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# TESTING RAINSCREEN WALL AND WINDOW SYSTEMS: THE CAVITY EXCITATION METHOD

NOTE: **DISPONIBLE AUSSI EN FRANÇAIS SOUS LE TITRE:**

ÉPREUVE DES MURS ET FENÊTRES À ÉCRAN PARE-PLUIE: LA MÉTHODE DE STIMULATION DE LA CAVITÉ

# Testing Rainscreen Wall and Window Systems: the Cavity Excitation Method

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# Executive Summary

The rainscreen principle is not new. It was proposed as early as the mid sixties by researchers of the Division of Building Research of the National Research Council of Canada and the basic principles were developed. It has been applied to certain exterior wall types but the performance of rainscreen walls remains largely unknown because of the absence of engineering data. It is only recently that interest has grown in the application of the rainscreen principle because face sealing and the drained cavity approach do not allow for the satisfactory control of moisture in construction cavities from rain or from condensation.

The rainscreen principle is well developed qualitatively but not quantitatively. There are no technical or engineering criteria to assist designers and few established prescriptions for the builder. The actual field performance of the rainscreen with respect to rain control is unknown and the relation to pressure equalization is also unknown. The Canada Mortgage and Housing Corporation (CMHC) recognized the need to undertake further research into the engineering and technology of the rainscreen principle. This project was commissioned by CMHC and Public Works Government Services Canada (PWGSC) to further advance the application of the rainscreen principle to exterior wall design and construction of both residential and commercial buildings.

This project included three distinct areas of interest. First, the development of a method to monitor the performance of existing rainscreen wall systems and to gain insight into the actual field pressure equalization performance. This work was also coupled to a laboratory investigation of the wetting and drying of a rainscreen cavity in a metal and glass curtain wall. Secondly, the development of a field performance and design compliance testing procedure. The procedure is termed the Cavity Excitation Method or CEM. It is a field test that does not require elaborate preparations and substantial mockup facilities. Third, the development of performance criteria for the design of rainscreen systems and the development of commissioning guidelines for rainscreen wall system.

This is the 2nd report of this project on rainscreen performance research. It involves both laboratory development and field testing of a new rainscreen testing procedure termed the Cavity Excitation Method (CEM). The laboratory work was undertaken in the construction laboratory of the Engineering Department of Queens University. The field work involved a building in Montreal, Quebec, "Le Clos St-André".

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# 1.0 Introduction

There are three common design approaches to rain penetration control for exterior walls and windows. These are the traditional face seal method, the cavity wall approach and the rainscreen principle. The rainscreen principle is the most current approach to long term performance and durability of walls for rain penetration control. It comprises several features among which are seals and baffles for the control of direct rain entry, the provision of capillary breaks to interrupt surface water drainage, the provision of internal flashings for drainage and weep holes and vents for a pressure equalized cladding. In addition, the inner wall cavity must be rendered airtight and the cavity must be compartmentalized.

There have been advances in research and development of the rainscreen principle and most of these were commissioned by the Canada Mortgage and Housing Corporation (CMHC). For example, there is a CMHC research project on rainscreen performance currently in progress at the National Research Council of Canada. This project is examining the effects of dynamic wind loading (sinusoidal loads at various frequencies) and water penetration control. There is also another CMHC project recently completed at Western University in London, Ontario, to study wetting patterns and the strategic locations of compartment seals. In addition, there are various private contributions of engineering data by manufacturers and a practical interest by designers in the development of a performance definition for the design of the pressure equalized wall and window systems.

While the rainscreen principle is sound conceptually and the qualitative attributes have been applied to various wall and window designs, there is little information on the quantitative aspects of its performance. For example, what level of pressure equalization is required to control rain penetration? Is there a difference in rain penetration control between a steady state wind and a gusting wind during a rain storm? How much water should be allowed to pass into the cavity or be stored in the cladding materials? How can the design be verified for performance and the construction for compliance? It is these and other questions that are explored in this study.

This study was commissioned by CMHC and Public Works Canada Government Services Canada (PWGSC). The study includes three areas of research. These are:

1) Development and testing of a monitoring method for the field performance of rainscreen wall and window systems,
2) The development of a field compliance test , the Cavity Excitation Method (CEM) for the evaluation of the construction quality of rainscreen systems,
3) A commissioning method for the design and construction of rainscreen wall and window systems.

This research report presents the findings of the second area of interest, the development of a field compliance test for a rainscreen wall and window system. The test objectives included determination of the overall air leakage areas from the venting, the compartment seals and the air barriers leaks. It also included a performance signature of the rainscreen dynamic response. The original concept was developed in the construction laboratory of Queens University, Ontario. The results of the laboratory exploration and development were used to formulate a test method that related the predicted pressure equalization performance of a rainscreen design with on the on-site compliance test results. The method has been termed the Cavity Excitation Method (CEM).

The research findings from the monitoring of rainscreen projects in the field, report no. 1, and the commissioning protocol study, report no. 3, are available from CMHC as separate reports. Report no. 1 is titled "Laboratory Investigation and Field Monitoring of Pressure Equalized Rainscreen Walls." and report no. 3 is titled "The rainscreen Wall: a Commissioning Protocol."

# 2.0 The Cavity Excitation Method

## 2.1 Rainscreen Performance Compliance

Currently, there is no simple method of assessing the performance or compliance of a new rainscreen wall system. The simplest approach remains cumbersome, expensive and intrusive of the construction process. It involves the construction of an enclosure to be attached outside of the cladding area to be tested (sometime several storeys above grade) to which an air pump, a rain rack and a system of instruments are attached . In addition, if the dynamic response is required, the chamber must be equipped with a piston or bellow suitable to reproduce frequencies and amplitudes in the range of the performance to be assessed.

For this reason an alternate method was proposed. It is believed that sufficient information about the static and dynamic performance of a rainscreen system may be obtained by using the cavity of the rainscreen system as the test chamber. It is then subjected to various air pressure and flow measurements to obtain basic leakage data and a rainscreen signature. The signature is then compared to laboratory validation data and then to the modeling results for compliance. The method is termed the Cavity Excitation Method or CEM.

To determine the feasibility of this method a laboratory exploration and development was undertaken on a conventional metal and glass curtain wall system and a subsequent field trial test was undertaken on a part of the brick veneer steel stud rainscreen wall of "Le Clos St-André" Condominium in Montreal. We examine first the laboratory development of the CEM method and then the results of the test trial on the rainscreen wall of "Le Clos St-André".

