CI/SfB			
Date: June 2001			

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CONFERENCE PAPER

No. 90 (2001)

Naturally Ventilated Houses In New Zealand – Simplified Air Infiltration Prediction

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Presented at the CIB World Building Congress,
Wellington, New Zealand, April 2001.

Funding for this research was provided by the Building Research Levy and the
Public Good Science Fund of the Foundation for Research, Science and Technology.

SUPPORTED BY THE BUILDING RESEARCH LEVY

ISSN: 0111-7505

NATURALLY VENTILATED HOUSES IN NEW ZEALAND – SIMPLIFIED AIR INFILTRATION PREDICTION

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ABSTRACT

The New Zealand Building Code and related Standards have never required residential buildings to meet airtightness targets. As a result, air infiltration has been a more or less accidental consequence of construction practices and materials chosen for other reasons. Ventilation provisions, in contrast, are more tightly regulated to control moisture and other indoor contaminants. In this context, air infiltration rates have to be understood because they can contribute to or detract from effective ventilation. Air infiltration rates must therefore be factored into the ventilation design process and be recognised by verification methods used to meet moisture control and energy efficiency targets in the New Zealand Building Code.

This paper discusses the changing airtightness profile of New Zealand houses and proposes a way of classifying homes into four airtightness categories. A simplified method for estimating average infiltration rates for these airtightness categories has been developed by modelled infiltration rates using the BREEZE program with New Zealand climate and building data. The simplified model draws on airtightness survey information and tracer studies to link average infiltration rates to the age and type of building. These are further refined with specific allowances for simple passive ventilators, a range of well defined leakage openings, such as gaps under doors, and then further modified according to the geographic location of the building and local wind shielding. A version of the method has been implemented in a revision of the Annual Loss Factor method for passive solar house designs and in new indoor moisture control solutions being developed for residential buildings.

KEYWORDS:

Air infiltration; Airtightness; Passive ventilation.

INTRODUCTION

The climate in most of New Zealand's coastal cities is temperate compared with northern European and continental North American standards. Expressed in Centigrade degree days to base 15^{o} C, the coastal climate of New Zealand ranges from 500 C.d in the North to 2000 C.d in the South. New houses in New Zealand are insulated to approximately R 1.5 m^{2}C/W with slightly higher levels soon to be required in cooler regions. Compliance with the efficiency requirements of the New Zealand Building Code can be demonstrated by calculating a Building Performance Index "BPI" using the Annual Loss Factor (ALF) passive solar design guide (Bassett et al 1990 and Stoecklein and Bassett 1999). This process sums the energy flows through the building envelope, including those due to infiltration and ventilation and contains a method for estimating average infiltration and ventilation air flows. The infiltration calculation tool developed in this paper is a refinement of earlier methods which were based on less well developed modelling procedures and physical data relating to New Zealand buildings.

Moisture is the key contaminant in New Zealand houses, because it supports the bio-contaminants implicated in an unusually high incidence of asthma by international standards. This has shifted the emphasis of moisture research in buildings away from interstitial moisture in construction cavities to the moisture in the environments inhabited by dust mites and moulds in living spaces. While it is too early to understand how ventilation contributes to the bigger picture of bio-contaminant control, it is possible to develop an indoor moisture design tool for meeting the moisture control criteria required by the New Zealand Building Code. Such a design tool is being developed (Cunningham, 1999) and the infiltration modelling described here forms part of this process.

AIRTIGHTNESS OF NEW ZEALAND HOUSES

Airtightness measurements have been completed on approximately 150 houses of various types and ages in New Zealand. A random sample of 80 houses built in the 1980's in major cities Wellington, Auckland and Christchurch (Bassett 1986a) contributes most to the database and the remainder have been accumulated over several years from various ventilation research projects. Earlier analysis of this data had established a simple correlation between the air leakage rate at 50 Pa and the complexity of the building determined as a summation of major joint lengths divided by the enclosed volume (Bassett, 1986b). The joint lengths included in this summation were the floor to wall perimeter, the wall to ceiling perimeter, wall-to-wall vertical joints at changes of wall orientation and boundaries of ceiling pitch. The relationship was used in the ALF passive solar design guide for estimating air infiltration heating loads in New Zealand houses (Bassett et al 1990).

