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Passive Ventilators in New Zealand Homes: Part 1 Numerical Studies and Part 2 Experimental Trials

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Synopsis

New Zealand homes have traditionally been ventilated through open windows and by background infiltration. In recent times, new materials and construction practices have led to more airtight buildings, and open windows are seen more and more as a security risk. These trends call for new ventilation options that are inexpensive and consistent with home security, weathertightness and draught control. This paper is part one of a study of passive ventilation options for NZ homes. It explores numerically a range of ventilator sizes and locations in typical homes modelled in the climate of major New Zealand cities. Part two offers experimental verification of the ventilator performance data calculated here.

A numerical multi-zone air flow model was used to calculate the effect of adding stack and window type passive vents to houses of a range of airtightness levels. Wind pressure was found to be the dominant driving force of air flows delivered by window-mounted passive ventilators. Stack ventilators reduced the strong dependence of window ventilator air flows on wind speed when both types were present in a building, but when the ventilation system made small changes to the overall airtightness of the house, the role of the stack ventilator was less obvious. A simple linear function linking ventilator opening area with average added ventilation rates is presented for wall-mounted passive ventilator systems in NZ buildings.

1. Background

In older homes in New Zealand, air infiltration alone has been sufficient to meet most ventilation needs [1] and the practice of opening windows may have been rarely necessary for critical contaminant control. The airtightness of New Zealand homes has, however, steadily changed [2] and those of more recent construction are more airtight than older houses; mainly because sheet interior linings which eliminate joints between materials, and more accurately gauged materials and fittings have become more widely used. Natural air infiltration will still provide useful ventilation, (particularly for larger more complex designs) but for more simple designs (often low cost housing [3] it is desirable to add a further 0.2-0.3 air changes per hour (ac/h) of secure and reliable background ventilation.

Ventilation provisions for new homes in NZ are now defined by Approved Document G4 of the New Zealand Building Code [4]. One acceptable solution to achieve this (G4/AS1) is to provide openable window areas of at least 5% of the floor area in each room. The aim of this work is to develop new ventilation solutions that are compatible with trends in the construction and occupancy of new homes.

2. Modelling passive ventilator performance

A numerical multi-zone airflow model developed by Walton [5] at the National Bureau of Standards was used to determine the marginal change to natural ventilation in New Zealand homes caused by adding passive ventilation openings. Air leakage and wind pressure coefficient datasets were developed for six buildings covering a range of airtightness levels seen in NZ houses. Each dataset corresponds to a real house and is based on measured airtightness and ventilation performance data. Agreement between measured and calculated natural ventilation rates in the living spaces of these houses has already been established in earlier work, with houses C,D and E in this study being the same houses as B,E and C in the earlier study of inter-zone leakage paths [6]. Figure 1 shows the spread in airtightness of houses A to F compared with the histogram of airtightness for houses constructed in New Zealand since 1960 [2].

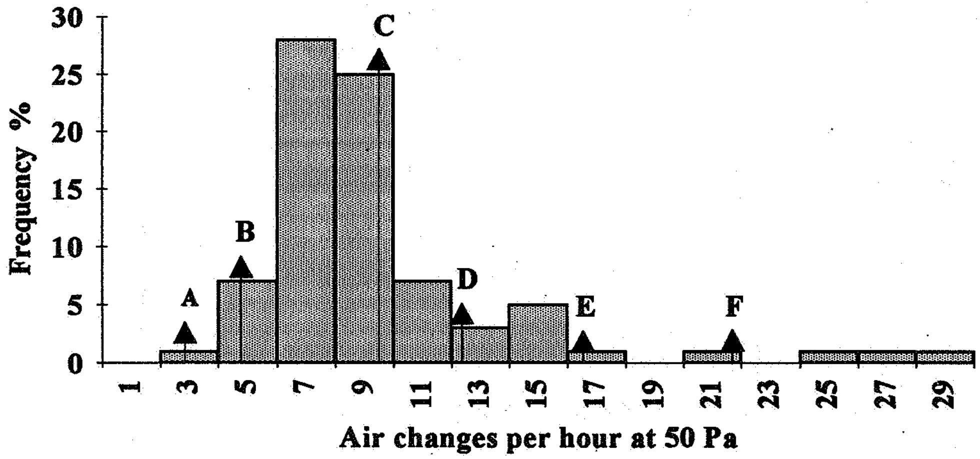

Figure 1: Airtightness of model houses compared with histogram of houses constructed since 1960.

