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A review of weathertight science in 2007

Author: Mark Bassett
Principal Scientist

Reviewer: Steve McNeil
Materials Scientist

Contact: BRANZ Limited
Moonshine Road
Judgeford
Private Bag 50908
Porirua City
New Zealand
Tel: +64 4 237 1170
Fax: +64 4 237 1171
www.branz.co.nz

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A REVIEW OF WEATHERTIGHT SCIENCE IN 2007

1. EXECUTIVE SUMMARY

1.1 Overview

The science of moisture and its management in walls and roof systems has advanced dramatically in the last 15-20 years predominantly from research in North America. This work was funded by a mix of government agencies, organisations like ASHRAE and larger builders to recover from a series of large scale systematic weathertightness failures. The following comments take a global view of progress towards solutions:

Are leaking buildings problems at an end? There is no evidence that systemic leaking building problems are at an end – the latest problem in Minnesota is thought to involve over half of recent stucco clad houses.

Why is there still a problem? The latest problems have been attributed to "an application gap" rather than a "fundamental knowledge gap". The Minnesota problem is explained as a failure to adopt adequate water management practices.

Have the solutions worked in North America? Although new systemic water leakage problems have appeared, they have been in non water-managed stucco walls. There are some cases of buildings being repaired a second time, but no reports of large scale systemic problems with water managed walls.

What are the next challenges in wall designs? It is becoming more difficult to achieve consistency between controlling rain water, indoor moisture and maintaining thermal efficiency, and in high performance buildings there is also some interaction with structural, fire and acoustic performance. This argues for unifying the design processes and ultimately for changes in the way codes and standards are structured.

What's happening in Europe? The systemic leakage problems seen in North America and New Zealand are uncommon in Europe. A more common topic in European research papers concerns the management of moisture in newly insulated stone or masonry heritage buildings. The science of driving rain and wetting patterns on facades and hygrothermal models like WUFI have been developed to solve these problems.

1.2 Advances in moisture science

Weathertightness models. There is no complete engineering model of weathertightness that factors in all the design and material variables as well as stochastic variables relating to weather and the quality of building. The closest approach is the Canadian MEWS model but this substitutes a series of "standard leaks" for a detailed understanding of the statistics of workmanship quality. The approach intended in NZ is to benchmark system performance against the field track record of common walls.

Moisture modelling. Several hygrothermal models have been benchmarked against measurements. These include WUFI, HYGRIC (IRC), DELFIN (European researchers) and Moisture Expert (ORNL). The updated WUFI 2D includes driving rain and liquid absorption. At present, only 1D versions of WUFI and HYGRIC (Walldry) are available to practitioners and even these require specialist knowledge.

Drainage. Effective drainage is widely acknowledged as being more important to rain water management than was previously thought. Walls designed to manage water should ideally be free of moisture traps eg absorbent claddings or joints that hold water, and should not track moisture to framing materials. Drainage plane studies have highlighted this issue (as have NZ studies) and it's importance may eventually lead to changes in E2/VM1 and E2/AS1.

Air leakage paths carry moisture. Air leakage paths are now acknowledged as contributing to water redistribution in walls but because this is a building tolerance/quality issue, little data is available to factor into cavity ventilation models. Anton tenWolde showed that these air flows could be two orders of magnitude more significant in moisture calculations than for energy calculations but this might not always be the case where air flows short circuit insulated areas.

Drainage planes. Studies in North America are starting to understand the water management potential of drainage planes. The biggest challenge in drainage plane design is minimising capillary held moisture, and at present, drainage plane solutions are quite specific in terms of materials and climate, unlike cavity solutions that can be more generic.

1.3 Scientific techniques

Moisture content tapes. New tapes are available that allow distributed moisture content measurements to be made in a walls. These contain conducting tracks that connect moisture pins together for an averaged impedance measurement. It is possible to detect the position of the electrical short (damp timber) along the length of the tape using time delay techniques. There may eventually be a version that detects condensation in an absorbent medium bridging the conducting paths.

Probabilistic modelling. An interesting approach to modelling has been developed that captures the variability of climate driven factors (heat flow and air flows) in the form of a probability density function. It allows the climatic variability to be carried along in calculations relating to a particular building design so that answers for building heat loss, for example, finally emerge as probability distributions. These answers carry a lot more information than mean values.

1.4 Codes Standards and Education in North America

Drainage planes. There are currently no specific references to drainage plane solutions in current building codes in North America. Building codes tend to take a conservative position and drainage plane manufacturers have to follow an alternative compliance path. A project is underway (Don Onysko and IRC) to support such a compliance application for the EIFS industry.

Air barriers. The only national building code to have progressed towards an air barrier is the Canadian Code. Cold region buildings must now have an air barrier on the outdoor side of sheathing. The ASTM 2357 test method can be applied to check on the performance of an air barrier.

Air/vapour barriers. Combining the two functions of an air barrier and vapour barrier into one layer is an interesting development in Canadian buildings. There are several advantages: The structural part of the building is at room temperature and being inside the insulation, does not thermally bridge the building. The wall is also simpler to build and the air/vapour barrier can be sealed around penetrations more easily. The system will not trap moisture between separated air and vapour barriers (a common problem with traditional cold climate designs). This may an opportunity worth investigating for NZ as energy efficiency requirements become more stringent.

Building envelope professional qualifications. The BEP qualification offered by the Institute of Architects British Columbia is a five module course concentrating on thermal and moisture with passing reference to other areas such as structure and acoustic. Essentially it has not set out to encompass all of the skills required in a cladding design but to supplement the traditional engineering courses available in these areas with an understanding of heat and moisture. Many of these skills were found to be missing in older architects and engineers in Canada in contrast to acoustic and structural training which has been well established for many years. The five module course takes about 9 days.

1.5 New Zealand Research

1.5.1 Drying water from walls

BRANZ/FRST funded research has strong international connections. The programme is collaborating with a group at the Fraunhofer Institute in Germany on the WUFI computer program which will be used to broaden the application of experimental data for the whole of NZ. It has also connected with researchers from other active teams in Canada and the US.

Cavities shown to manage water leaks. Cavities have been found to be more effective at managing leaks through the cladding than direct fixed walls (there is a 3 to 1 advantage for ventilated cavity walls). More importantly, they reduced the chance of water bridging across to the framed and insulated areas.

Climate and wall orientation are important. Drying rates from the back of an absorbent cladding – or from the building wrap, are slowest in the winter on the south side. It is likely therefore that south-side winter conditions will drive water management designs for walls.

Drainage is very important. Walls that drained well had cavities and non-absorbent claddings. Walls with an absorbent drainage path require longer to dry out and framing moisture content increases were measured during this time.

Weatherboard walls are an exception. Weatherboards were an exception in direct fixed claddings in BRANZ experiments. When painted on the backs they drained back out through the laps and were sufficiently well ventilated to dry retained water faster than monolithic direct fixed walls.

Cavities were no answer if the framing is wet. Drying rate measurements found water to dry slowly from timber framing, at a rate determined more by moisture transport rates in timber than on the presence of a cavity or other management strategy. This conclusion would not hold in walls with air and vapour barriers.

1.5.2 Understanding ventilation

Ventilation effects are the least understood part of water management. The BRANZ/FRST programme has concentrated on understanding ventilation in walls because it is the least well understood of the four processes (drainage, wicking, diffusion and ventilation) that move moisture about.

Tracer system developed. The research NZ team was the first to successfully use tracer methods to measure ventilation in cavities. Measurements have been used to support a Canadian developed theory of cavity ventilation in terms of climate and vent size.

Ventilation rates higher than expected. Ventilation rates were higher than expected in open rainscreen and drainage plane cavities because infiltration paths present in the construction turn out to be very effective air leakage sites. In BRANZ measurements, open rainscreen walls were just about as well ventilated as top vented drained and ventilated walls.

Parapet walls might be an exception. Infiltration paths may not be present in parapet walls and there is some field evidence of decay in the chilled timber high in some walls. A separate project is planned to investigate how cavities manage moisture in this special situation.

1.5.3 Window to wall joints

Window trim cavities – the physics of water management. The BRANZ/FRST programme has nearly finished a series of projects to understand the important design factors in the weathertightness, and subsequent drying from window trim cavities.

New rain/wind map of New Zealand. An analysis of NZ climate data has lead to a new wind pressure map (representing highest two ten minute periods of wind coincident with rain). This might be aligned with test pressures in a future update of E2/VM1

Air seals are important but so are the vents. The most significant factor in the performance of 200 window-to-wall joints tested at BRANZ was the air seal, or more accurately the area ratio: (vent between facing and cladding - generally the gap under the sill facing) to (the effective leakage area of the airseal). This ratio should exceed 10 and in this respect it duplicates the advice followed by curtain wall designers for pressure equalized designs.

Window facing widths. An adequate facing cover over the cladding and sealed jambs are the next most important attribute. There was some evidence of a trade-off between the facing cover dimension over the cladding and the leakage area ratio.

Capillary paths in the trim cavity. Continuous capillary paths were shown to track water deep into the trim cavity but window trim cavity clearances of 5 mm or greater are an effective solution. Perhaps the biggest risk of creating a capillary path is leaving out the backer rod and filling the trim cavity with foam.

Two part head flashings. This type of head flashing potentially blocks the vents and drainage path into the head cavities but a study with tracer gas methods has show that ventilation can be borrowed through vented battens from the. flanking cavities. This overcomes one problem but there may be outstanding questions about well a flashing of this type drains (it would hold water if not sloped properly).

Flat sill trays. Flat sill trays are sometimes used behind flange windows in the US. Studies in four NZ style windows at BRANZ are underway and are showing that significant quantities of water can be managed by evaporation and ventilation in the trim cavity. The experiments have also found the flat sill approach to be less tolerant of high moisture loads than sloped trays.

1.5.4 Durability of framing timber

Timber decay rates at fibre saturation. A study of framing timber decay rates has shown that untreated sapwood of all species have decayed significantly after 52 weeks at fibre saturation.

Decay is slower in heart woods and LOSP treated framing. Douglas fir and larch heartwood were more slowly overcome by decay fungi at 52 weeks. Macrocarpa and Lawson cypress heartwood were more resistant to decay with only minor decay present after 12 months. The major difference between the untreated heartwood and the LOSP treated framing groups after 12 months was that decay mycelium had spread much more readily on the surface of the heartwood samples. LOSP treated macrocarpa and Lawson cypress were largely free of decay on the surface.

Boron treated specimens resist decay. Boron diffusion treatment was almost totally successful in preventing decay over twelve-month exposure.

1.5.5 Building wraps

Little major degradation of wraps exposed to UV. The BRANZ/FRST study of the durability of building wraps is incomplete but early results show that synthetic wraps become more permeable to water vapour (not in itself a problem) and lose some mechanical strength (30% of their tensile and edge tear strength) after accepted UV exposure. This interim result clearly cannot be generalised to all synthetic materials.

Exposure of wraps to timber treatments is underway. The effect of timber treatment chemicals on the properties of wraps in contact with treated framing is being studied in an experimental design that includes untreated radiata pine and Douglas fir as control materials alongside H1.2 boric treated and H3.1 LOSP treated radiata pine. The initial cycle of exposures is complete and further exposure is about to start.

Adhesion of flashing tapes to wraps and in the presence of treated timber. A variety timber and building wrap combinations have been exposed outdoors and in climate chambers with strips of flashing tape attached. The initial cycle of exposures is complete and some interesting provisional trends in tape adhesion have been identified. Flat polyolefin faced tape specimens appear to have significantly less adhesion (twice as many strips peeled) when compared to the other tape types. Interestingly, the tapes appear to peel and curl more on untreated timber but this observation will need to be confirmed with more systematic work.

1.5.6 Weathertightness of claddings

Weathertightness of claddings in an E2/VM1 test. Careful measurements of the water leakage rate as a function of applied pressure (water leakage fingerprints) have been carried out to support future developments of E2/VM1. The results are not easily interpreted as leakage rates through a cladding on a building but do highlight the areas most prone to leaks.

Ranking the leakage sites – It was found that gravity leaks through cracks and other defects in timber weatherboards are much more significant than leaks through well fitting lap joints. For metal, plastic and composite the largest leaks were at butt jointers.

Lap joints and air carried leaks. The most significant dimension in a lap joint is the gap width rather than the overlap dimension. Larger gaps (> 3 mm) allowed air carried water to spatter across to the plane of the building wrap at test pressures around 50 Pa (a failed wet wall test in E2/VM1). Gap widths less than 2 mm filled with capillary held water and did not overflow until the test pressure exceeded the static head equivalent to the overlap (typically 250 – 350 Pa). An implication of this is that cupping effects and fixings that do not hold laps together will reduce the weathertight performance of weatherboard walls.

1.5.7 Experiences with E2/VM1

Although E2/VM1 was trialled with some common wall designs in its development phase, the following experiences from several years of application could be useful feedback in a future review of the VM.

Scope of E2/VM1. The scope is currently limited to open rainscreen and drained and ventilated cavity walls. In practice this does limit the development of mass walls and drainage path solutions but E2/VM1 can be expected to broaden into these areas when the science of water management is better developed.

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Common reasons for water bridging the cavity. A criteria for failure is water bridging across the cavity to the building wrap. This can occur for systematic reasons e.g. tracking back along an incorrectly sloped brick tie, or non systematic reasons e.g. water tracking across a nail splintered batten. A particularly common systematic reason for failure is water tracking across the end grain on a short batten on a window jamb line.

Capillary paths in window trim cavities. Earlier research projects have warned of the danger of tight trim cavities tracking water to the air seal. One of the more common ways this capillary path has been created in test specimens is by over filling the trim cavity with foamed-in air sealant.

Wet wall test for D1 performance. In BRANZ experience this is the most difficult part of the test to pass. Failures result from water accumulating on the back of the cladding eventually crosses to the 'dry' side of the cavity at sills and where elements bridge the cavity. 50Pa is a significant pressure but we have not yet seen claddings with a good field track record failing the test.

2. AN ENGINEERING BASIS FOR WEATHERTIGHTNESS

Engineering models of building performance are an important part of performance based codes. They confirm by calculation that a building design will cope with environmental loads (usually derived from a statistical understanding of the load). The best known examples are those for structural and thermal design - where the likelihood of load (a wind pressure or outdoor temperature) can be estimated and a design calculation completed to ensure the building responds appropriately. Engineering models have been slow to develop where one or more of the variables are difficult to express in statistical terms, e.g. workmanship quality and its influence on water leakage through claddings and air infiltration into the building.

Considerable progress has been made in recent years towards an engineering basis for the moisture tolerance of walls and roofs. Figure 1 provides a simplified view of the data and calculations needed to show whether a building is well enough water managed for its location. Many of the interconnections between boxes are omitted for simplicity and each box is coloured to reflect current knowledge in terms of the quality of available data and competence of calculation methods. The colour code is as follows:

- **Red** – Poor data available - no existing model
- **Yellow** – Case studies provide some data - model under development
- **Green** – Statistical basis for data - model complete and tested

The least well understood aspects of an "engineering model of weathertight design relate to the durability of damp materials and how to factor workmanship quality into a moisture load calculation. Work has started on the durability question but accounting for workmanship has been largely ignored by international research teams. It raises the question of how serious a defect in the weather defences of a building might be used to estimate a water entry load and test the capability of the water management system. Two approaches to the problem are possible:

- Define a series of defects (gaps in seals around windows, openings in claddings etc) and estimate a water leakage rate from rain intensities and wind data. This approach was taken by the MEWS project in Canada. An obvious problem with this approach is that water loads are affected by run-off which will be very building design dependent.
- Benchmark water management capabilities and water leakage characteristics of claddings against the field track record of cladding systems. Such an approach would suggest that a cladding with similar leakage characteristics and absorbency to brick veneer might need a drained and ventilated cavity in climates where brick veneer is successful. The benchmarking approach would be unable to cope with a totally new approach like a drainage plane.

