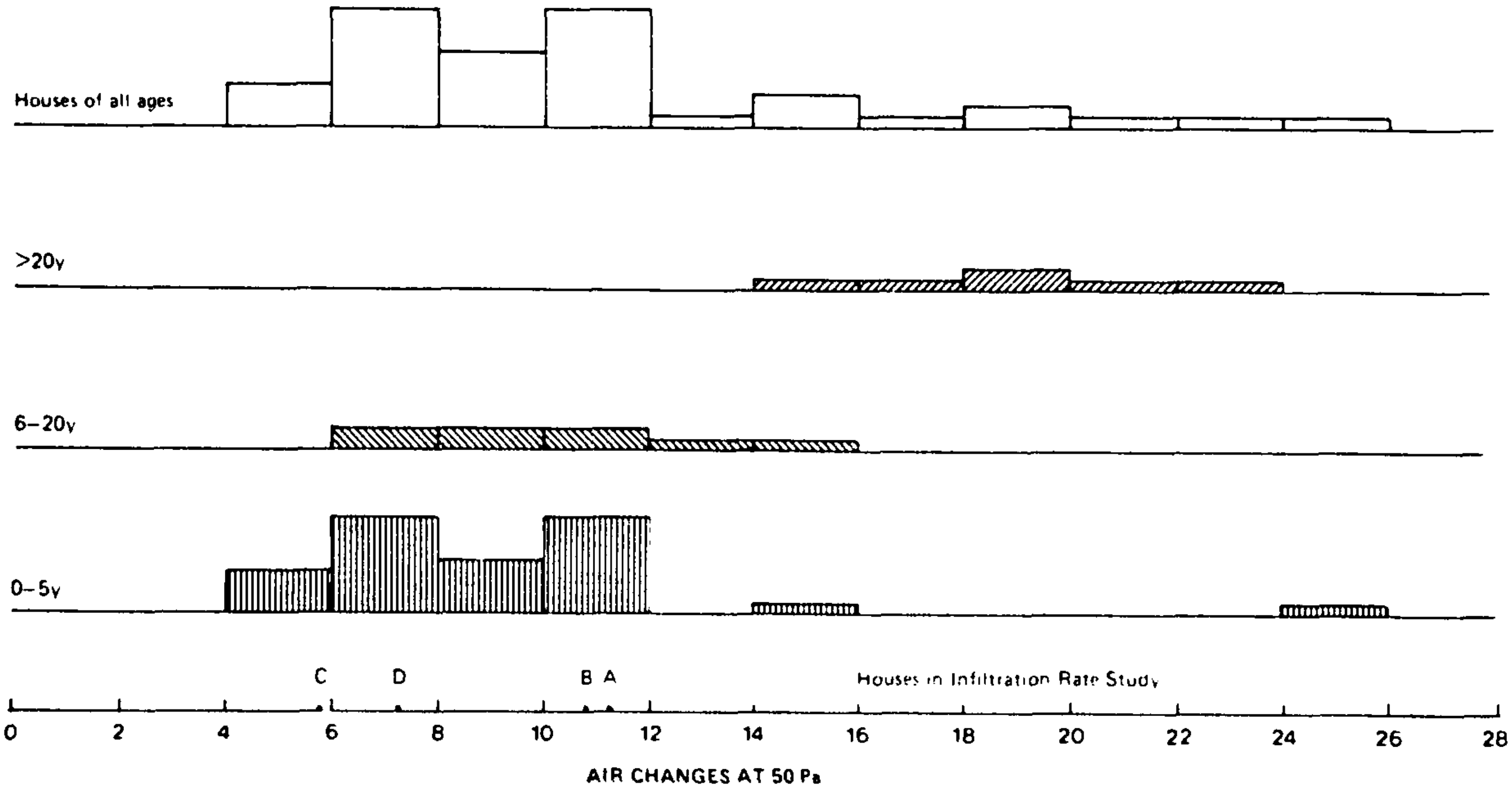

FIGURE 2: HISTOGRAM OF AIR CHANGE RATES @ 50 Pa FOR
40 NEW ZEALAND HOUSES

A histogram of house air tightness expressed in air changes/hour (ac/h) is given in Fig 2. The houses are divided into three age classes, chosen to approximately seperate insulated houses at the new end and houses with strip flooring at the old end. Interior strip wall lining has not been used for many years and the houses remaining with the original scrim and sarking are a small and decreasing percentage of the housing stock.

