Study Report NO.22
(1990)

WEATHERTIGHTNESS OF DOMESTIC CLADDINGS.

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REFERENCE

PREFACE

This is a report on an experimental study of the weathertightness of claddings for domestic buildings. It is part of a wider programme helping to develop weathertight roofs, claddings, and windows on all types of buildings.

This report is intended for research and development personnel involved with domestic cladding materials.

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KEYWORDS

From Construction Industry Thesaurus, BRANZ edition: Cellulose; Cement, Claddings; Fibrous reinforcement; Houses; Leakage; Metals; New Zealand; Panels; Polyvinyl chloride; Rain; Rain permeability; Sheets; Timber; Waterproofing; Weatherboarding; Weatherproofing; Wind loads.

ABSTRACT

Lightweight PVC and metal cladding materials were introduced into New Zealand with little information on their weathertightness. Their flashing and fixing details were quite different from traditional timber claddings and this made questionable their suitability for use in New Zealand.

An experimental programme was designed to measure the performance of each type of joint in PVC and metal cladding systems as well as in traditional weatherboard systems. This allowed for answers to the question "How should lightweight claddings be flashed and fixed to be as weathertight as traditional weatherboard claddings?" It also established more knowledge about rain leakage; in future this knowledge can be applied to new wall claddings.

BACKGROUND

New Cladding Systems

New Zealand houses have traditionally been clad in timber weatherboards or brick. Traditionally, water leaks through wall claddings have not been a severe problem in New Zealand except in exposed high wind areas.

In the last few years, a new range of lightweight claddings have been manufactured in New Zealand or imported. These new claddings are made of different (impermeable) materials, including sheet metal and plastics (typically PVC). When these new claddings appeared on the market in the mid-1980s, they were accepted as part of the natural process of innovation in building materials.

However, upon closer examination of these products, it was noted that the fixing and flashing details used were different from those used with traditional claddings, which caused concern about their weathertightness in New Zealand conditions. As building practices and climates in the countries of origin (USA, Canada, Australia) are significantly different from New Zealand, techniques and materials that performed well there may be incompatible with New Zealand conditions, or require different installation details.

A testing programme was designed to:

(1) determine the rain leakage performance of the full range of joints and flashings in the new lightweight impermeable cladding systems and compare them with traditional cladding systems whose long-term field performance is well known;

(2) enable BRANZ Advisory staff to make recommendations on the fixing and flashing of lightweight claddings for New Zealand residences (specifically for resistance to rain penetration); and

(3) collect information and experience that could be applied to other cladding systems not part of this sequence of tests.

Water Leakage

There are four main mechanisms driving water leakage into buildings. Capillary suction can cause water to be drawn into tiny openings in the body of permeable materials via surface tension. Gravity drainage can cause free flowing water to penetrate a building opening, usually due to an incorrectly detailed flashing. Rain drop momentum can cause raindrops to fly through openings large enough to admit them. Air pressure differences across building openings (higher pressure outside, lower pressure inside) can cause air flows which carry water with them.

The weathertightness literature clearly shows that wind-induced air pressure difference is the dominant mechanism driving water leakage through vertical elements (walls, thus claddings). (Svendsen, 1955; Marsh, 1977)

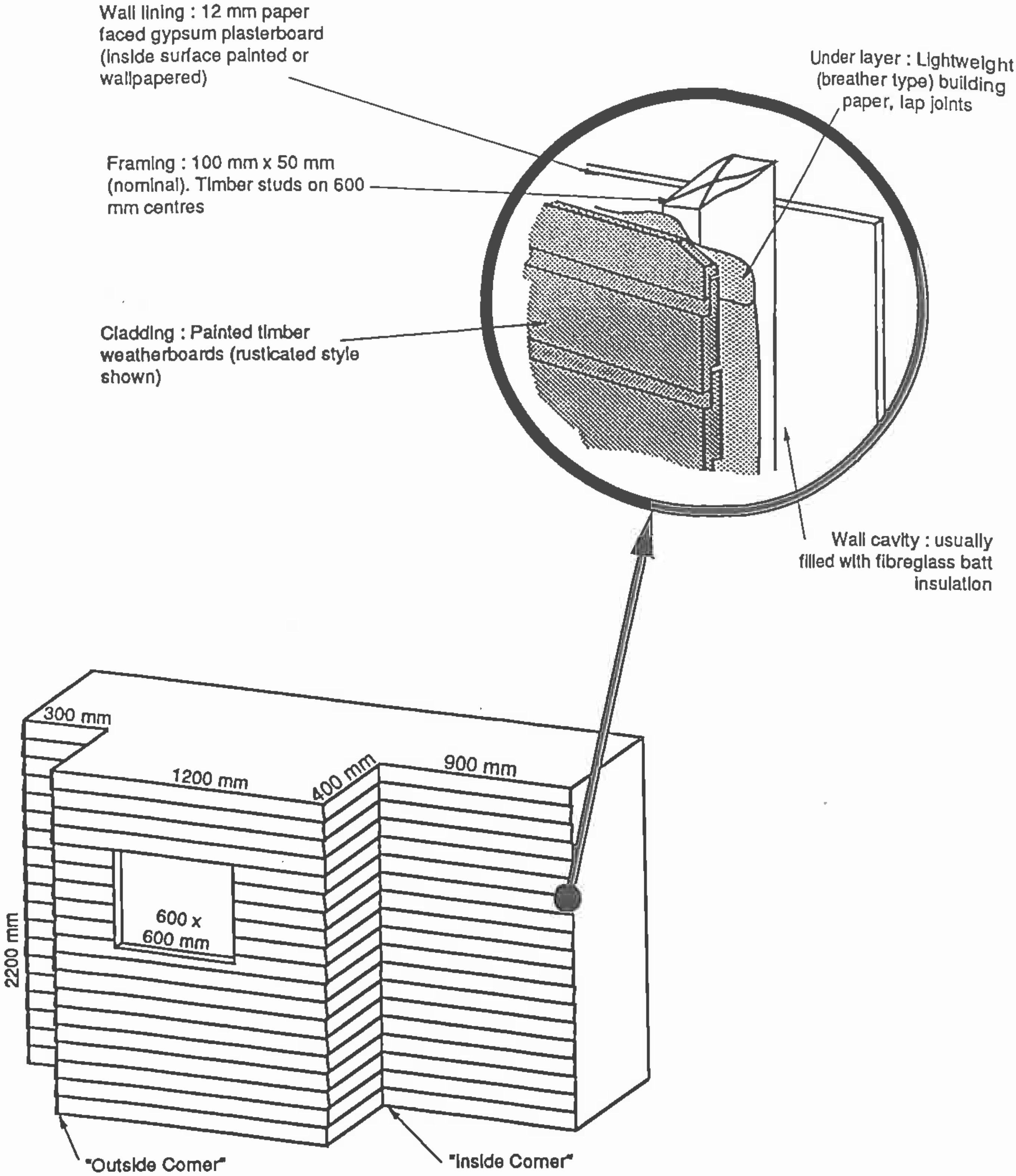


Figure 1 : Test Walls Representing Typical New Zealand Wall Construction

No standard tests for water leakage of impermeable wall elements were found in the literature. Standard tests exist for water leakage through permeable (masonry) walls (Agrement Board of South Africa, 1986; American Society for Testing and Materials (ASTM), 1974); but these are not relevant, as they are mostly influenced by capillary suction, not air pressure.

There are also standard tests for water leakage through windows and their surrounds (Standards Association of New Zealand, 1985; Standards Association of Australia, 1977; ASTM 1983a, 1983b), but these are not directly applicable to walls, as walls are built up of many different layers, and have junctions with other elements.

Thus a test was devised for water leakage of impermeable wall elements, based on the above standards, but accounting for the differences between impermeable wall claddings and either windows or porous walls. This test used wind pressure (including fluctuating pressure) as the main driving force behind water leakage, but allowed for the effects of other mechanisms (capillary suction, gravity drainage, and raindrop momentum).

EXPERIMENTAL DESIGN

Full-scale mockups of a typical New Zealand domestic wall section incorporating the claddings under test (as shown in Figure 1) were subjected to simulated rain (water spray) and wind (air pressure). Under these conditions, the rate of water entering the wall cavity was observed as a function of applied pressure difference (to the whole wall) at each water leakage location. Cladding air leakage rates and pressure distributions through wall elements were also measured.

Pressure distributions through a wall clad with a typical lightweight cladding are shown in Figure 2. As seen, the pressure difference across the entire wall, from inside to outside, is the sum of the pressure differences across each individual component of the wall.

The term "pressure difference" refers to the difference in pressure between one surface of a component and the other. It is sometimes referred to as "pressure drop" across a component, or simply "pressure across" a component.

The claddings tested in this programme cover the range of residential claddings available in New Zealand. They include three conventional timber claddings (horizontal rusticated, bevel-backed, and diagonal rusticated weatherboards); five lightweight horizontal PVC "weatherboard" claddings; three lightweight vertical PVC simulated "weatherboards"; two lightweight horizontal metal "weatherboards"; and one each of plywood shingles, cellulose fibre-reinforced cement sheet, and cellulose fibre-reinforced cement "weatherboards".

During the test the experimental team visually observed the cladding for evidence of water leaks.

With zero air pressure difference applied, the wall was examined for water leaks due to gravity drainage, capillary leaks, and momentum-driven rain

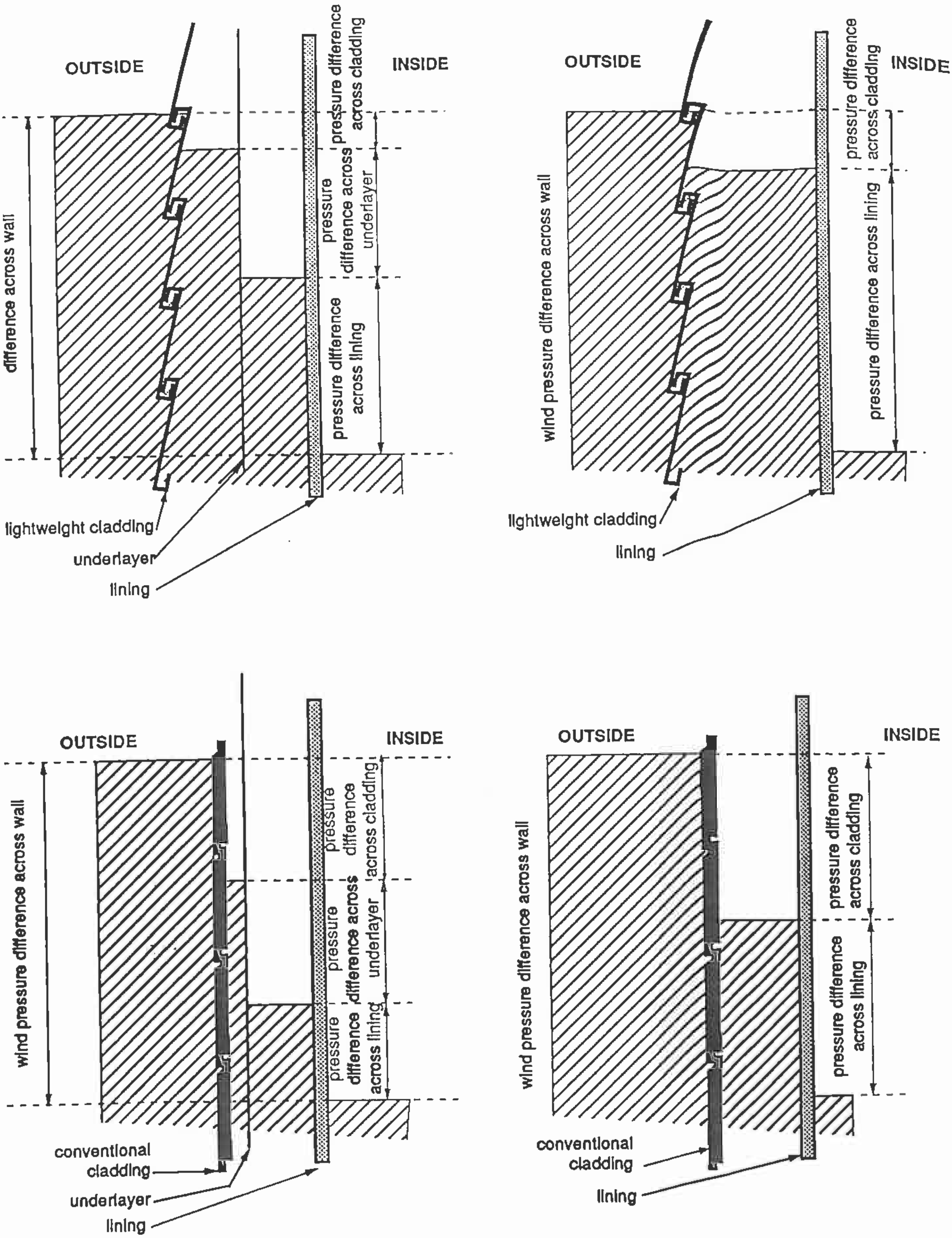


Figure 2 : Visualisation of Pressure Differences Across Wall Elements

entry. Mainly, though, the test revealed water leakage carried by air flows, driven by variable applied pressure differences.

It was expected that the other components of the wall, including the interior lining (usually gypsum plasterboard) and underlay (normally the building paper beneath the cladding) would affect the distribution of pressure differences in the wall.

This effect would be such that for a given cladding, the tighter the other components are, the less pressure difference would exist across the cladding. As seen in Figure 2, for both the lightweight and conventional claddings, less pressure difference acts across the claddings in the walls with both underlay and lining, than for walls with lining alone.

This effect was measured as the Pressure Drop Ratio. This is the ratio of the pressure difference acting across the element (in this case the cladding) divided by the pressure difference acting across the total wall.

Reducing the cladding pressure difference reduces water penetration through the cladding (Killip and Cheetham, 1984). To study this, each cladding was tested in a number of configurations incorporating other wall components.

Various joint flashing details were also tested for their effect on water leakage.

Test Setup

A mobile test apparatus used for commercial window rain penetration testing was leased and adapted for this project.

The wall section to be tested was mounted with simulated wind and rain acting on its exterior face (the "rain room" side) and experimental observations taken and conditions controlled from the other (the "control room" side), which would correspond in practice to the interior of a building.

The "rain room" of the rig contained four wide-dispersion high-volume water spray nozzles to provide total coverage of a window or wall section with simulated rain. For the purposes of these tests, only the top two nozzles were used. This ensured a higher pressure spray through them than if the available water supply had been shared between four nozzles, so raindrop momentum water leaks through the window joints could be sought. The total flow rate of water onto the test walls was normally 15 litre/min (170 ℓ/m^2 hr).

Although this amount of water was lower than recommended in the New Zealand Standard for Leakage Testing of Windows (SANZ, 1985), it was considered adequate as it has been shown that only about 1 mm/hour of rainfall (1 ℓ/m^2 hr) is enough to saturate the surface of an impermeable wall (Bishop and Brown, 1986).

The "rain room" also contained an outlet duct from a high-pressure low-volume air blower located in the control room. With a wall in place, and the access door clamped shut, the rain room could thus be pressurised to simulate wind.

The pressure in the "rain room" was controlled by a manually operable bypass damper on the outlet duct from the blower, and monitored with a "quarter-circle" manometer. The manometer was calibrated to 5000 Pa; test pressures only rarely exceeded 1000 Pa. The experimental setup utilised these existing features of the test rig, with other features purpose-built for these tests.

To allow simulation of gusting wind, and potential pressure equalisation of "drained joints", a controllable air leak was built into the wall of the "rain room" to allow pressure to be dumped, and for simulation of dynamic fluctuating wind, based on a similar device used by the CSIRO Division of Building Research in Australia. (Brown, 1986) This controllable air leak consisted of a 100 mm diameter brass pipe with a "butterfly" damper, which sequentially opened and closed a leakage opening between the pressurised "rain room" and the control room.

To generate a simulated gusting wind on the test wall, the blower pressurised the "rain room" to a chosen maximum total pressure difference with the butterfly damper closed. Then the motor rotating the butterfly damper was activated. As the butterfly damper was cycled, a sine wave of wind pressure was approximated. The frequency of the pressure wave (gust) could be altered by changing the voltage driving the motor. Typically one and three second cycle periods were used.

Model Test Walls

The wall sections under test were made to be full scale and as similar as possible to real residential walls, given the constraints of observability of water leaks and portability of the test walls. Portability was necessary so that several test walls could be built up outside the test rig, and interchanged for testing.

The wall sections were designed to:

(1) test the full range of cladding joint types found in residential walls;
(2) test the range of window flashings;
(3) have known, controlled, repeatable air leakage through the lining; and
(4) have linings that responded to air pressure difference realistically.

The test wall sections used were as shown in Figure 1. They were 2200 mm high and 2400 mm wide. The test wall frames were made so that the claddings could be removed and reapplied in different configurations. (The claddings were thus screwed rather than nailed to the frames for convenience.) A 400 mm projection from each test wall section was built to contain both inside and outside corners and a window.

Transparent rigid acrylic sheet linings were used instead of plasterboard so that water leaks could be seen with the wall lining in place. Steps were taken to ensure equivalent performance to gypsum plasterboard linings and are outlined below.

Each acrylic lining had four 50 mm diameter holes drilled through the lining thereby exposing stud cavities to the control room side, as shown in Figure 3. These holes could be blocked or opened, and simulated the effect of electrical outlets or other air leaks through the linings of exterior walls. Their size was empirically determined to give lightweight wall claddings a reasonable Pressure Drop Ratio, and their airtightness in this condition corresponded to field measurements of air leaky linings (Bassett 1987).

The linings were gasketed and sealed to the wall studs with compressible foam strips about 20 mm wide. These were screwed tightly through battens to ensure that the gaskets were compressed, so that no uncontrolled air leakage occurred. The studs and window trimmers (structural timber around the window frame) were also sealed together with silicone sealant to eliminate air leakage into or out of the stud cavities bordering the window.

Although real linings are not sealed like this, well-controlled, repeatable wall lining air leakage was desired for the tests.

Initially the entire test walls were examined for water leakage, but after a few tests it became apparent that water leakage was always concentrated at a few locations (as shown in Figure 3).