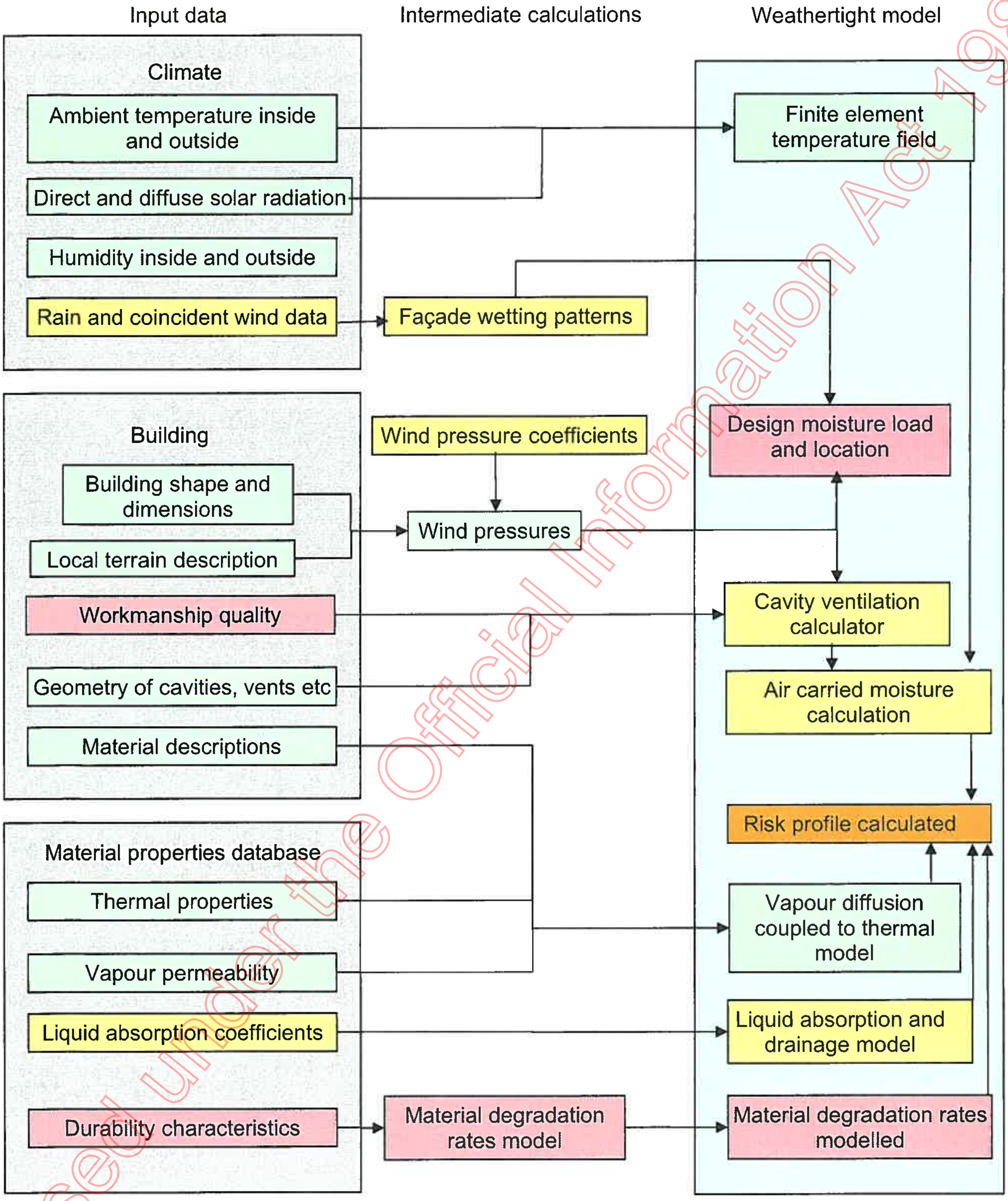

Figure 1. The components of a weathertightness model

Three major studies of moisture management in walls have been completed:

1. The MEWS project "Moisture management in exterior wall systems"
2. The ASHRAE funded 1091 project "Development of design strategies for rainscreen and sheathing membrane performance in wood frame walls"
3. California Energy Commission contract "Energy efficient and mould-resistant building materials and construction practices for new California homes"

2.1 The MEWS weathertightness model

MEWS (Moisture management for external wall systems) was developed in Canada at the Institute for Research and Construction (Kumaran et al. 2003). It is the only complete model available at this time that calculates a moisture load appropriate to a given climate and wall type, and then plots the hygrothermal response of the wall in terms of a climate related index. Climate data has been used to calculate a moisture index (MI) and a range of climate zones (41 zones in North America). A study of water leakage rates through 5 standard (but plausible) leakage sites into 17 walls provides a moisture load and final damp spot (normally the bottom plate). Finally the hygrothermal properties of materials in the wall and detailed climate data for the building site are used in the HygRIC model to calculate the wall drying response. Conditions in the wall are expressed in terms of an RHT index. This is a degree day type climate summation based on the time when both temperature and RH conditions exceed RH_x and T_x. It is expressed as follows;

$$RHT = \sum (RH - RH_x)(T - T_x) \quad for \quad RH > RH_x \quad and \quad T > T_x$$

Different values are chosen for RH_x and T_x. appropriate to the durability of materials in the wall. Figure 1 shows the main elements in the model.

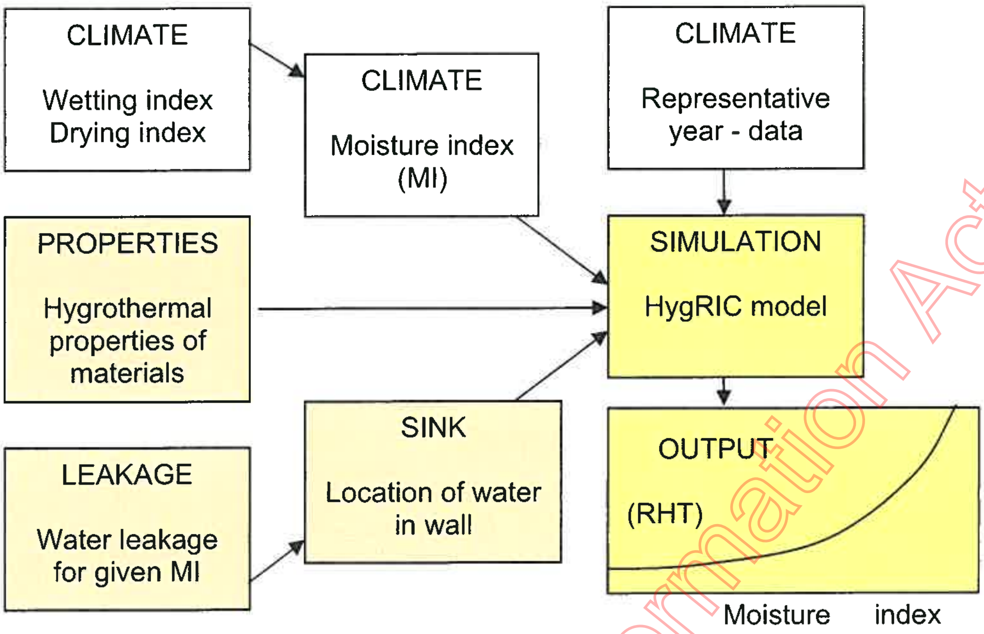

Figure 2. A schematic outline of the MEWS model

The model has been used extensively in Canada and owes its development to a consortium of industry partners and government agencies. Some alignment with field experience has been achieved to support the predictions made using HygRIC. While it might be questioned how closely the water entry studies align with water leaks in practice, at least the water leakage sites were plausible eg imperfect seals at window and duct penetrations. Unlike any other existing model framework, the MEWS approach takes the step of deriving water entry rates for a given climate.

2.2 The ASHRAE sponsored 1091 project:

The title of the ASHRAE 1091 project is "Development of design strategies for rainscreen and sheathing membrane performance in wood frame walls". The project aim was: Study the mechanics of ventilation in screen-type wall systems and assess the potential for ventilation drying of common above-grade residential wall systems. Three groups contributed to the programme:

- The Pennsylvania housing research/resource centre at Penn State University
- The Building Engineering Group at Waterloo University in Canada.
- The Building Technology Centre at the Oak Ridge National Laboratory.

This large study was managed by Eric Burnett, John Straube and Achilles Karagiozis in the above organisations and the twelve final reports are available from the ASHRAE website. A review of the programme is provided in Report 12 (Burnett 2004). The main contributions made towards understanding ventilation effects in water managed screen walls are as follows:

The physics of air flows through vents and cavities. The research team explored several ways of representing ventilation in wall cavities from the equations developed to understand air flow in ducts to a full CFD approach. In the end the former approach has been adopted for simple "design based" calculations of ventilation and moisture extraction rates in the water managed cavities. A CFD approach gives ventilation data with better spatial resolution but it may not be worth the extra effort in view of the uncertainties in vent sizes and because the flow is mostly in the laminar range.

Flow equations and flow characteristics developed. Piñon 2004 developed the ASHRAE duct flow equations and provided a wider range of flow coefficients for different vents and cavities (some obstructed with mortar). The group used these to calculate ventilation flows in a wide range of cavities, some of which included the gaps between weatherboards. Drying rates measured experimentally broadly agree with calculated drying rates from ventilation estimated using wind and temperature data.

Pressure coefficient data provided. The main drivers of ventilation in cavities are stack and wind pressures. The ASHRAE 1091 research team has measured some Cp's at vent locations on a similar test building to that built at BRANZ. This data has been used extensively and it has been generalised for larger buildings as well (Piñon 2004). This provides a way of calculating lateral air flows (between adjacent cavities and around the corners of the building) as well as vertical flows between top and bottom vents.

Hygrothermal models. A database of hygrothermal data (Kumaran 2002 and Karagiozis et al.2004) has been provided and the "Moisture expert" model developed to include ventilation effects. This model has been benchmarked against field data and used in a parametric study (Karagiozis 2004) of the sensitivity of drying rate to cavity depths and vent size etc. It has shown that the primary leakage resistance to the cavity ventilation is the vent opening rather than cavity dimensions, and that wind pressures generally predominate over stack pressures.

Ventilation wetting. The parametric application of "Moisture Expert" has shown that concern about ventilation wetting (ventilation actually adding water to the water managed cavity) are misplaced in US and Canadian climates. Some moisture content gains were seen in extreme situations (where material moisture contents were very low).

2.3 The California Gas-technology project

This project "A study of energy efficient mould resistant materials and construction practices for new California homes" is a comprehensive study of opportunities to improve the weathertightness of buildings in an undemanding climate www.gastechnology.org/mouldresearch. It does not develop any of the underpinning science like the MEWS and ASHRAE projects but it is a good example of a review of practices and opportunities for avoiding the widespread weathertightness failures seen in other parts of North America. Its particular strength is the way that it has involved a wide range of contributors from many sectors of the industry and in the way it has used demonstration homes and documentation for builders to pass on its most important messages. The study uses a range of existing resources:

- Existing literature on moisture in buildings
- Water damage claim records from the insurance industry
- Laboratory studies of some aspects of moisture management
- Hygrothermal modelling using existing programmes.

The study recommends many changes to building practices and standards and it promotes these with demonstration homes and builder oriented documentation. The following aspects of the study are interesting from a scientific point of view:

Drainage plane stucco walls. A wide range of drainage plane products are available in North America that are intended to drain water leaks through stucco claddings and from window reveals. These range from multiple layers of conventional wall wraps to special woven mats sometimes adhered to the WRB (water resistant barrier). Most of these were shown in the study to be effective capillary drainage paths but the measured drainage rates were very low (0.1 to >1.3 cc/minute.m). Drainage rates at the high end were attributed either to the presence of a proper drainage mat or cracks in the stucco cladding draining water back outside. Drainage openings at the base of the wall were sometimes found to be blocked by stucco.

Limited modelling in 1 D. Limited modelling of moisture in OSB sheathing was carried out using WUFI 1D in Californian climates. The modelling was acknowledged as not including ventilation and liquid absorption effects but showed little tendency for sheathing moisture contents to reach undesirable moisture levels.

Drainage from behind flange fixed windows. All of the vinyl windows in this study were flange fixed to the timber frame and therefore of limited direct interest in New Zealand. The preferred approach to managing water leaks through the window frame into the trim cavity behind the flange uses a sill pan, but instead of flashing outside, water is flashed into the drainage plane or weep screed behind the stucco cladding. The WRB is detailed around the frame and flashing tape applied (as in New Zealand) and the pan flashing added before the window. Creating a pan flashing with flashing tape and a back dam was generally unsuccessful and the joints between three piece moulded plastic flashings were difficult to make water-tight. Overall though, sill pans were recommended for new homes along with a functional drainage plane and an effective air barrier at the reveals. Further work was recommended to strengthen the link between these installation practices and long term performance.

3. THE LITERATURE ON WEATHERTIGHTNESS SINCE 2004

The paragraphs in this section report on recent building physics conferences in North America and the scientific literature since 2004. The following conferences were all attended by members of the NZ FRST funded programme where papers from the NZ research program were presented.

- The 3rd International Building Physics Conference Montreal 2006.
- BETEC seminar on building science applications Syracuse 2006
- The 11th Canadian Conference on Building Science and Technology Banff 2007

There was a strong moisture emphasis in all of these meetings (rain leaks, vapour diffusion from inside the inside of buildings and hyrothermal modelling), indicating that moisture problems are still a big issue. The Canadian papers are generally the most useful to leaky building studies in NZ because they relate to the same problem (an epidemic of water leaks) and because they relate to big enough systems to be useful, e.g. whole walls on a building rather than a single material in the laboratory. Studies in European universities still focus on moisture flows in homogeneous materials and the common problem of how to manage moisture in insulated stone or masonry buildings (sometimes heritage buildings). Other active areas are the science of driving rain and wetting patterns on facades, and the development of hygrothermal models like WUFI to solve these problems. The following bullet points highlight important points.

3.1 System performance

Moisture in parapet tops. A paper by Goncalves and Rousseau 2007 deals with a variation of the problem attracting some attention in NZ e.g. condensation and decay in cooler framing in parapet walls. An investigation of the temperature in parapet sections of curtain wall and recommendations for keeping humid air from chilled surfaces has been described. Because this particular study relates to curtain walling with apparently no difficulty in isolating some areas in the cavity from humid air, it is almost certain that a different approach will have to be taken in NZ.

Latest thoughts on vapour barriers. Polyethylene vapour barriers have been adopted into building codes and practices in Canada but are known to limit drying from within walls. A number of papers have been written e.g. Wilkinson et al. 2007 that talk about an optimum vapour permeance to cope with indoor moisture in winter and interstitial moisture from summer condensation or from rain water leaks. This is and example of physical properties having to be fine tuned to meet multiple objectives. The air/vapour barrier concept might overcome this problem but it not to have been applied to residential scale buildings.

Ventilation in roofs – influence on insulation and moisture control. Several papers deal with the moisture and energy performance of roofs but one paper Ciucasu et al. 2006 uses CFD methods to calculate S-factors (which compensate for ventilation in insulated systems). This is an interesting new analytical approach to cavity ventilation impacts on insulation. The work is a result of collaboration between ORNL and CRIR in France.

A new air/vapour barrier concept. An new wall system in Vancouver uses a single air/vapour barrier (typically a peel and stick) and does away with an insulated cavity trapped between an air and vapour barrier which has the potential to trap moisture. From the inside, the sequence starts with the indoor lining and structural cavity (the cavity might contain wiring and little else. The next layer is sheathing with the air/vapour barrier on the outdoor side. Next is the insulation (normally rigid fibre

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glass). Finally, the outer layers are the water managed cavity and the cladding, supported on the structural frame. A paper by Finch and Straube 2007discusses the placement of insulation in relation to the cavity and sheathing, drawing on long term moisture measurements and some modelling.

3.2 Moisture management in walls

Indoor moisture contributing to wall cavity condensation. A paper from Waterloo University (Finch et al. 2006) reported on large scale condensation on the insulated cavity side of sheathing. The building (multi story in Vancouver) had been retrofitted with a rainscreen cladding and the vapour barrier behind the wall lining had been eliminated. Condensation in a wall that has had its vapour barrier eliminated is of course interesting because it questions fundamental thinking on moisture movement into and out of cavity walls. In this case the problem was traced to sub-standard indoor moisture control and was ultimately cured with a better ventilation system. The message from this paper is that optimally water managed walls do not necessarily also manage moisture from indoors.

Wicking from condensation planes – a European approach. The DELFIN computer program has been used to model the effect of two insulation systems applied to the interior of a historic building in Amsterdam (Grunewald et al. 2006). Two options were explored: using vapour tight cellular glass and capillary active calcium silicate. The latter system turned out to more effectively manage water (mostly rain water) because it dried to the inside of the building. This is an interesting application of wicking water from a possible condensation plane in a wall to a point where drying can take place. It is an example of engineering the wicking and diffusion properties of solid walls to optimise moisture performance.

Drainage planes. John Straube 2007 investigated drainage in sub 1 mm gaps and found that effective drainage is possible with non absorbent materials in the drainage path. This paper summarises an MSc thesis (Smegal 2006). Another important point is that the scope for drainage plane solutions comes down, in part, to understanding likely moisture loads and this means moving away from the traditional rain leakage tests to more realistic rain intensities. It turns out that drainage rates through small gaps (0.5 mm) can exceed realistic rain intensities (in Canada) and likely leakage rates. The biggest single challenge for drainage planes is capillary trapped water and subsequent transfer through the building wrap into timber framing. Clearly absorbent materials and moisture traps should be avoided, but there are opportunities for ventilation drying, especially if the drainage path is a reasonably thick mat. A reasonable conclusion at this stage is that drainage plane solutions look possible but there is much more to proving they work than for conventional cavities.

The role of ventilation drying. Shi and Burnett 2006 have measured the capacity of specimen walls in the laboratory to dry from ventilation. WUFI simulations tend to support measured drying rates and illustrate the dominant role of ventilation (over vapour diffusion) in controlling cavity moisture. Some rare climatic conditions were shown to increase the moisture content of sheathing (and question the generality of the statement) but not to a worrying extent.

Conditions for mould growth. The conditions that support mould growth in untreated timber proposed in ASHRAE Standard 160P and IEA Annex 14 are questioned in a paper by Black and Straube 2007. A series of experiments with unseeded specimens appeared to be mould free at 95% RH at 26 C over long periods and suggested that the presence of liquid might be a key to starting the process.

Drip edge effectiveness. Saneinejad et al. 2006 makes a start to measuring the effectiveness of drip edges as a function of horizontal projection and the angle of the kick-out. As expected, edges with greater horizontal projection are more efficient at removing running water from a face. The paper shows that even minor horizontal projections are useful with efficiency figures of around 50% for 10 mm horizontal projections.

3.3 Instrumentation and laboratory methods

Detecting moisture with wide-band radio waves. Some preliminary experiments to measure changes in the dielectric constant of materials with radio waves are underway in Glasgow and have been described by Healy 2006. While the method does appear to have some sensitivity to moisture, this is not exclusive of other materials which means there is little prospect for a new diagnostic tool.