## 2.2 Laboratory Development of CEM

For the development of the CEM method, a metal and glass curtain wall sample was obtained from a Canadian curtain wall manufacturer. The sample consisted of a single bay window and spandrel assembly. Both the spandrel area and the glazing rabbet of the curtain wall sample were designed on the rainscreen principle. The development work was conducted in the construction laboratory of Queens University. The curtain wall system was mounted vertically with the spandrel section near the base and the vision glass above it (see Figures 1 and 2). The curtain wall was constructed of conventional aluminum mullions, a double glazed vision unit and a spandrel glass with metal back pan in the spandrel.

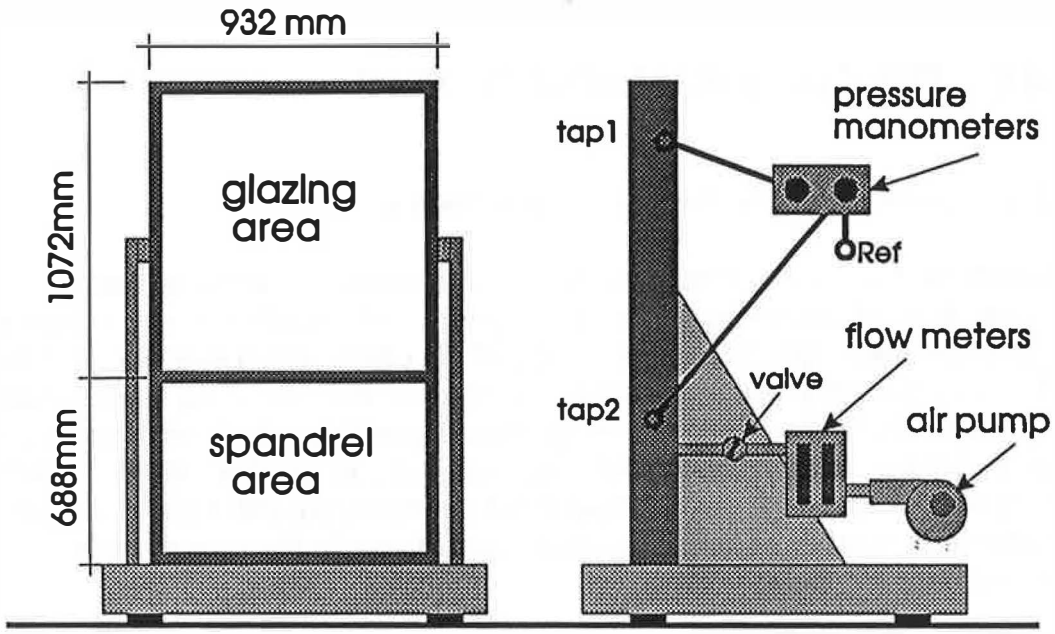



**Figure 1**
**Metal and Glass Curtain Wall Testing Facility**

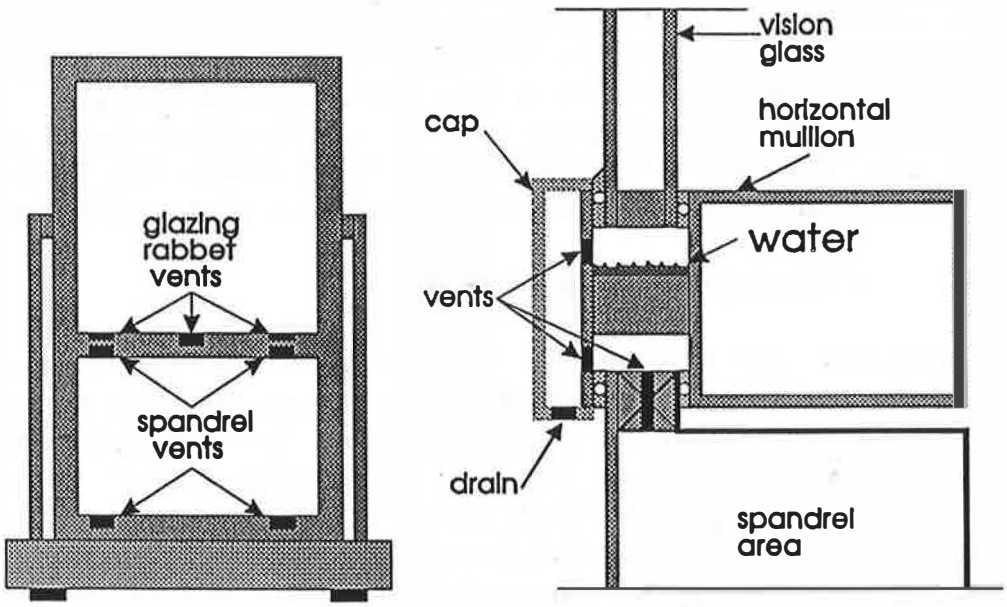



**Figure 2**
**Venting and Details**

The vision and the spandrel rainscreen cavities were equipped with vents and drains through the pressure plates and holes in the snap caps. For the purposes of this study the snap caps were removed to provide enlarged venting.

## 2.3 Equipment and Methodology

The sample curtain wall was instrumented with pressure taps (tubes) connected to the cavities of each rainscreen cavity. In addition, a connecting collar was mounted through the back pan to provide a quick connect air supply for the spandrel cavity. The rabbet space of the window cavity was also accessed through quick connect nozzles for compressed air. The pressure taps were connected in turn to electronic transducers which were read by a 486 laptop computer equipped with a data acquisition board and Labtek software. In addition, a bank of flow meters (Roto meters) were used to determine the flow of air into or out of the cavities. The flow measurements were read manually while all pressure data were read and recorded electronically.

It was determined in a previous study(1) that the performance of the rainscreen system is governed primarily by the following attributes; the cavity volume, the size of the cladding vents, the leakage area of the air barrier and the stiffness (flexibility) of the cladding and air barrier systems.

The CEM concept was developed on the basis that the rainscreen cavity could provide the required chamber and that several of the rainscreen attributes could be determined by air flow and pressure measurements. Further, it was hypothesized that part of the test could provide a signature of the rainscreen system much as a slump test for concrete provides a signature of final compressive strength. The CEM procedure was undertaken on the spandrel cavity of the rainscreen system and then on the rabbet space around the glass. The method involved four steps:

1) The cavity of the spandrel was pressurized (positive) progressively through various pressure differences and the air flows recorded and plotted. The test was repeated with vents open and vents sealed.