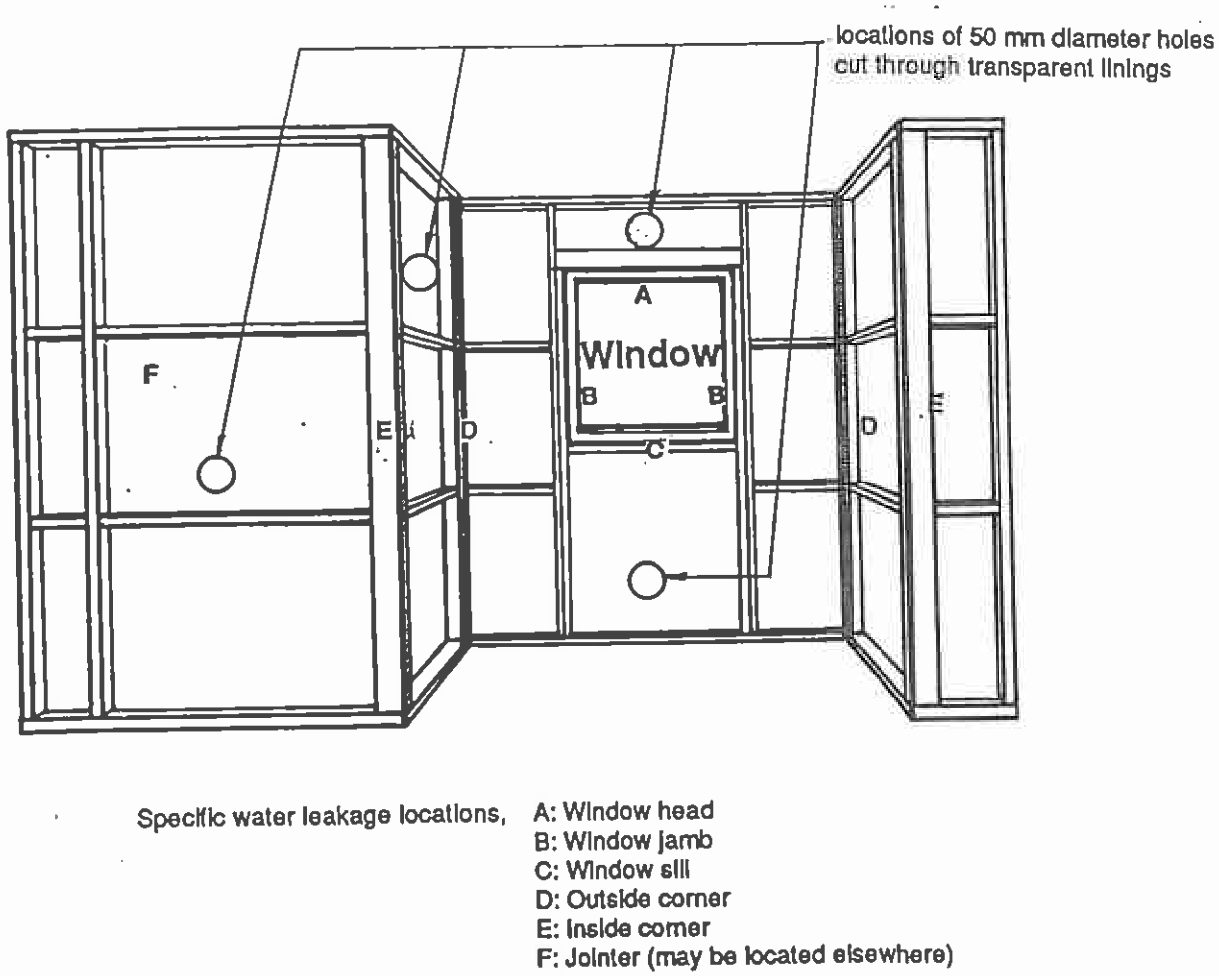


Figure 3 : Main Leakage Locations on Test Walls (View from inside - control room side)

Simulation of Wind Pressure Effects

The holes in the linings could be selectively opened or plugged to simulate the effect of a directional wind on a real building, with different pressures on different surfaces, as shown in Figure 4. Because wall cavity pressures tend to equalise between inside and outside pressures, a real building with a constant inside pressure will have pressure differences between adjacent wall cavities. In the test walls, the holes in the linings caused cavity pressures to equalise at different values, allowing pressure differences between cavities even without pressure differences between external surfaces.

The air leaks in the linings were simulated in stud cavities ranging from the largest to the smallest wall cavities. This method was used to see if there were observable volume effects, as larger cavities may require higher airflows to pressure equalise, so therefore may be less weathertight.

It was desired that the transparent linings behave as closely as possible to real wall linings. It was felt that the dynamic flexing of the claddings might have an effect of pumping water into the wall, so the design simulated the flexural stiffness of the gypsum plaster board linings used in typical New Zealand residences. It was calculated that 5mm thick acrylic sheet has essentially the same modulus of flexure as 12 mm thick gypsum plaster board, when used as a wall lining on the same on-centre stud spacing.

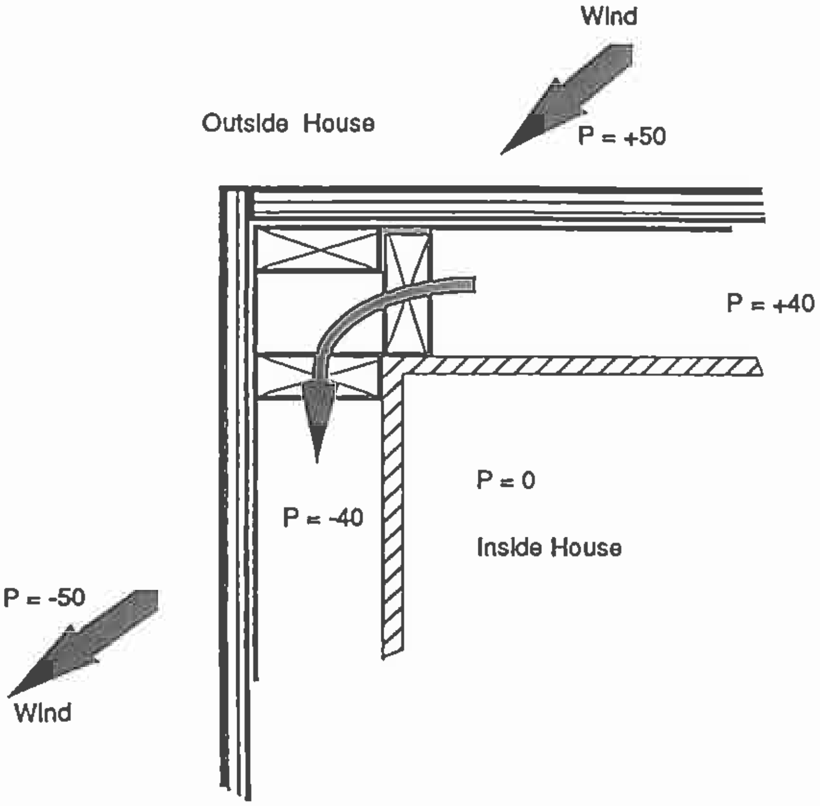
To simulate the effects of cladding underlays on rain water leakage through walls (in terms of pressure distributions, as well as blocking the direct transfer of water through the walls), a transparent polyethylene membrane was punctured (0.1% by area, or 5 mm holes on 140 mm centres) to have the same empirical, area-averaged air leakage permeability as lightweight breather building paper. This underlay was placed in the wall in the usual location for building paper, between studs and cladding, and was lapped at the seams in the same way as with conventional building paper.

The wall top and bottom plates were nailed to plywood representing floor and ceiling, and the studs in the corners were bevelled to allow visibility into the corner to look for water leaks there.

Air Leakage Tests

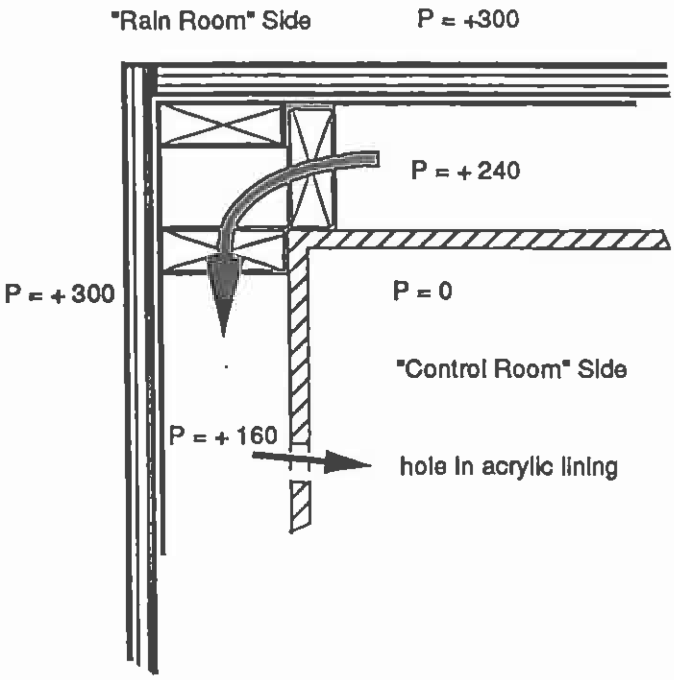
The airtightness of the claddings in relation to the other wall components was believed to be so important that special emphasis was given to this aspect of the testing.

The air permeability of each cladding was calculated as the area-averaged air leakage rate at 50 Pa applied pressure difference (Q 50). Pressure differences were measured across a precision orifice of known dimensions mounted in the acrylic lining, using diaphragm pressure transducers with digital readouts. At the same time, the inter-cavity and around-corner air leakage resistances were also measured for each cladding, and are reported elsewhere (Bassett, 1987).



Inter Cavity ▲ P = 80

Real Wall - Plan View



Inter Cavity ▲ P = 80

Test Wall - Plan View

Figure 4 : Simulation of Around-Corner Pressure Differences

TABLE 1 - DESCRIPTION OF INDIVIDUAL EXPERIMENTAL RUNS

Key: Y Normal use of this component
- Non-use of this component
* Non-standard use of this component, as described in "Comments"

RUN NUMBER	LINING	UNDERLAY?	FLASHINGS? USED?	MAX. PRESSURE (Pa)	COMMENTS?
Horizontal (Doublewalled) PVC					
1	Y	-	Y	500	Dynamic pressures
2	-	-	Y	200	
3	-	-	Y	500	Windy day - 30 Pa fluctuations
4	Y	-	Y	500	
29	-	Y	Y	500	
30	Y	Y	Y	1000	Weathertight to over 800 Pa
Horizontal Aluminium					
5	-	-	*	200	Jamb flashings lapped wrong
6	Y	-	*	500	Jamb flashings lapped wrong
7	Y	-	*	500	Jamb flashings lapped wrong
45	-	Y	Y	250	
46	Y	Y	*	1400	Better drip cap
47	-	-	*	220	Better drip cap
Horizontal Shiplap Timber					
8	-	-	*	350	Builders' window flashings
9	-	-	Y	350	Dynamic pressures
10	Y	-	Y	500	
56	-	Y	*	500	With/without scriber on window jamb
57	-	Y	*	500	Aluminium sill tray with soakers
Plywood Shingles					
11	-	-	*	250	Each corner flashing different
12	Y	-	*	500	Each corner flashing different
59	-	Y	*	500	Foam tape behind window facings
Horizontal PVC 1					
13	-	-	Y	90	
14	Y	-	Y	500	
15	Y	-	Y	350	Cladding moved on wall frame
58	-	Y	*	500	Foam tape behind window facings
73	Y	-	*	500	Aluminium sill tray with soakers
74	Y	-	*	500	Aluminium sill tray no soakers
75	Y	-	*	500	Polyethylene sill tray
76	Y	-	*	500	Building paper sill tray
77	Y	-	*	500	No sill tray
Diagonal Rusticated Timber					
16	-	-	Y	500	
17	Y	-	Y	500	
36	Y	Y	*	500	Better corners, dynamic pressures
37	Y	Y	*	500	Better corners, 25 mm holes only
60	-	Y	*	350	Painted and puttied corners
61	Y	Y	Y	500	25 mm holes open only
Vertical PVC 1					
18	-	-	Y	250	
19	Y	-	Y	1400	Wall broke loose from fittings
20	Y	*	Y	500	Breather building paper underlay
21	Y	Y	Y	500	

Horizontal Rusticated Timber					
22	-	-	Y	500	Spray nozzles too low
23	Y	-	Y	500	Spray nozzles too low
62	-	Y	*	350	Foam tape behind window facings
63	Y	Y	*	500	Foam tape behind window facings
64	Y	Y	*	500	Corners sealed with silicone sealant
65	*	Y	Y	500	25 mm holes
66	*	Y	*	500	25 mm holes foam tape behind facings
67	*	Y	*	500	25 mm holes, aluminium sill tray
68	*	Y	*	500	25 mm holes, polyethylene sill tray
Cellulose Fibre-Cement Boards					
24	-	-	Y	300	Spray nozzles too low
25	Y	-	Y	500	Spray nozzles too low
26	Y	-	Y	500	Sprays re-adjusted
54	Y	Y	*	500	Foam tape behind window facings
55	-	Y	*	500	Foam tape behind window facings
Cellulose Fibre-Cement Sheet					
27	-	-	Y	500	
28	Y	-	Y	500	
69	-	Y	*	500	No drip cap foam tape behind facings
70	-	Y	*	500	100 mm facings, foam tape removed
71	-	Y	*	600	100 mm facings, no foam tape
72	-	Y	*	600	50 mm facings, no foam tape
Horizontal (Foamed) PVC					
31	-	-	Y	300	
32	Y	-	Y	500	
44	-	Y	Y	200	Polyethylene underlay ruptured
Horizontal PVC 2					
33	-	-	*	130	No drip cap used
34	Y	-	*	600	Drip cap replaced at window head
35	Y	-	Y	500	Dynamic pressures
Horizontal PVC 3					
38	-	-	Y	120	Run twice to confirm repeatability
39	Y	-	Y	625	
Horizontal Coated Steel					
40	-	-	Y	200	Severe leak at sill
41	Y	-	Y	500	Severe leak at sill
42	Y	-	*	500	Aluminium sill tray
43	Y	-	*	500	Aluminium sill tray
Vertical PVC 2					
48	-	-	*	200	Tested without drip cap
49	Y	-	*	500	Drip cap replaced at window head
50	Y	-	*	600	Foam tape behind window facings
Vertical PVC 3					
51	Y	Y	*	500	Jamb flashing test
52	-	Y	*	500	Jamb flashing test
53	-	-	Y	200	

In several of the water leakage tests, the pressure difference across both the whole wall (wet side to dry side) and the cladding alone (wet side to wall cavity) were measured at the wall cavities which had the 50 mm diameter air leakage holes opened. This showed the distribution of pressure differences occurring across each wall component, and gave a measure of the pressure equalisation occurring across the cladding.

A main experimental error in pressure measurements originated from wind gusts. At worst, the uncertainty was ± 30 Pa.

Water Leakage Tests

The water leakage tests were performed by spraying the test wall cladding with water to saturate its surface with runoff, and slowly increasing the air pressure difference between the "rain room" and the control room in 50 Pa steps, by adjusting the bypass control damper.

At each step of pressure difference, the inside of the test wall was closely examined for water leakage anywhere on the test specimen. When water leakage was seen, its location and qualitative amount were recorded as a function of the applied pressure difference.

The grades of water leakage were defined on the Norwegian six-point scale (Sandberg, 1977) as:

(0) No Leakage;
(1) A Few Drops (about one drop every five seconds);
(2) Several Drops (about one drop per second);
(3) Slight Flow (a steady stream of drops);
(4) Medium Flow (a continuous stream where individual drops cannot be distinguished); and
(5) Heavy Flow (a large stream of water, about 6 mm in diameter or larger).

The applied pressure difference was usually increased to 500 Pa (corresponding to about a 30 m/s windspeed, with normal assumptions), or until the water leakage exceeded "Heavy Flow". Some tests reached much higher pressures as shown in Table 1.

The walls were tested in three main configurations each of which altered the extent of wind pressure equalisation across the wet wall component.

In the first, the wall section consisted of claddings alone on the test frames, with neither underlay nor interior lining.

In the second configuration, the claddings on the wall frames were backed with interior linings. The linings normally had the four 50 mm diameter holes through the lining open, exposing the stud cavities to the control room side.

In the third configuration, the claddings on the wall frames were backed with the punctured polyethylene underlay. Acrylic interior linings were used as before, with the 50 mm holes open.

Other configurations were variants of these, using fewer or smaller holes in the acrylic lining, or actual building paper instead of punctured polyethylene.

Some tests were repeated for both steady and fluctuating pressure differences, to see if differences occurred in the water leakage behaviour of the test walls.

A final series of tests were performed to check alternative flashing details around windows.

A list of all the water leakage test runs performed, with details of the configurations used for each test, is shown as Table 1. Each test run is described on a separate line. In each column of Table 1, "Y" indicates a standard use of that component (as described in the text of this report), "*" indicates a non-standard use of that component, as described in the "Comments" column of Table 1, and "-" indicates the non-use of that component. Test runs are subsequently referred to by their run number, as shown in Table 1.

Observed water leakage was recorded and presented graphically in a series of charts. The water leakage seen at each site for each cladding is plotted on the vertical axis, versus the total air pressure difference applied to the wall on the horizontal axis. A cladding that is weathertight typically showed very little water leakage even up to very high wind pressures, while a cladding that was not weathertight typically showed high water leakage at low applied wind pressures.

Figure 5 shows the forms of water leakage versus pressure difference graphs expected for the three main types of water leaks (exclusive of capillary suction) encountered during testing. The first, shown in Figure 5a, is water leakage caused by air flows. In this case, water leakage rates increase smoothly with increasing air flow rates, which rise with increasing pressure difference across the wall.

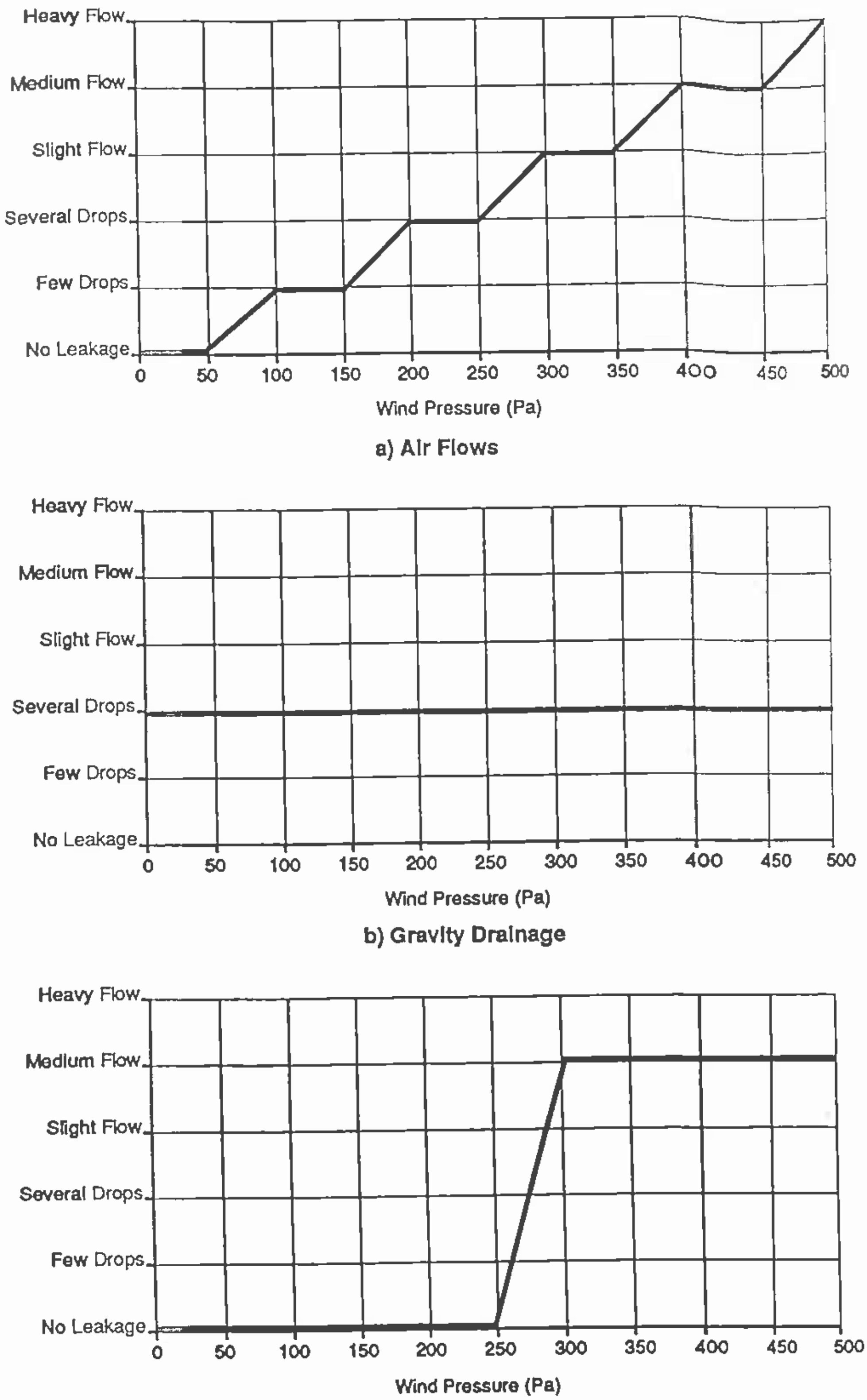
The second case, shown in Figure 5b, is gravity drainage, where water leakage occurs with no applied air pressure difference and continues independently of pressure difference. The third type, shown in Figure 5c, is an overflow situation, where water leakage starts abruptly at some pressure difference analagous to a dam or weir overflowing when the hydraulic pressure behind it is high enough to lift water over its top.

