DISTRIBUTION OF AIR PRESSURES IMPOSED BY WIND ON WOOD FRAMED WALL CONSTRUCTION

J.A. Thompson[1] and R.L. Quirouette[2]

Abstract

Understanding the requirements of an air barrier system and the distribution of air pressures within and around the building envelope under both steady state and gusting wind conditions, allows designers and builders to produce exterior walls which will provide the expected air leakage performance and the structural requirements of other elements within the walls.

This paper presents the results of laboratory study which tested six different wood frame wall assemblies under steady state and dynamic air pressures to determine the air pressure distribution throughout the assemblies given different degrees of air leakage through the air barrier systems.

Dynamic air pressure tests included both gust and decay tests under air pressure differentials of +/- 1000 Pa. Gust tests were conducted starting with a relatively low air pressure level and suddenly increasing the air pressure up to +/- 1000 Pa. across the wall. The decay tests were conducted by starting at +/- 1000 Pa. air pressure and then dropped off to zero. these tests were conducted at three initial pressure change rates ranging from 1800 to 6300 Pa/s with air pressures recorded continuously using a computer data acquisition system.

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Introduction

Air pressures due to wind on wood framed wall construction can lead to a broad range of damage to building envelopes. Exterior siding being ripped off the walls during high wind gusts present immediate concerns to owner and occupants. However, rupture, excessive deflection or displacement of materials and creep failure of components within the wall system result in long term durability problems, excessive energy costs and reduced levels of comfort within the buildings, all of which may go undetected for years.

From an air pressure load application perspective, there are two areas of interest, the steady state conditions that result from the expected hourly design load and the gusting conditions that often accompany wind driven rain.

In general, residential wood framed construction is built with polyethylene sheet material intended to provide the primary resistance to air flow through the exterior envelope ie: **the air barrier**. Design requirements for air barriers are provided in building codes, construction guidelines and other publications (1, 2, 3). The primary function of an air barrier is to control air leakage, therefore, a properly designed air barrier assembly will have a very low air leakage rate. In order to maintain low air leakage performance an air barrier assembly must be designed to structurally resist the peak wind induced pressures over the life of the building envelope.

The design of exterior walls has evolved to incorporate design principles such as the "Rainscreen Principle". In order to control water penetration from the exterior, exterior cladding is opened up to allow pressure equalization of the cladding to minimize rain penetration. In addition, the cladding is drained and vented to the exterior to promote drying of the wall assembly. In order to design these open rainscreen walls, an understanding of both the dynamic and steady static pressure distribution through the wall assembly is required.

The laboratory study used to prepare this paper was conducted at Morrison Hershfield Ltd's Construction Laboratory in Ottawa. The laboratory tests were conducted as part of a research project to investigate the Rainscreen Performance of wood frame wall construction under contract to the Canadian Mortgage and Housing Corporation. This paper presents some of the results of steady state and gust load distribution through two types of exterior wood framed walls.

Wall Assemblies

Exterior claddings studied were: vinyl siding, stucco and brick veneer. The test walls measured 2.4m by 2.4m mounted in an environmental test chamber as shown in Figure 1. The wood framing consisted of 38mm X 89mm wood studs on 405mm centres. In this paper, results for two cladding types are presented; vinyl siding on wood furring and brick veneer. The wall sections tested are presented in Figures 2 and 3.

Tests were conducted with three different air barrier system specifications, however, only two of these are presented in this paper, an "air tight" gypsum board and a gypsum board with a prescribed leakage area. Both cases are illustrated in Figures 2 and 3. The gypsum board was air sealed using foil tape along the joints and over the fasteners to produce a virtually zero leakage barrier. In order to provide a known leakage area through the gypsum board a 25mm diameter hole was drilled in the gypsum board as shown in Figure 1.

