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PRELIMINARY SURVEY OF AIR TIGHTNESS LEVELS IN NEW ZEALAND HOUSES

Mark Bassett*, M.Sc.

This paper gives air tightness results for 40 houses of varying age and construction detail. These are the first measurements of their type made in New Zealand, consequently they are an important early guide to the air tightness achieved in locally built houses. In particular they are an important step towards understanding the significance of air leakage in the loss of space heat during the winter mo[illegible] nd in the control of indoor moisture.

While the natural air change rate in a building is not directly related to envelope air tightness, air tightness is a useful measure of the resistance to air flow in much the same way that thermal resistance relates to heat flow. For air flow the driving force is a combination of wind pressure and, to a lesser extent in this country, buoyancy forces arising from the difference between indoor and outdoor temperature.

The use of air tightness data and weather information to calculate a natural air leakage rate is not particularly straightforward for a number of reasons. Windspeeds measured some distance away at the nearest weather station have to be compensated for site exposure differences, and the appropriate pressure coefficients and distribution of leakage opening for the building must be known. While the best approach is not yet clear, a number of air leakage rate models based on the air tightness result are proving to give reasonable predictions of natural air change rate. The best example is a model developed at Lawrence Berkeley Laboratories by Sherman[1].

1. AIR TIGHTNESS TEST METHOD

There are two well known ways of measuring the leakage characteristics of a building. The simplest of these employs a fan to hold a steady pressure difference between inside and outside while the leakage rate is measured. Results at a number of pressures are then combined in the form of a leakage function characteristic of the building. Pioneering air leakage tests carried out in Canada by Tamura and Wilson[2] used this method and it is now the test of air tightness performance required by the Swedish Building Code[3]. The second method applies a low frequency volume displacement and uses synchronous pressure measurements to arrive at the leakage rate. It has the advantage that the leakage characteristic at very low pressures can be separated from the effects of wind. The earliest study of this type is by Card et al[4]. It was followed later by Sherman et al[5] who studied the shape of the leakage function at low pressures.

The air tightness tests described in this report used the steady pressure method. A brief summary is given here. Figure. 1 shows the fan and air flow measuring equipment set up in a house. A 380 mm aerofoil fan was mounted in an adjustable door panel and fixed in place in an external door opening. It is driven by a lightweight 1600 W three phase motor. Synchronous speed control is achieved with an "Industrial Electronics and Automation Ltd" controller which synthesises adjustable frequency three phase power from a standard 230 V single phase outlet. Air flow measurements are made from the static pressure in the throat of a long-radius flow nozzle calibrated in the laboratory using Pitot Tube method of ASTM D3154-72. Pressures were measured using a digital manometer calibrated in 0-200 Pa and 0-2000 Pa ranges.

Each test was based on 6-9 indoor-outdoor pressure differences in the range 10-150 Pa, the lower limit being appreciably above wind pressure measured across the windward wall using an externally mounted pressure

* Research Officer, Building Research Association of New Zealand.

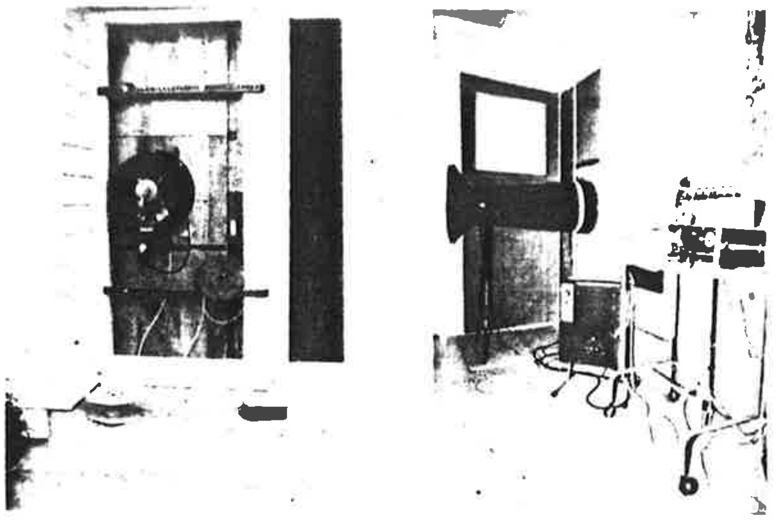

FIGURE 1 : Fan and air flow measuring equipment used for airtightness test

tap. In some of the leakier houses the maximum pressure was limited by the 2.5 m^3/s capacity of the fan but it never fell below 60 Pa.

2. RESISTANCE TO AIR FLOW THROUGH CRACKS

The air flow resistance of a building envelope is a parallel combination of leakage resistances from many sources. Each flow path will have a characteristic leakage function which in broad terms will lie between the extremes of orifice or turbulent flow, and laminar flow. These flow regimes are represented by the following general equation:

$$Q = C(\Delta P)^E$$

$$Q = \frac{1}{R}(\Delta P)^E$$

where

Q = Volume flow m^3/s
ΔP = Pressure difference Pa
R = resistance to flow
C = flow coefficient
E = exponent between 0.5 and 1.0

The leakage function can be quite complicated in detail, especially in the region where flow and pressure depend strongly on the Reynolds number. Nevertheless, it has become normal practice to use a simple leakage function of the above form to describe the total building leakage. The value of E depends on the relative contribution of kinetic and viscous forces to the energy loss incurred in flow. If the losses are primarily kinetic, E will be close to 0.5 rather than 1.0 which is approached in viscous flow.

