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VENTILATION TRENDS IN NEW ZEALAND HOUSING

M. R. Bassett

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Ventilation Trends in New Zealand Housing.

M.R. Bassett*

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Abstract

Ventilation is essential for indoor air quality and yet it is usually not a major consideration in house construction. Traditionally, the building codes have called for openable windows to provide ventilation, but growing security concerns, and the need for sound isolation in high density sub-divisions, mitigate against their use. Inadequate ventilation has been implicated in widespread dampness problems in NZ houses and in recent years linked with poor health. It has also been implicated in the formaldehyde problems that occurred in 1990.

This paper traces important changes in the airtightness of houses and relates these to changing levels of background ventilation. It describes recent research identifying simple (and often low cost) houses as most likely to be too airtight. These houses are also likely to have compounding problems of poor heating, minimal insulation and overcrowding. The paper also discusses the implications of the new code NZS 4303 "Ventilation for Indoor Air Quality" and how these targets might require significant changes to the way houses are built and managed.

*Building Physicist, Building Research Association of New Zealand, Private Bag 50908, Porirua, New Zealand.

1 Ventilating domestic buildings - codes and standards

Ventilation provisions for houses are regulated by NZS 1900 Chapter 4:1985 Model building by-law (1). For naturally ventilated buildings this standard requires openable window areas to be at least 5% of the floor area in each room. In June 1992 new building regulations (2) replace NZS 1900, but for naturally ventilated houses these offer an acceptable solution which takes the same approach of defining openable window areas. These provisions cannot guarentee adequate ventilation because there can be no assurance that the home occupier will open windows when ventilation is required. In contrast, a performance oriented standard would set target ventilation rates, then move on to acceptable solutions for achieving these levels that depend on building design and specification and not home occupier actions. A performance approach to natural ventilation in houses awaits further research, some of which is described later in this paper.

Outside the building code there are standards and recommendations that deal with indoor air contamination. NZS 4303:1990 Ventilation for Indoor Air Quality (3) is a New Zealand adaptation of the ASHRAE 62-1989 standard of the same name. For residential buildings, this standard gives the ventilation rates in units (l/s), listed in Table 1. Because it is often convenient to express ventilation rates in volume airchanges per hour (ac/h), a second column has been calculated for a 112 m^2 (about 1200 ft^2 floor area) house having 12 m^2 in the kitchen, 10 m^2 in the service areas and occupied on average by two people. The ventilation rates in Table 1 are typical of domestic building ventilation standards at the present time and should keep most pollutant concentrations within current guidelines. Moisture is a possible exception, and in New Zealand, it is a pollutant of major importance.

	Ventilation Rate	
Location	NZS 4303 l/s	equivalant ventilation for a 112 m^2 house ac/h
Living areas	0.35 ac/h or 7.5 l/s per person	0.35
Kitchens	25.0 l/s intermittent 12.0 l/s continuous	1.5
Baths/Toilets	25.0 l/s intermittent 10.0 l/s continuous	1.5
weighted average for occupied space		0.5

Table 1: Ventilation requirements for houses

The Department of Health have published time-weighted concentrations for a range of contaminants in the work place; "Workplace exposure standards for New Zealand" (4). For non-industrial buildings such as schools and homes, contaminant concentrations of concern are less well defined, and where no particular standard exists it has become common practice to adopt 1/10 TLV (Threshold limit value). Perhaps the most respected data is the World Health Organisation list of contaminant concentrations of concern (5) reproduced as Table C-4 in NZS 4303 (3). This provides action levels beyond which both ventilation and the source of contamination should be investigated. Early in 1990 a number of houses were found where formaldehyde was causing health problems. In these cases, the WHO action level of 0.1ppm was used to trigger further investigation of ventilation and formaldehyde source strengths.

1.1 Ventilation for moisture control

A consequence of insufficient ventilation can be the formation of condensation and the growth of mildew on walls. Trethowen (6) found this to be a common problem in New Zealand houses in 1971. A significant fraction of houses (45%) had some form of moisture problem, with mildew in wardrobes (25%), mildew on bedroom walls (20%) and mildew on other walls (11%) being the three most common problems. A higher frequency of problems which were thought to stem from lower use of space heating was found in the more northern towns. Reduced heating lowers the moisture carrying capacity of ventilation air. The factors involved in moisture control are:

1. Moisture emission rates (typically 5-10 kg/day in an occupied house but sometimes much higher).
2. The heat input into the building (solar heat gains, space heating etc).
3. The ventilation rate.
4. The thermal insulation of the building shell; floor, walls and ceilings.
5. The moisture storage capacity of building materials and furnishings.

The role these factors play in moisture control in houses has been reviewed by Trethowen (7) and Bishop (8). As an illustration of the interaction between heat input, ventilation, and the level of insulation, Figure 1 from Bishop (8) is included. This gives condensation threshold curves for a single glazed window and an insulated wall. The condensation threshold is the point at which condensation begins to form. For a point defined by a ventilation rate and indoor heat input values that lies to the left of the curve, condensation will form, and to the right it will dry out. The asymptotic nature of the moisture threshold curves show that a reasonable mix of ventilation and heat (eg 0.5 ac/h and 3000 W) is a more effective combination than a predominance of either ventilation or heat (eg 2.5 ac/h and 1000 W).

