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PAPER 2

THE INFILTRATION COMPONENT OF VENTILATION IN NEW ZEALAND HOUSES

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ABSTRACT

The air infiltration component of house ventilation is calculated and discussed in relation to winter space heat losses and measures necessary to control moisture. The airtightness of 80 houses sampled from three major urban areas was inspected for association with location, external cladding materials, and design features such as the shape and complexity of the building envelope. A useful correlation of airtightness with envelope complexity emerged which gives a coarse but useful way of forecasting airtightness from building design information. Winter season infiltration rates were calculated using hourly weather records, airtightness and wind exposure data and the Lawrence Berkeley Laboratory infiltration model. These infiltration rates represent the minimum ventilation rate currently achieved in New Zealand houses and are used in a discussion of the value of further improving house airtightness. Finally, results of surveying moisture problems in houses of known tightness are used to help establish the respective roles of ventilation and space heating in the control of indoor moisture in a temperate climate.

1. CURRENT VIEWS ON DOMESTIC AIR INFILTRATION

New Zealand houses do not have to conform to a standard for airtightness but they must have insulated walls, roof and floor. Infiltration heat losses have been ignored in the bid for more energy-efficient houses mainly because there has been little indication of the size of infiltration rates in relation to ventilation needs. It has nevertheless been expected that air infiltration could dominate space heat losses from insulated houses and therefore represent the next target for improved thermal performance.

Another aspect of house performance depending on ventilation is moisture control. Dampness problems are common in New Zealand because the warm maritime climate limits the moisture pick up capacity of ventilation air. The ventilation rate needed to cope with condensation depends on a number of lifestyle and house management factors but it is expected that this requirement will establish a limit to the degree of airtightness worth achieving in the absence of more sophisticated and expensive hardware to remove moisture.

2. AIRTIGHTNESS OF HOUSES

2.1 A Survey of House Airtightness

Airtightness results from a pilot survey of 25 houses in the city of Wellington (Ref 1), Fig 1 were used to help design a more extensive survey of a greater range of house types and geographic locations (Ref 2). This added a further 55 house results, giving a more secure basis for commenting on the airtightness of current and recent additions to the housing stock. All airtightness tests were made using the method of fan depressurization and equipment described in Ref 3.

The initial results of these surveys are given in Fig 1 which shows the distribution of house airtightness for each of three urban regions: Auckland, Wellington, and Christchurch. Houses built in these regions form about 50% of the new houses built in New Zealand during the period 1979-1984. Most houses in this age group (93%) have 50Pa airchange rates between 5-16 ac/h while the remaining 7% fall in the range 16-30 ac/h. A combined histogram of data for all regions is also shown in Fig 1.

A large group of houses (40%) falls within the 0-8 ac/h range occupied by conventional houses in very much colder climates such as those in Canada and Scandanavia. This finding conflicts with a widely held view within New Zealand that houses are typically quite loose by international standards. There are no special reasons for expecting to see houses of even modest airtightness. Since vapour barriers have not been found necessary to control cavity moisture they make no contribution to airtightness. Neither are gaskets used in joints nor 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-ground floors.

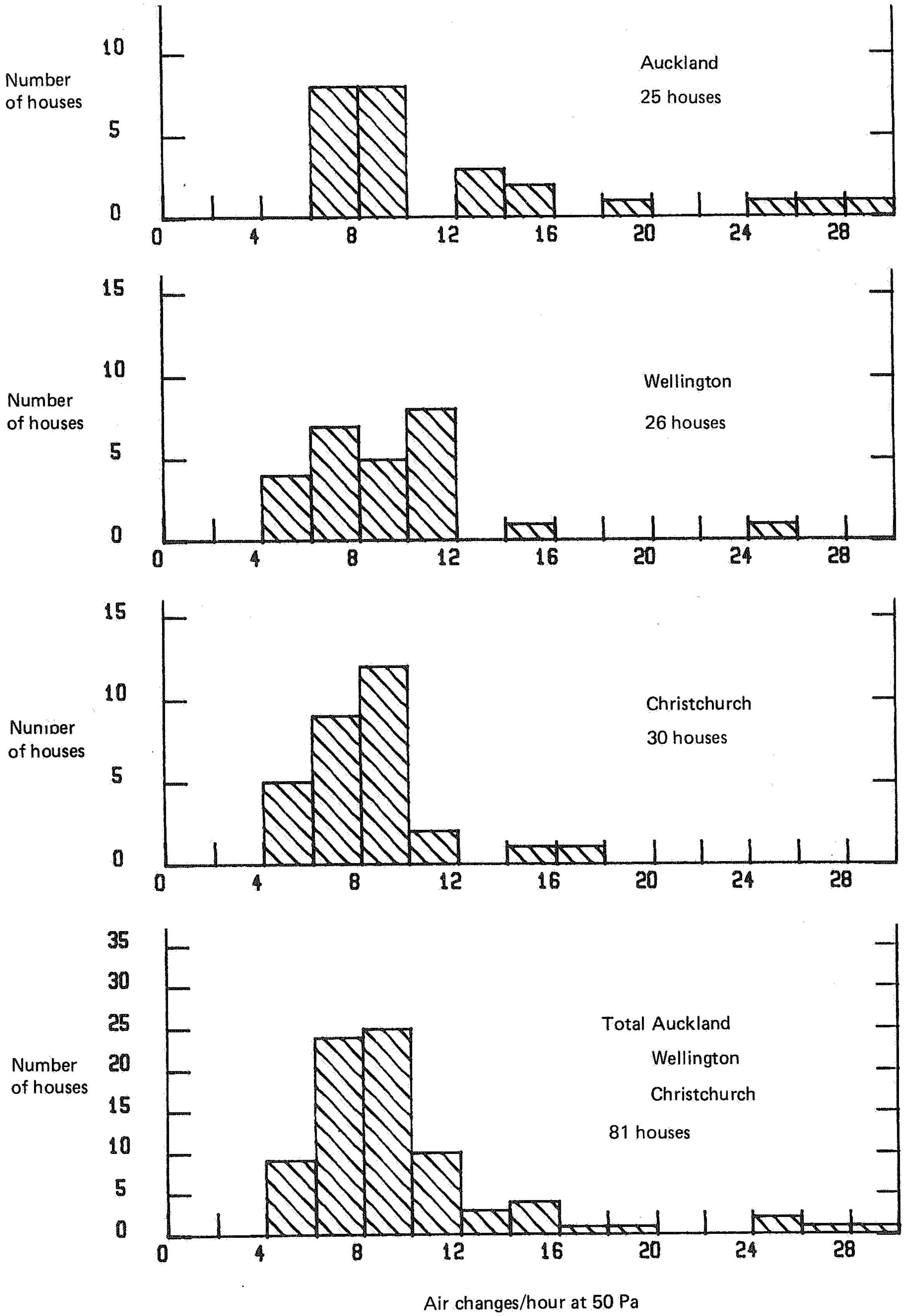


Fig 1: Histograms of house airtightness expressed as airchanges/hour at 50 Pa.