Although the equation is not a physically sound representation of whole house leakage, it is unusual for the residuals of an experimental data fitting process to be reduced to any helpful extent using a more involved equation.

3. DEFINITION OF AIR TIGHTNESS UNITS

Since the early work of Tamura and Wilson, a large number of air tightness tests have been performed and reported in the literature. The most frequently reported result is the number of volume air changes induced by a 50 pa indoor to outdoor pressure difference. It has the advantages of being unambiguous because all the terms are well defined, and readily achievable with modest equipment in even very leaky houses. Furthermore, air leakage caused by wind and temperature related pressure differences can easily be arranged to be small by testing on a windless day.

A second choice is the volume flow per unit of shell area at 50 Pa. Results of this kind are frequently given but the definition of shell area varies greatly. This can be either the internal or external surface area and it may or may not include the area of concrete slab floor or basement.

For comparative purposes the data is presented in four ways

a. Air changes/hour at 50 Pa. The volume in this case is the total enclosed volume including furnishings, internal and external wall cavities but not the roof or subfloor space.

b. The coefficient and exponent in the following generalised leakage function:

$$Q = C\,\Delta P^E$$

Because C and E are not independent of the units chosen or of the physical properties of air, it is necessary to standardise the units of Q to m^3/s of air at (20 °C, 101.3 kPa, 0% RH). The 95% confidence interval for C and E are also given where appropriate.

c. The leakage rate per unit shell area at 50 Pa. The units of this are $l/s.m^2$ and the surface area is that of the external walls floor and ceiling but excluding concrete slab floor.

d. The equivalent leakage area at 50 Pa. This is calculated as the area of sharp edge orifice required to pass the same volume flow at 50 Pa.

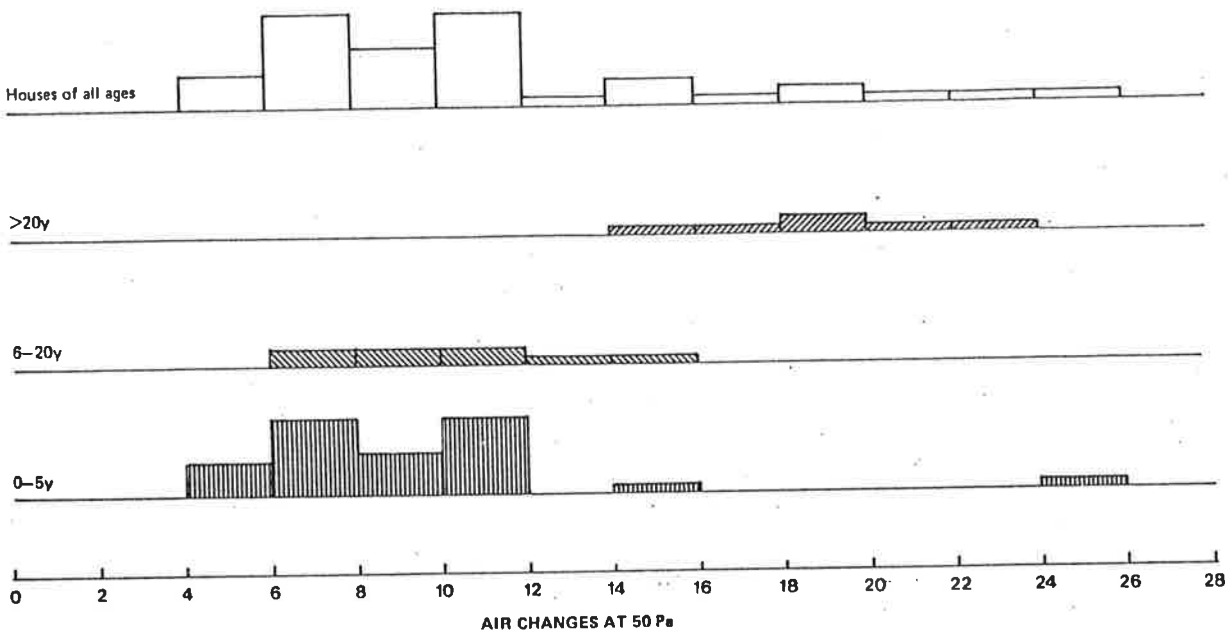

FIGURE 2: HISTOGRAM OF AIR CHANGE RATES @ 50 Pa FOR 40 NEW ZEALAND HOUSES

$$Aeq = \frac{Q}{Cd \left[\frac{2\Delta P}{\rho}\right]^{\frac{1}{2}}}$$

Aeq = Equivalent leakage area m^2
Q = Volume flow m^3/s
Cd = Discharge coefficient = 0.6
ρ = Density of air kg/m^3
ΔP = Pressure difference Pa

Once again Q and P are at (20^0C, 101.3 kPa,0% RH).

