A SURVEY OF AIRTIGHTNESS AND VENTILATION RATES IN POST 1994 NZ HOMES

S. McNeil[1], L. Quaglia[1], M. Bassett[1], G. Overton[1], M. Plagmann[1]

1 BRANZ
1222 Moonshine Road, Porirua, New Zealand
Corresponding author: steve.mcneil@branz.co.nz

ABSTRACT

The airtightness of 36 houses built since 1995 and across four cities in New Zealand (NZ) was measured. In a subset of 31 of these homes, the average ventilation rate was measured over several weeks in the winter using a perfluorocarbon tracer technique (PFT). These results can be added to earlier airtightness data to provide a platform for improving the air quality and energy efficiency of residential ventilation in NZ.

Earlier airtightness data from the mid 1990's showed a trend for newer houses to be more airtight than older houses, largely as a result of sheet lining materials replacing strip flooring and the development of more airtight joinery. This trend continued in this study, even though there are no airtightness requirements for houses in New Zealand. The average N_{50} result for houses built since 1995 was 6.7 air changes/hour (ACH), down from 8.5 ACH for houses built in the previous decade.

Most new houses meet NZ building code requirements for ventilation (window and door openings that exceed 5% of the floor area), but the PFT measurements showed that most houses struggled to reach recommended levels of ventilation (0.35-0.5 ACH during the winter) because the windows weren't open often enough.

In recent years it has become common for occupants to add additional supply-only ventilation to control moisture. Houses with operational supply-only ventilation systems generally had more than enough ventilation but there were several cases where the ventilation system had been turned off.

There was clear evidence of moisture problems in several of the more poorly ventilated houses.

KEYWORDS
Airtightness, Ventilation, Residential, Tracer

1 INTRODUCTION

The aim of this study was to provide airtightness data for newer (post 1994) houses and to measure the achieved ventilation rate during occupancy. The measurements should provide some insight as to whether a ventilation scheme that relies on occupants to open windows can be relied on, or whether factors such as wintertime, security and noise intrusion prevent this from being so.

Earlier work at BRANZ [1, 2, 3] compiled an airtightness database of 137 homes built from the 1930's to the mid 1990's. A summary of this is shown in Figure 1.