Test Procedure

As shown in Figures 2 and 3 the test walls were constructed in the test chamber with the cladding on the inside of the chamber. The tests were conducted generally following the procedures in ASTM E330 - Standard Test Method for Structural Performance of Exterior Windows, Curtain Walls and Doors by Uniform Air Pressure Difference. However, to produce the dynamic gust tests a dual chamber test setup was used as shown in Figure 1. By pressurizing the chamber furthest from the test wall a nominal pressure differential of between 50 and 100 Pa was produced across the test wall. Then by popping a balloon in the bulkhead wall a sudden gust was produced. Different gust rates were produced by using a different size of opening in which the balloon was mounted, three different opening sizes were used for each wall panel to produce initial gust rates of between 1800 and 6300 Pa/s. In all cases the target or peak gust level was 1000 Pa., with gust tests conducted under both positive and negative air pressure differentials (positive tests with the chamber air pressure above atmospheric). The initial gust rates were determined by measuring the initial slope of the gust curves.

Air pressure differential were measured at three pressure tap locations (Figures 2 and 3) using three Air Ltd digital micromanometers. The pressure readings were recorded with a Tecmar Labmaster A/D convertor board and an IBM PC/XT microcomputer at a rate of 0.015 s between sets of readings, with the duration of the "gusts" generally less than 2 s.

Results

Figures 4 through 7 are plots of the results for the vinyl sided walls subjected to both positive and negative gust tests at the highest gust rates. Table 1 is a summary of peak loads recorded from the vinyl sided walls. In all of these tests it is noted that most of the gust pressure is carried by the gypsum board air barrier with low pressures carried by the sheathing and almost no pressure carried by the cladding (less than 2%).

Figures 8 through 11 are plots of the results for the brick veneer wall gust testing, also for the highest gust rates. Table 2 is a summary of peak loads recorded for the brick veneer wall tests. As with the vinyl siding walls the gust pressures carried by the air barrier is highest with relatively low pressures on the sheathing. However, the cladding on the brick veneer walls did see significantly higher pressures compared to the vinyl siding wall tests. The reason for this is due to the smaller venting area in the brick compared to the vinyl siding. In addition the higher stiffness of the brick veneer will also have an effect.

Other trends observed with both walls are as follows.

- level of pressure carried by the outer layers of the construction increased as the gust rate increased.
- level of pressure carried by the air barrier decreased as the air leakage of the wall was increased (pressure carried by other components increased).
- no significant difference between negative and positive pressure performance for the brick wall but pressure carried by the sheathing on the vinyl siding walls were higher for the negative pressure tests.

In addition to the dynamic pressure tests steady state tests were also conducted. The results of these tests are similar to the dynamic tests with the air barriers carrying 85 to 95% of the pressure applied with the cladding carrying more of the pressures. This is due to the venting area of the cladding which is much longer than the 25mm diameter leakage hole and the very low leakage area of the "air tight" wall. This is consistent with the Rainscreen Principle pressure equalization as discussed in ref. 4, 5, 6 and 7.

Conclusions

Based on the testing presented in this paper design pressures for air barrier elements in exterior wood frame wall construction should be designed to resist the full design gust loads prescribed for the building site in the applicable building codes(1).

However, due to factors such as poor air tightness of the wall and possibly compartmentalization the level of design pressures for cladding elements are harder to establish. If the leakage area of the air barrier is high enough the cladding may see a significant level of pressure. In addition if the cavity space behind the cladding is connected to adjacent elevations of the building the effect of pressure equalization across the cladding may be eliminated.

Therefore, it is necessary to design both the air barrier elements within the wall construction and the exterior cladding elements for the full peak gust loads.

In order to establish realistic design pressures for cladding elements, further research to measure pressure levels on wall elements is required. This should be done by instrumenting buildings in order to record the pressure distributions through the wall construction over an extended period of time.