3. Air leakage details of six model houses

The six residential buildings modelled in this study are labelled A - F. All had suspended floors but houses A, B, C and F were clad in lightweight timber or fibre cement materials with insignificant leakage paths directly linking subfloor and roof space zones. Houses D and E, on the other hand, were brick clad with large leakage paths through the wall cavity connecting subfloor with roof space zones. These two groups of houses were modelled in much the same way [6] but with an extra leakage path linking subfloor with roof space for houses D and E. Figure 2 gives the node diagram for house C.

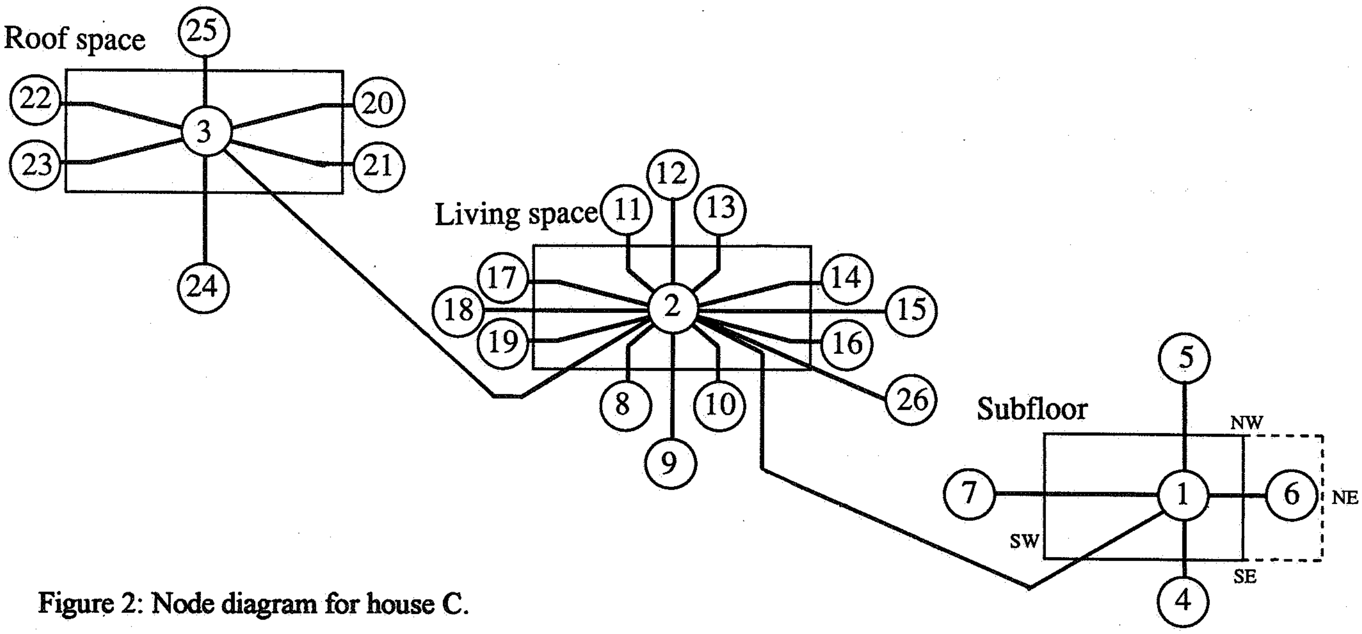

Figure 2: Node diagram for house C.

The basic geometry and airtightness characteristics for the 6 houses are given in Table 1, where N50 is the air leakage rate at 50 Pa expressed in air changes per hour, and the coefficient and exponent are those from the normal exponential equation linking air leakage rate Q with applied pressure ΔP.

$Q = C\ \Delta P^n$ where Q = Air leakage rate m^3/s
and ΔP = Pressure difference Pa

	House					
Factor	A	B	C	D	E	F
Floor area m^2	94	73	88	95	98	121
House volume m^3	255	175	210	229	234	276
Storeys one/two	one	one	one	one	one	two
Wind exposure	sheltered	sheltered	sheltered	sheltered	sheltered	sheltered
N50 ac/h	3.0	4.7	9.4	12.7	16.2	21.8
Coefficient C	0.0168	0.0174	0.0370	0.0522	0.0860	0.166
Exponent n	0.65	0.66	0.69	0.70	0.64	0.59

Table 1: Dimensions and airtightness characteristics of six example houses

Airtightness tests have given the overall leakage characteristics for each zone but have not located the specific leakage sites and their sizes over the building envelope. The distribution of leakage sites over the building and the wind pressure coefficients used, are described by Bassett [6].