2.2 Dependence on Envelope Complexity

The possibility of a correlation between some of the broad characteristics of houses and the air leakage rate under test pressure has been investigated. While it is well known that the air leakage rate will depend more fundamentally on the microscopic detail of cracks, there is value in looking for correlation with some of the bulk characteristics such as the surface area of the building envelope, the complexity of the plan or the types of material used in construction. There may even be regional differences arising from construction detail or choice of material. If this approach can be shown to succeed then a valuable, simple tool will be available to predict house airtightness at the planning stage.

Two factors of building geometry considered likely to have an influence on airtightness are the surface area of external envelope and the complexity of construction. They are defined here as follows:

Envelope area: Area of external walls + ceiling + floor
(where a floor is slab-on-ground it is excluded)

Envelope complexity: Joint length / Envelope area
where joint length is the total length of the following joints in the envelope:

1. Wall-Floor perimeter
2. Wall-Ceiling perimeter
3. Wall-Wall vertical lengths of joint at changes of wall orientation
4. Boundaries of changes in ceiling pitch

An earlier analysis of the Wellington data (Ref 3) showed that complex houses tended to be more leaky than those of simple design. The same conclusion holds for houses tested in Auckland and Christchurch so the data for all three regions can be combined as shown in Fig 2. Here the tendency for complex building shapes to be less airtight than an equal shell area of simple shape is illustrated.

Fitting the following linear equation to the data:

$$Q = A + B\,Je + CSa \qquad (1)$$

where
Q = Leakage rate at 50Pa m^3/s
A, B, C are the regression constants
Je= Joint length m
Sa= Envelope surface area m^2

gives the following coefficients:

	Coefficient	Standard deviation
A	0.1	0.1
B	4.7×10^{-3}	0.7×10^{-3}
C	-0.1×10^{-3}	0.4×10^{-3}

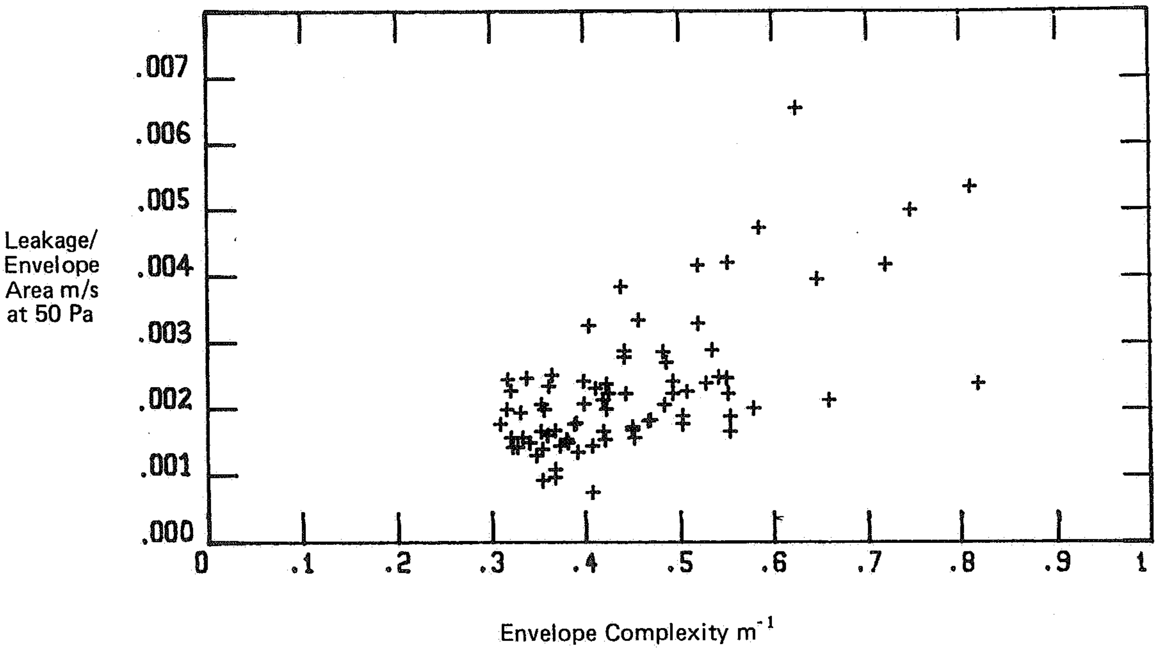


Fig 2: Measure of building envelope complexity against leakage/shell area at 50 Pa.