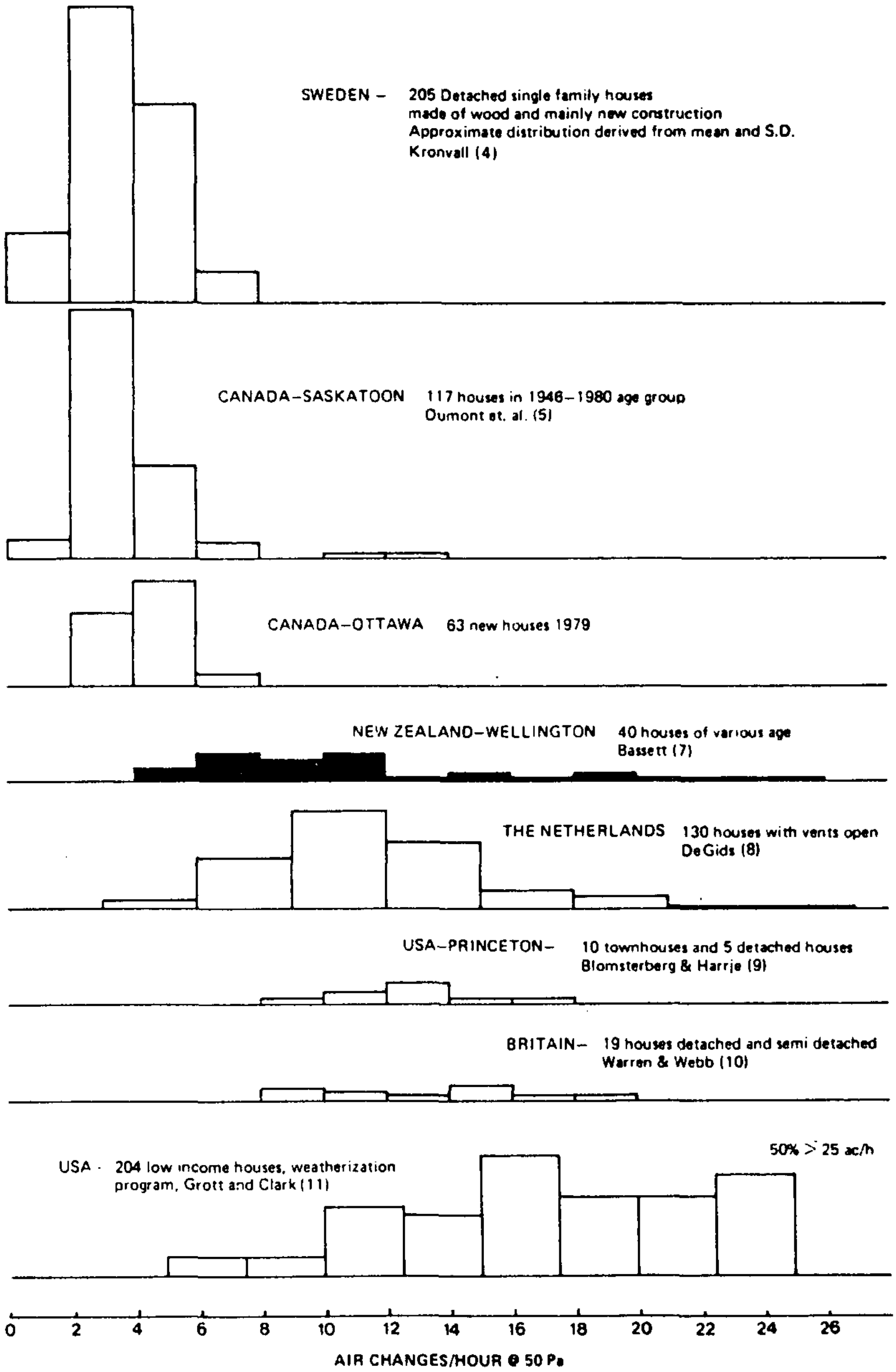

FIGURE 3: RELATIVE AIR TIGHTNESS OF HOUSES

Most results lie in the range 4 to 26 ac/h with 75% between 4 and 12 ac/h. Subdividing by age group shows the (0-5)y and (6-20)y groups to be indistinguishable but that the (21+)y age group represented by 6 houses was less air tight at 16-24 ac/h.