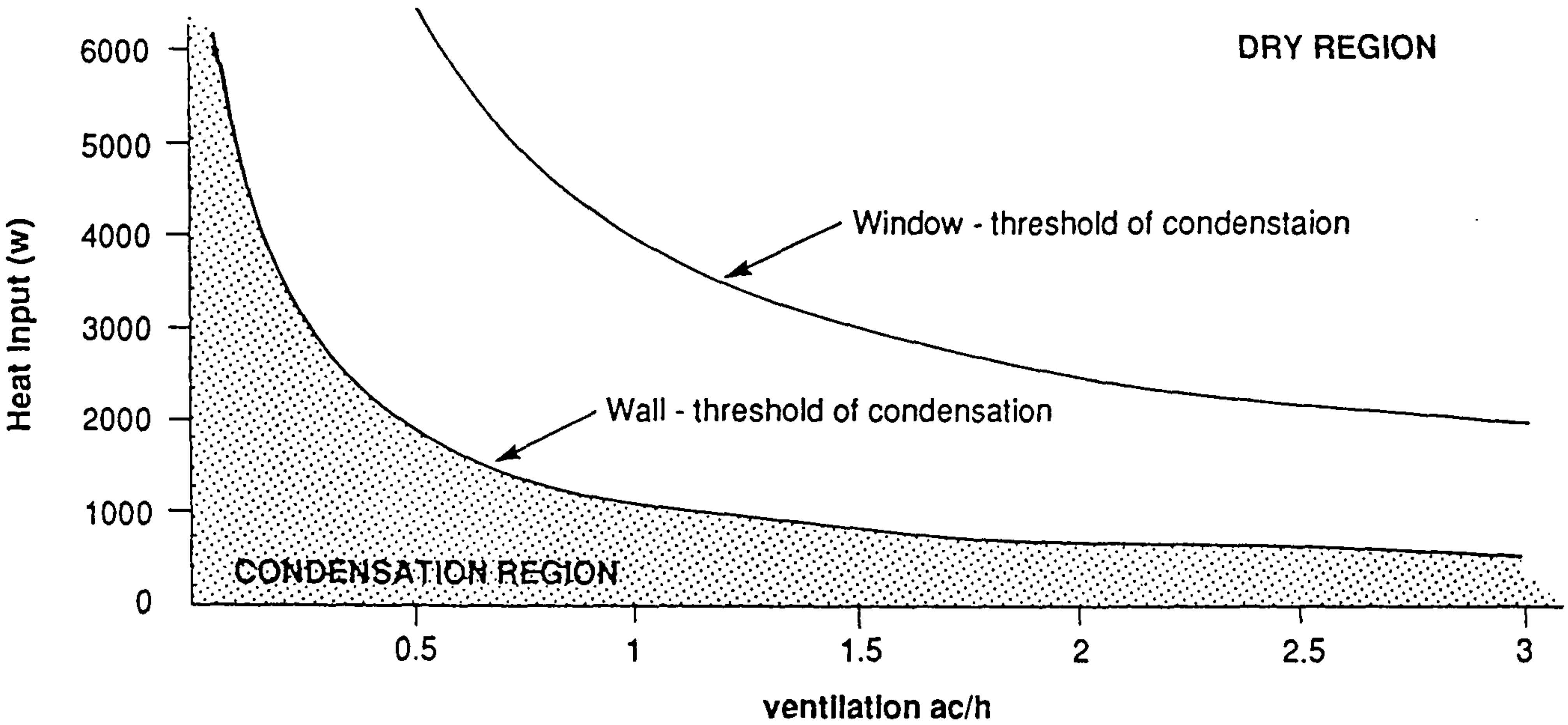

Figure 1: Condensation threshold curves for an insulated wall and a single glass window

Most houses built since 1977 have been insulated to NZS 4218P:1977 Minimum thermal insulation requirements for residential buildings (9). This will have helped reduce indoor moisture problems by increasing the average temperature of indoor air and of wall surfaces. At present there are no survey results directly comparable with the Trethowen survey of 1971 (6) but there are indications that dampness problems persist. As part of the airtightness survey of newly constructed houses (1985) in Christchurch and Auckland (10) a questionaire was filled in to rank dampness problems with a moisture score. In a total of 55 houses 2 reported severe mould on walls with condensation running off windows, 13 reported some mould on walls and the remainder had no problems more serious than condensation on windows.

1.2 Health implications of indoor moisture

Dampness and mildew are known to degrade interior finishes and furnishings but links with poor health are less obvious and more difficult to establish. A recent survey by Kearns et al (11) has explored the health and housing difficulties of urban New Zealanders living in Auckland and Christchurch. Dwelling related health problems including running noses, colds, rheumatism, headaches and asthma symptoms were found to have some association with dampness and coldness. Interestingly a greater proportion of dampness and coldness problems were reported in Auckland with closer analysis of the data showing socio-economic status to be a factor; leading to an inability to afford heating.

A recent survey of dampness and health in 597 houses in the UK by Platt et al (12) showed that adults living in damp and mouldy dwellings were more likely to report nausea, vomiting, constipation, blocked noses, breathlessness, backache, aching joints, fainting and bad nerves than those living in dry dwellings. These differences remained after controlling for economic position and cigarette smoking. For children, living in damp dwellings was associated with a greater prevalence of wheezing, sore throats, runny noses, coughing, headaches, and fever and with the exception of coughing these differences were unaffected by the introduction of controls for smoking in the household, employment and overcrowding.

1.3 Ventilation practices in residences

Open windows are the most obvious but by no means the only source of ventilation in houses. Another source is the air that leaks through defects in the building shell. This is called air infiltration. It has always been present although its contribution to ventilation and building thermal efficiency has not been well understood. Open windows give user regulated fresh air but the following factors work against their use for all ventilation needs:

1. Security concerns sometimes lead to closed windows while the building is occupied and almost always when unoccupied.

2. Closing the windows reduces the transmission of sound from outside.

3. Accurately regulated ventilation is difficult to achieve without draughts.

Window opening habits have not been surveyed in NZ but are known to be highly variable. In this context air infiltration can be quite important because it represents the minimum ventilation rate that can ever be achieved, and the lower limit for ventilation heat losses. If it is to be argued that a basic level of ventilation (say 0.5 ac/h) should be somehow built into houses during construction, so that indoor air quality needs are met irrespective of user controlled ventilation, then air infiltration (or a substitute for it) should be carefully examined.

