STUDY REPORT

SR 299 (2013)

Rigid Sheathing and Airtightness in New Zealand

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Funded by BRANZ from the Building Research Levy

Ministry of Business, Innovation & Employment

The work reported here was jointly funded by BRANZ from the Building Research Levy, and the Ministry of Business, Innovation and Employment.

ISSN: 1179-6197

Preface

This report forms part of a BRANZ study on the use of rigid sheathing which in turn forms part of the Weathertightness, Air Quality and Ventilation Engineering (WAVE) programme at BRANZ. For more information about WAVE, please visit www.branz.co.nz.

Acknowledgments

WAVE is funded by the Building Research Levy and the Ministry for Business, Innovation and Employment.

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Abstract

The use of rigid sheathing is increasing in New Zealand construction. Rigid sheathing (or rigid underlay) is now mandatory for NZS 3604 style construction in extra-high wind zones and there is anecdotal evidence of rigid sheathing increasing in popularity for practical reasons as well.

This study measures the airtightness of six wall specimens with different configurations of underlay, including battened plywood sheathing. It is shown that walls with rigid sheathing are likely to be more airtight than current typical construction, where the interior lining acts as the main air barrier.

About a third of new homes are under ventilated and so any further increase in airtightness will also increase the need for supplemental ventilation in New Zealand homes.

The decision to make rigid sheathing mandatory in extra-high wind zones is supported by results from this study which show that screw pull-out can occur in the field of the interior lining at a total pressure of 900 Pa for walls with rigid sheathing. Rigid sheathing is calculated to increase this pressure to 1650 Pa.

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1. INTRODUCTION

The New Zealand standard for timber-framed construction, NZS 3604, was updated in 2010 and now includes an extra-high wind zone (Standards New Zealand, 2010). To accommodate this, the Department of Building and Housing's compliance document for weathertightness, E2/AS1, requires a rigid underlay (or rigid sheathing) to be used in the new wind zone (Department of Building and Housing, 2011).

There is anecdotal evidence that the use of rigid sheathing is increasing in general. This may be partly due to the changes in E2/AS1 but also because there are several practical benefits when using a rigid sheathing including:

- ease of use, especially when dealing with penetrations
- increased durability from "redundancy" in the wall system
- increased robustness of the drained cavity – less risk of insulation bulging and reducing cavity depth
- the potential to "close-in" the framing earlier
- the potential to remove the air barrier function from the interior lining

Rigid sheathing is often referred to as a "rigid air barrier" in New Zealand. This creates a degree of confusion as there is no airtightness requirement in the New Zealand Building Code. Additionally, overseas, where sheathing is widely used and airtightness is often a requirement, the sheathing is usually not the designated air barrier. Overseas, the sheathing often functions as a bracing element, but here in New Zealand, that role is usually performed by the interior lining or dedicated metal bracing elements.

As an example of why rigid sheathing does not necessarily function as an air barrier, it is reasonably common for sheathing to be run horizontally in North American construction and to have a gap between the sheets (to allow for expansion). Such an arrangement is not going to function as an air barrier, because air can simply flow through the gaps in the sheathing. Therefore if, for some reason, it is desired to have an air barrier in New Zealand construction, it is necessary to consider the air barrier as a complete system, not just a collection of materials that have low air permeance.

If rigid sheathing is run vertically and battened over the joints, it can potentially form part of an air barrier system and this is the focus of this study. Specifically, how is the airtightness of a wall affected when rigid sheathing is used?

1.1 Airtightness in New Zealand and Overseas

As mentioned previously, there is no airtightness requirement in the New Zealand Building Code, but there are many countries where airtightness is a required performance criteria for buildings. In some countries the drive to minimise uncontrolled airflow through the structure is motivated by moisture problems and in other countries, energy savings are the main motivation. An airtight building is also desirable for the efficient use of mechanical ventilation systems.