Moisture detection tapes. An interesting development of the pin moisture probe for measuring timber moisture contents was presented by a group from DETEC Systems in British Columbia (Vokey 2006). They offer a tape with two copper tracks which can be tacked to framing or sheathing members in a wall. Small pins hammered through the tracks into timber then act as moisture pins and the electrical impedance of the tape reflects the wettest part under the tape. So far the method has been used to warn some owners of problems in their building. There is apparently a method to locate the wettest part along the tape using a time delay method (TDR). It has been questioned whether the system could be used as a time of wetness sensor. It turns out that if the physical properties of the top layer could be modified to be absorbent but not hygroscopic, then it might be possible to calibrate the tape to measure condensation. There is a four track version of their tape that can be configured as two legs of an impedance bridge to help locate wet spots. The paper describing these used the new materials in test walls with spray bars to wet the exterior. Leaks in the cladding can be more quickly located and fixed at an early stage of the buildings life.

Transient airtightness methods. This approach to airtightness measurement described by Mattsson and Claesson 2006 is a little unusual in that it measures building air leakage from a single pressure fluctuation induced in the building. It takes account of building envelope flexibility and the resulting temperature fluctuation. The traditional coefficient and exponent can be worked out by fitting the pressure decay curve to a simple formulae. It turns out that the volume change correction is significant enough to limit the application to specialised laboratory situations. Agreement can eventually be achieved with the long winded steady pressure method that everyone uses but the equipment for the transient method looks expensive and the data open to misinterpretation.

3.4 Mathematical tools

Probabilistic modelling. An interesting paper from Chalmers University in Sweden (Pietrzky and Hagentoft 2006) shows how to capture the variability of climate driven factors (heat flow and air flows) in the form of a probability density function. It allows the climatic variability to be carried along in calculations relating to a particular building design so that answers for building heat loss, for example, finally emerge as probability distributions. These answers carry a lot more information than mean values and would be valuable to air conditioning system designers etc.

Computational fluid dynamics. There are many papers reporting on the application of CFD methods to ventilation studies and as part of HAM models. There is no doubt that the method is now well established and (apart from arguments over turbulence models) widely used. The main limitation to its application in buildings is knowledge of the boundary conditions. These are often very complicated and poorly defined when it comes to generalising CFD results to a large number of buildings.

HAM Models. Heat and mass transfer models continue to evolve with sometimes reasonable agreement with experiment. There are three models that now include ventilation as well as vapour and mass transport coupled to temperature fields. These are the Canadian model HygRIC, the ORNL model “Moisture Expert” and WUFI. All have been released commercial as one dimension models but 2D versions with ventilation are still in the research domain.

4. WEATHERTIGHTNESS RESEARCH IN NEW ZEALAND

4.1 Early BRANZ research

The weathertightness research programme at BRANZ started in the early 1980,s with an early focus on commercial building claddings – particularly curtain walls which were starting to be designed with pressure equalised drained joints. BRANZ research contributed to the global effort needed to ensure that the performance gains from the pressure equalised approach could be realised in commercial cladding designs. At the same time, a range of fundamental research questions were addressed e.g. the physics of weather grooves was advanced and research started on residential cladding performance (particularly plastic weatherboard claddings) and on a range of window related issues. The following is a brief summary of research to the mid 1990’s.

Residential cladding studies. A study of the weathertightness of residential claddings was completed and results published by Bishop and Bassett 1990. This work showed that air carried water was an important failure mechanism of board type claddings with conventional window detailing and suggested that wind barriers were important to the performance of screen type claddings in windy locations and in the absence of an internal lining. The work also found that wider window facings improved the performance of window to wall joints.

Drained joint case studies. This project gathered together 20 case studies of water leakage problems in high-rise cladding systems in Australia and New Zealand in a publication by Bassett, Bishop and Brown 1991. It described the failure mechanism, the remedial action taken, and the principals involved in all the case studies. At this time there was considerable interest in the performance of pressure equalised joints although the principals was not always applied properly at intersections and expansion joints.

Weather groove detailing. This project developed a theoretical basis for weather groove shapes and trailed several groove geometries in a range of materials. The science was published Burgess 1991 and the results embodied in many bulletins and BRANZ publications since that time. The project has provided valuable information for the BRANZ Advisory and Appraisals processes and helped counteract a drift to inadequately sized weather grooves.

Dynamic weathertightness test development. This work was assisted by the Building Research Establishment in the United Kingdom where a range of test methods for applying realistic pressures (including lateral pressure gradients) on residential claddings was investigated by Mayo and Burgess 1994.

Roof underlays. This project was partially funded by FRST and CHH Roofing and was completed in 1995. The project found there to be little gained by a roof underlay under tile roofs. (Cunningham et al. 1994 and Burgess 1994 and 1995).

Pressure equalisation performance of commercial claddings. This project ran through the mid to late 1990's and developed a theory linking pressure equalisation performance (called the PEP ratio) with the cavity size and the size and location of air leakage openings. The model was checked against measured pressures in several commercial claddings in the Wellington area. The work was published by Burgess 1995 and 2000.

Drained glazing rebates. This project is partially funded by the insulated glazing industry and the aluminium window industry, and trialled a range of drainage details and the exposure of the edge seal of Insulated Glass Units (IGU's) to high humidity and liquid water. Results from this project were discussed with IGU manufacturers.

4.2 Structure of the FRST/BRANZ weathertightness programme

BRANZ weathertightness research changed direction in the late 1990's to work on an engineering basis for the weathertightness performance into walls. It attracted FRST funding in 2003 and began to fill in the missing pieces needed for a computer based model of moisture management in walls. Figure 2 outlines the steps along the way in three sub-programmes:

- **Developing the WUFI program** (an existing model including vapour diffusion and a thermal model in 2 dimensions) to include all of the driving forces of moisture (blue boxes).
- **Understanding and developing a model of ventilation in cavities** (green boxes). This is having to be developed from grass roots.

MRB SMcN

- **Understanding the durability of materials** in moist environments (brown boxes).

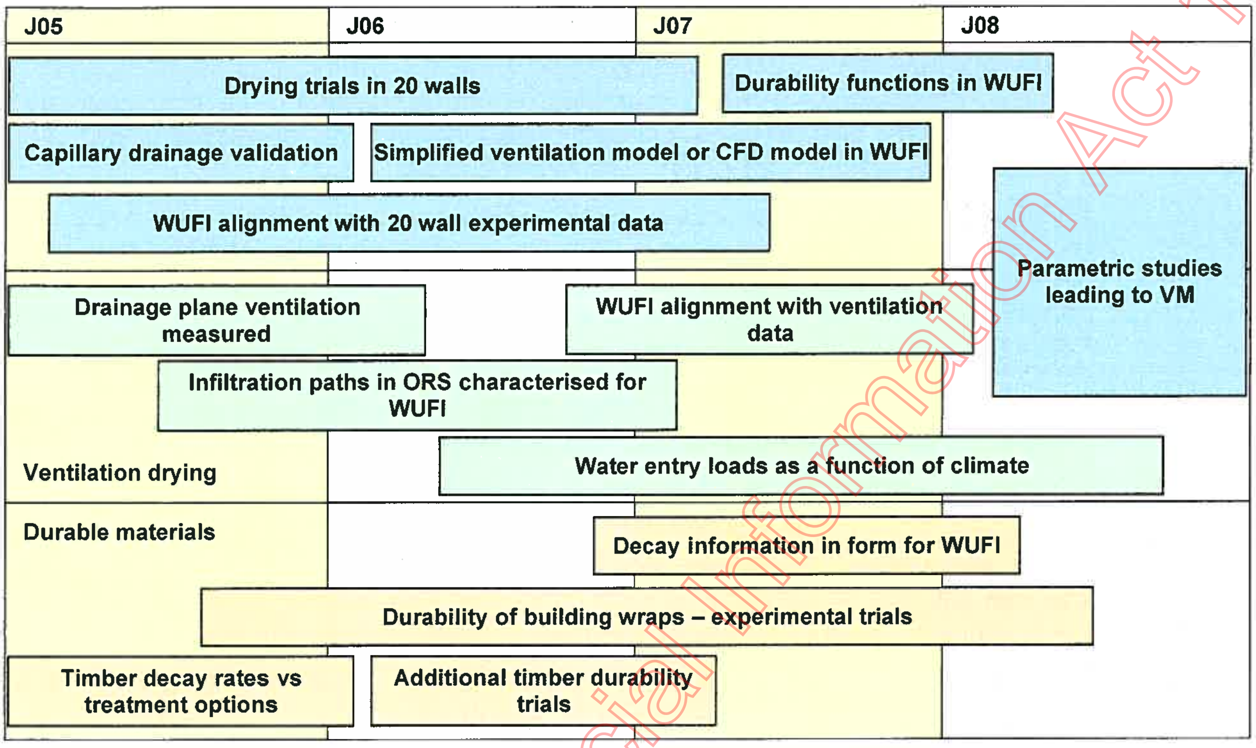

Figure 3. An outline of the FRST/BRABZ programme leading to a computer based assessment of water management in walls (WUFI)

In addition to this programme, the following projects have been funded by the Building Research Levy as in Figure 2:

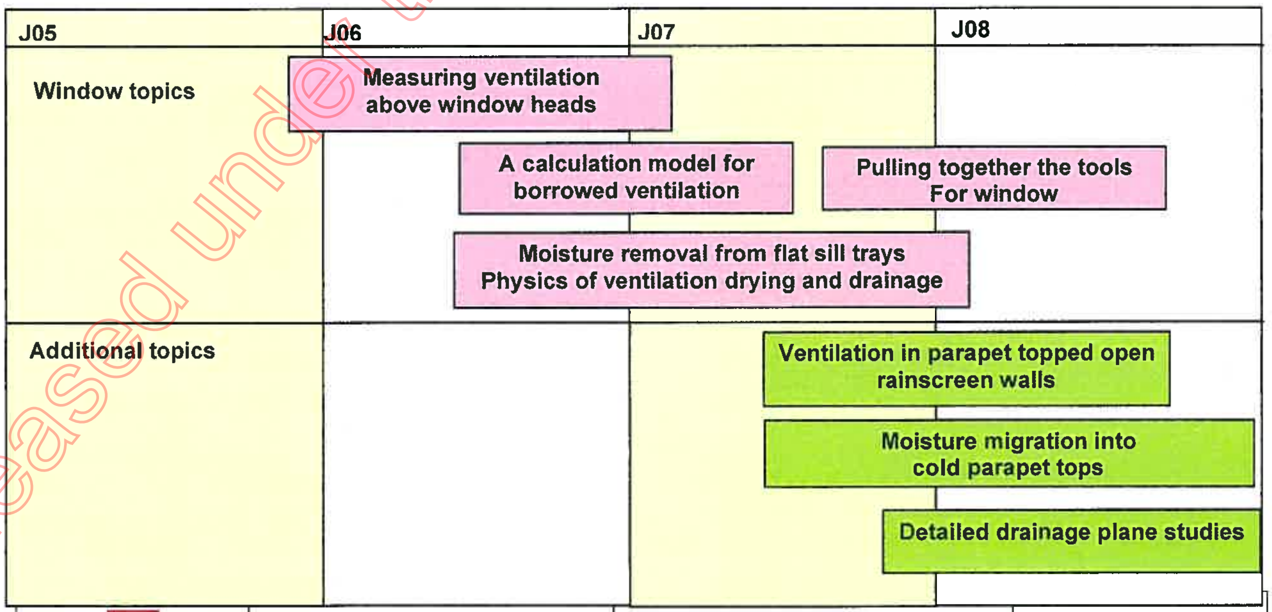

Figure 4. An overview of new weathertightness research topics funded by the Building research Levy

4.3 Water management in walls – measured performance

A series of New Zealand-based drying rate measurements have been completed in specimen walls mounted in the test building shown in Figure 5. The north and south facing long walls each contain 10 wall panels 1.2 m wide by 2.4 m high, and there are two panels on the east and west sides. The internal frame in each wall creates an 800 mm by 600 mm central measurement zone surrounded on four sides by a guard area. All of the walls have the same building wrap (spun bonded polyolefin), insulation (R 2.2 fibreglass) and internal lining (painted paper-faced gypsum board), but have different claddings and water management details as outlined in Table 1. Some of the fibre-cement walls were painted on their inwards facing surface to factor in cladding absorbency as a system variable.

Figure 5. Experimental building at BRANZ for measuring drying rates from walls

Table 1. Experimental walls showing cladding and approach to water management.

Wall	Cladding	Water management	Wall	Cladding	Water management
1	Fibre-cement	Open rainscreen	13	Fibre-cement	Direct-fixed
2	Fibre-cement	Open rainscreen	14	Fibre-cement	Direct-fixed
3	Fibre-cement	Open rainscreen	15	Brick veneer	Drained & ventilated
4	Fibre-cement	Drainage plane	16	Fibre-cement	Drained & ventilated
5	Stucco	Direct-fixed	17	Fibre-cement	Drained & ventilated
6	EIFS	Drainage plane	18	Weatherboard	Direct-fixed

7	Fibre-cement	Direct-fixed	19	Fibre-cement	Open rainscreen
8	Fibre-cement	Open rainscreen	20	Fibre-cement	Direct-fixed
9	Weatherboard	Direct-fixed	21	EIFS	Drainage plane
10	Fibre-cement	Drained & ventilated	22	Stucco	Direct-fixed
11	Fibre-cement	Drained & ventilated	23	Fibre-cement	Drainage plane
12	Brick veneer	Drained & ventilated	24	Fibre-cement	Drainage plane

The experimental walls fall into the following four categories from a water management point of view:

Drained and ventilated walls with a cavity vented at the top and bottom eg brick veneer.

Open rainscreen walls with a cavity vented only at the base of the wall.

Drainage plane walls with a drainage mat behind the cladding that is vented at the base.

Direct fixed walls with no deliberate cavity.

At this stage there is nearly three years of drying rate measurements from various positions in these walls. Each wall has been dosed with a known quantity of water and its moisture response measured in terms of the humidity in the cavities and timber moisture contents. Water was released in the following three locations in all of the walls on separate occasions and in different seasons:

- **On the back of the cladding** – simulating a leaking cladding
- **On the insulation side of the building wrap** – simulating condensation on the wrap
- **On framing at a stud/dwang junction** – see Figure 6 below showing dosing point and pin moisture content measurement points.

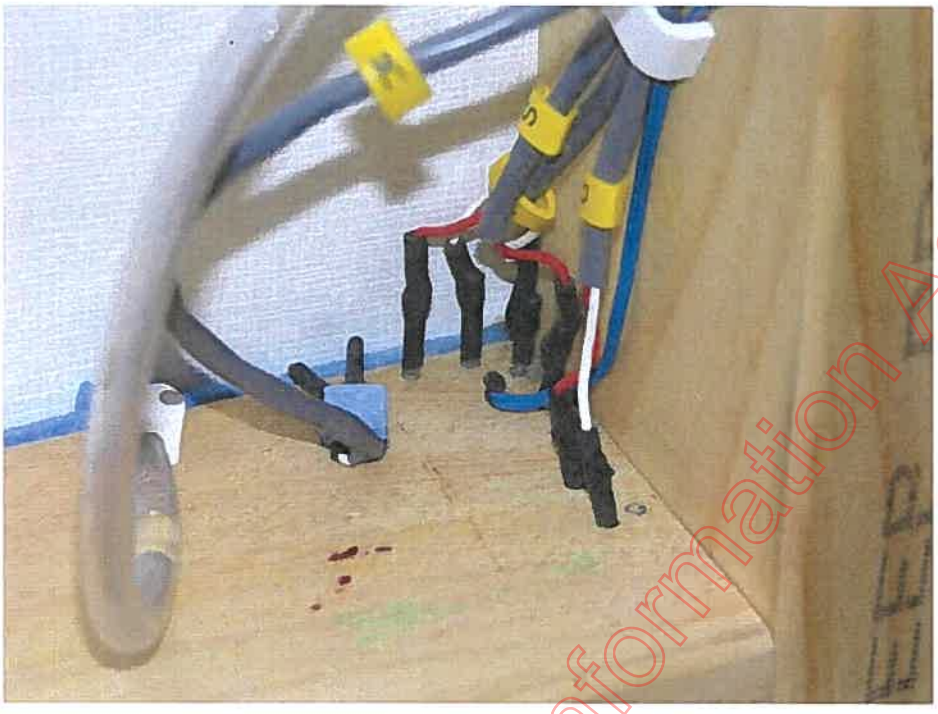

Figure 6. Location of moisture pins in relation to stud/window sill framing.

Drying rates measured to date are given in Figure 7 for all three locations but still missing are winter drying data from the back of the cladding. This will be measured mid 2007.