References

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4. Ganguli, U and Quirouette, R.L., Pressure Equalization Performance of a Metal and Glass Curtain Wall, Proceeding of 1987, IRC Paper No. 1542
5. Ganguli, U. and Dalgliesh, W.A., Wind Pressures on Open Rain Screen Walls: Place Air Canada, Journal of Structural Engineering, Vol. 114, No. 3, March 1988, RC Paper No. 1525.
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TABLE 1: SUMMARY OF PEAK AIR PRESSURES ON WALL COMPONENTS FOR THE VINYL SIDING WALLS

a) "Air Tight" Gypsum Board

Test No.	Initial Gust Rate (Pa/s)	Total Air Pressure Across Wall (Pa)	Across Air Barrier (Pa)	Across Sheathing (Pa)	Across Cladding (Pa)
157	1800	1070	1037	70	10
158	2700	1018	979	89	10
159	4100	1008	958	116	15
160	1900	-1059	-1022	-62	-2
161	3200	-1002	-962	-83	-18
162	5100	-1020	-961	-115	-17

b) 25mm dia hole in Gypsum Board

Test No.	Initial Gust Rate (Pa/s)	Total Air Pressure Across Wall (Pa)	Across Air Barrier (Pa)	Across Sheathing (Pa)	Across Cladding (Pa)
163	2100	1043	912	148	4
164	2800	1016	886	145	12
165	4400	1026	878	177	17
166	2100	-1006	-855	-150	-10
167	3100	-985	-834	-154	-17
168	4700	-984	-819	-172	-20

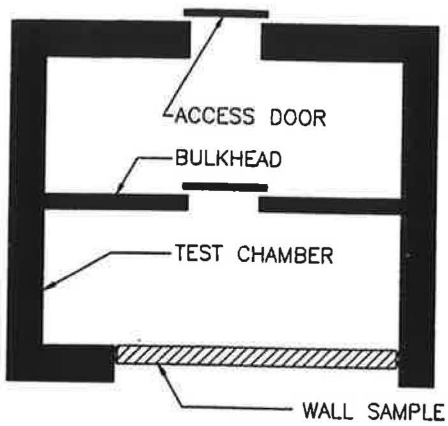
TABLE 2: SUMMARY OF PEAK AIR PRESSURES ON WALL COMPONENTS FOR THE BRICK VENEER WALLS.

a) "Air Tight" Gypsum Board

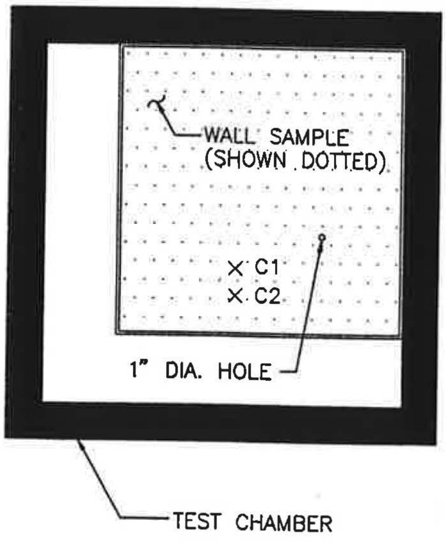
Test No.	Initial Gust Rates (Pa/s)	Total Air Pressure Across Wall (Pa)	Across Air Barrier (Pa)	Across Sheathing (Pa)	Across Cladding (Pa)
229	2100	1055	1016	56	111
230	3800	1032	984	73	194
231	5000	985	928	83	253
232	2200	-998	-962	-53	-95
233	3300	-1028	-985	-71	-155
234	5800	-1043	-979	-88	-240

b) 25mm Diameter hole in Gypsum Board

Test No.	Initial Gust Rates (Pa/s)	Total Air Pressure Across Wall (Pa)	Across Air Barrier (Pa)	Across Sheathing (Pa)	Across Cladding (Pa)
235	2200	1038	883	131	132
236	3800	1045	883	145	219
237	4800	996	824	147	258
238	2200	-1010	-858	-128	-111
239	3500	-1070	-903	-145	-181
240	6300	-1054	-859	-155	-282