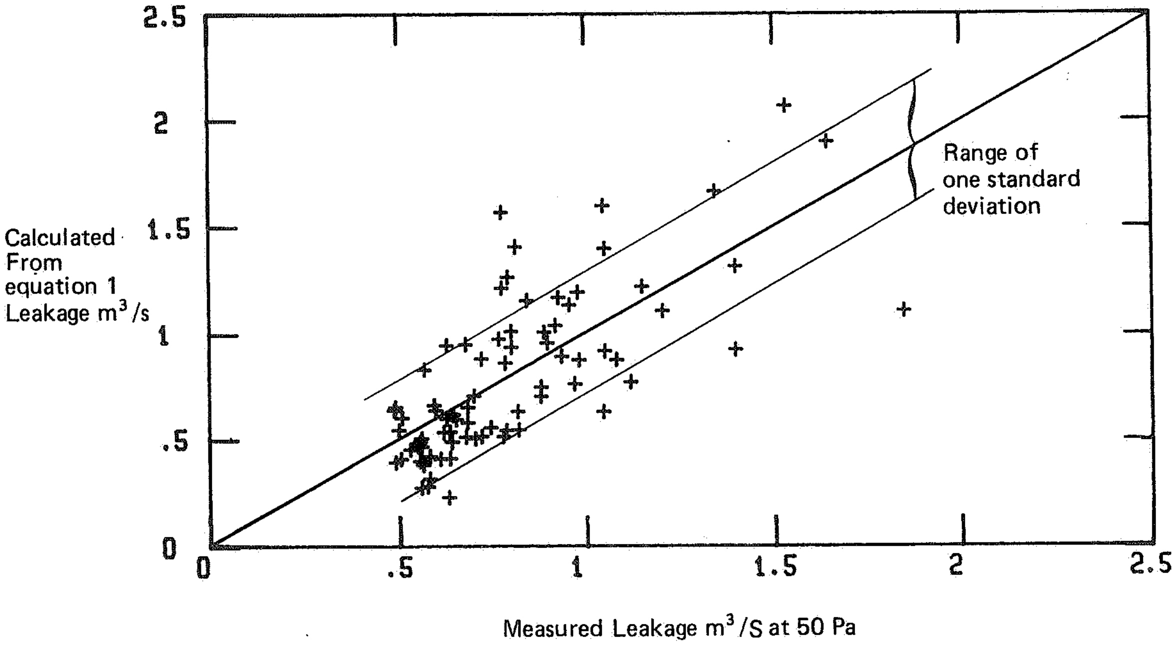


Fig 3: Measured leakage at 50 Pa against leakage correlated with a measure of building joint length. See equation 1.

Joint length is clearly more strongly related to airtightness than envelope area. Reversing the order of variables in the regression confirms that houses of large envelope area tend also to have longer joint lengths but that envelope area alone is a much less significant factor in the model. Over 50% of the variance in the leakage rate data is accounted for, yielding predictions within one standard deviation (0.3 m^3/s) of the measured value. Fig 3 shows the correlated component plotted against measurement, indicating that the resolution of the model does not extend much beyond giving an answer in terms of high, average, or low; but guidance of this sort may be useful in the future for distinguishing broad house types that could benefit from improved airtightness from those that need some form of ventilation control. Reinhold and Sonderegger (Ref 4) have calculated house airtightness values from tables of component leakage resistance. Their more detailed approach gave predictions falling within 20% (range of 1 standard deviation) of final measured values.

2.3 Regional and Cladding Material Effects

The 80 airtightness results are spread across three urban areas and two external cladding types. The cities Auckland, Wellington and Christchurch were chosen to cover a large range of the New Zealand climate with winter degree day values of 400 dd (base 18 °C) for Auckland in the north to 1100 dd for Christchurch in the south. The objective was to see whether local construction methods and materials have an influence on airtightness.

In some countries, masonry buildings are more airtight than those of timber construction. Kronvall Ref 5 has shown that concrete houses in Sweden are 46% tighter on average than those made of wood. The closest equivalent to concrete houses in New Zealand are those clad with a veneer of masonry. In Auckland and Christchurch the airtightness of houses with masonry and alternative cladding types were measured. With envelope area and crack length effects removed from the data, the adjusted mean leakage rates in Table 1 can be used to resolve regional and cladding type differences.

Location	Cladding Type	Adjusted Mean leakage rate in m^3/s at 50Pa	Standard Error of Mean
Auckland	masonry	.95	.10
	other	.89	.07
Christchurch	masonry	.76	.06
	other	.74	.10
Wellington	other	.76	.05

Table 1 Adjusted mean leakage rates in m^3/s at 50 Pa for three locations and two cladding categories.

Houses in Auckland are less airtight than those in Wellington and Christchurch but the difference is 20% and of limited practical importance. There is no evidence that masonry clad houses are more or less airtight than those clad with alternative materials.

3. INFILTRATION RATES

3.1 Method and Assumptions

An earlier comparison (Ref 6) of infiltration rates calculated using the LBL model (Ref 7) with measurements made using a tracer gas showed the calculation procedure to be as good as our ability to choose the appropriate wind exposure factor. Similar conclusions are drawn by Liddament and Allen (Ref 8) and Grimsrud Modera and Sherman (Ref 9).

A range of infiltration rates have been calculated using the LBL model, the building airtightness data presented in this paper and data on the way leakage openings are distributed around the envelope taken from (Ref 6). A reference building of median tightness was defined with a typical distribution of leakage openings. Hourly weather records, assumed indoor temperatures and wind exposure factors were then used to calculate infiltration rates averaged over a winter season.

3.1.1 Reference Building of Median Tightness

Beginning with the power law equation (2) for the leakage rate under test pressures, an effective leakage area can be defined by equation (3).

$$Q = C\Delta P^{n} \qquad (2)$$

$$L = C\sqrt{\frac{\rho}{2}}\,(\Delta P)^{(n-\frac{1}{2})} \text{ for } \Delta P = 4\text{Pa} \qquad (3)$$

where L = effective leakage area m^2
Q = volume flow rate m^3/s
n = exponent
ρ = density of air kg/m^3
ΔP = pressure difference across envelope Pa

Effective leakage areas were calculated for 80 houses using equation (3). The median effective leakage area is $0.71 m^2$ and the 10 and 90 percentile values are $0.41\ m^2$ and $1.25 m^2$ respectively. Data from Ref 6 were used to assign 20% of the effective leakage area to windows and doors with the remainder area weighted to walls, roof and floor. This generalisation allows wind and stack parameters of the LBL model in equation (4) to be considered independent of building type with all the variation in airtightness characteristics lumped into the effective leakage area.

$$Q = L\,(fs\,\Delta T + fw\,V^2)^{\frac{1}{2}} \qquad (4)$$

Q = infiltration rate m^3/s
L = effective leakage area at 4 Pa m^2
ΔT = indoor-outdoor temperature difference K
fs = stack parameter
V = wind speed at the house m/s
fw = wind parameter

Infiltration rates for the reference building can then be adjusted to suit another building in the same climate and exposure class by scaling in the proportion of the effective leakage areas. The reference building has national average values for the floor area and perimeter length of $135\ m^2$ and 56 m respectively.

3.1.2 Indoor Temperature Profiles

Calculation of stack induced leakage requires a knowledge of both indoor and outdoor temperatures. Three indoor temperature profiles were modeled to represent heating regimes of continuous, intermittent and zero heating. The intermittent and zero heating regimes were based on temperature records made in occupied houses. Implementing these first involves calculating an indoor temperature for the unheated case which floats on average 6 °C above outdoor temperature. The indoor temperature swings are phase delayed 3 hours and damped by a factor found appropriate to light-weight houses. In the intermittent heating regime the minimum temperature between 5 and 10pm is 18°C and in the continuously heated case the indoor temperature is 20°C at all times.

3.2 Calculated Infiltration Rates

Average infiltration rates have been calculated for a 4 month (May-August) winter season using hourly weather records (Ref 12). Average air change rates are given in Table 3 for the reference house of median tightness located in 4 cities and exposed to the wind in varying degrees. The wind exposure classes are the same as those given in (Ref 9) except that the local shielding and terrain class numbers are taken to be the same. The exposure classes described in Table 2 encompass quite a wide range and it is likely that most houses will be either medium exposed or medium sheltered.

