THE DEVELOPMENT OF TEST PROCEDURES AND METHODS TO EVALUATE AIR BARRIER MEMBRANES FOR MASONRY WALLS

Prepared for:

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Canada Mortgage and Housing Corporation (CMHC), the Federal Government's housing agency, is responsible for administering the National Housing Act.

This legislation is designed to aid in the improvement of housing and living in Canada. As a result, the Corporation has interests in all aspects of housing and urban growth and development

Under Part V of this Act, the Government of Canada provides funds to CMHC to conduct research into the social, economic and technical aspects of housing and related fields, and to undertake the publishing and distribution of the results of this research. CMHC therefore has a statutory responsibility to make widely available, information which may be useful in the improvement of housing and living conditions.

DISCLAIMER

This study was conducted by Ortech International for Canada Mortgage and Housing Corporation under Part V of the National Housing Act. The analysis, interpretation and recommendations are those of the consultants and do not necessarily reflect the views of Canada Mortgage and Housing Corporation or those divisions of the Corporation that assisted in the study and its publication.

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1. SUMMARY

The Building Performance Centre (BPC) at Ortech INternational was contracted by Canada Mortgage and Housing Corporation (CMHC) to evaluate the performance of a number of commercial masonry wall air barriers to aid in the development of a performance standard. Primarily the intent of the project was:

- Establish performance criteria and test procedures to evaluate "as installed" masonry air barrier systems with respect to air leakage and structural performance.

- Assess the proposed evaluation process by testing a number of commercial air barrier systems in accordance with the procedures established.

- Recommend a prescriptive evaluation for masonry air barrier materials based on available test results provided by manufacturers and a review of current methods identified as applicable for air barrier components.

In fulfillment of the contract BPC has completed the evaluation of eighteen air barriers on a number of block wall substrates.This report outlines the results of the evaluation.

2. BACKGROUND

Masonry walls alone are not an effective air barrier. Construction details such as mortar and expansion joints, steel beams, component interfaces etc., also increase the air permeance of the masonry wall. Recently a number of commercial air barrier systems have been developed for masonry applications. These systems, designed to significantly reduce the air leakage through masonry walls, were primarily conceived from a requirement for the "integration of an effective air barrier" as outlined in the National Building Code of Canada. Unfortunately, there are currently no formal performance criteria, standard specifications or test methods to qualify or evaluate these products. To date the design engineer, builder, architect or owner does not have a method to assess the performance of an air barrier nor is there a clear cut method of comparing air barrier products. Owing to the number of products such as the spray and trowel-on, adhesive back, torch applied, and mechanically fastened systems being offered as "an effective air barrier", there is clearly a need to develop a standard procedure to evaluate the performance of the "as installed" air barrier system.

Among the list of variables that should be assessed are; air permeance or leakage rate, adhesion to masonry substrates under gust and sustained wind loads, permanent deformation and damage under gust and sustained wind loads, variation in applied thickness (and its affect), and strength. The evaluation of an installed barrier should ideally be carried out on homogeneous masonry substrates and on masonry walls incorporating typical construction details such as brick ties, steel columns, gaps etc. Where applicable the sample membrane should also include typical joints and other application details. In addition to the "installed barrier" performance, the development of a standard for air barriers should include an assessment of a number of prescriptive requirements for each system component. Many suitable prescriptive test procedures are currently available and include for example tear strength, dimensional and low temperature stability, water vapour permeance, resistance to plastic flow, tensile and elongation at peak load, fatigue water leakage etc. These are all important properties of the components of an air barrier system that would influence the overall performance of the as installed system.

In this case the evaluation procedures investigated, involved the performance of fifteen "as installed" air barrier systems with respect to the characteristics outlined below rather than prescriptive procedures for air barrier system components.

- **Initial Air Leakage**: Air leakage of each membrane was determined over a range of pressure differentials. Classification of each air barrier in accordance with the levels proposed by the National Research Council for Type I, II, and III as proposed in "An Air Barrier For the Building Envelope, National Research Council Canada , Proceedings Building Science Insight '86". Using the recommended system air barriers are classified based on the following criteria:

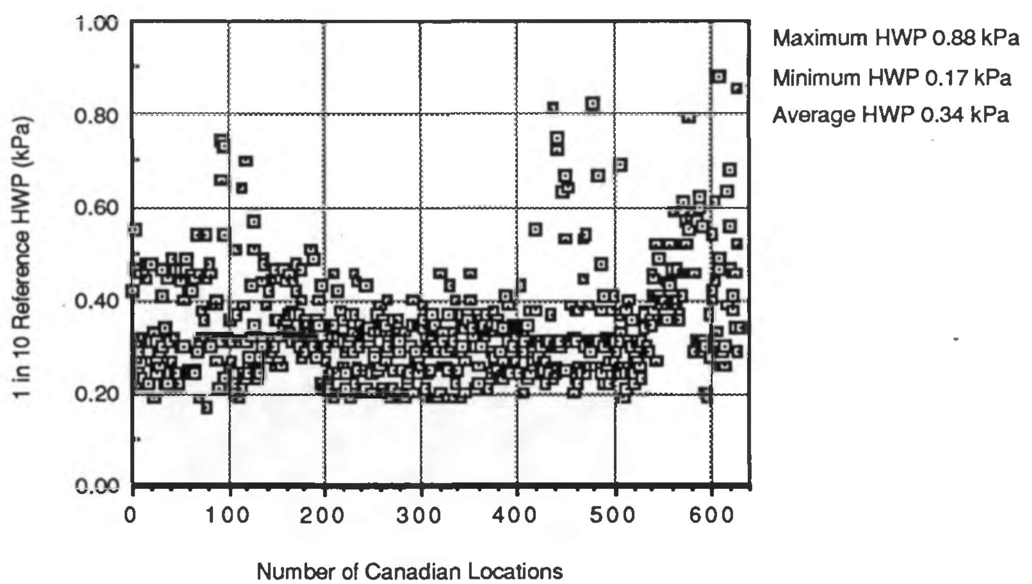
Type	Maximum Allowable Air Leakage Rate	Indoor Building Humidity
I	0.15 l/s/m^2	Low
I	0.10 l/s/m^2	Moderate
III	0.05 l/s/m^2	High

- **Membrane Adhesion Under Gust Wind Load**: Evaluation of the membrane with respect to delamination, deformation, and permanent damage which would impair its primary function as an air barrier when subjected to a -3000 pascal pressure differential for a period of ~10 seconds (Structural performance under gust wind load). This test pressure was selected based on; past experience testing masonry air barriers and was considered a reasonable estimate of potential gust wind loads derived from the National Building Code of Canada (NBC) using the "Simplified Calculation Procedure" and the 1 in 10 chance of occurrence reference hourly wind pressures for cladding, and the following assumptions:

- Safety Factor = 1.5
- q = Reference Hourly Wind Pressure value of 0.34 kPa.
- C_g = Gust Effect Factor = 2.5
- C_p = Pressure Coefficient = 1.5
- C_e = Exposure Factor = 1.58

These values are similar to those adopted in the user guide of the CAN/CSA -A440-M90, for use in wind load calculations for windows. In this case the reference hourly wind pressure represents the average of those given in Chapter 1 of the Supplement of the NBC for building heights not exceeding 100 m.

Canadian "1/10" Reference Hourly Wind Pressures

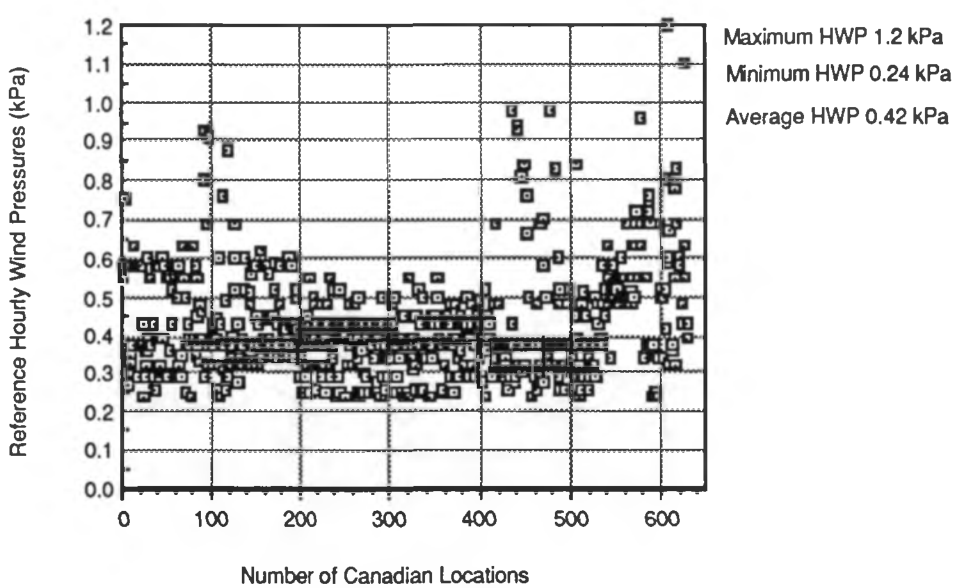


After the evaluation the membrane air leakage was re-checked and where applicable, the percentage of membrane delaminated from the block wall substrate was calculated. Failure was deemed evident if the air leakage at 75 Pa was > 0.15 $l \cdot s^{-1} \cdot m^{-2}$ or % delamination > 15% of total area. With respect to the percent delamination criteria, the 15% value was arbitrarily chosen based on data relating to the regression of air barrier performance from previous evaluations carried out in the laboratory. As such, this value requires further analysis.

- **Membrane Adhesion Under Sustained Wind Load**: Evaluation of the membrane under a static pressure differential of 1000 Pascals for a period of one hour with respect to delamination, deformation, and permanent damage which would impair its primary function as an air barrier (Structural performance under sustained wind load).

  In this case the test pressure and duration were derived from the National Building Code of Canada (NBC) using the 1 in 30 chance of occurrence reference hourly wind pressures (HWP) and no additional factors were employed. Although actual sustained wind loads will vary for building heights, shapes and surrounding terrain the graph below illustrates that the majority of locations have HWP's far below that selected for the evaluation.

Canadian "1/30" Reference Hourly Wind Pressures



It of interest to note that these conditions are the same as those outlined in the Draft ASTM Air Barrier Standard, " Standard Practice for Selection of an Air Infiltration Barrier (AIB) for Low-Rise Buildings.

Again after the evaluation the membrane air leakage was re-checked and where applicable, the percentage of membrane delaminated from the block wall substrate was calculated. Failure was deemed evident if the air leakage at 75 Pa was > 0.15 $l \cdot s^{-1} \cdot m^{-2}$ or % delamination > 15% of total area.

- **Membrane Performance under Stack Effect (Creep) Load**: Creep, the natural progressive deformation of a material under a constant stress was evaluated on representative membrane samples designed to bridge gaps in masonry construction by the application of a constant negative pressure differential of 250 Pa across the membrane for a period of 24 hours.
  For this evaluation the pressure differential was believed to be of sufficient magnitude to simulate the potential stack effect in buildings which may occur for an extended period of time and was selected based on information outlined in a publication by the National Research Council Of Canada (Canadian Building Digest CBD 104) .
  Membrane deflection over time and visible changes in membrane uniformity were monitored and used to assess the performance of the selected samples.

- **Membrane Uniformity**: The applied thickness of each test membrane was measured at a number of points over the sample to provide an indication of the variability and overall applied thickness of the test membranes.

- **Prescriptive Data :** A list of prescriptive test data for each product supplied by manufactures participating in the program was compiled. This list was used as an indicator of; the type of prescriptive data available for air barriers, the variability of the type of data and the suitability of the information with respect to the intended use of the product as an air barrier.

3. EVALUATION PROCEDURES & TEST METHODS

The project was carried out in two phases consisting of; Phase I, the evaluation of nine air barrier membranes (twenty-three block wall substrates) and, Phase II,the evaluation of six air barrier membranes (fifteen block wall substrates) and a blank block wall (no membrane) as outlined below in Section 3.1. The block wall substrates were constructed using tradesmen provided by the Ontario Chapter of the Canadian Masonry Contractors Association in a manner considered commensurate with normal building practice. The membranes were then installed by the membrane manufacturers.

