Ensuring the New Zealand Building Stock is Moisture Tolerant

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Abstract

BRANZ's Weathertightness, Air quality and Ventilation Engineering (WAVE) programme aims to develop solutions to moisture related problems that currently plague New Zealand homes such as leaky buildings and indoor mould.

WAVE comprises four work streams: weathertightness; ventilation; interstitial moisture; and indoor air quality technology. The research aims to pull these four areas together to develop a unified model of moisture and other contaminants in buildings.

This paper provides an overview of the programme and describes some selected highlights:

- **Airtightness and Ventilation of NZ homes**

  A survey of airtightness of NZ homes showed that new buildings are built more airtight than ever before, despite no code requirement to do so. Although this is likely to reduce homeowner's energy bills, it may inadvertently cause an indoor moisture problem unless supplemental ventilation is provided.

- **WALLDRY-NZ – An educational tool for cavity design**

  Water leakage rates through various claddings were measured and incorporated into an educational tool, WALLDRY-NZ. This tool was used to educate building professionals about the impact on wetting and drying potentials arising from design choices in the range of NZ climates.

A successful WAVE programme will provide a performance basis for weathertight design - removing some of the guesswork from current practice and ensuring a dry and safe future for the New Zealand building stock.

Keywords: Weathertightness, Ventilation, Education

1. Introduction

The WAVE (Weathertightness, Air Quality and Ventilation Engineering) programme is a 6-year programme that began in October 2009. The work is jointly funded by the Building Research Levy and the Ministry of Business and Innovation

WAVE is developing practical solutions to problems that currently plague New Zealand homes such as leaky buildings and indoor mould. The programme also aims to help avoid future issues resulting from changes to materials, designs and construction methods.

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Ultimately, the long term goal is for New Zealand to have homes that manage moisture properly and provide safe indoor environments.

In short, this programme recognises that the performance of the building envelope is linked to the environment within the building and aims to form a complete model of how buildings manage contaminants (including moisture). This would allow designers and builders to assess the impact of any features they want to implement.

The WAVE programme is split into four complementary work streams:

- Weathertightness
- Ventilation
- Interstitial moisture
- Indoor air quality

This paper focuses on highlights from the weathertightness and ventilation work streams: a survey of ventilation in NZ homes; and the development of an educational tool for building surveyors.

2. Airtightness and Ventilation of NZ homes

2.1 Introduction

Previous work, for houses built up until 1994 [1, 2, 3], shows the airtightness of new homes has increased over time even though there is no requirement for airtightness in the NZ building code. This study aimed to see if that trend was continuing and to investigate the relationship between airtightness and in-service levels of ventilation.

The airtightness of 36 houses built since 1995 and across four cities in New Zealand (NZ) was measured using a standard blower door test. 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) [4, 5]. The results provide a baseline for discussions about adequate ventilation provisions in NZ homes and will be used in an experimental facility at BRANZ to determine alternative cost-effective ventilation techniques.

2.1.1 Airtightness of NZ homes

The average airtightness result (at 50 Pa) from houses built before WWII was around 19 ach (air changes per hour) 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.

Newer construction practices are likely to have continued to influence the airtightness of houses. Recent examples of changes are the widespread use of bonded plaster cornices or a square stopped interior plaster finish, and the adoption of air seals around window and door assemblies to control rain penetration. [6]

2.1.2 Ventilation in NZ homes

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 the background infiltration was high. In newer houses, the changes in construction discussed above have closed down many infiltration paths and it may be necessary to actually open the windows to provide adequate fresh air.

2.2 Experimental Method

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.

2.2.1 Airtightness measurements

A blower door test to EN13829[8]was completed on each of the 36 houses .

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

$$Estimated\ Infiltration\ Rate = \frac{ach\ @\ 50Pa}{20} \qquad \text{(Equation 1)}$$

2.2.2 Ventilation Measurements

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

A Perfluorocarbon Tracer (PFT) technique [4, 5] was used and the equipment and analysis were supplied by the UK’s Building Research Establishment (BRE). The technique involved deploying passive tracer gas sources and activated carbon sampling tubes in a building for several weeks. The resultant concentration of tracer in the sampling tubes was then used to calculate an average ventilation rate.

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.