Some selected airtightness requirements from national building codes and energy saving initiatives are shown in Table 1. Note that the units for measuring airtightness vary and in some cases the requirements relate only to wall specimens, not whole buildings. A normalised value for air changes per hour (ach) at 50 Pa has been calculated for each case.

Table 1-1 International Airtightness Requirements (Limb [2001], Kluttig-Erhorn et al [2007], NBCC [2001])

Country	**Airtightness Requirement**	**Form of Requirement**	**Approximate Normalised Value (ach) @ 50 Pa**
Belgium	• **Mechanically ventilated** 3 ach @ 50 Pa • **Mechanically ventilated with heat recovery** 1.0 ach @ 50 Pa	Standard for ventilation systems	• **Mechanically ventilated** 3 ach • **Mechanically ventilated with heat recovery** 1.0 ach
Canada	0.05 to 0.2 l/s.m^2 @ 75 Pa (for opaque, wall specimens – not whole buildings. Value depends on ability of wall to dry to the outside)	Recommendation in Code	1.1 to 4.6 ach
Czech Republic	• **Naturally ventilated** 4.5 ach @ 50 Pa • **Mechanically ventilated** 1.5 ach @ 50 Pa • **Mechanically ventilated with heat recovery** 1.0 ach @ 50 Pa	Code/regulation	• **Naturally ventilated** 4.5 ach • **Mechanically ventilated** 1.5 ach • **Mechanically ventilated with heat recovery** 1.0 ach
Denmark	1.5 m^3/hr per m^2 of floor area @ 50 Pa	Code/regulation	0.5 ach
Germany	• **Naturally ventilated** 3.0 ach @ 50 Pa or 7.8 m^3/hr per m^2 of floor area • **Mechanically ventilated** 1.5 ach @ 50 Pa or 3.9 m^3/hr per m^2 of floor area	Code/regulation	• **Naturally ventilated** 3.0 ach • **Mechanically ventilated** 1.5 ach
Germany – Passivehaus	• **Mechanically ventilated with heat recovery** 0.6 ach @ 50 Pa	Voluntary standard	• **Mechanically ventilated with heat recovery** 0.6 ach
France – Effinergie	0.6 m^3/hr per m^2 @ 4 Pa	Voluntary standard	2.6 ach
International Energy Conservation Code	7 ach @ 50 Pa	Code/regulation	7 ach
Norway	4 ach @ 50 Pa (houses)	Recommendation	4 ach

		in Code	
Netherlands	720 m^3/hr @ 10 Pa (class 1 buildings between 250 and 500 m^3)	Code/regulation	7 ach
Sweden	0.8 l/s per m^2 @ 50 Pa	Code/regulation	2.4 ach
Switzerland	0.75 m^3/hr per m^2 @ 4 Pa	Code/regulation	3.3 ach
Switzerland – Minergie	• **Mechanically ventilated with heat recovery** 0.6 ach @ 50 Pa	Voluntary standard	0.6 ach
UK	10 m^3/hr per m^2 @ 50 Pa	Code/regulation	8.3 ach
USA – ASHRAE	Depends on location. Predominantly (0.4 ach @ 4 Pa)	Voluntary standard	2.1 ach
USA – ASTM E1677	0.3 l/s.m^2 @ 75 Pa (for opaque, wall specimens – not whole buildings)	Standard for air barriers	6.9 ach (N.B. ASTM E1677 says this is equivalent to 1-2 ach but the working is unclear)

The normalised values assume the following building parameters: volume = 300 m^3, surface area = 250 m^2 and floor area = 100 m^2.

To convert requirements that are at pressures other than 50 Pa, the following relationship is assumed:

$$Q = C\Delta P^{0.66} \tag{1}$$

Q is the flow rate and the ΔP is the pressure difference.