3.1 AIR BARRIER MEMBRANES

For the program, four torch applied, four adhesive applied, four trowel applied and two mechanically fastened and three spray applied air barrier membranes were evaluated. Each sample membrane was applied by the manufacturer to a 1.2 m x 1.2 m x 0.140 m, plain block wall substrate, a block wall with brick ties and for the torch and adhesive applied membranes, a block wall incorporating a 50 mm x 910 mm center gap to simulate bridging. Membranes of sheet type fabrication included a minimum of one lap joint. For Phase I, all of the block wall substrates had been fully cured under ambient temperature and humidity conditions for a minimum of two months prior to membrane application. After application the membranes were allowed to fully cure under the same conditions for an additional two months. For Phase II, the eighteen block wall substrates were only allowed a two to three week cure period under ambient temperature and humidity conditions prior to membrane application. The membranes were then evaluated within three to forty days of application. Each wall was tested with respect to air leakage and adhesion under applied wind load (gust and sustained conditions). For the membranes applied to gap walls all were subjected to a twenty-four hour creep load evaluation. All testing was conducted in accordance to the procedures outlined in Sections 3.2. Prescriptive data for each sample supplied by the membrane manufacturer was also compiled for review. The sample and wall numbers as well as product type and description are outlined in the following Table. In addition to the samples listed, three spray-on polyurethane foam insulation-air barrier membranes were evaluated. For these membranes testing was conducted at the manufacturers expense using the same test protocol as previously described.

Prior to testing each sample was assigned an identification number and a series of wall numbers.

Sample Masonry Air Barrier Membranes

Test Phase	Sample No.	Wall Nos.	Type	Description
II	0	37	Not Applicable	No Air Barrier Installed
I	1	1,2,3	Torch Applied Walls Primed	Polyester reinforced SBS Modified Bitumen with Thermofused Plastic Films.
I	2	4,5,6	Torch Applied Walls Primed	Glass fleece reinforced SBS Modified Bitumen with Thermofused Plastic Films.
II	3	7,8,9	Torch Applied Walls Primed	Glass Fibre Reinforced (Non-Woven) SBS Modified Bitumen
II	4	10,11,12	Torch Applied Walls Primed	Glass Fibre Reinforced (Non-Woven) SBS Modified Bitumen
I	5	13,14,15	Adhesive Applied Walls Primed	Self Adhesive Bitumen with Modified Thermoplastic Polymers.
I	6	16, 17, 18	Adhesive Applied Walls Primed	Adhesive faced Bituthane sheet membrane.
II	7	19, 20, 21	Adhesive Applied Walls Primed	SBS Modified Bitumen Polyester Reinforced.
II	8	22, 23, 24	Adhesive Applied Walls Primed	Multiply Polyethylene with Polymer Modified Asphalt.
I	9	25, 26	Trowel Applied	Two component Liquid Rubber Compound (Difunctional Polybutadiene)
I	10	27, 28	Trowel Applied	One component Elastomer Bitumen.
I II	11	29, 30 40	Trowel Applied With Sheet Mem.	Solvent type Synthetic Rubber based Insulation Adhesive.
I	12	31, 32	Trowel Applied	Bitumen Based Cold Adhesive.
I	13	33, 34, 35	Mechanically Fastened	Three ply laminate sheet, PVC coated polyester scrim fabric.
II	14	36, 38	Mechanically Fastened	Coated, Steel Reinforced Extruded Polystyrene Panel(s).

Sample Masonry Air Barrier Membranes (Continued)

Test Phase	Sample No.	Wall Nos.	Type	Description
II	15	41	Spray-Applied	Summer Application polyurethane foam insulation/air barrier.
II	16	42	Spray-Applied	Winter Application polyurethane foam insulation/air barrier.
II	17	43	Spray-Applied	Low Flame Spread polyurethane foam insulation/air barrier.

3.2. TEST PROCEDURES

Testing was carried out using the procedures outlined below with the apparatus shown in Figure 1. As illustrated, the test sample was sandwiched between a chamber and perimeter clamping frame with the membrane facing the open side of the chamber. For the evaluation the closed cell neoprene gasket on the face of the chamber was compressed onto the barrier to provide the edge seal. The neoprene seal was supplemented with high vacuum grease to insure the seal integrity and prevent lateral leakage. Both the air leakage and wind load testing were then conducted using negative pressure differentials. For the air leakage tests, air permeates the membrane from the interior or wall side to the exterior or chamber side and air leakage through the block back-up wall is not considered a variable. Using this configuration only air leakage through the membrane demarcated by the compressed edge seal gasket is measured. For the block wall with no membrane, the procedure was modified to prevent lateral leakage. In this case, a continuous air impermeable membrane was applied to the entire wall, with the exception of a 1 m^2 opening on the front and rear surfaces. For the determination of air leakage of the wall, the opening on the rear surface of the wall was first masked with a double layer of polyethylene and the extraneous membrane leakage over a 0 to 100 Pa pressure range was measured. The polyethlyene was then removed and the total leakage recorded over the same pressure range. The air leakage of the wall was then determined by subtracting the extraneous membrane leakage from the total leakage.

3.2.1 Air Leakage

The air leakage testing was carried out in accordance with the procedure outlined in ASTM E283 "Standard Test Method for Rate of Air Leakage Through Exterior Windows, Curtain Walls and Doors". Air leakage through each membrane was measured over a range of pressure differentials between 25 and 500 pascals (Pa) using a mass flow transducer (Hastings Model HFM200-H, Serial No. 351, Flow Range 0-0.08 l/s or Datametrics Model 1205, Serial No. 3590, Flow Range 0-2.50 l/s) in conjunction with a computer / data acquisition system combination. Both flow meters are calibrated routinely using a Buck Calibrator. Pressure differentials were measured using an electronic micromanometer (Air Instrument Resources Limited, Model MP3KDS, Serial No. 3260, Resolution 0.1 Pa). This instrument is calibrated routinely by the manufacturer. To establish equilibrium at each test pressure differential the air leakage was measured over a period of five minutes at each pressure point. The recorded air leakage rates were then plotted and a regression line analysis of data conducted to determine the variables outlined in the flow curve equation:

$$Q/A = C \cdot \Delta P^n$$

Where:

Q = volume flow rate of air

A = leakage area

C = flow coefficient, volumetric flow rate per unit area per unit pressure difference.

n = flow exponent characteristic of laminar (~ 1.0) or turbulent (~ 0.5) flow.

From the regression analysis of the data, the calculated air leakage was deemed non-detectable when the correlation coefficient between measured and calculated data was < 0.98. In the absence of a published set of criteria each barrier was then classified as Type I, II, or III for comparative purposes.

3.2.2 Membrane Adhesion Under Gust Wind Load.

The adhesion testing was carried out using a procedure similar to that described in ASTM E330, "Standard Test Method for Structural Performance of Exterior Windows, Curtain Walls and Doors by Uniform Static Pressure Difference". For the gust wind simulation, each sample was subjected to a -3000 Pa pressure difference for a period of approximately ten (10) seconds.

During the testing the differential movement of the membrane and substrate were visually monitored. Upon completion of each test, the membrane was inspected for areas of delamination and/or cracking. Where delamination of the membrane had occurred the delaminated area was demarcated, removed from the substrate,weighed and the area of delamination determined by integration[1]. The percent delamination was then calculated according to the following equation:

$$\% \text{ Delamination} = \frac{\text{Area of Delamination}}{\text{Total Membrane Area}} \times 100$$

[1] Upon removal of the delaminated membrane, white paint was applied the exposed block to increase contrast between the substrate and membrane for subsequent photographs.

An indication of non-visible membrane damage was determined by repeating the air leakage test at a 75 Pa pressure differential.

As previously stated, failure of the membrane was deemed to have occurred if the air leakage at 75 Pa > 0.15 $l \cdot s^{-1} \cdot m^{-2}$ or % delamination > 15% of total area.

3.2.3 Membrane Adhesion Under Sustained Wind Load.

The sustained wind load testing was carried out in the same manner using a negative pressure difference of 1000 Pa applied for a period of one (1) hour.

Again after completion of test, the membranes were visually inspected for areas of delamination and/or cracking and the air leakage test at 75 Pa repeated and failure of the membrane was indicated if the air leakage at 75 Pa > 0.15 $l \cdot s^{-1} \cdot m^{-2}$ or % delamination > 15% of total area.

3.2.4 Membrane Uniformity.

The applied thickness of the test membranes (where applicable) were measured using a depth gage or digital calipers depending on the membrane type. These values were then compared to the thicknesses specified in the specification literature provided by each manufacturer. Measured thickness was used as an indication of the test sample versus specified thickness for installation.

3.2.5 Membrane Creep under Stack Effect Load

For the samples applied to walls incorporating a gap the membrane creep test was carried out in the same manner used for the gust and sustained wind loads using a negative 250 Pa pressure differential applied for a period of 24 hours. Over this period mid-span deflection of the membrane was periodically measured and at the conclusion of the test the membrane was visually inspected for areas of delamination, damage or deformation not measured during the test.

4. TEST RESULTS

The results of the air leakage and wind load testing are provided in the following sections and in Tables A-1 Appendix A. A representative plot of air leakage versus pressure differential for the block wall substrate without an installed air barrier is given in Figure 2. Post test photographs of a number of representative samples have also been included in Appendix B. Note that Sample

No. 5 on Walls 14 and 15, totally delaminated prior to the initial air leakage testing and consequently were not evaluated.

4.1 Air Leakage

Air Leakage Summary of Results

Sample No.	Block Wall Description & No.	Membrane Application	Flow Coefficient C (l/s/m²) Calculated	Flow Exponent n Dimensionless Calculated	Initial Air Leakage ΔP=75 Pascals (l/s/m²) Calculated	Barrier Type Proposed
0	Brick Tie Wall-37	No Membrane	2.22E-02	0.9233	11956.3E-04	N.A.
1	Plain Wall-1	Thermofused	2.80E-05	0.6053	3.82E-04	III
	Brick Tie Wall-2	Thermofused	56.5E-05	0.8216	196.0E-04	III
	Gap Wall-3	Thermofused	Non-Detect.	Non-Detect.	Non-Detect.	III
2	Plain Wall-4	Thermofused	0.11E-05	1.0800	1.16E-04	III
	Brick Tie Wall-5	Thermofused	1.80E-05	0.8969	8.65E-04	III
	Gap Wall-6	Thermofused	Non-Detect.	Non-Detect.	Non-Detect.	III
3	Plain Wall-7	Thermofused	Non-Detect.	Non-Detect.	Non-Detect.	III
	Brick Tie Wall-8	Thermofused	40.1E-05	0.7898	121.4E-04	III
	Gap Wall-9	Thermofused	Non-Detect.	Non-Detect.	Non-Detect.	III
4	Plain Wall-10	Thermofused	Non-Detect.	Non-Detect.	Non-Detect.	III
	Brick Tie Wall-11	Thermofused	89.0E-05	0.7372	214.6E-04	III
	Gap Wall-12	Thermofused	Non-Detect.	Non-Detect.	Non-Detect.	III
5	Plain Wall-13	Adhesive	4.51E-05	0.9353	25.5E-04	III
	Brick Tie Wall-14	Adhesive	Pretest Failure	Pretest Failure	Pretest Failure	N.A.
	Gap Wall-15	Adhesive	Pretest Failure	Pretest Failure	Pretest Failure	N.A.
6	Plain Wall-16	Adhesive	1.55E-05	0.7714	4.33E-04	III
	Brick Tie Wall-17	Adhesive	130.0E-05	0.8404	489.5E-04	III
	Gap Wall-18	Adhesive	2.64E-05	0.6219	3.87E-04	III
7	Plain Wall-19	Adhesive	1.41-05	0.7017	2.92E-04	III
	Brick Tie Wall-20	Adhesive	130.0E-05	0.6610	225.6E-04	III
	Gap Wall-21	Adhesive	2.18E-05	0.6574	3.72E-04	III
8	Plain Wall-22	Adhesive	N.D.	N.D.	N.D.	III
	Brick Tie Wall-23	Adhesive	200.0E-05	0.6034	270.6E-04	III
	Gap Wall-24	Adhesive	Non-Detect.	Non-Detect.	Non-Detect.	III

Air Leakage Summary of Results (Continued)

Sample No.	Block Wall Description & No.	Membrane Application	Flow Coefficient C (l/s/m²) Calculated	Flow Exponent n Dimensionless Calculated	Initial Air Leakage ΔP=75 Pascals (l/s/m²) Calculated	Barrier Type Proposed
9	Plain Wall-25	Trowel	76.1E-05	0.5595	85.2E-04	III
	Brick Tie Wall-26	Trowel	9.41E-05	0.7864	28.1E-04	III
10	Plain Wall-27	Trowel	1.77E-05	0.9697	11.6E-04	III
	Brick Tie Wall-28	Trowel	230.0E-05	0.6896	451.6E-04	III
11	Plain Wall-29	Trowel	430.0E-05	0.5340	431.3E-04	III
	Brick Tie Wall-30	Trowel	2.64E-05	0.9545	16.3E-04	III
11	Gap Wall-40	Trwl/Sht	4.36E-05	0.7922	13.3E-04	III
12	Plain Wall-31	Trowel	47.1E-05	0.8302	169.7E-04	III
	Brick Tie Wall-32	Trowel	1160.0E-05	0.6518	1934.7E-04	Fail
13	Plain Wall-33	Mechanical	6.62E-05	0.8352	24.4E-04	III
	Brick Tie Wall-34	Mechanical	14.5E-05	0.8972	69.8E-04	III
	Gap Wall-35	Mechanical	0.75E-05	0.9411	4.38E-04	III
14	Plain Wall-36	Mechanical	14.4E-05	0.9001	70.2E-04	III
	Gap Wall-38	Mechanical	11.2E-05	0.9141	58.0E-04	III
15	Plain Wall-41	Spry Applied	Non-Detect.	Non-Detect.	Non-Detect.	III
16	Plain Wall-42	Spry Applied	0.97E-05	0.8291	3.46E-04	III
17	Plain Wall-43	Spry Applied	Non-Detect.	Non-Detect.	Non-Detect.	III

N.A. : Not Applicable.