Sampling tubes were placed in 4 rooms in each house, typically the lounge, bathroom, kitchen, and master bedroom. There were several important considerations when it came to the location of the source and sampling tubes:

- Source and sampling tubes needed 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 were not placed in direct sunlight or within 1.5 metres of heat sources. The temperature was also measured at each source location using Dallas DS1923 iButtons.

2.3 Results

A summary of the results from the work is shown in Figures 2 and 3.

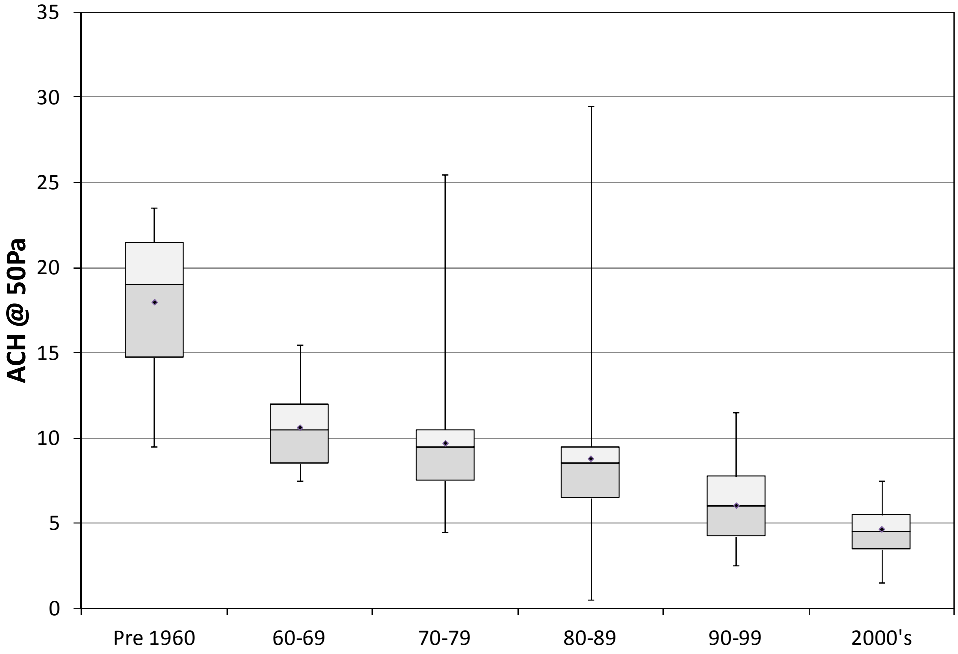


Figure 2: Airtightness Measurements of NZ Homes

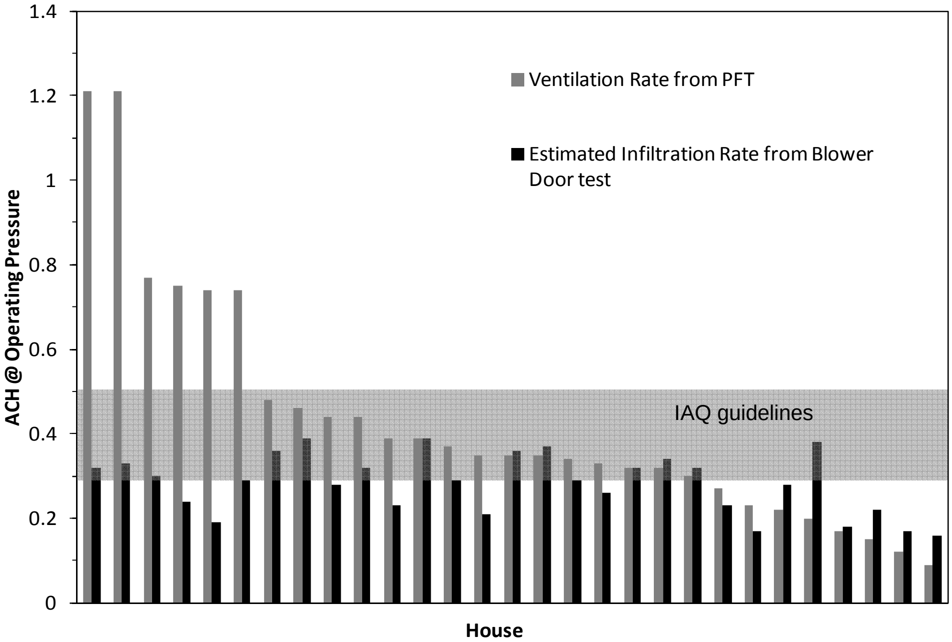


Figure 3: Measured Ventilation Rates and Estimated Infiltration Rates

Figure 2 shows how the airtightness measurements from this study compare with those from previous airtightness surveys in NZ.