2) With vents sealed and the cavity pressure at its highest, the air supply was quickly shut off and the decay of the cavity pressure was recorded and plotted.

3) The cavity pressure was then reversed (negative). Procedures 1 and 2 were then repeated.

(1) *Morrison Hershfield Ltd., "A Study of the Rainscreen Concept Applied to Cladding Systems on Wood Frame Walls", August 3, 1990, 43 p., figures, Printed and distributed by Canada Mortgage and Housing Corporation, Ottawa.*

4) During the highest pressurization and before disconnecting the air pump the spandrel glass cover and the metal back pan deflections were measured.

The resulting measurements were plotted on graphs. The graphs will be found in Appendix "A".

The observed data obtained from the first part of this study was used to validate the calculation parts of the method. From the measurements of flows and pressures for both the open and sealed vents, the vent areas were calculated for comparison with the nominal areas and to obtain the total leakage area of the components surrounding the spandrel cavity. The data analysis and calculations follow.

## 2.4 Vents and Air Leakage Areas

In graphs PF1 and PF2 of Appendix "A", the vent areas (slots) were open and the flow and pressure characteristics of the spandrel cavity were measured in two ways; first, by pressurizing the cavity and second by depressurizing the cavity. In both cases, the observed data were analyzed to determine a best fit curve. Using the results of the fitted curve, the flow measured at 75 Pa indicated a leakage of $7.15 \times 10^{-3}$ $m^3/s$, for the case of PF1, and $6.97 \times 10^{-3}$ $m^3/s$, for the case of PF2, respectively, the average being 7.06 X 10-3 $m^3/s$.

In graphs PF3 and PF4 of Appendix "A", the intentional vents (slots) were closed and the system re-tested for flow and pressure characteristics. At 75 Pa, the indicated leakage rates were noted to be $3.28 \times 10^{-3}$ $m^3/s$ and $3.16 \times 10^{-3}$ $m^3/s$ respectively. The average of both flows is $3.22 \times 10^{-3}$ $m^3/s$. The results of two of these plots are reproduced in Figure 3 that follows.

From the results noted above, the effective vent area was determined and compared with the nominal (measured area of slots) vent area using the standard flow equation;

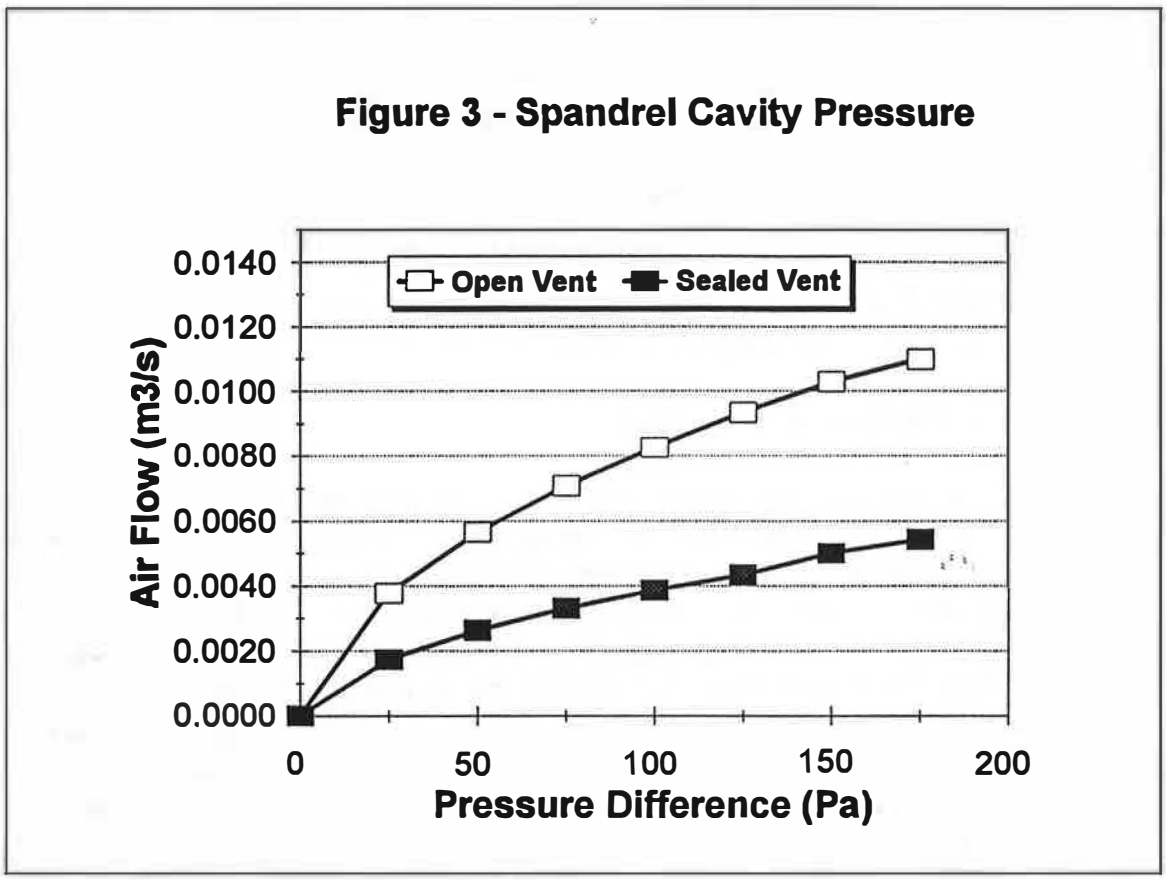
$$Va = Q / [0.61 \times (2 \times \Delta P/\rho)^n]$$

where:

| | | |
|---|---|---|
| | Va | is the vent area ($m^2$) |
| | Q | is the flow rate of air ($m^3/s$) |
| | $\Delta P$ | is the pressure difference (Pa) |
| | $\rho$ | is the density of air (1.12 $kg/m^3$) |
| | 0.61 | is a constant |
| | n | is an exponent from the fitted curve |

For the spandrel cavity with sealed vents the calculated extraneous leakage area (Ea) is;

$$Ea = 3.22 \times 10^{-3} / [0.61(2 \times 75/1.12)^{0.57}]$$
$$= 0.000320 \ m^2$$