Type III Air Leakage at 75 Pascals ≤ 500.0E-04 l/s/m2

Phase II testing indicated by **Sample Numbers** in **"Bold"** typeface.

4.2 Membrane Adhesion under Gust Wind Load

Gust Wind Load Summary of Results

Sample No.	Block Wall	Membrane Description Application	Initial Air Leakage ΔP=75 Pa ($l/s/m^2$) Calculated	Post Gust Air Leakage ΔP=75 Pa ($l/s/m^2$) Measured	Membrane Delamination ΔP=3000 Pa (%) Measured	Test Result Barrier Type Proposed
1	Plain Wall-1	Thermofused	3.82E-04	2.50E-04	6.57	Pass/III
	Brick Tie Wall-2	Thermofused	196.0E-04	200.2E-04	7.43	Pass/III
	Gap Wall-3	Thermofused	Non-Detect.	Non-Detect.	2.11	Pass/III
2	Plain Wall-4	Thermofused	1.16E-04	Non-Detect.	0.00	Pass/III
	Brick Tie Wall-5	Thermofused	8.65E-04	12.3E-04	0.00	Pass/III
	Gap Wall-6	Thermofused	Non-Detect.	Non-Detect.	0.00	Pass/III
3	Plain Wall-7	Thermofused	Non-Detect.	Non-Detect.	0.00	Pass/III
	Brick Tie Wall-8	Thermofused	121.4E-04	125.1E-04	0.00	Pass/III
	Gap Wall-9	Thermofused	Non-Detect.	Non-Detect.	0.00	Pass/III
4	Plain Wall-10	Thermofused	Non-Detect.	Non-Detect.	5.90	Pass/III
	Brick Tie Wall-11	Thermofused	214.6E-04	254.0E-04	0.00	Pass/III
	Gap Wall-12	Thermofused	Non-Detect.	Non-Detect.	3.06	Pass/III
5	Plain Wall-13	Adhesive	25.50E-04	50.8E-04	~40.00	Fail
	Brick Tie Wall-14	Adhesive	Pretest Fail	Pretest Fail	100.00	N.A.
	Gap Wall-15	Adhesive	Pretest Fail	Pretest Fail	100.00	N.A.
6	Plain Wall-16	Adhesive	4.33E-04	5.80E-04	~0.5	Pass/III
	Brick Tie Wall-17	Adhesive	489.5E-04	507.2E-04	0.00	Pass/II
	Gap Wall-18	Adhesive	3.87E-04	4.40E-04	0.00	Pass/III
7	Plain Wall-19	Adhesive	2.92E-04	Non-Detect.	0.00	Pass/III
Note.	Plain Wall-19	Adhesive	2.92E-04	Non-Detect.	0.00	Pass/III
	Brick Tie Wall-20	Adhesive	225.6E-04	237.0E-04	0.00	Pass/III
	Gap Wall-21	Adhesive	3.72E-04	3.40E-04	0.00	Pass/III

Note: Membrane surface temperature raised to 33 °C.

Gust Wind Load Summary of Results (Continued)

Sample No.	Block Wall	Membrane Description Application	Initial Air Leakage ΔP=75 Pa (l/s/m^2) Calculated	Post Gust Air Leakage ΔP=75 Pa (l/s/m^2) Measured	Membrane Delamination ΔP=3000 Pa (%) Measured	Test Result Barrier Type Proposed
8	Plain Wall-22	Adhesive	Non-Detect.	Non-Detect.	2.15	Pass/III
	Brick Tie Wall-23	Adhesive	270.6E-04	285.2E-04	17.14	Fail/III
	Gap Wall-24	Adhesive	Non-Detect.	4.8E-04	9.10	Pass/III
9	Plain Wall-25	Trowel	85.2E-04	26.3E-04	0.00	Pass/III
	Brick Tie Wall-26	Trowel	28.1E-04	19.9E-04	0.00	Pass/III
10	Plain Wall-27	Trowel	11.6E-04	7.70E-04	0.00	Pass/III
	Brick Tie Wall-28	Trowel	451.6E-04	329.7E-04	0.00	Pass/III
11	Plain Wall-29	Trowel	431.3E-04	438.0E-04	0.00	Pass/III
	Brick Tie Wall-30	Trowel	16.3E-04	23.7E-04	<1.0	Pass/III
11	Gap Wall-40	Trwl/Sht	13.3E-04	23.2E-04	16.00	Fail/III
12	Plain Wall-31	Trowel	169.7E-04	211.3E-04	0.00	Pass/III
	Brick Tie Wall-32	Trowel	1934.7E-04	1823.0E-04	<0.5	Pass/Fail
13	Plain Wall-33	Mechanical	24.4E-04	20.0E-04	0.00	Pass/III
	Brick Tie Wall-34	Mechanical	69.8E-04	77.0E-04	0.00	Pass/III
	Gap Wall-35	Mechanical	4.38E-04	10.1E-04	0.00	Pass/III
14	Plain Wall-36	Mechanical	70.2E-04	71.0E-04	0.00	Pass/III
	Gap Wall-38	Mechanical	58.0E-04	50.9E-04	0.00	Pass/III
15	Plain Wall-41	Spry-Applied	Non-Detect.	Non-Detect.	0.00	Pass/III
16	Plain Wall-42	Spry-Applied	3.5E-04	5.8E-04	0.00	Pass/III
17	Plain Wall-43	Spry-Applied	Non-Detect.	Non-Detect.	0.00	Pass/III

Phase II testing indicated by **Sample Numbers** in **"Bold"** typeface.

4.3 Membrane Adhesion under Sustained Wind Load

Sustained Wind Load Summary of Results

Sample No.	Block Wall Description / No.	Membrane Application	Initall Air Leakage ΔP=75 Pa ($l/s/m^2$) Calculated	Post Sustained Air Leakage ΔP=75 Pa ($l/s/m^2$) Measured	Air Barrier Delamination Sust/(Total) (%) Measured	Test Result Barrier Type Proposed
1	Plain Wall-1	Thermofused	3.82E-04	3.50E-04	7.42/(13.99)	Pass/III
	Brick Tie Wall-2	Thermofused	196.0E-04	202.0E-04	0.00/(7.43)	Pass/III
	Gap Wall-3	Thermofused	Non-Detect.	Non-Detect.	0.00/(2.11)	Pass/III
2	Plain Wall-4	Thermofused	1.16E-04	0.8E-04	0.00/(0.00)	Pass/III
	Brick Tie Wall-5	Thermofused	8.65E-04	8.4E-04	8.32/(8.32)	Pass/III
	Gap Wall-6	Thermofused	Non-Detect.	Non-Detect.	0.00/(0.00)	Pass/III
3	Plain Wall-7	Thermofused	Non-Detect.	Non-Detect.	3.74/(3.74)	Pass/III
	Brick Tie Wall-8	Thermofused	121.4E-04	126.1E-04	0.00/(0.00)	Pass/III
	Gap Wall-9	Thermofused	Non-Detect.	Non-Detect.	2.00/(2.00)	Pass/III
4	Plain Wall-10	Thermofused	Non-Detect.	Non-Detect.	35.86/(41.76)	Fail/III
	Brick Tie Wall-11	Thermofused	214.6E-04	230.0E-04	3.80/(3.80)	Pass/III
	Gap Wall-12	Thermofused	Non-Detect.	Non-Detect.	29.67/(32.73)	Fail/III
5	Plain Wall-13	Adhesive	25.50E-04	266.0E-04	~60.00/(100)	Fail/III
	Brick Tie Wall-14	Adhesive	Pretest Fail	Pretest Fail	100.00	Fail
	Gap Wall-15	Adhesive	Pretest Fail	Pretest Fail	100.00	Fail
6	Plain Wall-16	Adhesive	4.33E-04	2.70E-04	~0.5/(<1)	Pass/III
	Brick Tie Wall-17	Adhesive	489.5E-04	541.1E-04	0.00/(0.00)	Pass/II
	Gap Wall-18	Adhesive	3.87E-04	5.40E-04	0.00/(0.00)	Pass/III
7	Plain Wall-19	Adhesive	2.92E-04	Non-Detect.	0.00/(0.00)	Pass/III
	Plain Wall-19	Adhesive	2.92E-04	Non-Detect.	0.00/(0.00)	Pass/III
	Brick Tie Wall-20	Adhesive	225.6E-04	237.0E-04	0.00/(0.00)	Pass/III
	Gap Wall-21	Adhesive	3.72E-04	71.0-138E-04	0.00/(0.00)	Pass/III

Sustained Wind Load Summary of Results (Continued)

Sample No.	Block Wall Description / No.	Membrane Application	Initail Air Leakage ΔP=75 Pa (l/s/m^2) Calculated	Post Sustained Air Leakage ΔP=75 Pa (l/s/m^2) Measured	Air Barrier Delamination Sust/(Total) (%) Measured	Test Result Barrier Type Proposed
8	Plain Wall-22	Adhesive	Non-Detect.	Non-Detect.	19.50/(21.65)	Fail/III
	Brick Tie Wall-23	Adhesive	270.6E-04	2488.3E-04	40.99/(58.13)	Fail/Fail
	Gap Wall-24	Adhesive	Non-Detect.	5.1E-04	27.36/(36.46)	Fail/III
9	Plain Wall-25	Trowel	85.2E-04	Non-Detect.	0.00/(0.00)	Pass/III
	Brick Tie Wall-26	Trowel	28.1E-04	11.8E-04	0.00/(0.00)	Pass/III
10	Plain Wall-27	Trowel	11.6E-04	9.1E-04	0.00/(0.00)	Pass/III
	Brick Tie Wall-28	Trowel	451.6E-04	267.6E-04	0.00/(0.00)	Pass/III
11	Plain Wall-29	Trowel	431.3E-04	448.0E-04	0.00/(0.00)	Pass/III
	Brick Tie Wall-30	Trowel	16.3E-04	22.8E-04	< 1.0/(<1.0)	Pass/III
11	Gap Wall-40	Trwl/Sht	13.3E-04	5151.7E-04	29.70/(45.70)	Fail/Fail
12	Plain Wall-31	Trowel	169.7E-04	258.2E-04	0.57/(0.57)	Pass/III
	Brick Tie Wall-32	Trowel	1934.7E-04	1908.0E-04	< 0.5/(<0.5)	Pass/Fail
13	Plain Wall-33	Mechanical	24.4E-04	19.0E-04	0.00/(0.00)	Pass/III
	Brick Tie Wall-34	Mechanical	69.8E-04	77.0E-04	0.00/(0.00)	Pass/III
	Gap Wall-35	Mechanical	4.38E-04	96.0E-04	0.00/(0.00)	Pass/III
14	Plain Wall-36	Mechanical	70.2E-04	70.3E-04	0.00/(0.00)	Pass/III
	Gap Wall-38	Mechanical	58.0E-04	50.1E-04	0.00/(0.00)	Pass/III
15	Plain Wall-41	Spry Applied	Non-Detect.	Non-Detect.	0.00/(0.00)	Pass/III
16	Plain Wall-42	Spry Applied	3.5E-04	3.5E-04	0.00/(0.00)	Pass/III
17	Plain Wall-43	Spry Applied	Non-Detect.	Non-Detect.	0.00/(0.00)	Pass/III

Phase II testing indicated by **Sample Numbers** in **"Bold"** typeface.

4.4 Membrane Creep under Stack Effect Load

Membrane Creep under Stack Effect Load Summary of Results

Sample No.	Block Wall	Membrane Description Application	Maximum Membrane Deflection (mm)	Membrane Damage Visible	Test Result Barrier Type
1	Gap Wall-3	Thermofused.	0.38	None	Pass/III
2	Gap Wall-6	Thermofused.	0.60	None	Pass/III
3	Gap Wall-9	Thermofused.	1.52	None	Pass/III
4	Gap Wall-12	Thermofused.	2.53	None	Pretest Fail./III
5	Gap Wall-15	Adhesive	Pretest Fail.	N.A.	Pretest Fail.
6	Gap Wall-18	Adhesive	0.43	None	Pass/III
7	Gap Wall-21	Adhesive	2.47	None	Pass/III
8	Gap Wall-24	Adhesive	Omitted	N.A.	N.A.
11	Gap Wall-40	Trwl/Sht	Pretest Fail.	N.A.	N.A.
13	Gap Wall-35	Mechanical	0.10	None	Pass/III
14	Gap Wall-38	Mechanical	0.03	None	Pass/III

Air leakages monitored during the evaluation did not reveal any appreciable increase in air leakage.