Figure 3 shows how the average ventilation rate compares with the estimated infiltration rate for each house. Results are sorted so the measured ventilation rate decreases from left to right.

Also in Figure 3 is a shaded area representing 0.3 to 0.5 ach, the amount of ventilation deemed necessary to provide adequate indoor air quality [9]

2.4 Discussion and Future Work

It is clear that the trend to more airtight construction is continuing despite the lack of any building code requirements to so do. Compared to the previous survey (80's and early 90's homes) there was a reduction in the mean airtightness result from 8.5 ach to 6.7 ach. Incidentally, the floor area of the newer houses was also bigger than those in the last survey, increasing from 115m^2 to 155m^2. The recent airtightness results also fell in a tighter range suggesting more consistency in construction.

Figure 3 suggests about two-thirds of all new homes are likely to need ventilation on top of the background infiltration to achieve acceptable levels of indoor air quality. The results show that this doesn't always happen.

There is a wide variation in terms of the average ventilation rate achieved in modern NZ homes. Six of the surveyed homes had ventilation levels far in excess of international guidelines, potentially wasting energy and compromising thermal comfort. Three of these over-ventilated homes had supply-only ventilation systems installed, suggesting that the control of these systems could be improved somewhat.

At the other end of the spectrum, eight homes had ventilation levels below international guidelines. In these cases, the occupants are not providing the extra ventilation they need by opening windows or using fans etc. Evidence of indoor moisture problems e.g,.mould and condensation were observed in several of these houses.

Overall, NZ newer homes are on the border of becoming too airtight, if infiltration is to be relied on to supply fresh air. It would also appear that a ventilation scheme that relies on open windows is too unreliable. Modern lifestyles, security and energy costs are some of the reasons why occupants may not open windows as much as is needed.

The remainder of the ventilation work in the WAVE programme aims to improve the control algorithms for supply-only ventilation systems and develop possible alternatives that account for the wide range of airtightness in the existing NZ housing stock and adapt to occupant behaviour.

3. WALLDRY-NZ – An educational tool for cavity design

3.1 Introduction

WALLDRY-NZ is currently a Microsoft Excel-based computer program that encapsulates much of BRANZ's previous weathertightness research in one model [10].

WALLDRY-NZ was developed to bring flexibility to cavity wall design. The model is used in an interactive teaching environment, showing how alternative design choices influence water entry loads and ventilation drying rates in a wide range of climate zones within New Zealand. The tool allows students to develop practical intuition about the importance of cavity vent dimensions. This is useful basic knowledge for surveyors and building inspectors.

Walls designs with ventilated and drained cavities were widely adopted in New Zealand [6] after a systemic moisture failure in buildings of risky design and with direct-fixed barrier claddings. For the new cavities, sizes and vent areas from brick veneer and cavity stucco walls were simply copied for use with different claddings. An understanding of how cavity dimensions and vent sizes influenced ventilation drying and drainage was unavailable at the time but this has since been assembled by earlier studies [10]

In New Zealand, industry training has played an important part in remediating leaking buildings and bringing designers and builders up-to-speed with the new risk-based building code requirements for weathertightness. The New Zealand Institute of Building Surveyors (NZIBS) runs a training course for building surveyors who work for the NZ Government initiated Weathertight Homes Resolution Service. This week-long course covers diagnosis and remediation along with more fundamental material on timber decay and the physics of moisture. WALLDRY-NZ has a role in this course.

A comprehensive model of all the water entry and escape routes in buildings is still some way off, but several models have been developed to account for the influence of climate on water leakage and wall drying. Among the most prominent of these are the Canadian MEWS methodology [11] and ASHRAE 1091 research project [12]. This ASHRAE project provided much of the scientific underpinnings of cavity ventilation and ventilation drying on which WALLDRY is based.