The airtightness of mid 1980's houses in three main urban areas Auckland, Wellington and Christchurch has been sampled by Synergy (13) and Bassett (14). No significant regional differences in house airtightness were found so the data was combined to give the national average data shown in Figure 3. For houses built after 1980, 93% had 50 *Pa* airchange rates between 5-16 *ac/h*. At the time, this indicated houses were more airtight than expected, and effectively eliminated arguments in favour of making houses more airtight to save energy.

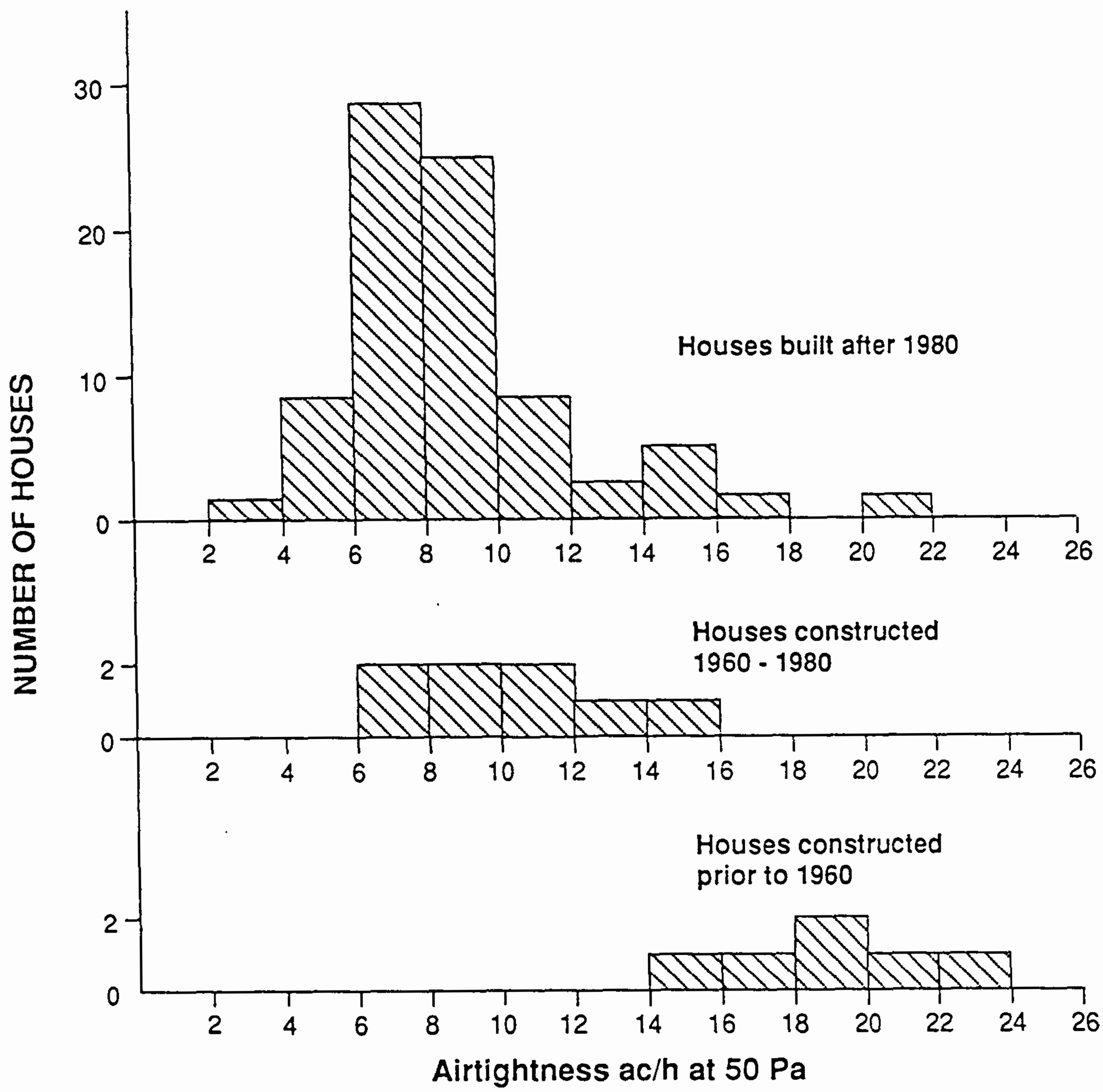

Figure 3: Airtightness of New Zealand houses measured at 50 Pa

2 The air infiltration role in ventilation

2.1 The airtightness of houses

The air leakage characteristics of houses can be measured with a blower door as illustrated in Figure 2. This device lowers the indoor air pressure slightly with a fan that extracts 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 in comparisons with buildings of different types, age or location around the world.