4. PRELIMINARY AIR TIGHTNESS RESULTS

4.1 House Age Groups and Construction Types

The houses used in this survey do not represent the housing stock in the correct proportions of age and construction type. An important group of newly constructed timber frame houses is, however, well represented and it is intended that supplementary data for masonry construction and other specific types and ages be added at a later date.

Methods used for selecting houses were responsible for the distribution of ages. BRANZ staff houses form the older group and more recent houses were taken from the 1979 listing of building permits for Upper Hutt City.

Twenty six houses were less than five years old and the remaining fourteen evenly distributed between 6y - 20y and 21y and older categories. These age classes were chosen to approximately separate insulted houses at the new end and houses with strip flooring at the older end. Sheet interior wall lining has been used for many years and there is a relatively small percentage of houses remaining with original sarking with scrim and wall paper finishing.

4.2 Air Tightness Listed By Airchanges/hour @ 50 Pa

A histogram of volume airchange rates at 50 Pa is given in Figure 2. Most results lie in the range of 4 to 26 ac/h with 75% in the range 4 to 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.

Two main factors are thought to have a bearing on envelope air tightness, namely the deployment of materials and overall design complexity. The first of these concerns the choice of materials, for example the selection of ceiling tiles or the type of window joinery. The second concerns plan details, for example the external surface area to volume ratio. Two houses in the (0-5)y age group were quite leaky and although no causative link was established, it was noted that one (ac/h @ 50 Pa = 24.4) was an A frame design with exposed beams and fitted infill panels and easily visible cracks of extended length. The second (ac/h @ 50 Pa = 14.2) had tongue-and-groove timber ceilings following a complicated roof profile. Unfortunately there is no established way of quantifying these factors short of a detailed account of the individual crack details as practiced by Etheridge[6] and this is known to be extremely difficult. An important early conclusion is that complicated houses are more leaky than those of simple construction.

Houses are known to settle with time but there is little evidence in the literature to show that houses become less air tight as they age. The question could only be answered by repeatedly testing a group of houses over a number of years.