The main purpose of the infiltration model was to segregate simple modern buildings requiring ventilation top-up for moisture control, from older less airtight buildings where draught control measures might usefully improve energy efficiency. Several difficulties were encountered with the industrial use of the method. First it was sometimes used outside its calibrated range, eg for large commercial buildings, and secondly, the association between the selected joints and building airtightness was sometimes thought of as implying that these were the main leakage points in houses. In fact the method simply rested on the observation that more complicated houses were generally less airtight than those of simple design.

In the most recent version of ALF (Stocklein and Basssett 1999), a more direct linkage between building description and the building airtightness at 50 Pa has been developed. Four building descriptions have been defined in Table 1.

Table 1: Classifications of residential building airtightness.

Type description	Airtightness ac/h at 50 Pa	Building description
Airtight	5 ac/h	Post 1960 houses with a simple rectangular single story floor plan of less than 120 m^2 and airtight joinery (windows with airtight seals).
Average	10 ac/h	Post 1960 houses of larger simple designs with airtight joinery.
Leaky	15 ac/h	Post 1960 houses of more complex building shapes and with unsealed windows.
Draughty	20 ac/h	All pre 1960's houses with strip flooring and timber windows.

The building classifications in Table 1 take account of the age, size, and complexity of the building plan in a relatively qualitative way. Complex designs are taken as having a floor plan that is other than a simple rectangle or L shape. Often these will have multiple floor levels, more complex architectural features such as dormer or bay windows and multifaceted external walls. Pre 1960's houses are known to be less airtight than recent buildings because the strip lining materials common in this era provided many more leakage paths than sheet lining materials used in newer buildings. Figure 1 shows measured airtightness values (airchanges at 50 Pa) plotted against the airtightness classification (expressed in ac/h at 50 Pa). In statistical terms, this simple association accounts for 50% of the variance in measured airtightness and in this respect, is similar to the earlier and more detailed model based on a summation of major joint lengths. Estimating the airtightness of a building must be accepted as uncertain without a blower-door test, but the proposed four classifications should at least separate buildings according to those of airtight design requiring ventilation assistance from those that might benefit from air tightening for energy efficiency reasons. The uncertainty in airtightness predicted this way has a standard deviation of approximately one classification.

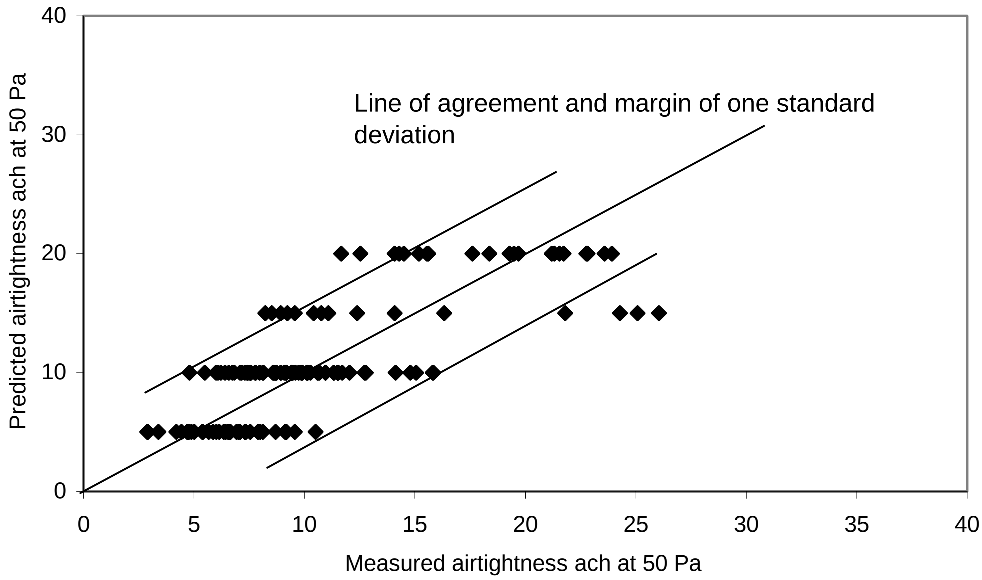


Figure 1: Building airtightness measurements compared with airtightness classifications.