2.2 An International Comparison

House air tightness results are available for a number of countries. A selection of this data appears in Fig 3 and while not exactly equivalent in terms of age selection etc, it does immediately confirm that houses in cold climates are tighter on average than those in more mild climates. More importantly however, it shows that a large block of New Zealand houses less than 5 years old fall within the 0-8 ac/h range occupied by conventional houses in Canada and Sweden. This result has contested the view held within New Zealand that the typical house was exceedingly loose by international standards.

There are no special reasons for expecting to see air tight houses. Since vapour barriers have not been found necessary to control cavity moisture they make no contribution to air tightness. Neither are gaskets used in joints or special control of tolerances of timber frame joints to be found. However, in recent years there has been wider use of sheet lining materials both internally and externally together with prelaid particle board or slab on grade floors. We also noted that the tightest houses were architecturally quite simple.

2.3 Air tightness and Design Complexity

Two houses in the (0-5)y age group were quite leaky and it was noted they both had an unusually complicated shape. This raises the possibility that some design details influence air tightness in a way that can be identified and used at the stage buildings are designed.

In Fig 4 we attempt to show how the leakage rate at 50 Pa per m^2 shell area depends on shell complexity. As a measure of the latter, we added together the perimeter length of top and bottom plate together with vertical lengths of exterior corners and the boundaries of changes of ceiling pitch. This total has been divided by shell area to give a notional measure of shell complexity. Fig 4 shows this variable plotted against the leakage rate at 50 Pa divided once again by shell area. Leakage around doors, windows and through vents and chimneys has also been subtracted to ensure the leakage rate is as shape specific as possible.

Fig 4 suggests a subdivision of houses into the following four groups:

1.	Average tightness and average shell complexity	23 houses
2.	Below average tightness and average shell complexity	0 houses
3.	Below average tightness and above average shell complexity	5 houses
4.	Average tightness and above average shell complexity	3 houses