Name	Description
Exposed	Flat terrain with few obstacles and well separated from other buildings.
Medium exposed	Rural area with low buildings some obstruction within two house heights.
Medium sheltered	Urban or industrial area and obstruction around most sides of building.
Sheltered	Center of city with large obstruction surrounding perimeter within two house heights.

Table 2 Description of wind exposure classes

Table 3 shows that the inter-city effect on the infiltration rate is less than that of altering the wind exposure class. Similarly, changing the indoor temperature from a relatively high standard of continuous heat to the unheated case has only a small effect on the infiltration rate, although it will be more important as far as heat loss and condensation control are concerned, see Table 4).

City	Exposed	Medium exposed	Medium sheltered	Sheltered
Auckland	0.61	0.46	0.33	0.25
Wellington	0.72	0.54	0.39	0.28
Christchurch	0.56	0.46	0.37	0.32
Invercargill	0.63	0.50	0.40	0.33

Table 3 Winter average infiltration rates in air changes per hour for a house of median tightness and constant indoor temperature of 20 °C.

The distribution of daily infiltration rates is shown in Fig 4 and Fig 5 for the house of median tightness in Wellington and Christchurch. While the mean infiltration rates are comparable, the distributions (which are characteristic of local weather patterns), are quite different.

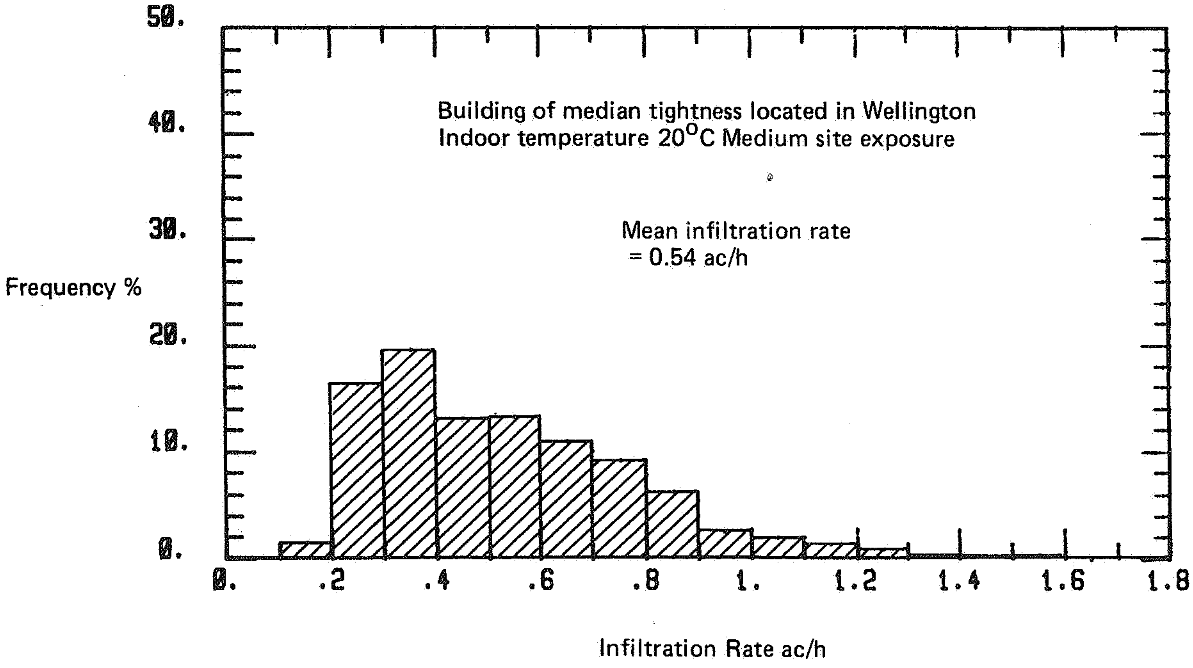


Fig 4: **Frequency distribution of day average infiltration rates for a winter season**