MODELLING AIR INFILTRATION RATES

The infiltration modelling described here has used the UK BREEZE model (BRE, 1995) to translate building airtightness values into average infiltration rates according to the building location in New Zealand and local wind shielding. The infiltration calculations described here are part of more extensive modelling of pollutant control and ventilation system effectiveness in residential buildings.

Modelling assumptions and experimental verification

Agreement between modelled infiltration rates and those measured experimentally with tracers, is known to depend on assumptions made about the distribution of leakage openings around the building and on the quality of wind pressure coefficients chosen to represent wind shielding from local terrain and other buildings. In this study, the results of infiltration measurements in six houses have been used to help standardise the distribution of air leakage openings in the building envelope and wind pressure coefficients for detached buildings in urban and rural settings. Six houses (houses A to F in Table 2) have been modelled and compared with measured infiltration rates. The buildings are single story with suspended floors and airtightness values between 6 and 16 ac/h at 50 Pa. Earlier measurements of the leakage associated with windows and doors, and with top and bottom plate areas (Bassett 1984) has suggested the following allocation of leakage openings to the building envelope:

- Allocate 40% of the leakage area to external walls, on an area-weighted basis.
- Area-weight the remaining leakage area to walls, ceiling and floor.
- Equally proportion wall leakage openings between lower level (0.5 m above floor level) and high level (2 m above floor level) openings.

In practice, leakage openings are distributed in a more complex and building-dependent way and yet calculated and measured ventilation rates plotted in Figure 2 for buildings A to F, fall reasonably close to a line of agreement (SD = 0.13 ac/h).

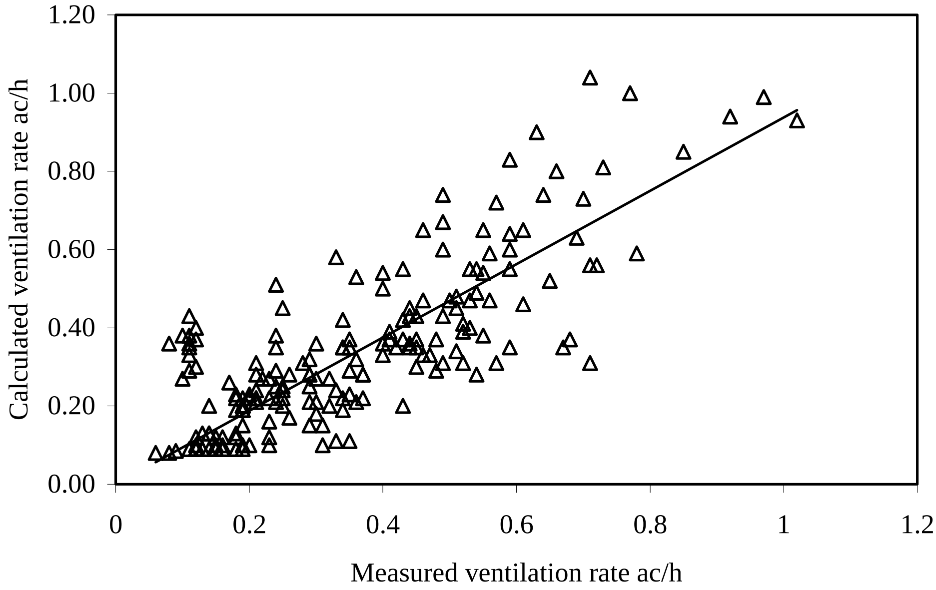


Figure 2: Measured and calculated infiltration rates over half-hour periods for buildings A to F.