For the spandrel cavity with vents open, the calculated vent area plus extraneous leakage area (Ta) is;

$$Ta = 7.06 \times 10^{-3} / [0.61(2 \times 75/1.12)^{0.54}]$$
$$= 0.000822 \text{ m}^2$$

If the sealed vent leakage area (Ea) of the spandrel cavity is subtracted from the total leakage area (Ta) we then obtain the calculated vent area (Va);

$$Va = Ta - Ea$$
$$= 0.000822 - 0.000320$$
$$= 0.00050 \text{ m}^2$$

The vent holes for the spandrel cavity consist of 4 slots, 2 at the bottom and 2 at the top. The bottom slots measured 6.35 mm high by 25.4 mm and the top slots measured 6.35 mm high by 34.9 mm. The holes are also rounded at each end. The computed total area of venting was 0.00077 $m^2$. Comparing the calculated vent area to the measured slot area, we find a difference of (0.00077 - 0.00050 = 0.00027 $m^2$). The difference between the two vent areas is large and while it is believed that the nominal area measurements were correct they do not account for the actual flow resistance. The air leakage path is actually obstructed behind

the vent slots by a tube like spacer bar. Therefore, it is the calculated vent area that is correct for purposes of performance and not the nominal vent area. The actual vent area is therefore 0.00050 $m^2$. This conclusion is also supported by the results of the dynamic testing explained further on.

It is noted therefore, that the flow and pressure measurements provide a simple method of determining the total leakage area of the rainscreen cavity and the effective vent area. There remains to develop a method of discriminating between the area of the vents, the compartment seals and the air barrier leakage area. This is addressed in the CEM field tests on "Le Clos St-André".

## 2.5 A Rainscreen Signature

It is believed that every rainscreen cavity has a unique signature if subjected to a pressure decay test. If the volume of the rainscreen cavity is known or easily determined from drawings and field measurements and the vent area and air leakage areas have been determined, it can be shown that the rainscreen cavity will exhibit a pressure decay rate that is unique for the particular rainscreen attributes. These attributes include the cavity volume, the air leakage areas of vents, compartments and air barriers and the flexibility conditions of the air barrier and the cladding. This decay rate can then used to determine compliance of the rainscreen attributes in the field with the design performance requirements.

The pressure decay of any volume is an exponential function. The corresponding exponents and coefficients of an exponential decay curve are easily determined by analysis. However, before analyzing the results of an exponential decay curve of a rainscreen cavity, it is important to understand a few basics related to cavity volumes and their behavior when pressurized or depressurized.

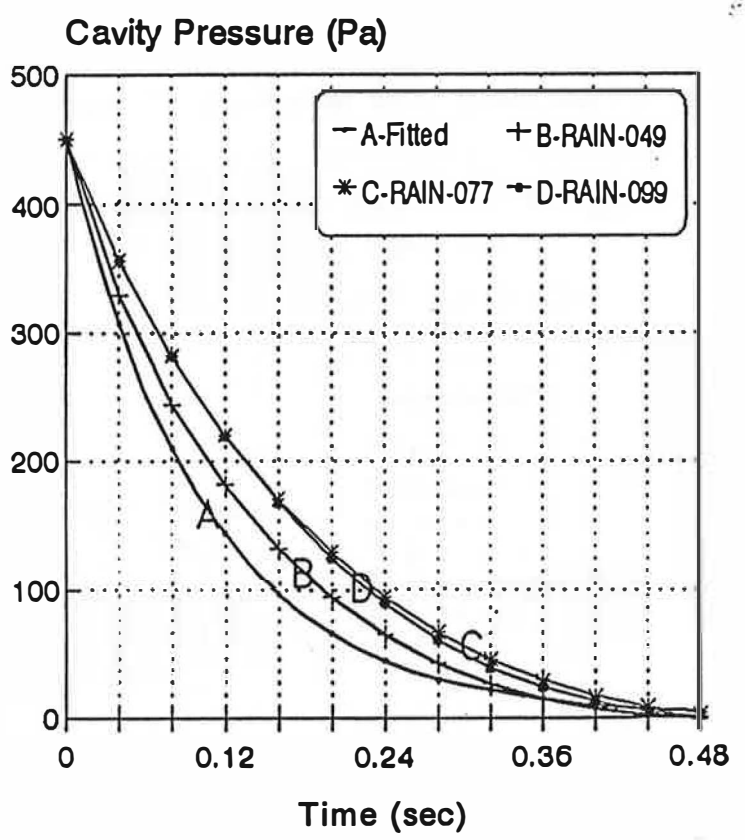
In a fixed (rigid cavity) volume, having known vent areas, the rate of pressure decay will be faster than with a cavity of the same nominal volume and vent area but bound by a flexible cladding and a flexible air barrier. This is because the decay of a pressurized cavity volume with flexible (non rigid) components will take longer to occur as it must discharge a corresponding larger volume of air than a rigid volume with the same air leakage areas.

Further, if the stiffness of the cladding and air barrier are different, there will be a corresponding difference in the dynamic performance of the rainscreen cavity when subject to a pressure load such as wind acting on the façade. For a rainscreen with a rigid cladding and a flexible air barrier, the cavity volume will pressure equalize slowly compared to a rainscreen with a flexible cladding and a rigid air barrier. However, the decay curve of both situations may be the same.

For this reason, the stiffness of the cladding and air barriers must be determined separately.

In the experimental mockup of the rainscreen curtain wall at Queens University, the spandrel area and the rabbet space of the glazing area were pressurized to a given level and then allowed to decay to atmospheric conditions. The pressure decay conditions were recorded and plotted (Graphs Pd-1 to Pd5 of appendix A). While in the pressurized state, the deflections of the spandrel glass and the metal backpan were also measured. For each decay test, the data was analyzed to determine the best fitting curve and the corresponding exponential function.