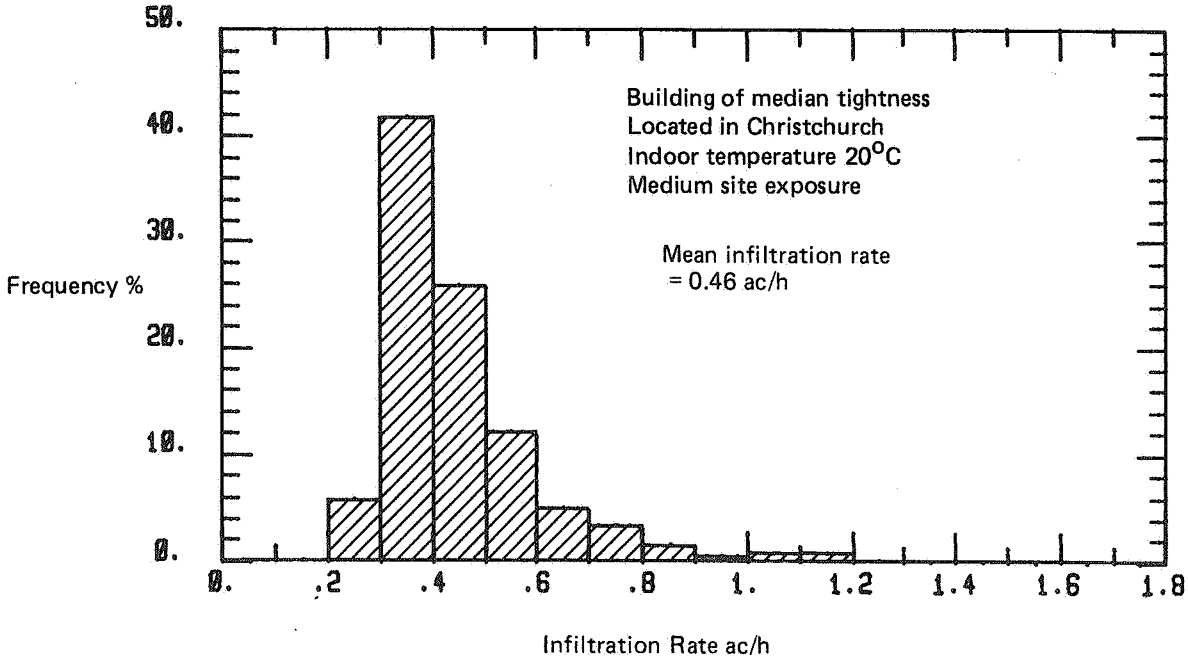
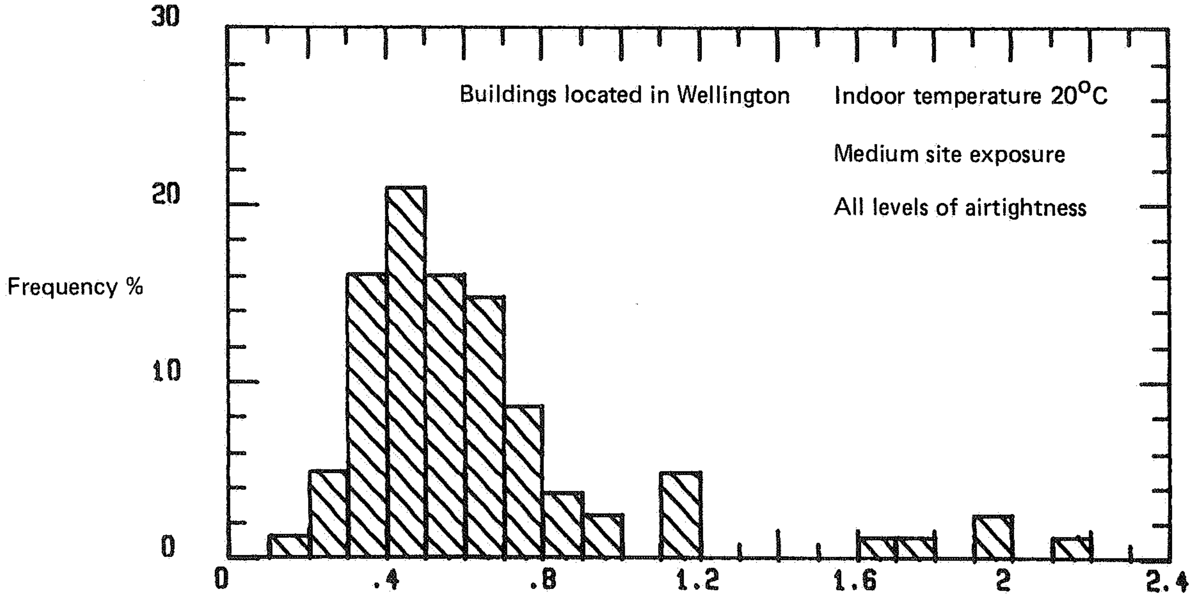


Fig 5: **Frequency distribution of day average infiltration rates for a winter season**

An indication of the range of infiltration rates in houses can be gained by scaling the distribution of airtightness by the ratio of effective leakage areas as outlined in section 3.1.1. Examples are given in Figs 6,7, and 8 of the distribution of winter infiltration rates for houses over the full range of airtightness but with fixed medium exposure. In fact the wind exposure will vary with house location and this will broaden the distribution slightly but not undermine its value in indicating the range of minimum infiltration rates. Since it is universal practice for home owners in New Zealand to add extra ventilation by opening windows, the infiltration rates in Figs 6,7 and 8 must be regarded as the lowest that can be achieved in existing houses and not representative of actual house ventilation rates. Another factor not accounted for is the action of combustion appliance flues which can drive additional infiltration. For the moment, air leakage through vents, flues and open windows is ignored because it is the uncontrolled infiltration or the 'lower infiltration limit' that is of interest.



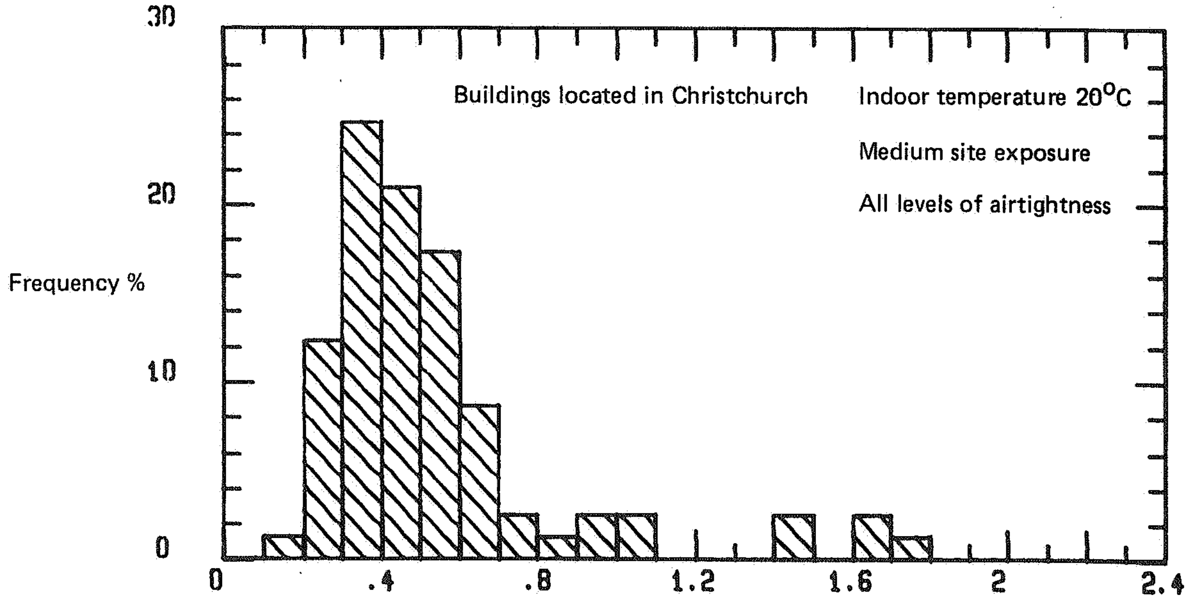


Fig 6 and 7 : **Mean winter infiltration rates for buildings over the entire range of air tightness but with fixed wind exposure class.**