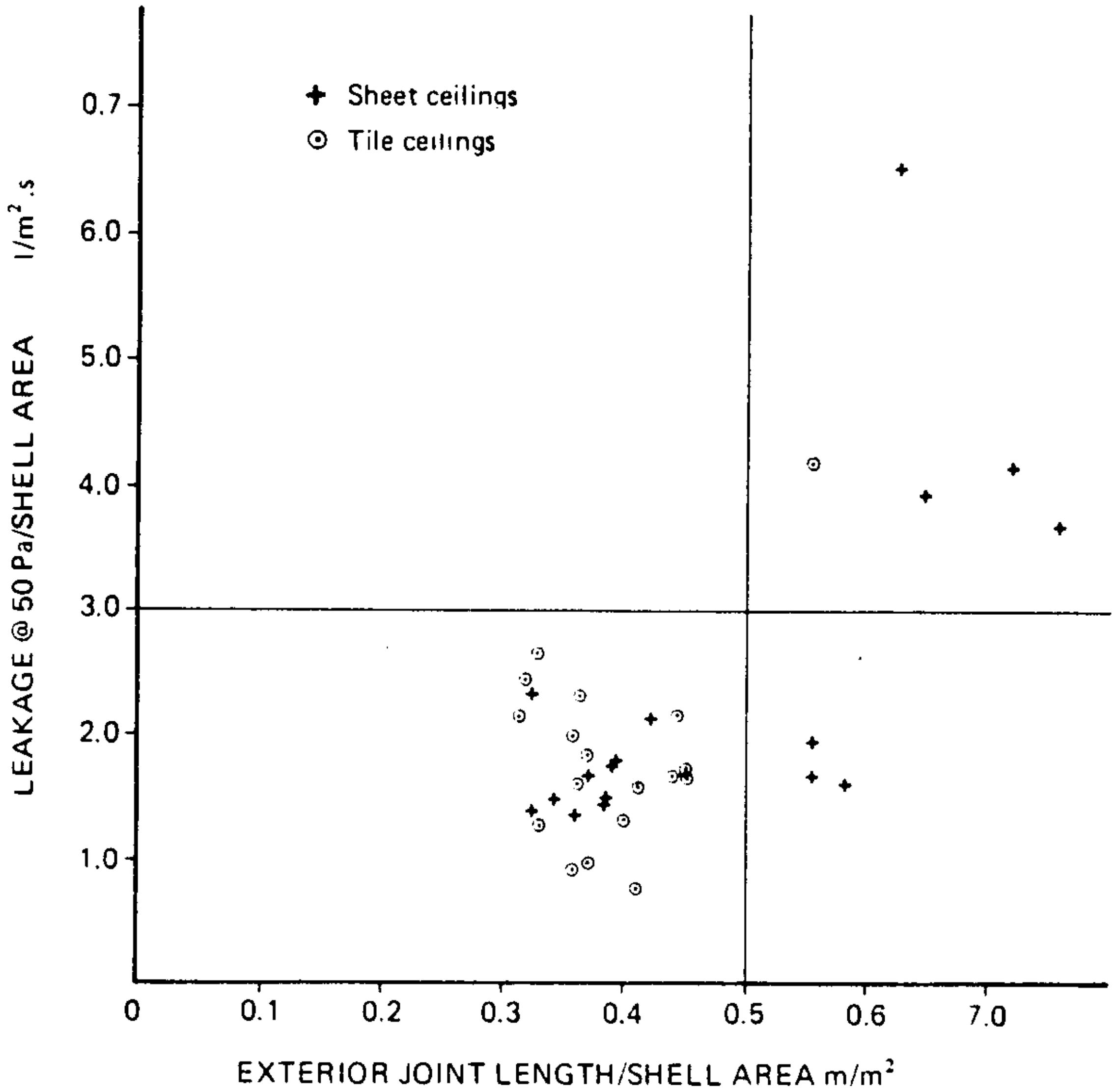

FIG 4 : MEASURE OF BUILDING SHELL COMPLEXITY AGAINST LEAKAGE/SHELL AREA @ 50 Pa

It seems that while some houses of complicated shape can be less air tight than average, this is not always the case. There are eight houses of above average shell complexity. Five have higher than average leakage rates but the other three are about average. It can however be said that there is a high degree of association between shape and tightness since there are no examples of average houses with high leakage rates.

2.4 Air Leakage through Solid Materials

Diffusion of air through the solid components of a building such as its walls, floor and ceiling warrants investigation because these areas are orders of magnitude larger than the size of cracks and joints. It is possible that diffusion through materials of quite high resistance could be important. Air diffusion resistance measurements were made in the laboratory for a range of interior and exterior lining materials. A summary of the results are given in Table I together with a brief physical description of each material. Of immediate note is the single order of magnitude resolution of the diffusion resistances. Although the accuracy of the experiment is rather better than this, there were often wide differences between wall board samples manufactured in different batches. The resolution of the data reflects these differences, as well as being quite adequate for the present purpose.

TABLE I

BULK AIR FLOW RESISTANCE OF COMMON BUILDING MATERIALS

LOCATION	DESCRIPTION	APPLIED COATING	DENSITY (Kg/m^3)	THICKNESS (mm)	ORDER OF MAGNITUDE RESISTANCE MNs/m^3
Floor	Flooring grade wood chip board	Unpainted	700	20	10
	Flooring grade wood chip board	Varnish paint system			10^4
Exterior walls	Exterior grade plywood	Unpainted	900	4	10
	Asbestos cement board	Unpainted	1500	6	10
Interior wall and ceiling	Paper coated gypsum plaster board	Unpainted	750	9.5	10
	Paper coated gypsum plaster board	Alkyd paint system			$>10^7$
	Paper coated gypsum plaster board	Acrylic paint system			10^5
	Paper coated gypsum plaster board	Vinyl wall paper			10^3
	Interior grade wood chip board low density	Unpainted	600	10	1
		Acrylic paint system			10^5
	Low density wood fibreboard	Prepainted	330	13	1
	High density wood fibreboard	Unpainted	1130	5	10
	High density wood fibreboard	Acrylic paint system			10^4
	High density wood fibreboard	Varnish paint system			10^6
	High density wood fibreboard	Alkyd paint system			$>10^7$
	Glass fibre reinforced gypsum plaster board	Unpainted	910	8	1
	Melamine formaldehyde laminate for wet areas		1130	5	$>10^7$

AIR FLOW RESISTANCE OF TILE OR BOARD MATERIALS INCLUDING JOINTS

LOCATION	DESCRIPTION	APPLIED COATING	DENSITY (Kg/m^3)	THICKNESS (mm)	ORDER OF MAGNITUDE RESISTANCE MNs/m^3
Exterior walls	Lapped weatherboards	Alkyd paint system		18	10^{-1}
	Rusticated weatherboards	Unpainted		18	10^{-2}
Ceiling	Low density wood fibreboard ceiling tiles	Prepainted		13	10^{-1}

The air flow resistance is defined by equation 1

$$R = \frac{A\,\Delta P}{Q}\;10^{-6}\quad\frac{MNs}{m^3} \tag{1}$$

where R is the leakage resistance in MNs/m^3
A is the area of material in m^2
Q is the volume flow rate of air in m^3/s
ΔP is the air pressure difference across the material in N/m^2

As an aid to interpreting Table 1, a reference air flow resistance can be calculated to give a volume flow rate of 2×10^{-5} $m^3/m^2.s$ @ 50 Pa. This is about 1% of the average leakage rate/m^2 of shell area for New Zealand houses less than five years old.