**Figure 4** - Pressure Decay of Spandrel Cavity



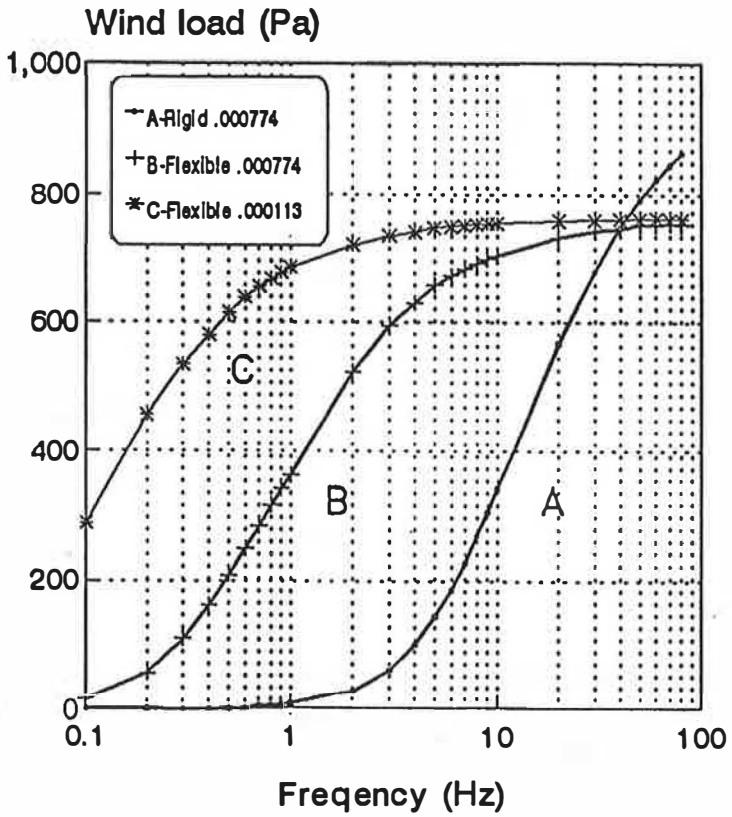

In figure 4 above, the observed decay rate of the spandrel cavity of test Pd-3 was plotted as curve A. The other 3 curves were obtained by modeling the cavity performance using different values for vent areas and component stiffness. Note that curve B is the closest fit to curve A. Curve B was obtained by modeling the spandrel cavity decay rate using the effective vent area determined

previously and by using the measured deflections of the glass and metal backpan. To demonstrate the uniqueness of this decay curve, the graph also shows 2 other curves, C and D. These curves were also obtained by modeling the spandrel cavity decay rate but with slightly different vent areas and flexibility characteristics. In curves C and D, the vent areas were selected as 0.00077 $m^2$ and 0.00099 $m^2$ respectively. For each vent area condition, the flexibility of the spandrel glass and the metal backpan were varied to obtain the closest match to curve A, the measured performance. The input data for the modeling of the rainscreen cavity for curve B provided the closest fit to the measured performance of curve A. This indicates that the modeling program Rain can be used to predict the pressure decay characteristics of a rainscreen system in the field.

## 2.6 Frequency Response ("S") Curve

From the information obtained above, the dynamic pressure equalization characteristic (frequency response) of the spandrel cavity can then derived. This representation has been termed the rainscreen "S" curve. By inputting the

**Figure 5** - Pressure Equalization Performance of Spandrel Section of Curtain Wall



measured data from the curtain wall rainscreen spandrel into the Rain V2.0 computer program, (soon to be available from CMHC) and simulating the pressure equalization performance from 0.1 Hz to 50 Hz, the pressure equalization performance of the cladding was obtained and plotted. The input data included the cavity volume, the vent area, the leakage area and the measured flexibility of the spandrel glass and the metal pan. The curtain wall rainscreen pressure equalization performance was then simulated for three conditions, a rigid volume (no flexibility), a flexible volume with the snap caps removed and a flexible volume, with the snap caps installed.

In figure 5 above, the vertical axis represents the air pressure difference across the cladding while the horizontal axis represents the wind gust frequency. Note the results at the 2 Hz frequency. This is the frequency at which the RAIN V1.0 program predicts pressure equalization performance.

The dynamic performance predicted for the three conditions noted above is highly variable. While the case of the rigid volume appears to pressure equalize at or below 5% at 2 Hz, the other two conditions indicate that the pressure equalization performance diminishes rapidly. In the case of the flexible cavity volume having a vent area of 0.00077 m2, the cladding experiences a 55% load and in the case where the vent area is limited to the small holes in the snap caps, 0.000113 m2, the cladding experiences a load of 75%. Clearly the size of the vents and the stiffness characteristics of the cladding and the backpan significantly affect the dynamic pressure equalization performance.

Using the results of the CEM decay test, it has been shown that the dynamic attributes of a curtain wall may be determined in the laboratory or in the field for comparison with the original rainscreen design. However, the method requires considerable knowledge of the structural properties of the materials and systems composing the exterior wall and of basic structural design concepts.

## 3.0 CEM Field Testing

The CEM test procedure was undertaken in the field on a rainscreen wall in a new condominium building, "Le Clos St-André", in Montreal, Quebec. "Le Clos St-André is an 8 storey building constructed with a concrete frame and an infil brick veneer steel stud rainscreen exterior wall. "Le Clos St-André" is also one of the IDEAS Challenge winners, a CMHC competition to promote the design and construction of innovative technical features in high-rise construction.

The test rainscreen wall comprised a one storey high area located on the East wall along the 7th floor (see appendix B). The section was compartmentalized horizontally along the floor and ceiling and vertically with 2 sheet steel compartment seals about 1.5 m (5 feet) apart. The exterior wall was composed as follows; exterior brick, air space (cavity), 50 mm (2") mineral fiber insulation, exterior gypsum with all joints taped with an elastomeric membrane (air barrier), 150 mm (6") steel stud with cavity insulation, polyethylene film vapour barrier and an interior gypsum board finish. The insulation in the steel stud cavity, the polyethylene film and the finish gypsum board were not installed at the time of the testing.

The CEM test was conducted on January 4, 1996, using a 1000 cfm. duct fan with flow measuring capabilities, an integral positive shutting damper, 8" flexible duct, 8" collar, ACR temperature and humidity monitoring equipment, an oscilloscope with memory storage and a smoke generator.

The fan pressurizing equipment and sensors were attached to the walls by cutting an 8" hole in the back of the air barrier gypsum board, installing cavity temperature and humidity sensors behind the brick and connecting a collar and flexible duct. The system was checked for leaks and the operation of all measuring devices were verified.

The indoor temperature was measured and found to be 15$^{o}$C while the outdoor temperature was found to be -16$^{o}$C. The indoor relative humidity was measured and found to be less than 20%. In addition, the cavity temperature between the brick and the insulation was found to be -8$^{o}$C at ambient condition. It was also noted that the exterior wall was subjected to a weak stack effect pressure of 10 to 12 Pa across the air barrier.