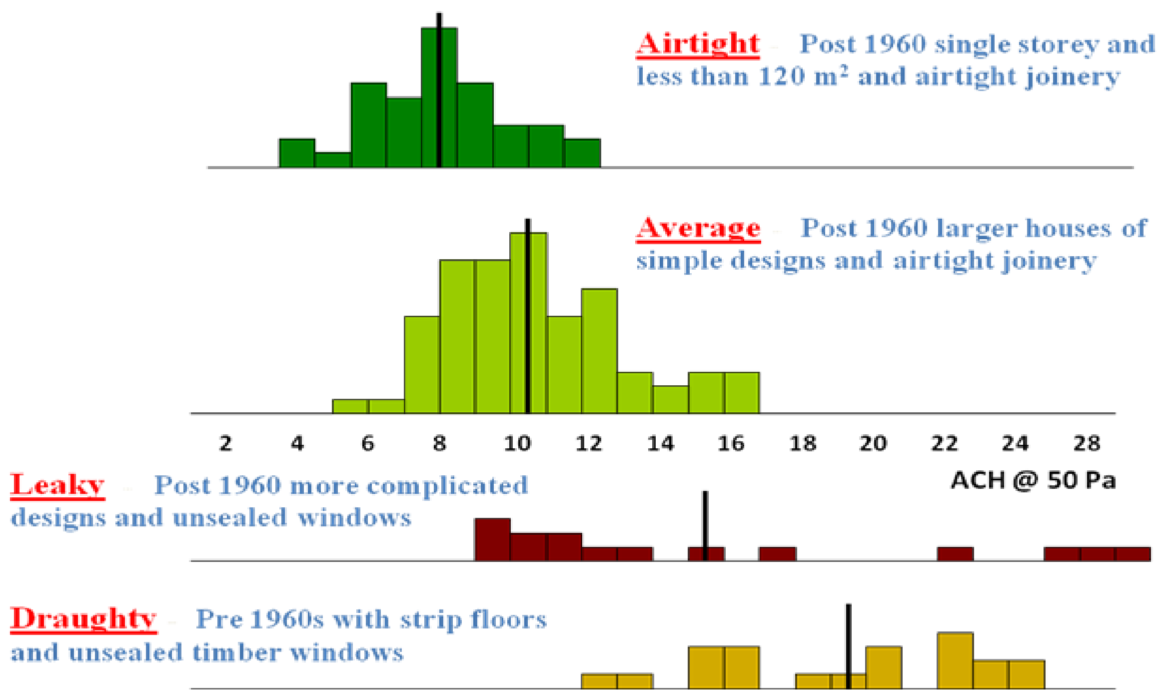

Figure 1 – Summary of earlier house airtightness in New Zealand

The airtightness of New Zealand homes has increased over time, even though there is no requirement for airtightness in the NZ building code. The average N_{50} result from houses built before WWII was around 19 ACH but this reduced dramatically to 8.5 ACH for houses built between 1960 and 1980. A significant contributor to envelope air-tightening around 1960 was the shift from suspended tongue and groove flooring to sheet floor construction and slab-on-ground floors. Another change at a similar time was the shift from timber joinery to aluminium framed doors and windows, as well as a reduction of open fireplaces. This brought the opportunity to fit better air seals around opening windows and doors, at the same time improving the weathertight performance of domestic joinery. By the mid 1990's the mean airtightness result was 6.7 ACH.

In the USA, Sherman [4] reported a similar two-fold reduction in average N_{50} measurements over a similar time period. In this case the changes were largely voluntary but were also influenced by the 'weatherization programme' to improve the energy efficiency of low income homes. In contrast, Stephen [5] reports little change in the N_{50} measurements in UK houses over a similar period. Much more dramatic changes in N_{50} are reported in Canada and Sweden where mandatory airtightness targets were adopted to reduce the energy loss consequences of uncontrolled ventilation. A second driver of airtight construction in these cold climates is the need to control exfiltration to prevent interstitial condensation.

In NZ, materials and construction practices are likely to have continued to influence the airtightness of houses. Recent examples of changes are the widespread use of bonded plaster cornice or a square stopped interior plaster finish, and the adoption of air seals around window and door assemblies. In 2005, the NZ Building Code - Clause E2/AS1[6], changed to require air seals to be fitted around door and window assemblies. The aim was to improve the degree of pressure moderation across the joints between window frame and cladding and improve the weathertightness of what was seen as a weak point in window installation.

In terms of ventilation, building code requirements for residential buildings are often quite unsophisticated in countries with temperate climates. In New Zealand, occupants are expected to open windows for ventilation and the NZ Building Code offers an acceptable solution 'G4 Ventilation'[7] requiring window and door openings to be at least 5% of the floor area. It is clear from the airtightness measurements of older houses that window opening may have been unnecessary to meet ventilation needs because of the background infiltration. In newer houses, the changes in construction discussed above have closed down natural ventilation paths and it may be necessary to actually open the windows to provide adequate fresh air.

Ventilation also has a large part to play in the control of indoor moisture. Indoor moisture has always been the most pressing indoor air quality issue in New Zealand houses. A 1971 survey [8] reported moisture problems in half of the surveyed houses and later surveys [9,10] have shown that little has changed.

In the past it has been difficult to measure ventilation rates in homes because conventional tracer methods were too intrusive and expensive to use in large numbers of houses. This study used passive samplers and emitters that are more easily deployed [11,12] and to provide the first survey of ventilation achieved in NZ homes.

The study described here will help to provide a picture of the current housing stock and how New Zealander's currently ventilate their houses. This information will then be used in the wider WAVE (Weathertightness, Air Quality and Ventilation Engineering) programme at BRANZ. One of the aims of WAVE is to provide guidance on suitable ventilation options that are optimised for moisture control, energy efficiency and the airtightness of the house.