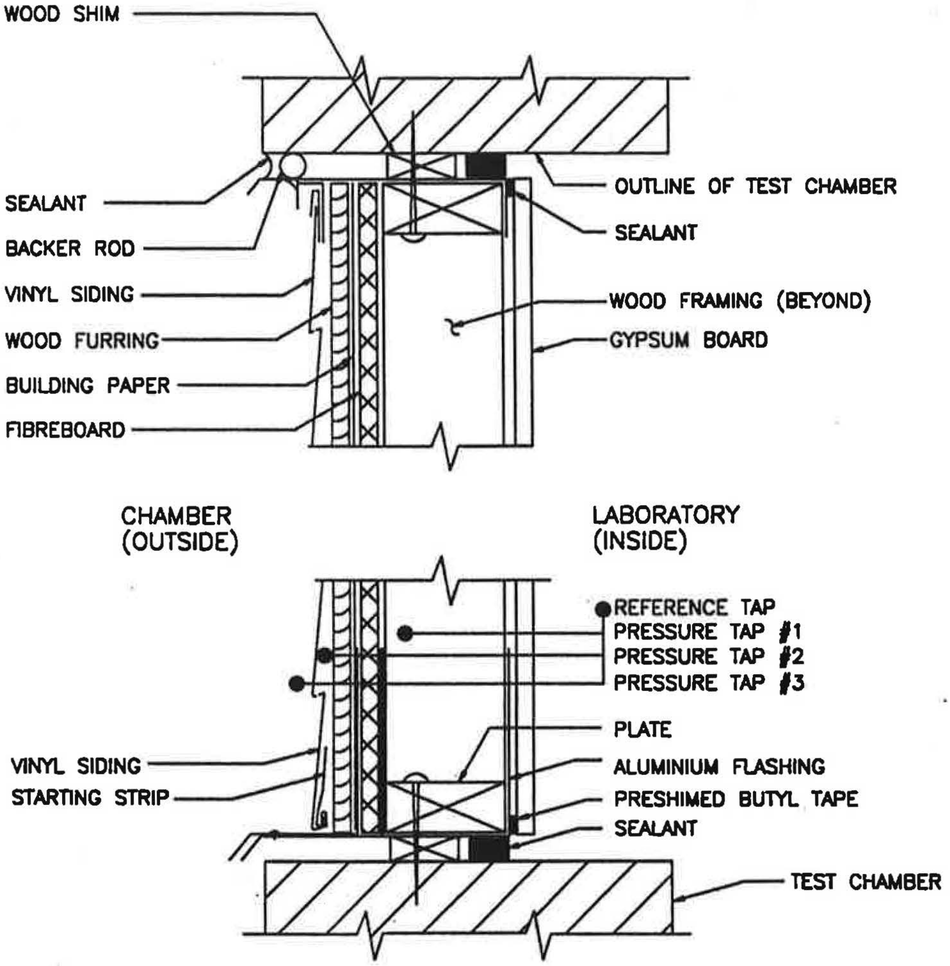


PLAN
TEST CHAMBER



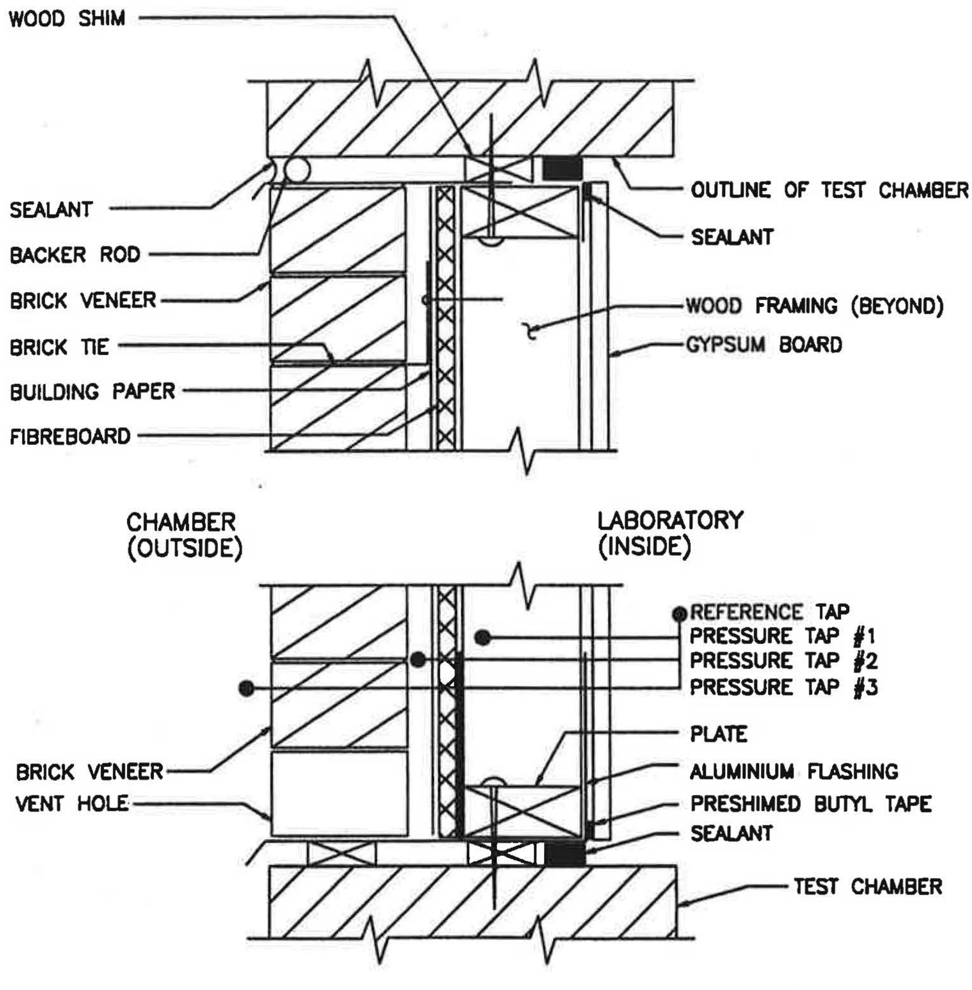
ELEVATION
TEST CHAMBER

FIGURE 1



SECTION THROUGH VINYL CLAD
EXTERIOR WOOD FRAME WALL

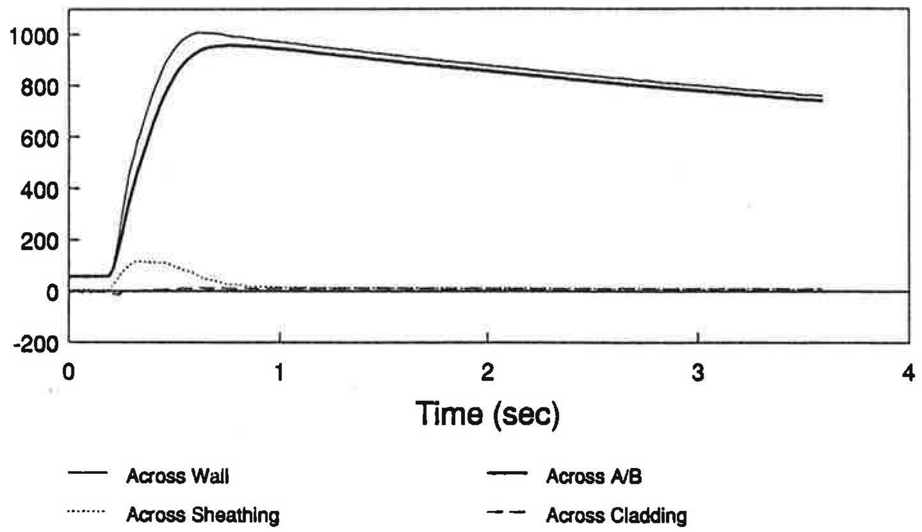