RESULTS

The amount of water leakage of each of the claddings was observed at each major location where water was seen to leak through the claddings as a function of pressure difference across the test wall under different configurations of lining, underlay, and flashings.

One of the most important discoveries was that claddings of the same basic type had similar air and water leakage characteristics. This allowed the claddings to be grouped generically into:

(1) conventional claddings (the three timber and one cellulose fibre-reinforced cement sheet cladding);



a) Air Flows

b) Gravity Drainage

c) Overflow

Figure 5 : Expected Shapes of Water Flow vs. Wind Pressure Graphs for Different Water Leakage Mechanisms

(2) lightweight horizontal claddings (horizontal PVC, metal, plywood, and cellulose fibre-reinforced cement planks); and
(3) lightweight vertical claddings.

The cellulose fibre-reinforced cement plank cladding was included in the group of lightweight horizontal claddings. This was done even though it is typically painted like the conventional claddings and its use predated those of the other lightweight claddings; its performance as tested was much more similar to the lightweight group.

Air Leakage Results - General

The characteristic air leakage of each cladding was measured (as discussed earlier). The mean measured air leakage rate is found for the four cavities, and reported in litres per second per square metre of cladding surface area, at a pressure difference of 50 Pa (the "Q 50" rate).

The mean of the air leakage rate is used because the local rate varies between cavities, being generally higher in cavities bordering the window edges. The pressure difference is specified because air leakage is not usually linearly proportional to pressure difference.

The mean air leakage rate for each cladding is reported in Table 2. Also shown in Table 2 is the cladding Pressure Drop Ratio, as defined in the previous section.

TABLE 2 - CLADDING AIR LEAKAGE RATES AND PRESSURE DROP RATIOS WHEN TESTED WITH STANDARD LININGS

Cladding description	Air Leakage (Q 50) (ℓ/m^2 s)	Pressure Drop Ratio
LIGHTWEIGHT		
Horizontal (Doublewalled) PVC	46.2	0.32
Horizontal (Foamed) PVC	73.3	0.21
Horizontal Coated Steel	89.4	0.17
Cellulose Fibre-Cement Boards	91.7	0.16
Vertical PVC 2	97.6	0.04 to 0.44
Horizontal PVC 1	107.6	0.08
Horizontal PVC 2	116.7	0.07
Horizontal PVC 3	121.5	0.07
Vertical PVC 3	145.9	0.04
Horizontal Aluminium	159.3	0.09
Vertical PVC 1	189.8	0.07
Plywood Shingles	283.4	0.07
CONVENTIONAL		
Cellulose Fibre-Cement Sheet	18.0	0.88
Diagonal Rusticated Timber	21.1	0.64
Horizontal Rusticated Timber	35.8	0.59
Horizontal Shiplap Timber	43.6	0.60

The ("Q 50") air leakage rates of the conventional cladding varied between 18 and 44 ℓ/m² s, with a mean of 30 and a standard deviation of 11, and those of the lightweight claddings varied between 46 and 283 ℓ/m² s, with a mean of 127 and a standard deviation of 63.

Thus the measured air leakage of the lightweight claddings was significantly higher than that of conventional claddings. The two groups of claddings' air leakage rates are non-overlapping when the cellulose fibre-cement board is classified as a lightweight cladding. If it were tested painted, as it would have been used in the field, its air leakage may change significantly, as a result of the cracks between boards being partially or fully sealed by the paint film.

The measured air leakage rates for each group of claddings are shown in Figure 6, as a histogram with increments of 10 ℓ/m² s of air leakage on the horizontal axis, and the number of claddings of each type in each range on the vertical axis. This histogram graphically demonstrates the qualitative difference between conventional claddings and the lightweight claddings in terms of measured air leakage rates.

Pressure Distributions Through Walls

The pressure differences across each part of the wall cavity were measured to determine which components supported the highest pressure differences.

The pressure distributions reported in this section were measured in the cavity directly below the window in the test wall (with 50 mm diameter hole), unless otherwise noted.

A typical pressure distribution is shown in Figure 7. This was measured in Run 46, across a wall with a lightweight horizontal cladding, the acrylic sheet lining with four holes, and a breather paper underlay. The pressure differences across each wall element were in a constant proportion to each other at each step up to 500 Pa total applied pressure difference. This independence of Pressure Drop Ratio with respect to applied pressure difference is the normal result seen from the tests. The Pressure Drop Ratios observed in this test run were: for the acrylic lining, 0.52; for the underlay, 0.44; and for the cladding, 0.04.

The relatively small pressure difference across the cladding is the important feature of this graph. Because this cladding pressure difference is felt to be the main force that drives water leakage, the achievement of airtight linings and underlays can be very beneficial for weathertightness.

Pressure distributions were compared for a wall with a lining and the same wall with a lining and underlay. This is shown in Figure 8, where the pressures measured across the same lightweight wall cladding for these two configurations are plotted as a function of the total pressure difference applied to the wall, in 50 Pa steps of total applied pressure difference.

As can be seen, when tested with a lining (Run 6), the cladding pressure difference was about 0.08 of the total applied pressure difference (Cladding Pressure Drop Ratio = 0.08), but when tested with an underlay in

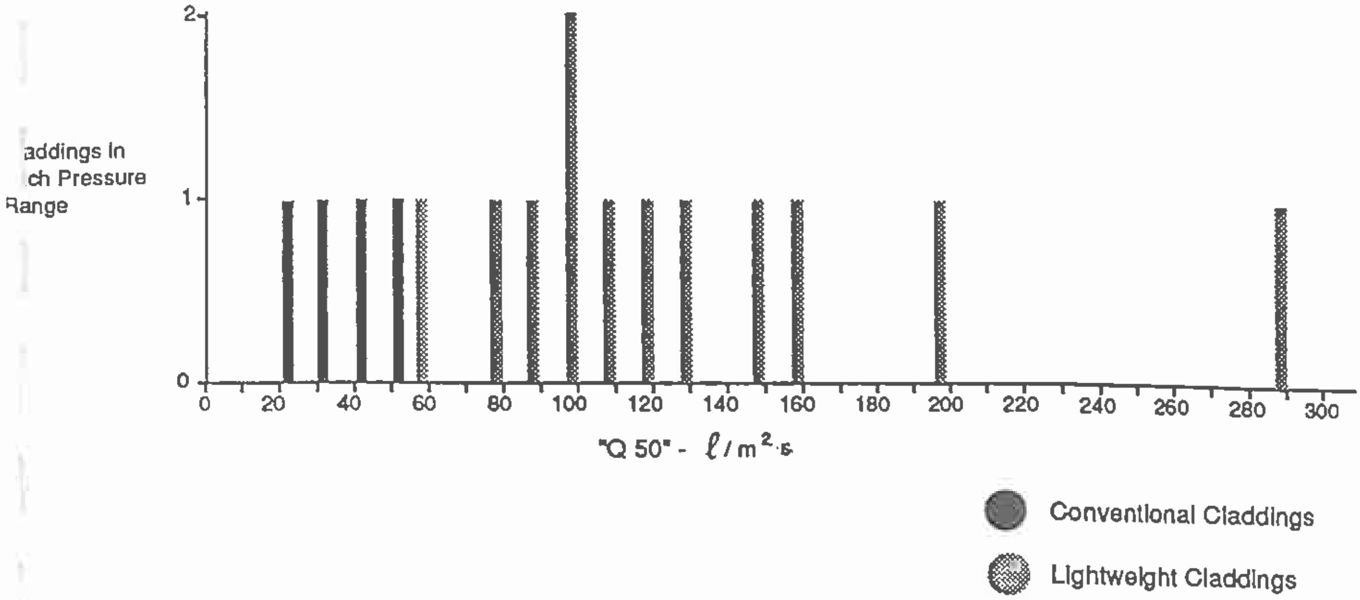


Figure 6 : Distribution of Cladding Air Leakages at 50 Pa

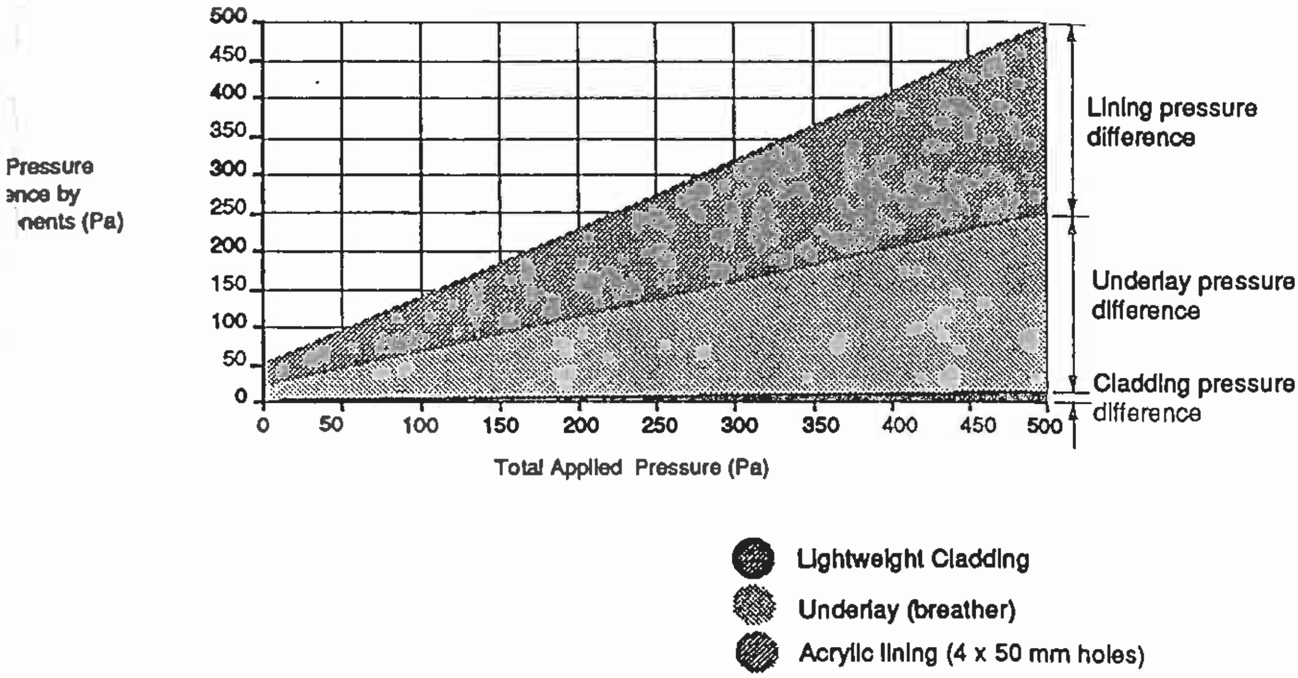


Figure 7 : Wall Component Pressure Distribution

addition to the lining (Run 46), the cladding Pressure Drop Ratio was reduced to only 0.04. The small fluctuations in the two lines are probably due to difficulties in resolving these very small pressure differences. Figure 8 clearly shows that adding an underlay to a wall reduces the pressure differences across claddings.

When taken over the whole set of results, the pressure difference across the cladding is seen to be inversely related to the air leakage rate in Figure 9. This figure shows a plot of the cladding Pressure Drop Ratio as a function of cladding air leakage rate ("Q 50") for walls incorporating the "standard linings" (with the four 50 mm diameter holes) with each cladding. The curve plotted on Figure 9 shows the curve of best fit through all of these results.

As seen in Figure 9, the Pressure Drop Ratios for lightweight claddings were typically in the range 0.05 -0.30, compared to 0.40 - 0.60 for the conventional claddings. In general, cladding Pressure Drop Ratio was reduced to under 0.10 for any cladding air leakage rate above about 100 ℓ/m^2 s at 50 Pa.

In other words, the lightweight claddings showed much lower pressure differences across themselves than did conventional claddings, in walls tested with an identical lining. This causes the types of pressure difference distributions across wall components shown diagrammatically in Figure 2.

The differences in Pressure Drop Ratio shown in Figure 9 would be likely to be even more pronounced for conventional claddings if they were painted, as is normally done in practice. With the joints between boards sealed with the paint film, the conventional claddings would probably have been more airtight, and thus exhibited an even higher Pressure Drop Ratio.

The one anomalous result in Table 2 and Figure 9, the 0.44 Pressure Drop Ratio at 100 ℓ/m^2 s, was measured for a lightweight vertical PVC cladding which had a distinctly different Pressure Drop Ratio in each wall cavity monitored. No explanation was found for this result, but it was noted that other cavities in this same wall during the same test showed Pressure Drop Ratios as low as 0.04, more in line with the pattern followed by other claddings.

Though this is an extreme result, it illustrates the variations in airflow resistances seen around discontinuities in the claddings.

Water Leakage Results - General

The water leakage performance of claddings of the same basic group (e.g. lightweight vertical, lightweight horizontal, or conventional) were quite similar. This was thought to be in part due to the similarity in air permeabilities ("Q 50" rates) within the groups, and the observation that most water leakage appeared to be pressure difference driven.

The water leakage sites were grouped by location (for reporting) into the three window edges (head, jamb, and sill); inside and outside corners; jointers; and joints between boards. All water leakage sites are shown in Figure 3.

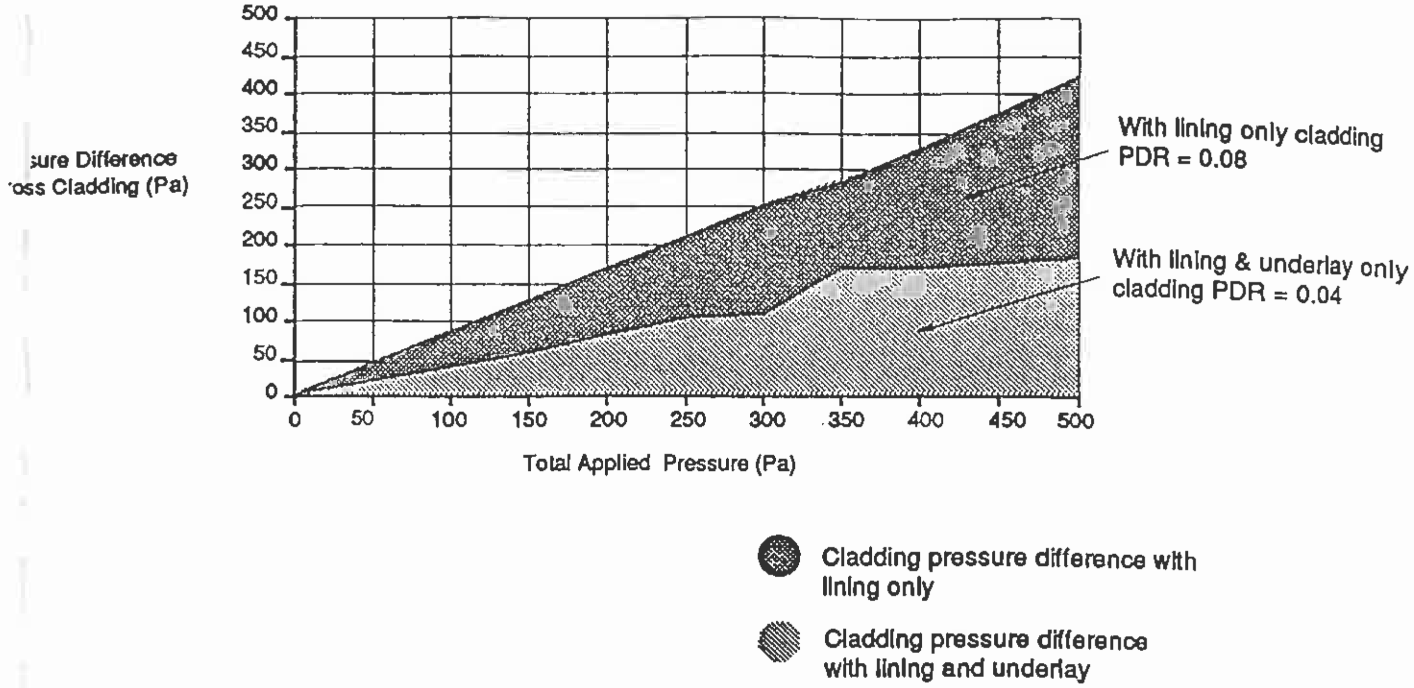


Figure 8 : Cladding Pressure Difference as a Function of Wall Components and Total Applied Pressure

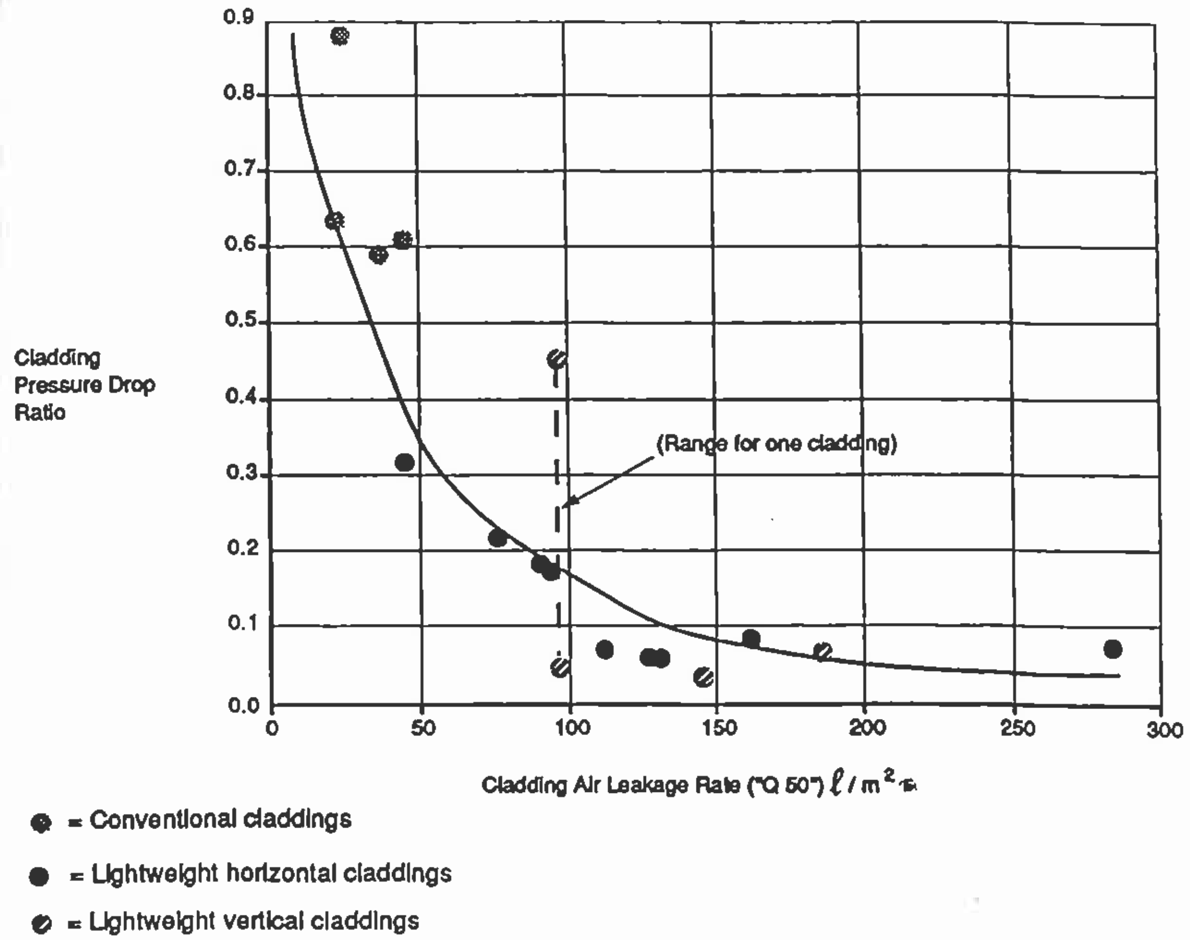


Figure 9 : Cladding Pressure Drop Ratio as a Function of Air Leakage Rate

In general, the test walls with more layers, including cladding, lining and underlay, performed better than those with lining and cladding, which in turn performed better than those with claddings alone. This was expected, as the extra layers beyond the cladding tended to reduce the pressure difference acting across the cladding.