4. Results of simulations

4.1 Natural infiltration in the example houses

The range of infiltration rates for houses A-E located in the Wellington winter climate is given in Figure 3. Here the median and quartile infiltration rates are calculated assuming medium heating (heating schedules indicated below) and plotted against the airtightness coefficient . The median and quartile have been chosen to represent the spread of the highly skewed distribution of natural infiltration rates. Houses A and B are the two most in need of added ventilation. Houses C,D, and E have median infiltration rates marginally less than 0.5 ac/h and house F is unlikely to need ventilation from any other source.

High heating - Indoor temperature at 20 °C at all times.
Medium heating - Indoor temperature floating 6 °C above outdoors with time lag and a minimum of 12 C°.
Low heating - Indoor temperature floating 6 °C above outdoors with time lag.

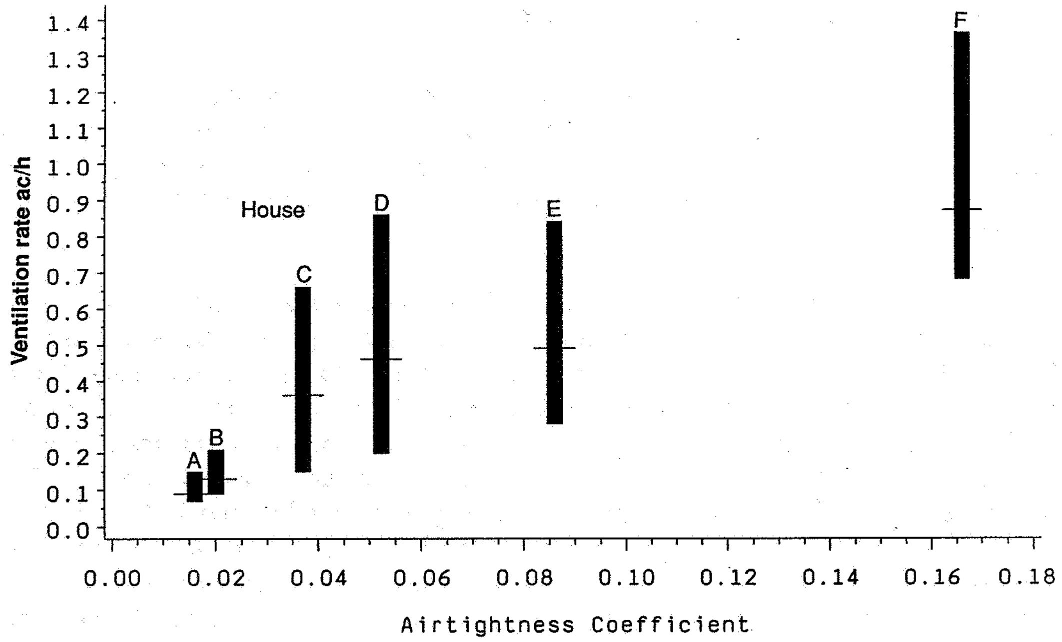

Figure 3: Median and Quartiles of hourly infiltration rates in houses A - F in the Wellington winter with a medium level of heating.

Turning now to the influence of indoor and outdoor climate. Figure 4 gives median and quartile infiltration rates plotted against winter heating degree days, for house C in the four climates and with High, Medium and Low levels of heating. The level of heating is clearly less important than location. Most of the location effect is considered to be a wind speed effect illustrated by the median infiltration rates increasing from Christchurch to Invercargill to Auckland to a high in Wellington in line with the same trend in mean wind speeds of 2.20, 2.22, 3.16 to 3.73 m/s respectively.