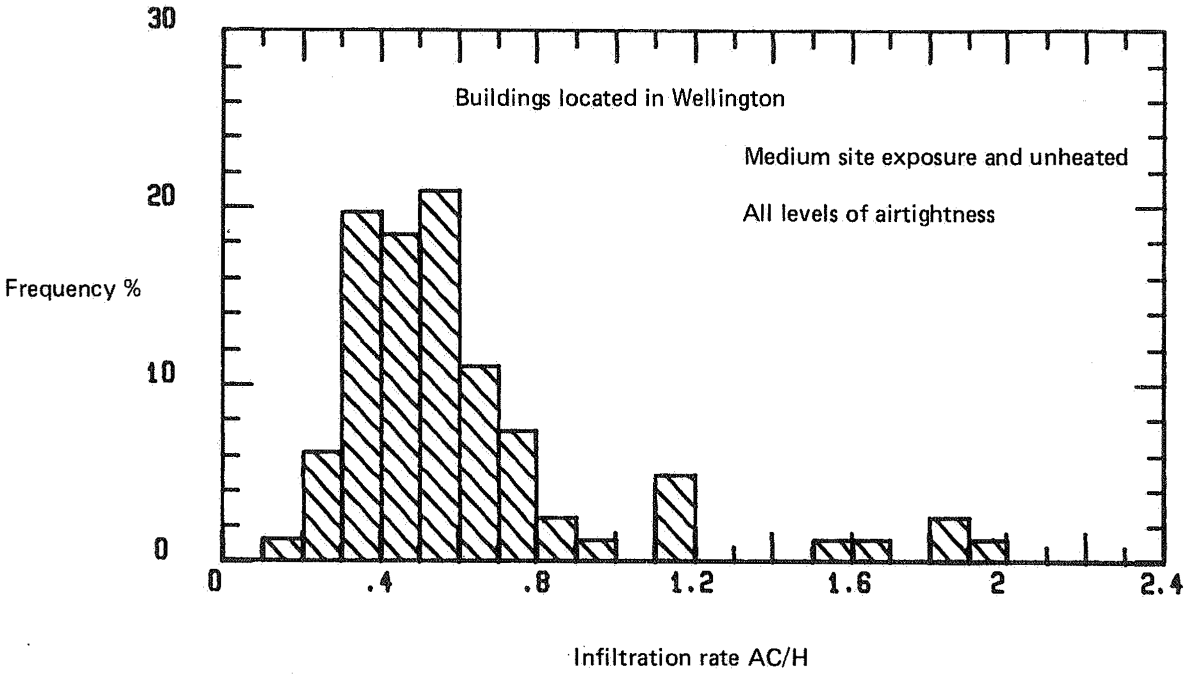


Fig 8 : **Mean winter infiltration rate for buildings over the entire range of air tightness but with fixed wind exposure class.**

3.3 Space Heat Loss through Infiltration

Average infiltration heat losses have been calculated and presented in Table 4. The data applies to the reference building of median tightness with two levels of site exposure and three alternative standards of heating.

Location	Standard of heating Continuous		Intermittent		No Heating	
Auckland	0.40	0.30	0.32	0.23	0.32	0.23
Wellington	0.61	0.44	0.41	0.28	0.37	0.25
Christchurch	0.73	0.61	0.36	0.29	0.28	0.21
Invercargill	0.83	0.68	0.41	0.32	0.30	0.23
Wind Exposure	ME	MS	ME	MS	ME	MS

Wind Exposure classes ME=Medium exposed
MS=Medium sheltered

Table 4 Average infiltration heat loss in Kw for a house in winter

These heat losses can be placed in perspective with conduction heat losses through walls roof and floor. For the reference building heated continuously, medium exposed and insulated to the standard required in new houses (see heading of table 5), air infiltration makes up 15% of the total fabric heat loss in all four cities. For a house of loose construction at the 90 percentile of airtightness the fraction rises to 25% and for a house of tight construction at the 10 percentile it is 10%. In practice there will be an additional component of user-supplied ventilation but in these calculations it is not considered part of the building fabric loss. Mean winter day heat loss profiles due to infiltration are given in Figs 9 and 10 for the reference house located in four cities. The data show that heat loss is more sensitive than the infiltration rate to indoor/outdoor temperature differences.

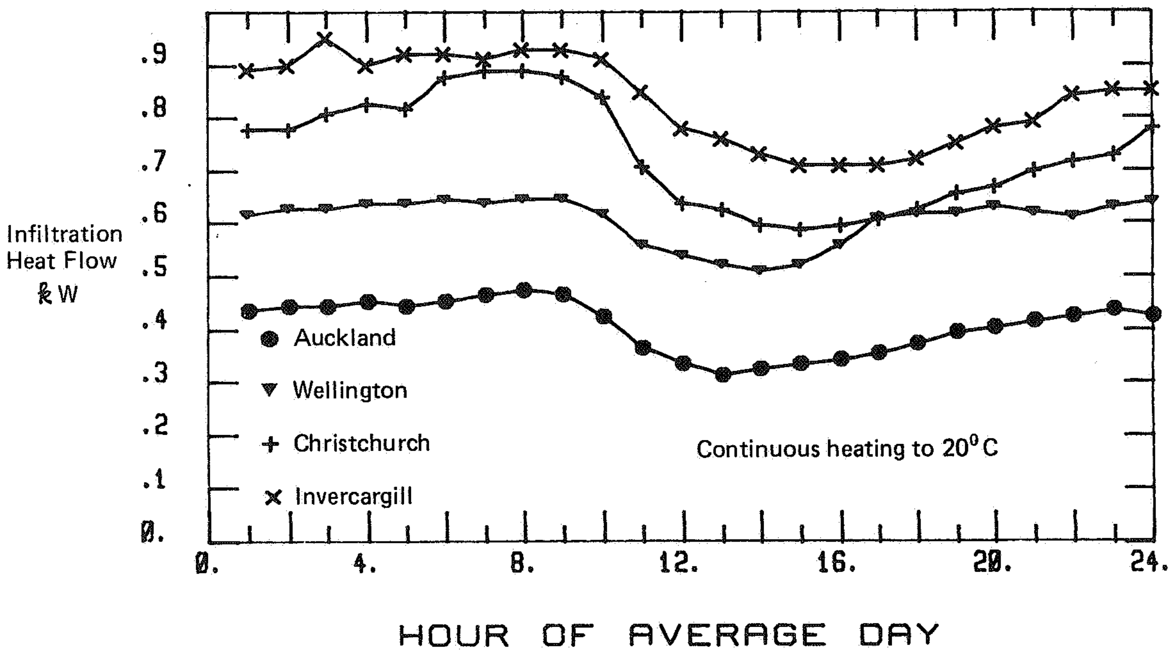


Fig 9: Winter average infiltration heat loss for a reference building sited with medium wind exposure and heated continuously to 20° C