Phase II testing indicated by **Sample Numbers** in **"Bold"** typeface.

4.5 Membrane Uniformity

Sample No.	Membrane Description Application	Manufacturers Specified Thickness (mm)	Sample Measured Thickness (mm)	Maximum Deviation (mm)
1	Thermofused.	3.00±0.200	3.34±0.396	+ 0.536
2	Thermofused.	3.00±0.200	3.07±0.029	0.00
3	Thermofused.	2.50	2.75±0.119	+ 0.369
4	Thermofused.	2.70	2.49±0.023	- 0.233
5	Adhesive	1.00	1.08±0.025	+ 0.105
6	Adhesive	Unavailable	1.21±0.118	N.A.
7	Adhesive	1.00	1.41±0.045	+ 0.455
8	Adhesive	1.00	1.29±0.052	+ 0.342
9	Trowel	1.50	1.98±0.25	+ 0.730
10	Trowel	1.0 (minimum)	3.25±0.95	+ 3.200
11	Trowel	0.90 (minimum)	7.37±6.40	+ 12.87
	Sheet	1.50	1.10±0.099	- 0.490
12	Trowel	Unavailable	7.00±5.00	N.A.
13	Mechanical	0.457	0.390±0.010	-0.077
14	Mechanical	76.2	74.5±2.96	- 4.96
15	Spray Applied	50.8	51.4±6.72	+ 7.30
16	Spray Applied	50.8	54.3±8.32	+ 11.82
17	Spray Applied	50.8	53.2±11.21	+ 13.61

4.6 Prescriptive Data Summary

The prescriptive data provided by each manufacturer is outlined in the following table. Note that only the test standards (when supplied) have been included. As the intent of the investigation is to determine the degree of continuity of the information provided by the membrane manufacturers, the prescriptive test results have not been included.

Prescriptive Data Summary Table

Test Description	Applicable Standard	Sample Number 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15 16 17
Breaking Strength	CGSB 37-GP-56M (ASTM D412/D751)	√	√			√								√		
Ultimate Elongation	CGSB 37-GP-56M (ASTM D412/D751)	√	√	√	√	√	√	√	√	√	√			√		
Cold Bending	CGSB 37-GP-56M (ASTM D146)	√	√	√	√	√	√	√	√							
Softening Point	ASTM D3686	√	√			√										
Static Puncture	CGSB 37-GP-56M	√	√			√	√									
Tensile Strength	ASTM D412 ASTM C1623			√	√	√	√	√	√	√	√				√	√
Cycling over Crack (-26 °C)	Manufacturers Modified ASTM C836						√		√							
Cycling over 25 mm Crack (-26 °C)	Manufacturers Modified ASTM C836						√		√							
Peel Adhesion	Manufacturers Method	√	√		√	√	√		√				√			√
Puncture Resistance Blunt Object	ASTM E154					√	√		√							
Puncture Resistance Sharp Object	ASTM D781						√		√							
100% Modulus	ASTM D412									√						
Hardness	ASTM D2240									√						
Tear Strength	ASTM D624 DIN 53859									√						
Tear Resistance	Federal Std. 191 Method 5136 UEAtc par. 5.4.1					√								√		
Shear Strength	ASTM C273															√

Prescriptive Data Summary Table (Continued)

Test Description	Applicable Standard	Sample Number 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15 16 17
Water Vapour Transmittance	ASTM E96			√	√		√	√	√	√	√	√		√		√
Environmental Resistance	Not Listed									√						
Cold Resistance	Federal Std. 191 Method 5136													√		
Water Absorption	ASTM D1288 ASTM D2842						√							√		√
Flammability	MVS 302/Not Listed										√	√		√		
Chemical Resistance	Not Listed									√	√	√				
Recovery	CGSB 37-GP-M86										√					
Extensibility After Heat Aging	ASTM C836										√					
Coating Adhesion	ASTM D751													√		
Aging (Long Term Flexibility)	CGSB 71-GP-24M				√							√				
Fatigue Strength	Man. Method 100,000 cycl over gap				√											
High Temp. Creep	Loaded Membrane at 48 °C.				√											
Dimensional Stability	CGSB 37-GP-M86 Modified ASTM D2126				√											√
Flame Spread	CAN/ULC S102 CAN/ULC S127															√
Density	ASTM D1622															√
Open Cell Content	ASTM D2856															√
Thermal Conductivity	ASTM C518															√

5. DISCUSSION

With respect to the evaluation of membrane air leakage before and after the gust and sustained wind load testing the results of the testing show that the air leakages of the membranes were extremely low over the range of pressure differentials used. In fact for some of the membranes, great difficultly was experienced in obtaining stable flow rates due to variations in barometric pressure during the evaluation. Coupled with the systematic determinate and indeterminate errors associated with the test instrumentation and standard calculation methods employed, the reported leakage rates for the membranes with leak rates less than 0.001 l/s/m^2 should only be viewed as reasonable estimates of the order of magnitude of air leakage rather than absolute values.

From the results of the initial air leakage evaluations it is apparent that for the majority of the forty one samples tested, the air leakage rates at a 75 Pascal pressure differential were far lower than the proposed 0.05 l/s/m^2 maximum rate for Type III air barriers. In fact 26 % of the membranes exhibited no detectable leakage over the range of pressure differentials employed for the air leakage evaluation. Initially the air leakages at a 75 Pascal pressure differential ranged from;

- Non-detectable (50%) to 0.02 l/s/m^2 for the torch applied membranes.
- Non-detectable (17%) to 0.05 l/s/m^2 for the adhesive applied membranes.
- 0.0012 to 0.05.l/s/m^2 (with one sample membrane at 0.190.l/s/m^2) for the trowel applied membranes.
- 0.0002 l/s/m^2 to 0.007 l/s/m^2 for the mechanically fastened systems.
- Non-detectable (67%) to 0.0004 l/s/m^2 for the spray-on polyurethane samples.

It is also interesting to note that the substrate and membrane cure period differences (torch, adhesive and mechanical) for the first and second phase of the program did not appear to influence the initial air leakage rates recorded.

For all of the membranes evaluated (excluding the mechanically fastened and spray-on polyurethane systems), the inclusion of brick ties had an affect on the air leakage of the walls. For 82 % of the brick tie walls the membrane air leakage rates were higher than those recorded for the membranes on plain wall substrates. The remaining trowel applied membranes showed a reduction in air leakage when applied to a brick-tie wall.

In characterizing the type of flow exhibited by the masonry air barrier membranes evaluated, the overall average dimensionless flow exponent, n calculated for all of the walls indicates that the air flow through the membranes is a combination of laminar ($n \leq 1$) and turbulent flow ($n \geq 0.5$), with $n_{avg.} = 0.79$. Further analysis of the data shows that:

- For the torch applied membranes, 67% $n > 0.75$, and 33% $n < 0.75$, with $n_{avg.} = 0.82$.
- For the adhesive applied membranes, 22% $n > 0.75$, and 78% $n < 0.75$, with $n_{avg.} = 0.71$.
- For the trowel applied membranes, 56% $n > 0.75$, and 44% $n < 0.75$, with $n_{avg.} = 0.82$.
- For the mechanically fastened systems, 100% $n > 0.75$, with $n_{avg.} = 0.85$.
- For the one spray-on polyurethane sample $n = 0.85$.

For the air leakage rates measured after the gust load tests, the results clearly illustrate that the membranes were, for the most part unaffected. For the gust wind load only one membrane failed to meet the Type III requirements with the remaining barriers showing no change (19% of the walls), a marginal increase (47% of the walls) or decrease (31% of the walls) in measured air leakage rate. This is of particular interest for the trowel applied membranes as past evaluations have demonstrated that some membranes show a significant increase in air leakage after being subjected to a gust wind load. Although it cannot be definitively stated, the fact that the air leakage rate of these membranes did not change after the gust load is believe to be due to the two month membrane curing period prior to testing. No trowel membranes were evaluated in the second phase of testing.

With respect to the post sustained wind load air leakage rates recorded, again the majority of walls were unaffected. In this case, one membrane failed to meet the air leakage requirements (i.e. air leakage at 75 Pa was > $0.15\ l \cdot s^{-1} \cdot m^{-2}$) with the remaining barriers showing no change (23% of the walls), a marginal increase (44% of the walls) or decrease (33% of the walls) in measured air leakage rate.

For the wind load evaluations the results of the testing indicate that both the gust and sustained wind load conditions selected were sufficient to demonstrate the effects of wind loading on the adhesion of air barriers applied to masonry walls.

When subjected to the -3000 Pascal pressure differential for a period of ~10 seconds, 28 % of the membranes tested showed some evidence of delamination ranging between <0.5% and 7.5%, with an additional three (8 %) of the membranes showing appreciable delamination (> 15 %). Once again differences in the results between Phase I (one failure) and II (two failures) were difficult to assess.

The results of the sustained wind load testing were much more dramatic than the gust load evaluation results. In this case, 55% of the membranes showed some evidence of delamination during the 1 hour sustained wind load evaluation at a 1000 Pascal pressure differential. Of these membranes 44% showed delamination ranging between 0.5% to 8 % delamination and 11% failed the test with membrane delamination ranging between 27% to 60%. In comparing differences in the results between Phase I and II, there may be some significance to the fact that all four failures occurred in Phase II. Within the scope of the program this may be an indication that the wall and membrane curing periods are of prime importance, although this is not supported by the results of the air leakage, gust and stack testing. It is interesting to note that for one of the membranes (Membrane No. 6 - Wall 16), despite the total 100% delamination observed, the air leakage rate of the membrane did not increase substantially. The remainder of the membranes were not affected by the sustained wind load.

The membrane creep load evaluation, carried out on the air barriers applied to the walls which incorporated a 50 mm x 910 mm gap (Walls-3, 6, 18, 35) showed that all of the membranes tested were not affected by the conditions employed. No evidence of permanent deformation, damage or delamination under a 250 Pascal pressure difference for a period of 24 hours was observed. Maximum membrane mid-span deflections ranged between 0.03 mm and 2.53 mm. Air leakages monitored during the tests demonstrated that the air leakage of the membranes was not affected by the creep load conditions. For Sample Number 8, the delaminated areas of the membrane were accidentally removed after the sustained wind load testing. For this reason it was omitted from the stack effect evaluation.

From a comparison of the measured thicknesses of the applied membranes with those provided by the manufacturers only one membrane (16 total) was within the specified tolerance. Of the remaining membranes eleven were over and four were under the thickness given in the manufacturers product literature.

The examination of the prescriptive data provided by the manufacturers was considered to be a cursory overview and requires further analysis. In reviewing the prescriptive data compiled for all of the membranes it is apparent that, of the twenty-eight tests listed, by far the highest percentage of quoted testing relates to the strength characteristics of the membrane materials. In addition the review indicates that a high percentage (71%) of the manufacturers quote water vapour transmittance data as many of these materials are marketed as vapour retarders. For the remainder of the tests listed there is little continuity in the information supplied and for many of the air barriers evaluated, the prescriptive data specifically relates to roofing membranes. In addition where a specific characteristic is evaluated, the test methods given differ between manufacturers. This makes product comparison difficult. Further, in some cases the test methods given have been modified again making product cross-comparison difficult. Overall the review indicates that the prescriptive data provided by air barrier manufacturers does not provide an adequate means of evaluating the prescriptive properties of an air barrier. This is an important point in that those properties such as water vapour transmittance, resistance to water leakage, aging etc. are of prime concern and should be uniformly addressed.

6. CONCLUSIONS & RECOMMENDATIONS

From the review of the information outlined in this report and through consultation with the participating manufacturers and contractors the following comments and recommendations were viewed appropriate.

- The ASTM E283 "Standard Test Method for Rate of Air Leakage Through Exterior Windows, Curtain Walls and Doors", method employed for the evaluation for the determination of air leakage for masonry air barriers, was viewed acceptable. Using this method air leakage over a range of pressure differentials to provide flow coefficient and flow exponent data is appropriate in view of the low air leakages rates characteristic of these materials.
- In the absence of an alternative means of classifying air barrier leakages the Type I, II, III classification system proposed by the National Research Council (NRC) was considered an appropriate means of rating masonry air barriers for air leakage. Although the values associated with these categories are higher than those of the majority of membranes

evaluated, consideration should be given to the fact that the test process is conducted under ambient laboratory temperature and humidity conditions. Actual "in situ" conditions may have a profound influence on the membrane air leakage properties which may more closely align actual air leakages to the values proposed. This however requires further investigation in either a laboratory or field setting.