Necessary Flashing Improvements

In general, the most severe water leakages seen were around the windows. In efforts to reduce the water leakage here several methods were tried, some of which were tested as variables and are discussed separately later, and some of which were adopted as "necessary and standard", used in all the water leakage tests, and discussed here.

One of these techniques was the use of a drip cap flashing at the window head to deflect water flowing down the wall surface above the window outward and over the window head, rather than allowing it to flow behind the window facing and into the window head joint. Preliminary tests using alternative details showed severe water leakage at the window head. Thus the use of a drip cap was adopted as "necessary and standard". This flashing is shown in Figure 10.

Another technique in this category was plugging the inside of the joint between the window and its surrounding studs and trimmers, usually with a compressible foam polyethylene "backer rod", to make an air seal between the window and frame. When tested without these seals gross water leakage occurred in the wide gaps between the window and the wall framing.

Finally, as seen in Figure 10, the ("J-trim") window jamb flashings were always made to drain water to the outside of the wall cavity. Windows with flashings drained to the outside showed much less water leakage into the wall than windows where this was not considered. Though manufacturers' installation instructions often omitted these details, they were found to be necessary to avoid severe water leakage.

Figure 11 compares the water leakage around windows observed in a pair of tests (Runs 5 and 47) performed on a lightweight horizontal cladding with no lining. In the time intervening between the tests, the cladding was removed and replaced on the wall frame, and the window flashings were improved with the addition of a drip cap at the window head and an allowance for drainage to the outside for the jamb flashings.

As is seen from Figure 11, there is a major reduction in water leakage around the window, from "Medium Flow" and "Heavy Flow" at the jamb and sill respectively, to only "Several Drops" and "Few Drops" there at most pressures.

The reduction in water leakage at the sill seen at the highest pressures in Figure 11 is probably due to either difficulties resolving such a small flow, or diversion of this leakage to another location.

Corner flashings were used with conventional claddings only. (Lightweight claddings provided their own corners.) The corner flashings used were all 100 mm wide (50 mm on both sides of the corner) and lapped so that

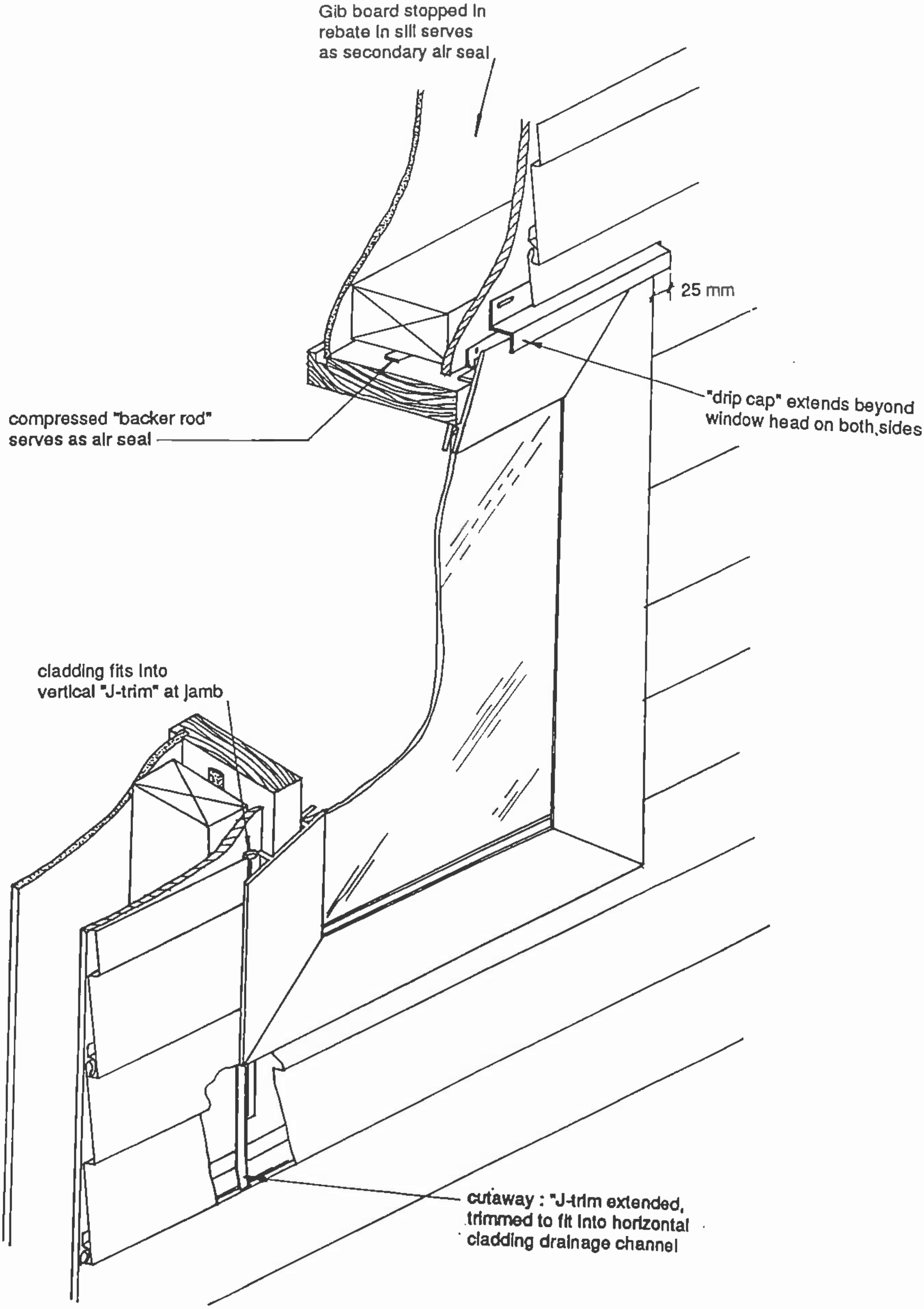


Figure 10 : Necessary and Standard Window Flashing

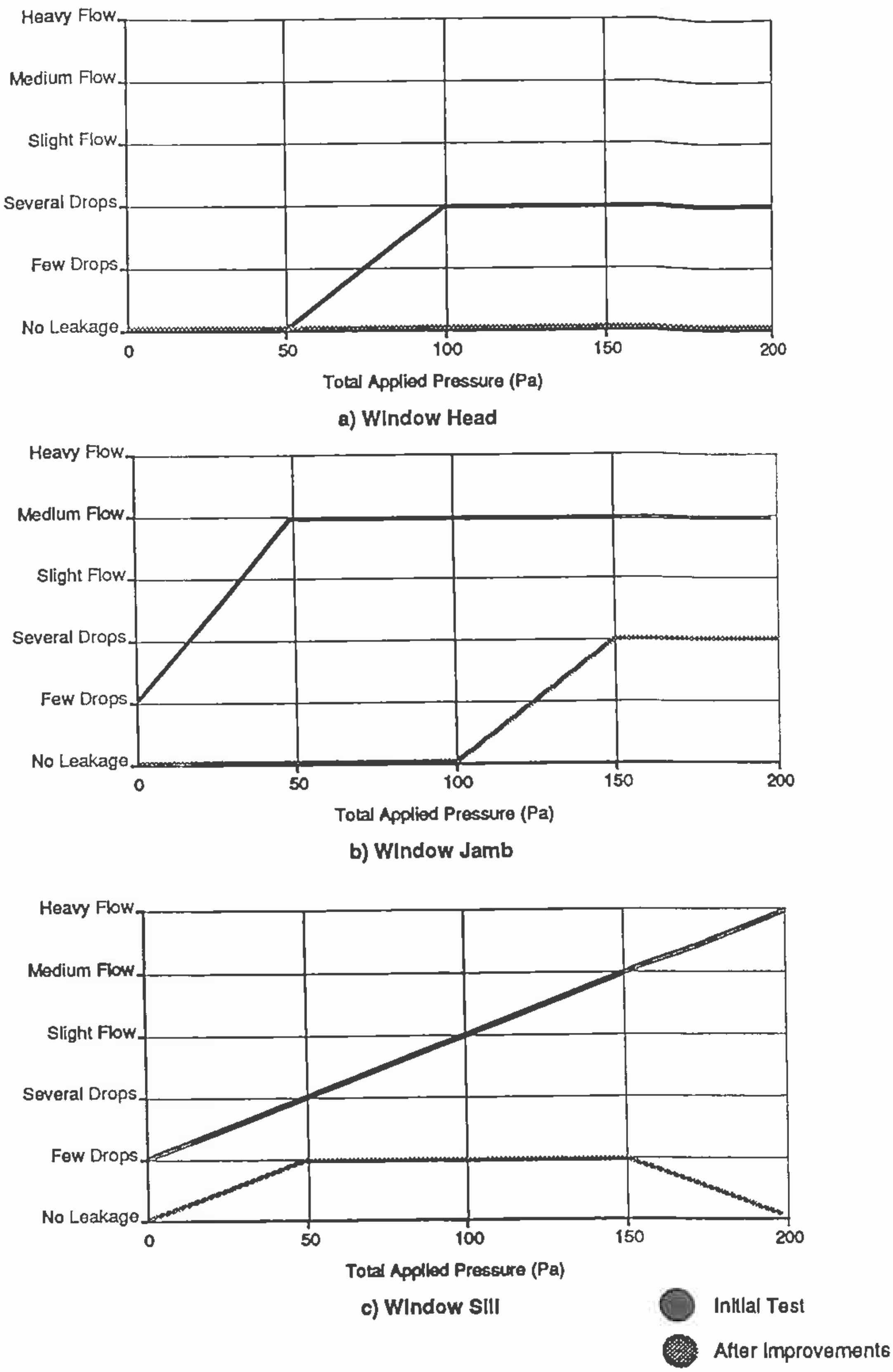


Figure 11 : Results of Window Flashing Improvement Tests

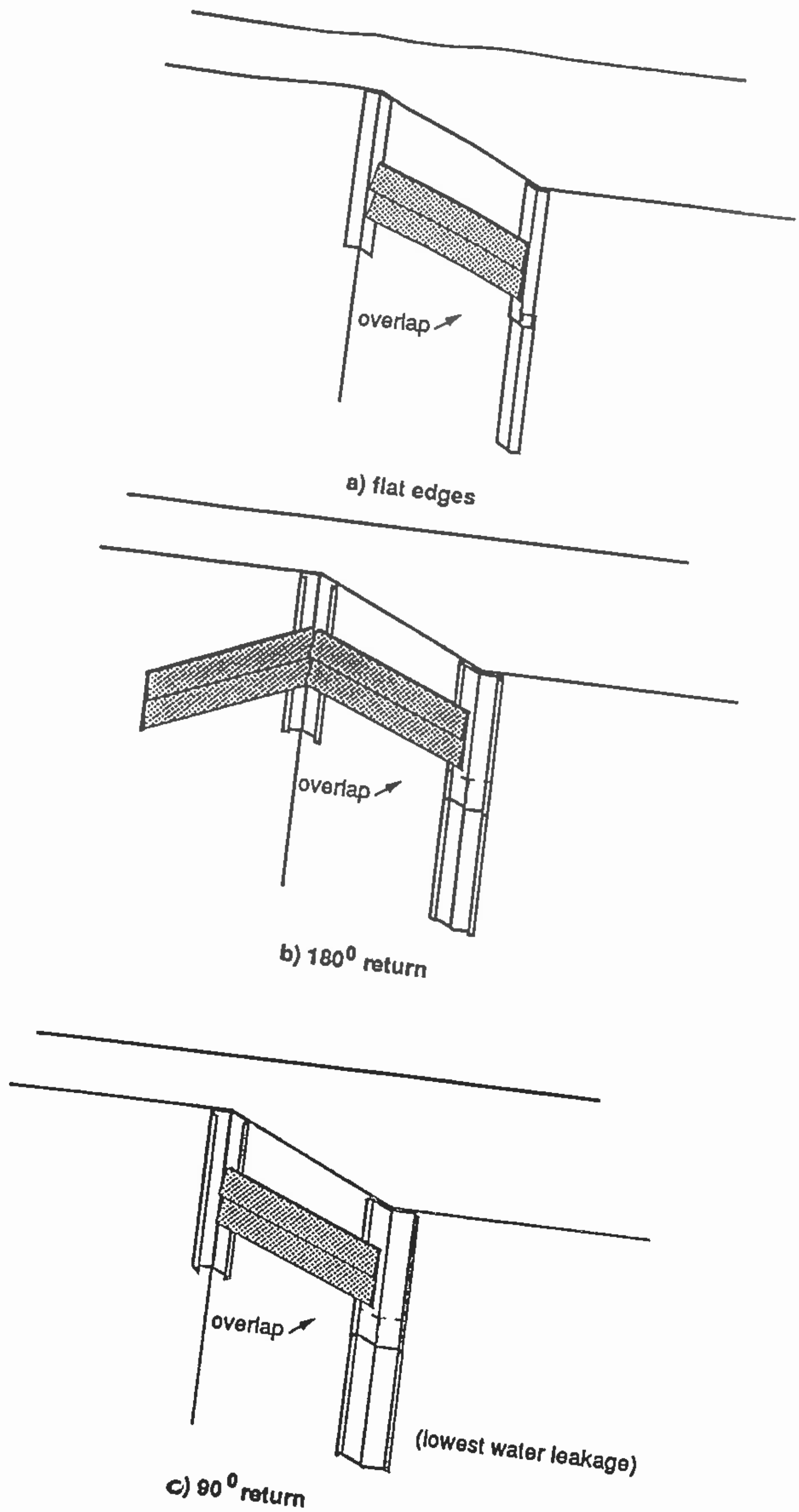


Figure 12 : Corner Flashing Return Shapes Tested

downward flowing water stayed on the outside of the flashings. The return shape at the edges of corner flashings were varied in some tests, from no folds, to folded 90 degrees, to folded 180 degrees, as shown in Figure 12.

When tested on a lightweight cladding with no lining or underlay (Run 11), flashings with folded edges leaked significantly less water than flat-edged flashings (a Few Drops versus Slight Flow at the same pressures). Flashing edges folded 90 degrees appeared to leak slightly less than those bent 180 degrees, but this difference was much less apparent than the differences between folded edges and flat edges.

When tested with the standard lining in place in addition to the cladding (Run 12), the same patterns held, but water leakage at corners was greatly reduced. In this configuration, no leakage was noted around the flashings with edges turned 90 degrees.

Repeatability of Results

Figures 13 (a) and 13 (b) show the observed water leakage at the window jamb for each cladding in the "lightweight horizontal" group, and the mean value of water leakage, which is the value plotted in the following section. This is obtained by assigning numerical values linearly from 0 to 5 for the six grades of water leakage for each cladding, configuration, and applied pressure difference. The mean value of water leakage for each group at each location is then found and plotted versus pressure difference.

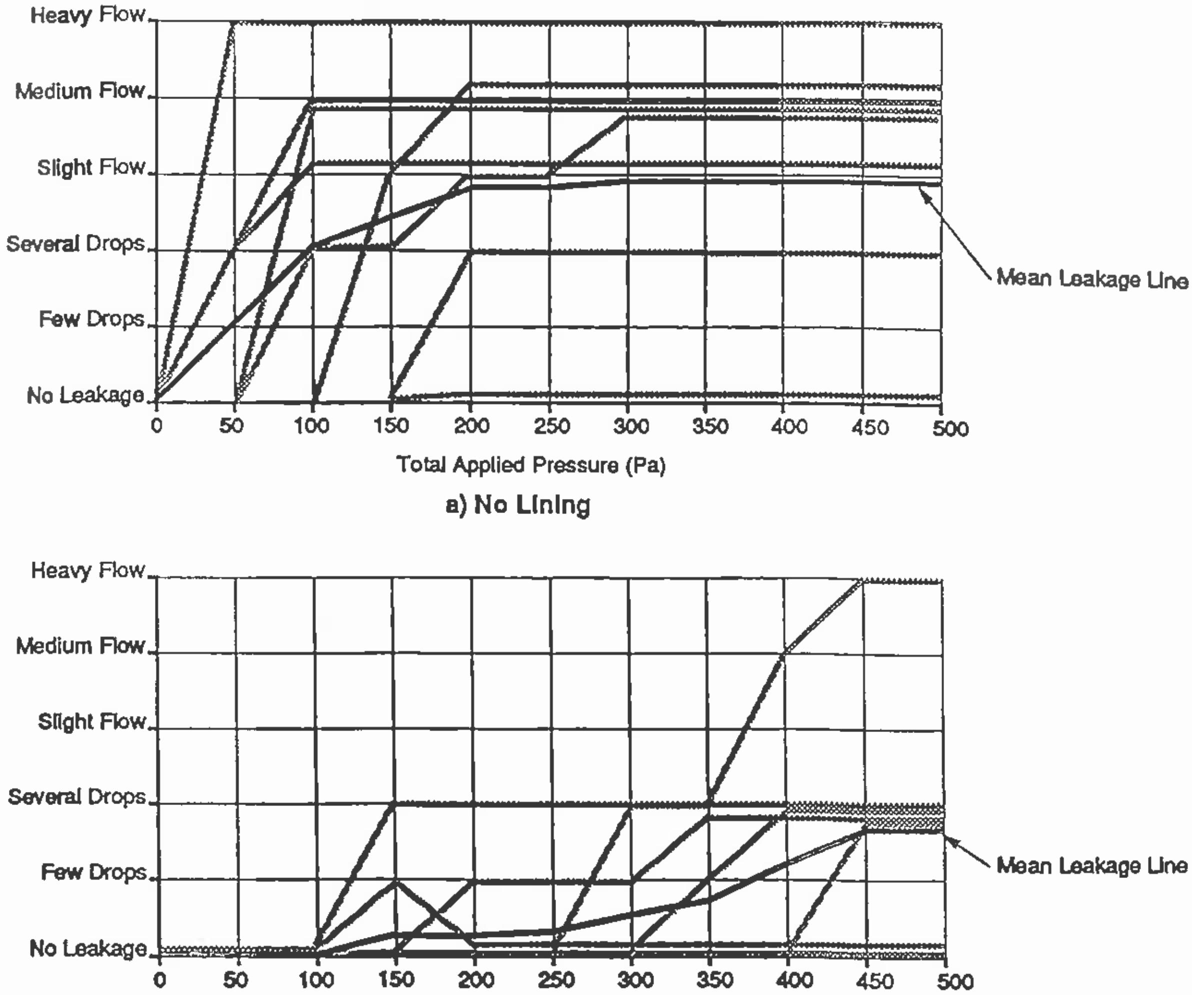
Figures 13 (a) & (b) illustrate some of the larger amounts of scatter seen in the water leakage performance at a given location for a cladding group. Although the scatter is significant, the results are consistent enough that trends can be clearly seen.