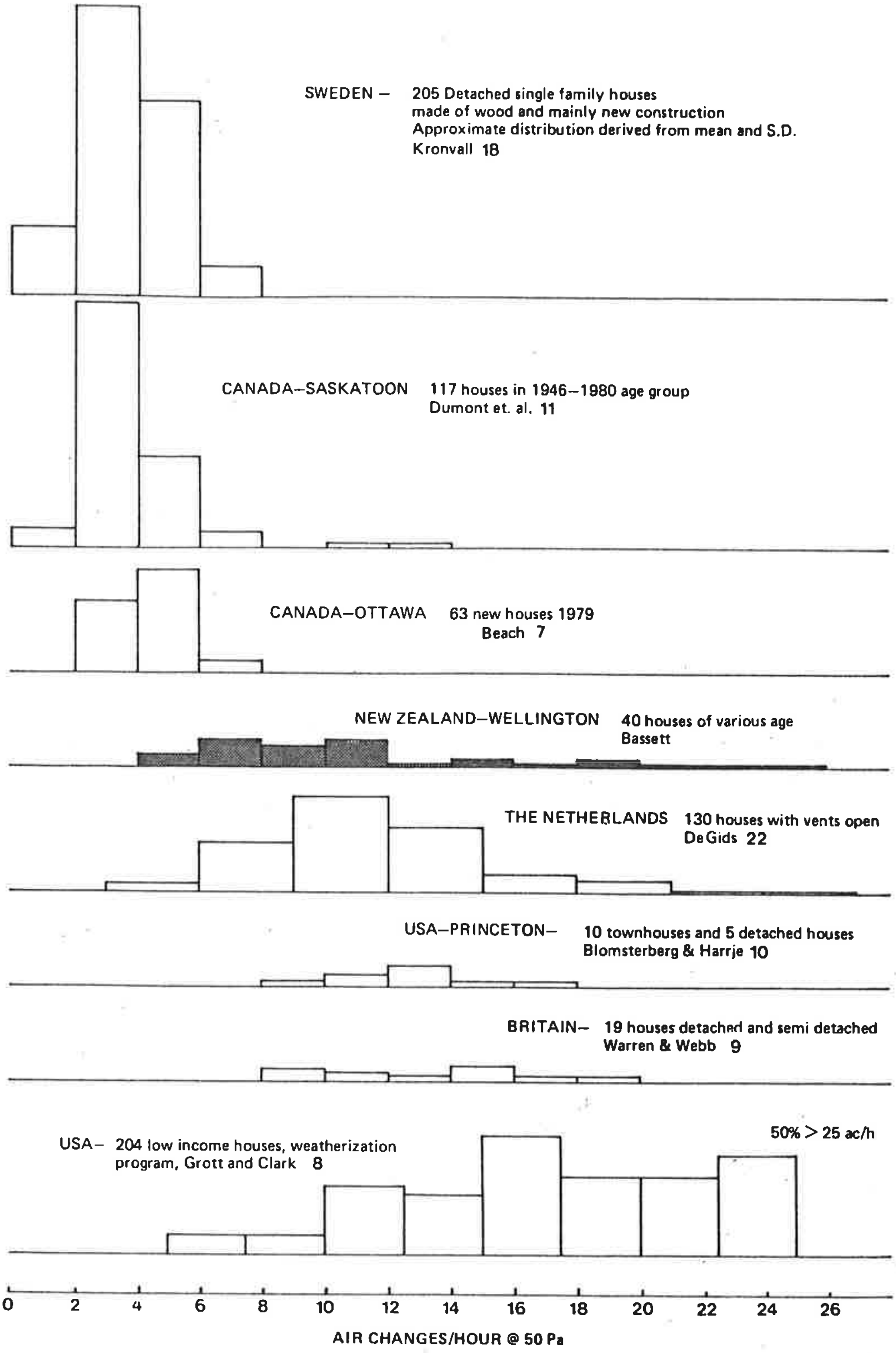

FIGURE 3: RELATIVE AIR TIGHTNESS OF HOUSES

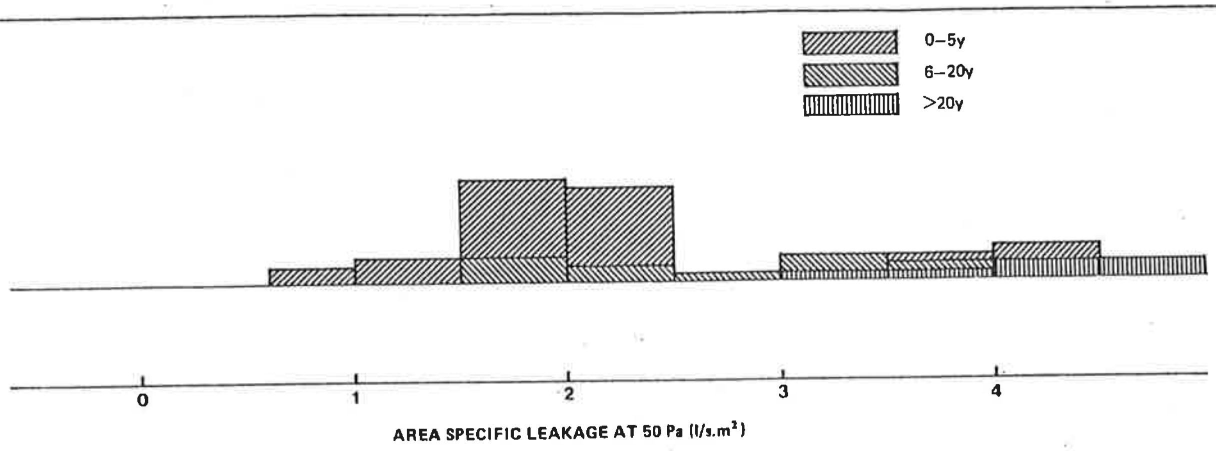

**FIGURE 4: AREA SPECIFIC LEAKAGE AT 50 Pa
40 NEW ZEALAND HOUSES IN DEFINED AGE GROUPS**

4.3 Alternative Listings of Air Tightness

Air tightness might be expected to depend on the surface area of the building envelope so that dividing the air leakage rate at 50 Pa by the shell area should give less spread of results.

Figure 4 gives the leakage rate/m^2 shell area and when compared with Figure 2, little difference can be seen. The results are spread over a similar range with the same separation by age, indicating in effect, that most houses have similar surface area to volume ratios.

The third alternative way of expressing results in terms of an exponent and coefficient in the following equation

$$Q = C(\Delta P)^E$$

has been pursued and a histogram of exponent E is given in Figure 5. The value of E ranges from 0.55 to 0.8 and in this respect is similar to findings of Beach[7] (Figure 5) for new houses in Canada. On physical grounds E must lie within the range 0.5 to 1 but exponents outside this range have been reported by Grot and Clark[8]. Departures of this nature arise through a combination of experimental uncertainty and the tightness of the envelope changing with applied pressure, for example the fit between window sash and frame can improve as the indoor pressure is reduced.

5. INTERNATIONAL COMPARISON OF AIR TIGHTNESS LEVELS

Air tightness results are available for houses in a number of countries. A selection of these appear in Figure 3 and show that houses in colder Canadian and Scandinavian climates are tighter than measurements available for the UK and USA. The results for the New Zealand sample of (0-5)y houses lies about midway. While it is difficult to make a valid comparison with the measurements of Warren and Webb[9] in the UK and those of Blomsterberg and Harrje[10] because the ages are mixed, it will be noticed that 40% of New Zealand houses in the less than 5y age group fall within the (0-8) asc/h at 50 Pa range occupied by the results of Beach for new houses in Ottawa, Canada.