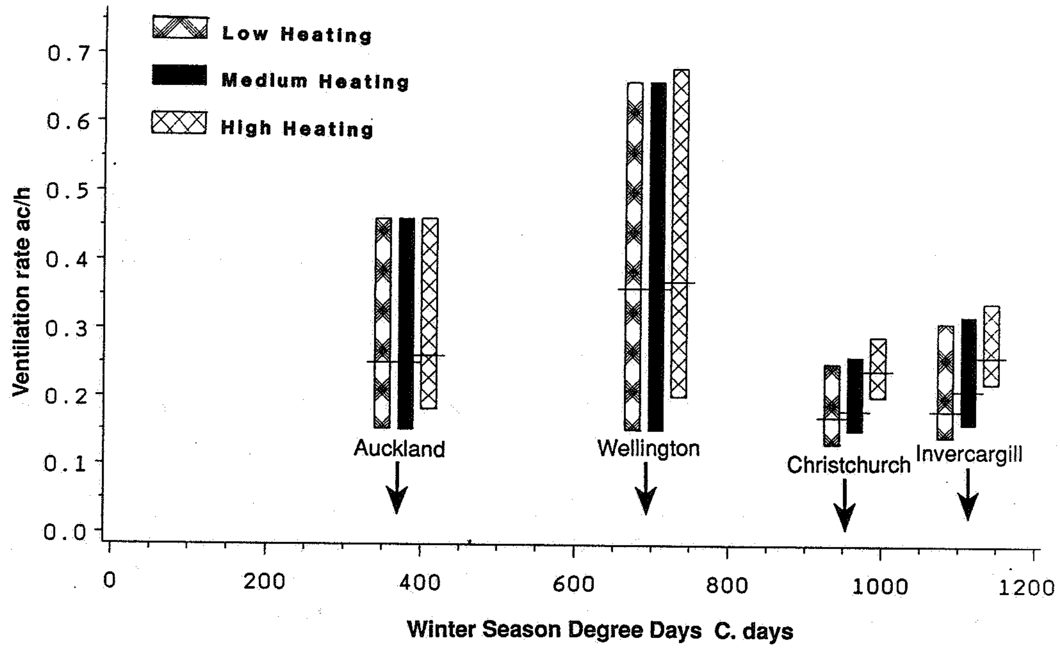

Figure 4: Median and Quartile ventilation rates for house C modelled in four climates and with three levels of heating.

4.2 Marginal changes attributed to ventilation openings

The marginal change in natural ventilation attributed to window ventilators and stack shafts has been determined for all six buildings in a matrix of climate, ventilator mix and ventilator size. Window vents were modelled as a single opening at mid stud height in proportion to wall area for each wall orientation, and stack ventilation was modelled as a single shaft from ceiling level to an external wind pressure coefficient of -0.15.

Adding three combinations of window and stack ventilators to house A in the Wellington climate changed both the range and median of the natural ventilation rate. Figure 5 shows the data plotted against the total building airtightness coefficient. Because the building has been modelled in the Wellington climate, the range of ventilation rates indicated here by the quartiles will be the extreme of the four available urban climates. Adding a single stack vent of increasing size has marginally increased the ventilation rate in the early stages but beyond this, the internal pressure has been dominated by the vent and the air pressure difference across the other leakage openings has changed no further with increasing vent size. An equal mix of vent type or window vents alone has increased the median ventilation rate in approximate proportion to the total house airtightness coefficient. As the effect of the ventilators begins to dominate the leakage openings in the house envelope, a significant difference between a window only and a mixed ventilation system emerges. The mixed system (equal window and stack vent size) achieves a more uniform ventilation rate than a window vents only system.

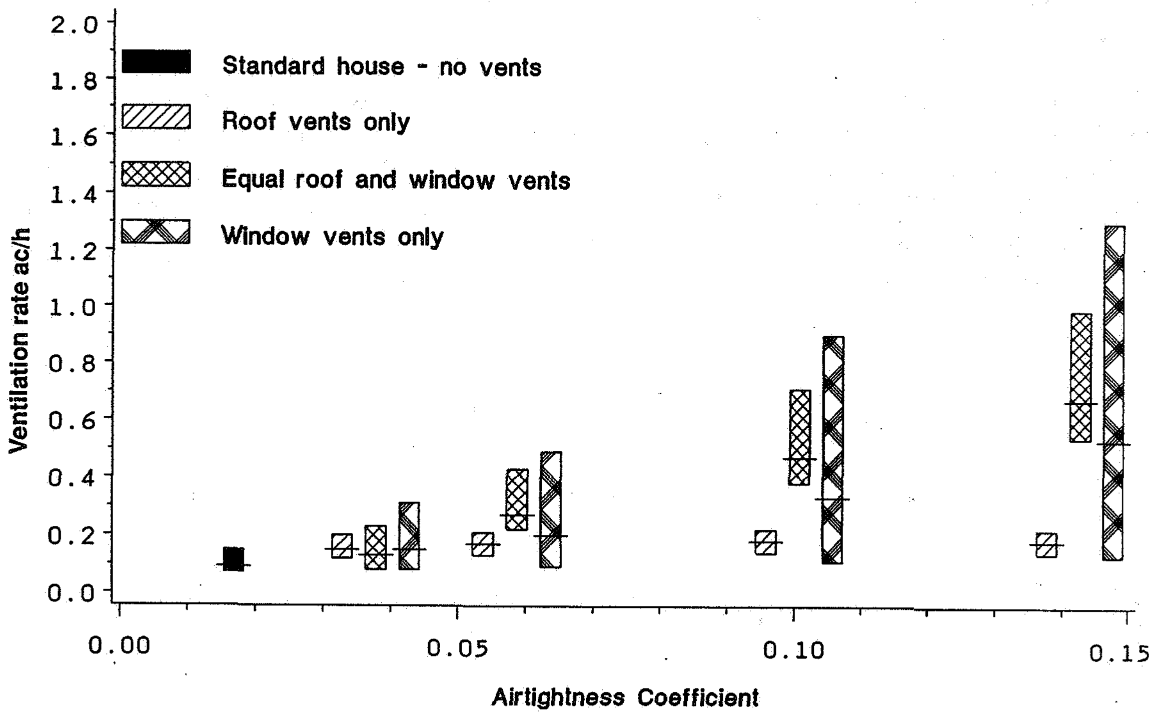

Figure 5: Ventilation rate trends in house A in the Wellington winter climate with increasing passive ventilator size.