Mapping New Zealand into infiltration climate zones

The climatic drivers of air infiltration (air temperatures and wind speed) vary over New Zealand on a regional and local micro-climatic scale. Local effects are accounted for with wind pressure coefficients chosen to reflect local shielding around the building and regional effects are accounted for by appropriate climate data. New Zealand extends from latitude 35 degrees to 47 degrees South and average winter temperatures vary from 12 C in the North to 4 C in the South. Average wind speeds have a strong geographical dependency through the influence of mountain ranges that traverse much of the country. In this study, New Zealand has been mapped into infiltration zones on the basis of average annual air temperatures and wind speeds using the simplified infiltration model of Grimsrud et al, 1981. In this model the average air leakage rate is expressed in air leakage and climatic terms as follows:

$$Q = L\left[f_s^2 \Delta T + f_w^2 v^2\right]^{1/2} \qquad 1$$

Where: Q is the infiltration rate [m^3/s],
L is the effective leakage area [m^2],
ΔT is the average indoor – outdoor temperature difference [K],
f_s is the reduced stack parameter [m/s/K$^{1/2}$],
v is the average wind speed at roof height [m/s] and
f_w is the reduced wind parameter.

The reduced wind stack parameters can be calculated from assumptions made earlier about the distribution of leakage openings in the building envelope, using expressions for intermediate parameters R and X in terms of the leakage area in the ceiling L_c and the leakage area in the floor L_f:

$$R = \frac{L_c + L_f}{L} \quad \text{and} \quad X = \frac{L_c - L_f}{L}$$

With the absolute indoor temperature *T*, the acceleration due to gravity *g*, and the height above ground of the ceiling H_h, f_s is expressed as:

$$f_s = \frac{1}{3}\left(1+\frac{R}{2}\right)\left[1-\frac{X^2}{(2-R)^2}\right]^{\frac{3}{2}}\left(\frac{gH_h}{T}\right)^{\frac{1}{2}}$$

The reduced wind parameter is expressed in terms of terrain classes for the weather station and the building site as follows:

$$f_w = C(1-R)^{\frac{1}{3}}\left[\frac{\alpha_h\left(\frac{H_h}{10}\right)^{\gamma_h}}{\alpha_m\left(\frac{H_m}{10}\right)^{\gamma_m}}\right]$$

Where: C is the shielding coefficient for the house site,
α_h, γ_h are the terrain class constants for the house,
α_m, γ_m are the terrain class constants for the wind measurement site,
H_m, H_h are the heights of the wind measurement and building respectively [m].

Zones of infiltration rate per unit of effective leakage area "Q/L" have been calculated from terrain parameters chosen for the meteorological stations in the main centres of population (50 sites) and for a reference building in an urban area. With these wind exposure classes and the air leakage distributions discussed earlier, equation 1 reduces to:

$$Q = L\left(0.0216\Delta T + 0.409v^2\right)^{\frac{1}{2}}$$

The value of *Q/L* has been calculated from average air temperature and wind speed data, an assumed indoor temperature of 20° C and plotted on a map of New Zealand. Figure 4 shows the country mapped into four infiltration zones appropriate to average *Q/L* values of 0.55, 0.6, 0.65 and 0.85 m/s. While the infiltration classes will not adequately represent mountainous or sparsely populated areas, the data will provide a scaling basis for correcting base level infiltration rates for geographical location.

Wind exposure classifications

The local wind pressure coefficients chosen to represent the 13 buildings modelled in likely urban and rural settings are those defined for rectangular buildings by Liddament, 1986. These coefficients apply to walls and pitched roofs of buildings in exposed rural and sheltered suburban settings. Where the building has a crawl space with perimeter ventilation openings, wind pressure coefficients of one exposure class less than applying to wall and roof areas have been used. Experience gained from modelling buildings A to F has shown that the "exposed" coefficients apply to buildings in rural locations and the "semi-exposed" to suburban locations. The "sheltered" coefficients have rarely been applied.

Building descriptions and average infiltration rates

Annual average infiltration rates have been calculated for the 13 buildings in Table 2 for 13 New Zealand climates and three wind exposure classifications. The buildings (labelled A to M) vary in size, airtightness and number of stories, and are considered to encompass most of the existing population of detached residential buildings in New Zealand. Larger multi-tenanted buildings, industrial and commercial buildings are not represented.

Table 2: Floor areas and airtightness characteristics for buildings A to M.