FIGURE 2



SECTION THROUGH BRICK VENEER EXTERIOR WOOD FRAME WALL

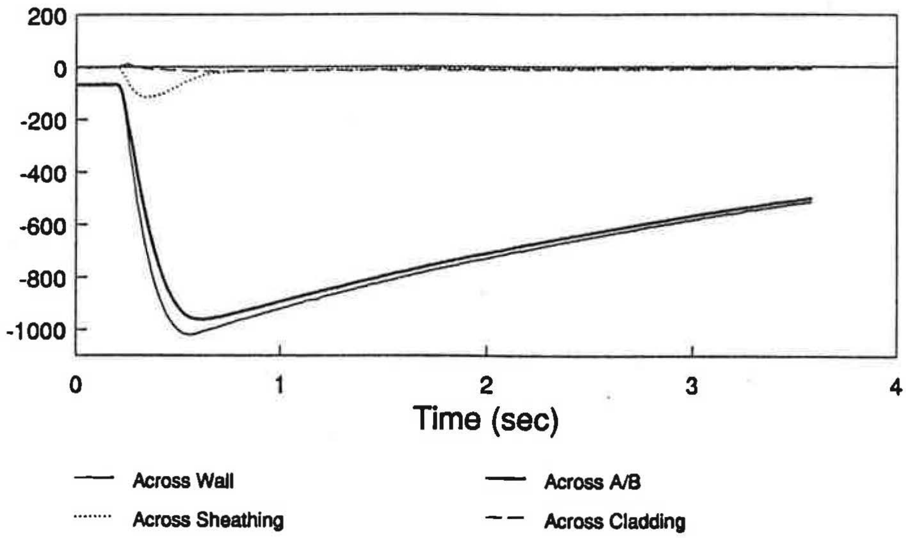
FIGURE 3

FIGURE 4: Vinyl siding wall
'Air Tight' gypsum board Air Barrier