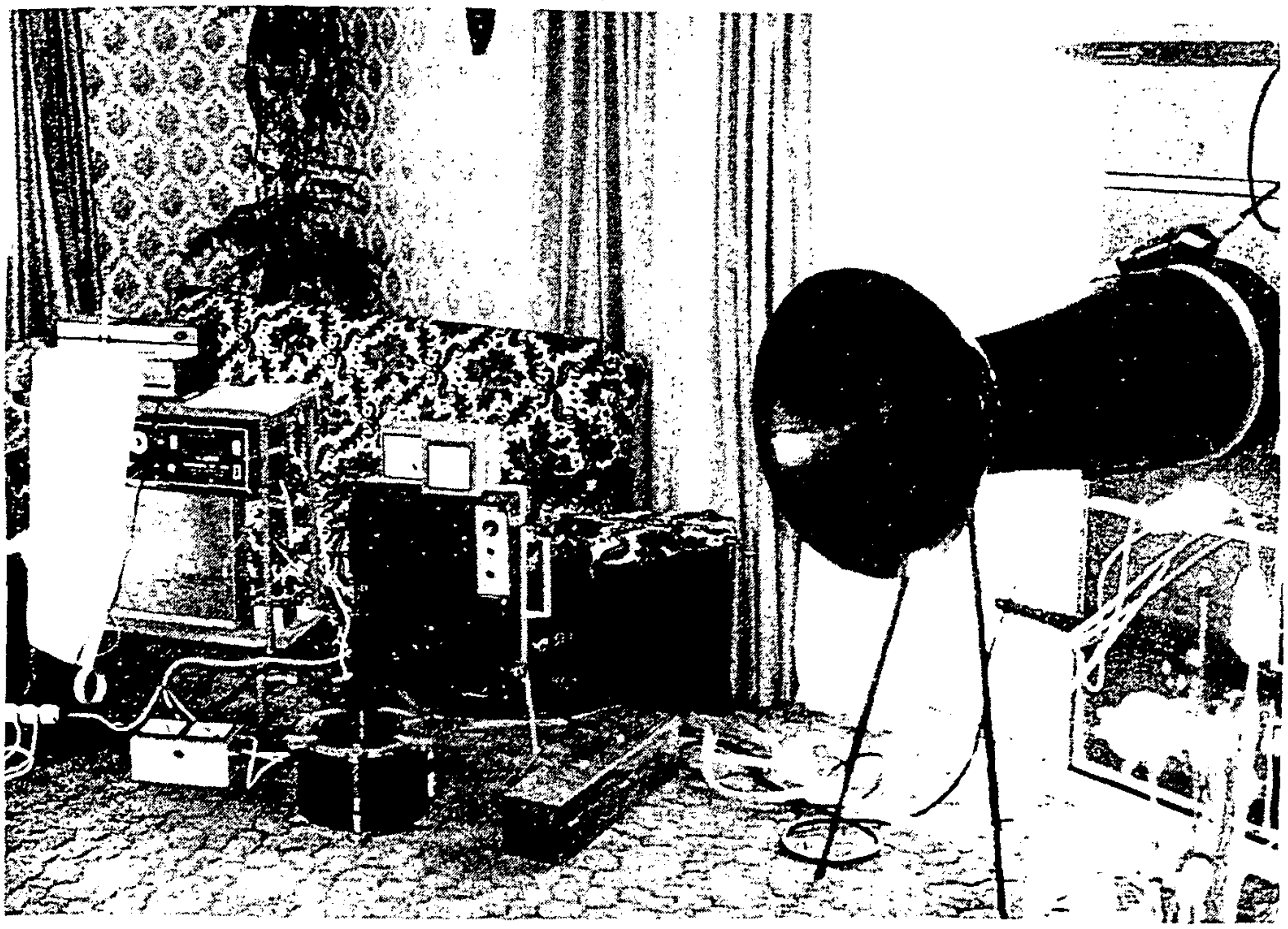

Figure 2: Blower door and associated instrumentation for measuring building airtightness

2.2 An international comparison of house airtightness

The comparison of house airtightness given in Figure 4 shows New Zealand houses to be no less airtight than recent housing in a range of other countries. Approximately 40% of the NZ houses fall within the 0-8 ac/h range occupied by conventional houses in very much colder climates such as those in Canada and Scandinavia. There are no special reasons for expecting to see houses of even modest airtightness in NZ. Vapour barriers have not been found necessary to control cavity moisture in NZ and therefore 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. These changes have reduced the number and size of leakage openings in the building shell.