- The ASTM E330, "Standard Test Method for Structural Performance of Exterior Windows, Curtain Walls and Doors by Uniform Static Pressure Difference", was deemed an appropriate method to evaluate the structural and adhesive properties of the "as installed" membranes under gust, sustained and stack load conditions. Further work to determine the effect of pretest wall and membrane curing times is indicated by the result of the evaluation.
- The gust and sustained wind load conditions employed for the evaluation provided an adequate means of assessing the comparative, "as installed" performance of masonry air barriers. To more adequately address actual field performance further consideration should be given to the wind load levels and application periods selected.
- The stack effect load conditions require further analysis to determine the suitability of the load period. Based on the results of this evaluation, the stack effect test not appear to affect the performance of masonry air barriers.
- The review of the prescriptive data provided by the membrane manufacturers indicates an unacceptable degree of variability in information exists in the industry. Further work to assess the applicability of the procedures listed is required.
- From consultation with the participants of the project, there is a consensus that a performance standard for masonry air barriers should be developed. This standard would include both performance and prescriptive requirements for masonry air barriers and could be written using the research information currently being compiled by CMHC. Additionally it is recommended that the data outlined in this report be reviewed by a representative cross-section of the masonry air barrier industry to assess its usefulness and identify areas of future work in this area.

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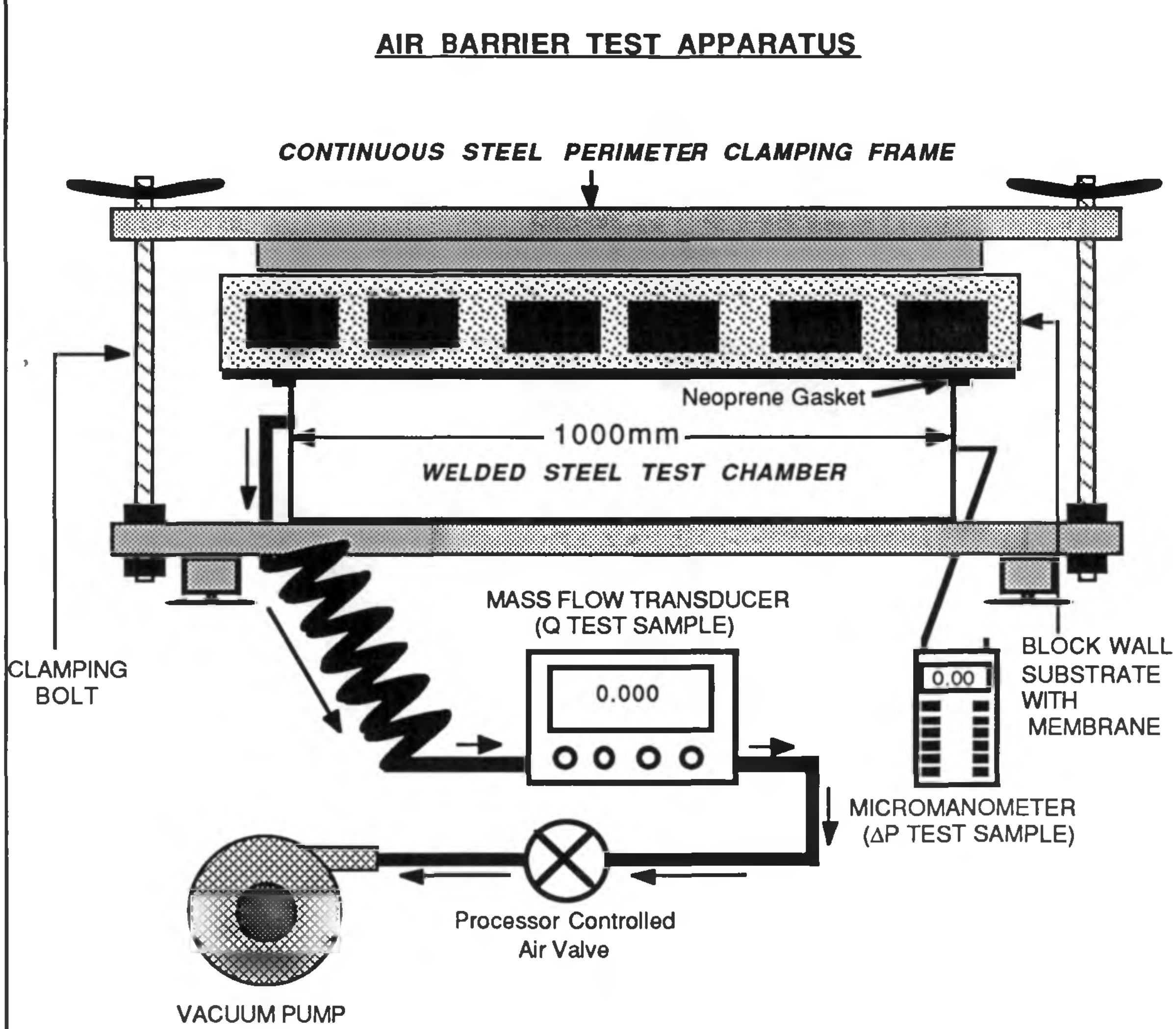

ORTECH INTERNATIONAL	
Drawing No.: 005	Invent. No.: 07973
Contr act.: DWS	02/02/83
Scale: 1:10	**Air Barrier Apparatus BPC**
Dwg by: G.Hildebrand	Date: 09/10/88

Figure 1

Air Barrier Test Apparatus

Wall No. 37 Brick Tie Wall - No Air Barrier

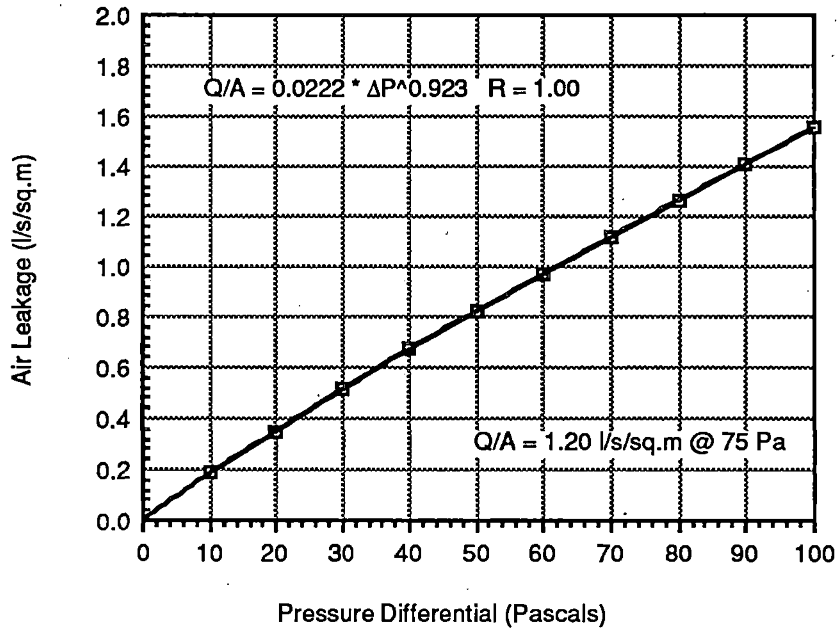

Figure 2.

Appendix A
Summary of Results

AIR BARRIER PERFORMANCE EVALUATION SUMMARY TABLE

Sample No.	Block Wall Description & No.	Membrane Application	Performance Data: Flow Coefficient C (l/s/sq.m)	Flow Exponent n (Dimensionless)	Initial Air Leakage ΔP=75 Pascals (l/s/sq.m)	Post Gust Air Leakage ΔP~75 Pascals (l/s/sq.m)	Post Sustained Air Leakage ΔP~75 Pascals (l/s/sq.m)	Air Barrier Delamination (%)	Creep Load Deflection (millimeters)	Air Barrier Thickness (millimeters)
0	Brick Tie Wall-37	No Membrane	2.22E-02	0.9233	1.19563	N/A	N/A	N/A	N/A	N/A
1	Plain Wall-1	Thermofused	2.80E-05	0.6053	0.00038	0.00025	0.00035	13.99	N/A	3.34 ± 0.396
	Brick Tie Wall-2	Thermofused	5.65E-04	0.8216	0.01961	0.02002	0.0202	7.43	N/A	3.34 ± 0.396
	Gap Wall-3	Thermofused	Non-detectable	Non-detectable	Non-detectable	Non-detectable	Non-detectable	2.11	0.38	3.34 ± 0.396
2	Plain Wall-4	Thermofused	1.09E-06	1.0800	0.00012	Non-detectable	7.97E-05	0.00	N/A	3.07 ± 0.029
	Brick Tie Wall-5	Thermofused	1.80E-05	0.8969	0.00087	0.00123	0.00084	8.32	N/A	3.07 ± 0.029
	Gap Wall-6	Thermofused	Non-detectable	Non-detectable	Non-detectable	Non-detectable	Non-detectable	0.00	0.60	3.07 ± 0.029
3	Plain Wall-7	Thermofused	Non-detectable	Non-detectable	Non-detectable	Non-detectable	Non-detectable	3.74	N/A	2.75 ± 0.119
	Brick Tie Wall-8	Thermofused	4.01E-04	0.7898	0.01214	0.01251	0.01261	0.00	N/A	2.75 ± 0.119
	Gap Wall-9	Thermofused	Non-detectable	Non-detectable	Non-detectable	Non-detectable	Non-detectable	2.00	1.52	2.75 ± 0.119
4	Plain Wall-10	Thermofused	Non-detectable	Non-detectable	Non-detectable	Non-detectable	Non-detectable	41.76	N/A	2.49 ± 0.023
	Brick Tie Wall-11	Thermofused	8.90E-04	0.7372	0.02147	0.02540	0.02301	3.80	N/A	2.49 ± 0.023
	Gap Wall-12	Thermofused	Non-detectable	Non-detectable	Non-detectable	Non-detectable	Non-detectable	32.73	2.53	2.47 ± 0.040
5	Plain Wall-13	Adhesive	4.51E-05	0.9353	0.00256	0.00508	0.02660	100.00	N/A	1.08 ± 0.025
	Brick Tie Wall-14	Adhesive	Pretest Failure	Pretest Failure	Pretest Failure	Pretest Failure	Pretest Failure	100.00	N/A	1.08 ± 0.025
	Gap Wall-15	Adhesive	Pretest Failure	Pretest Failure	Pretest Failure	Pretest Failure	Pretest Failure	100.00	N/A	1.08 ± 0.025
6	Plain Wall-16	Adhesive	1.55E-05	0.7714	0.00043	0.00058	0.00027	< 1.00	N/A	1.21 ± 0.118
	Brick Tie Wall-17	Adhesive	1.30E-03	0.8404	0.04895	0.05072	0.05411	0.00	N/A	1.21 ± 0.118
	Gap Wall-18	Adhesive	2.64E-05	0.6219	0.00039	0.00044	0.00054	0.00	0.43	1.21 ± 0.118

AIR BARRIER PERFORMANCE EVALUATION SUMMARY TABLE

Sample No.	Block Wall Description & No.	Membrane Application	Performance Data Flow Coefficient C (l/s/sq.m)	Flow Exponent n (Dimensionless)	Initial Air Leakage ΔP=75 Pascals (l/s/sq.m)	Post Gust Air Leakage ΔP~75 Pascals (l/s/sq.m)	Post Sustained Air Leakage ΔP~75 Pascals (l/s/sq.m)	Air Barrier Delamination (%)	Creep Load Deflection (millimeters)	Air Barrier Thickness (millimeters)
7	Plain Wall-19	Adhesive	1.41E-05	0.7017	0.00029	Non-detectable	Non-detectable	0.00	N/A	1.41 ± 0.045
	Plain Wall-19-2*	Adhesive	2.33E-05	0.6262	Non-detectable	Non-detectable	Non-detectable	0.00	N/A	1.41 ± 0.045
	Brick Tie Wall-20	Adhesive	1.30E-03	0.6610	0.02256	0.0237	0.0237	0.00	N/A	1.41 ± 0.045
	Gap Wall-21	Adhesive	2.18E-05	0.6574	0.00037	0.0003	0.0071-0.0138	0.00	2.47	1.41 ± 0.045
8	Plain Wall-22	Adhesive	Non-detectable	Non-detectable	Non-detectable	Non-detectable	Non-detectable	21.65	N/A	1.29 ± 0.052
	Brick Tie Wall-23	Adhesive	2.00E-03	0.6034	0.02707	0.02852	0.24883	58.13	N/A	1.29 ± 0.052
	Gap Wall-24	Adhesive	Non-detectable	Non-detectable	Non-detectable	0.00048	0.00051	36.46	N/T	1.29 ± 0.052
9	Plain Wall-25	Trowel	7.61E-04	0.5595	0.00852	0.00263	Non-detectable	0.00	N/A	1.98 ± 0.25
	Brick Tie Wall-26	Trowel	9.41E-05	0.7864	0.00281	0.00199	0.00118	0.00	N/A	1.98 ± 0.25
10	Plain Wall-27	Trowel	1.77E-05	0.9697	0.00117	0.00077	0.00091	0.00	N/A	3.25 ± 0.95
	Brick Tie Wall-28	Trowel	2.30E-03	0.6896	0.04516	0.03297	0.02676	0.00	N/A	3.25 ± 0.95
11	Plain Wall-29	Trowel	4.30E-03	0.534	0.04313	0.04380	0.04480	0.00	N/A	3.18 ± 1.0
	Brick Tie Wall-30	Trowel	2.64E-05	0.9545	0.00162	0.00237	0.00228	< 1.00	N/A	~3 to ~12
11 & Sheet	Gap Wall-40	Trowel / Adhesive Sheet	4.36E-05	0.7922	0.00133	0.00232	0.51517	45.70	Failed Sustained	7.37 ± 6.40 1.10 ± 0.099
12	Plain Wall-31	Trowel	4.71E-04	0.8302	0.01698	0.02113	0.02582	0.57	N/A	7.00 ± 5.00*
	Brick Tie Wall-32	Trowel	1.16E-02	0.6518	0.19347	0.18230	0.19080	< 0.5	N/A	7.00 ± 5.00*