Building ID	Floor area m^2	Stories	Floor Construction	Airtightness ac/h @ 50Pa	Effective envelope leakage area m^2
A	84	1	Suspended	15.2	0.0825
B	88	1	Suspended	8.7	0.0370
C	98	1	Suspended	16.1	0.0937
D	97	1	Suspended	6.5	0.0161
E	95	1	Suspended	11.7	0.0530
F	69	1	Suspended	9.1	0.0368
G	150	1	Slab-on-ground	10.0	0.0700
H	240	2	Slab-on-ground	10.0	0.1120
I	150	2	Slab-on-ground	10.0	0.0700
J	69	1	Suspended	3.0	0.0154
K	96	1	Suspended	10.0	0.0447
L	240	2	Slab-on-ground	5.0	0.0560
M	240	2	Slab-on-ground	18.0	0.2016

Hourly records of climate data for New Zealand cities have previously been packaged into reference years for building energy calculations (van der Werff et al, 1990). This data has been further processed into frequency bins by wind speed and air temperature for 13 reference sites. Table 3 contains data applying to Wellington.

Table 3: Frequency distribution of air temperatures and wind speeds for Kelburn, Wellington.

	Outdoor air temperature range in degrees C						
Wind speed	-5 to 0	0 to 5	5 to 10	10 to 15	15 to 20	20 to 25	25 to 30
0 to 2 m/s	0%	3.3%	13.5%	4.9%	0.2%	0.26%	0%
2 to 4	0%	0.3%	7.2%	7.5%	0.1%	0.66%	0%
4 to 6	0%	0.1%	8.4%	9.9%	0.5%	0.89%	0%
6 to 8	0%	0.0%	10.5%	8.9%	0.3%	0.91%	0%
8 to 10	0%	0.0%	7.9%	4.3%	0.1%	0.22%	0%
10 to 12	0%	0.0%	4.3%	3.1%	0.0%	0.16%	0%
12 to 14	0%	0.1%	2.3%	1.0%	0.0%	0.05%	0%
14 to 16	0%	0.0%	0.8%	0.4%	0.0%	0.05%	0%
16 to 18	0%	0%	0%	0.1%	0.23%	0%	0%
18 to 20	0%	0%	0%	0%	0.1%	0%	0%
20 to 22	0%	0%	0%	0%	0%	0%	0%

The wind speeds measured at weather stations have been corrected to apply to a 3m high building using terrain parameters for urban areas (Grimsrud et al, 1981). Wind direction averaged infiltration rates have then been calculated for each bin for two indoor-outdoor temperature cases. Where the bin temperatures are below 15 ^{o} C, it has been assumed that indoor temperatures exceeded outdoor temperature by 10 ^{o} C and for the higher temperature bins, a temperature differential of 5 ^{o} C has been assumed. This simplification is a reflection of buoyancy forces being generally smaller than wind pressures in the New Zealand climate (Bassett 1994). The climate averaged annual infiltration rates are plotted in Figure 3 against measured building airtightness value (ac/h at 50 Pa) for the buildings with suspended floors (buildings A to F and J to K). Simple linear relationships have then been established between the airtightness of buildings and the average infiltration rate along with factors that convert between regional infiltration classes and wind exposure descriptions. These are summarised below as a simplified method for estimating infiltration rates.