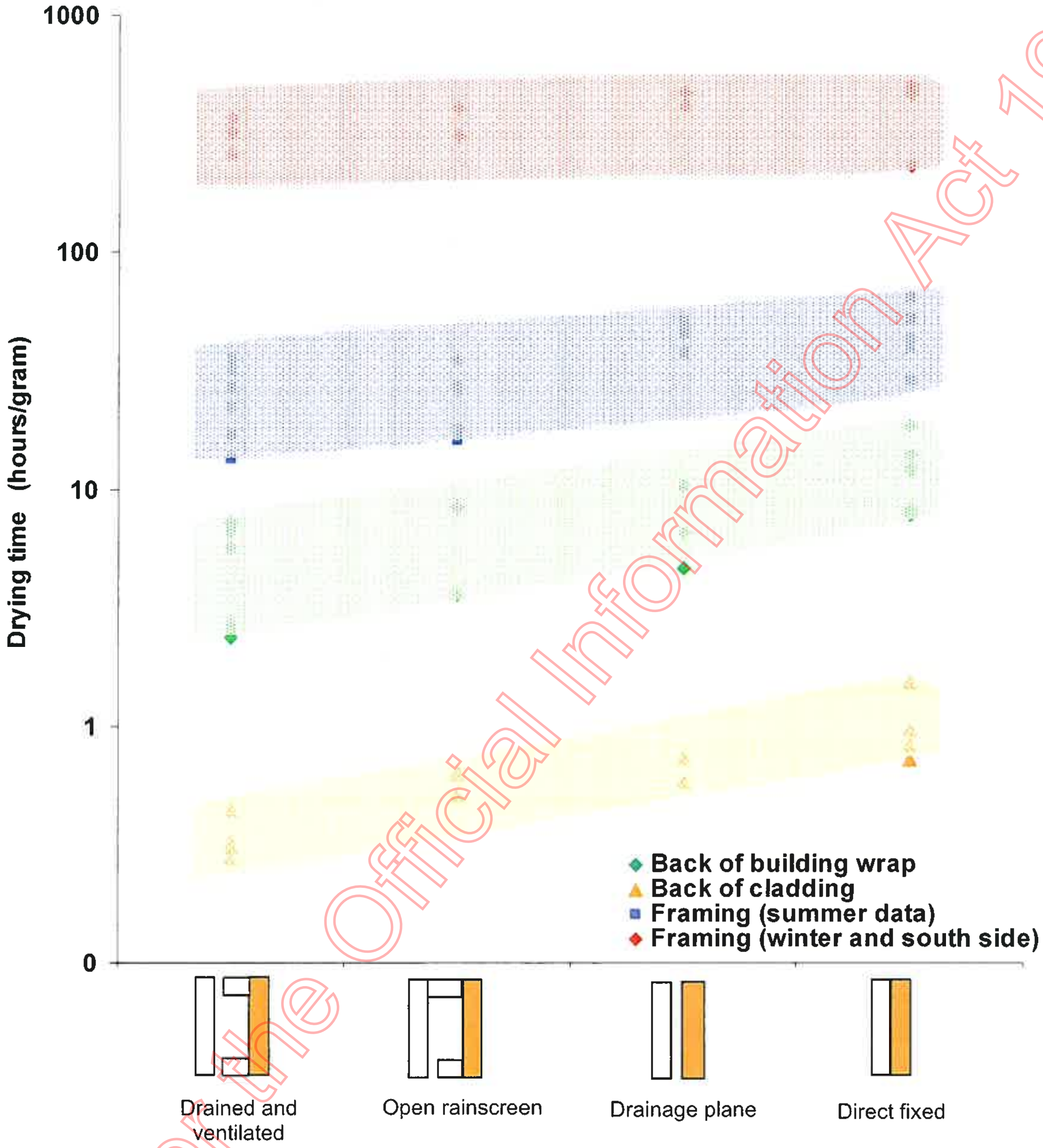

Figure 7. Drying rates for water released in three locations in 24 experimental walls.

There is some spread in the drying times for each wall type due to wall orientation and cladding differences. More detailed discussion of these results can be obtained in McNeil and Bassett 2007 but the main messages in the data are highlighted in Figure 7 with the help of shaded areas that group together the same type of data. At this stage, Figure 7 relates to only one building in Wellington, but the following observations can be made:

(i) Drying from insulated spaces (the back of the building wrap) –

(a) The year and orientation averaged drying rates show the water managed walls dealing with moisture trapped in the insulated areas (on the back of the building wrap) more effectively than the non-water managed direct-fixed designs.

(b) Warmer summer conditions and north orientations (where higher surface temperatures were recorded) approximately halved the drying times in all wall types.

(c) Cladding types were found to influence drying rates in the insulated cavities of direct-fixed walls. Here the drying times were higher (by a factor of 1.5) in walls with stucco and other monolithic claddings than weatherboard claddings (which are naturally ventilated).

(ii) Drying from water managed cavities –

(a) The ventilated cavity walls dealt with water trapped on the back of the cladding or on the building wrap more effectively than the non water managed direct fixed walls. This can be seen as faster drying times for the water managed walls and the envelope of the data points (shown as shaded bands of colour) sloping down towards the ventilated cavity walls).

(b) Non-absorbent claddings in our experimental walls retained very little water and this clearly reduced the need for ventilation drying. It is quite common now to hear North American researchers emphasising this point and we note that some manufacturers have responded by coating the backs of their claddings to reduce absorbency. If the cladding is absorbent, then the drying data shows that drained and ventilated and open rainscreen walls recover quicker than those with direct fixed claddings. On average there is a 3 to 1 advantage here for the ventilated cavity walls.

(c) Bevel-backed weatherboard successfully drained out introduced water within two or three laps below the water leak.

(iii) Drying from the framing

(a) The cavity designs did not help dry water from framing in these experiments. This can be explained in terms of the drying rate being limited by much slower moisture transport rates in timber. In a round about way it emphasises the importance of preventing water from reaching the insulated cavity in the first place. In comparative terms, water escaped a hundred times faster from the back of the cladding than from framing (1000 faster than in the winter).

(b) The final point that needs to be made is that drying rates will be different in other parts of New Zealand and for many wall types not represented in our experimental building.

4.4 Progress towards a model of ventilation drying

The science of ventilation inside walls has had to be developed from grass-roots in this programme. Various researchers eg Burnett and Straube 1995 and Pinon et al. 2004 have explored the physics of air flow in ducts and developed equations for air flow rates in terms of the driving pressures at vents (wind and stack pressures) and the geometry of vents and cavities. Beyond this, CFD models can handle localised turbulence rather more effectively than the duct flow models but all of these approaches are limited by the following missing information:

- Measured ventilation rates in wall cavities to check model predictions
- A detailed understanding of vent sizes and infiltration paths in walls
- A database of wind pressure coefficients with adequate special resolution

This program set out to deal with the all of these points and results available can be summarised as follows:

4.4.1 A carbon dioxide based tracer method

These studies used an infra-red gas monitor (manufactured by Edinburgh Instruments Ltd) to measure the concentration of a tracer gas carbon dioxide. The dual wavelength infra-red sensor was calibrated in the 0 to 3% range and assembled, together with gas lines and solenoid valves, to deliver tracer and sample air from any wall cavity. Figure 8 shows the CO_2 detector and sampling solenoids and Figure 9 shows the main components in the system and the layout of sampling and dosing points in a brick veneer wall cavity. Greater detail of the equipment can be found in papers by Bassett and McNeil 2005, 2006.

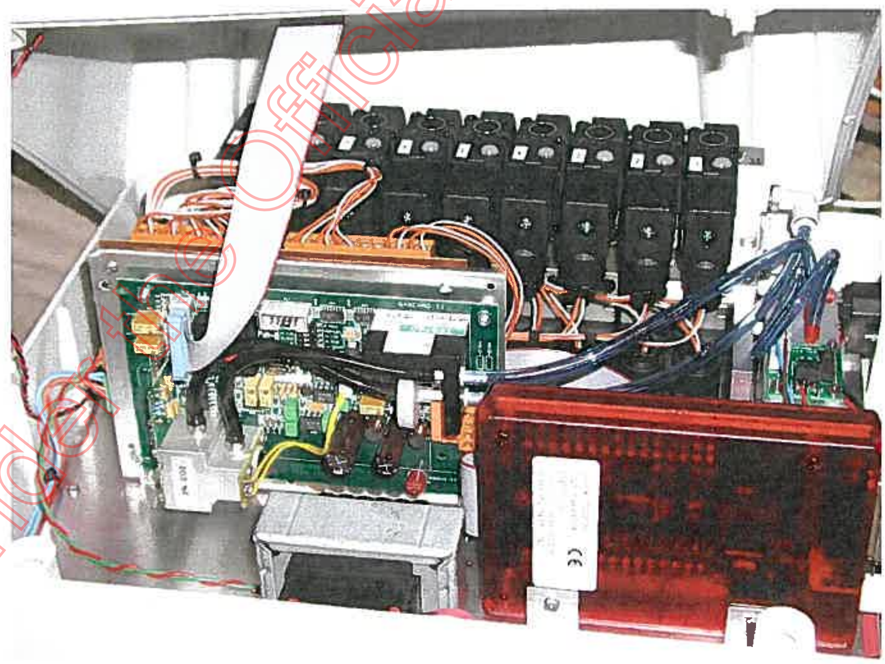

Figure 8. Infra-red absorption detector equipment used to measure ventilation rates.

The tracer gas CO_2 can be absorbed in some building materials, particularly cement-based claddings, but this was generally avoided by painting all fibre-cement claddings (to alter their water absorption characteristics). A more detailed discussion of CO_2 absorption and how it is dealt with in tracer studies is provided by Bassett and McNeil 2006.

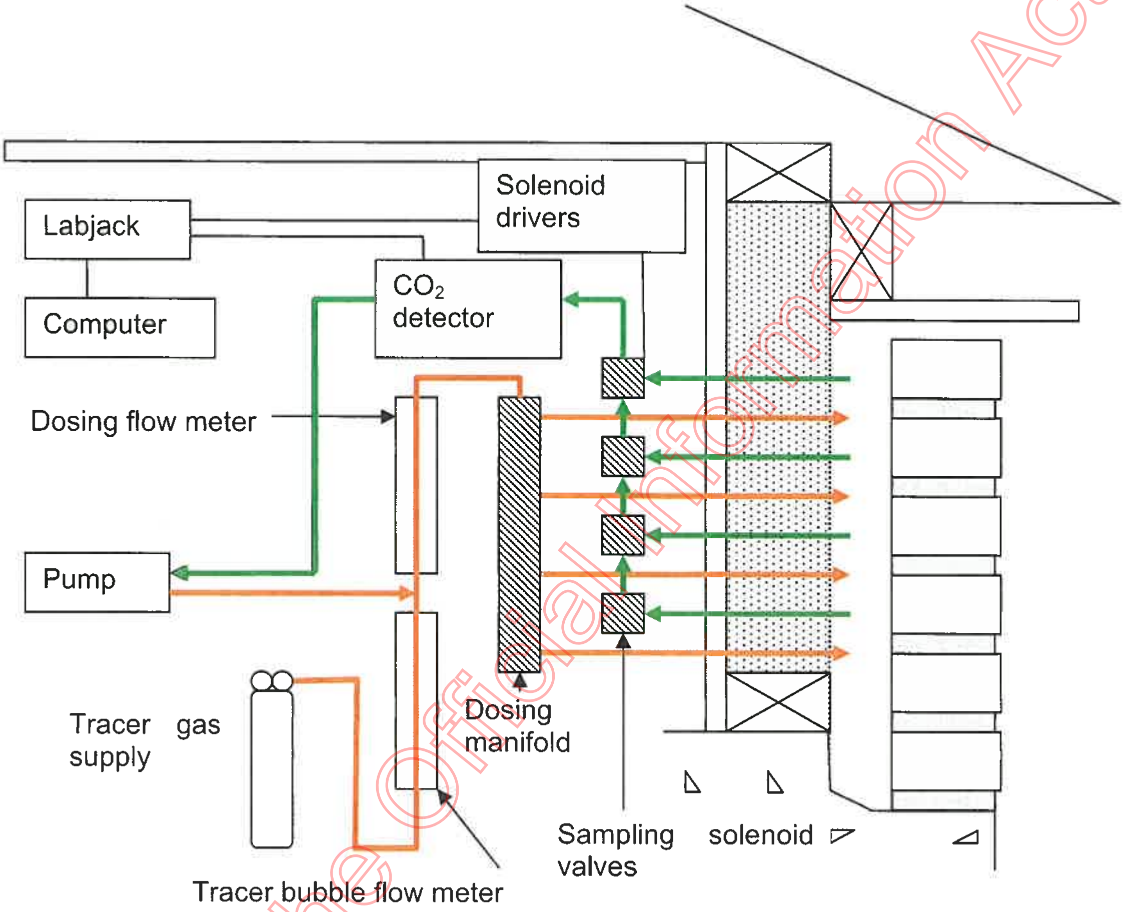

Figure 9. Components of the tracer system and a brick veneer wall cavity. Sampling lines are in green and dosing lines in orange.

Ventilation rates can be calculated from tracer concentration in the cavity with equation (1). Generally these concentrations were measured at several points in the cavity and the values for *C* are averages for the whole cavity.

$$q = \frac{g}{b(C-c)} \qquad (1)$$

Where:
q = air flow rate in cavity per m of wall length (l/s.m)
g = tracer emission rate (cc/s)

C = measured average tracer concentration in the cavity
c = atmospheric concentration of tracer
b = breadth of the cavity (typically the gap between battens in mm).

4.4.2 Results and conclusions of ventilation measurements

A tracer-based method was successfully developed and used to measure ventilation rates in a wide range of wall cavity types. Ventilation rates have been measured over three orders of magnitude (0.03 to 5 l/s.m) and while the method seems unsuitable for tracking instantaneous air flows, day average ventilation rates have aligned reasonably well with flow rates calculated from site meteorological data and measured air flow resistances. Additional conclusions are as follows:

Open rainscreen walls. Measured ventilation rates in open rainscreen wall cavities were much higher than can be explained in terms of fluctuating air pressures. Calculations carried out by Burnett and Straube 1995 based on fluctuating wind pressures estimated ventilation rates in the range 0.001 to 0.01 l/s.m (more than an order of magnitude less than those measured here). An alternative to the fluctuating pressure model has been advanced that involves infiltration paths around the perimeter of the cavity, and the ventilation rates calculated using measured infiltration path resistances agree reasonably well with the ventilation data as shown in Figure 10. The high average measured ventilation rate in the experimental walls (0.4 l/s.m) and later measurements in a series of trade built EIFS walls on another experimental building at BRANZ (average 0.7 l/s.m) confirm that infiltration paths play an important role in the water management capability of open rainscreen walls.

Drained and ventilated walls. In drained and ventilated cavities the average ventilation rates (over 60 days of measurement) was 1.4 l/s.m compared with 1.5 l/s.m predicted from climate data. The ventilation rates were higher than in open rainscreen wall cavities, but the difference between the two wall types was less than expected and unlikely to be that significant.

Drainage plane walls. Preliminary ventilation rates measured in a drainage plane wall cavity are an order of magnitude lower than those in the open rainscreen walls, averaging 0.04 l/s.m. More work will be required to understand ventilation processes in walls of this type.

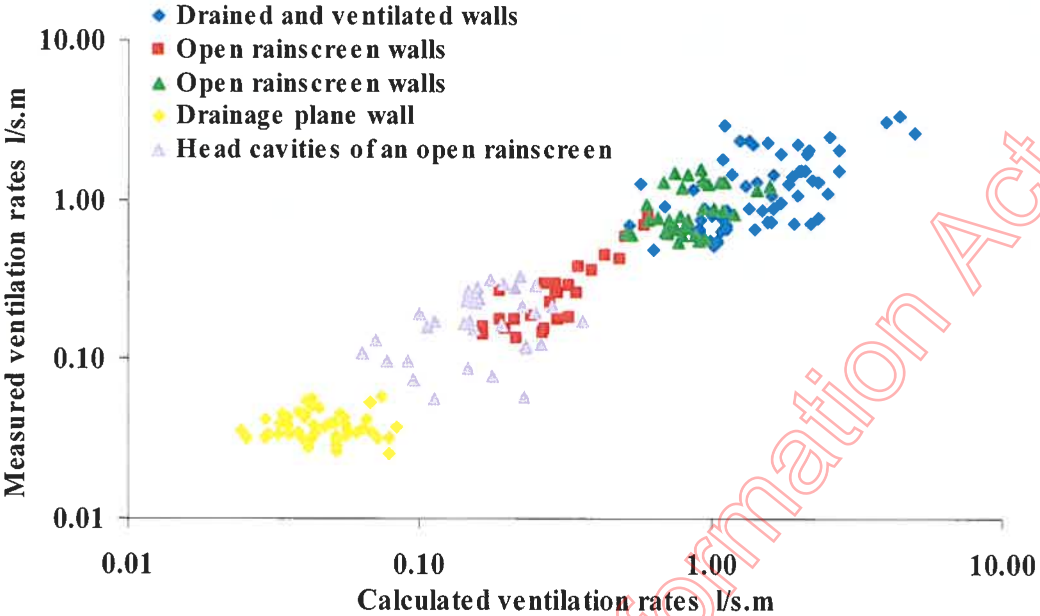

Figure 10. **Comparison between measured and modelled ventilation rates in a range of water managed wall cavities.**

4.4.3 Measuring effective vent sizes and infiltration leakage paths

It has been shown by Bassett and McNeil (2006) that infiltration paths contribute significantly to ventilation rates in open rainscreen wall cavities and that the effective leakage area of these are needed to model the ventilation process. The dimensions of all purpose-built vents can be measured during construction, but for irregularly shaped openings between bricks, and infiltration paths in open rainscreen cavities, a fan pressurisation method has been used to measure effective leakage area. Figure 11 illustrates the equipment used to measure effective leakage areas lumped into leakage openings at positions A, B, C and D in Figure 11. These vent locations were reasonably well defined in the experimental walls because they were clad internally and externally with single sheets (with the exception of brick claddings), limiting infiltration sites to the perimeter of the wall. Effective leakage areas A were determined by fitting the air flow rate Q and ΔP to Equation 2. The value of ΔP was typically in the range 5 to 50 Pa.

$$Q = ACd\left(\frac{2\Delta P}{\rho}\right)^{n} \tag{2}$$

For modelling the air flows under natural conditions, Burnett and Straube (1995) were followed in setting the discharge coefficient Cd = 0.61 and the flow exponent n = 0.5 for large slot openings between bricks. Effective leakage areas at C and D were measured for the brick veneer cavities which combine the purpose-built vents and equal shares of the background infiltration around the perimeter of the veneer cladding. In this case, leakage openings at A and B were considered to be relatively small and lumped with the leakage areas at C and D. The effective leakage area of the purpose-built vents was taken as the difference between results for vents open and vents closed measurements expressed as Equation 2.