For house C modelled in the Wellington climate and with the same ventilator options, a similar pattern emerges. Figure 6 shows that where a major change has been made in the building airtightness level with passive vents, then the spread of ventilation depends strongly on the mix of stack and window vents. For less extreme changes there is less difference between a mixed window and stack system and a window vents only system.

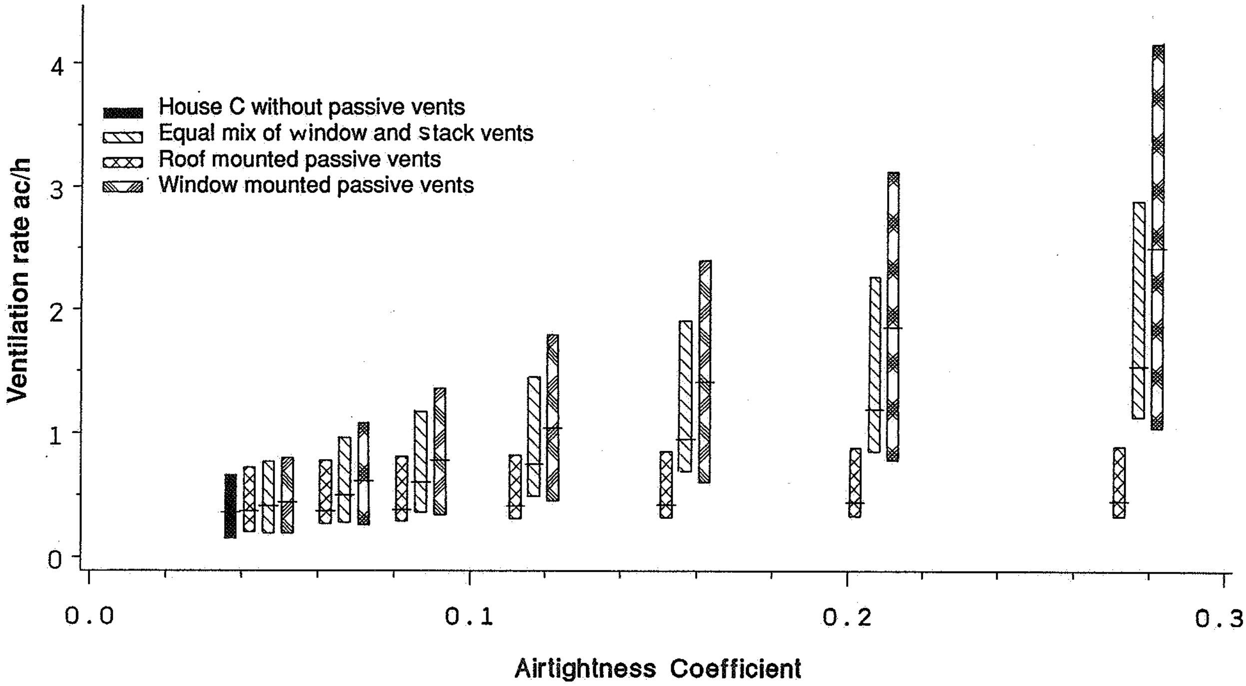

Figure 6: Changes to median and quartile natural ventilation rates in house C fitted with different ventilator options.

A more detailed look at the distribution of ventilation rates with the three ventilator mixes modelled in Figure 6 is given in Figures 7 and 8. In Figure 7 the effect of a relatively significant (100% or 0.03) change to the airtightness coefficient of house C is examined. Compared to the pattern of natural air infiltration calculated for the building, the addition of window vents and mixed vents has increased the frequency of ventilation rates above 0.5 ac/h at the expense of the lower ventilation rates. At times of low wind speed, stack driven airflows have provided ventilation rates of around 0.3 ac/h resulting in a more compact distribution of ventilation rates being delivered by the mixed stack and window vent system.

