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House Airtightness Variation with Age

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SUMMARY - This paper focuses on changes to the air tightness of houses in the first year after construction. Monthly blower door results for 7 houses are presented and the seasonal and longer term effects compared with equivalent measurements in a variety of overseas climates. The picture that emerges is of small airtightness changes in stable coastal climates and larger seasonal swings where the summer to winter temperature differences are more extreme. There are some exceptions in the New Zealand data, however, that could be attributed to water leaks in the roofs of two houses..

1. AIR INFILTRATION AND HOUSE VENTILATION

The airtightness of housing has been studied because background air leakage can contribute to ventilation, and hence to building energy efficiency and indoor air quality. There have been considerable changes in building materials and construction methods over the years, and the background ventilation provided by air infiltration has been shown by Bassett (1992) to have generally declined. This has provided the motivation to design and build ventilation systems that more accurately cater for energy efficiency and indoor air quality.

There are no targets for house airtightness in NZ building codes, and yet when windows are kept closed for security or sound isolation reasons, air infiltration will be the sole provider of ventilation. Indoor air quality codes; for example NZS 4303:1990 Ventilation for acceptable indoor air quality, call for a basic level of ventilation of around 0.5 ac/h (air changes per hour) and it can be argued that this should be an aspect of house performance; like weathertightness and structural integrity, rather than an aspect of house management. Then, indoor air quality needs would not depend on user controlled ventilation. Variation in the airtightness of houses with age and building type, becomes an important part of studies leading to an adequate base level of ventilation that is independent of the occupier. This paper focuses on changes in building airtightness following construction.

1.1 House airtightness measurements

The air leakage characteristics of houses can be measured with a blower door as illustrated in Figure 1. This device lowers the indoor air pressure slightly, with a fan extracting a measured air flow from the building. The airtightness result that is most often quoted is the air leakage rate at an international standard pressure of 50 Pa expressed as volume air changes per hour ac/h. Typically these air leakage rates are around 20 times the leakage rate driven by normal wind and stack pressures, and therefore not directly indicative of natural infiltration. Rather, they are a property of the building alone, that can be referenced to building code requirements for house air leakage performance if they exist, or used in comparisons of buildings of different types, age or location around the world.

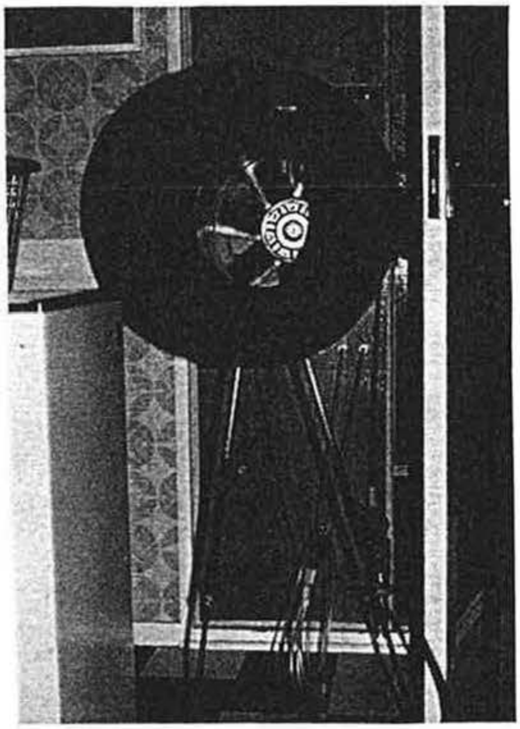

Figure 1 Blower door for measuring building airtightness

The airtightness of mid 1980's houses in three main urban areas; Auckland, Wellington and Christchurch has been sampled by Synergy (1986) and Bassett (1985). No significant regional differences in house airtightness were found, so the data was combined to give the national average data shown in Figure 2. For houses built after 1980, 93% had 50 Pa air change rates between 5-16 ac/h. At the time, this indicated houses were more airtight than expected, and tempered arguments in favour of making houses more airtight to save energy.