To measure leakage paths to inside the building a blower door has been used to equalise room and cavity pressures. This effectively closes down the infiltration paths to inside the building and the effective leakage areas of these infiltration paths to be resolved as the difference between two measurements [(A+B+C+D) – (C+D)] and shared equally between A and B.

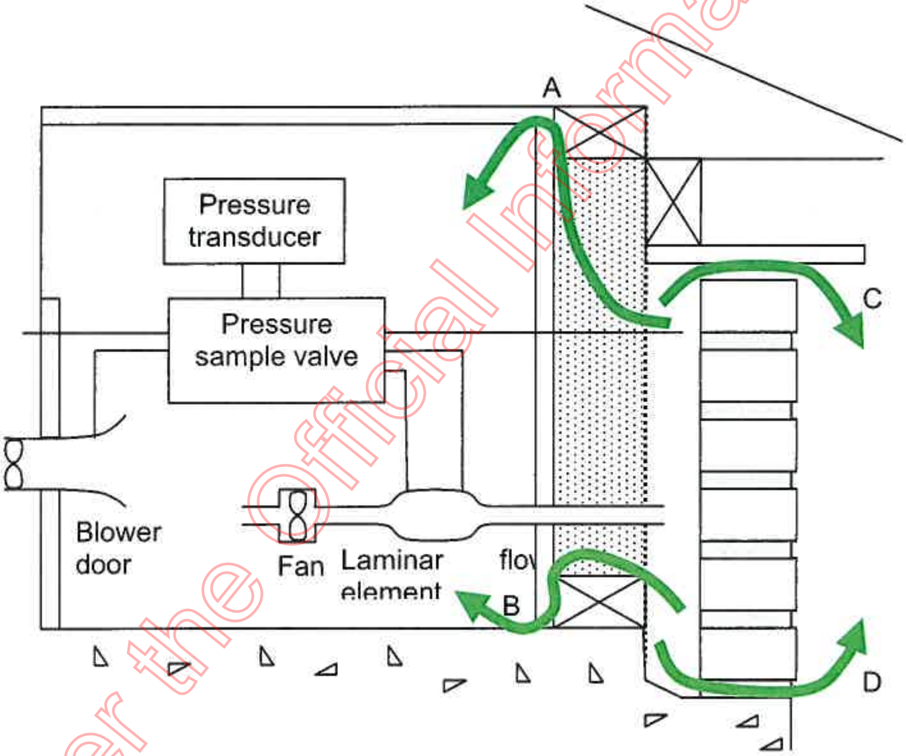

Figure 11. Equipment for measuring the leakage areas of vents and infiltration paths.

4.4.4 Modelling ventilation in cavities

Cavity flow rates have been modelled using the duct flow equations developed by Burnett & Straube (1995). Here the ventilation rate Q is expressed in terms of the pressure distribution across the various air flow resistances in the cavity. The total pressure driving the ventilation process ΔP_{total} can then be expressed in terms of wind and stack pressures.

$$\Delta P_{total} = \xi \frac{\rho}{2}\left(\frac{Q}{A_{vent1}}\right)^2 + \xi \frac{\rho}{2}\left(\frac{Q}{A_{vent2}}\right)^2 + \frac{Q\,h}{4611\,\gamma\, d^3\, b}$$

The applied pressure difference between the top and bottom vents is:

$$\Delta P_{total} = \Delta P_{stack} + \Delta P_{wind} \quad \text{Where:}$$

$$\Delta P_{wind} = \frac{\rho}{2} v^2 \left(C_p^{top\,vent} - C_p^{bottom\,vent} \right)$$

$$\Delta P_{stack} = 3465\,h \left(\frac{1}{T_{cavity}} - \frac{1}{T_{outside}} \right)$$

Where :
Q = air flow rate in cavity (m^3/s)
ρ = density of air (kg/m^3)
ξ = a lumped flow resistance of 0.5 at the entrance and 0.88 at the exit
A = sectional area of opening in (m^2)
h = height of the cavity (m)
γ = is a roughness factor of 0.8 for brick veneer and 1.0 for other walls
d = depth of cavity (m)
b = breadth of cavity – typically the gap between battens (m)
T = temperature absolute (K)
v = wind speed at roof height (m/s)
C_p = wind pressure coefficient relative to wind speed at roof height.

More recent practice has been to follow the equation and coefficients used by Piñon et al. 2004 which can be written as follows:

$$\Delta P = \frac{\rho}{2} \left(\frac{f\,h}{D_h} V_{cavity}^2 + \sum \left(C_{vent}\, V_{vent}^2 \right) \right) \tag{3}$$

where:
D_h = hydraulic radius of the vent (m)
C = flow coefficient of a vent
f = flow coefficient
V = velocity of air in duct or vent (m/s)

The velocity V is more conveniently expressed in terms of a volume flow Q and the cross sectional area A and equation 3 can be rewritten:

$$\Delta P = \frac{\rho}{2} \left(\frac{f\,h\,Q_{cavity}^2}{D_h\;A_{cavity}^2} + \sum \frac{C_{vent}\;Q_{vent}^2}{A_{vent}^2} \right) \tag{4}$$

Where the hydraulic diameter of the cavity is $D_h = \frac{4bd}{2(b+d)}$

and the friction factor f can be expressed as follows when air flows are laminar (When the Reynolds number $Re < 2300$):

$$f = \frac{96\ A_{cavity}}{66400\ D_h\ Q}$$

The pressures that drive air through the vents and cavities are generally low and the flow can be described as laminar most of the time, although Straube 2004 has shown that transitional or turbulent zones can sometimes exist near vents. A range of values for f and C have been determined for openings in thick and thin materials by Piñon et al. 2004.

Some of flow calculations involve a number of connected cavities and the flow equations through each vent and duct have to be solved simultaneously to preserve mass balance. This has been carried out using a numerical method originally developed by Walton 1981.

4.4.5 Wind pressure coefficients

One of the most important tasks identified earlier has been to support ventilation rate calculations with wind pressure coefficient data. A variety of data sources have been investigated but data recently published by Piñion et al 2004 for buildings < 4 floors has been mined for average pressure differences due to wind. It should be recognised that the data traces back to relatively few wind pressure measurements at top and bottom vent locations on one single story building. There has been considerable discussion about the wind pressures driving cavity ventilation and it has been recognized that these need to reflect both time and spatial variations in wind pressure. Burnett and Straube 1995 suggested that the average standard deviation of the wind pressure might more accurately represent both spatial and temporal variations in wind pressure.

4.5 Window to wall joints

Window to wall joints have formed part of the BRANZ research programme on several occasions and the following research questions have been addressed:

Dimensional factors. Understand the influence of the various dimensional parameters on the weathertight performance of window to wall joints (direct fixed).

Two part head flashings. Measure ventilation in head cavities above windows to see if ventilation might be borrowed from cavities flanking the window where a two part head flashing closes off the traditional ventilation path.

Flat and sloped sill trays. Develop the physics of water loss from flat and sloped sill trays to support decisions about their application.

4.5.1 Dimensional factors

The weathertight performance of more than 200 window-to-wall joints was measured in the laboratory using the equipment and procedures based on AS/NZS4284:1995 (Bassett et al. 2003). Windows were installed following Figure 12 but with several of the dimensions, the quality of the air-seals and vent sizes changed. The weathertight performance limit of each window-to-wall joint was measured and expressed as the static air pressure difference at the point where significant water (about 10 cc) entered the trim cavity. It has been expressed as a climate zone (suitable for the window) following a study of coincident wind and rain data for 40 meteorological stations McNeil et al. 2003. This produced the map of weathertight zones in Figure 13 and the wind pressures associated with the new zones are given in Table 2 along with two additional zones chosen arbitrarily for taller or more exposed buildings. Zone 1 has also been expanded to include a wider range of pressures (0 to 150 Pa) because there are few buildings in areas where (0 to 75 Pa) might apply.

Table 2. Suggested wind-pressure zones for rating the weathertight performance of window-to-wall joints.

Wind and rain climate Zones	Applicability	Range of wind pressures
1	Limited South Island inland sites	0 to 75 Pa
	Most inland towns	76 to 150 Pa
2	Most coastal towns	151 to 300 Pa
3	More exposed or taller buildings	301 to 500 Pa
4	More exposed or taller buildings	Above 500 Pa

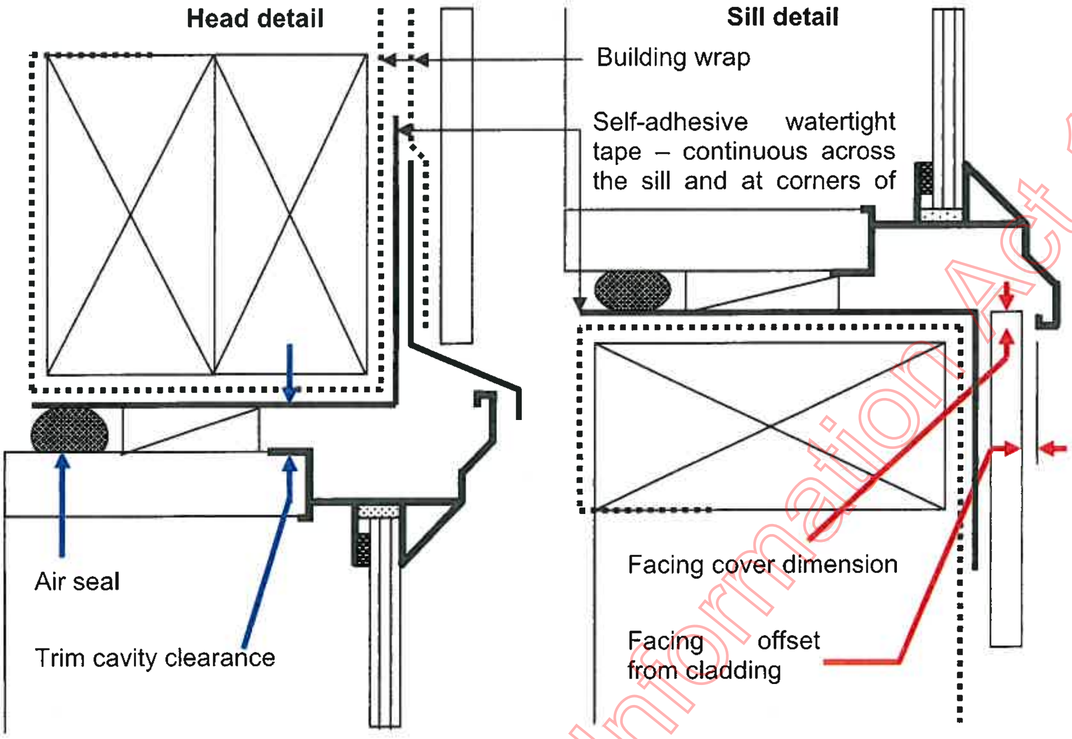

Figure 12. Sectional views of head and sills of windows in the experimental trials showing key dimensions. (sill trays omitted to ensure that water leaks could be seen)

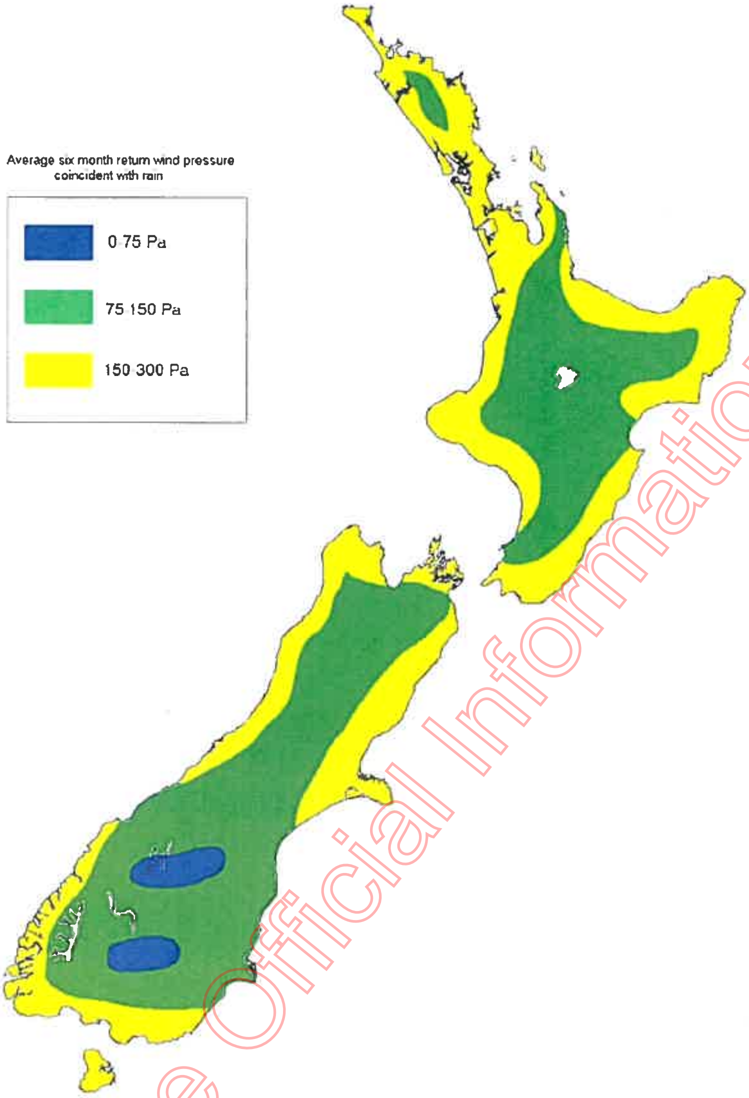

Figure 13. Map of New Zealand showing climate zones 1, 2 and 3 (Table 3).

Figure 14 shows how the percentage of joints tested, with zone 4 performance steadily increasing as the prioritised list of design requirements in Table 3 is enforced on the data. When all the requirements in Table 3 are applied, all the compliant cases have zone 4 weathertight performance.

Table 3. A sequence of priorities and design criteria for window-to-wall joints

Condition	Priority
Ensure that the rainscreen to air seal leakage area ratio exceeds 10	1
Minimise capillary-tracking by ensuring the trim cavity clearance exceeds 5 mm and the facing offset exceeds 2 mm	2
Ensure that the facing cover over the cladding exceeds 10 mm	3
Seal the jamb facings to the cladding	4

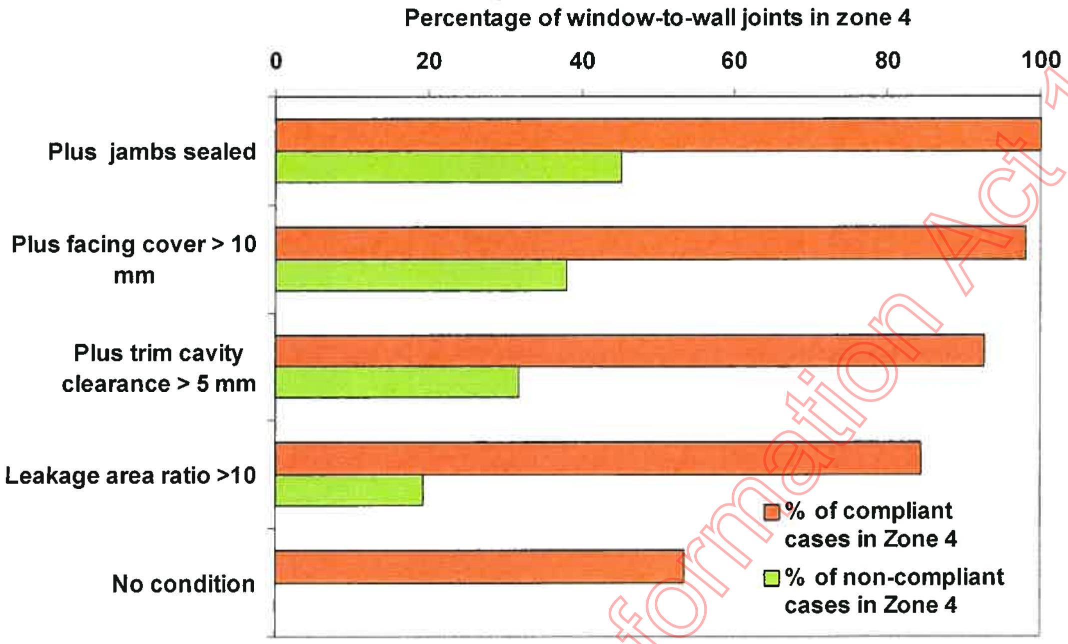

Figure 14. The percentage of window-to-wall joints with zone 4 performance as the sequence of conditions in Table 3 is applied cumulatively.