2 EXPERIMENTAL METHODS

2.1 SELECTION OF HOUSES

The airtightness and ventilation survey was split across 4 different cities in New Zealand: Wellington; Palmerston North; Dunedin; and Auckland. A database of building consents was used to obtain a random sample of consents for houses built after 1994 and these homeowners were contacted via a letter, resulting in a final total of 36 houses.

Of these 36 houses, 8 had supply-only positive pressure ventilation systems installed in the roof space. These systems distribute filtered roofspace air throughout the home depending on temperature measurements in the living space and roofspace.

2.2 AIRTIGHTNESS MEASUREMENTS

A blower door test to EN13829[13] was completed on each of the 36 houses and then the opportunity was taken to measure the contribution of a range of different leakage paths. This was carried out by progressively sealing up openings in the envelope and repeating the blower door test.

In general, the following 3 tests were completed on each dwelling:

- A standard N_{50} test with no openings sealed
- A test with specific ventilation openings sealed. In most cases these ventilation openings consisted of extract fans in bathrooms and kitchens, some of which were simply ducted to the roof space (not outside).
- A final test with all obvious leakage openings sealed. The most obvious leakage openings to be sealed were around internal garage doors, and defective seals around attic access hatches.

The airtightness measurements were also used to give an estimate of the infiltration through the envelope using Equation 1.

$$Estimated\ Infiltration\ Rate = \frac{N_{50}\ result}{20} \qquad \text{Equation 1}$$

2.3 VENTILATION MEASUREMENTS

Ventilation measurements were performed in 31 of the 36 houses during winter. Winter was chosen because it was perceived that ventilation would be at its lowest i.e. windows are open less often.

A Perfluorocarbon Tracer (PFT) technique[12] was used and the equipment and analysis was supplied by the UK's Building Research Establishment (BRE). The technique involves deploying passive tracer gas sources and activated carbon sampling tubes in a building for a period of time. The resultant concentration of tracer in the sampling tubes can then be used to calculate an average ventilation rate.

Plans for each house were obtained to allow the room volumes to be pre-calculated. Key dimensions were measured upon arrival to ensure the plans matched the building and any differences were marked on the plans and the locations of sources and samplers modified accordingly.

The tracer sources were distributed around the home in a volume weighted manner, with the bathroom being chosen as a reference volume in all cases. Figure 2 shows a typical floor plan with tracer sources marked in red, and sampling tubes in blue.

Sampling tubes were placed in 4 rooms in each house, typically the lounge, bathroom, kitchen, and master bedroom. These were left in place for at least three weeks, but sometimes this was as long as 4 weeks because of occupants' unavailability. There were several important considerations when it came to the location of the source and sampling tubes:

- Source and sampling tubes need a good degree of separation to ensure the sampler collects tracer that has been well mixed in the zone.

- Both sources and sampling tubes needed to be located as far as practicable from windows/doors to allow incoming air to mix within the zone.

- Temperature has a direct influence on the emission rate; the sources should not be in direct sunlight or within 1.5 metres of heat sources. The temperature was also measured at each source location using Dallas DS1923 iButtons.