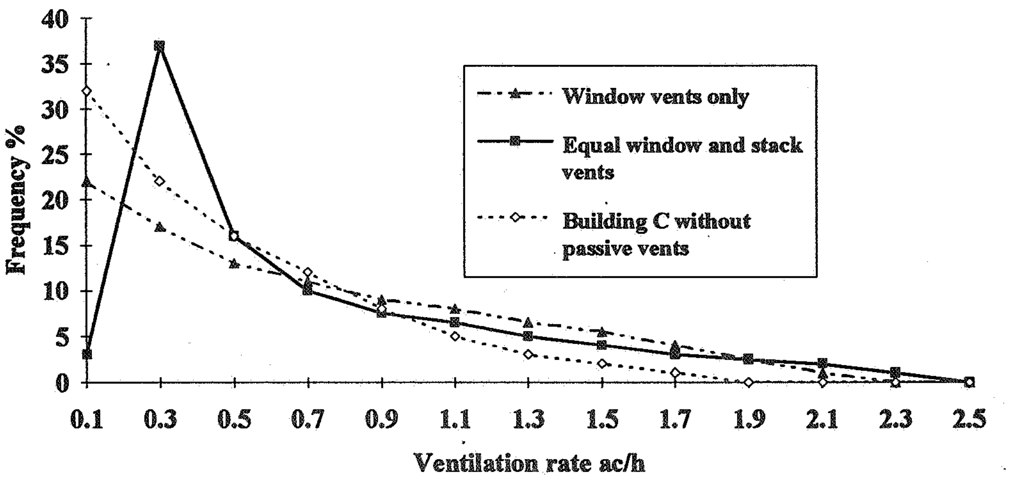

Figure 7: Distribution in hourly ventilation rates for house C without passive vents and with two different ventilator systems.

With larger vents in house C, (4.6 times the original airtightness coefficient, ie. 0.17) Figure 9 shows that the trends in Figure 7 have strengthened in this extreme case where the ventilation system dominates infiltration. Very low ventilation rates (less than 0.5 ac/h) were essentially shifted into the 0.5 - 1.0 ac/h range by the combined window and stack system. Very high ventilation rates driven by high wind speeds are also less common with the mixed arrangement of ventilators.

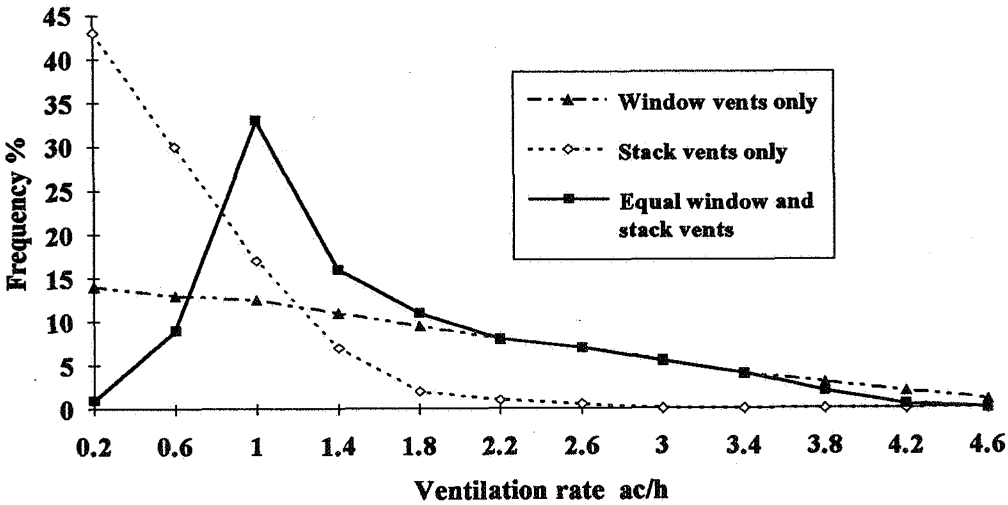

Figure 8: Distribution of ventilation rates in house C with three ventilation strategies contributing to an overall airtightness coefficient of 0.17.

4.4 Generalised guidance on ventilator sizes

Although the detailed performance of a ventilator system will depend on a large number of factors such as building geometry, location and wind exposure, an indication of the likely effect of the following two most promising passive ventilator configurations in common house types can be determined.

1. Window ventilators distributed around the building pro-rata with wall area.
2. An equal mix of window and stack ventilators.

A further series of simulations has been completed for each of these two ventilation strategies applied to houses A,C,E and F located in each of the four city climates and with typical urban sheltered exposure to wind (tracer gas measurements of air infiltration rates in houses has shown that most houses in urban subdivisions can be described with the sheltered level of wind exposure [6]). The marginal change in the average natural ventilation rate was determined for changes in building airtightness coefficient in the range 0.03 to 0.1. An example of the effect of this is given in Figures 9 and 10 for a 0.05 change in overall building airtightness coefficient. In Figure 9 the marginal increase in the average ventilation rate is averaged over the four houses and plotted against mean wind speed. In Figure 10 the ventilation rate data is climate averaged and plotted against the building (before addition of passive vents) airtightness coefficient.