3.2 Method

The details of all the research that contributed to WALLDRY is beyond the scope of this paper. However, the challenge for WALLDRY was to encapsulate the following into a single tool.

- Driving Rain Data for NZ
- Water Entry through weatherboards and brick veneers
- Ventilation Drying Rates – and how this is altered by wall design

3.2.1 Driving Rain Data

WALLDRY-NZ can provide the average daily rain load in l/m^2.day on each of 8 wall orientations. Alternatively, the average rain intensity can be selected for periods when it is raining. Rain and wind loads for 10 and 20 year return periods are also provided as a function of site exposure, orientation and building height. This latter data is provided to help select rain loads and wind pressures for testing.

Rain loads on facades were calculated using seven years of hourly climate data (1995-2002) for 40 sites using the procedure outlined by Sahal and Lacasse [13]. Wind speeds at the meteorological sites were adjusted to represent wind speeds at building height using the common power-law profile and terrain coefficients from Grimsrud et al [14].

Seasonal and annual average values of wind speeds are provided in WALLDRY-NZ to show that there are significant differences between coastal cities and those located inland. Figure 4 gives the average wind speed (at a building height of 4m) for a semi-sheltered building in Auckland.

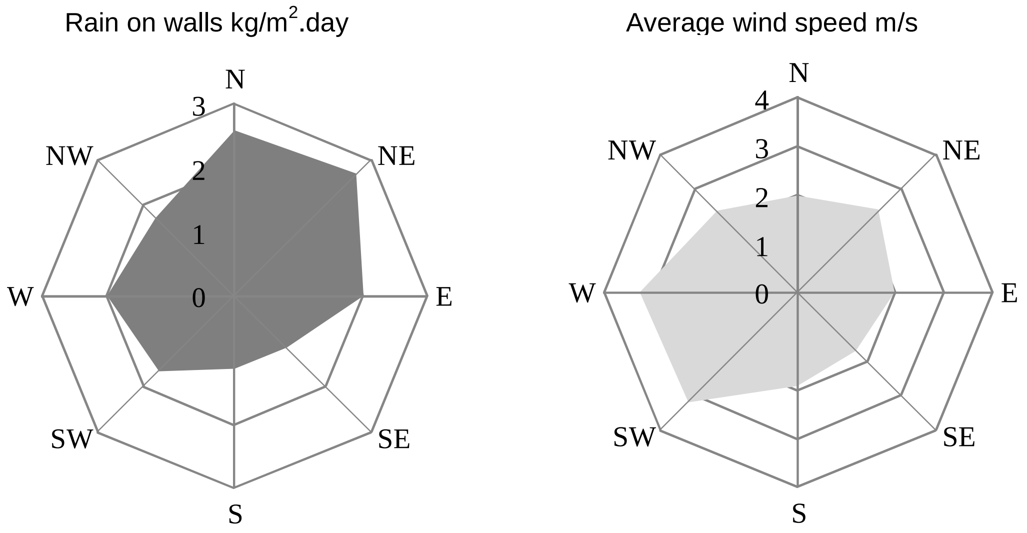


Figure 4: Yearly average rain and wind data for a 4m high brick veneer house with no eaves in a semi-sheltered area of Auckland.

As with much of New Zealand, there is a strong tendency for westerly airflows over the building although this is often not the prevailing direction for rain loads on walls. In Figure 2 the building receives its highest average rain load from the NE direction. Overall, the data in WALLDRY-NZ gives designers and building surveyors an appreciation of how wind and rain on a building vary with location and building geometry.

3.2.2 Water Entry Through Claddings

Weatherboard and brick veneer claddings are particularly common in New Zealand and the water entry rates calculated in WALLDRY-NZ are derived from leakage rate measurements for these claddings reported by Bassett et al [15]. This data gives leakage rates for a range of incident rain loads and the air pressure difference across the cladding in 12 weatherboard walls (painted and unpainted) and three brick veneer walls.