This equation is used to calculate a value for the flow coefficient C, which in turn is used to calculate the adjusted flow rate at 50 Pa. In the Canadian case, it has been assumed that the leakage of a whole building is an order of magnitude greater than the leakage through an opaque wall specimen. This assumption is based on the different ASTM requirements for the airtightness of materials, air barrier assemblies and whole buildings respectively (Anis, 2006). Because of the assumptions made, the normalised comparison should be treated as a very rough approximation.

The United States does not have a national energy code but Kluttig-Erhorn et al (2007) state that local code officials generally follow the International Energy Conservation Code which has a required airtightness of less than 7 ach @ 50 Pa (or a verified installation checklist). Several other local codes exist in the USA such as the Washington State Energy Code and the Seattle Energy Code which require buildings to undergo an airtightness test but do not require them to pass a prescribed value (Air Barrier Association of America, 2013).

In New Zealand, airtightness has been less of a concern. However, modern New Zealand homes are more airtight than older homes (Overton et al, 2013).

The average airtightness result (at 50 Pa) from houses built before WWII was around 19 ach but this reduced dramatically to 8.5 ach for houses built between 1960 and 1980. A significant contributor to envelope air-tightening around 1960 was the shift from suspended tongue-and-groove flooring to sheet floor construction and slab-onground floors. Another change at a similar time was the shift from timber joinery to aluminium-framed doors and windows.

Newer construction practices have continued to influence the airtightness of houses. Recent examples of changes are the widespread use of bonded plaster cornices or a square-stopped interior plaster finish and the adoption of air seals around window and door assemblies to control rain penetration. For houses built since 2000, the mean airtightness level was at 4.5 ach at 50 Pa.

The airtightness of New Zealand homes and how it varies with the date of construction is shown in Figure 1.1 (Overton et al, 2013).

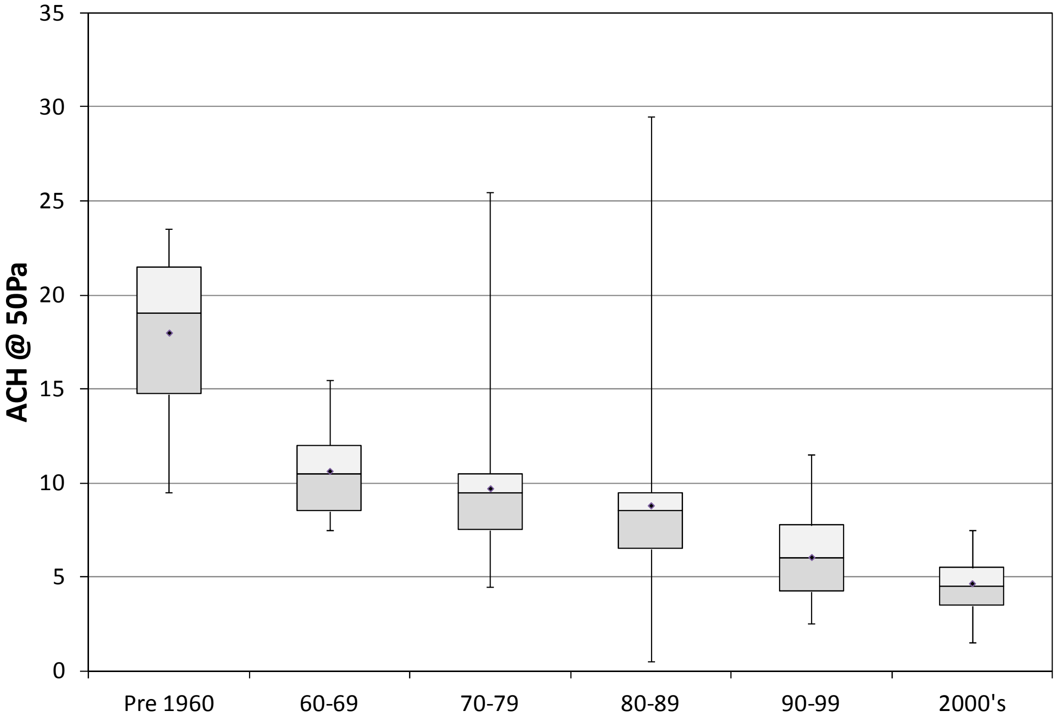

Figure 1-1 Airtightness Measurements of New Zealand Homes (Overton et al, 2013)

For homes built since 1995, research has shown that about one third have ventilation levels below international guidelines for indoor air quality (Overton et al, 2013). This is because the air infiltration (related to the airtightness) through the building envelope is not always supplemented by extra ventilation.