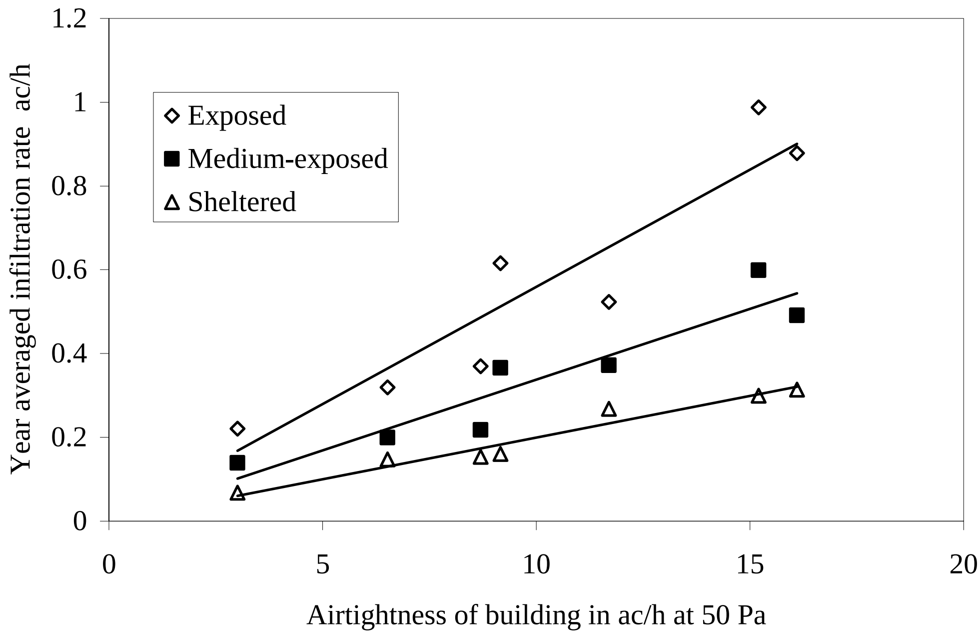


Figure 3: Climate averaged infiltration rates calculated using the BREEZE model for buildings with suspended floors with three wind exposure classifications.

SIMPLIFIED INFILTRATION CALCULATIONS

The following simplified method for estimating average infiltration rates has been designed to form part of more extensive tools for evaluating the thermal or moisture control performance of residential buildings in New Zealand. The method consists of the following four steps:

Step 1 Choose a base level infiltration rate using airtightness data or a building description.
Step 2 Adjust the base level infiltration rate for passive vents and chimneys etc.
Step 3 Adjust for geographic location in New Zealand.
Step 4 Adjust for local exposure to wind.

Infiltration calculation - Step 1

The general building descriptions in Table 4 can be used to choose a base level average infiltration rate that can later be refined to reflect the building and its location. Selecting a base level infiltration rate can be difficult where buildings have additions from a later period or have been relined. In this situation, the infiltration rate appropriate to the original building description has been found to align reasonably closely to blower-door test results, but some corrections are offered in Step 2.

Table 4: Base level average infiltration rates for four building classifications.

Type description	Base level infiltration rate ac/h	Building description
Airtight	0.3 ac/h	Post 1960 houses with a simple rectangular single story floor plan of less than 120 m^2 and airtight joinery (windows with airtight seals).
Average	0.5 ac/h	Post 1960 houses of larger simple designs with airtight joinery.
Leaky	0.7 ac/h	Post 1960 houses of more complex building shapes and with unsealed windows.
Draughty	0.9 ac/h	All pre 1960's houses with strip flooring and timber windows.

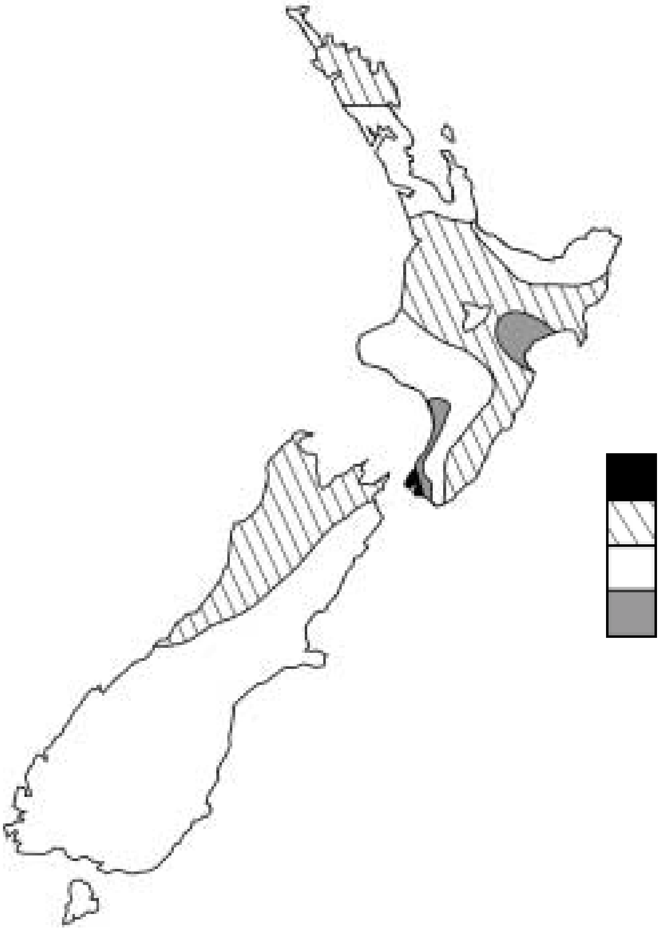
Infiltration calculation - Step 2 - adjustments for specific air leakage openings