Some of the early tests were repeated, to see if the results were reproducible. Figure 14 shows the results obtained from two consecutive tests (Runs 6 and 7) on a lightweight horizontal cladding with the standard lining, performed several hours apart. As can be seen, the major water leaks are generally (though not precisely) reproducible.

Figure 15 compares the results of the same two tests that were shown in Figure 11, in the water leakage locations for equivalent tests. Again, these were performed on a lightweight horizontal cladding with no lining, with several weeks intervening between the tests, during which time the cladding was removed and replaced on the wall frame.

Except for the left outside corner, which leaked significantly more water on the retest, the water leakage was generally repeatable, with leaks at each location beginning at approximately the same pressure difference and reaching the same maximum amount.

Dynamic (applied pressure difference) tests gave essentially the same results as static pressure difference tests. The water leakage of claddings appeared to be the same at the same instantaneous pressure difference, regardless of whether that was the transient peak of dynamic pressure difference or a constant static pressure difference.



a) No Lining

b) Standard Lining

Figure 13 : Measured Individual and Mean Water Leakages, Lightweight Horizontal Claddings, at Window Jamb

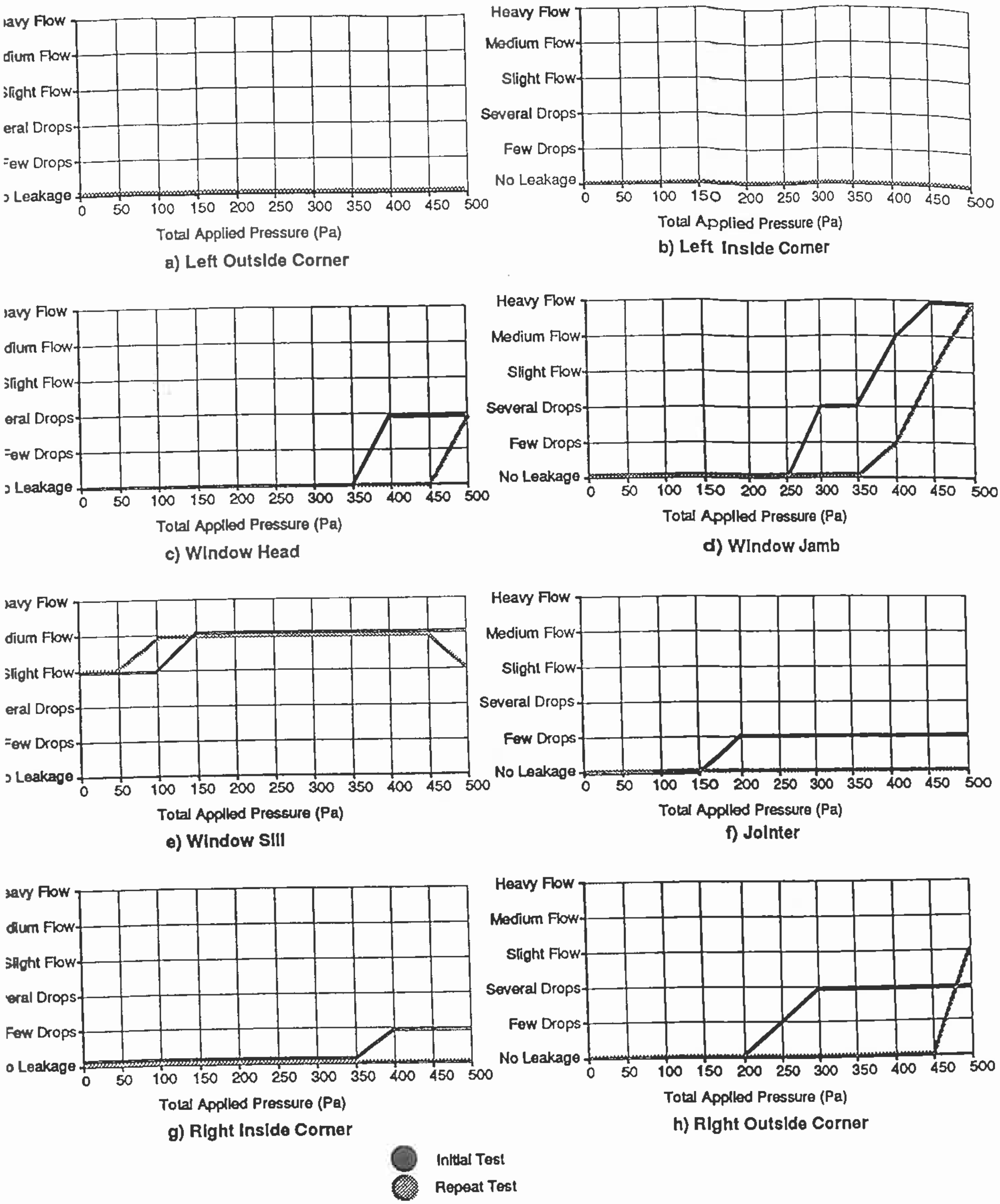


Figure 14 : Results of Consecutive Tests, Same Lightweight Cladding Standard Lining

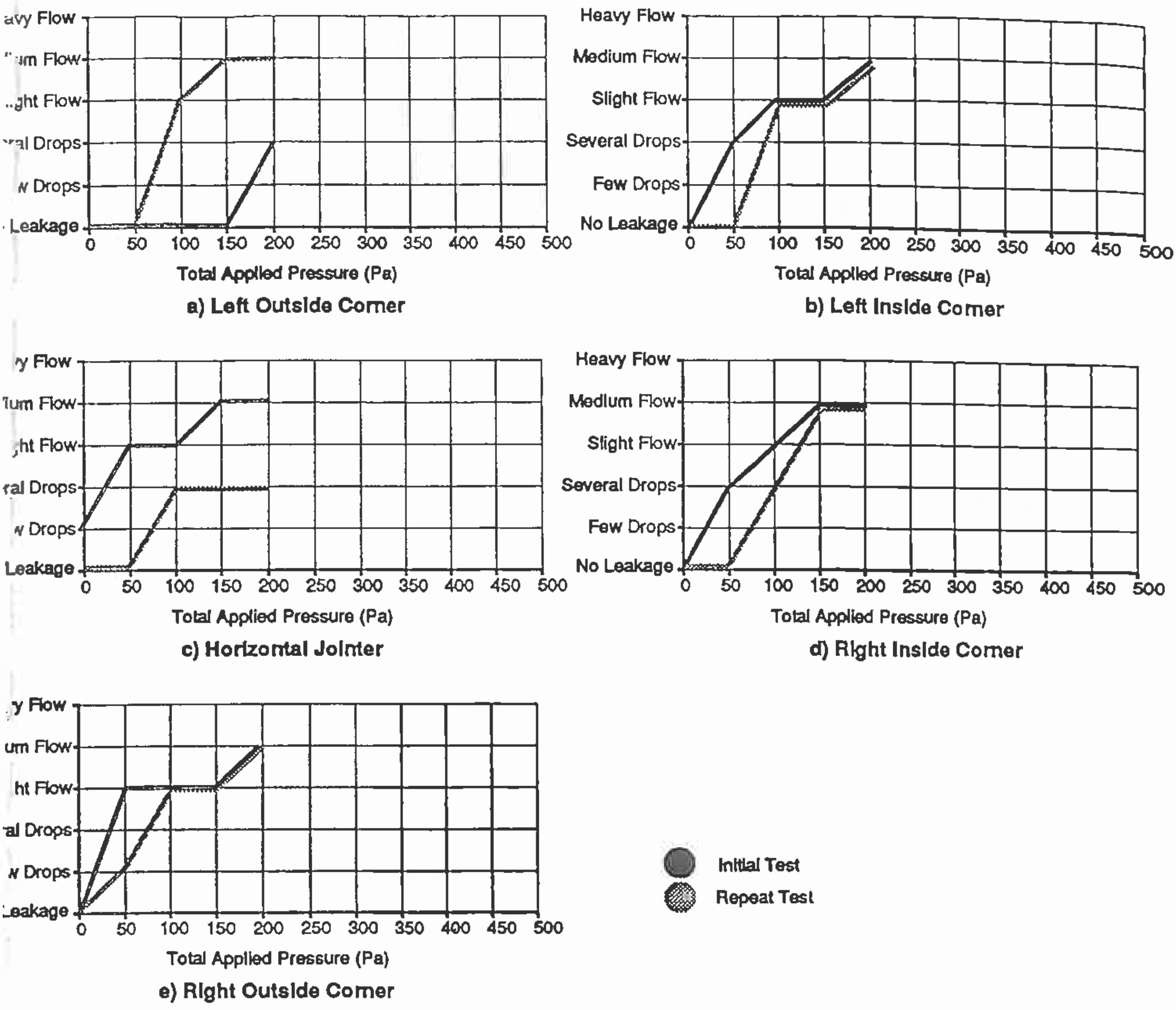


Figure 15 : Results of Non-Consecutive Tests, Same Lightweight Cladding, No Lining

Water Leakage Results - Specific Locations

Figures 16 through 20, and 24 summarise the observed water leakage characteristics of each type of cladding at each major leakage site. Each figure gives the results for a particular water leakage site. This is in turn subdivided into one graph each for the three main types of claddings (lightweight vertical, lightweight horizontal, conventional) and one line per graph for each of the main configurations of other wall elements used (none - i.e. cladding tested alone, acrylic lining with four 50 mm holes, acrylic lining with four 50 mm holes and punctured polyethylene underlay).

The values plotted in these figures are the mean water leakage for each cladding group at each configuration and applied pressure difference, as described previously.

The plotted lines of water leakage versus pressure difference for the lightweight claddings when tested with no linings or underlays are stopped at 200 Pa (the median and mode of maximum pressure to which the lightweight claddings were tested). The last step in these lines assumes no further increases in water leakage for the three samples with tests terminated below 200 Pa, which is a "liberal" assumption. Thus it is likely that the last step of these lines slightly under-reports the actual mean water leakage at 200 Pa.

Window Head Water Leakage

Figure 16 shows the mean measured water leakages at the window heads for each of the three groups of claddings. The conventional claddings showed lower water leakages than lightweight claddings when no lining was in place, and the cladding tested in isolation. However, the lightweight claddings performed better than conventional claddings which included other layers in the wall.

The lightweight horizontal and vertical claddings performed very similarly overall, though there was slightly more water leakage through vertical claddings at the window head.

With a lining in place in the wall, both vertical and horizontal lightweight claddings were very similar in water leakage performance to conventional cladding at the window head. But with an underlay included in the test wall in addition to the lining, both lightweight claddings were notably better in water leakage performance at the window head than conventional claddings.

Window Jamb Water Leakage

Figure 17 shows the mean measured water leakages at the window jambs of the three groups of claddings. With no lining or underlay in place, the conventional claddings performed very similarly to the lightweight horizontal claddings, up to the maximum pressures tested.

However, as the conventional claddings' measured water leakage did not increase between 200 and 500 Pa, and the lightweight claddings water

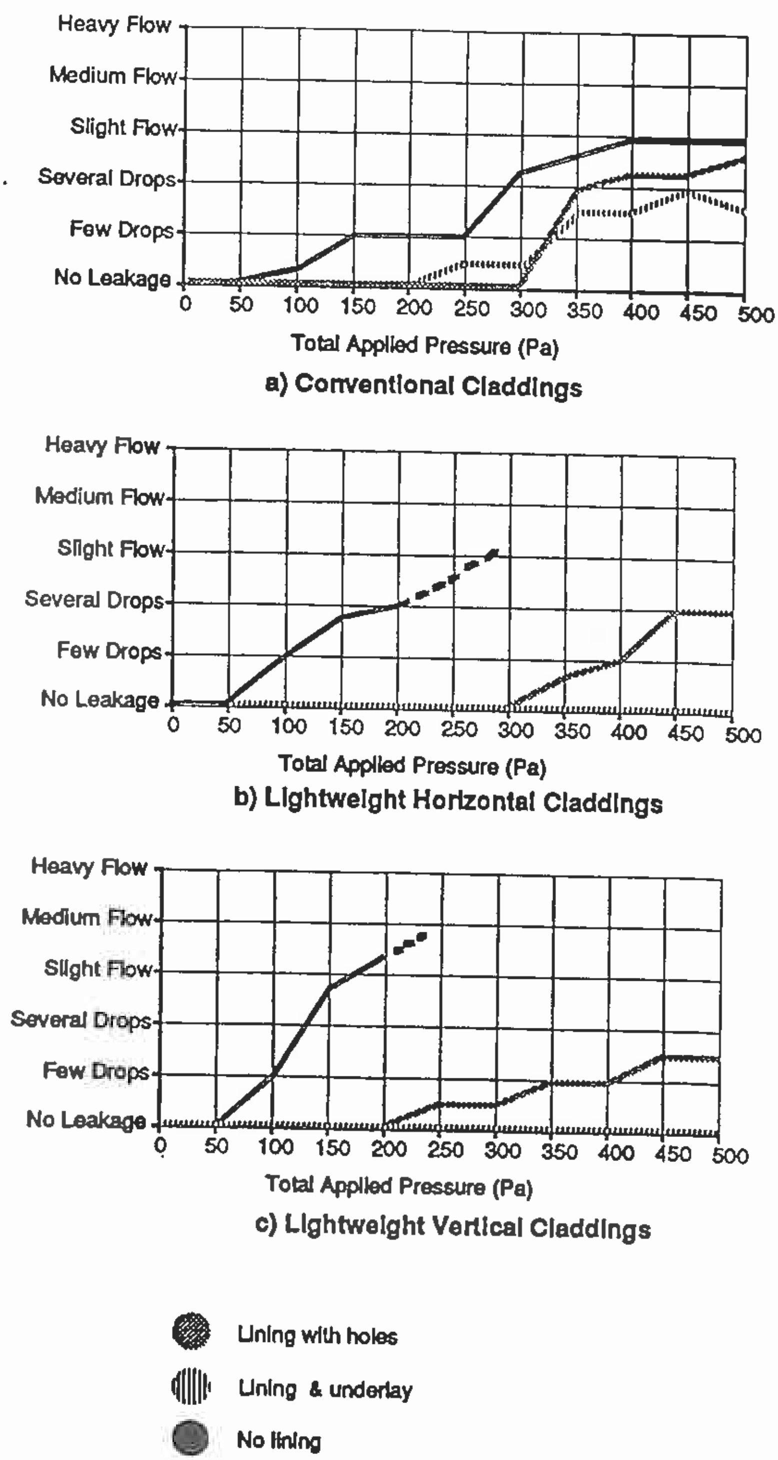


Figure 16 : Mean Water Leakage at Window Heads

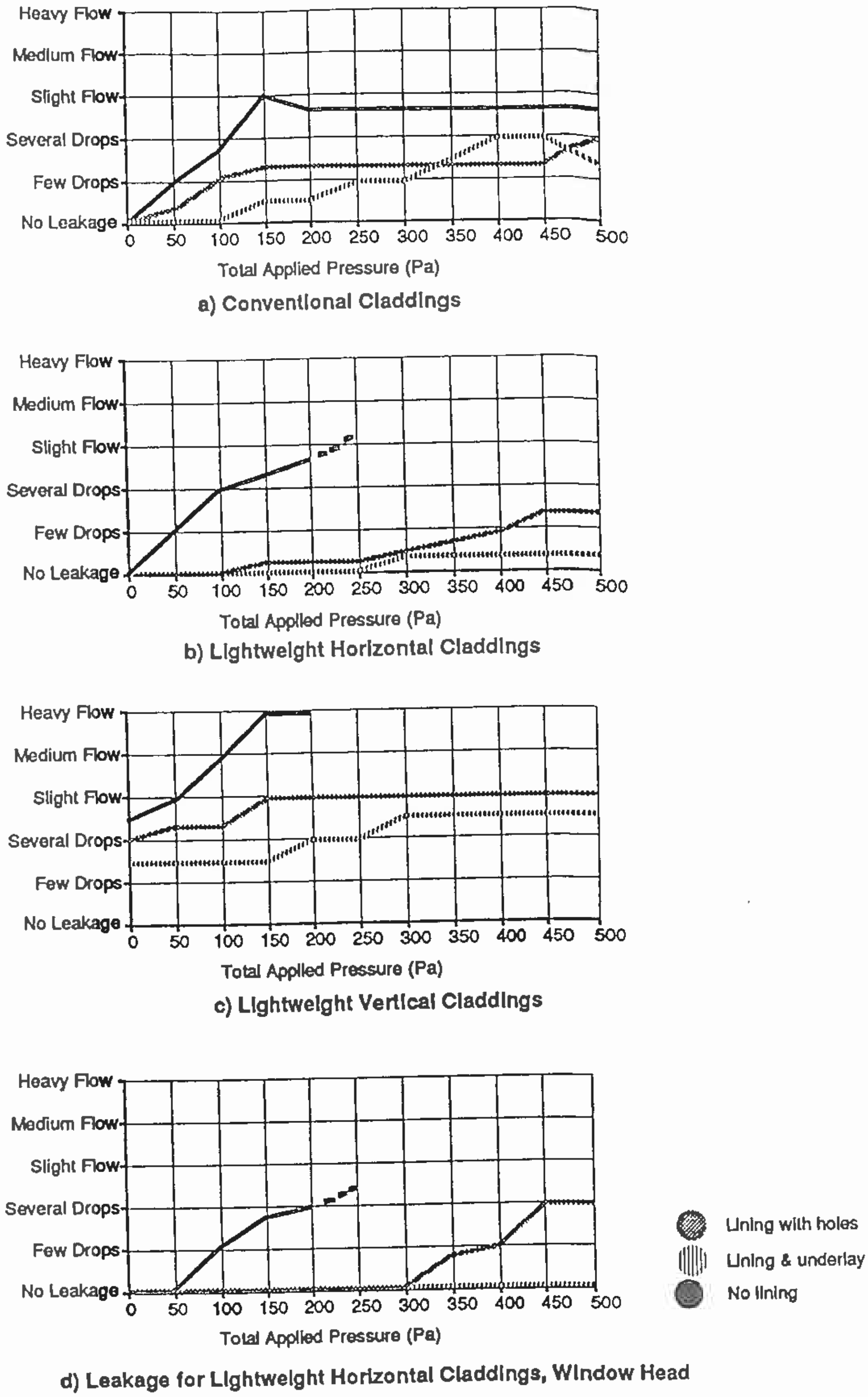


Figure 17 : Mean Water Leakage at Window Jambs

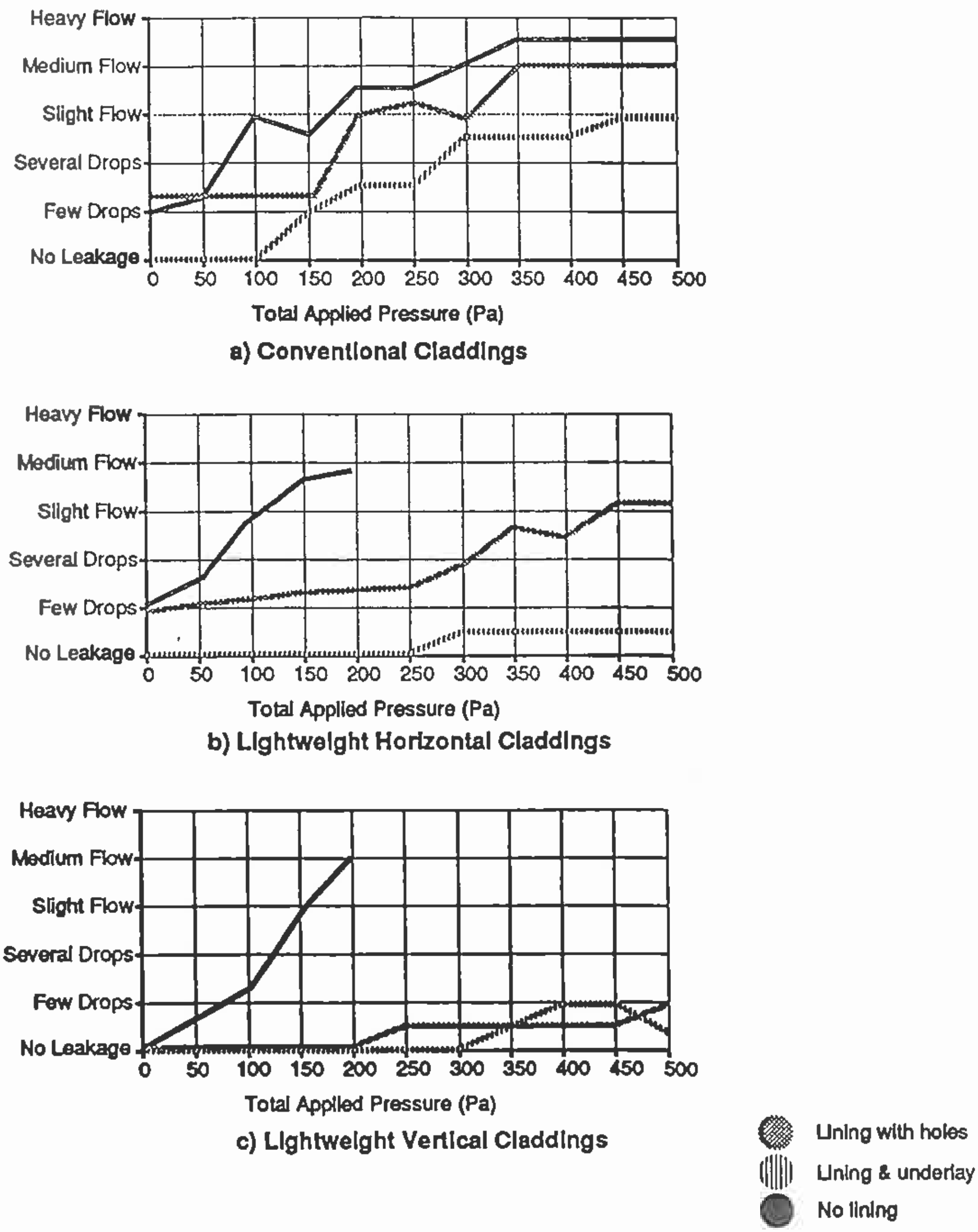


Figure 18: Mean Water Leakage at Window Sills

leakage was increasing when their tests were terminated, it is likely that the lightweight claddings would have leaked more water than conventional at higher pressures.