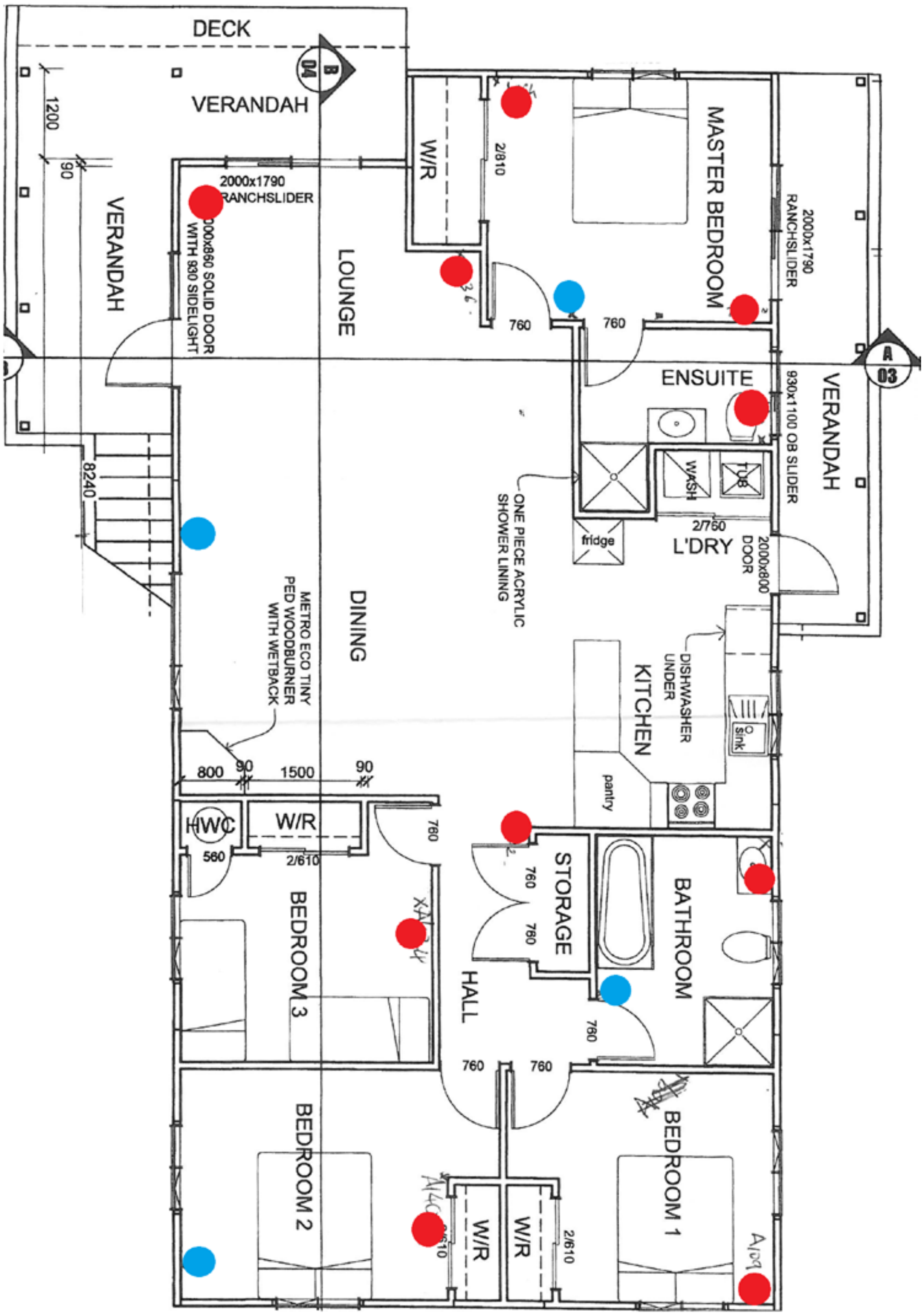

Figure 2 – Typical distribution of tracer sources and sampling tubes

3 RESULTS

3.1 AIRTIGHTNESS

The N_{50} results for the 36 houses are shown in Figure 3. Figure 4 shows the effect from sealing ventilation and obvious leakage openings (final test).