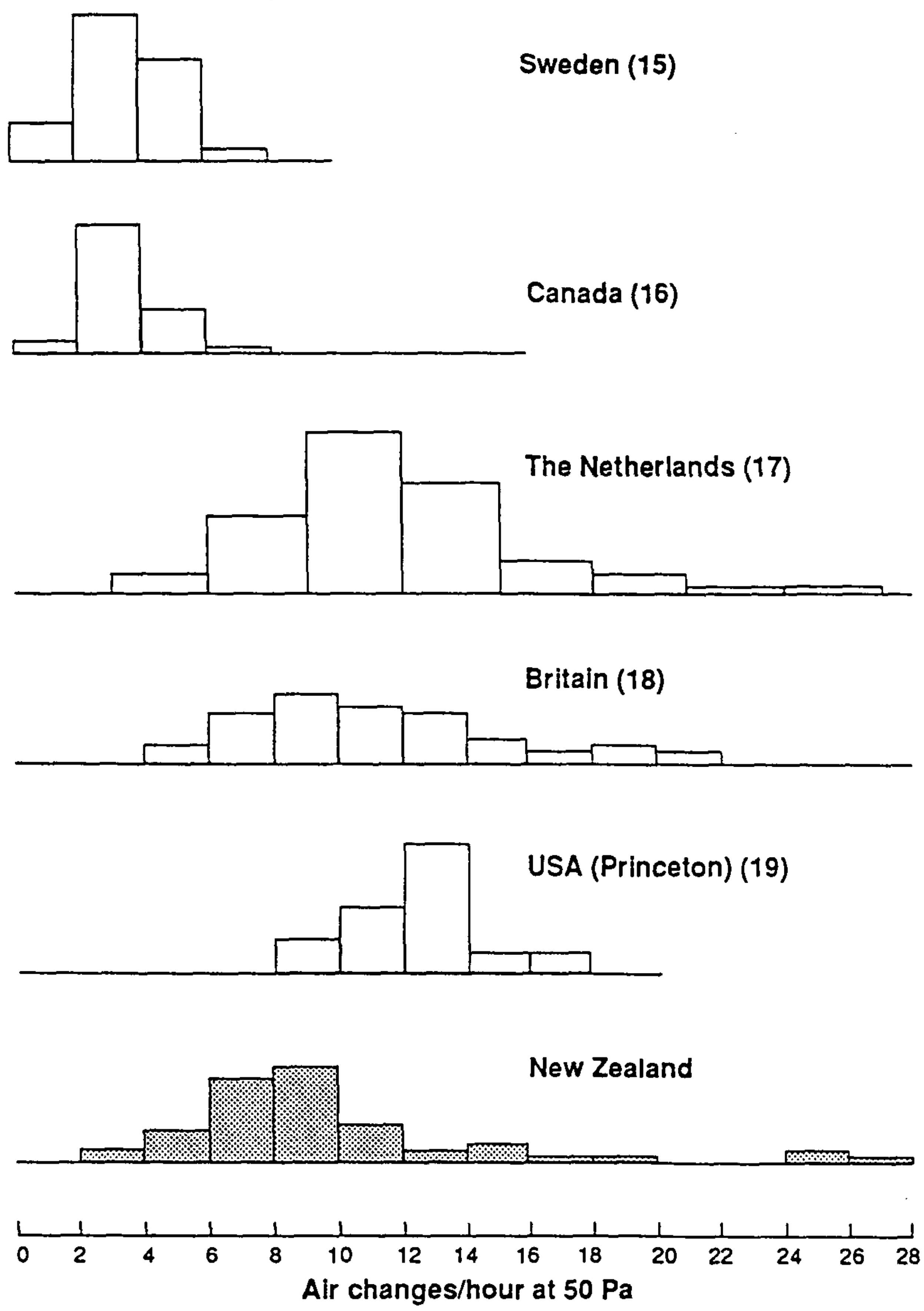

Figure 4: Relative airtightness of houses measured at 50 Pa

Energy efficient houses in cold climates often have to meet stringent airtightness standards. In Sweden (20), for example, detached houses must be more airtight than 3 ac/h at 50 Pa. This cold country approach to ventilation reduces air infiltration to a minimum for energy efficiency reasons. At the same time, fresh air needs have to be satisfied with a mechanical ventilation system, often incorporating heat recovery for further energy savings. Interestingly, there is a small percentage of houses (about 4%) in the New Zealand survey that fell into this super airtight category. These houses are too airtight for buildings having no assured mechanical or passive source of ventilation.

2.3 Airtightness of doors and windows

Draught sealing materials are readily available for retrofitting to opening joints around doors and windows. This might give the impression that most of the air leaks in a house lie in these areas, but a survey of window and door leakage (21) has shown that it is unusual for this to be more than 25% of total house leakage. Results of the 20 house survey of door and window leakage are given in Table 2 expressed as a leakage rate per meter of opening joint.

Window and door joinery type	Leakage/m at 50 Pa $L/s.m$
Aluminium extrusion	0.5 ± 0.5
Timber moulding	4 ± 1

Table 2: Mean leakage rates through opening joints in the window and door joinery of 20 houses

Windows are the only component in a house that have to meet airtightness requirements in New Zealand. NZS 4211:85 Specification for performance of windows (22) defines three levels of airtightness. When converted to a leakage per meter of joint at 50 Pa, the two levels applying to houses are as follows:

Grade 2 - 0.3 $L/s.m$ (Intended for air conditioned buildings)
Grade 8 - 1.0 $L/s.m$ (General purpose - residential buildings)

Although grade 2 is more airtight than necessary for domestic buildings, many windows achieve this level because of the airseals used to make them weathertight.

2.4 Airtightness dependence on construction and age

Only a small group of 6 pre-1960 houses have been airtightness tested in NZ. The results are shown in Figure 3 and while this is too small a number to properly define the characteristics of houses this age, the data suggests that houses with strip interior lining (match lining wall panelling, and tongue and groove flooring) are less airtight than more recent houses lined with sheet materials (particle board flooring and paper sheathed plaster board walls and ceilings). Detailed studies 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 (and hence air leakage sites) lead to more airtight construction.

Another interesting possibility is that houses of simple construction (having fewer leakage sites) will be more airtight than larger and more complicated designs. Such a relationship has been found in new houses of conventional type and used as a simple tool for predicting house airtightness in the ALF passive solar design guide (23). Although an over simplification of the many leakage sites in buildings, this model usefully predicts the airtightness of conventional timber framed houses from plan drawings with the following results:

1. It shows that more airtight houses are those of simple design. The implication of this is that low cost houses may often be under-ventilated.

2. Houses of more complex design could benefit from being made more airtight during construction.

3 Air infiltration contribution to ventilation

Airtightness data for a house can be transformed into air infiltration rates using the following extra information:

1. The wind exposure category of the building, and the wind speed and direction.

2. Indoor and outdoor temperatures.

3. The distribution of leakage openings around the building.

The daily pattern of infiltration is known to depend on all the factors listed above, but in the New Zealand climate it has been found (10) to be much more dependent on wind speed than on indoor/outdoor temperature differences. This means that infiltration will be quite variable and not always well matched to ventilation needs. The best that can be hoped, is for the average infiltration rate to lie somewhere near the 0.5 ac/h required for general indoor air quality. The approximate range of average winter air infiltration rates for houses in the Wellington climate is given in Figure 5. Although medium wind exposure and constant indoor heating to 20 C have been assumed, the mean infiltration rate does lie quite close to 0.5 ac/h (0.54 ac/h). Moving to the Christchurch climate in figure 6 narrows the distribution and reduces the mean rate infiltration rate to 0.46 ac/h. This work (10) has shown that most houses have average winter infiltration rates in the desirable 0.5-1.0 ac/h range without the building industry having to work to airtightness targets. There are however about 20% of new houses that would benefit from added background ventilation.