## 3.1 Methodology

The initial tests consisted of pressurizing the cavity to varying levels while measuring the flow rates. This measurement was undertaken repeatedly for 3 ranges of the fan equipment adapters. During one of the tests, the smoke generator was used to inject smoke into the rainscreen cavity while observers noted the locations of the smoke leakage. For the decay test the cavity pressure was raised to 100 Pa and allowed to stabilize. Then the fan pressure was quickly shut off with the intervening damper and the cavity pressure decay noted and recorded using an oscilloscope. The same test sequence was repeated with the fan operating in the depressurization mode with the exception of the smoke testing. During the depressurization tests, the flows, pressure differences, as well as the cavity temperature and humidity were also recorded.

The purpose of recording the temperature and humidity of the rainscreen cavity during the depressurization test was to obtain the psychometric information on the mixing of outdoor, cavity and indoor air. As it is not possible to obtain the individual leakage areas of the vents, compartments and the air barrier directly from a single pressure test, it was hypothesized that the temperature difference, humidity difference, wind pressure or stack effect across the exterior wall could be used as the 2nd and even 3rd variables to solve the problem. During the on-site CEM testing at "Le Clos St-André", there was a significant temperature difference and a light stack effect pressure at the top of the building. Both conditions were used in the final analysis.

## 3.2 Analysis and Results

The results of the pressurization testing were analyzed and converted to equivalent leakage areas (ELA) and plotted against the air pressure difference (Figure 6). It was found that the total leakage area of the cladding, compartments and the air barrier averaged to 0.017m$^2$ (app. 26 in.$^2$). With 4 standard weep/vent holes serving the cavity, the total vent/weep hole area was calculated to be 0.0039 m$^2$ (5.9 in.$^2$). There remained 0.0125 m2 (19 in.$^2$) to allocate between the compartment seals and the air barrier. This was determined by analyzing the results of the air flow and pressure characteristics of the cavity subjected to a light stack effect pressure and the results of the psychometric analysis.

As the leakage area of the cavity must be a constant, the change in leakage area of 0.00049 m2 (0.75 in.$^2$) at the beginning of the pressure test (Figure 6) was attributed to the neutralizing effect of the fan pressure against the stack effect. As the cavity pressure rose to be equal with the indoor pressure thereby neutralizing any leakage from inside the building to the cavity, the leakage area of the air barrier was revealed. This difference was also corroborated by the

psychometric analysis of the equilibrium conditions of the cavity air temperatures.

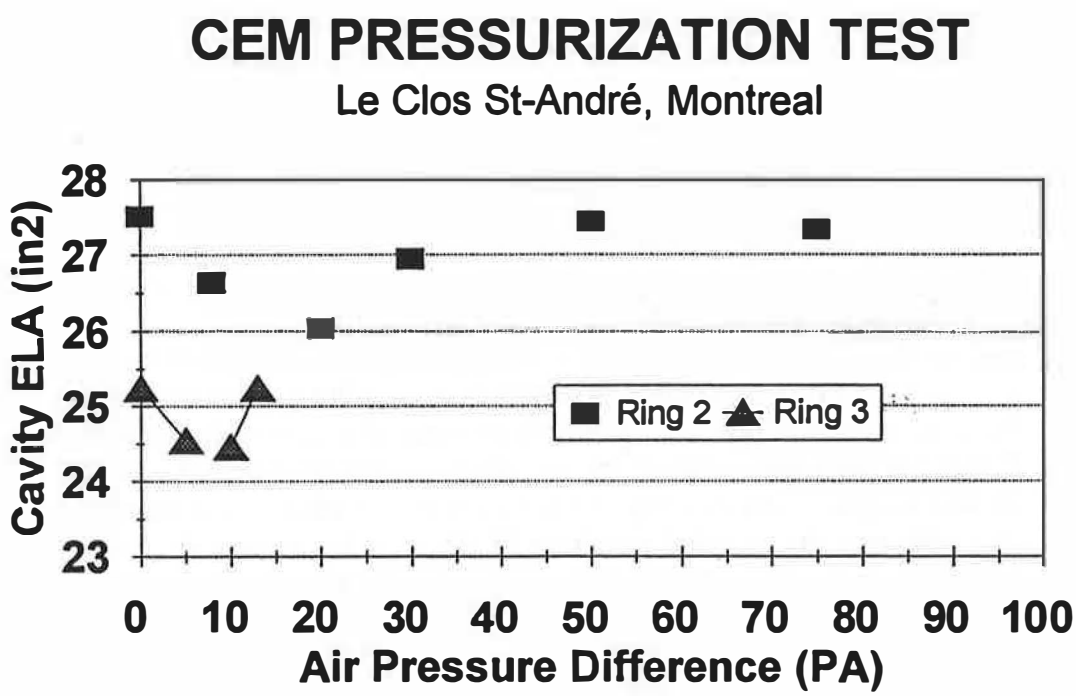



Figure 6

From this analysis and the observations of the smoke testing, it is believed that the air barrier plane in the cavity of the rainscreen area exhibits no more than 0.00049 $m^2$ (0.75 in.$^2$) of leakage area or 1.1 $cm^2/m^2$ of wall. The vent/weep area included 4 openings totaling 0.0039 $m^2$ (5.9 in.$^2$). The remaining leakage area, 0.0125 m2 (19 in.$^2$), was attributed to compartment seal leakage in the brick expansion joints. It is also noted that the large area of opening in the compartment seals is the primary cause that the cavity temperature never reached outdoor conditions during depressurization. The suction pressure drew air primarily from the adjoining cavities at -8$^o$C. This was also confirmed with the smoke test as smoke was seen exhausting from all areas adjacent to the compartment area.

In the final analysis of rainscreen wall at "Le Clos St-André", it was determined that the wall would pressure equalize satisfactorily for conditions of uniform exterior wind pressure. Specifically, the static pressure equalization should

transfer 92% of the wind load to the air barrier and 8% to the cladding. Under dynamic conditions of pressure (gusting), 2 Hz, the wind load should transfer 85% of the load to the air barrier and 15% to the cladding. When the wind pressures cause a significant gradient to occur, the pressure equalization of the cladding would greatly diminish due to the compartment seal leakage.

The field CEM tests were completed in one day. They did not require major preparations on the building and they provided all of the essential information to determine the pressure equalization performance of the rainscreen assembly.

The CEM method is best undertaken during warm or cold weather conditions to use the psychometric properties of air and to take advantage of stack effect and possibly wind pressures. As unusual as it may appear, the CEM method provides the most data during unfavorable weather conditions.