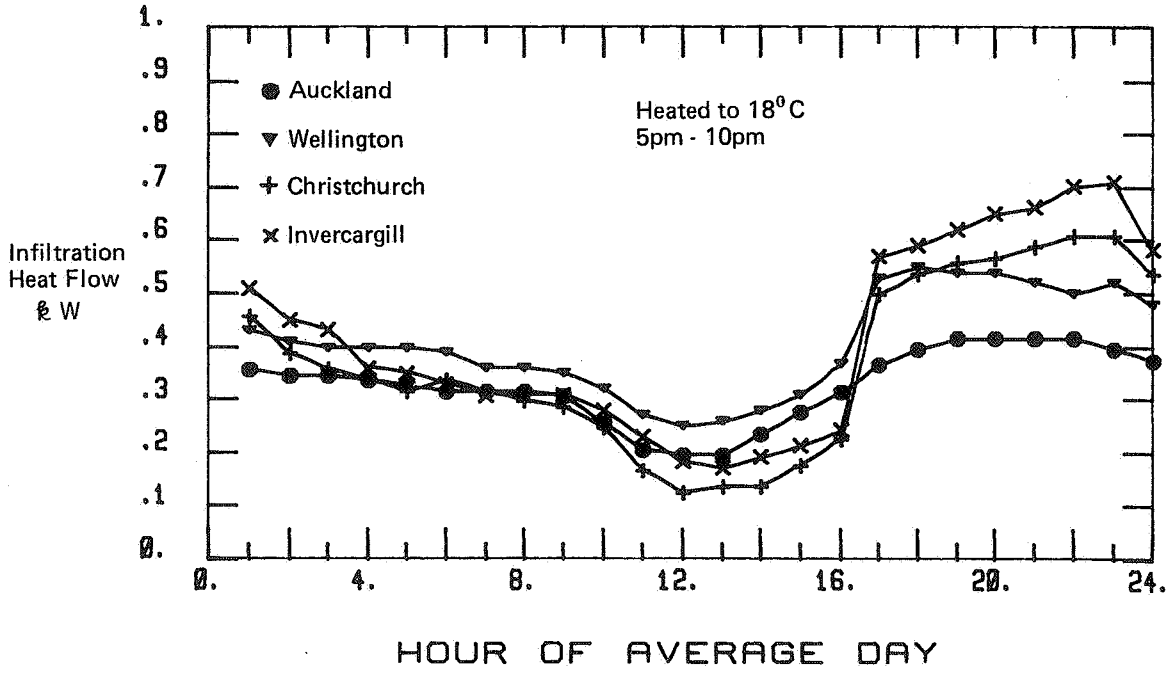


Fig 10: Winter average infiltration heat loss for a reference building sited with medium wind exposure and heated intermittently

4. VENTILATION TO CONTROL MOISTURE

In this section an attempt is made to relate levels of mould/condensation observed in houses with the measured airtightness.

4.1 Indoor Moisture Control

The contaminant most likely to place a lower limit on desirable ventilation rates is moisture. Trethowen (Ref 10) has calculated moisture release rates in houses and balanced these against removal rates in ventilation air and by diffusion. Ventilation is the more important process but the optimum air change rate depends very much on the moisture release rate and the standard of heating. Outdoor relative humidity is generally quite high in the main residential areas in New Zealand, for over half the time it is over 80%. Consequently the moisture pick up capacity of ventilation air is sensitive to the indoor/outdoor temperature difference. Ventilation rates sufficient to avoid mildew on walls have been calculated for a wide range of conditions but for the purposes of this paper a limited range of data is given in Table 5 based on the following assumptions.

Moisture emission rate g/s	high	low
bedrooms	0.03	0.008
kitchens	0.3	0.07

Relative humidities - Outdoor relative humidity is 90%, a value exceeded for 20-50% of the time at urban meteorological stations. The relative humidity at which mildew will grow is taken to be 90% at the wall surface temperature.

Thermal insulation	Roof R=1.9, Walls R=1.5, Floor R=1.3 m^2K/W
Standard of heating	As described in Section 3.1.2
Room size	The room volume is $36m^3$

	Low	Moisture Load				High
Outside temperature^{o}C	5	10	15	5	10	15
	Required Ventilation rates in air changes/hour					
Bedroom						
unheated	0.3	0.2	0.2	1.1	0.8	0.6
continuously heated	0.1	0.1	0.1	0.4	0.5	0.5
Kitchen						
unheated	2.6	1.9	1.4	11.0	8.2	6.0
continuously heated	0.8	1.0	1.0	3.5	4.5	4.5

Table 5: Ventilation rates (ac/h) needed to avoid mildew on walls for given conditions.

Ventilation air sufficient to prevent surface mildew can not always be supplied by infiltration. In bedrooms with a low rate of moisture release or a high standard of heating, natural infiltration will be normally sufficient but in wet areas such as a kitchen or bathroom, additional ventilation will usually be necessary.

4.2 Survey of Moisture Problems

Moisture problems in houses were surveyed in 1972 by Trethowen (Ref 11). House age and external cladding types were recorded and found to have little influence on the incidence of moisture problems. During the survey of house airtightness in Christchurch and Wellington, moisture problems were again surveyed to look for association with airtightness. The questionnaire in Table 6 was completed by the home occupier and a moisture score worked out as the total of the highest bedroom score and the lounge score in two categories 'mould on wallpaper' and 'condensation on windows'. For a house free from condensation problems the condensation score is 4 and for severe dampness problems it is 16.

MOULD ON WALLPAPER

Severity	Lounge	Score	Bedroom 1	Bedroom 2	Bedroom 3	Score
None		1	*	*		1
slight	*	(2)			*	(2)
common		3				3
severe		4				4

CONDENSATION ON WINDOWS

Severity	Lounge	Score	Bedroom 1	Bedroom 2	Bedroom 3	Score
none		1	*			1
condensate forms but doesn't run		2		*		2
condensate forms and runs	*	(3)			*	(3)
pools of water on sills and floors		4				4

Total moisture score 10

Table 6 Example of a filled-in moisture questionnaire

The average moisture scores for Auckland and Christchurch were 6.6 and 5.8. respectively, supporting the earlier conclusion of Trethowen (Ref 11) that moisture problems were more prevalent in warmer regions of New Zealand. For both locations there is no useful correlation between the fan-induced leakage rate and the moisture score. Data for both cities have been pooled in Fig 11 to show that occupants of comparatively tight houses are no more likely to report surface condensation problems than occupants of houses of loose construction.