There are significant differences in construction detail between Canadian and New Zealand houses but the one that might be expected to contribute to air tightness most of all is the vapour barrier. Since 1960 this has taken the form of polyethylene sheet fixed under the wall and ceiling lining. Recent attempts to build air tight houses in Saskatoon, Canada, have upgraded this vapour barrier with attention to detailed sealing of joints to achieve an "air barrier". Results of Dumont et al[11] show that the mean air change rate @ 50 Pa 3.6 ac/h for average post 1960 houses could be reduced to an average value of 1.5 ac/h with sufficient attention to detail. The point of this discussion is to show that the vapour barrier found in the walls and ceiling of houses in very cold climates may not make a sizeable contribution to air tightness unless special attention to detail at joints is taken. The author makes the cautionary comment that such measures are unlikely to be desirable in New Zealand houses.

6. LEAKAGE THROUGH OPENABLE DOOR AND WINDOW JOINERY

Homeowners are frequently aware of air leakage around doors and between window frame and sash. Materials for draft stopping these areas are readily available and it may be considered that the bulk of air leakage is from this source. In this survey, the air tightness of openable windows and doors in 20 houses was measured by testing the complete house before and after taping exposed cracks. This way the leakage attributed to the crack between window frame and sash and between door and jamb could be determined for a range of joinery types. The results should not, however, be viewed as a comprehensive survey of window and door air tightness, but more as a guide to the approximate size of leakage from this source.

6.1 Analysis of Measurements

The approach taken in analysing the data has been to fit a linear function of the following form to the 20 results.

$$Q_j = \alpha(L_A) + \beta(L_W)$$

Q_j = air leakage around windows and doors @ 50 Pa (ℓ/s)

L_A = length of crack around aluminium framed joinery (m)