3.2.2.1 Weatherboards

The measurements showed that leaks in weatherboard walls depended more on build quality than on the fundamental geometry of weatherboards. Leakage sites were often at cracks, fixings and at lap joints which had opened up between weatherboards that had cupped in the sun. The fundamental geometry of the overlap joint was found to be only a secondary factor although there was no doubt that bevel backed board designs drained out water at lap joints more effectively than rusticated designs. This dependency on condition and build quality means that accurate water leakage rates will be difficult to predict in practice. In order to move forward, three leakage classifications have been selected to capture the range of leakage for weatherboard claddings in WALLDRY-NZ:

Leaky. Representing timber weatherboards that have weathered and cupped or been installed with significant gaps in the horizontal overlaps (2-3 mm).

Average. Represents well maintained painted timber or reconstituted timber weatherboard wall with few obvious defects (cracks at fixings knot holes etc).

Low. Represents plastic and metal weatherboards with tight fitting (clip together) overlaps and effective butt jointers.

The water leakage rate, L (g/m$^{2.}$.h), for each of these classifications is calculated in WALLDRY as follows:

$$L = A + B\Delta P^2$$

(Equation 2)

Where A and B are constants (see Table 1) and *ΔP (Pa)* is the air pressure difference across cladding.

Table 1:. Water leakage characteristics representing weatherboard claddings

Water Leakage classification	*A* *g/m^2.h*	*B* *g/m^2.h.Pa$^{0.5}$*
Leaky	100	0.1
Average	1	0.05
Tight	0.1	0.0001

3.2.2.2 Water Entry through Brick Veneer

Water leakage characteristics of brick veneer walls have been studied [15] and were again found to vary with build quality. Leakage rates in three walls were measured in the range (100 – 300 g/m^2.h) at high rain loads (3 l/m^2.min) and zero air pressure difference. These leakage rates were similar to those measured by Drysdale and Wilson [16] (100 – 300 g/m2.h) but other authors report leakage rates over a wider range eg Newman and Whiteside [17] measured leakage rates (300 – 2000 g/m^2.h). Both Newman & Whiteside and Drysdale & Wilson, relate higher leakage rates to cracked mortar joints. They report that water leakage through brick veneer walls occurs primarily at leakage paths between mortar and brick which in turn relate to build quality and in-service loads.

Instead of a detailed physical model, the leakage rates calculated in WALLDRY-NZ are based on the measured leakage characteristics of three brick veneer walls and a simplified model (see Figure 5).