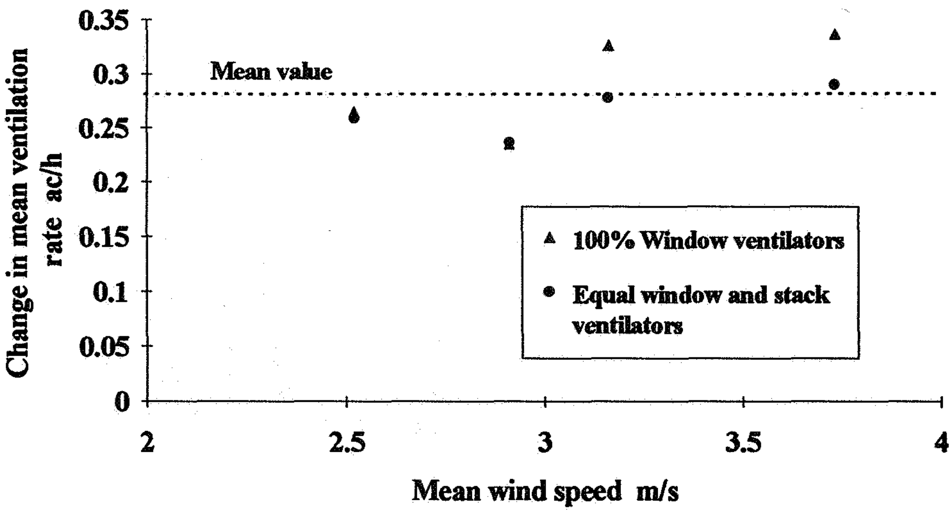

Figure 9: Marginal changes in the average ventilation rate in houses A,C,E and F modelled in four city climates and plotted as a building average against mean wind speed.

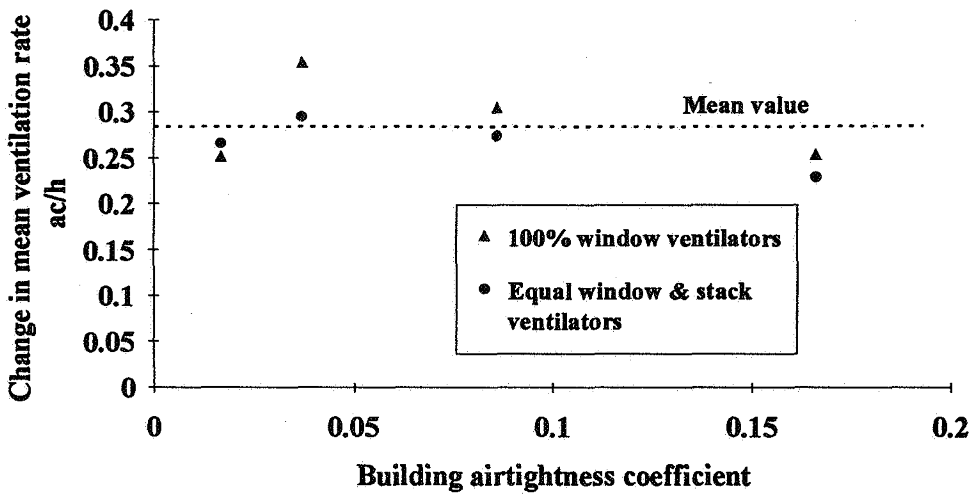

Figure 10: Marginal changes in the average ventilation rate in buildings A,C,E and F modelled in four city climates and plotted (climate averaged) against building airtightness coefficient.

The average marginal changes to the ventilation rate (building and climate averaged) have then been plotted in Figure 11 against the airtightness coefficient of the ventilator system.