Therefore if New Zealand homes become more airtight, the need for specific ventilation provision will become even greater. To assess the effect on airtightness arising from different options for wall underlay, including the use of rigid sheathing, a series of tests were performed to measure both the airtightness and the pressure drop through the wall assembly.

2. EXPERIMENTAL METHOD

Six 2.4 m high by 2.4 wide wall specimens were tested using the general procedure outlined in ASTM E283-04, *Standard Test Method for Determining Rate of Air Leakage Through Exterior Windows, Curtain Walls and Doors Under Specified Pressure Differences Across the Specimen*. ASTM E283 is referenced by ASTM E1677, *Standard Specification for an Air Barrier (AB) Material or System for Low-Rise Framed Building Walls.* This was chosen because there is no New Zealand standard for measuring airtightness of wall specimens.

2.1 ASTM E283

ASTM E283 requires a test specimen to be sealed into or against one face of an air chamber, supplying air to or exhausting air from the chamber at the rate required to maintain the specified test pressure difference across the specimen and measuring the resultant air flow through the specimen.

The procedure in ASTM E283 was modified slightly to obtain further information about the airtightness of the test specimens and to better align with existing New Zealand tests such as E2/VM1 (Department of Building and Housing, 2011). The main modifications are shown below.

Table 1-2 Modifications to ASTM E283 in this Study

ASTM E1677/ASTM E283	Modification
Interior lining has an electrical socket with two open knockouts	Interior lining had a 20 mm diameter hole cut in it. This is the same size hole used in E2/VM1
Cladding is simulated, i.e. partially clad	Wall was fully clad with clear acrylic sheet over a 20 mm cavity. Note that this study was concerned with the whole wall, not just the component that was specifically the air barrier. Acrylic allowed visualisation of the wall whilst maintaining normal construction style
Pressure is measured in chamber	Pressure measured in chamber and other locations to gain information about pressure drop through the wall
Tested at pressures 50, 62, 75, 87 and 100 Pa (typically)	Tested at 10, 25, 50, 75, 100, 125, 150, 200, 250, 300, 350 Pa. This was done to obtain more detailed information

Tests we conducted on three configurations for each specimen (see Section 2.2) and each configuration was tested in both flow directions, i.e. positive and negative pressure.

In addition, at the completion of the tests on Specimen C (see Section 2.2) the pressure in the chamber was ramped up to assess the mode of failure of the air barrier components in a typical New Zealand wall.

2.2 Description of Wall Specimens

Six walls were built using the same general construction. The only differences between specimens were in the nature of the underlay and the presence or otherwise of a cavity closer.

2.2.1 General Construction

All walls were 2.4 m high x 2.4 m wide and timber-framed. Studs were at 600 mm centres and dwangs at 800 mm centres. The specimens were clad with clear acrylic sheet over a cavity formed by timer battens. Flexible wall underlay was stapled to the framing at 300 mm centres and support tape was run vertically between battens. The timber frames were insulated using R 2.0 fibreglass placed in the stud space. The walls were lined on the interior using screw-fixed 10 mm thick gypsum plasterboard. The lining was sealed at the sides, top and vertical joint using masking tape. A 20 mm diameter hole was drilled in the plasterboard to simulate leakage at an electrical socket.

2.2.2 Specific Details

Descriptions of each wall specimen are shown in Table 2-2. Unless specified, "tape" refers to masking tape. The bold text represents the key features of each specimen.