The conclusions from this study are presented graphically in Figure 14 and can be summarized as follows:

The airseal and wet-side vents. The most significant factor in the performance of the 200 window-to-wall joints concerned the air seal; or more accurately the area ratio: of the vent between facing and cladding (generally the gap under the sill facing) to the effective leakage area of the airseal. Figure 15 shows how the percentage of windows meeting each of the zone performance targets depends on the leakage area ratio. It turns out that this ratio should exceed 10 and in this respect it duplicates the advice offered by curtain wall designers for pressure equalized designs.

Window facing widths. An adequate facing cover over cladding and sealed jambs are the next most important attributes. There was some evidence of a trade-off between the facing cover dimension over the cladding and the leakage area ratio.

Capillary paths in the trim cavity. Continuous capillary paths were shown to be a significant problem and window trim cavity clearances should be 5 mm or greater. Note that the results of this investigation rely on the water leakage test procedures in (AS/NZS 4284:1995) to simulate wind and rain effects on New Zealand buildings. Although the procedures have established a good track record with the window industry over many years, it has sometimes been questioned whether the procedure adequately simulates the momentum of wind-driven rain. For buildings in exposed locations, this may increase the minimum facing cover dimension. There are two further limitations to these conclusions as follows:

- **One window profile tested.** The tests were all carried out with small windows of a profile that is common in New Zealand. Future work might investigate more complex windows, larger sliding doors, as well as window profiles available in other countries.
- **Workmanship tolerances not explored**. All of the window-to-wall joints tested here were built in the laboratory where no attempt was made to factor workmanship tolerances into the installation. Consequently, it may be necessary to increase window cover dimensions or change other details to reflect site practicalities.

Sill trays necessary. A further issue is that of water leaks through the window mitres into the trim cavity. Sill drainage was found to be necessary to cope with this particular problem.

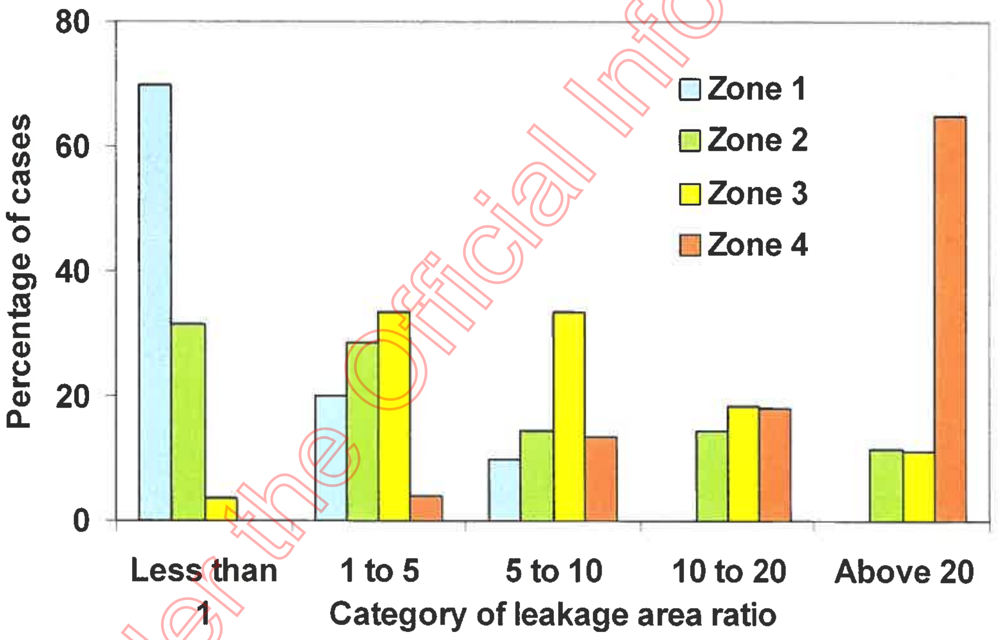

Figure 15. The failure profile of window-to-wall joints by leakage area ratio.

4.6 Ventilating the cavities above window heads

The head flashings described in E2/AS1 can sometimes be difficult to install and alternative two part flashings have been proposed. There will be a number of other issues connected with two part head flashings but a research project was started at BRANZ to show whether the cavities above two part head flashings could successfully borrow ventilation from cavities flanking the window through vented battens. Figure 16 shows the traditional head detail with a ventilation path over the head flashing and the alternative two-part flashing effectively blocking the ventilation path. Two long windows (2.5 m by 0.5 m) and surrounding wall structure were built into the north and south walls of a laboratory on the BRANZ site in Wellington. The window on the south side was a conventional design with vents and drainage paths above the head flashing and the window on the north used a two part head flashing (as illustrated in Figure 16), with vented battens between cavities.

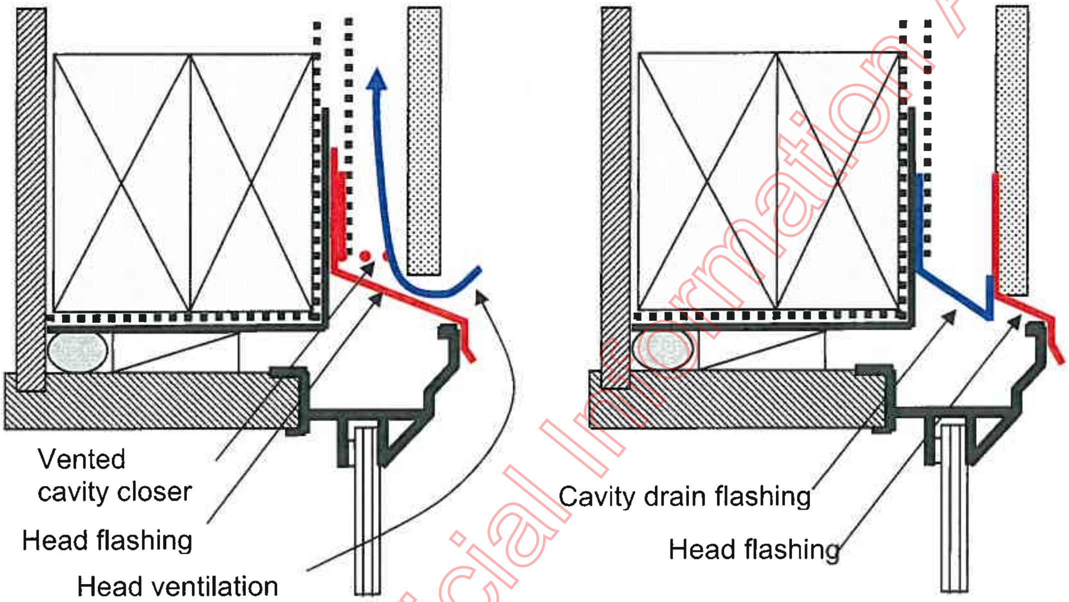

Figure 16. Traditional window head flashing on left and a two part head flashing shown on the right.

All of the engineered vents to outside were limited (to a nominal 1 mm gap) by the closer strip at the base of the cavities and the vented battens had nominal 5 by 20 mm slots on 50 mm on centres. The walls surrounding the windows were insulated with fiber-glass and lined with Tyvek wall wrap. Internally the walls were lined with paper reinforced gypsum plaster board with all joints were taped to simulate a stopped interior wall. On the outside a fiber-cement cladding was screw fixed to the battens without any special airtightening of the cladding to batten joint. Figure 17 shows the arrangement of cavities and the vents used to represent engineered vents and infiltration paths that are described in Table 4.

Table 4. A description of the vents and infiltration paths identified in Figure 17.

Ventilation paths (in Figure 3)	South window – (head cavities vented over head flashing)	North window – (head cavities vented through battens)
Red	Engineered vents through cavity	Engineered vents through cavity

	closer (nominally a 1 mm gap)	closer (nominally a 1 mm gap)
Blue	Infiltration paths around battens	Engineered vents in battens (nominally a 1.8 mm gap)
Orange	Engineered vents over window heads (nominally a 1 mm gap)	Infiltration paths
Green	Infiltration paths between cladding and battens	Infiltration paths between cladding and battens

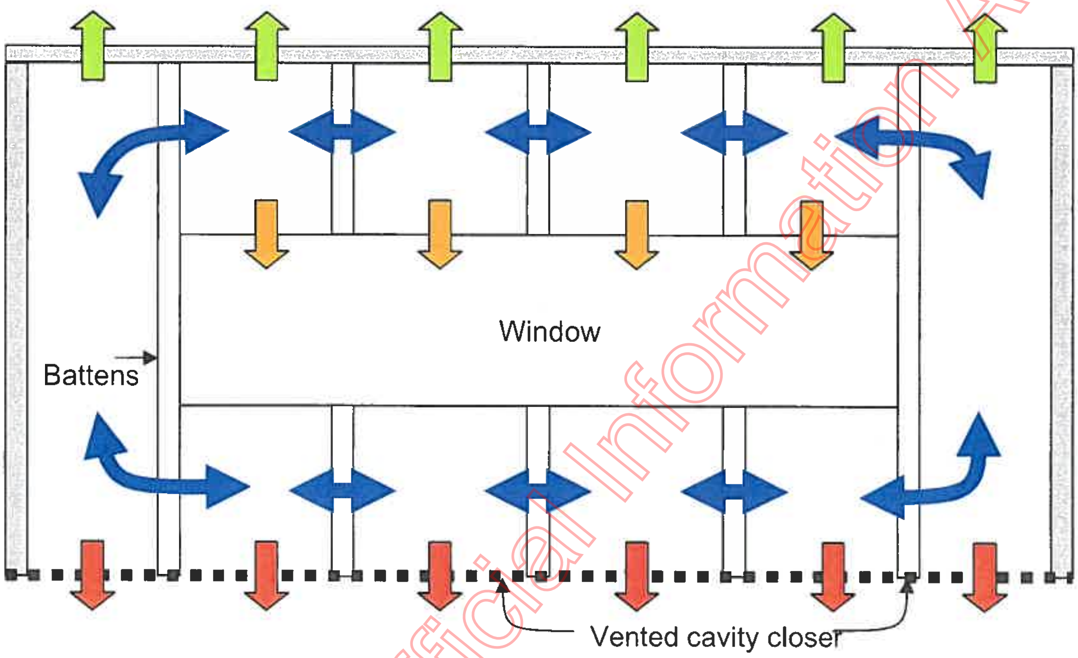

Figure 17. **Cavities surrounding the experimental windows showing vents that represent the engineered vents and infiltration paths in the water managed head cavities.**

This research described here is in its final stages and should therefore be regarded as indicative at this point. The work has shown that ventilation can be successfully borrowed from cavities flanking windows through ventilated battens and it looks likely this can be generalized to a wider range of buildings, window sizes and locations in New Zealand. Additional conclusions include:

Agreement between measurement and calculation. Ventilation rates in the experimental water managed cavities above window heads were successfully measured and compared with calculated ventilation rates modelled from cavity air leakage characteristics and local weather data.

Ventilation can be borrowed. Ventilation rates measured in the 2.5 m length of cavity ventilated above the window head flashing averaged 0.66 l/s compared with 0.46 l/s for the cavity vented laterally through vented battens. The day average ventilation rates (0.1 to 0.6 l/s.m) are similar to day averages measured in the water managed cavities of experimental open rainscreen walls (0.2 to 0.9 l/s.m).

Infiltration is important once again. Although the experimental window head cavities were designed to be ventilated in quite different ways, it turned out that infiltration paths in the construction played a more important role in the ultimate ventilation performance than the purpose built vents. Infiltration was almost half of the total ventilation in cavities with vented battens and almost all of the ventilation in cavities vented above the head flashing. Figure 18 compares calculated ventilation in both types of window head cavity with three infiltration path scenarios. It can be seen that ventilation in cavities with engineered side vents are relatively insensitive to closing down the infiltration paths compared with cavities vented over the window head flashing. A promising basis for ventilating head cavities has been established using vented battens.

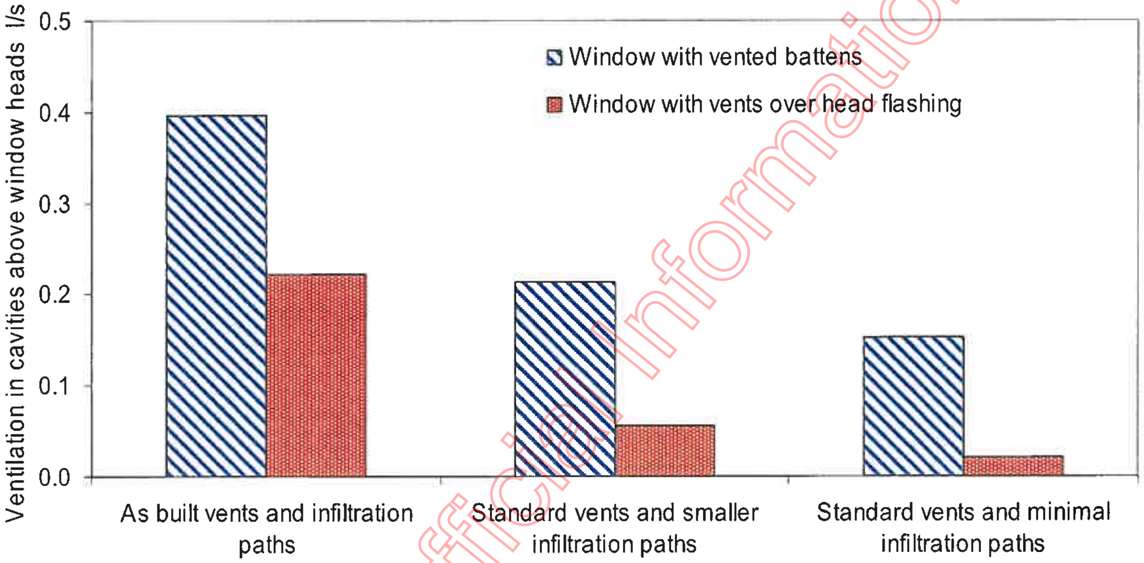

Figure 18. Average ventilation rates in cavities above window heads with three infiltration assumptions.

4.7 Flat and sloped sill trays

Sill trays described in E2/AS1 are sloped for drainage but they can be difficult to install under windows with narrow facing dimensions. Flat sill trays are used in some countries and a research project (incomplete at this stage) is exploring the physics of water removal by drainage and evaporation in the New Zealand climate.

A series of four windows were installed in an experimental building with instrumentation to measure framing moisture contents along with temperatures and humidity in the trim cavities. Two windows had flat sill trays and two were sloped at 5 degrees for drainage. All of the windows were installed into timber frame openings with the building wrap cut diagonally in the opening and fixed back to the frame with flashing tape over the sill and head areas. Moisture pins were fixed into the timber framing and in the window reveal along with a thermocouple junction at each location to allow for a temperature correction. At this stage it has been established that sloped sill trays successfully drain to outside and flat trays accumulate water and drain periodically. The ventilation rates measured in the trim cavity will have some capacity for drying water from flat trays but there is some work required to tie together the relationship with outdoor climate and vent sizes around the window.

4.8 Framing timber durability measurements

Two projects on the decay resistance of framing timber form part of the FRST funded weathertightness research programme and although incomplete, the project concerned with decay is measuring decay rates in a range of framing timber species at fiber saturation. It is part of a wider programme to understand the durability of building materials used in the water managed parts of walls or other areas accessible to water leaks. Short pieces of 90 x 45mm framing timber of the species listed below were inoculated with brown rot decay fungi and installed in filleted stacks in sealed tanks. The groups included heartwood, sapwood, LOSP treated and boron treated samples.

The fourteen species/treatment combinations were as follows:

1. Radiata pine, untreated, kiln-dried controls.
2. Douglas fir, untreated air-dried sapwood.
3. Douglas fir, untreated air-dried heartwood.
4. Douglas fir, boron treated (pressure diffusion), air-dried sapwood.
5. European larch, untreated air-dried sapwood.
6. European larch, untreated air-dried heartwood.
7. Lawson cypress, untreated air-dried sapwood.
8. Lawson cypress, untreated air-dried heartwood.
9. Lawson cypress, boron treated (pressure diffusion), air-dried sapwood.
10. Lawson cypress, air-dried LOSP treated (tributyltin naphthenate), sapwood.
11. Macrocarpa, untreated air-dried sapwood.
12. Macrocarpa, untreated air-dried heartwood.
13. Macrocarpa, boron treated (pressure diffusion), air-dried sapwood.
14. Macrocarpa, air-dried LOSP treated (tributyltin naphthenate), sapwood.

After 12 months there was severe decay in the untreated radiata pine and in the untreated sapwood of the other species. Decay was becoming established in the untreated heartwood of Douglas fir and larch but only isolated minor spots on the macrocarpa and Lawson cypress. There was isolated light decay in LOSP treated Lawson cypress and macrocarpa, mainly at the joints. These results are shown in Figure 19 as bar a graph.