When linings were added to the test walls, the lightweight horizontal claddings distinctly outperformed the conventional claddings. An underlay in addition to the lining reduced water leakage even further.

It must be noted, though, that the conventional claddings were tested unpainted, and with no scribers at window jambs. They were probably less weathertight in this configuration than they would have been in actual practice.

The vertical lightweight claddings showed significant water leakage at zero applied pressure difference (showing that some leaks were not air leakage driven). When a lining and underlay were added to the vertical lightweight claddings, an improvement was noted, but water leakage still occurred, again starting at zero applied pressure difference.

Window Sill Water Leakage

Figure 18 shows the mean measured water leakages at the window sills of the three groups of claddings. Both conventional and lightweight horizontal claddings showed some water leakage at zero applied pressure difference. This leakage also occurred for both claddings when the lining was added, but stopped for the lightweight horizontal cladding when the underlay was added to the lining in the wall test section. As this effect could not be attributed to a reduction in pressure difference acting across the cladding (the water leak began before any pressure difference was applied), it was felt that the underlay was simply hiding the water leakage at the window sill, by giving it a drainage track to below the window sill. The leakage probably ran down the underlay behind the studs below the window before becoming visible.

The conventional claddings performed very similarly to both orientations of lightweight claddings when the claddings were tested in isolation, at least up to the maximum pressures the lightweight claddings were tested to. When the air-flow-driven water leaks for the horizontal claddings predominated over the gravity drainage leaks, the similarity with the lightweight vertical claddings became more apparent.

None of the lightweight vertical claddings leaked water at zero applied pressure difference, but those tested above about 150 Pa with no lining performed similarly to the two types of horizontal claddings. When other wall layers were added (first lining, then an underlay), the water leakage dropped to near zero, even at high applied pressure differences.

Outside Corner Water Leakage

Figure 19 shows the mean measured water leakages at the outside corners of the three groups of claddings. The water leakage at the two outside corners for each cladding was summed, and the mean of this sum was reported. None of the claddings showed any water leakage before a pressure difference was applied, indicating an absence of gravity flow leakage paths.

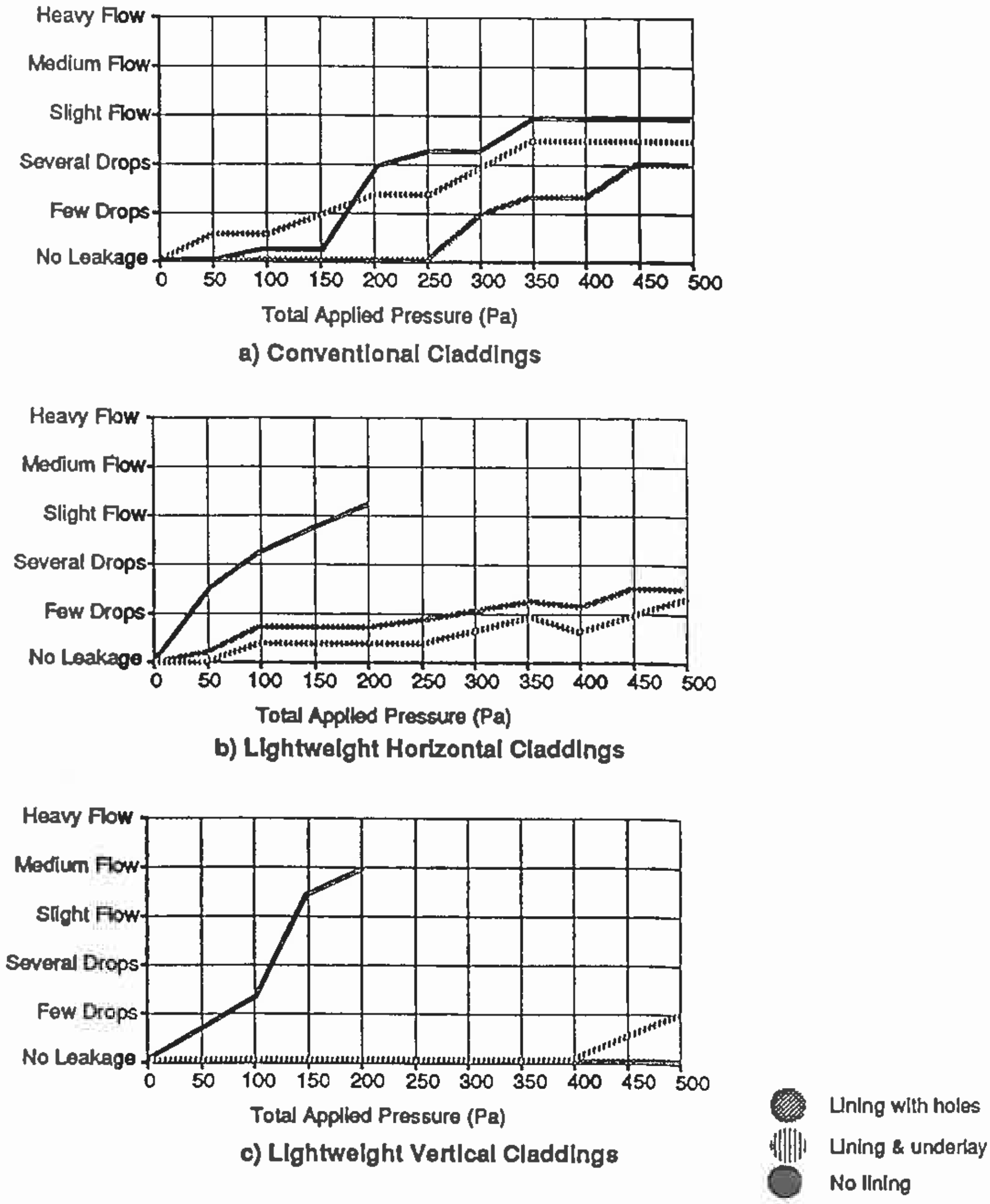


Figure 19 : Mean Water Leakage at Outside Corners

Water leakage through the outside corner of the conventional claddings was seen to be quite low, compared with leakage at most of the window joints. The leakage showed the normal reduction in flow at a given pressure difference when more layers were added to the wall, except at low pressure differences. Then, more water leakage was seen in the wall with lining and underlay than for the wall with the cladding alone.

This effect only showed up when both the lining and the underlay were present in the test wall, which possibly indicates a "wicking" effect caused by the underlay being in close proximity to the cracks at the corner joint. It could also be due to the racking and disturbance of the structure of the test walls as they were moved into and out of the test rig (and sometimes with the claddings removed and replaced) between tests.

The lightweight horizontal claddings showed fairly severe water leakage when tested alone, but less when tested with a lining, and slightly less again when an underlay was added.

The lightweight vertical claddings also showed severe water leakage at the outside corners when tested by themselves, but almost no water leakage at all when tested with other layers in the wall.

Inside Corner Water Leakage

The water leakage at the inside corner was interesting as one cladding - the diagonal rusticated timber - leaked much more water than the others. It exhibited the most severe water leaks seen in this project, and is considered important enough to be discussed separately later. The results of the diagonal timber cladding were removed from the conventional group's results before these were analysed for this water leakage location.

Then, the mean measured water leakages for each group at both inside-facing corners of the test walls (summed for both corners, as for the outside corners), are as shown in Figure 20. All the other types of claddings performed very similarly at this location, though again with the caveat that the lightweight claddings tested in isolation may have leaked more water at higher pressures if they were tested at those pressures.

There was no observed water leakage at zero applied pressure difference, and the greatest measured water leakage only approached "slight flow" at the highest pressure difference applied.

All three types of claddings showed significant reductions in water leakage when tested with a lining, and no water leakage when tested with a lining and underlay.

Jointer Water Leakage

Figure 21 shows the mean measured water leakage recorded at the jointers sealing butt joints between boards (vertical jointers for horizontal boards; horizontal jointers for vertical boards) for the two groups of lightweight claddings.

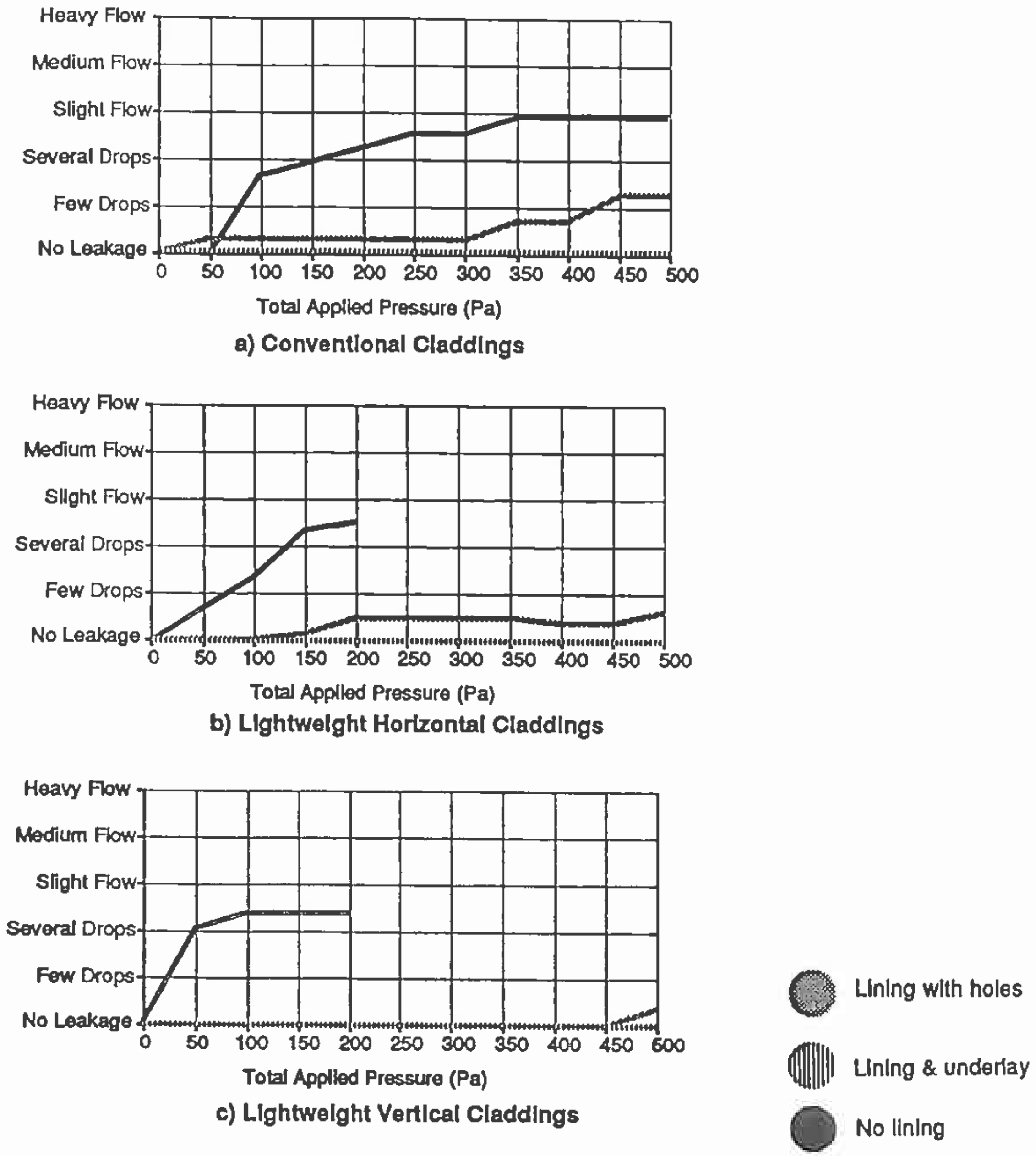


Figure 20 : Mean Water Leakage, Inside Corners, Excluding Diagonal Timber

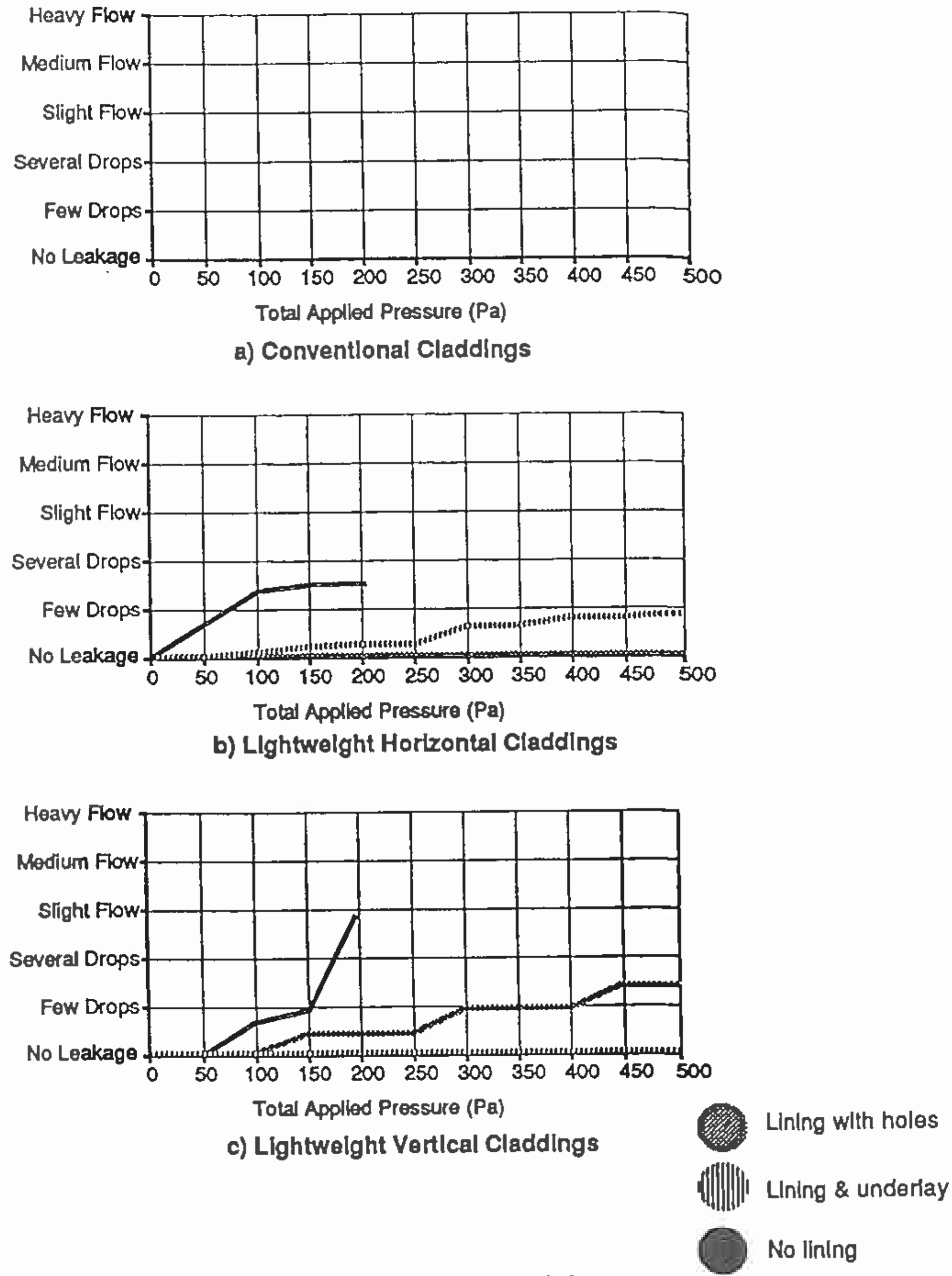
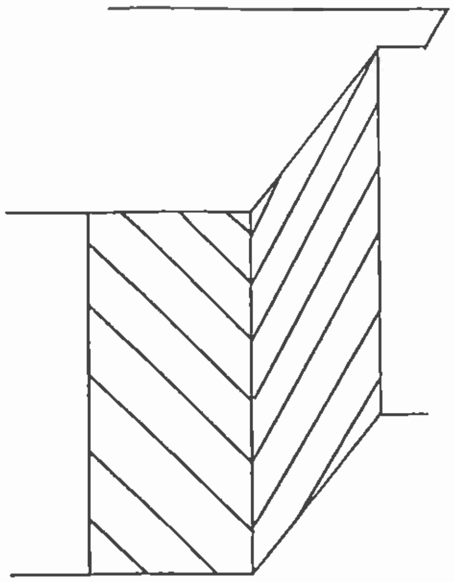
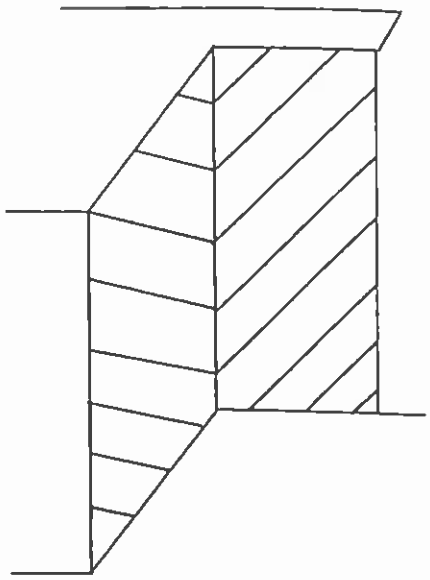


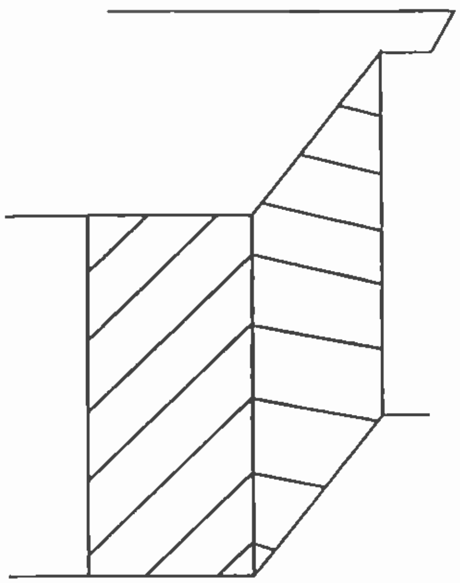
Figure 21 : Mean Water Leakage, Jointers.