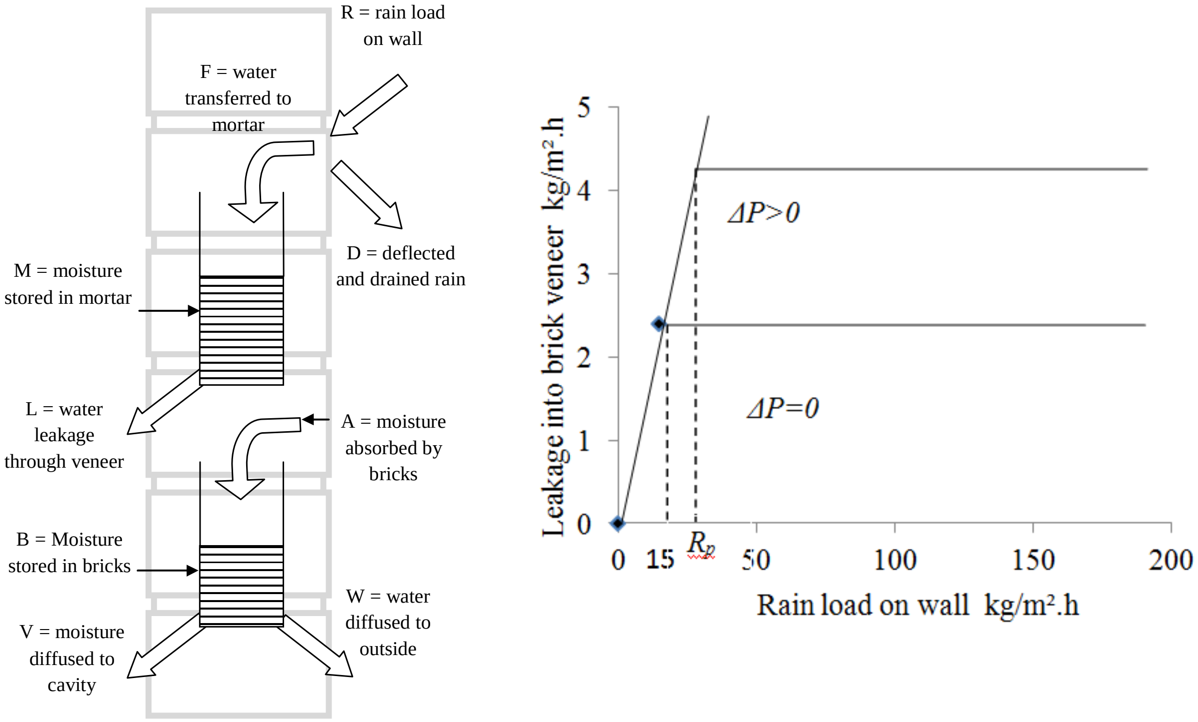


Figure 5: Simplified Model of Leakage and variation of leakage with pressure

The experiments showed that equilibrium value of *L* was independent of the rain load within the range of *R* = 15–200 kg/m^2.h [15] and depended on the air pressure difference as in equation 7:

$$L(\Delta P, R) = 2.4 + 0.416\Delta P \text{ (kg/m}^2\text{.h)} \qquad \text{(Equation 3)}$$

L(ΔP,R) must eventually fall to zero as *R* approaches zero and WALLDRY assumes this happens linearly (see Figure 2)

The measured water leakage rate (L) through the three brick veneer walls was found to increase steadily from dry, to an equilibrium value once the reservoir in mortar joints and bricks was saturated. The water leakage rate for one of the experimental walls increased to a steady value of 2.4 kg/m^2.h after 180 minutes. The water stored in the mortar joints and in the bricks in this particular wall is taken as the maximum value of moisture stored, *M, in WALLDRY*.

Water vapour diffusion from the brick and mortar *V* into the water managed cavity has been considered because it potentially adds to the moisture load to be dealt with by drainage and ventilation drying. Wetting and drying rates to inside *V* and outside *W* have been calculated using the two dimensional heat and mass transfer model WUFI [18]. Starting from a saturated wall, *V* and *W* were calculated in four seasons and for walls facing north, south, east and west in three climate zones. Drying rates were found to depend primarily on wall orientation while the fraction of drying to the wall cavity depended primarily on the cavity ventilation rate. With a fresh air cavity ventilation rate set at 12 ach (2 l/s.m) following Bassett et al [10], an average 8% of water absorbed in the bricks dried into the cavity and the remainder to the exterior. When this diffused moisture V was added to the leakage rate L, it contributed an average 15% to the total moisture load in the brick veneer cavity.

3.2.2.3 Summary of Leakage

Average water leakage rates are presented in Figure 6 as a percentage of rain loads for the three weatherboard wall categories and a brick veneer wall. These have been averaged over 7 years of weather data for 33 population centres in New Zealand and four wall orientations. The data has been presented on a logarithmic scale because the average percentage of rain load leaking through the wall varies over a range of three orders of magnitude. Figure 6 also presents the leaking percentage of rain loads as a function of wind exposure, indicating that the leakage category is by far the dominant factor.