$R(1\%) = 2.5$ MNs/m^3

A quick scan of the air flow resistances for solid materials in Table 1, shows that only unpainted lining materials are likely to contribute significantly to measured leakage rates. The normal practice of interior decorating by painting greatly increases the air flow resistance to the point where air leakage can be considered insignificant.

Samples painted with an alkyd paint system proved to be tighter than our equipment could measure and a lower limit is recorded in Table 1. Water vapour diffusion and errors in measuring temperature and pressure changes have determined this lower limit.

Board or tile materials with joints included in the leakage measurement have lower air flow resistances. However, of the three examples in Table 1, the two outdoor sheathing materials are likely to be fixed in series with a much higher resistance interior lining. This leaves the ceiling tile system as the only lining material in wide use with significant joint system leakage. In a house with average leakage characteristics and a low density wood fibre tile ceiling, leakage through joints in the ceiling could contribute 10% of air leakage under air tightness test. Further reference can be made to Fig 4 where houses are separated into those with tile ceilings and those with sheet ceilings. In the average tightness average complexity classification there is no significant difference that can be attributed to ceiling type. A 10% difference if present would be significant at the 80% level.

2.5 Other Leakage Openings

Measurement of air leakage through building components has progressed to the point where we have data for the following

1) Windows - leakage between frame and sash

2) Doors - leakage between door and frame

3) Chimneys and heating appliance flues

4) Fitting of plumbing supply and waste pipes

Leakage openings yet to be studied include the joint at the top and bottom plate and the fitting of window and door components to the wall lining.

2.5.1 Windows and Doors

Windows and door leakage measurements were completed using the technique of masking joints and remeasuring the total house leakage rate. Windows and doors of all types were masked together and statistical methods used to resolve differences attributed to joinery type. The most important difference is that between aluminium and wood framed joinery with the following leakage rate and 95% confidence interval applying at 50 Pa pressure difference.

Window and Door Joinery Type	Leakage/m @ 50 Pa l/s.m
Aluminium extrusion	0.5 ± 0.5
Wood moulding	4 ± 1

The current New Zealand Specification for performance of Windows[12] defines three grades of leakage. When converted to a leakage rate at 50 Pa they are as follows:

Grade A	0.3 l/s.m
Grade B	1.0
Grade C	2.0

On the basis of the survey results, the average contribution of windows and doors to leakage in a house less than 5 years old is 17% and for houses older than this it is 23%. These values were worked out on the basis of 100m^2 floor area together with the average proportions of timber and aluminium joinery found in the 40 house survey houses. These leakage proportions can be compared with 15 to 24% measured by Tamura[13] in Canada and 40% measured by McIntyre and Newman[14] in a single house in the U.K.

2.5.2 Towards Improved Air Tightness - Location of Major Leaks

While a house is under air tightness test, it is a relatively simple matter to look for major leaks by detecting draughts. On a number of occasions leakage openings discovered this way were blocked and a new tightness test performed to measure the improvement. It is helpful to compare the size of some of these leaks with chimneys and other common vents, and with the house envelope leakage using the equivalent leakage area (Aeq) concept. These are given in Table 2.

Table 2

		Aeq m^2	Relative Size
1.	Average 100 m^2 house in survey sample	0.113	100%
2.	Brick chimney and open fire place	0.022	19%

3.	Cracks around openable doors and windows	0.019	17%
4.	Electrical switch board detail, one case	0.009	8%
5.	100 mm flue and freestanding fireplace with all dampers open	0.008	7%
6.	Bath toe space detail, average of 3 cases	0.007	6%

Of immediate note is the relatively small Aeq of chimneys and workmanship details compared with the envelope equivalent leakage area. It was found to be quite difficult to make major improvements to houses in this test sample within the practical constraints of taping over accessible cracks. For example, blocking the cracks around openable windows and doors to simulate a weatherstripping operation reduced the overall leakage by between 17 and 23%. This indicates that a large variety of leakage openings contribute to the total and that the location and size of many of these are not yet known for N.Z. houses.