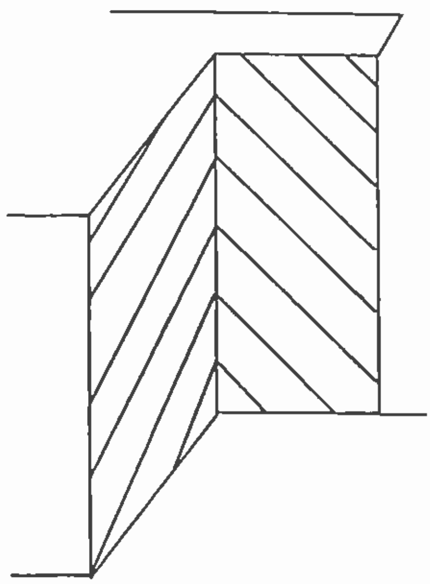
Outside corner converging grooves



Inside corner converging grooves leaked severely



Outside corner diverging grooves



Inside corner diverging grooves

Figure 22 : Orientation of Rustication Grooves at Corners of Diagonal Timber Cladding (viewed from outside)

For conventional claddings, jointers were not used, but tight butt joints through the thicker boards served the same function. These were seen to perform very well, with no water leakage observed even when tested in isolation.

For the lightweight horizontal claddings, the water leakage through jointers was also very small, even with no lining or underlay in place on the test wall. When the lining was added, water leakage dropped even further. When the underlay was added to the wall with the lining, water leakage stopped altogether.

For the lightweight vertical cladding, water leakage through the (horizontal) jointers was appreciable only when the cladding was tested by itself. When a lining and underlay were added to the wall, water leakage was reduced to low levels, though significantly more water leakage was noted when an underlay was used, than when just a lining was used with the cladding, again probably due to the underlay touching the jointer and wicking water from it into the cavity.

Diagonal Cladding Inside Corner Water Leakage

The diagonal (timber) cladding water leakage results were similar to the rest of the group of conventional claddings, except for an inside corner joint, where the measured water leakage was much higher than on any other cladding or joint.

Figure 22 shows the orientations of diagonal cladding in the four corners tested. The severe water leakage occurred at the inside corner, where water running off two sets of downward-sloping grooves converged.

Figure 23 shows the results of testing of the diagonal timber cladding at that inside corner.

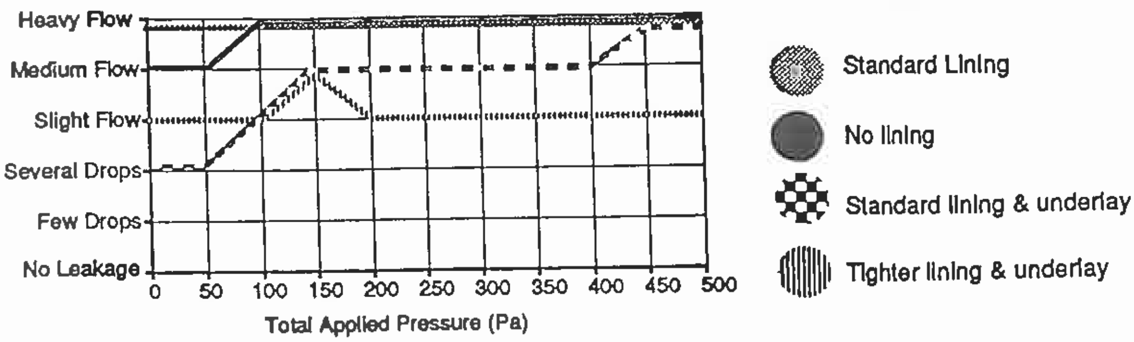


Figure 23 : Leakage at Inside Corner of Diagonal Timber Cladding

With no lining on the wall (Run 16), the water leakage ranked as "Medium Flow" even with no applied pressure difference, and "Heavy Flow" when pressure was applied. With a lining in addition to the cladding in the wall (Run 17), the water leakage was consistently "Heavy Flow" at this location. With an underlay and lining in the wall (Run 36), the water leakage still reached "Medium Flow" at 150 Pa, and even when the air leakage paths in the lining were reduced by 75% (50 mm diameter holes plugged and 25 mm ones opened up instead) (Run 37) the water leakage was only reduced to "Slight Flow".

The water leakage observed for the diagonal cladding at this point is much higher than any other, probably because of the channelling effect of the diagonal grooves in the timber weatherboards. These forced most of the water runoff from the two adjacent walls into the corner. The quantity of runoff concentrated at that point overwhelmed the drainage capacity of the vertical joints at both the outside and the inside of the corner, between the flashing and the cladding, and the water simply overflowed into the wall. When a pressure difference was applied, even more water was forced in.

Between Board Water Leakage

Water leaks in the joints between boards of the claddings were rarely noted in any type of cladding tested. They were observed only in the more airtight claddings tested with no linings, and were of the "overflow" type where water leakage increased in a step rather than climbing with increasing pressure difference.

In both the sheet and plank types of cellulose fibre-reinforced cement claddings there were some incidents of wetting of inter-board joints, but these appeared to be due to a water permeability of these cladding materials (when unpainted), rather than due to pressure difference driven water leakage.

Water Leakage Results - Window Flashing Improvements

Beyond the "necessary and standard" flashing improvements, several other details were tested.

Window Facing Improvements

Two alternative methods for reducing water leakage around windows were tested. These modified the window/wall joint so it was more effectively protected from the rain spray.

One test was performed with no treatment to this joint beyond the "necessary and standard" polyethylene foam backer rod at the interior of the joint (Run 28).

A second test (Run 69) used an open cell compressible foam gasket at the outside of the joint (adhesive fixed to the inside of the window facing, between the facing and the plane of the wall), as shown in Figure 24.

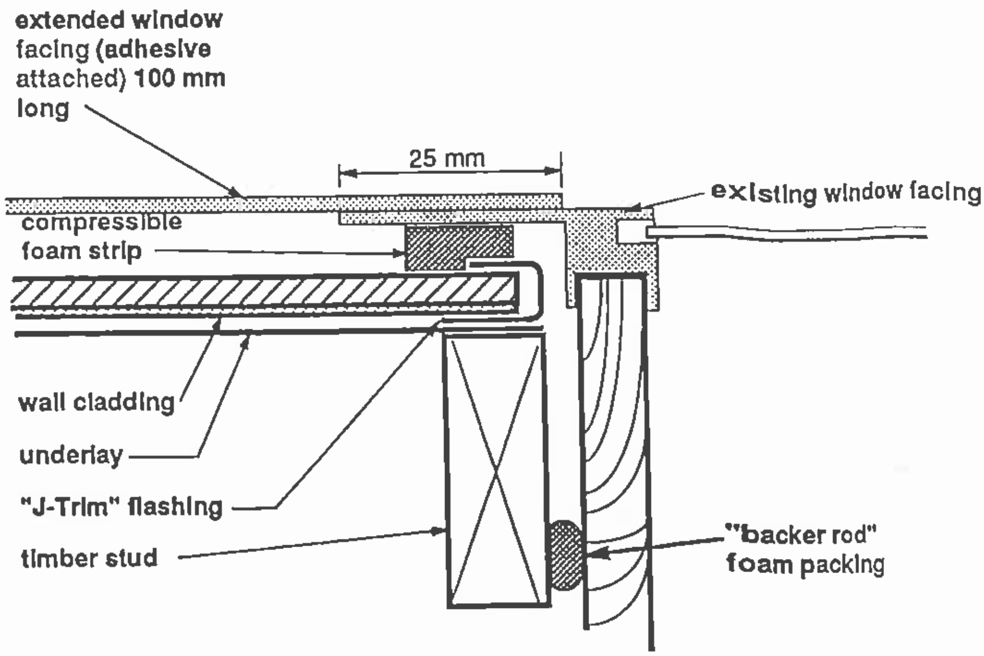


Figure 24 : Window Flashing Improvements - Plan View

A third set of tests (Runs 70 and 71) used a 100 mm wide strip of aluminium fixed to the outside of the window facing at the jambs and sill of the window (the head was protected by a drip cap), to increase the effective facing width from about 25 mm in a stock aluminium window to that used in traditional timber windows. This is also shown in Figure 24.

Figure 25a shows the results of testing for water leakage at the sill of the window/frame joint of test walls clad in a conventional (timber) cladding using the standard lining, and the configuration described above. The result for the 100 mm facing extension is the mean water leakage from two tests.

As can be seen from Figure 25a, there was a significant water leakage at this joint when there was no treatment to the outside junction of window and frame (though the water leakage decreased with increasing pressure difference, different from the normal result). When the compressible gasket was placed between the window facing and the wall, the water leakage dropped significantly, though at high pressure differences it was similar to that with no treatment at all. Finally, when the 100 mm wide facing was in place, insignificant water leakage was detected for the duration of the test.

Figure 25b shows the measured water leakage for the same set of test walls, but at the jamb of the window/frame joint. The same conditions and configurations of window treatments were used.

At the jamb, there was no water leakage before a pressure difference was applied using any of the window treatments. With no treatment of the exterior window-and-frame joint, water leakage increased with increasing pressure, up to very high levels at the highest pressure differences used. This probably accounts for the reduction in water leakage at the sill, as the total window water leakage increased with pressure.

With a foam rubber gasket placed between the window facing and the wall, there was a significant reduction in water leakage, to very low levels. With the window facing increased to 100 mm, and the rubber gasket removed, the water leakage was reduced even further. Virtually the same performance level was achieved with a 50 mm wide facing (result not shown).

At the end of two of the tests with the wider facings, the window was removed from the wall, and the patterns of water on the sample wall were examined to determine how far behind the edge of the facing water had penetrated. Along both jambs, in both tests, water had clearly splashed in behind the facings between 25 mm and 30 mm for the whole height of the jamb.

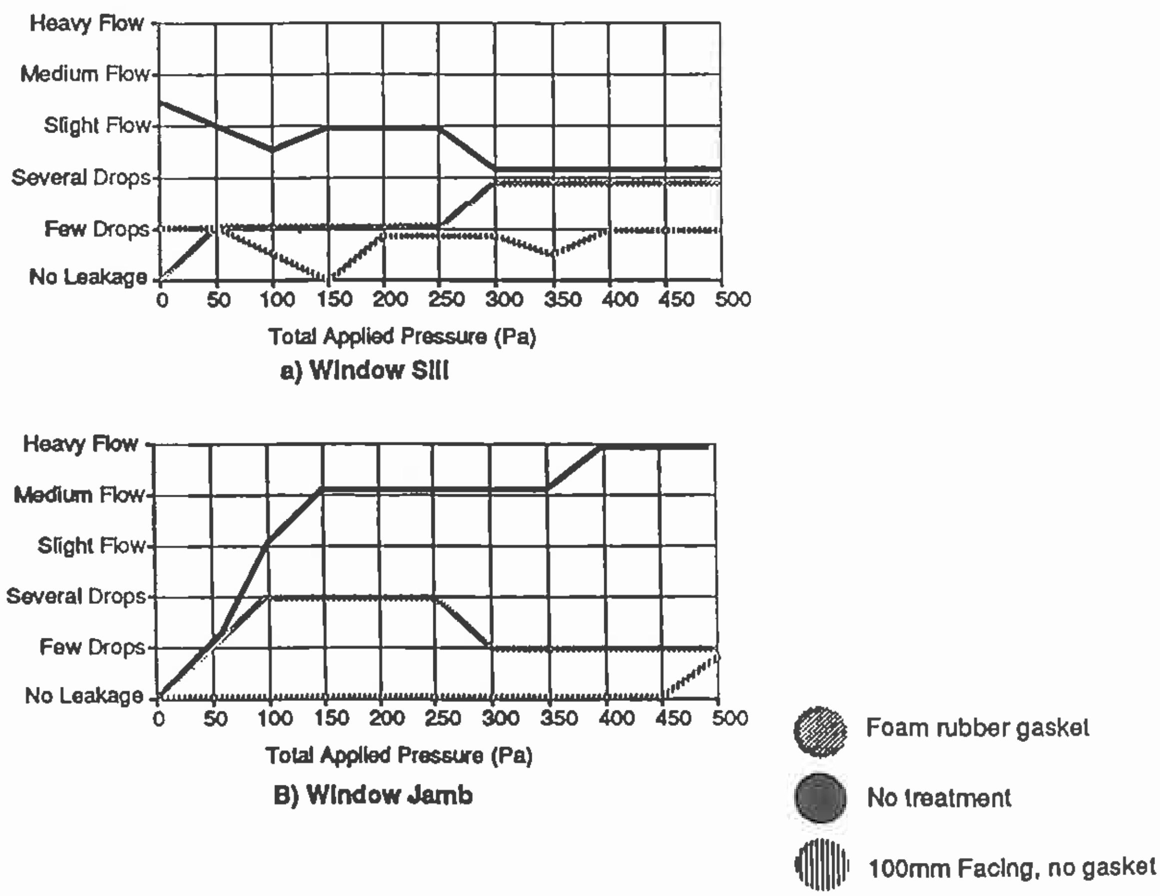


Figure 25 : Leakage for Extended Window Facings, Conventional Cladding

Sill Tray Improvements

To reduce water leakage at window sills, a series of alternative sill trays were tested, to determine what type of flashing was most effective in reducing water leakage at this point.

The "classic" sill tray is a metal flashing, slightly wider than the window opening, cut into the studs on either side of the window opening, and sloped to drain any penetrating water out (New Zealand Technical Correspondence Institute, 1966). However, due to the shape of modern windows (flat sills underneath), and the desire for faster construction, this design has been discontinued.

The tests looked at a number of alternatives, including folded aluminium (Runs 73 and 74), lapped building paper (Run 76) and polyethylene sheets (Runs 68 and 75). Each of these covered the window sill trimmer board and were lapped over the joint between it and the top of the cladding underneath the window.

"Soakers" of folded aluminium fashioned to contact the studs bordering the window jambs and lap over the edges of the (aluminium) sill tray were used in one test (Run 73). They appeared to reduce the water leakage but did not eliminate it.

Figure 26 shows the results of water leakage testing with different sill trays. Each of the sill trays reduced the water entering at these joints, though none of them was effective in eliminating it. The building paper and aluminium flashings seemed to show the greatest reduction in water flow. This could be due to the returns folded into the backs of both of

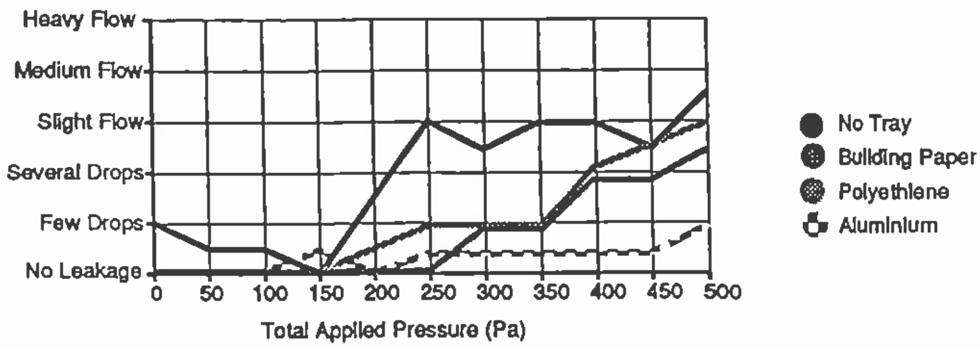


Figure 26 : Window Sill Leakage with Different Sill Tray Materials, Lightweight Claddings

these flashings, allowing them to help serve as air seals at the back of the joint.

The sill tray testing showed that without provision for drainage (the trimmer board under the window sloping to outside) a method for ensuring a weathertight joint at the window sill was not found.

DISCUSSION

The results of the air and water leakage testing carried out on domestic claddings have some important implications about the properties and uses of domestic claddings in New Zealand. These implications are discussed below.

Air Leakage

From the air leakage testing, it is clearly seen that the lightweight claddings and the conventional claddings tested in this project are quite different in terms of their air tightness. The conventional claddings had measured air leakage rates ("Q 50") of 30±11 ℓ/m^2 s compared with the lightweight cladding air leakage rates of 127±63 ℓ/m^2 s.

The results of these tests showed that the higher the air leakage rate through a cladding, the lower the pressure differences across the cladding when assembled into a typical wall.

The reason for this can be seen by representing the air flow pattern through the wall as a circuit, with each of the major wall components considered as an air leakage resistance. Such a representation is described in a paper detailing air tightness tests on the same claddings (Bassett 1987), and expanded upon in Appendix 1.

Electrical circuit analysis techniques are used to predict the air flows and pressures experienced at different points through the wall. Here, air leakage resistances correspond to electrical resistances; air pressures to voltage; and air flows to current.

Using these techniques and the definition of air leakage resistance, or "ALR-value" in Appendix 1, the ALR-value of each wall element is calculated and used to predict the pressure differences occurring across other combinations of claddings and linings.

Table 3 shows the air leakage resistances calculated for each wall cladding (from their "Q 50" rates), and the standard wall lining used in each test (from the cladding ALR-value and measured Pressure Drop Ratio).

Figure 27 shows the theoretical pressure distributions and air flow rates at 50 Pa applied pressure difference for two test walls (one using a lightweight and the other a conventional cladding) in three configurations: cladding alone; with a lining; and with a lining and underlay.