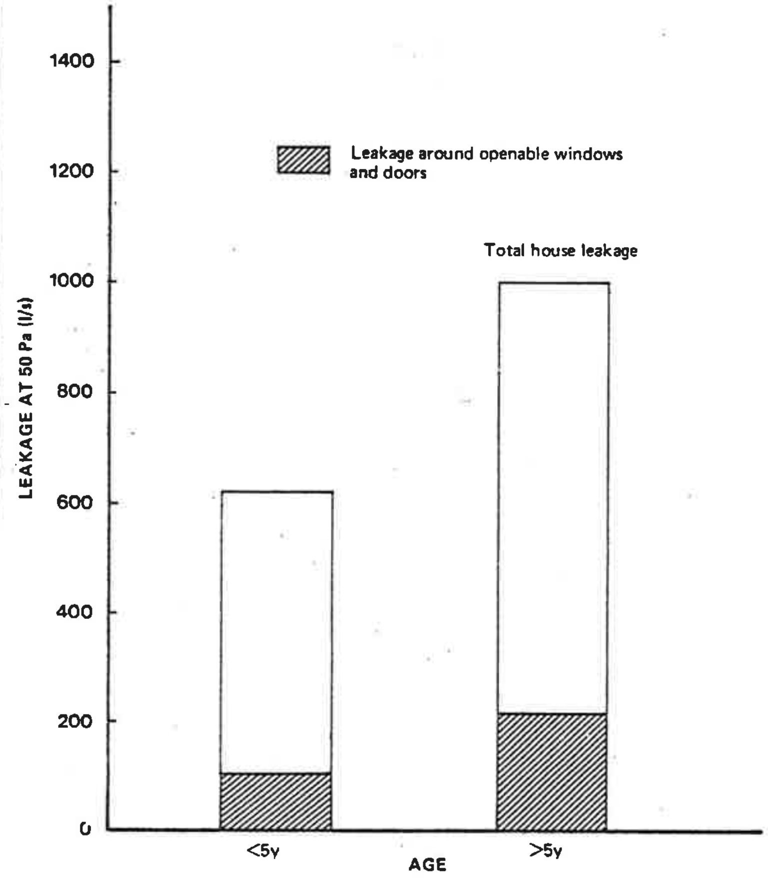

FIGURE 6: CONTRIBUTION OF LEAKAGE AROUND OPENABLE WINDOWS AND DOORS BY AGE GROUP

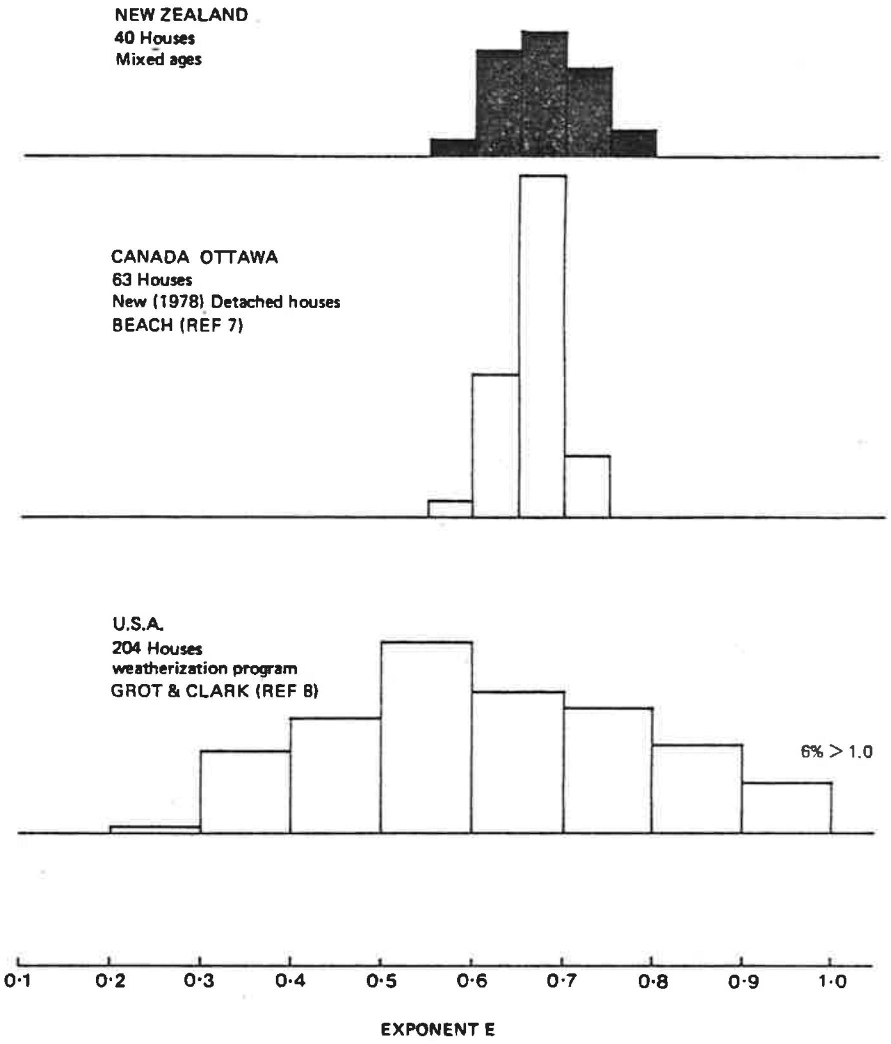

FIGURE 5: EXPONENT OF TOTAL BUILDING LEAKAGE FUNCTION NEW ZEALAND HOUSES AND COMPARATIVE DATA

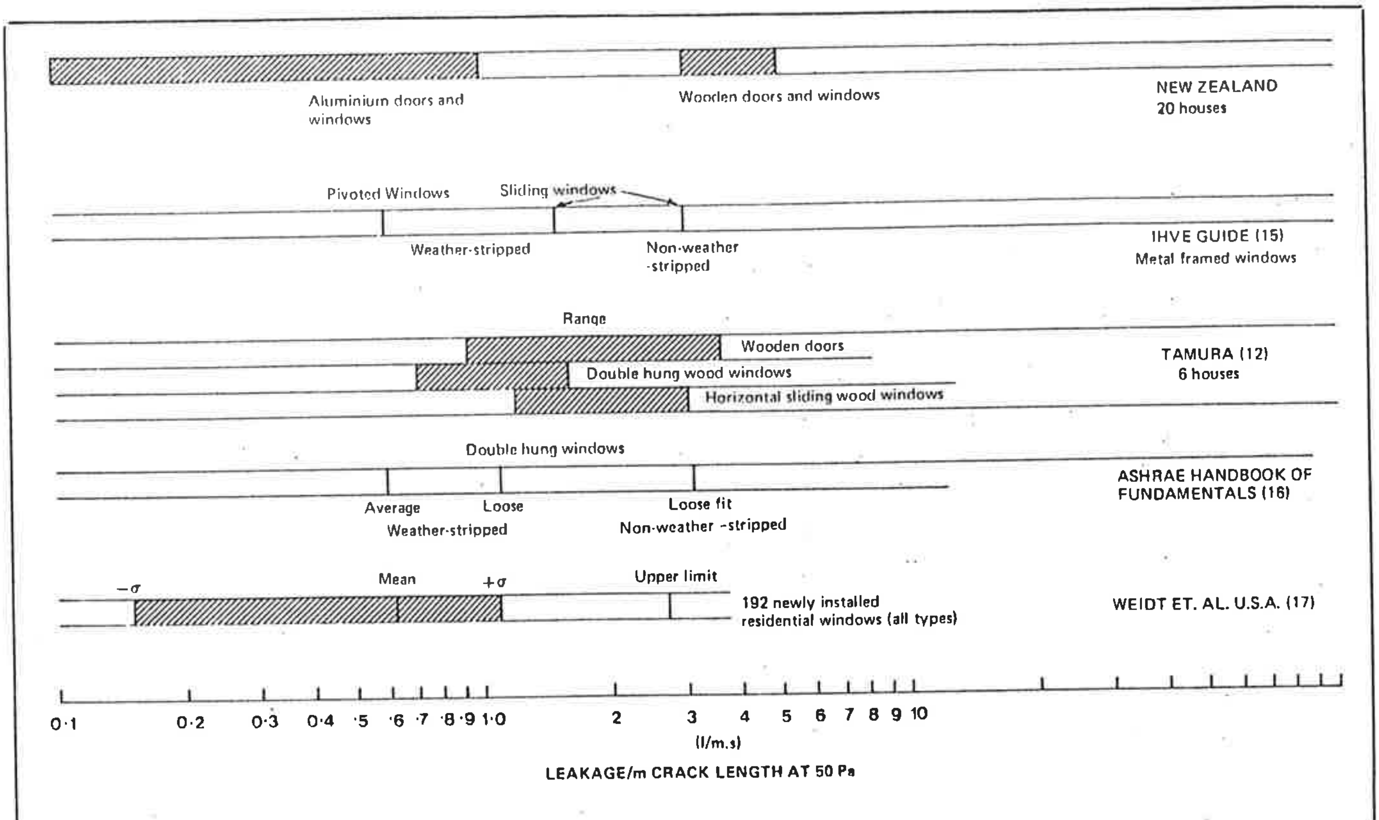

FIGURE 7: RESULTS OF WINDOW/DOOR LEAKAGE TESTS

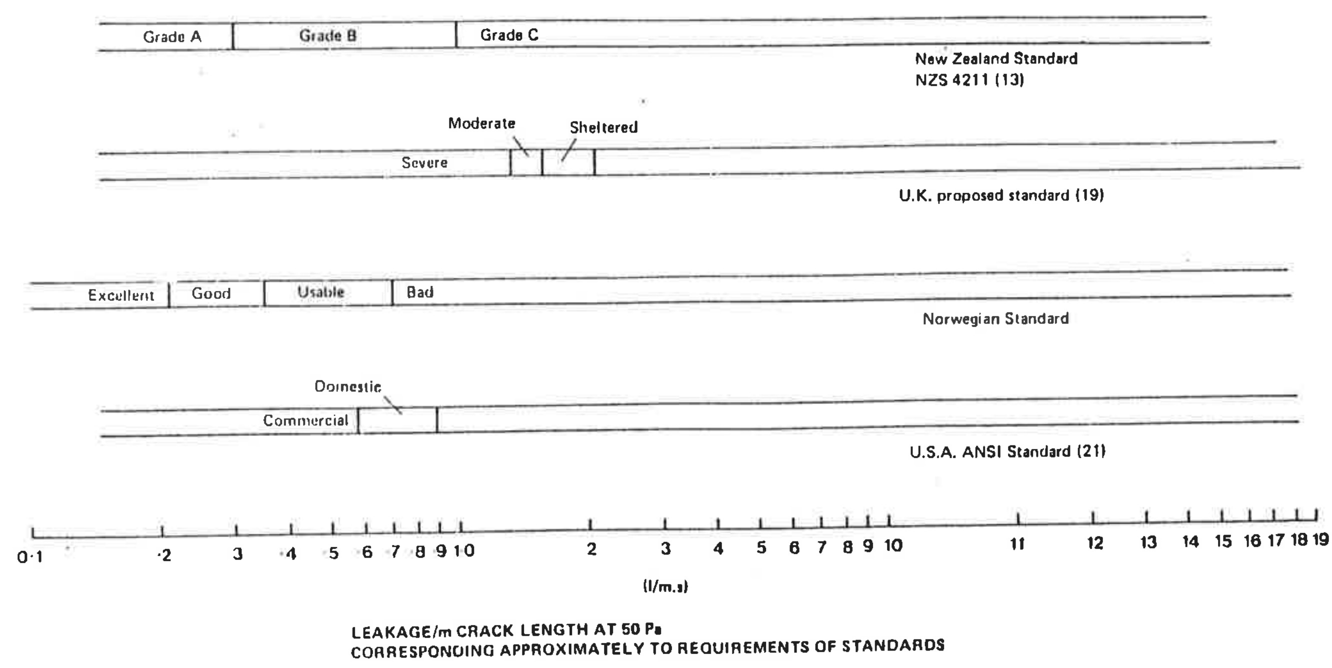

FIGURE 8: STANDARDS FOR WINDOW AIR LEAKAGE

L_B = length of crack around wood framed joinery (m)

α β = length and type specific leakage rates @ 50 Pa (ℓ/s.m)

A more detailed separation into different categories of window and door would be useful but the data is not comprehensive enough to give statistically reliable results. Provisional values for α and β are:

$\alpha = 0 \pm 1$ ℓ/s.m (specific leakage for aluminium joinery @ 50 Pa)

$\beta = 4 \pm 1$ ℓ/s.m (specific leakage for wooden joinery @ 50 Pa)

The zero value for α means that the leakage rate was too small to be resolved using this technique. There is a suggestion that leakage around doors makes a major contribution to the value of β. Four separate measurements of door to frame leakage ranged from 8-15 ℓ/s.m with a mean value of 9 ℓ/s.m. Although the wooden joinery tested in this survey is less air tight than joinery made of aluminium, it must be remembered the houses were much older, 20 years on average compared with four years for aluminium joinery. Two houses in the $\leq$5y age group, fitted with wooden windows weatherstripped with a neoprene gasket, had leakage rates of 2.1 and 2.5 ℓ/s.m @ 50 Pa compared with the mean leakage rate for wooden joinery of 4.6 ℓ/s.m.