## 4.0 Conclusions and Recommendations

The CEM method was developed and applied to a rainscreen curtain wall system in the laboratory and a brick veneer rainscreen wall on a building in Montreal. It was determined that flow and pressurization measurements of the air into and out of the rainscreen cavity provided adequate information to determine the total leakage areas from the vents, the compartments and the air barrier. The CEM method was applied on site in less than one day.

It was also determined that the dynamic decay test of the CEM method provided a unique signature for a rainscreen wall, but that further work was required to better understand the effects of cladding and air barrier flexibility and to better relate the pressure decay test to the "S" curve performance.

The on site conditions of temperature, humidity and air pressures from other sources such as stack effect and wind provided sufficient information to determine the individual leakage areas of the vents, the compartment seals and the air barrier system.

The CEM method is viable and promising. It is a multi variable analysis method but simple to apply in the field. The Rain II computer program provides the designer with the CEM characteristics for field compliance. To improve reliability of the method however, we recommend the following additional research;

1) The steady state and dynamic pressure equalization performance criteria for acceptable rainscreen performance should be further researched.
2) A comparison of the results from standard test methods and the CEM method should be undertaken for comparison purposes.
3) Development of a field assessment method for the deflection of materials and assemblies is necessary for the dynamic analysis.

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# Appendix
# "A"

Laboratory Testing,
Queen's University

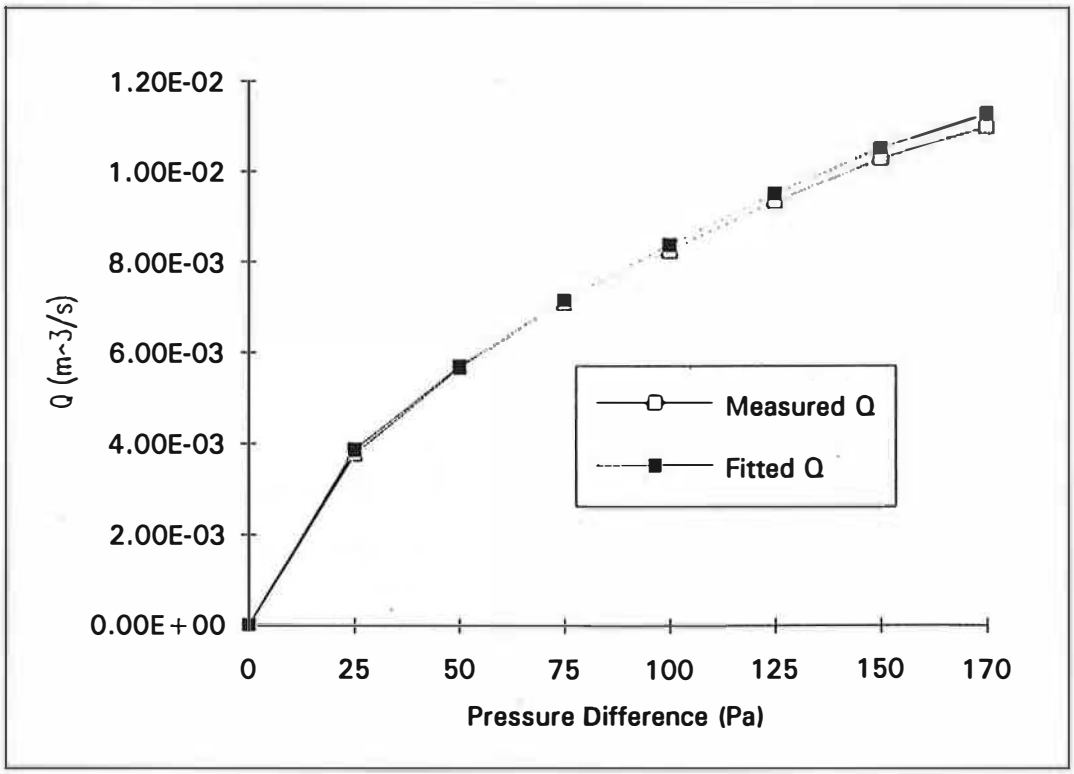
# GRAPH PF-1
# SPANDREL CAVITY PRESSURE-FLOW RELATIONSHIP

| Summary of Test Conditions | |
|---|---|
| Direction of Air Flow through Connected Source | Into Cavity |
| Vision Unit Perimeter Seal | 1 |
| External Snap Caps | Off |
| Pressure Plate Openings | |
| Area | .000774 m^2 |
| Status | Open |

**Notes to Vision Unit Perimeter Seal:**

1. **Pressure plates installed over bead of silicone sealant**
2. **Outer face of pressure plates sealed to outer side wall of mullion**

| Summary of Test Results | | | |
|---|---|---|---|
| Measured P (Pa) | Measured Q (m3/s) | Fitted Q (m3/s) | |
| 0 | 0.00E+00 | 0.00E+00 | |
| 25 | 3.78E-03 | 3.86E-03 | Equation of fitted curve: |
| 50 | 5.66E-03 | 5.70E-03 | |
| 75 | 7.08E-03 | 7.15E-03 | |
| 100 | 8.26E-03 | 8.40E-03 | Q = 6.37E-04 P^0.56 |
| 125 | 9.35E-03 | 9.52E-03 | |
| 150 | 1.03E-02 | 1.05E-02 | |
| 170 | 1.10E-02 | 1.13E-02 | |