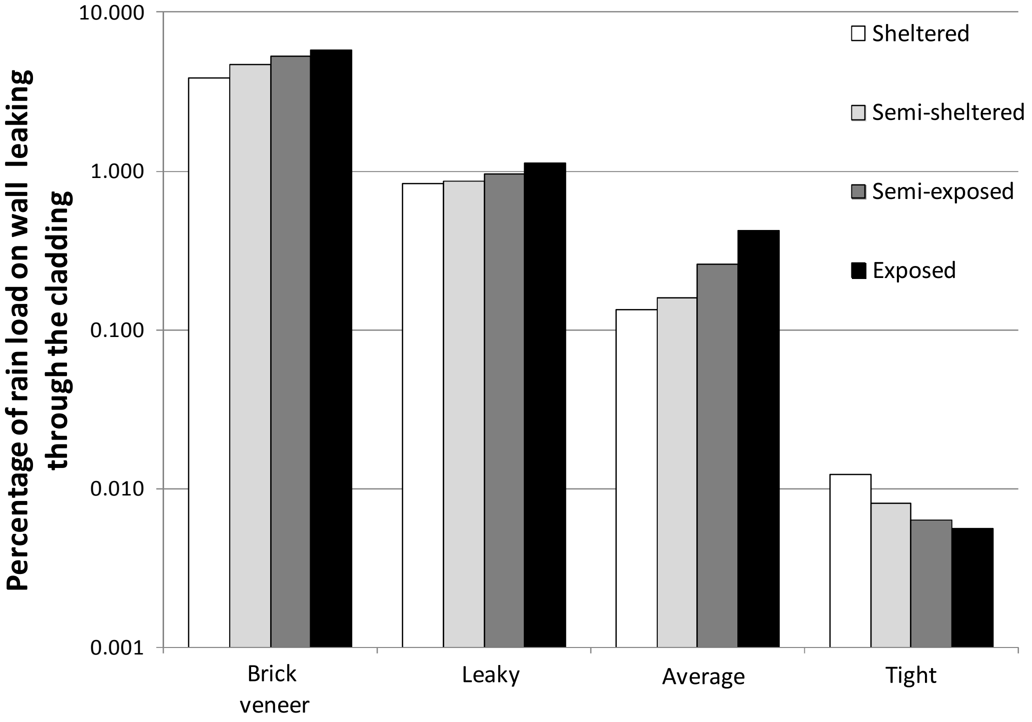


Figure 6: The average percentage rain loads penetrating four cladding classifications as a function of wind exposure.

3.3 Ventilation Drying

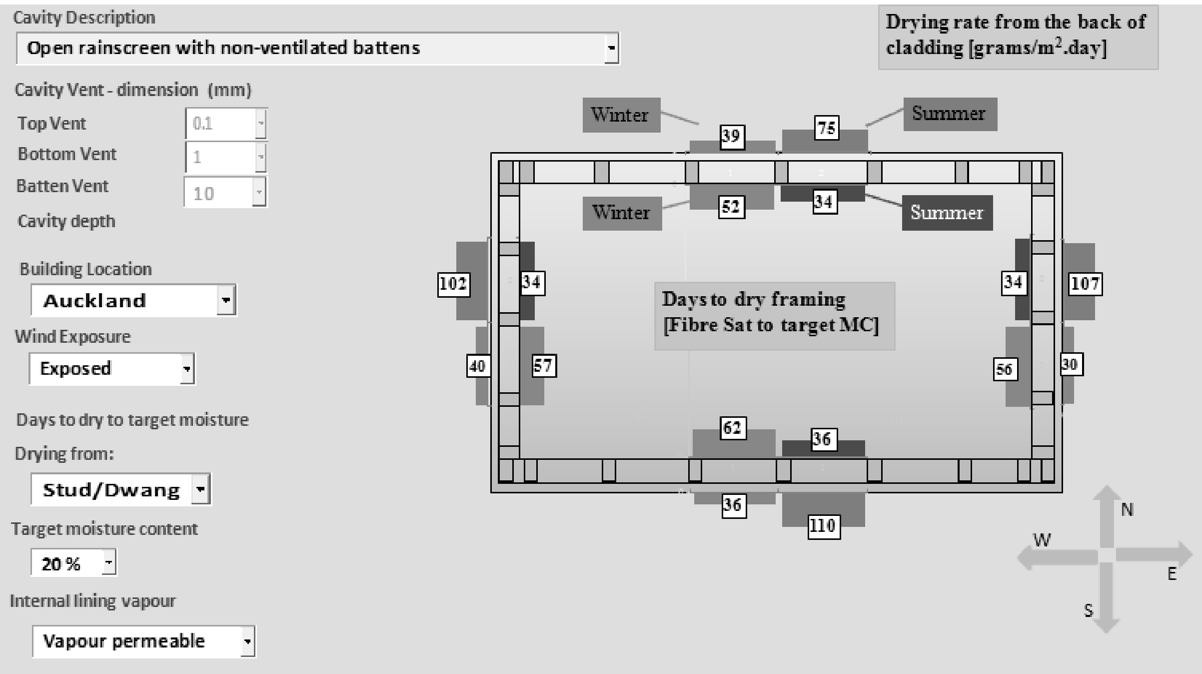
The ventilation drying rate calculations in WALLDRY-NZ are described in earlier papers [10]. These calculations have simply been applied to a wider range of climate and vent and cavity dimensions. Earlier studies showed that air infiltration paths play an important part in ventilation drying and this has to be accounted for as well specific opening at vents. This is particularly important where cavities are vented only at the base of the wall, and where ventilation might otherwise be considered to be “single sided”. In practical terms this meant all of the water managed cavities around a house had to be modelled to ensure that all of the infiltration paths are accounted for.