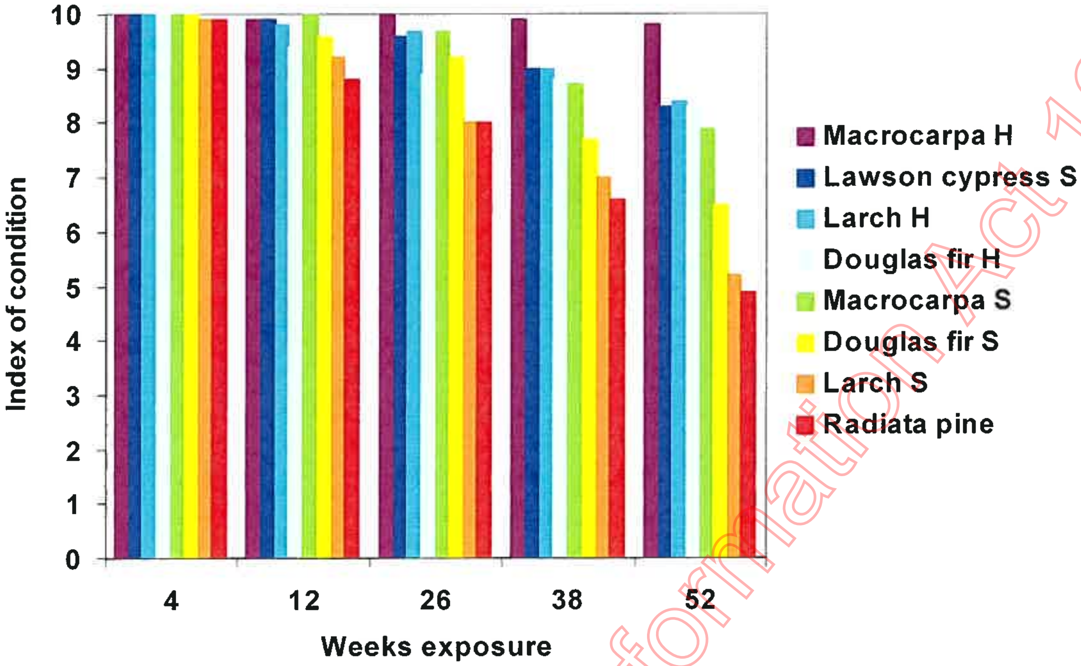

Figure 19. Illustration of relative decay rate in untreated framing timber at fibre saturation

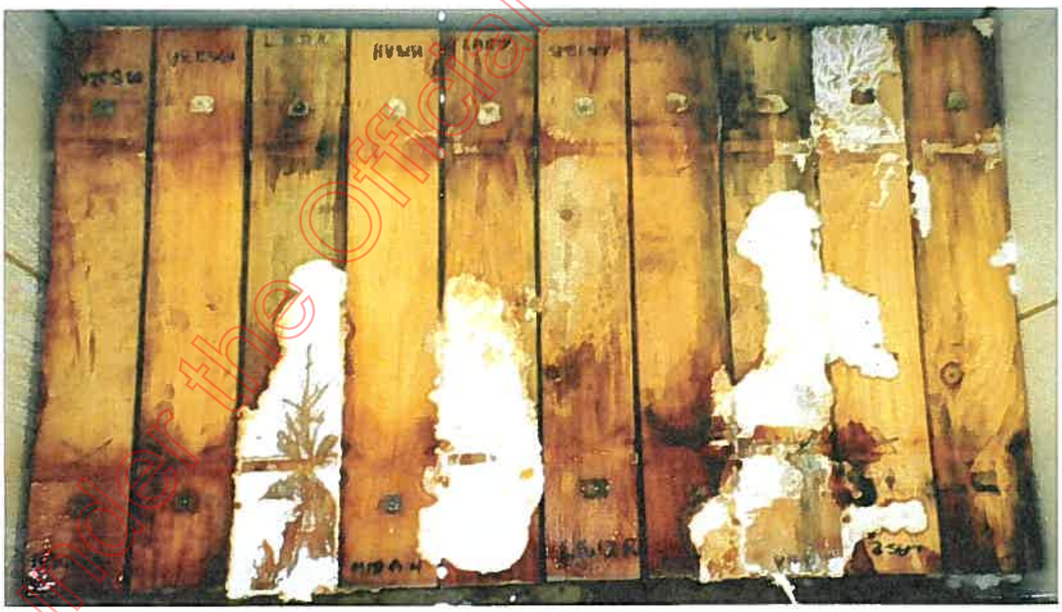

Figure 20. After exposure for 38 weeks. Moderate/severe decay in all samples with extensive mycelium growth (larch, D. fir and Lawson's sapwood).

After 52 weeks the untreated sapwood of all species contains a significant amount of decay. While untreated radiata pine has decayed more rapidly than other species the extent of the decay in the sapwood of the other species might suggest that significant amounts of sapwood should be avoided where there is a risk that the framing could become wet.

The heartwood of Douglas fir and larch has shown some resistance to decay but this is slowly being overcome where decay fungi are vigorously active. The macrocarpa and Lawson cypress heartwood have shown much greater resistance to decay as only minor decay was present after the first 12 months. The major difference between the untreated heartwood and the LOSP treated framing groups after 12 months is that the decay mycelium has spread much more readily on the surface of the heartwood samples.

Boron diffusion treatment has been almost totally successful in preventing decay over a twelve-month exposure period. Minor decay in the heartwood of one sample is probably the result of poor preservative treatment into the heartwood, something that is to be expected with this type of treatment. Heartwood penetration is not a requirement of the H1.2 treatment specification.

Apart from one Lawson cypress sample, the LOSP treated macrocarpa and Lawson cypress were largely free of decay on the surface. There were minor decay patches on the surface of one macrocarpa sample and internally in the sapwood of another but overall LOSP treatment has largely prevented decay in the first 12 months. The decay that is present in three samples suggests that occasional pieces of LOSP treated sapwood will be susceptible to decay if exposed to wetting for prolonged periods.

4.9 Building wraps and flashing tapes

The following paragraphs start a discussion on the changing role and technical requirements of building wraps. Also included is an update on recent studies at BRANZ of the durability of wraps and flashing tapes.

The building wrap is only part of a water management system. Building wraps provided a second line of defence against water entry in early NZ code documents and standards. In these times, the "building paper" was expected to provide all of the water management past the cladding. Recent code and standards documents have followed the 4D's model with a cavity now doing most of the water management job – providing a drainage path, a capillary gap and a ventilation escape route for moisture. The building wrap still plays an important part by forming the boundary between the water managed and insulated parts of a wall.

Building wraps an international commodity. There is little international agreement on the physical properties, units for expressing these, test standards and building code requirements for building wraps. But conceptually, building wraps all strive for vapour permeability, water and air tightness, and adequate durability (Baker and Bomberg 2002). Although there is no agreement on properties, most wraps can be sold in many countries, creating an international market for most products. The same cannot be said for roof underlay products where there are much bigger differences in the properties in codes and standards.

Innovative building materials. The hygrothermal models like WUFI make it possible to tune the vapour and wicking properties of materials to meet changing seasonal demands eg Kunzel 1999. In countries with large summer/winter temperature swings a wrap/retarder with a very low vapour resistance in the presence of high humidity (to help dry out a damp cavity) and a high vapour resistance to prevent summer vapour drives into walls from outside is desirable. There are several products available to meet this need with even larger vapour resistance changes than kraft papers but they are still only boutique products in the market place.

Penetrations in wraps. A Canadian study (CMHC 2004) has measured much higher (10 times) moisture transfer rates through staple fixed wraps than through the unfixed material. It turns out though that these liquid moisture flows are small compared to vapour transport and therefore of limited concern. The study does illustrate the importance of testing the system (including fixings and laps) rather than virgin material.

Air flow resistance targets for wraps. Countries with cold climates have been working towards airtight enclosure to reduce uncontrolled infiltration and improve energy efficiency. This drives many building wrap providers to increase the air flow resistance of their products (the same as reducing the air permeability) as far as is consistent with the product being permeable to water vapour (a smaller molecule than oxygen or nitrogen molecular atomic pairs). Figure 21 gives air flow resistances of products available in NZ and air barrier targets for other countries. There is a large range available in NZ that are used interchangeably. Some like Tyvek, meet international airtightness targets (e.g. Canadian air barrier types) while others fall well short of the air flow resistance requirement for an air barrier in E2/AS1. A NZ study found it hard to justify air flow resistance targets in NZ buildings to reduce wind wash of heat from insulated cavities. So until it becomes necessary to tighten NZ houses to reduce ventilation heat losses, it is thought unlikely there will be a need for special targets for building wraps.

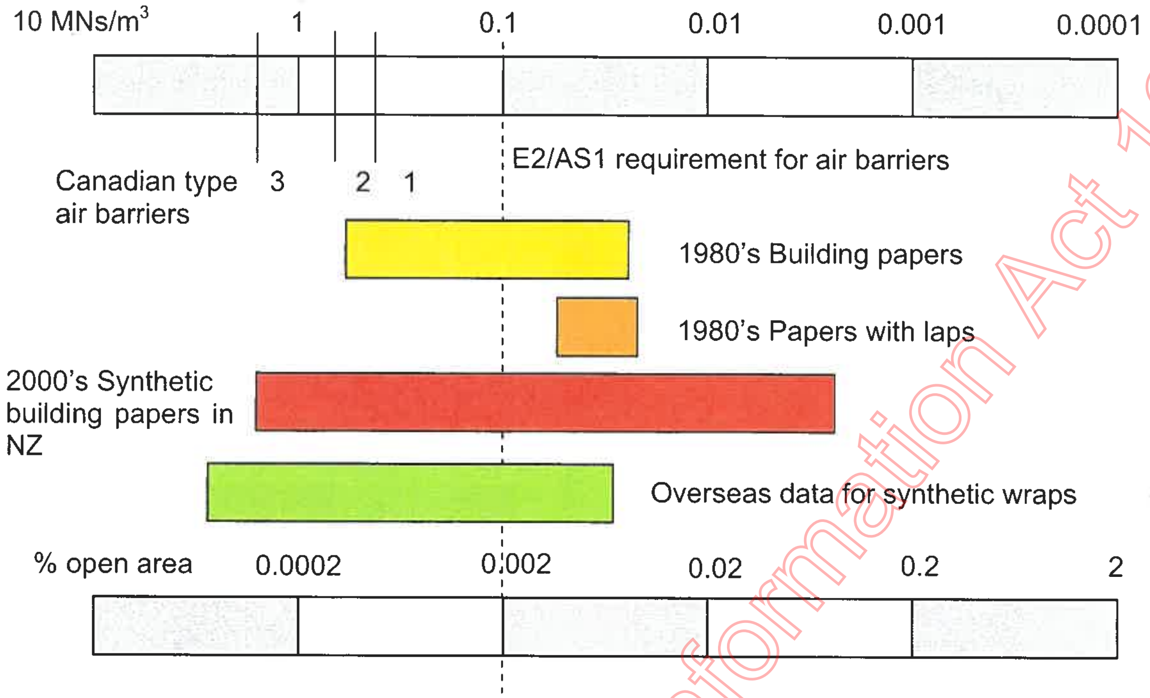

Figure 21. Air flow resistances of wall wraps available in NZ and overseas.

High performance air barriers. References are commonly made to the difficulty of achieving air tight buildings in practice. Even with continuous high air flow resistance air barriers, poor workmanship all too often leads to air leakage paths at the junctions between wall and floor, between wall and ceiling, and at the connections of windows and door frames with walls. A corollary is that the properties of air barriers are hardly worth discussing until infiltration paths have been dealt with. An air barrier is unlikely to meet cold country airtightness requirements without adequate attention to infiltration paths around penetrations, at top and bottom plates, around windows and through power outlets. A universal theme in the literature is the requirement that an air barrier layer must be rigid. Unsupported membranes are seen as difficult to seal around penetrations and movement under fluctuating wind pressures is considered to exacerbate the problem. The long term durability of unsupported air barriers has also been questioned.

New work started on exposure standards for wraps. Recent studies at BRANZ (as part of the FRST funded weathertightness programme) have been exposing wraps to natural weather to better understand the link between natural and accelerated exposure. One of the current accelerated options is a 90 day exposure (at least 2000 MJ/m² of incident solar energy in the wavelength range 320 – 800 nm) at the Allunga Exposure Laboratory near Townsville in North Queensland. Another is 500 h exposure in a QUV A accelerated weatherometer. The studies are incomplete at this stage but early results show that synthetic wraps become more permeable to water vapour (not in itself a problem) and lose some mechanical strength (30% of their tensile and edge tear strength) but mostly remain mechanically fit for purpose.

Exposure of wraps to timber treatments. The effect of timber treatment chemicals on the properties of wraps in contact with treated framing is being studied as part of the FRST weathertightness research programme. Limited data is available at this stage but the experimental design includes untreated radiata pine and Douglas fir as control materials alongside H1.2 boric treated and H3.1 LOSP treated radiata pine. Timber specimens have been exposed outdoors and in climate cabinets in combination with the common building wrap types: bitumen impregnated Kraft paper, non-woven polypropylene and spun-bonded polyethylene. The initial cycle of exposures is complete and the samples have been collected to measure the physical properties. The samples will again be exposed in autumn when incident UV/solar radiation intensity has fallen (to exclude solar degradation from the degradation process).

Figure 22. Samples of building wrap weathering in contact with timber treatment chemicals

Adhesion of flashing tapes to wraps and timber. The same timber and building wrap combinations described above have been exposed outdoors and in climate chambers with strips of flashing tape attached as in Figure 22. Samples were made by covering three sides of a three meter long stick of framing timber with building wrap and then applying approximately 30 strips of flashing tape over the wrap and right around the timber. The tape was overlapped onto itself by about 30 mm. Three flashing tape types have been included in the study: aluminised; creped polyolefin; and flat polyolefin. The initial cycle of exposures is complete and some interesting provisional trends in tape adhesion have been identified. Flat polyolefin faced tape specimens appear to have significantly worse adhesion (twice as many strips peeled) when compared to the other two tape types. Interestingly, the tapes appear to peel and curl more on untreated timber types but this observation will need to be confirmed by more systematic work.

Figure 23. Samples of flashing tape attached to building wraps and exposed to the weather

Durability of flashing tapes. Adhesion tests of flashing tapes to building wraps show that both the wrap and underlying framing treatments are influential. Early observations also suggest that the flat polyolefin faced tape will retain adhesion to itself and to the building wrap covering the timber, but that adhesion fails in the area where it is stuck to the timber itself. This tentative observation will need to be confirmed by more systematic work.

4.10 Weathertightness of wall claddings

Wall claddings play a dominant role in keeping water out of buildings and Approved Document E2/VM1:2005 requires wall claddings to keep water from the wall wrap with 50 Pa of applied air pressure across the cladding. At the time this VM was developed there was little performance data available relating to residential cladding systems but E2/VM1 is concerned about “D1” performance and a performance target was required. The FRST funded research program at BRANZ is helping to piece together performance information to help with future reviews of this requirement. The data summarized in the following paragraphs was measured in E2/VM1 equipment and therefore gives no indication of water leakage rates in service. This is because the test relates to the cladding only and applies a very high rain intensity and artificially generated wind pressures. Figure 24 illustrates a wall frame and cladding in the test chamber along with spraying equipment and a fan.

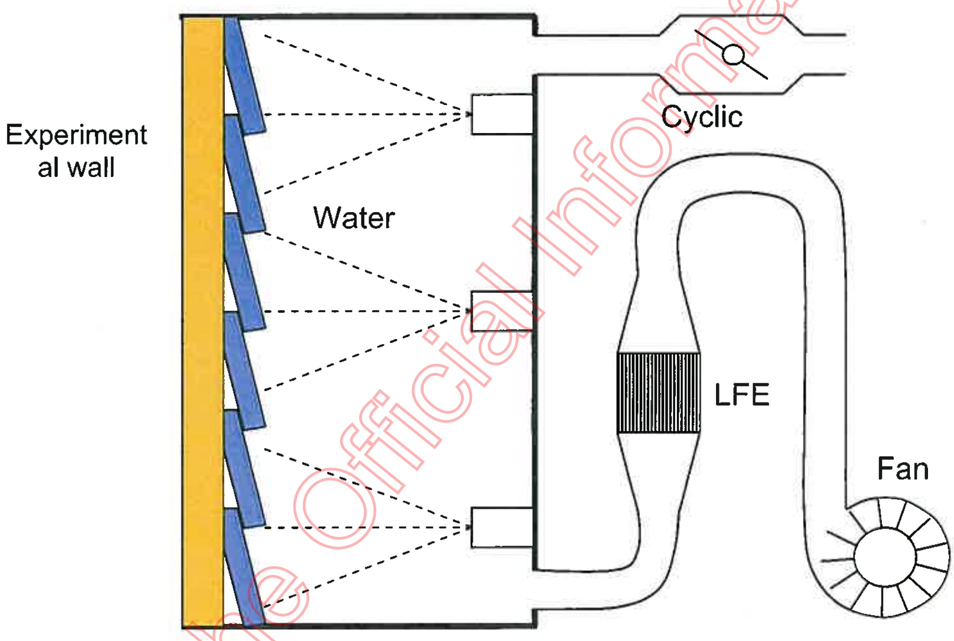

Figure 24. Experimental wall mounted in a pressure box with water sprays and cyclic damper

Water leakage rates were measured as a function of applied pressure for each of the walls listed in Table 5 and plotted in Figures 25 and 26 for unpainted and painted specimens respectively. Because water leakage rates through the cladding were difficult to measure, an uncertainty of 50% has been assigned to data, but the water leakage finger print is still clearly defined because leakage rates range over several orders of magnitude. It must be emphasized once again that these leakage rates are a result of extreme applied pressure and water flow rate and will almost never be replicated on a building. The value of the data is in ranking the importance of leakage sites and understanding it develops of how test requirements in E2/VM1 might be aligned with the established track record of claddings.