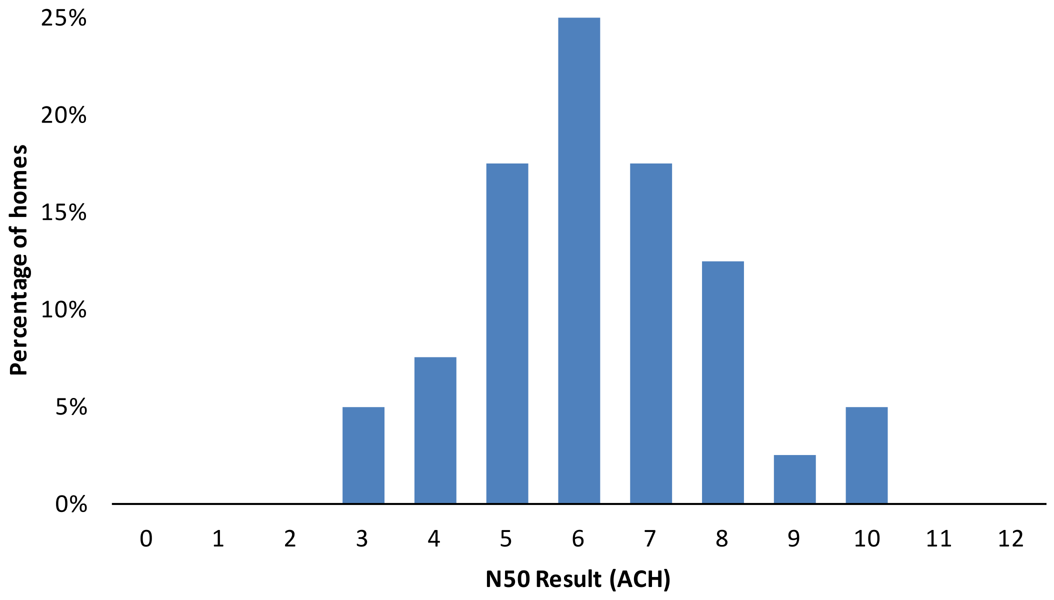

Figure 3 - Distribution of airtightness measurements for post 1994 homes

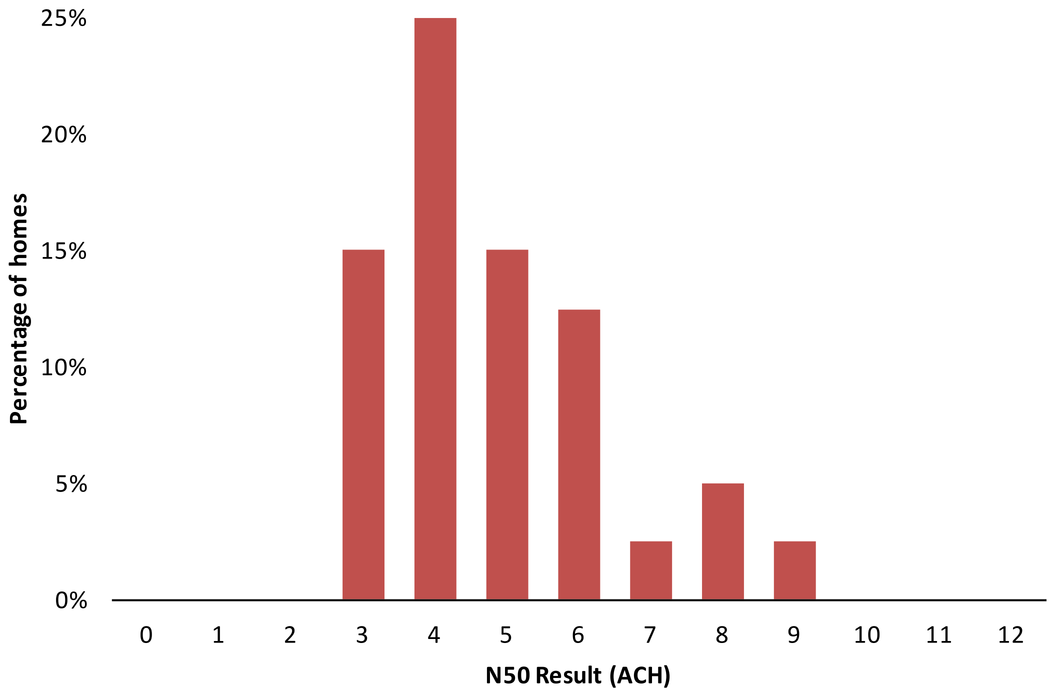

Figure 4 - Distribution of airtightness results, with specific ventilation and obvious leakage openings sealed

3.2 VENTILATION SURVEY

The results of the ventilation survey are plotted in Figure 5, against the estimated rate from the airtightness measurements (using Equation 1). Circled on the right are several outliers, three of which had a supply only roofspace sourced ventilation system. A line of slope 1 is also plotted.