A number of corrections can be applied to base level infiltration rates (Stoecklein and Bassett, 1999). These extend the method to deal with passive ventilators and defined leakage openings and are recorded here for completeness in Table 5 as follows:

Table 5: Corrections to base level infiltration rate applied for specific leakage openings.

Building feature to be allowed for in infiltration terms	Correction
Addition of passive ventilators to windows (40,000 mm^2)	Add 0.2 ac/h
Unused open fireplace	Add 0.1 ac/h
Solid fuel heater with flue restrictor	Add 0.05 ac/h
Large leakage area under door of 0.02 m^2	Add 0.1 ac/h
Old leaky windows replaced with gasket sealed windows	Subtract 0.2 ac/h
Internal strip lined walls relined with sheet materials	Subtract 0.1 ac/h

Infiltration calculation - Step 3 - Adjustment for regional location in New Zealand



Average infiltration rates can now be adjusted for climatic regions identified below in Figure 4 as shaded areas but representing only major centres of population. These can be corrected by multiplying the infiltration rate from Step 2 by the factor shown in the key:

Key to regions in Figure 4

1.3 Regional correction factors

1.1

1.0

0.9

Figure 4: Infiltration zones for residential buildings in New Zealand.

Infiltration calculation - Step 4 - Adjustment for local wind exposure

Finally, the infiltration rate must be corrected for local wind exposure according to the factors in Table 6 and Figure 5.

Table 6: Wind exposure descriptions and adjustments.

Local exposure description		**Multiplication factor**
Exposed	Rural setting with few surrounding trees and buildings	1.3
Semi-Exposed	Open urban residential setting	1.0
Semi-Sheltered	High density urban residential	0.7
Sheltered	Centre of a large city with surrounding taller buildings	0.5

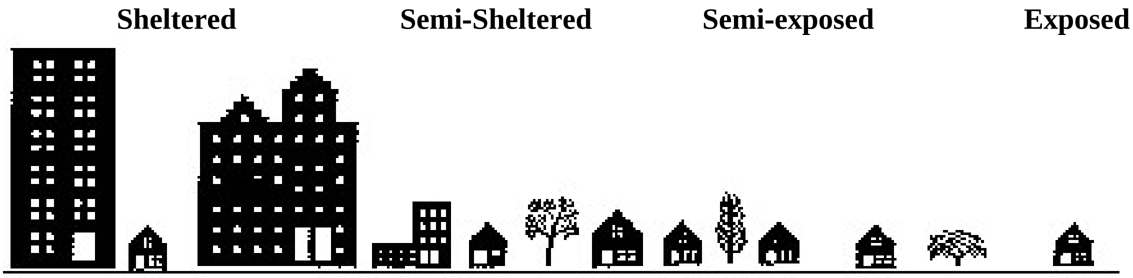


Figure 5: Wind exposure classes in relation to building density.

CONCLUSION

A simple procedure for estimating average air infiltration rates for residential buildings in New Zealand is proposed for use in thermal and moisture design and compliance verification tools. Tracer studies and airtightness measurements have been used to arrive at generalised wind pressure coefficients and leakage distributions in residential buildings which have then formed the basis of more generalised infiltration modelling. The simplified model developed assigns an airtightness classification to the building in question and then follows a path of correcting for obvious air leakage sites, the regional location of the building in New Zealand and local wind exposure. The next stage of the program will add the effects of passive ventilators and complete a simplified guide to designing and accounting for ventilation in New Zealand houses. This will draw on earlier studies of how contaminants disperse in homes and on field trials of window mounted passive ventilators.

ACKNOWLEDGEMENTS

This work was funded by the Building Research Levy and the Foundation for Research, Science and Technology. The assistance of Catherine Anderson from Queens University Belfast is gratefully acknowledged.

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