AIR BARRIER PERFORMANCE EVALUATION SUMMARY TABLE

Sample No.	Block Wall Description	Membrane Application	Performance Data: Flow Coefficient C (l/s/sq.m)	Flow Exponent n (Dimensionless)	Initial Air Leakage ΔP=75 Pascals (l/s/sq.m)	Post Gust Air Leakage ΔP~75 Pascals (l/s/sq.m)	Post Sustained Air Leakage ΔP~75 Pascals (l/s/sq.m)	Air Barrier Delamination (%)	Creep Load Deflection (millimeters)	Air Barrier Thickness (millimeters)
13	Plain Wall-33	Mechanical	6.62E-05	0.8352	0.00244	0.00200	0.00190	0.00	N/A	0.390 ± 0.01
	Brick Tie Wall-34	Mechanical	1.45E-04	0.8972	0.00696	0.00770	0.00770	0.00	N/A	0.390 ± 0.01
	Gap Wall-35	Mechanical	7.54E-06	0.9411	0.00044	0.00101	0.00960	0.00	0.10	0.390 ± 0.01
14	Plain Wall-36	Mechanical with Joint	1.44E-04	0.9001	0.00700	0.00710	0.00703	0.00	N/A	74.50 ± 2.96
	Gap Wall-38	Mechanical	1.12E-04	0.9141	0.00579	0.00509	0.00501	0.00	0.03	74.50 ± 2.96
15	Plain Wall-41	Spray Applied	Non-detectable	Non-detectable	Non-detectable	Non-detectable	Non-detectable	0.00	N/A	51.38 ± 6.72
16	Plain Wall-42	Spray Applied	9.66E-06	0.8291	0.00035	0.00058	0.00035	0.00	N/A	54.27 ± 8.32
17	Plain Wall-43	Spray Applied	Non-detectable	Non-detectable	Non-detectable	Non-detectable	Non-detectable	0.00	N/A	53.21 ± 11.21

Phase I testing indicated by Sample Numbers in Plain Text.
Phase II testing indicated by Sample Numbers in Bold Text.

Appendix B

Photographs.

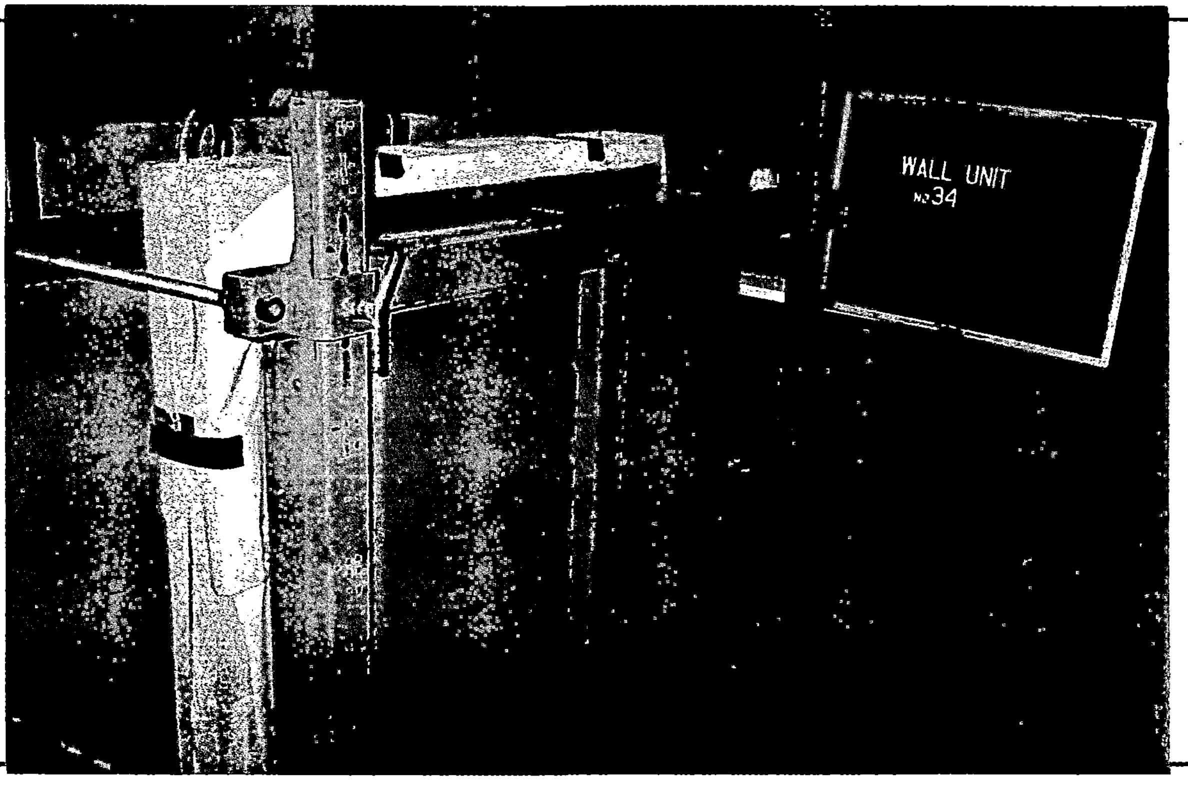

Figure B-1 View of Apparatus Installed on Barrier.

Figure B-2 Post Test View of Sample Number 1 - Thermofused Air Barrier

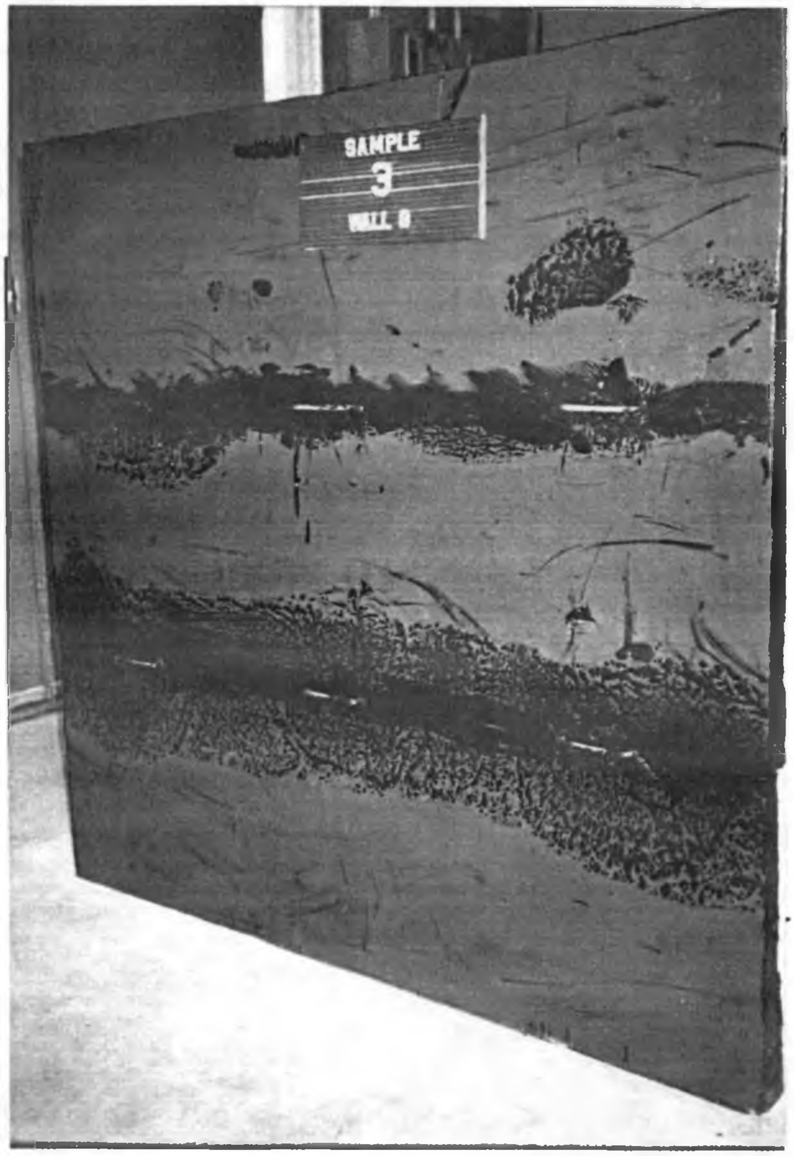

Figure B-3

Post Test View of Sample Number 3 on Brick-Tie Wall - Thermofused Air Barrier .

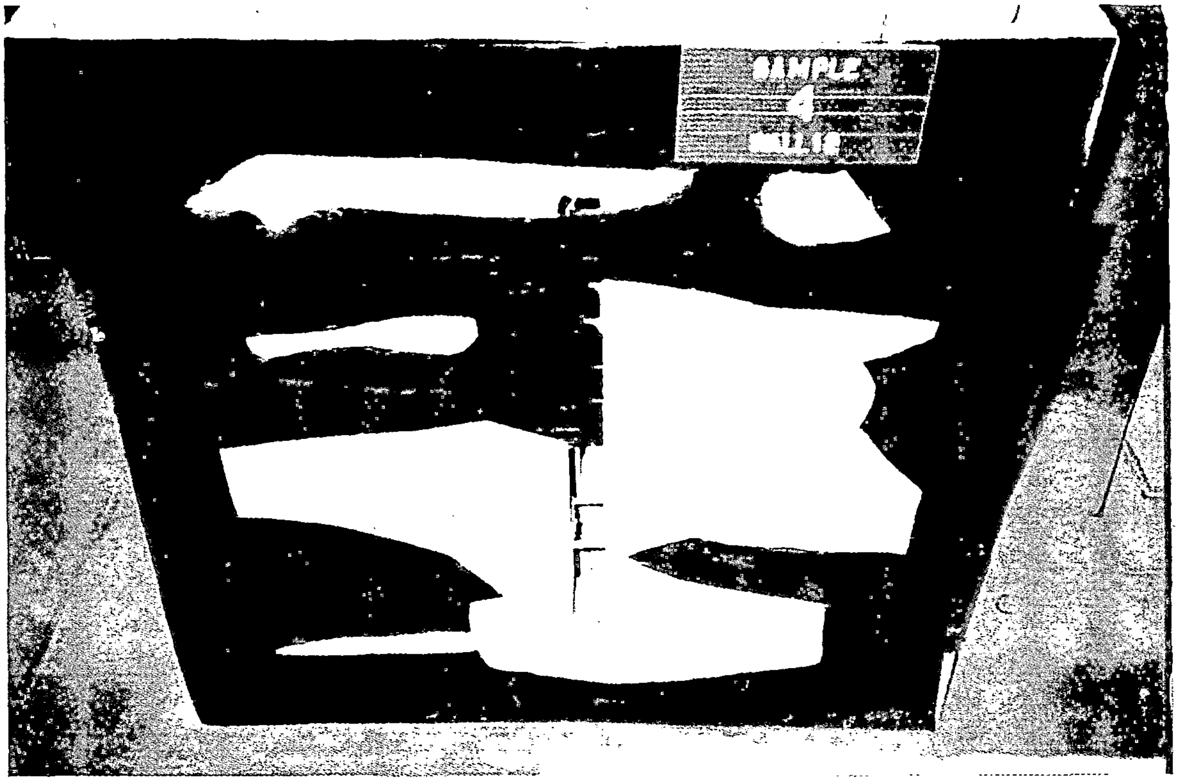

Figure B-4 Post Test View of Sample Number 4 on Gap Wall - Thermofused Air Barrier