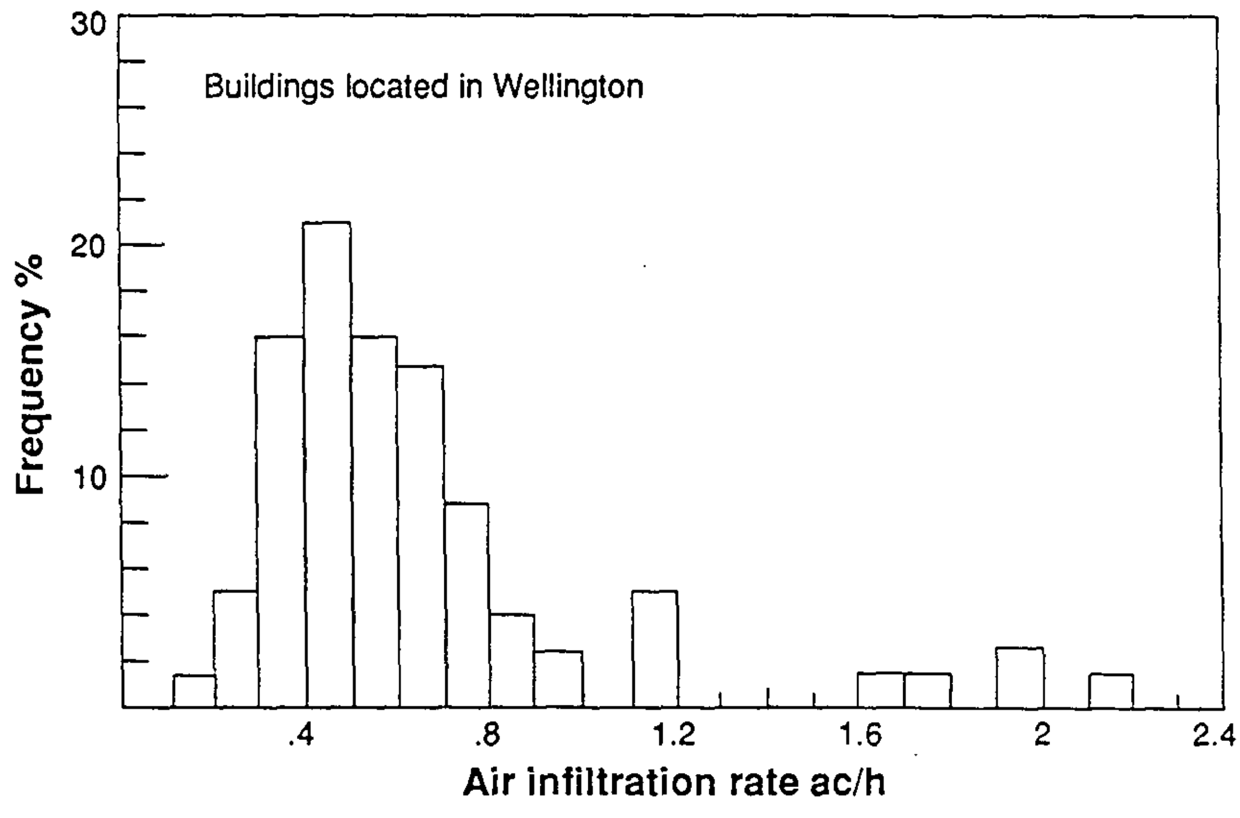

Figure 5: Mean winter infiltration rates for buildings of all airtightness levels located in the Wellington climate.