3. AIR INFILTRATION RATES PREDICTED AND MEASURED

3.1 Infiltration Rate Measurements for Four Houses

Air infiltration rate, wind speed and temperature measurements are available for four of the houses in the air tightness survey. The measurements were made by Clarkson[15] using the tracer gas decay method and SF_6 as a tracer material. On site wind speed measurements were made above roof height and were similar in strength to wind speeds measured at a meteorological station less than 10 km away. The work was completed in the summer when indoor/outdoor temperature differences were less than 3°C.

Three of the houses (A, B and C) are similar in type, size and sheathing materials. They are detached single storey houses with about 100 m^2 floor area, suspended particle board floors and similar interior lining materials. House D is semidetached with a concrete block party wall. It is split level, has a basement underneath and a skillion roof lined with particle board.

Air tightness data for the four houses is marked on Fig 2 and Fig 4. House C is rather tighter than A, B and D which in terms of leakage rate at 50 Pa/Shell surface area are quite similar.

Air infiltration rates at three wind speeds between 2 and 10 m/s were found within experimental error to form a linear relationship with windspeed. A series of 16 measurements had been made in two similarly sited houses and found to be largely independent of wind direction which at house level generally bore no relation to wind directions measured in the free air stream. The following values of air changes/km of wind run were recorded.

Table 3

HOUSE	Air Changes/km wind run
A	0.053
B	0.045
C	0.012
D	0.020

3.2 Infiltration Rate Predictive Models

The application of two infiltration rate prediction models has been investigated. One was developed at Lawrence Berkeley Laboratory in California by Sherman et al[16] and has a strongly analytical basis. The second was developed by Shaw[17] based on a correlation of measurements made in Canadian houses.

3.2.1 The LBL Model

The basic form of the air infiltration model is:

$$Q = L\sqrt{fs^2\,\Delta T + fw^2\,V^2}$$

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 (m/s)
f_w is the wind parameter

The various constants were calculated and appear in Table 4. As indicated by the authors, the stack and wind parameters are relatively insensitive to uncertainties about the distribution of leakage openings. The critical choice is the generalized shielding coefficient used in calculating the wind parameter fw from building and weather station site information. It accounts for shielding around the building by other structures and topographical features. The following two shielding classes were assumed for results shown in Fig 5 and Table 4.

Shielding Class	C'	Description
III	0.24	Some obstructions within two house heights
IV	0.18	Obstructions around most of perimeter

TABLE 4

BUILDING	L m^2	fs	fw	C'
A	0.070	0.13	0.17	0.24
			0.13	0.18
B	0.089	0.13	0.17	0.24
			0.13	0.18
C	0.027	0.13	0.18	0.24
			0.14	0.18
D	0.029	0.16	0.15	0.24
			0.11	0.18

With low indoor/outdoor temperature differences and wind speeds above 2 m/s the predicted leakage rate is a linear function of wind speed. Calculated values of air changes/km wind run are compared with measured date in Fig 5.