Table 1-3 Descriptions of Test Specimens

Specimen Name	Description
A	As general construction but: • **Horizontal joint in flexible underlay was lapped** by 300 mm at approximately mid height of the specimen • Flexible underlay was taped to sides and top of frame • **Cavity closer present** at base of drained cavity
B	As general construction but: • **Horizontal joint in flexible underlay was lapped** by 300 mm at approximately mid height of the specimen • Flexible underlay was taped to sides and top of frame • **Cavity closer omitted** at base of drained cavity
C	As general construction but: • **Horizontal joint in flexible underlay was taped using PVC joining tape** at approximately mid height of the specimen • Flexible underlay was taped to sides and top of frame • **Cavity closer present** at base of drained cavity
D	As general construction but: • **Horizontal joint in flexible underlay was taped using PVC joining tape** at approximately mid height of the specimen • Flexible underlay was taped to sides and top of frame • **Cavity closer omitted** at base of drained cavity
E	As general construction but: • **Horizontal joint in flexible underlay was taped using PVC joining tape** at approximately mid height of the specimen • Flexible underlay was taped to sides, top of frame **and bottom plate** • **Cavity closer present** at base of drained cavity
F	As general construction but: • **Two 2.4 m high by 1.2 m wide, 8 mm thick plywood sheets were nailed to the outside of the framing at 300 mm centres** • **Horizontal joint in flexible underlay was lapped** by 300 mm at

	approximately mid height of the specimen • Flexible underlay was taped to sides and top of frame • **Cavity closer present** at base of drained cavity

For all the walls, the following configurations were tested:

- all edges of interior lining sealed and 20 mm hole taped – the background leakage case
- with the bottom edge of the interior lining unsealed – typical installation method
- with 20 mm hole untaped – to simulate typical as-built condition (with electrical sockets etc.)

2.3 Test Equipment

2.3.1 Test Chamber

BRANZ's E2/VM1 rig was used as a test chamber. This rig consists of an open chamber with water spray equipment and a fan.

The wall specimens were clamped to the open face. The valves for the water were closed off and all other apertures such as the door at the rear of the rig were sealed as best as possible.

A laminar flow element was connected to the fan. Tubing to the chamber was either connected to the high pressure or low pressure side of the fan, resulting in positive or negative chamber pressures respectively.

2.3.2 Pressure Measurements

A single pressure transducer was used during the test and a switch unit was used to select the pressure difference to be measured by the transducer.

Pressure taps were located at the following locations:

- main chamber
- between the cladding and the building wrap
- between the building wrap and the interior lining (i.e. in the insulation)
- ambient pressure outside of the chamber
- across the flow transducer

2.3.3 Flow Measurement

A Laminar Flow Element (LFE) was used to measure the volumetric flow rate through the fan. The LFE was connected to the high pressure side of the fan.

The LFE model number was Meriam F15/37 50M R2-2. Earlier calibration had calculated a factor of 1.55 to convert from l/s to Pa and this value was used in this particular study.

2.4 Calculation of Airtightness

To be classified as an air barrier system, ASTM E1677 requires the flow to be a maximum of 0.3 l/s.m^2 @ 75 Pa.

The above flow rates were found as follows:

- the flow through each specimen was calculated using the previously calibrated relationship between pressure and flow for the LFE
- for each configuration, a power law relationship between flow (Q) and pressure difference (P) was fitted to the data. The relationship is similar to that in Equation 1 but the exponent is also unknown
- the airtightness of the overall specimen, i.e. with the hole and the bottom edge of the interior lining un-taped, was found by subtracting the flow associated with background leakage for the same pressure
- the resultant power law relationship was used to calculate the leakage at 75 Pa
- the flow at 75 Pa for both positive and negative pressures was averaged to give the end result

3. RESULTS

3.1 Airtightness

ASTM E283 normally quotes the results as a leakage rate at 75 Pa. The average results for the six specimens in their as-built configuration is shown in Table 3-1.