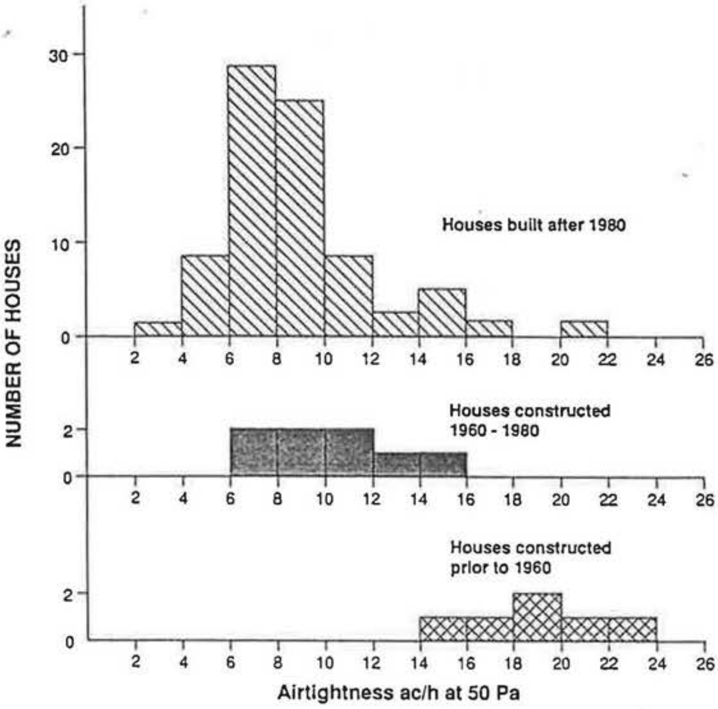

Figure 2 Airtightness of New Zealand houses measured at 50 Pa

Only a small group of six pre-1960 houses have been airtightness tested in NZ. While this is too small a number to properly define the characteristics of houses this age, the data in Figure 2 shows that houses with strip interior lining (match lining wall panelling, and tongue and groove flooring) are likely to be less airtight than more recent houses lined with sheet materials (particle board flooring and paper sheathed plaster board walls and ceilings). Detailed studies by Bassett (1987) have shown that the interior lining has more control over building airtightness than external claddings, so it is not surprising that building materials that reduce the number of joints internally, lead to more airtight construction.

2.0 AIRTIGHTNESS CHANGES AFTER CONSTRUCTION

There are several ways in which the airtightness of timber framed buildings might be expected to change soon after completion. As construction moisture dries out and foundations settle, the building may become steadily less airtight. Superimposed on this, may be a cyclic change caused by seasonal fluctuations in the moisture content of the materials. Several studies have measured airtightness changes in houses and shown that there are considerable differences between locations and house types. Kim and Shaw (1984) found a 20% seasonal swing in the air leakage rate at 50 Pa of two Canadian houses. They found higher air leakage in the winter when indoor and outdoor atmospheric moisture concentrations were at their lowest. In Sweden, Elmroth and Logdberg (1980) measured a 70% increase in the air leakage rate at 50 Pa of five houses during the first year they were occupied. In another Swedish study, Carlsson and Kronvall (1984) found no significant change in fifteen timber framed houses, re-measured 1 to 4 years after construction. In the UK, Warren and Webb (1980) found evidence of a 40% increase in air leakage in one house during the winter, and an 83% increase in the airtightness of three other houses one year after construction. In the USA, Persily (1982) measured a 22% seasonal swing in the BRAT test house with higher leakage in the winter. Also in the USA, Harrje et al (1983) found minimal changes in two test homes in Maryland in a series of year round airtightness tests. More recently, Dickinson and Feustel (1986) looked for seasonal airtightness variations in three sets of houses in widely differing US climates. They found the largest seasonal swings (12% to 34%) in Truckee, CA, in the Sierra Nevada mountains. Unlike the Canadian study of Kim and Shaw (1984) they found the lowest leakage rates coincided with winter. In the San Francisco Bay area where seasonal differences are less marked, the airtightness of three houses remained constant within experimental error. The data discussed above does not clearly indicate if the airtightness of New Zealand houses should change seasonally or in the longer term.

2.1 Relative Humidities in New Zealand

Since most NZ houses are located in low lying coastal regions where the atmospheric relative humidity remains relatively constant, this might suggest small seasonal airtightness changes. Figure 3 gives the relative humidity for three centres of population; Auckland in the north of the country, Lower Hutt in the central region where the test houses of this study were located, and Invercargill in the south. The data was provided by the NZ Meteorological Service (1985). Looked at in isolation of other effects, these relative humidity changes would drive small timber moisture content changes within the range of 15-20%.