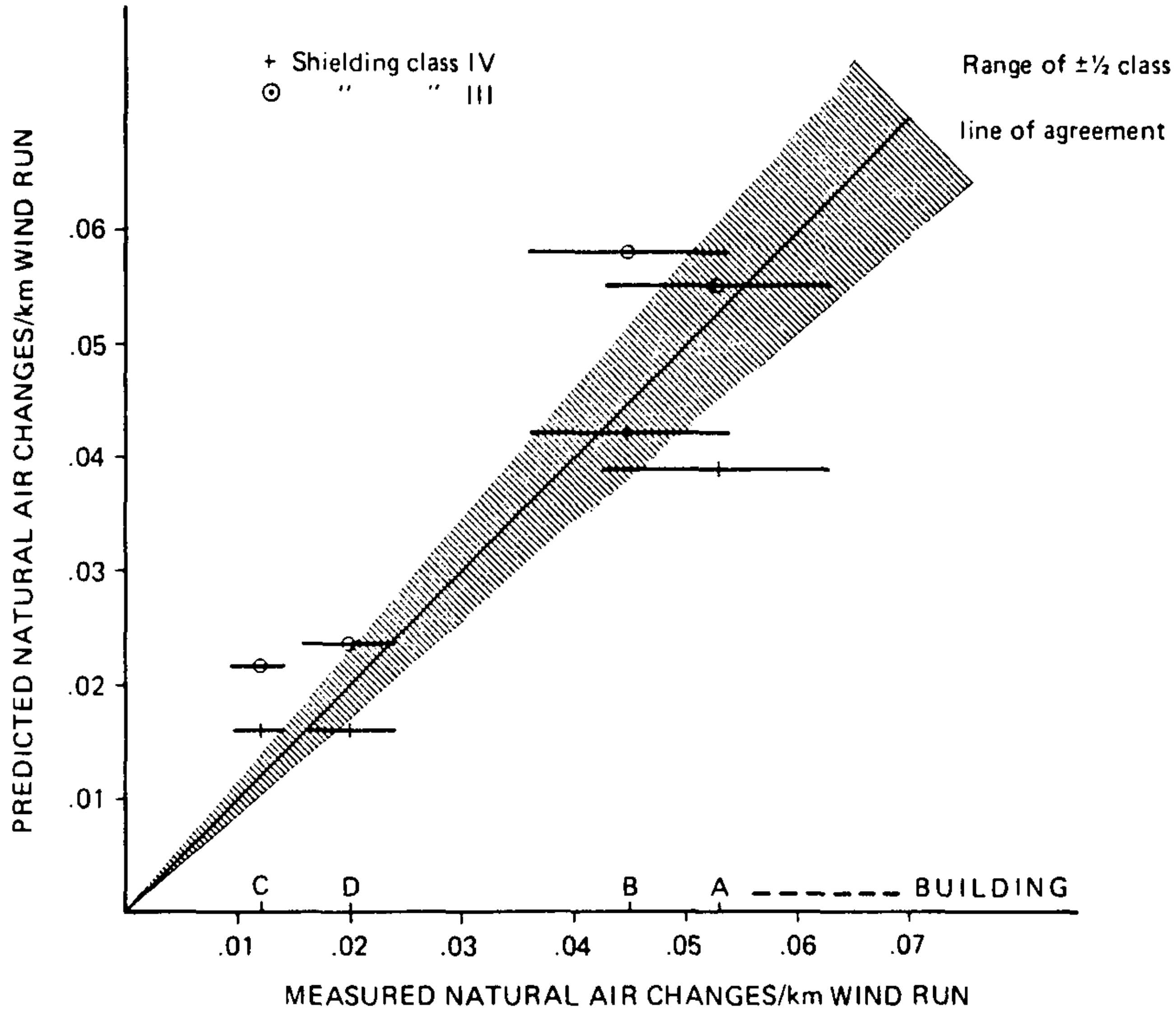

Fig 5 : CORRELATION OF INFILTRATION RATE PREDICTIONS USING 'LBL' MODEL WITH EXPERIMENT

Fig 5 indicates reasonable agreement between predicted and measured air change/km wind run but that we may have to learn more about choosing appropriate shielding classes.

3.2.2 The Shaw Model

This model identifies three climate regimes based on wind speed and indoor/outdoor temperature. Our data falls into regime II where the dominant driving force is wind pressure. In this case the air change rate can be calculated from wind speed, building air tightness coefficient and exponent with an option of either high or low wind exposure.

As before with the LBL model, the predicted air change rate is more strongly influenced by the choice of shielding factor than experimental errors in the building air leakage characteristics. We simple chose the mean of the extreme shielded and exposed cases and calculated air change rates for wind speeds between 2 and 10 m/s. While not exactly linear in wind speed, little error is incurred in representing the predictions in terms of ac/km wind run as before. The results appear in Fig 6.

Uncertainty in the shielding factor can not easily be indicated but results generally agree with experiment within the range of shielded to exposed site exposure.