A single rectangular building shape has been used to model ventilation into and between wall cavities [10] Fresh air ventilation rates into each cavity were calculated along with re-circulated ventilation from adjacent cavities. The total ventilation made up of air from adjacent cavities and fresh air can be much higher (20 times) the fresh air ventilation rate in cavities with no internal partitioning (brick veneer) and twice the ventilation rate in conventional open rainscreen cavities with non-vented battens. However, for the purposes of WALLDRY, moisture removal rates have been conservatively calculated from fresh air ventilation rates.

Several additional assumptions have been made in calculating ventilation drying rates. The first is that the whole wall is assumed to be uniformly wet. The earlier study [10] showed that non-uniform wetting could be accounted for in ventilation drying rate calculations but in practice the pattern of wetting is unknown and variable. WALLDRY-NZ also ignores water trapped in capillary joints e.g., junctions between wall battens and the cladding, so consequently the drying rates should be viewed as a drying potential rather than an actual drying rate.

3.4 WALLDRY-NZ USED EDUCATIONALLY

WALLDRY-NZ has been used to train building designers, regulators and surveyors in the physics of moisture in buildings. A screenshot from the current version of WALLDRY is shown in Figure 7



Cavity Description: Open rainscreen with non-ventilated battens

Cavity Vent - dimension (mm)
Top Vent: 0.1
Bottom Vent: 1
Batten Vent: 10
Cavity depth

Building Location: Auckland

Wind Exposure: Exposed

Days to dry to target moisture

Drying from: Stud/Dwang

Target moisture content: 20 %

Internal lining vapour: Vapour permeable

Figure 7: A screenshot of WALLDRY. The main outputs are on the right – a potential drying rate and the time needed for saturated framing to dry.

The model has been applied to study ventilation drying in relation to water leakage rates through common claddings, with the following educational outcomes:

- A prevailing westerly airflow can be clearly seen in wind roses for coastal cities in New Zealand. The highest rain loads are often from quite different directions, and depend on the building wind exposure and the presence of eaves. This data has a role in building design.
- WALLDRY-NZ shows that cavity ventilation drying rates depend more on the size and location of vents in walls than on where the building is located in New Zealand. Also illustrated is the significant role that infiltration plays in walls with only bottom

vents, and the role that vented battens can play in engineering alternative ventilation paths in these walls.

- The potential for ventilation drying in most cavity walls exceeds the estimated water entry loads. Although instantaneous water leaks may drain out along a non-absorbent drainage path, ventilation drying will almost always have the capacity to deal with water absorbed in absorbent claddings over time.

4. The future of the WAVE programme

BRANZ’s Weathertightness, Air quality and Ventilation Engineering (WAVE) programme is scheduled to finish in October 2015.

By that time the following needs to be achieved:

Weathertightness:

- Quantify the water leakage at joints, particularly at windows, to allow upstands and other geometry to be determined using experimental data.
- Further understand the behaviour of different types of weatherboard to provide alternative solutions to designers.

Ventilation:

- Measure the moisture removal effectiveness of different ventilation systems using a experimental test house at BRANZ. Model this so that the results can be extended across NZ.
- Work with industry to improve the control functions of existing ventilation systems.

Interstitial Moisture:

- Provide guidance to industry on the role ventilation can play in managing moisture in roof spaces. Currently there is no provision for this in the building code with all water management dependent on the roof underlay.

Indoor Air Quality:

- Measure the effectiveness of photo-catalytic oxidisers at reducing fungal contaminant concentrations
- Develop a technique that integrates the findings from across the programme e.g. combine a model of moisture transport in the roof space with a model of ventilation in the living space.

A successful WAVE programme will provide a performance basis for weathertight design - removing some of the guesswork from current practice and ensuring a dry and safe future for the New Zealand building stock.

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