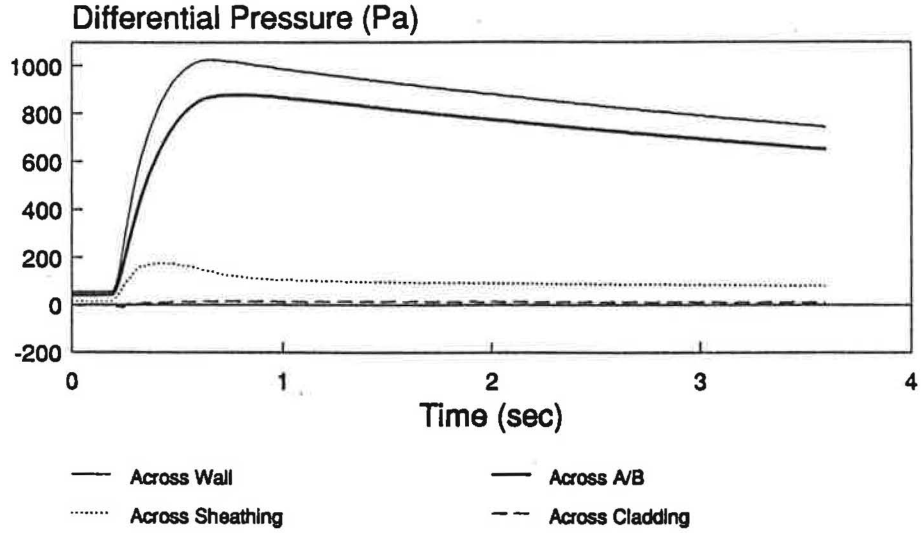
Initial gust rate: 4100 Pa/s
Test No. 159

FIGURE 5: Vinyl siding wall
'Air Tight' gypsum board Air Barrier



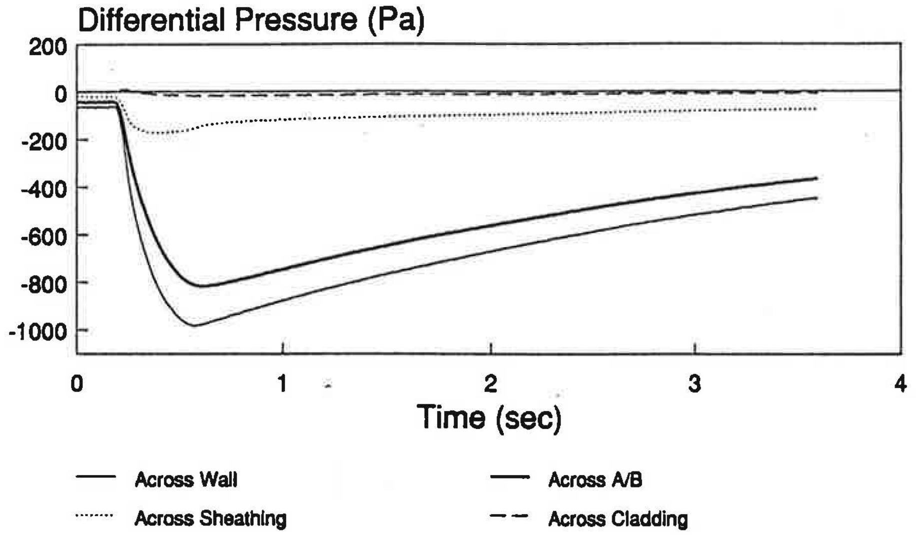
Initial gust rate: 5100 Pa/s
Test No. 162