6.2 Summary of Window and Door Leakage Results

Leakage around doors and windows is compared to total house leakage in Figure 6. Here, the leakage for an average $\leq$5 year old house is compared with that of a >5 year old house. The floor area is 100 m² in both cases and the proportions of timber and aluminium frame joinery, are the floor area weighted averages of those that occurred in 40 houses. It is also worth noting that an allowance has been made for the door occupied by air tightness test equipment. For houses less than 5 years old the fraction of leakage through doors and windows is 17% and for the older group it is 23%. These leakage proportions can be compared with 15 to 24% measured by Tamura[12] in Canada and 40% measured by McIntyre and Newman[13] in a single house in the U.K.

Figure 7 summarises window leakage measurements and shows the sample of older New Zealand wooden windows to be similar to those measured by Tamura in Canada and comparable with average data given in the IHVE guide[15] and the ASHRAE Handbook of Fundamentals[16]. Also of note is the similarity between leakage rates for aluminium joinery in this country and the measurements of Weidt et al[17] for newly installed residential windows in the U.S.A.

6.3 Standards for Window Air Leakage

There are standards for window air tightness giving leakage rates at a range of pressures. Often the applied pressure is much higher than the reference 50 Pa used in air tightness studies because of the need to test for frame distortion at peak wind speeds. For comparative purposes Figure 8 gives flow rates at 50 Pa converted using the following equation:

$$Q_{50} = Q(n)\left[\frac{n}{50}\right]^{0.65}$$

n = standard pressure Pa

Where leakage rates are given on an area basis the following approximate conversion is used:

L(ℓ/m².s) equivalent to 4(ℓ/m.s)

The New Zealand Standard NZS 4211 "Specifications for performance of windows"[14] gives three levels of air tightness. They are labelled A, B and C in order of decreasing performance and approximate leakage rate at 50 Pa are: grade A 0.3 ℓ/s.m, grade B 1 ℓ/s.m and grade C 2 ℓ/s.m. Leakage rates at 50 Pa are shown in Figure 8 from a number of standards. While the log scale tends to compress the range (for example there is a 10 to 1 difference between the most stringent Norwegian standard and the New Zealand grade C classification) the figure does show the New Zealand and Scandinavian requirements to be comparable in magnitude and range.

7. 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 concept. Figure 9 shows the relative sizes of a number of leakage openings compared with the mean Aeq for a 100 m² house less than five years old. These are

		Aeq	Relative Size
1.	Average 200 m² 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 + freestanding fireplace all dampers open	0.008	7%
6.	Bath toe space detail, average of 3 cases	0.007	6%

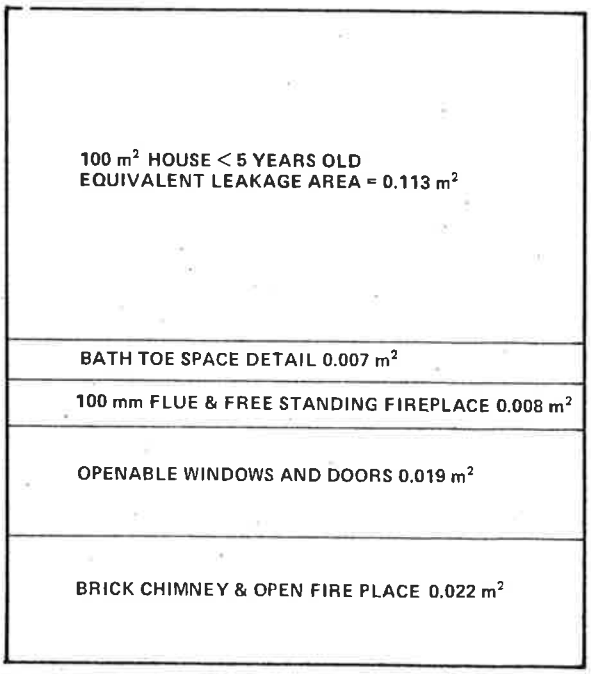

FIGURE 9: EQUIVALENT LEAKAGE AREA @ 50 Pa (m²)

Various leakage openings compared with average Aeq for 100 m² house less than 5 years old

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 weather stripping 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 New Zealand houses.

8. CONCLUSIONS

The sample of 40 houses in Wellington were all 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 six 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 total envelope leakage in houses less than five years old and 23% in houses older than this.

3. The air tightness test has only limited application in locating leakage openings for weather stripping attention because the leaks are typically many and widely spaced rather than few in number and easily accessible.

Finally, it must be re-emphasised that envelope air tightness is not simply related to the natural air infiltration rate and that an optimum range of air tightness is not yet established. Since there is a trade-off between ventilation to control moisture and pollutants, and the loss of space heat during the winter, it is possible for a house to be either too air tight or too loose.

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