Table 1-4 Average Airtightness Results for Positive and Negative Pressures

Specimen	Airtightness Level
A	0.24 l/s.m^2 @ 75 Pa
B	0.37 l/s.m^2 @ 75 Pa
C	0.21 l/s.m^2 @ 75 Pa
D	0.39 l/s.m^2 @ 75 Pa
E	0.16 l/s.m^2 @ 75 Pa
F	0.13 l/s.m^2 @ 75 Pa

3.2 Pressure Drop Across Interior Lining

The percentage pressure drop across the interior lining is shown in Table 3-2. Where the value is above 50% it means that the interior lining was acting as the main air barrier in the wall.

Table 1-5 Percentage of Total Pressure Difference Acting on the Interior Lining

Specimen	Approximate Pressure Drop Across Interior Lining
A	65%
B	80%
C	55%
D	88%
E	45%
F	28%

In each case the remainder of the pressure drop occurs across the sheathing/underlay layer.

3.3 Structural Strength

Under a positive pressure, the mode of failure for Specimen C was the interior lining pulling away from the screw fixings in the field of the sheets. This occurred at a chamber pressure of approximately 900 Pa. From the earlier measurements, 60% of this total pressure drop would have occurred across the interior lining, corresponding to a pressure of 540 Pa.

Under a negative pressure the mode of failure was the wrap pulling through the staple fixings. However, although this occurred at a few points, the wrap was then restrained by the cladding, thereby preventing further failure. The wrap layer was still resisting approximately 40% of the pressure, as it had done throughout the test.

4. ANALYSIS AND DISCUSSION

4.1 Airtightness

The results show that the airtightness of opaque walls depends on the sheathing/underlay configuration.

The only specimens that did not meet the ASTM E1677 requirement for air barriers (0.3 l/s.m^2) were Specimens B and D. These specimens do not represent "real" New Zealand walls because of the absence of a cavity closer. It was surprising how well the cavity closer sealed the bottom of the wall. Although the cavity closer was only stapled to the framing at 300 mm centres, its effect was similar to taping the bottom edge of the flexible underlay completely shut (as in Specimen E).

The specimens which most represent current "normal" practice were Specimens A and C which had airtightness levels of 0.24 l/s.m^2 and 0.21 l/s.m^2 respectively and both meet the airtightness requirement of ASTM E1677. The ASTM E1677 result relates only to an opaque wall specimen. Real walls, which will contain doors, windows and junctions to the floor and ceiling etc., are likely to behave quite differently. Using the rough approximation that the leakage of a whole building will be an order of magnitude larger than that through an opaque specimen at 75 Pa, then the normalised whole building leakage rate (see Section 1.1) for an airtightness of 0.21 l/s.m^2 is 4.8 ach. There is reasonable agreement between this crude estimate and the average airtightness for houses built since 2000 in New Zealand of 4.5 ach.

If battened rigid sheathing is employed, then the wall will become more airtight. Specimen F was the most airtight of all the specimens with a flow of 0.13 l/s.m^2. This leads to an approximate normalised whole building airtightness of 3.0 ach. The approximate airtightness of the whole building assumes that the rigid sheathing forms part of a continuous air barrier. Further field testing would be desirable to measure the airtightness of whole buildings where rigid sheathing is used to see how the results compare with this estimate.

An airtightness of 3.0 ach is similar to the requirements in countries where additional ventilation is the norm (see Table 1-1). If houses in New Zealand are to be built to such levels of airtightness then additional ventilation will be necessary to avoid moisture and/or health issues.

Whereas in many countries the use of ventilation systems has motivated the drive for airtight buildings, New Zealand is heading towards a situation where the airtightness of buildings is driving the need for a ventilation system.