Figure B-5 Post Test View of Sample Number 5 on Plain Wall - Adhesive Applied Air Barrier

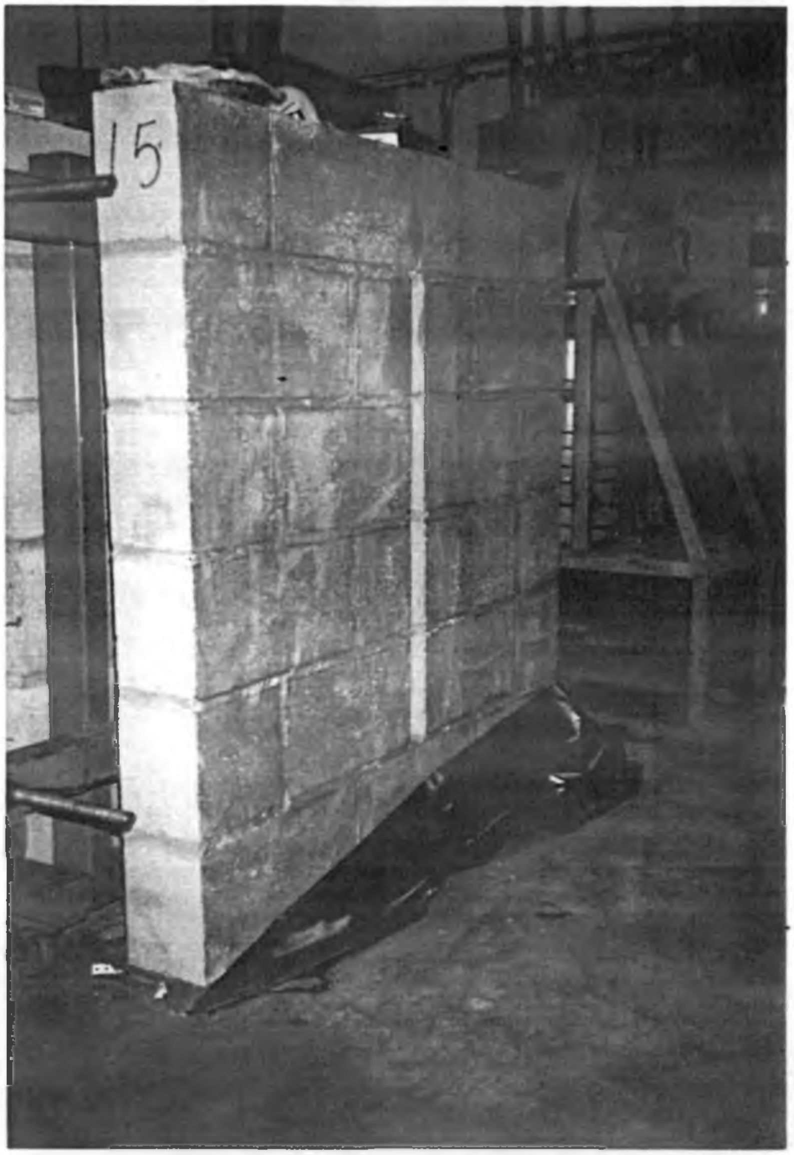

Figure B-6

Pretest View of Sample Number 5 on Gap Wall - Adhesive Applied Air Barrier .

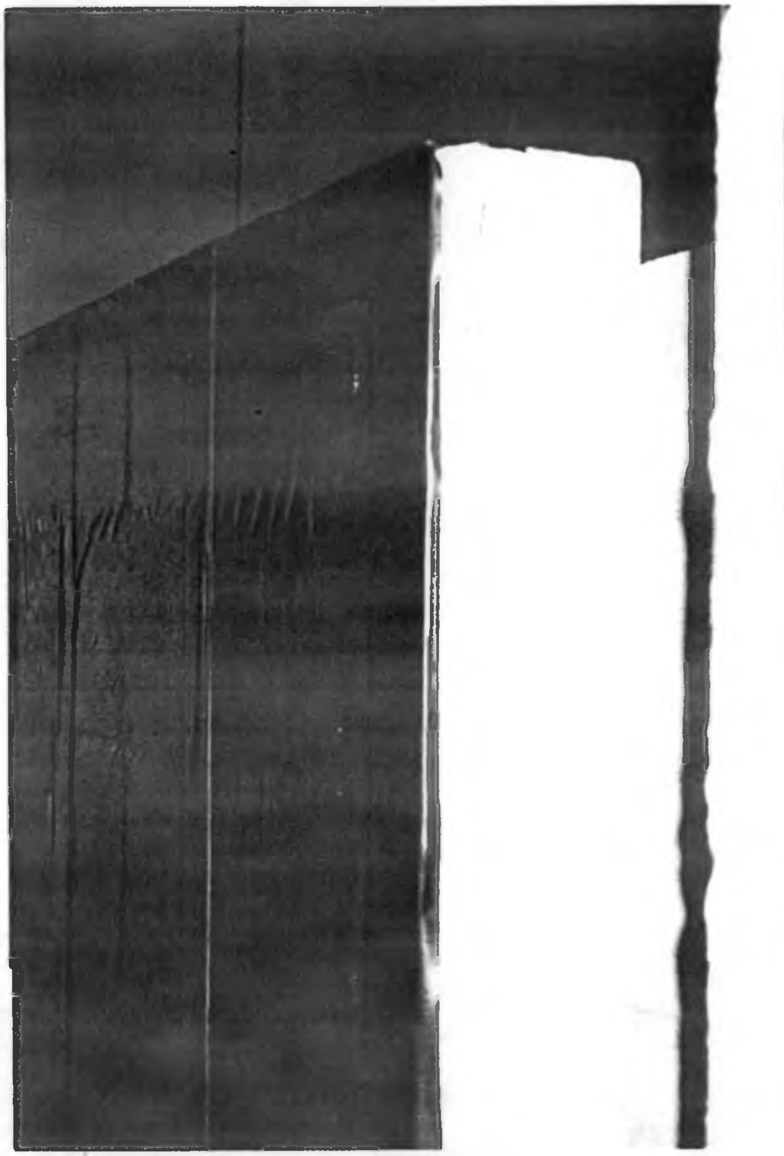

Figure B-7

Post Test View of Sample Number 6 on Plain Wall - Adhesive Applied Air Barrier .

Figure B-8

Post Test View of Sample Number 6 - Adhesive Applied Air Barrier .

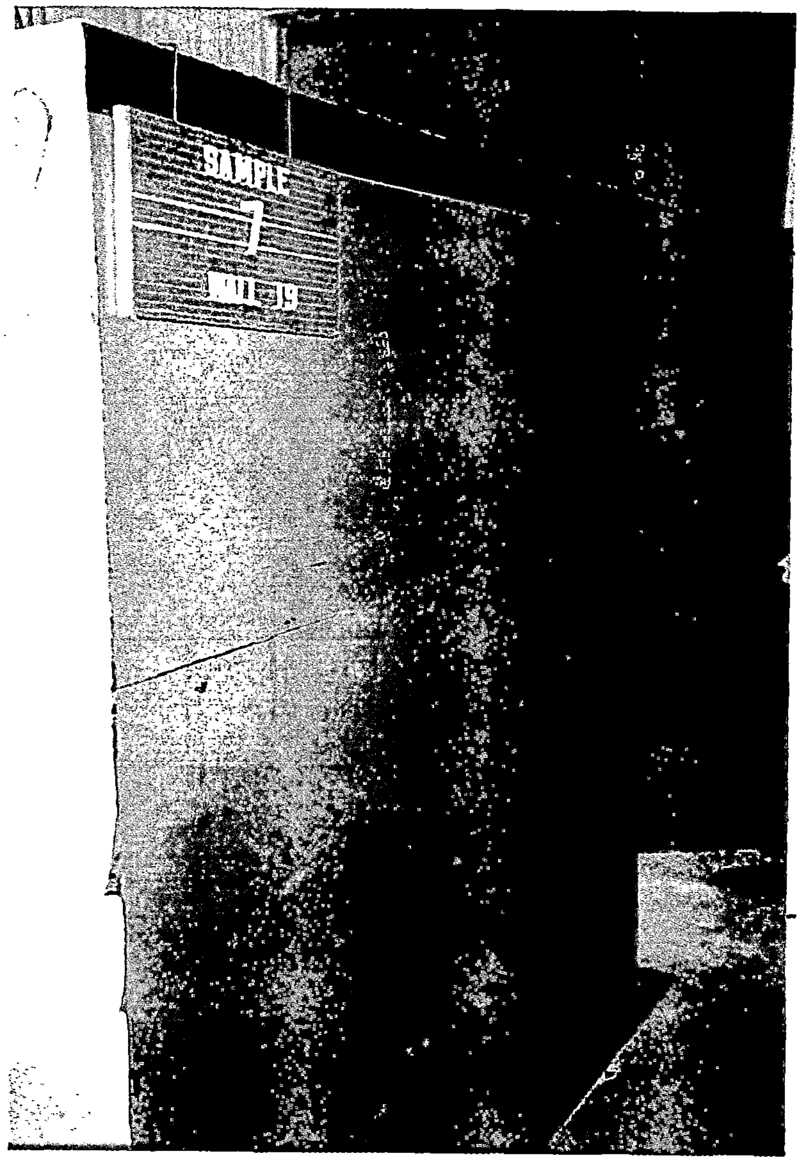

Figure B-9

Post Test View of Sample Number 7 on Plain Wall - Adhesive Applied Air Barrier .

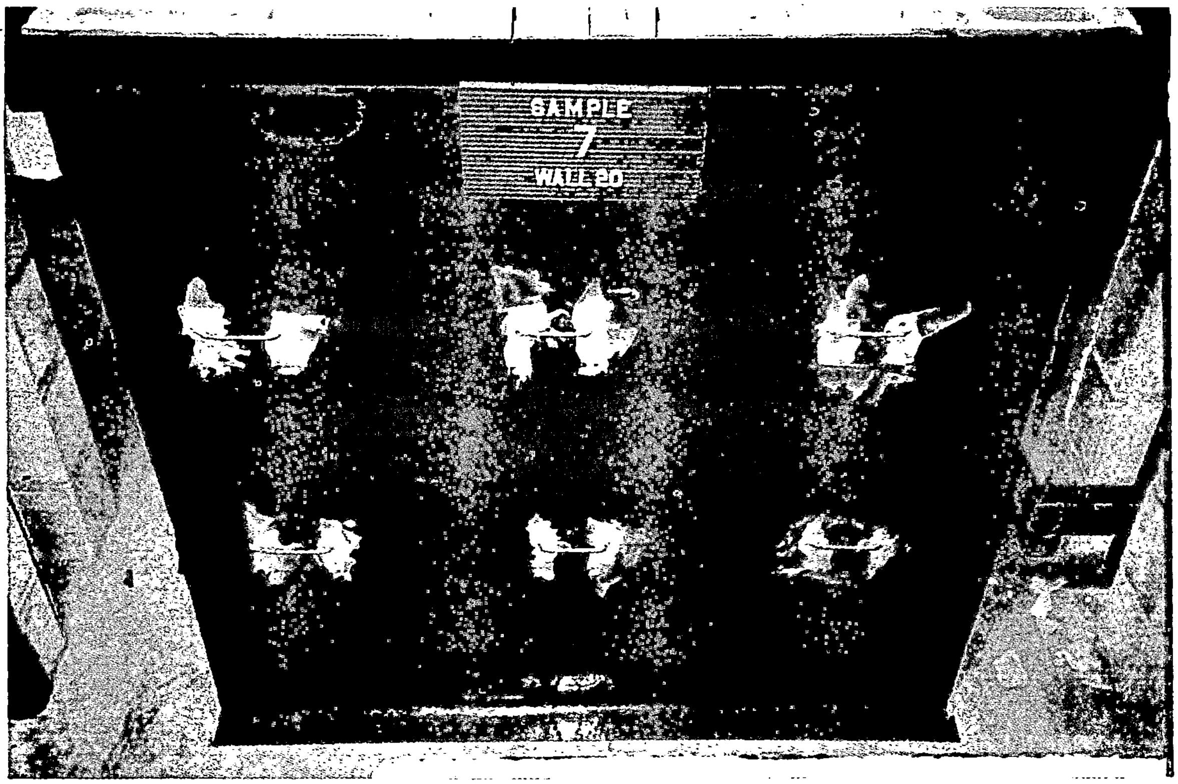

Figure B-10 Post Test View of Sample Number 7 on Brick-Tie Wall - Adhesive Applied Air Barrier