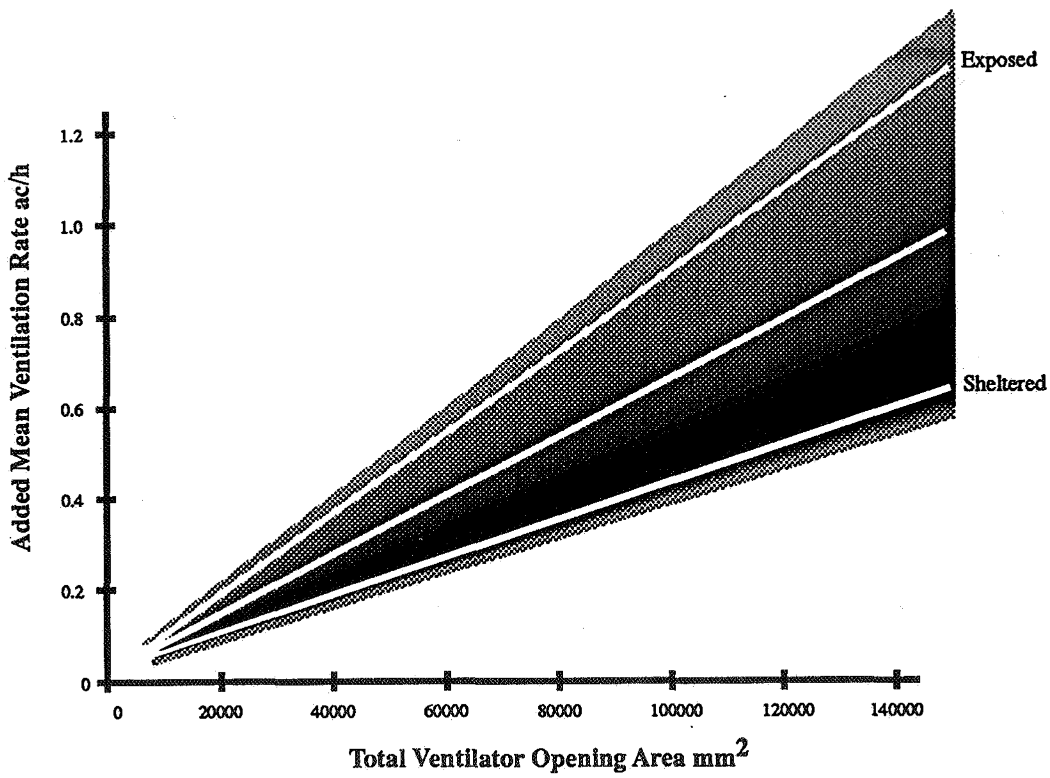

Figure 11: Average change in ventilation rate as a function of ventilator airtightness coefficient for a limited range of climate and building variables.

Figure 11 gives an indication of the average change in natural ventilation that can be expected from the addition of window ventilators or an equal mix of window and stack vents. A band has also been included to indicate the ranges appropriate to most buildings in urban sheltered locations (shown in dark shading) and for less common exposed locations (shown in lighter shading). These data are based on limited simulation of four buildings in four New Zealand city climates and experimental support for these conclusions is given in part two [7] of this paper. Earlier in this paper it was indicated that approximately 0.2 - 0.3 ac/h of additional ventilation would usefully boost natural ventilation in the more airtight types of homes to closer to the 0.5 ac/h level recommended for adequate indoor air quality. The addition of 0.2 ac/h would require passive ventilation with an area of 40,000 - 60,000 mm². This is comparable with the (DoE, 1990) requirements [8] which define passive ventilator sizes to provide background ventilation in habitable rooms in the UK. Trickle ventilators must have an open area of not less than 4,000 mm² in each room.

5. Conclusions - passive ventilators for NZ homes

A numerical study of the performance of passive ventilation systems in New Zealand homes has been completed. This simulated the performance of a variety of window and stack ventilator configurations in six houses sited in four New Zealand city climates. Changes to average ventilation rates and to the distribution of hourly ventilation rates were examined and the following conclusions drawn:

1. Air flow rates through passive vents in typical New Zealand building and climate combinations were shown to be primarily wind driven. The time averaged performance of ventilator systems containing stack components were little different from window only systems unless the ventilation system made large changes to the airtightness of the building.

2. The average ventilation rates delivered by passive systems containing a mix of stack and window ventilators were comparatively insensitive to indoor temperatures. A single stack ventilator on its own made little change to average ventilation rates in the four example houses, even when this dominated the airtightness of the house.

3. The distribution of hourly ventilation rates depended on the proportions of stack and window ventilators. Mixed window and stack ventilation systems came the closest to delivering an ideal (0.5 to 1.0 ac/h) distribution of hourly ventilation rates, particularly when added to the more airtight house types.

4. When the passive ventilation system made a small change to the airtightness of the house, the difference between mixed stack and window vent systems and window only vent systems was small. This would generally be the case unless the house is particularly airtight.

5. An approximate window ventilator sizing guide has been proposed consisting of a linear relationship between the ventilation rate added to a house and the airtightness coefficient of the ventilation system.

A further report [7] describes the measurements of air flows delivered in a number of passive ventilated houses as verification of the results calculated here. There are additional considerations such as acoustic isolation and possible effects of passive vents in fire still to consider.

6. References

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