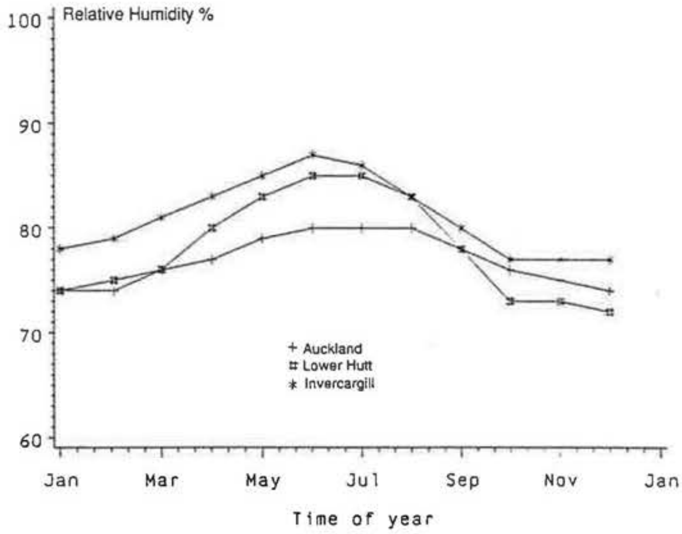

Figure 3 Monthly mean outdoor relative humidities in three locations

Relative humidities (RH) in the living space and construction cavities of houses are usually very different to that of the outdoor air. Ground-water evaporation and heat retention in the soil will have a controlling effect on the RH of the subfloor air. In the roof space, high summer temperatures can reduce framing timber moisture contents with consequential RH changes. These effects have been modelled by Cunningham (1984) and supported with field evidence by Trethowen (1988a and 1988b. The RH in the living space has also been shown by Trethowen (1976) to be heavily influenced by moisture released indoors and to be buffered against outdoor swings in RH by moisture in the framing and linings. Because the plane of highest leakage resistance in NZ houses has been shown by Bassett (1987) to be located at the interior lining, it is not unreasonable to expect that indoor RH will have more influence on airtightness than the outdoor RH. The common lining materials in New Zealand houses are gypsum plaster board and particle board and these are known to be at least as dimensionally stable as Pinus radiata framing timber in the longitudinal direction. In all, there are effects that might result in seasonal building airtightness swings and others that might indicate stability. Because it is not possible to estimate the effect that moisture content changes will have on house airtightness, an experimental approach has been taken.

3 EXPERIMENTAL DESIGN FOR MEASURING HOUSE AIRTIGHTNESS VARIATION

A programme of monthly visits was organised to each of seven occupied houses to measure the size of airtightness changes over the first year after construction. The moisture contents of the top and bottom plates were also estimated by recording the weights of samples of framing timber kept in the roof and subfloor spaces. The samples were each about 800 mm long with sealed end grain, and held in direct contact with the top and bottom plate so the moisture transfer time constant would be similar to that of the framing. Two samples were maintained at each location and they were all oven dried at the end of the survey to give per cent by dry weight data. Houses were always inspected prior to airtightness testing to see if the occupants had added draught strips since the last visit. This problem was minimised by volunteering to supply and apply draught seals free of charge. In this way, the effect of any change could be determined with back to back airtightness measurements.

3.1 Test Houses

The seven houses used in this airtightness survey were all completed early in 1985 as rental accommodation for the Housing Corporation of New Zealand. All were light timber framed, on suspended floors and with roll formed galvanised steel roofs. Houses 3, 4 and 5 were completely detached and built to very similar plans by the same building contractor. The other four houses (1,2 and 6,7) were made up of two duplex units. The roofs of all houses were pitched except houses 3, 4 and 5 which had cathedral ceilings in the living area. Skylights in the cathedral part of houses 4 and 5 were found to leak in heavy rain and were roofed over, together with the skylight in house 3, midway through the survey. The building dimensions and predominant materials are listed in Table 1.

Table 1 Description of Test Houses

House	1	2	3	4	5	6	7
Type	Duplex		Detached single storey			Duplex	
Floor area m^2	94	94	72	73	69	71	72
Volume m^3	225	225	294	198	180	194	194
Exterior wall m^2	290	290	252	242	233	238	238
Exterior walls	Fibre cement weather boards						
Interior walls	Paper coated gypsum plaster board						
Floors	Prelaid high density particleboard						
Windows	Timber framed						

4.0 RESULTS AND DISCUSSION

4.1 Airtightness of Test Houses

Early airtightness tests showed the seven houses to be divided into a very airtight group of two, with the remaining five slightly less airtight than the average for recent construction. With two exceptions, the houses maintained the same level of airtightness over the year with no obvious seasonal change. After a full year, the most pronounced change was 9% of the first measurement made soon after construction. At the end of the year the mean leakage rate at 50 Pa had decreased 2%. Figures 4 and 5 give the trends in house airtightness over the year.

Two houses (4 and 5) became more airtight over the winter but after a full year there was no residual change. They were in fact the two houses with rain water leaks around skylights in the cathedral ceiling. Rain water leaks were absent in House 3 in the same group and because the airtightness of house 3 remained constant over the year, rain leaks have to be considered a possible cause for the air tightness swings in houses 4 and 5.