FIGURE 6: Vinyl siding wall
25 mm hole in gypsum board Air Barrier



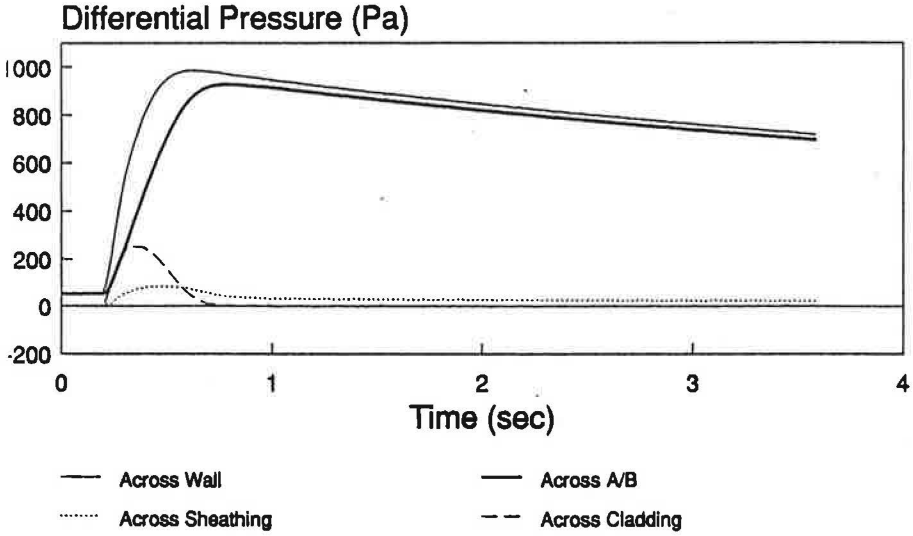
Initial gust rate: 4400
Test No. 165

FIGURE 7: Vinyl siding wall
25 mm hole in gypsum board Air Barrier



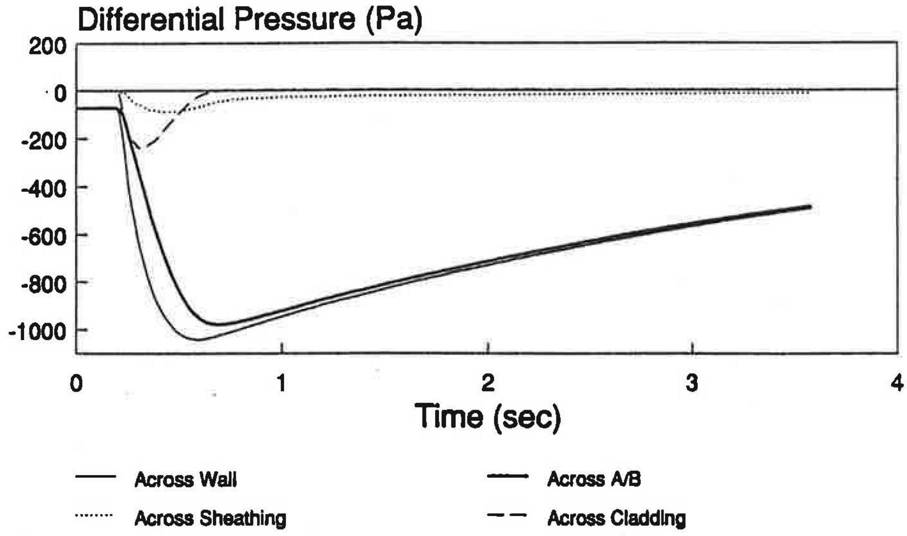
Initial gust rate: 4700 Pa/s
Test No. 168