4.2 Pressure Drop Across Interior Lining

Specimens A and C best represent "normal" practice and in each of these cases, the majority of the pressure drop was across the interior lining. Therefore, in the majority of existing New Zealand walls the interior lining is likely to be the main air barrier, not the flexible underlay. This is perhaps another reason to avoid the term "rigid air barrier" as a general term for rigid sheathing, since gypsum plasterboard could justifiably be called a “rigid air barrier” as well.

In Specimen F, 70% of the pressure drop was across the rigid sheathing. Therefore, if battened rigid sheathing is used, it takes over from the interior lining as the main air barrier (assuming continuity with components of the air barrier system).

In airtight construction, the location of the air barrier is generally not a crucial decision (unlike the location of a vapour barrier, if one is to be used). However, one potential disadvantage of having the interior lining as the air barrier, is that any damage or alteration to the lining potentially affects the airtightness.

4.3 Structural Strength

The structural integrity test was limited by the fact it was performed on one specimen only, but it is felt the identified mode of failure (screw pull-out) was accurate and that the failure strengths were in line with expectations.

This suggests that an air barrier other than the interior lining may be advisable where the serviceability limit state (SLS) pressure is expected to exceed 900 Pa. This pressure is based on the interior lining taking 55% of the wind pressure (Specimen C) and having a failure pressure of 500 Pa. This SLS pressure could be increased by increasing the strength of the failed component e.g., alternative fixings or lowering the load on each fixing (more fixings).

Assuming the same failure criteria, the presence of battened rigid sheathing would increase the allowable SLS pressure to approximately 1650 Pa. This is based on the interior lining having to see 30% of the total load (Specimen F).

It is felt that the current recommendation that a rigid sheathing be used in the extra-high wind zone of NZS 3604 is sensible. The above analysis suggests this could be extended all the way down to the high wind zone, but there is little evidence from the field to support such a move.

4.4 General

In the process of testing each wall specimen, it became apparent that the pressure just inside the cladding was nearly identical to the main chamber pressure.

This means that in all of the wall specimens the *static* pressure moderation performance was good. The choice of air barrier may have an impact on the *dynamic* pressure moderation performance however, but that was beyond the scope of this experimental work.

5. CONCLUSIONS

- typical E2/AS1 cavity walls (Specimen A and Specimen C) meet the ASTM requirement for an air barrier of 0.3 l/s.m^2 @ 75 Pa. In these walls the interior lining was the main air barrier, taking approximately 60% of the total applied pressure
- walls with battened rigid sheathing are more airtight than typical current construction. In this study, Specimen F was the most airtight at 0.133 l/s.m2 @ 75 Pa. In this case approximately only 30% of the pressure was taken across the interior lining

- if battened rigid sheathing has a similar effect on whole building airtightness, then the need for supplemental ventilation will become even greater in New Zealand homes. Whole building airtightness with rigid sheathing was roughly estimated to be 3 ach @ 50 Pa compared with 4.5 ach @ 50 Pa for existing houses built since 2000. Further field testing would be desirable to validate this estimate. About a third of newer homes are under ventilated and this proportion will increase if homes become more airtight without complementary measures to ensure adequate ventilation
- with typical current construction (Specimen C), screw pull-out (a serviceability failure) occurred at a pressure difference of about 500 Pa across the gypsum plasterboard interior lining. This corresponded to a total pressure of 900 Pa
- rigid sheathing lowers the pressure resisted by the interior lining meaning that screw pull-out will not occur until approximately 1650 Pa SLS. Therefore rigid sheathing may prevent screw pull out in cases where the SLS pressure is higher than 900 Pa. This corresponds to the NZS 3604 high wind zone and above. However, given the lack of field evidence regarding failures of the interior lining, it is recommended that the current requirement for rigid sheathing in the extra-high wind zone only is left unchanged
- pressure moderation across the cladding was essentially 100% under the static conditions used in this study for all test specimens. The choice of underlay may have an effect on the dynamic pressure moderation but that was beyond the scope of this study

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