The eleven wall claddings are described in Table 5.

Table 5. Description of weatherboard claddings

Ref	Weatherboard type	Width of board (mm)	Material	Coating	Weathergrooves
A	Bevel backed	140	Timber	Primed	2 by 5 mm
B	Bevel backed	190	Composite	Primed	No
C	Rusticated	180	Timber	Primed	2 x 2 by 3mm
D	Flat sheet	220	Composite	Primed	No
E	Rusticated	140	Cedar	Natural	2 x 4 by 3mm
F	Interlocking	140	uPVC	Natural	No
G	Interlocking	160	Aluminium	Natural	No
H	Vertical board & batten	175 and 50	Timber	Natural	4 by 4 mm
I	Bevel back	140	Composite	Primed	No
J	Interlocking	190	Aluminium	Natural	No
K	Interlocking vertical	160	Aluminium	Natural	No

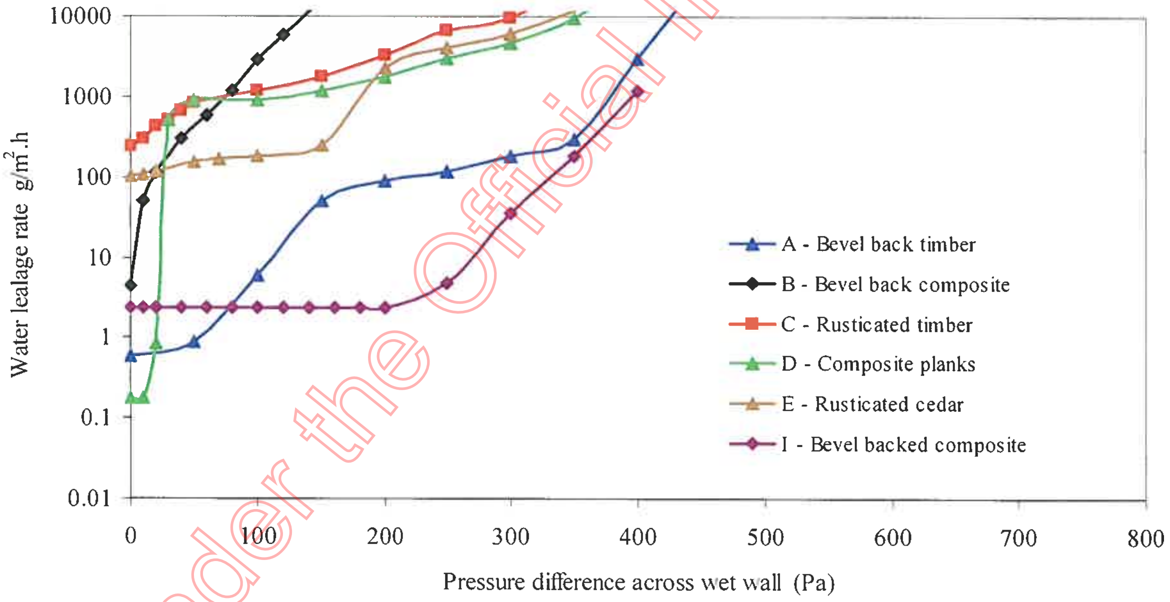

Figure 25. Water leakage rates as a function of pressure difference across the cladding

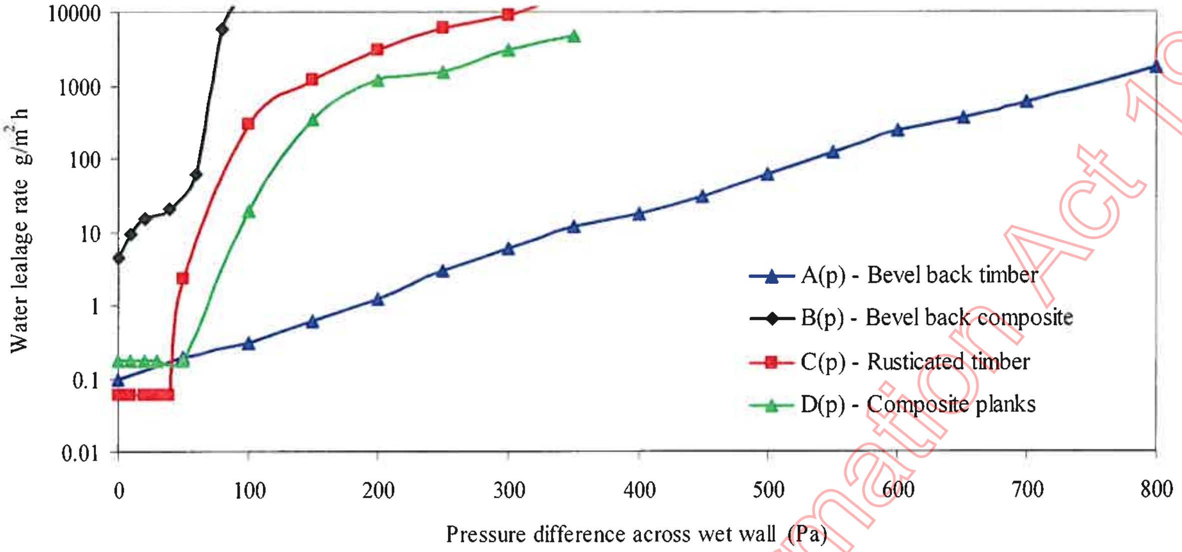

Figure 26. **Water leakage rates as a function of pressure difference across the cladding where (p) indicates that the finished wall has been painted.**

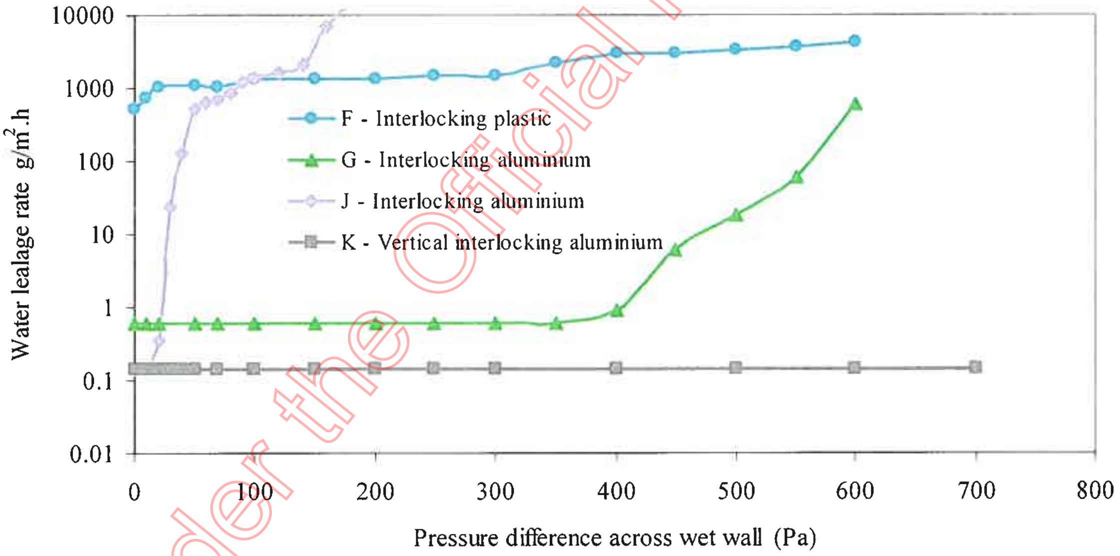

Figure 27. Water leakage rates as a function of pressure difference for plastic and metal weatherboards.

The following observations can be taken from Figures 25, 26 and 27:

Gravity leaks in weatherboards. Gravity leaks through fixings, defects such as knots in timber and butt jointers were responsible for major water leaks at zero applied pressure. There were no gravity leaks through defects in uPVC, metal or composite boards but there were sometimes gravity leaks at jointers between boards. Jointers were responsible for major leaks in walls F and J.

Effect of painting weatherboards. Painting the walls is shown in Figure 26 to improve the weathertightness of walls A, B, C and D. Leaks at zero pressure in wall C were reduced dramatically but it would have to be expected that paint filled joints will open up over time through seasonal dimensional changes in timber.

Weathertightness of butt jointers. Butt joints between weatherboards were the least weathertight point in 3 walls (C, E and F). This shows how badly performing butt joints can dramatically degrade the weathertight performance of a wall.

Air carried leaks. Air leaks were the next most significant point for water entry. Wall B was put together with secret nails that did not hold the laps tightly together. Gaps in the range of several mm were measured and a water leakage characteristic determined for the whole wall on the basis of the lap joint openings taking values (<1 mm, 1 – 2 mm, 2 – 3 mm, >3 mm). Figure 28 shows the leakage rate exceeding 1000 g/m^2.h (the point at which water was often observed to spatter across to the wrap) at less than the "wet wall" test pressure in E2/VM1. Painting wall B reduced the size of the leaks (effective leakage area reduced from 7800 to 5000 mm^2/m^2) and reduced water leakage rates as shown in Figure 29.

The effect of weathering. Age and weathering is known to cause timber weatherboards to cup and distort in a way that might open up lap joints and the butt joints between boards. The only wall in this study to have been exposed outdoors was wall E (unpainted rusticated cedar) and it was shown to have become less weathertight after this exposure.

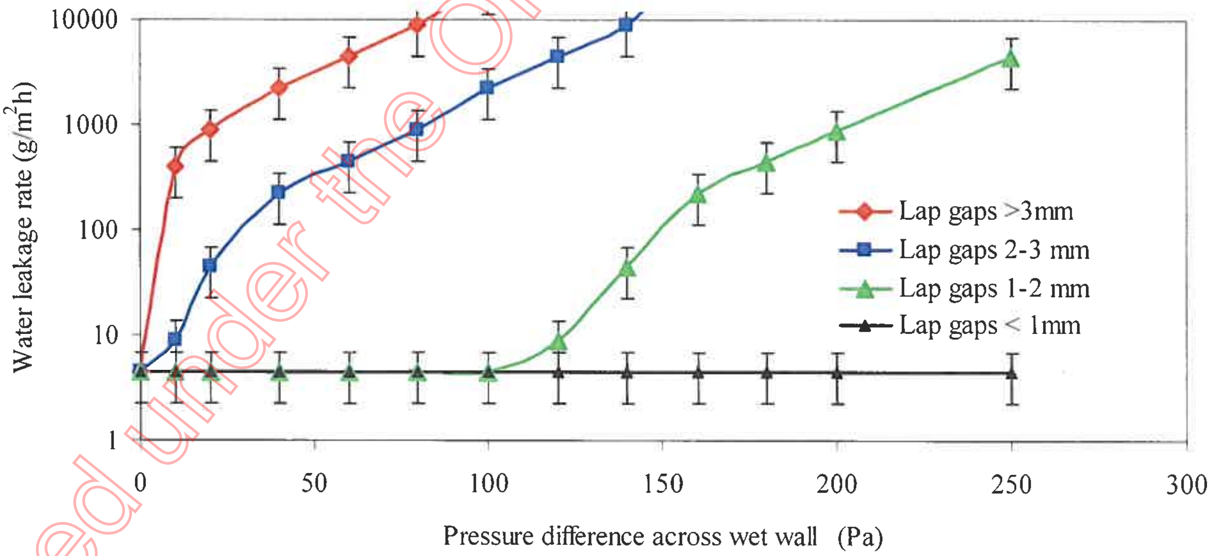

Figure 28. Leakage rates for wall B with gaps between lap joints ranging from <1 mm to >3 mm

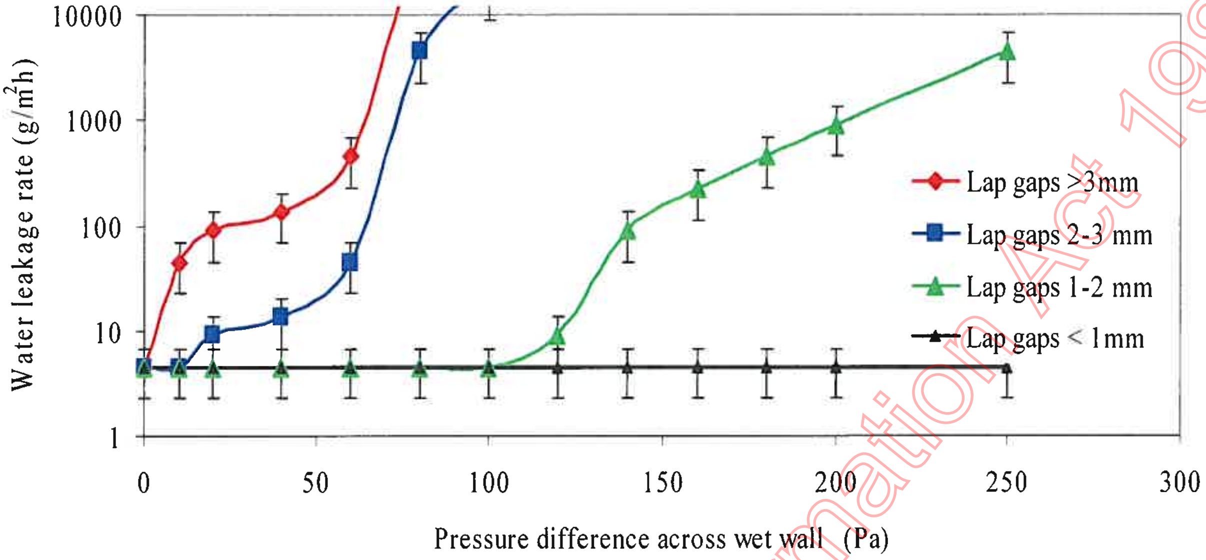

Figure 29. Leakage rates for painted wall B with gaps between lap joints (<1 mm to >3 mm before painting)

The following points can be taken from the data remembering that the leakage data relates to an E2/VM1 weathertightness test rather than leakage that might be expected in practice.

Ranking the leakage sites. It is a commonly held view the overlap dimension between weatherboard claddings is critical to weathertight performance but this view is not supported by this study of 11 weatherboard walls. It was found that gravity leaks through cracks and other defects in timber weatherboards are more significant than leaks through well fitting lap joints. For metal, plastic and composite the largest leaks were located at butt jointers.

Lap joints. The most significant dimension here is the gap width rather than the overlap dimension. The larger gaps (> 3 mm) allowed air carried water to spatter across to the plane of the building wrap at test pressures around 50 Pa that would be interpreted as a failed "wet wall" test in E2/VM1. Joints with gap widths less than 2 mm filled with capillary held water and did not overflow until the test pressure exceeded the static head equivalent to the overlap (typically 250 – 350 Pa). It might not be widely appreciated that cupping effects and fixings that do not hold the laps together will reduce the weathertight performance of weatherboard walls.

E2/VM1. All of the walls in this study would have passed the "wet wall" test in E2/VM1 except wall B with large gaps between weatherboards. The gravity leaks present in other walls drained down the back of the cladding and outside through lap joints with no significant spatter at 50 Pa. A problem that might be addressed though is the performance of jointers used with composite, plastic and sometimes metal claddings. The study sometimes found major water leaks at jointers in otherwise high performance claddings. In the wider context of managing water in walls, this will be more a significant problem if the cladding is absorbent than if it drains freely outside.

5. COMMERCIAL TESTING TO E2/VM1

E2/VM1. This procedure has been used by BRANZ for several years in a commercial product appraisal environment. It has also been used to help industry clients develop flashing solutions in new cavity walls (complete with windows, parapet walls and corners). Although E2/VM1 was trialled with some common wall designs in its development phase, the following experiences from several years of application could be useful feedback in a future review of the VM.

- **Scope of E2/VM1**. The scope currently includes open rainscreen and drained and ventilated wall designs but excludes mass walls and other types of drained assemblies like drainage planes (for which D3 performance cannot be taken for granted). In BRANZ experience this has limited progress towards several new water managed wall solutions.

- **Tests for D2**. The test procedure deliberately creates defects in the outer wall cladding and checks that water leaking into the cavity is either retained on the back of the cladding or successfully flashed outside. Because there are significant advantages to drainage over absorption, it is likely the test will eventually have to measure both drained and absorbed components.

- **Common reasons for water bridging the cavity**. A criteria for failure is water bridging across the cavity to the building wrap. This can occur for systematic reasons e.g. tracking back along an incorrectly sloped brick tie, or non systematic reasons e.g. water tracking across a nail splintered batten. A particularly common systematic reason for failure is water tracking across the end grain on a short batten on a window jamb line.

- **Capillary paths in window trim cavities**. Earlier research projects have warned of the danger of tight trim cavities tracking water to the air seal. One of the more common ways this capillary path has been created in test specimens is by over filling the trim cavity with foamed-in air sealant.

- **Wet wall test for D1 performance**. In BRANZ experience this is the most difficult part of the test to pass. Failures are primarily water accumulating on the back of the cladding eventually crosses to the 'dry' side of the cavity at sills and where elements bridge the cavity. 50Pa is a significant pressure but we have not yet seen claddings with a good field track record failing the test.

- **Corner details**. Because there is often so much framing at internal or external corners, it can be difficult to see water leaks and how well they have been controlled. Bearing in mind that the pressure gradients expected around the corners of buildings are not simulated in the test, this might argue for less emphasis on testing corners.

- **Footer and cavity closer performance in the wet-wall test**. Spatter is common at 50 Pa, and often rises several 100mm from the opening. It is unlikely that this is seen in practice and is not causing a problem in tests.

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