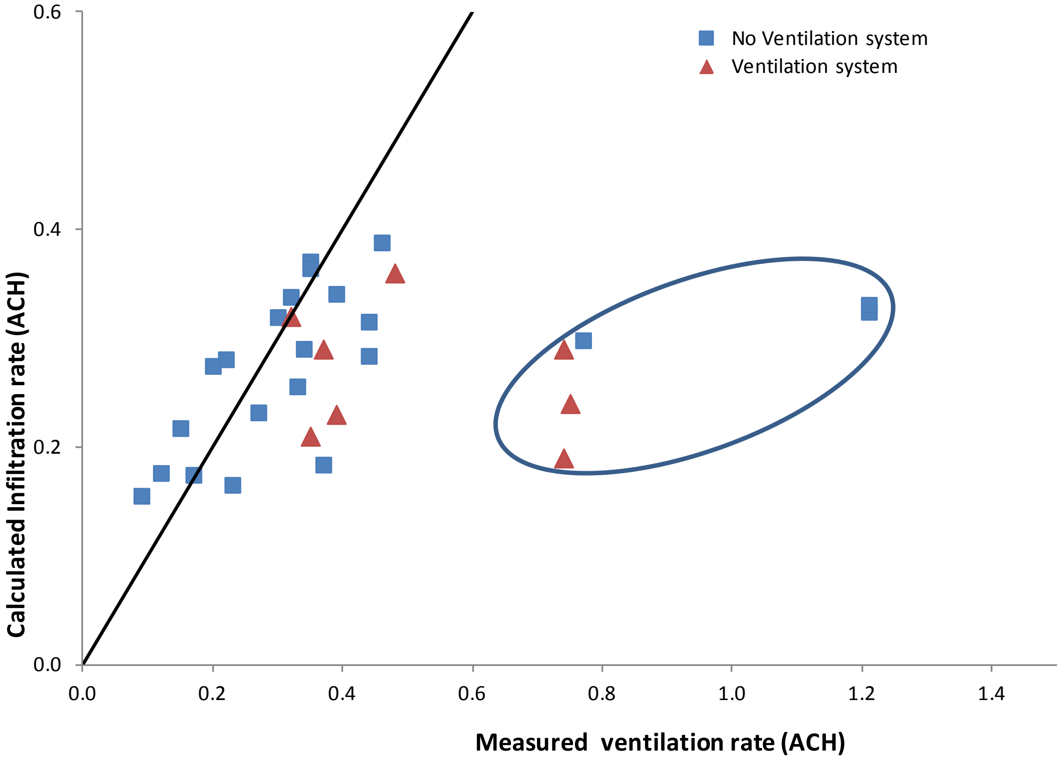

Figure 5 - Infiltration vs. measured ventilation (ACH), with outliers circled

4 DISCUSSION

4.1 AIRTIGHTNESS

The most important change from the earlier surveys was the significant reduction in the mean N_{50} result from 8.5 ACH to 6.7 ACH. The floor area of the newer houses was also bigger than those in the last survey, increasing from $115m^2$ to $155m^2$ (and not including internal access garages). The recent N_{50} results also fell in a much tighter range (7.8 to 3.1 ACH), suggesting more consistency in construction.

Much of the difference between Figures 3 and 4 was due to the leakage under internal access garage doors. On average, a drop in the N_{50} result of 1.4 ACH was noted when the internal access for the garage spaces was sealed from the rest of the house.