FIGURE 8: Brick veneer wall
'Air Tight' gypsum board Air Barrier



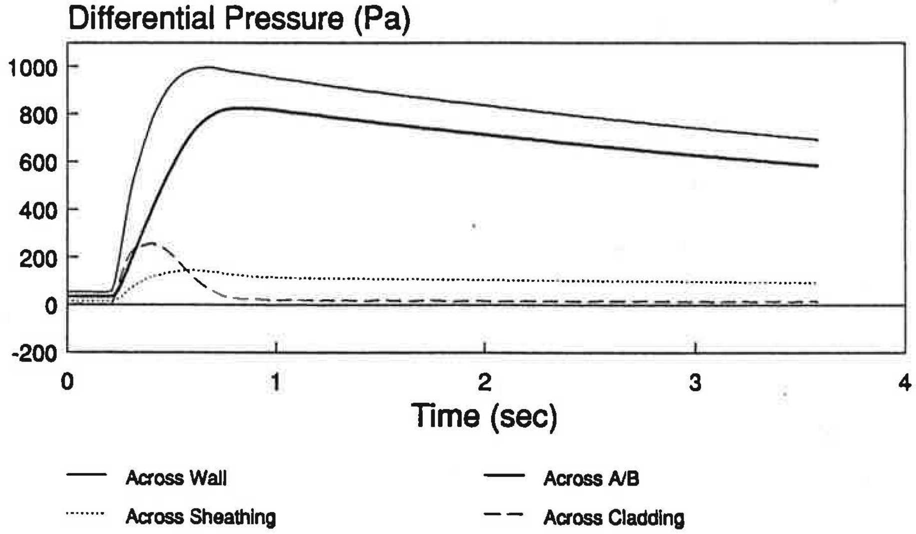
l gust rate: 5000 Pa/s
No. 231

FIGURE 9: Brick veneer wall
'Air Tight' gypsum board Air Barrier



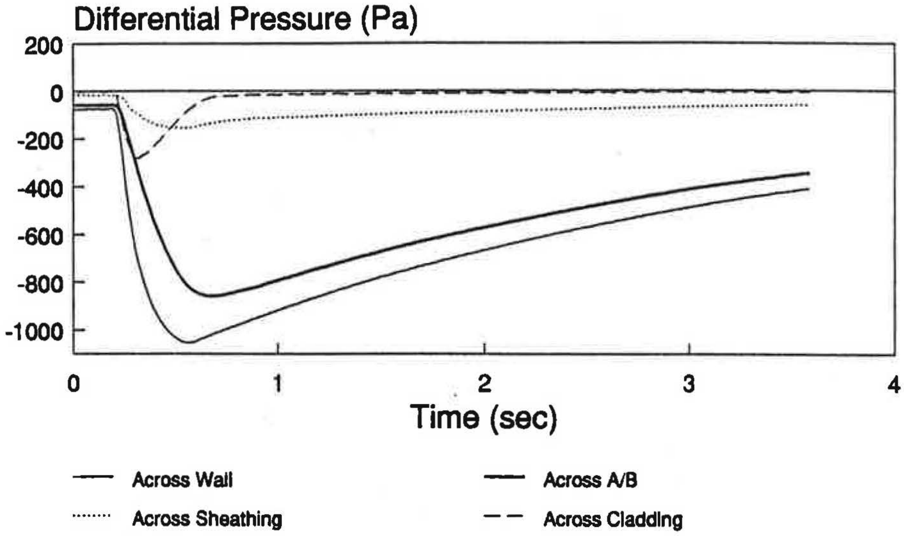
Initial gust rate: 5800 Pa/s
Test No. 234

FIGURE 10: Brick veneer wall
25 mm hole in gypsum board Air Barrier



Initial gust rate: 4800 Pa/s
Test No. 237

FIGURE 11: Brick veneer wall
25 mm hole in gypsum board Air Barrier



Initial gust rate: 6300 Pa/s
Test No. 240