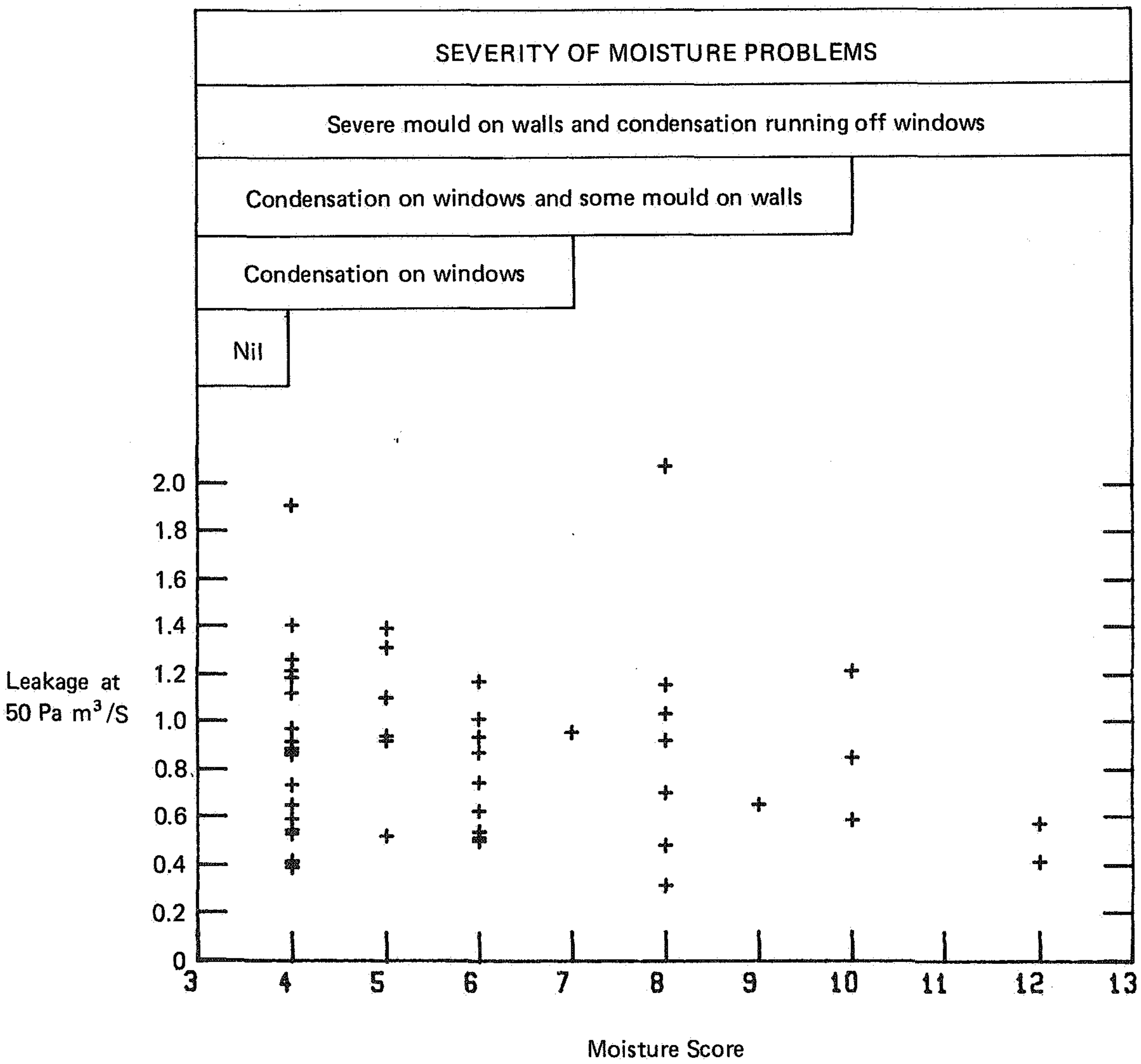


Fig 11: **Leakage rates at 50 Pa for houses in Christchurch and Auckland against moisture scores**

This survey result is consistent with the observation that even in houses of comparatively loose construction there will be times when the infiltration rates given in Table 3 will not provide sufficient ventilation (see Table 5). This will occur when moisture release rates, low indoor heating and a lack of supplementary ventilation coincide to an unfavourable extent. Because these aspects of house management are so important and so individual it is not possible to say that infiltration rates are generally excessive or insufficient for moisture control, except for wet areas such as kitchens and bathrooms for which it can be said that infiltration alone is unlikely to provide sufficient ventilation.

4.3 Options for Improved Moisture Control

A number of strategies exist for removing moisture from room air. Some require additional hardware to dehumidify or regulate the supply of air through a heat exchanger, together with some degree of improved airtightness. These options have not yet been investigated in detail. For the moment it is assumed that houses will continue to be constructed in the same airtightness range and operated with extra ventilation from open windows. In this case there are a number of strategies which help reduce the likelihood of mildew and other surface dampness problems.

1. A uniform standard of insulation in wall, ceilings and floor will help raise the indoor dew point and interior surface temperatures to discourage condensation.

2. Ventilators close to the point of moisture release in kitchens and bathrooms reduce the need for very high room ventilation rates. Popular examples are fan extraction hoods and window-mounted extraction fans.

3. Single glass windows with a catch and drain channel can allow condensation to escape outside. The amount of moisture removed this way is small compared to ventilation but condensation on windows can then be more easily tolerated.

5. CONCLUSIONS

On the basis of airtightness and air infiltration rate measurements, infiltration rates have been calculated for houses with windows doors and vents closed. This defines a lower limit for ventilation and allows the following comments to be made.

Airtightness

1. The airtightness of houses tested in the 0-5 year age group falls largely (93%) in the range 5-16 ac/h at 50 Pa. A significant proportion (40%) are tighter than 8 ac/h at 50 Pa.

2. A large part (50% of the variance) of building airtightness correlates with a measure of joint length. This is a simple summation of boundary edge lengths between floor, wall and ceiling and it can be used as a guide to whether a building is likely to have high, medium or low airtightness.

Infiltration rates

3. Calculated infiltration rates are sensitive to the building airtightness and the degree of exposure to wind. They are less sensitive to the indoor temperature and to the city in which the building is located.

4. Calculated mean season infiltration rates generally fall in the range 0.2-1.0 ac/h. Unusual combinations of airtightness and wind exposure are required to give winter infiltration rates outside this range.

5. The infiltration load on space heating has been calculated for an insulated house ranging between the 10 and 90 percentile levels of airtightness. It represented from 10 to 25% of the fabric heat loss.

6. There will be times in most houses when infiltration alone gives insufficient ventilation to control condensation. In general, the standard of heating and the extent of supplementary ventilation determined by the building occupier, will have more control over condensation than will air infiltration.

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