Internal garage doors therefore present an opportunity for increasing airtightness, and reducing infiltration from an unheated (and potentially polluting) part of the building.

4.2 VENTILATION SURVEY

There are clearly two groups of houses in Figure 5: those where the estimated infiltration rate and the measured ventilation rate are similar (25 cases) and those (6 cases) where additional ventilation (either from opening windows or supply-only ventilation systems) has been provided.

In the larger group, the small difference between the estimated infiltration rate (0.28 ACH) and the measured ventilation rate (0.32 ACH) indicates limited window opening by the occupants over the period. The measured ventilation rate of 0.32 ACH sits at the lower end of guidelines for acceptable indoor air quality [14]. In addition, observations of the presence of mould and mildew were made at several of the homes studied, evidence of excess indoor moisture.

The PFT technique is a longer-term, time-averaged measurement method and thus does not lend itself well to resolving small, short-term changes in ventilation performance. However, it is clear that window opening and the operation of extract systems in bathrooms and kitchens has added less than 0.2 ACH on top of the background air infiltration in most of these houses.

Overall, there is limited evidence of window opening providing the ventilation needed to control moisture and provide good indoor air quality in the more airtight homes constructed in the last 15 years.

Eight homes in Figure 5 were fitted with supply only ventilation systems. Three of these systems were shown to substantially increase ventilation above background infiltration to around 0.7 ACH. In the other 5 cases, little additional ventilation was provided by systems, several of which were apparently turned off to save energy during the period of PFT measurements.

5 CONCLUSIONS

This paper reports the results of a survey of house airtightness in New Zealand along with average ventilation rates measured using the PFT method. The conclusions of this study are as follows:

- **The airtightness of New Zealand homes continues to increase**. The average airtightness of houses built between 1994 and 2011 in this survey was an N_{50} of 6.7 ACH. Between 1960 and 1994 the average N_{50} was 9.7 ACH, dropping to 8.5 ACH for houses built in the early 90's. For even earlier houses it was 19 ACH at 50 Pa. This change has occurred without any intervention by the New Zealand Building Code.
- **Internal access garages have a large impact on airtightness**. The door into the garage was found to be a weak point in the envelope, contributing an average 1.4 ACH to the N_{50} result. A more effective door in this location would reduce the infiltration of potentially contaminated air from this unheated zone in the building.
- **Measured ventilation rates are similar to estimated infiltration in many houses**. Comparing the average infiltration (approximated as the N_{50} result divided by 20) and measured ventilation rates, resolves the ventilation added by small kitchen and bathroom ventilators and by opening windows. In 24 of the 30 cases the average infiltration rate of houses without mechanical ventilators is 0.28 ACH and the measured ventilation rate 0.32 ACH and in several of these houses indoor dampness was evident. In the six cases where infiltration had clearly been supplemented with additional

ventilation, three of these were fitted with a supply ventilation system and in the other three this was achieved by opening windows.
- **Reliance on open windows for ventilation may not be adequate** This passive ventilation solution appears to have worked adequately at times when New Zealand homes were not particularly airtight. Since 1960, a wider choice of large sheet lining materials and changes in the standard of interior finish have increased the airtightness to the point where window opening is now questioned as a ventilation source for moisture control and indoor air quality. Particularly with modern lifestyles, and when there are security concerns.
- **The control algorithms for supply only ventilation systems may have scope for improvement**. Eight homes were fitted with roof-space sourced supply only ventilation systems that distribute filtered roof-space air under a simple temperature controlled regime. Three of these boosted the average ventilation well above the background infiltration but in five cases there was little evident change. The data indicates significant differences in the operation and control of these supply only systems.

This work has provided a platform on which to discuss ventilation options for New Zealand housing. The survey has shown that the trend to more airtight houses has continued in the last decade and that that occupant controlled ventilation by opening windows is limited and too unreliable for indoor moisture control. The next steps in the WAVE programme will investigate alternative ventilation solutions that adapt to window opening in a temperate climate and are optimised for indoor moisture control [15].

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