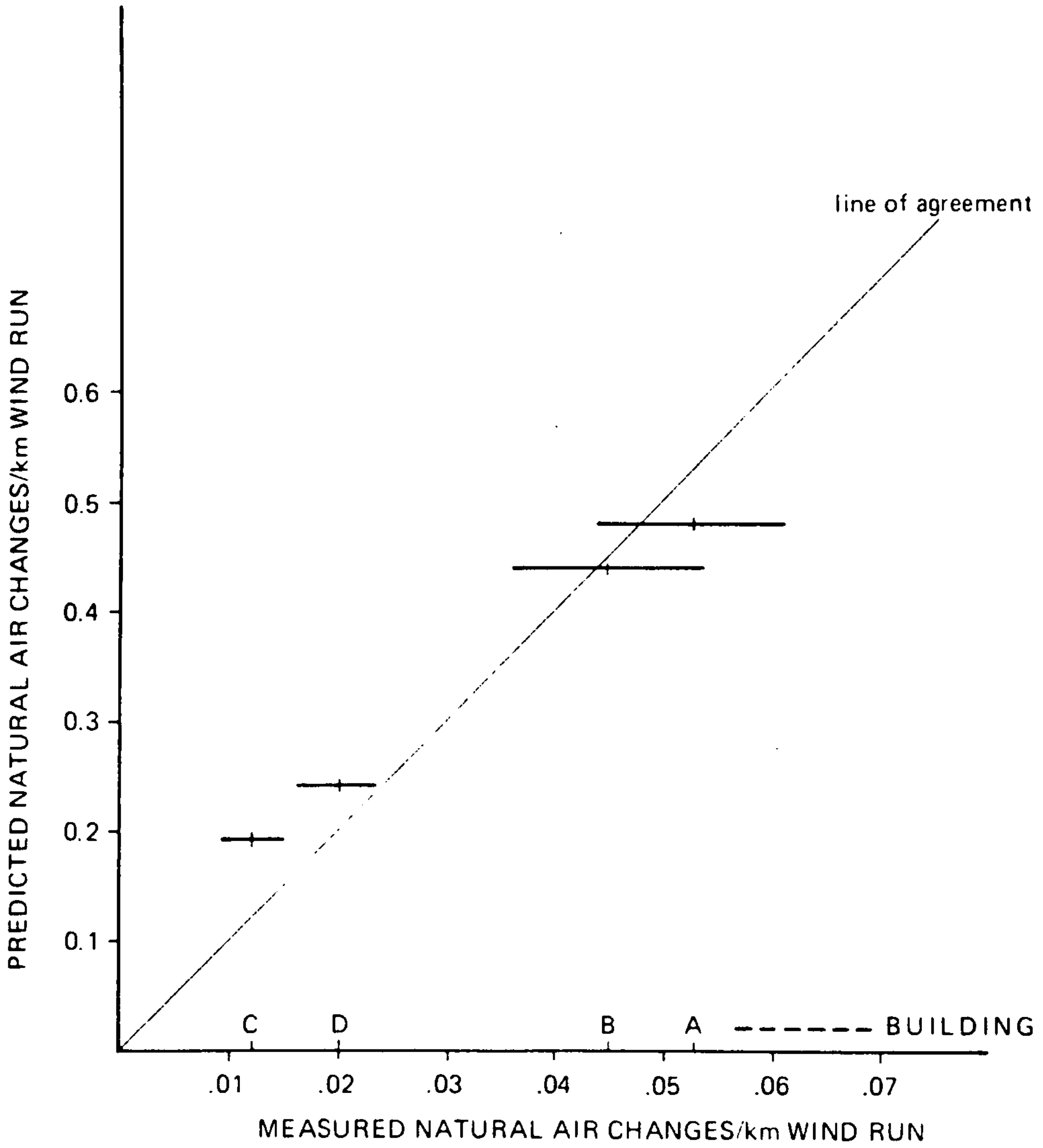

Fig 6 : CORRELATION OF INFILTRATION RATE PREDICTIONS USING SHAW MODEL WITH EXPERIMENT

4. CONCLUSIONS

The following conclusions arise from house, component and material air tightness tests.

For a sample of 40 houses of timber frame construction clad mostly with woodbased sheet materials.

1. Houses in the age groups (0-5)y and (6-20)y were not significantly different in terms of air tightness. The mean air change rate @ 50 Pa being 9 ac/h ± SD 3 ac/h. The greater-than 20y age group represented by 6 houses were less air tight with a mean air change rate @ 50 Pa of 19 ± SD 3 ac/h.
2. Air leakage around openable doors and windows made up 17% of the average envelope leakage in houses less than 5 years old and 23% in houses older than this.
3. The air tightness test was found to have limited application in locating leakage openings for weather stripping attention because leaks were typically many and widely spaced rather than few in number and easily accessible.

A survey of material leakage resistances showed:

4. That leakage through solid interior lining materials should contribute less than a few per cent to air tightness test results, and much less when painted.
5. Joints around low density fibre board ceiling tiles were expected to add 10% to house leakage rates but no evidence of this was detected in house air tightness tests.

Preliminary attempts at natural infiltration prediction show:

6. That wind speed and air tightness dependence agrees with experiment to the limit of our ability to assign wind exposure factors to the building site.

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