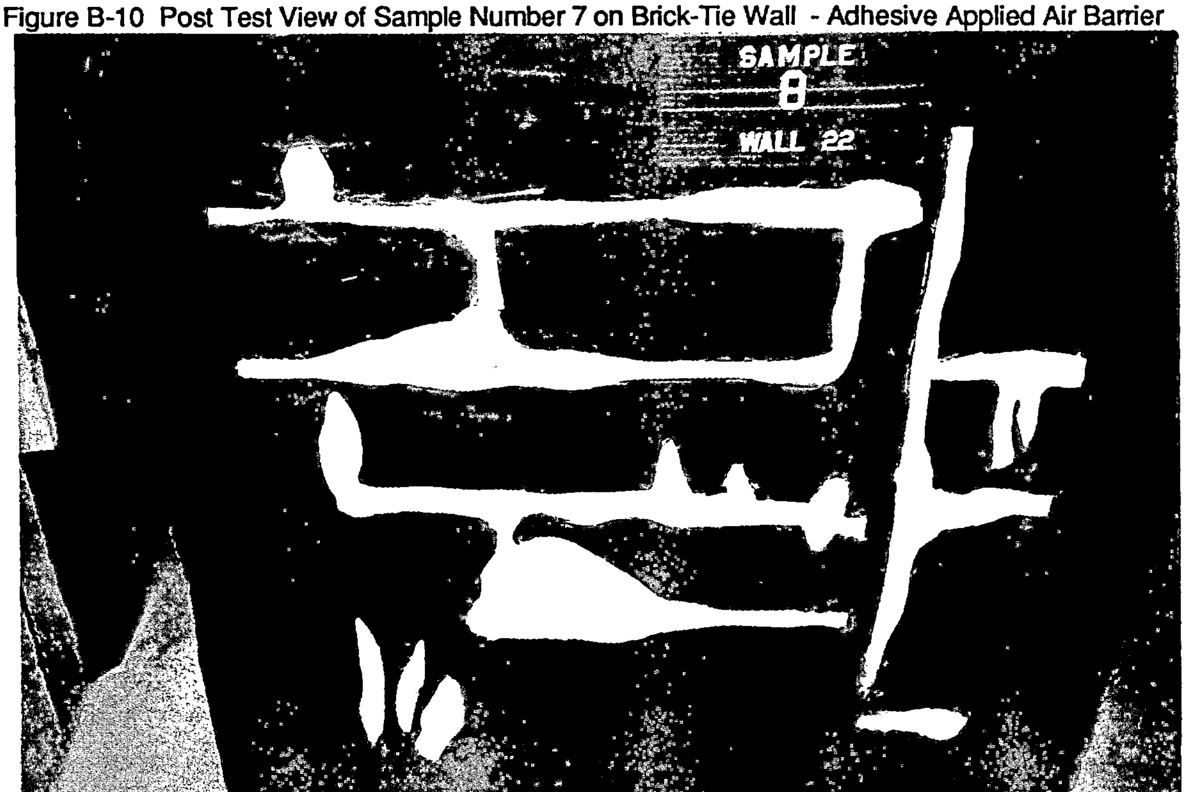

Figure B-11 Post Test View of Sample Number 8 on Plain Wall - Adhesive Applied Air Barrier

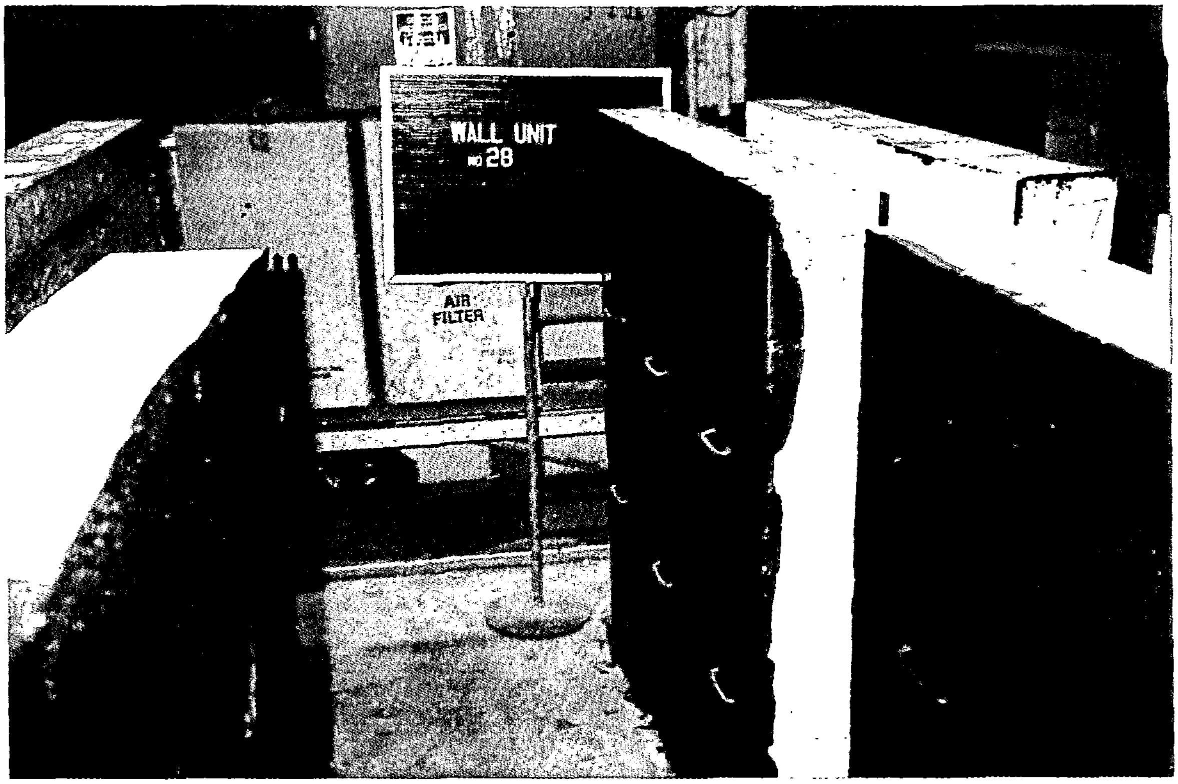

Figure B-12 Post Test View of Sample Number 10 on Brick-Tie Wall - Trowel Applied Air Barrier

Figure B-13 Post Test View of Sample Number 11 on Brick Tie Wall - Trowel Applied Air Barrier

Figure B-14

Post Test View of Sample Number 11 on Gap Wall - Trowel/ Sheet Applied Air Barrier .

Figure B-15 Post Test View of Sample Number 12 on Brick-Tie Wall - Trowel Applied Air Barrier

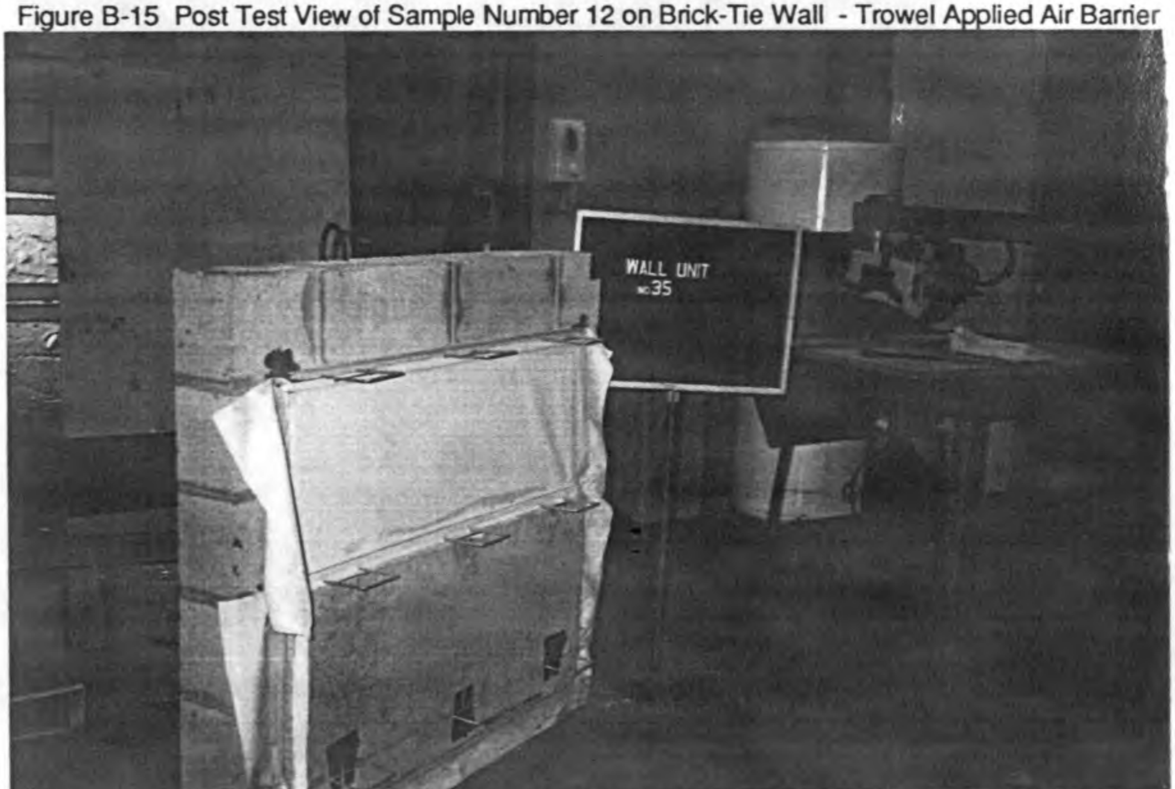

Figure B-16 Post Test View of Sample Number 13 on Brick-Tie Wall - Mechanical Applied Air Barrier

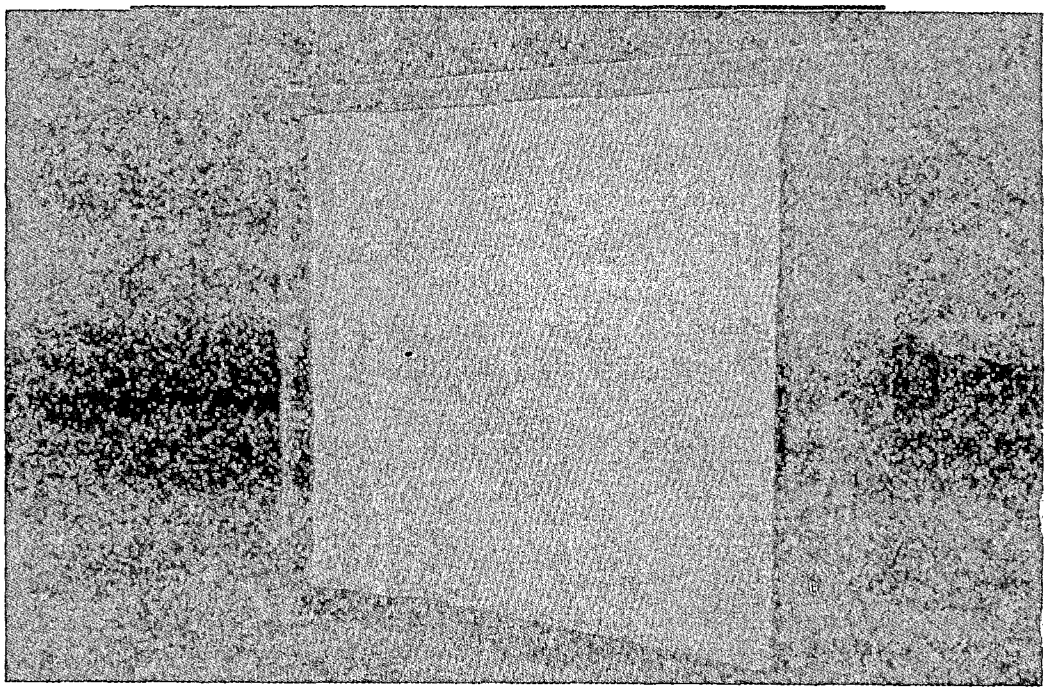

Figure B-17 Post Test View of Sample Number 16 on Plain Wall - Spray Applied Air Barrier

Appendix C

Test Instrumentation.

Test Instrumentation

Measured Variable	Instrument Employed	Accuracy
Air Flow	Hastings Flow Transducer Model HFM200-H, Serial No. 351 (0-5 Volt Output)	0.5 % of reading
Air Flow	Datametrics Flow Transducer Model 1205, Serial No. 3590 (0-10 Volt Output)	0.5 % of reading
ΔP Wall	Air Inst. Resources Ltd Micromanometer Model MP3KDS, Serial No. 3260. (0-1 Volt Output)	1 % of reading ± 1 count.
Ambient Temperature	Iron/Constantan Thermocouple with data acquisition system. EMF $\propto$ Temperature	0.5 % of reading.
Barometric Pressure	Princo Instruments Inc.Barometer Fortin Type Model 435	Not Availabe
Dew Point and R.H.	Novasina Digital Hygrometer Model MIK 3000-E	1 % of reading.
Data Acquisition	Analog Connection ACSE Model HA-ACSE-16	0.05 % of voltage reading.