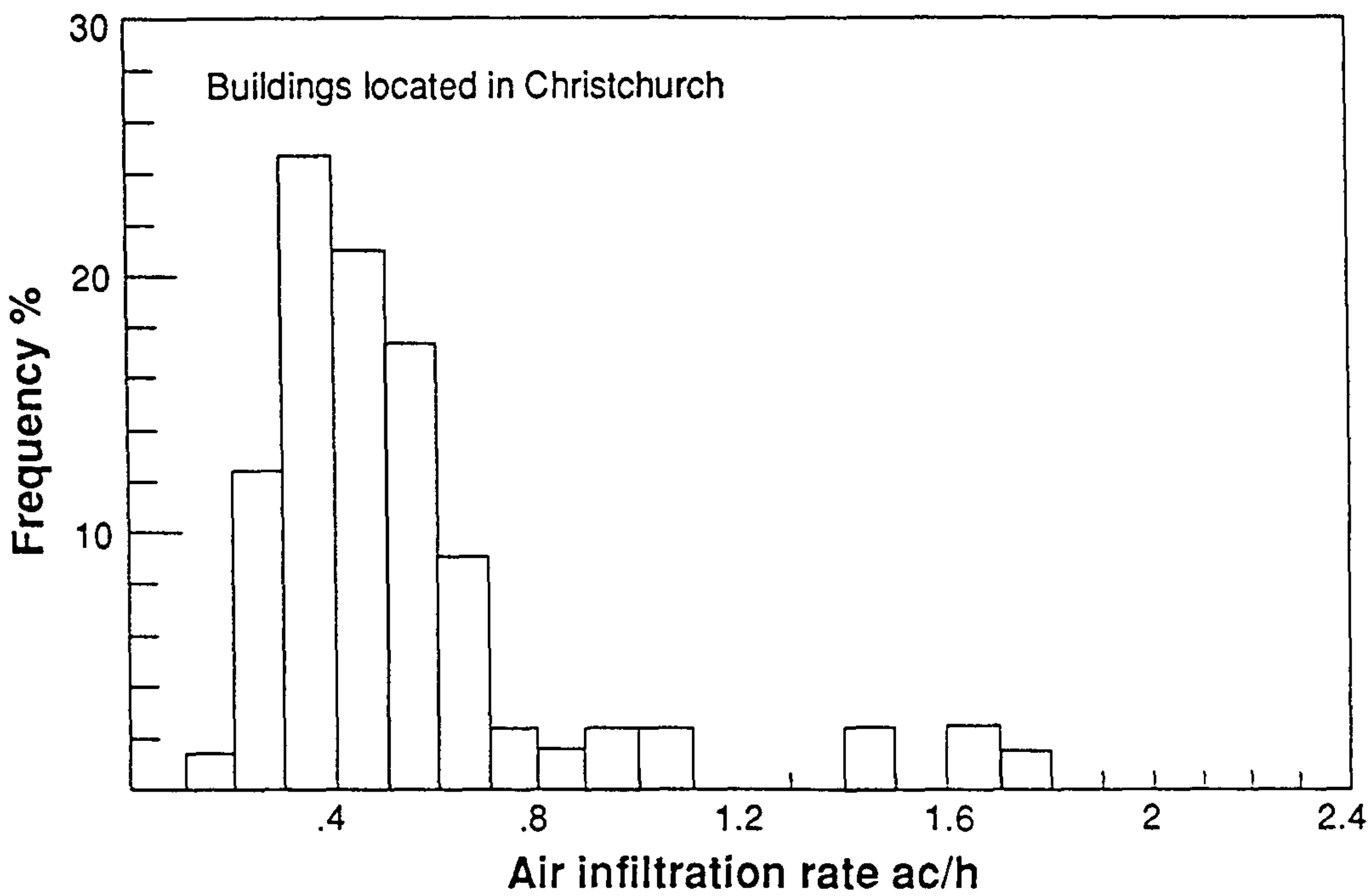

Figure 6: Mean winter infiltration rates for buildings of all airtightness levels located in the Christchurch climate.

3.1 Case study - Ventilation patterns in two houses

Two houses have been singled out as case studies to give examples of the make-up of ventilation in occupied houses. Both were new rental properties located in the Wellington area. House A is exceptionally airtight and house B is closer to average airtightness. Further specifications are summarised in Table 3.

Details	House A	House B
House floor area	94 m^2	72 m^2
Occupancy	Retired couple	Working couple
Airtightness	3.5 ac/h at 50 Pa	9.6 ac/h at 50 Pa
Wind exposure	sheltered	sheltered

Table 3: Physical details of two houses subjected to ventilation measurements.

Total ventilation rates were measured over four two week periods using a passive perfluorocarbon tracer method. During the second period the occupants were on holiday so the air change rate would be made up of air infiltration alone. Measured ventilation and calculated infiltration rates are presented in Figures 7 and 8 for Houses A and B.

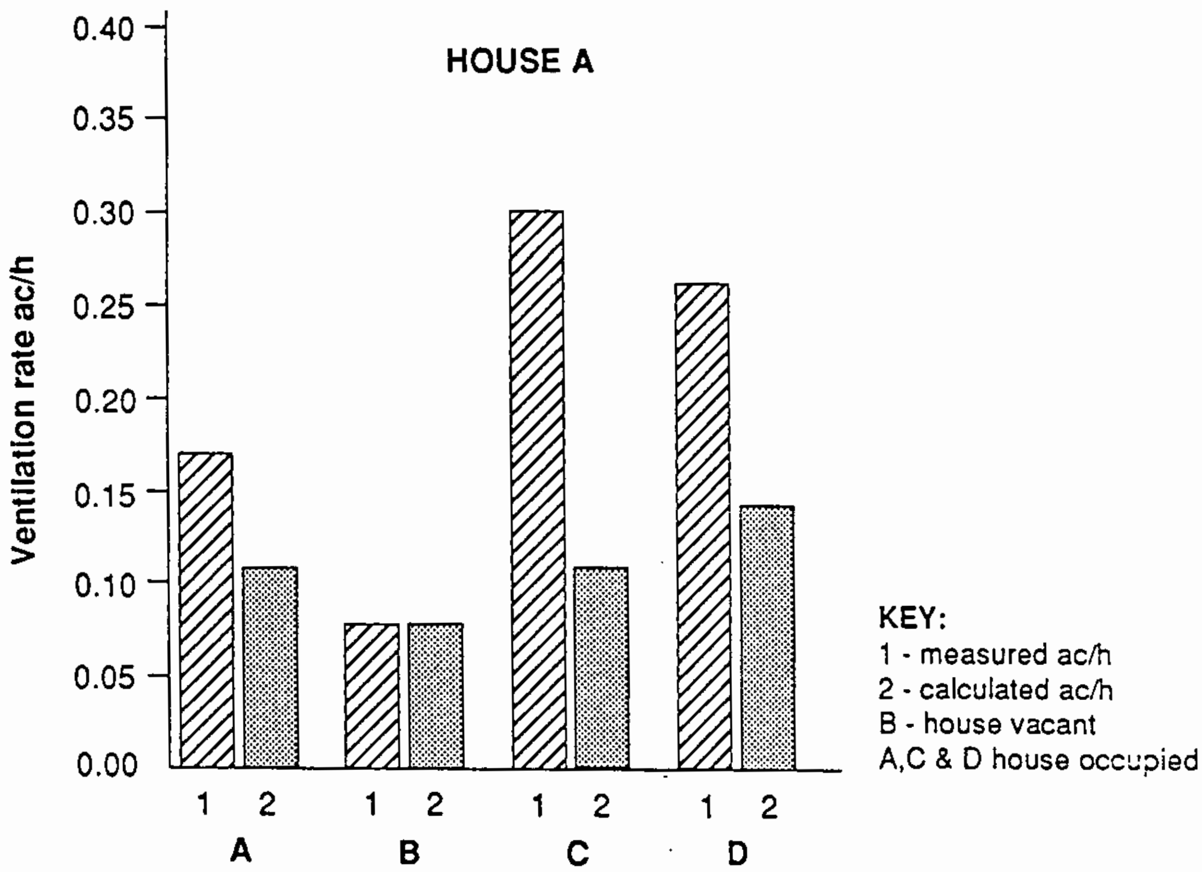

Figure 7: Ventilation rates measured in house A compared with calculated air infiltration for the same period.