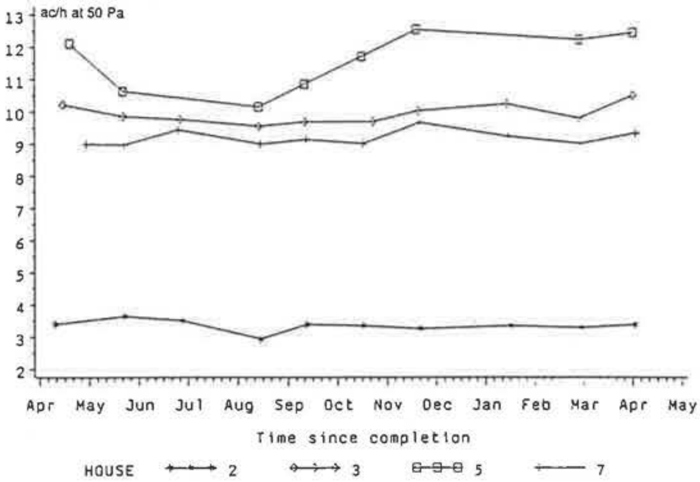

Figure 4 Airtightness variation of houses 2, 3, 5 and 7 during the first year after construction

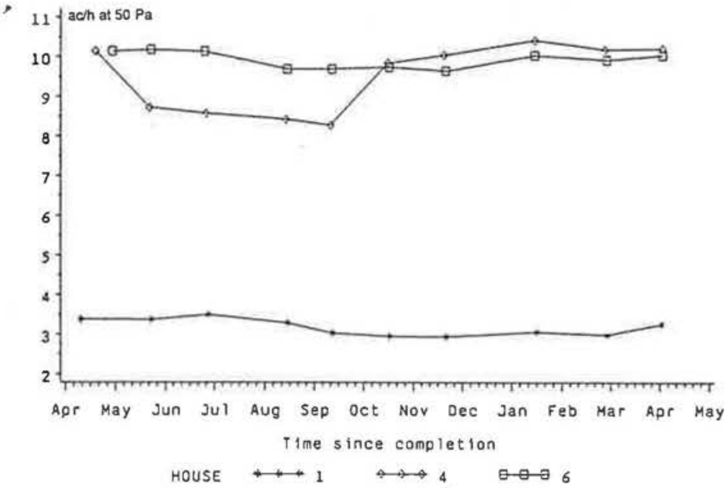

Figure 5 Airtightness variation of houses 1, 4 and 6 during the first year after construction

4.2 Framing moisture contents

An analysis of timber sample moisture contents shows a significant seasonal swing in the roof space and a less evident swing in the subfloor space. Figure 6 shows the average moisture contents in these two locations averaged over all seven houses.

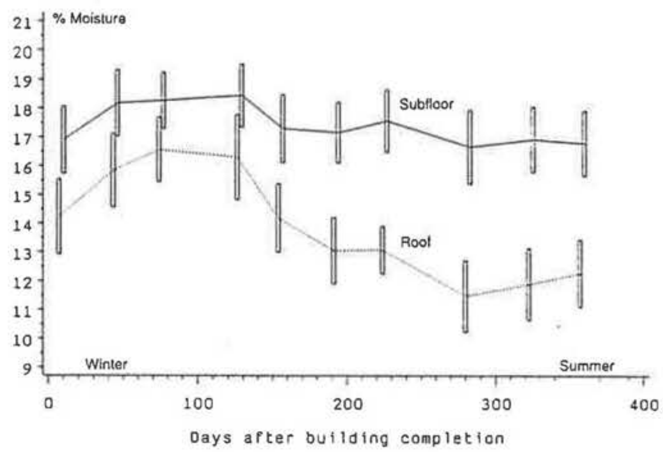

Figure 6 Mean framing moisture contents for all survey houses following construction

If the sample moisture contents continue to change seasonally then they can be characterised with a periodic function as follows:

$$MC(\%) = Mean(\%) + Amplitude(\%) * Sin\left[\frac{(days - 155)}{365}\right]$$

where:

MC(%) = Timber moisture content in w/w %
Mean(%) = Long term mean moisture content w/w %
Amplitude(%) = Seasonal moisture content swing w/w %
days = Days since 1 January

Constants and uncertainties are given in Table 2 for timber samples in the roof space and subfloor.

Table 2 Constants relating to timber moisture contents with 95% confidence interval estimates

	Mean	Amplitude
Roof space	13.7 ± 0.2	2.6 ± 0.4
Subfloor	17.4 ± 0.2	0.8 ± 0.4

Roof-space and subfloor sample moisture contents varied little between houses, indicating that the seasonal airtightness swings in houses 4 and 5 could not be attributed to moisture content changes at the perimeter of the subfloor or pitched roof sections.

CONCLUSIONS

This study of the air tightness characteristics of new houses during their first year of occupancy found the following:

1. Repeated blower door tests on seven new houses found no significant residual change in airtightness after one year.

2. There were no significant seasonal airtightness swings in five houses. Two houses did show a seasonal trend to increased air tightness in the winter. This has been tentatively attributed to roof water leaks.

3. The moisture contents of the top and bottom plates of all seven houses changed seasonally by 2%-3% but with no effect on measurable house airtightness.

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