The air flow rates are seen to decrease drastically as more layers are added to the walls, and the cladding Pressure Drop Ratio drops dramatically when other wall layers are added to the cladding in the wall,

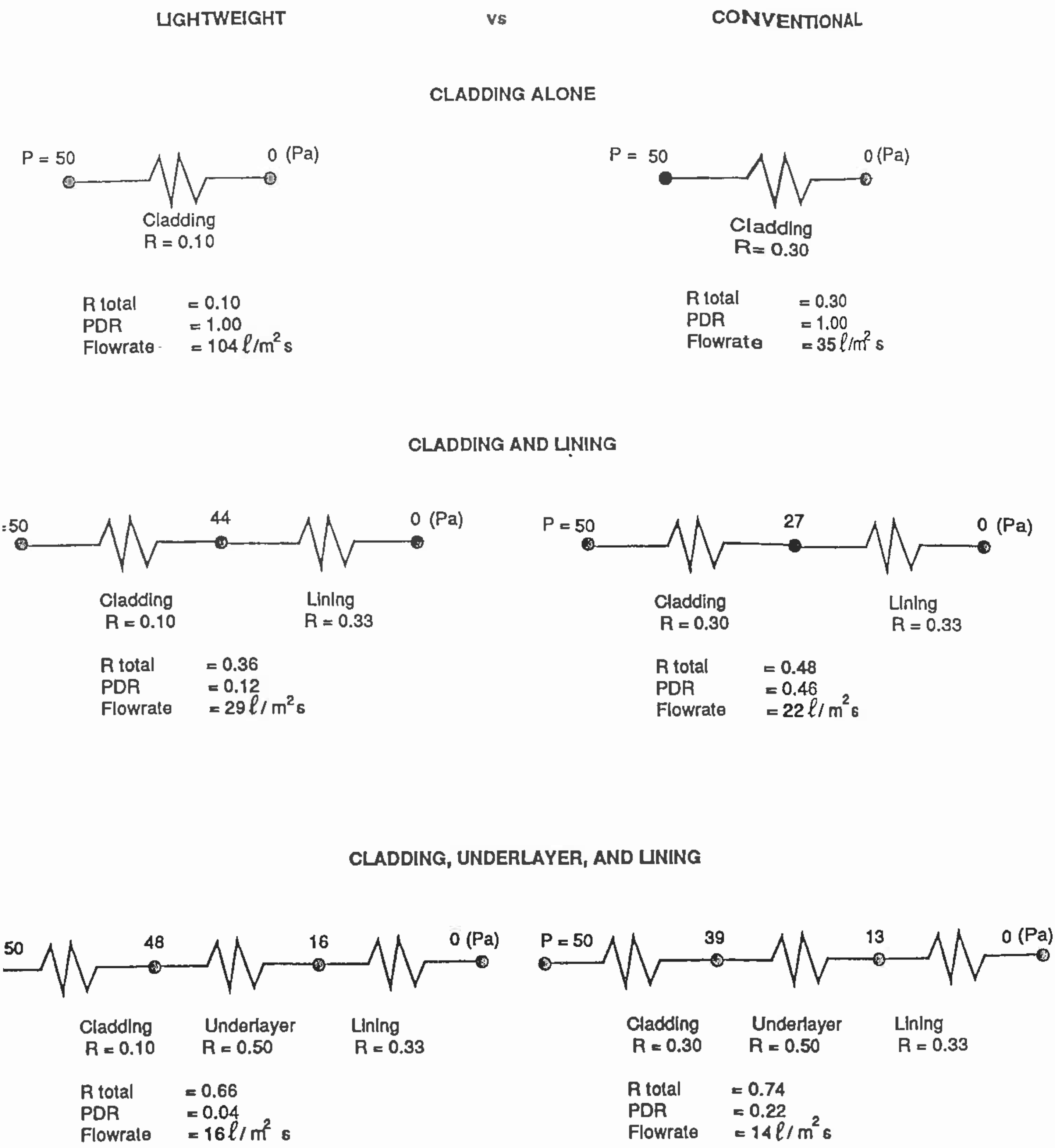


Figure 27 : Wall "Airflow R-Value" Network Solutions

especially for the lightweight cladding. This is as shown in Figure 8, with the pressure difference across the cladding being only a small fraction of the total applied pressure difference.

From this, the reason for the inverse relationship between cladding air flow rate and Pressure Drop Ratio as seen in Figure 9 becomes clear. For the same configuration of wall elements, the less airtight the cladding, the lower its ALR-value, and the less of the wall pressure difference it supports. And as the air leakage resistances of the other wall elements are increased, the pressure difference across the cladding also drops.

The lining air leakage resistance data in Table 3 was analysed to show a mean ALR-value for this set of constructions of 0.31 ±0.10). This value was used to draw the "best fit" curve in Figure 8.

The lining ALR-value of 0.31 is similar to the (air) leakiest linings seen in field tests, of ALR = 0.20 -0.25 (Bassett 1987), behind cupboards or at electrical switchboards. As tighter linings would reduce the pressure difference across the wall claddings (and possibly reduce the water leakage), simulating air leaky linings is in keeping with the conservative, worst-case nature of these tests.

TABLE 3 - CALCULATED CLADDING ALR-VALUES AND RESULTING LINING ALR-VALUES

Cladding description	Cladding Air Leakage (Q 50) (ℓ/m²s)	Cladding ALR-Value ($m^2s\ Pa^n/\ell$)	Lining ALR-Value ($m^2s\ Pa^n/\ell$)
LIGHTWEIGHT			
Horizontal (Doublewalled) PVC	46.2	0.226	0.356
Horizontal (Foamed) PVC	73.3	0.143	0.315
Horizontal Coated Steel	89.4	0.117	0.303
Cellulose Fibre-Cement Boards	91.7	0.114	0.308
Vertical PVC 2	97.6	0.107	0.721 to 0.124
Horizontal PVC 1	107.6	0.097	0.421
Horizontal PVC 2	116.7	0.090	0.423
Horizontal PVC 3	121.5	0.086	0.407
Vertical PVC 3	145.9	0.072	0.483
Horizontal Aluminium	159.3	0.066	0.263
Vertical PVC 1	189.8	0.055	0.260
Plywood Shingles	283.4	0.037	0.174
CONVENTIONAL			
Cellulose Fibre-Cement Sheet	18.0	0.581	0.176
Diagonal Rusticated Timber	21.1	0.494	0.351
Horizontal Rusticated Timber	35.8	0.292	0.235
Horizontal Shiplap Timber	43.6	0.240	0.188

Using the techniques of calculating air leakage resistances as shown in Appendix 1, a continuous underlay was measured to have an AIR-value of 0.4 in this test, compared to the discontinuous one at 0.2.

In summary, the test results show that in a wall, the pressure difference across each (series) element is distributed approximately according to that element's airtightness. So, using either (lightweight) claddings with lower air tightness, or other wall components (lining, underlay) with higher air tightness, reduces the fraction of the total air pressure difference that acts on the cladding, when assembled into a wall.

The practical application of this is: to ensure a low cladding Pressure Drop Ratio, the wall underlay and lining must be much more airtight than the cladding. As penetrations through the lining are common, a tight underlay is necessary to reduce the pressure difference across the cladding.

An underlay with an airtightness at least equal to continuous building paper will generally produce a sufficiently low cladding Pressure Drop Ratio to stop air-pressure-driven water leakage. An underlay of this air tightness is called a "wind barrier", as an indication of its role.

Water Leakage - General

The most common type of water leak seen in the testing is water leakage caused by air flows driven by pressure differences across the claddings (as shown in Figure 5a). These water leaks can be diminished by reducing the pressure difference acting across the cladding, as discussed previously.

Other types of water leaks seen included "gravity drainage" leaks (as in Figure 5b), which are not much affected by increasing pressure difference, and (rarely) "overflow leaks" (as in Figure 5c), which increase abruptly with pressure difference.

When the claddings were tested in isolation, with no other components in the wall, the lightweight horizontal claddings showed on average as much water leakage as the conventional ones (up to the maximum pressures to which the lightweight claddings were tested), but the lightweight vertical claddings showed slightly more. Note, however, that the conventional claddings were tested unpainted, thus they were probably not as weathertight as they would have been in actual use.

It is hypothesised that the lightweight claddings would have leaked more water if they were tested in isolation to the same pressures as conventional; as their water leakage was usually still increasing when their tests were terminated.

When the claddings were tested in a "typical" wall configuration, with the "standard" lining, both the lightweight horizontal and vertical claddings leaked less water than the conventional claddings, with only small water leaks even up to high applied pressure differences.

An exception to this is the water leakage at the jamb of the lightweight vertical claddings, and the sill of the lightweight horizontal claddings, where gravity drainage leaks were prominent in the tests.

When the claddings were tested with wind barrier underlays in addition to the standard lining, the lightweight claddings performed better still, showing insignificant water leaks up to the highest pressure differences used, except for the aforementioned window jamb water leakage site for lightweight vertical claddings, and occasional "wicking" effects where the back of the cladding touched the underlay and allowed water to flow down it.

Thus, with the lining and underlay of the airtightness used, the lightweight claddings were significantly more weathertight than the (unpainted) conventional claddings.

The lightweight claddings also showed a greater reduction in water leakage when other wall layers were added than did conventional claddings. This is primarily a result of the lower air leakage resistances of the lightweight claddings, which lead to even greater reductions in the pressure difference acting across the claddings. (Figure 27).

The water leakage results were almost identical when tests were performed with either static or dynamic pressure differences. This shows that pressure equalisation occurs very quickly in the wall cavities (much more quickly than the 1 cycle/sec driving frequency used in testing). From this it is inferred that the volume of air flow needed to equalise pressure is small compared with normal steady air flow.

In some of the tests (for example, at window heads), the observed water leakage dropped with increasing pressure difference. This physically unlikely effect can be explained by noting that in these cases the water leakage at an adjacent location increased at the same time, leading to the likely explanation that the water leakage was simply diverted to a different location.

Water Leakage - Specific

The most significant water leaks seen in testing occurred around windows. Without special attention, the joint between window frame and wall was less weathertight than inter-board joints, corners, or jointers. This was considered to result from the greater air flows through the outer skin of the wall at window surrounds, and from the limited rain screen effect of narrow window facings.

At the window head, when tested in isolation, the conventional claddings were more weathertight than the lightweight ones. But with linings in place, the reduction in air pressure difference across the lightweight claddings allowed them to outperform the (unpainted) conventional ones.

At the window jamb, the horizontal lightweight claddings performed as well as the conventional claddings when tested in isolation (up to the maximum pressure tested), and performed better when tested with a lining, or lining and underlay. The lightweight vertical claddings showed notable water leaks at the jamb, including gravity-driven water leaks, possibly due to structural deflection and lack of adequate support.

At the window sill, gravity-driven water leaks were seen in both conventional and lightweight horizontal claddings. It was hypothesised that this was due to the horizontal framing (trimmer) board below the window sill, which was not sloped to outside for drainage. However, the standard pattern of water leakage reductions with reduced cladding pressure difference continued.

At the inside wall corner, all the claddings performed similarly, and well, with the exception of the diagonal cladding where the grooves of both facing walls drained into the corner.

At the outside wall corner, lightweight claddings needed a lining and underlay to perform as well as conventional claddings. This was especially so for vertical lightweight claddings.

At jointer elements between boards, all horizontal claddings performed well, with no significant water leakage noted. Vertical claddings with horizontal jointers did show some water leakage problems, though. This was possibly due to the horizontal jointers holding up the runoff of water down the cladding, and allowing it to bridge cracks so that air pressure difference could blow it through.

Water leaks caused by bubbling up between boards were not a severe problem. Although there were some instances of this phenomenon noted, in general the claddings (especially with linings and underlays) did not experience a large enough pressure difference to lift water over the lap of the weatherboards.

Previously published reports of water leakage testing have shown water leakage problems not repeatable between tests (Carruthers and Newman, 1977). This led to a concern that differences in assembly of the claddings on the test frames could lead to non-repeatable performance. This did not appear to be the case in these tests, perhaps because the lining airtightness was designed to be consistent, with controlled air leakage.

In the tests that were repeated, the observed water leaks were reproducible, at least in terms of the maximum flowrates encountered at each location. Also, averaging over many samples led to increased confidence in the results obtained.

Diagonal Timber Cladding Water Leakage

In all cases tested, diagonal timber weatherboards were unable to be made weathertight at an inside corner where downward sloping rustication grooves in two adjacent walls converged (as shown in Figures 22 and 23). This was probably caused by the channelling of water down diagonal rustication grooves in the boards to concentrate at the vertical corner joint. The most severe water leaks seen in all the testing were at this location.

Even with both a continuous underlay and a lining four times tighter than standard, water leakage at this location did not fall below "Slight Flow" throughout the testing.

However, the other corners of this test wall did not exhibit this problem. At the other inside facing corner, water drained away from the corner along the grooves in both facing walls. And at the outside facing corner where the grooves in both facing walls drained toward the corner, water leakage of this magnitude was not noted.

There were also significant water leaks at the window jambs where the diagonal cladding boards drained into the jambs. This was probably due to the same channelling effect as the problem with inside corners.

Window Results

Severe water leakage occurred through the gap between window frame and surrounding framing timber when this gap was left open. This appeared to be due to the high air flows occurring through that gap.

Windows without a drip cap flashing at the head showed major water leaks there, even with other window head flashing details.

Window jamb flashings that did not drain out of the wall cavity, showed severe water leakage into the wall.

Very early in the testing, techniques were adopted as "necessary and standard" to prevent severe water leakage at these locations during our tests.

These techniques included plugging the gap between the window frame and the surrounding framing timber with compressible closed-cell foam "backer rod", "drip cap" flashings at the window head, and jamb flashings which drained to the outside of the wall.

Increasing the facing of windows from 25 mm to 50 or 100 mm made the window joint much more weathertight. The water leakage paths seen on the back of the wider window facing showed that water splashed 25 to 30 mm around the back of a window facing. Thus a window facing of 50 mm may be sufficient to greatly reduce the water leakage around window joints.

Using a compressible foam strip outside the wall surface, to seal the gap between window facing and wall also reduced water leakage significantly. However, there was no indication of the durability of the strip at this position.

With vertical weatherboards, water leaks at the window jambs were very prevalent, possibly due to the poor support of the cladding edges at this point. Thus, it was necessary to ensure that the cladding-to-window-jamb joint was supported to avoid flexing and opening when under wind pressure, and that the drainage channel down the window jamb drained to outside the cladding.

Sill trays were found to reduce water leakage at window sills, but none of the sill trays tested eliminated it.

The failure to eliminate water leakage at the sill through flashings was felt to be due to the limitation of the horizontal (not sloped) trimmer boards under the window sill that did not allow drainage out.

CONCLUSIONS

Air Leakage

1) All of the lightweight (PVC or metal) claddings in the survey were appreciably less airtight than traditional (timber and reinforced cement sheet) claddings.

2) The addition of an underlay between the linings and claddings in tests greatly reduced the wind pressure difference across the cladding, especially for lightweight claddings.

3) The less airtight the wall cladding, the lower the pressure difference was across the cladding. It is clear that low airtightness claddings will be required to be shielded from direct penetration of airborne rain drops at their joints.

4) The tighter the inner layers of the wall, the lower the pressure difference was across the cladding.

5) To reliably reduce cladding pressure difference, an underlay should be continuous, with no gaps or holes. An underlay of this tightness is called a "wind barrier" in this report.

6) Air pressure difference distributions across wall elements can be predicted from air leakage rate (Q50) data using air leakage resistances (ALR-values).

Water Leakage - General

7) The most significant rain leaks were driven by air leaks which were in turn caused by pressure differences across the cladding.

8) The claddings within each of the chosen groups (unpainted conventional, lightweight horizontal, lightweight vertical) all had similar performance in terms of water leakage.

9) The lightweight claddings were found to be at least as weathertight as unpainted conventional claddings when tested with a lining. Tighter linings or underlays lowered the water leakage.

10) When tested in isolation (no lining or wind barrier) lightweight vertical claddings were less weathertight than unpainted conventional claddings, and lightweight horizontal claddings were generally as weathertight as unpainted conventional claddings (though not tested to pressures as high as the conventional).

11) When tested in isolation (no lining or wind barrier) lightweight horizontal claddings appeared to be generally as weathertight as unpainted conventional claddings (though not tested to pressures as high as the conventional).

12) All the lightweight claddings in this study appeared to be adequately shielded from direct penetration of airborne rain drops at their joints.

Water Leakage - Specific

13) The joint between window frame and wall was the most difficult joint to make weathertight. Special attention was required to make this joint as weathertight as inter-board joints, corners, or jointers.

14) Windows using a drip cap head flashing and jamb flashings that were made to drain to an internal gutter in the cladding, or out of the wall cavity, were much more weathertight than those using other window flashing details.

15) Increasing the width of the window facings from 25 to 100 mm greatly reduced the observed water leakage.

16) Lightweight vertical claddings often leaked at the window jamb, possibly due to a lack of sufficient structural support there.

17) Diagonal timber weatherboards were not able to be made weathertight, in the corners where water drained in from the diagonal channels.

18) Sill trays were found to reduce water leakage at window sills, but none of the sill trays tested eliminated it. This was felt to be due to horizontal trimmer boards below the window sill that did not allow drainage out of the gap there.

19) Leaks caused by bubbling up between boards were seen only in tests on the more airtight claddings when these claddings were tested alone.

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APPENDIX - AIR FLOW RESISTANCES

The air flow through building elements is governed by the equation:

$$Q = C\,\Delta P^{n}$$

where Q = air flowrate (ℓ/s m^2)
C = flow coefficient (ℓ/s m^2 Pa^n)
ΔP = pressure difference across element (Pa)
n = flow exponent (dimensionless, between .5 and 1)

This process is equivalent to the flow of electricity (or heat), where flow is proportional to voltage (or temperature difference) divided by an electrical (or thermal) resistance:

$$Q = \Delta P / R, \text{ so}$$

$$R = \frac{\Delta P^{(1-n)}}{C}$$

where R = air flow resistance (m^{2}s Pa/ℓ).

A difficulty with this definition is that the air flow resistance defined this way is not independent of the pressure difference across it. Thus this definition is not used, and a more useful one is derived.

In series circuits where the total air flow resistance is the sum of the series resistances, the applied pressure is distributed across the series air flow resistances. This makes the system non-linear, and precludes a simple solution to the circuit.

However, a modified air flow resistance, called the Air Leakage Resistance (or ALR-value) here can be defined to be independent of the applied pressure:

$$ALR = \Delta P^{n} / Q \qquad \text{(equation 1)}$$

where ALR = Air Leakage Resistance ($m^2 s\ Pa^n/\ell$)

Then, assuming the flow exponent is the same for each element, the pressures and flows acting across and through each element can be calculated more easily. The only complications are that the modified resistances in series must be added according to the formula:

$$ALR\ total^{1/n} = ALRa^{1/n} + ALRb^{1/n} \qquad \text{(equation 2)}$$

where ALR total = total series modified air flow resistance
ALRa, ALRb = individual air flow resistances in series

and the pressures acting across each series element are calculated as:

$$\frac{\Delta Pa}{\Delta P\ total} = \frac{ALRa^{1/n}}{ALR\ total^{1/n}} \qquad \text{(equation 3)}$$

where ΔPa = pressure difference across element a ΔP total = pressure difference across total system

The advantage of this method is that pressure ratios are now directly proportional to ALR-value ratios (raised to a power between 1 and 2).

To calculate individual element ALR-values, equation 3 can be combined with equation 2 and rearranged as:

$$ALRb = ALRa\ \left(\frac{\Delta P\ total}{\Delta Pa} - 1\right)^{n} \qquad \text{(equation 4)}$$

The application of this technique is demonstrated in the following example. The cladding and lining airflow resistances for the Lightweight Cellulose Fibre-Cement Board cladding (with air leakage rate and pressure drop ratio described in Table 1) are calculated.

The flow exponents for all the walls tested are taken as 0.6 (Bassett,1987).

Thus the units of ALR value to be used throughout are $m^2 s\ Pa^{0.6}/\ell$.

This cladding had an air leakage rate of 91.7 $\ell/m^2 s$ at a pressure difference of 50 Pa. So, from equation 1,

$$\text{ALR cladding} = 50^{0.6}/91.7 = 0.114$$

And, for a wall which can be represented as two series elements, "cladding" and "lining", the lining ALR value can be calculated from equation 4, knowing the cladding ALR-value and Pressure Drop Ratio. With a cladding Pressure Drop Ratio of 0.16, equation 4 yields:

$$\text{ALR lining} = 0.114 \left(\frac{1}{0.16} - 1\right)^{0.6} = 0.308$$

This process can be extended to calculate the airflow resistance of other layers in multi-layer walls. One simple way to do this is by lumping the ALR-values of the other wall elements together as one element, using equation 2:

For the wall in the previous example:

ALR cladding + lining =

$$= (0.114^{1/0.6} + 0.308^{1/0.6})^{0.6} = 0.342$$

Noting that the underlayer Pressure Drop Ratio from Figure 7a is about 0.54, the Pressure Drop Ratio of the cladding and the lining combined is 0.46. Then, applying equation 4:

$$\text{ALR underlayer} = 0.342 \left(\frac{1}{0.46} - 1\right)^{0.6} = 0.377$$