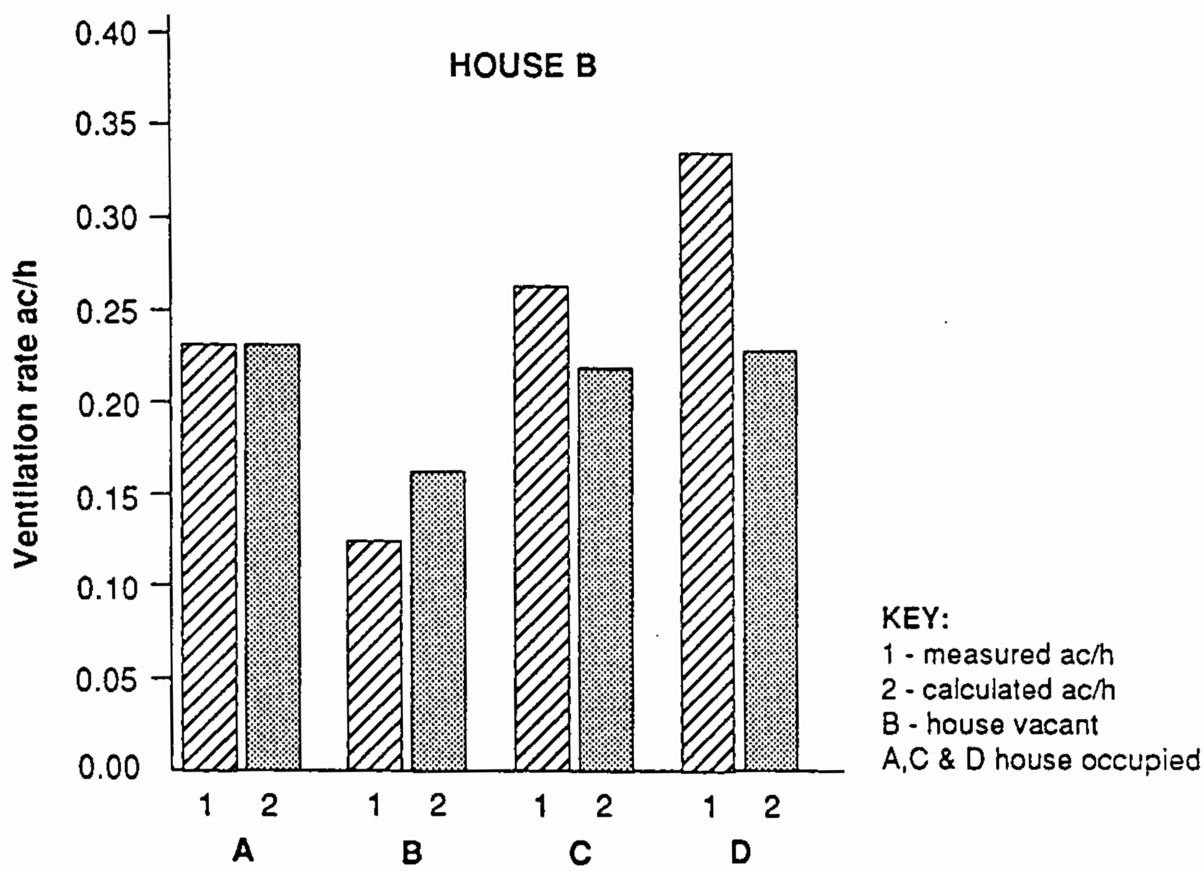

Figure 8: Ventilation rates measured in house B compared with calculated air infiltration for the same period.

In house A the infiltration rate for the unoccupied period compares well with measurement, but in house B it is overpredicted. One possible reason for this is the difficulty of selecting the correct wind exposure rating for this building site. The main point of the data though, is to show that very low ventilation rates can be measured in occupied houses. House B is of average airtightness yet the ventilation rate averaged only 0.3 ac/h while the the building was occupied. In house A, air infiltration contributed on average 0.12 ac/h with the occupants adding a similar rate to bring up a total 0.23 ac/h. Open windows have contributed to ventilation in both houses but the occupants have failed to achieve a ventilation rate that would satisfy the NZS 4303 (3) overall house average of 0.5 ac/h.

3.2 Background ventilation under house control

The trend in Europe and North America is for house ventilation to be prescribed in performance terms. This takes the form of building code target ventilation rates (after the style of NZS 4303 (3)) for different areas in the building. At the next building code level of acceptable solutions come two options. Mechanical ventilation is the first and favoured option in cold climates where heat recovery is economic. In more temperate climates passive ventilators are favoured for reasons of simplicity and cost.

Passive ventilators are not yet common in NZ, but where used in other countries, they consist of fixed vents strategically sized and placed in the building envelope. Typically these consist of ventilators in windows, and in high moisture areas, stack ducts from ceiling level through the roof to vent at a slightly negative wind pressure area (usually at the ridge of the roof). Airflows driven through the ducts by wind and stack pressure differences can give reasonably constant ventilation if the load is shared between stack and wind driven pressures. A research project is in progress at BRANZ to develop the best strategy for passive venting of New Zealand houses. This work has used computer modelling techniques and is at the stage of confirming predictions with tracer gas measurements in real buildings. At the present stage it has been found that the wind pressures that dominate air infiltration also dominate ventilation through passive ducts. While this limits the consistency of passive ventilation, there is, neverthless an opportunity to replace some of the air infiltration lost to more airtight house construction.

4 Conclusions

1. Ventilation is a key part of providing indoor air quality and for controlling indoor moisture. Common problems with indoor dampness and some indoor air quality issues lead us to question the suitability of air infiltration and opening windows for ventilation.

2. In older houses, natural air infiltration provides enough ventilation to cater for air quality and moisture control needs. The trend in new housing is towards more airtight construction, mainly as a result of sheet material internal linings and accurately gauged components.

3. Houses of simple design have been found to be more airtight than larger and more complex houses. This means that most simple (and mostly low cost) houses will need extra ventilation by conscientious window opening. This may be unrealistic to expect in houses occupied by people unable to afford heating, or where security is considered a risk.

4. A start has been made in developing passive ventilators for window systems. This should give an option of extra ventilation that is consistent with security and not wasteful of space heat.

5. Links between dampness in houses and poor health have emerged in housing surveys in other countries. This should be used in New Zealand as an argument for further research into energy and cost efficient ways of making moisture disposal an accepted part of building performance.

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