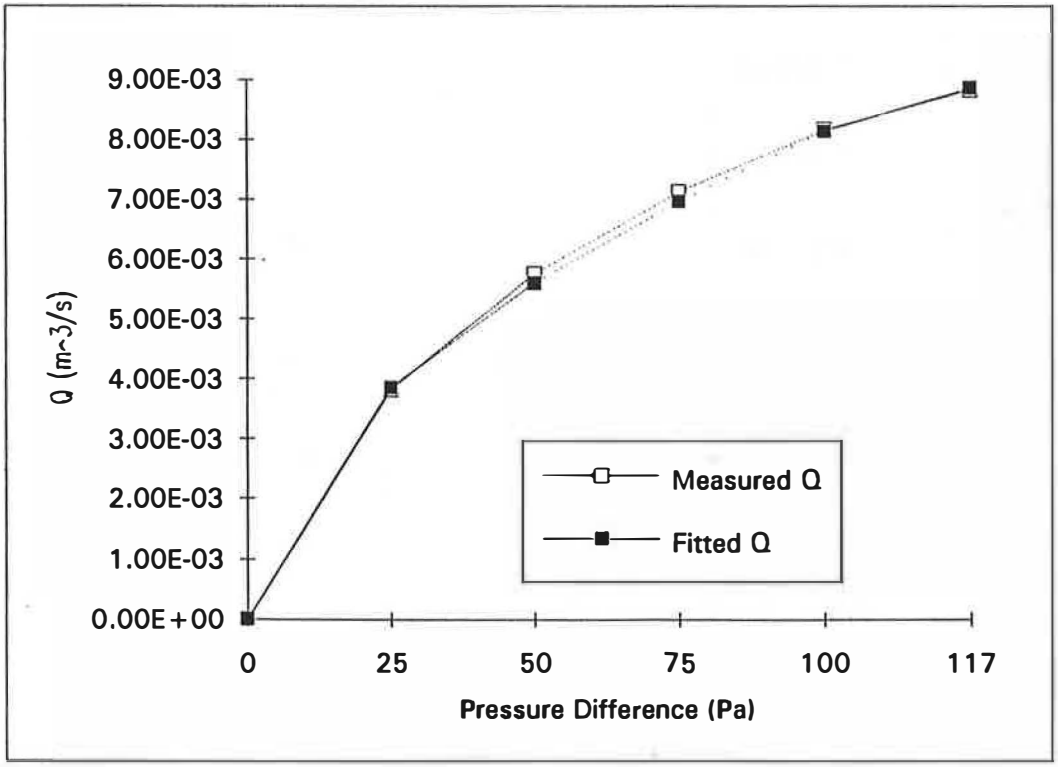
# GRAPH PF-2
# SPANDREL CAVITY PRESSURE-FLOW RELATIONSHIP

| Summary of Test Conditions | |
|---|---|
| Direction of Air Flow through Connected Source | Out of Cavity |
| Vision Unit Perimeter Seal | 1 |
| External Snap Caps | Off |
| Pressure Plate Openings | |
| Area | .000774 m^2 |
| Status | Open |

Notes to Vision Unit Perimeter Seal:

1. Pressure plates installed over bead of silicone sealant
2. Outer face of pressure plates sealed to outer side wall of mullion

| Summary of Test Results | | | |
|---|---|---|---|
| Measured P (Pa) | Measured Q (m3/s) | Fitted Q (m3/s) | |
| 0 | 0.00E+00 | 0.00E+00 | Equation of fitted curve: |
| 25 | 3.82E-03 | 3.85E-03 | |
| 50 | 5.76E-03 | 5.60E-03 | Q = 6.77E-04 P^0.54 |
| 75 | 7.13E-03 | 6.97E-03 | |
| 100 | 8.17E-03 | 8.14E-03 | |
| 117 | 8.83E-03 | 8.86E-03 | |



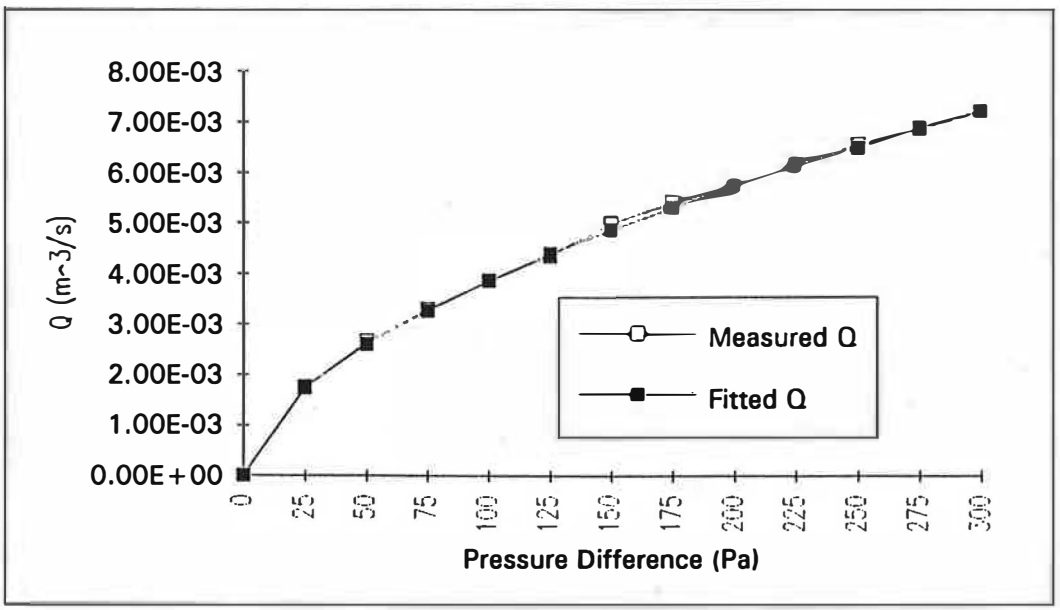
# GRAPH PF-3
# SPANDREL CAVITY PRESSURE-FLOW RELATIONSHIP

| Summary of Test Conditions | |
|---|---|
| Direction of Air Flow through Connected Source | Into Cavity |
| Vision Unit Perimeter Seal | 1 |
| External Snap Caps | Off |
| Pressure Plate Openings | |
| Area | .000774 m^2 |
| Status | Closed |

**Notes to Vision Unit Perimeter Seal:**

1. **Pressure plates installed over bead of silicone sealant**
2. **Outer face of pressure plates sealed to outer side wall of mullion**

| Summary of Test Results | | | |
|---|---|---|---|
| Measured P (Pa) | Measured Q (m3/s) | Fitted Q (m3/s) | |
| 0 | 0.00E+00 | 0.00E+00 | |
| 25 | 1.75E-03 | 1.75E-03 | |
| 50 | 2.64E-03 | 2.60E-03 | Equation of fitted curve: |
| 75 | 3.30E-03 | 3.28E-03 | |
| 100 | 3.87E-03 | 3.87E-03 | |
| 125 | 4.34E-03 | 4.39E-03 | Q = 2.80E-04 P^0.57 |
| 150 | 5.00E-03 | 4.87E-03 | |
| 175 | 5.43E-03 | 5.32E-03 | |
| 200 | 5.76E-03 | 5.74E-03 | |
| 225 | 6.18E-03 | 6.14E-03 | |
| 250 | 6.56E-03 | 6.52E-03 | |
| 275 | 6.89E-03 | 6.88E-03 | |
| 300 | 7.22E-03 | 7.23E-03 | |



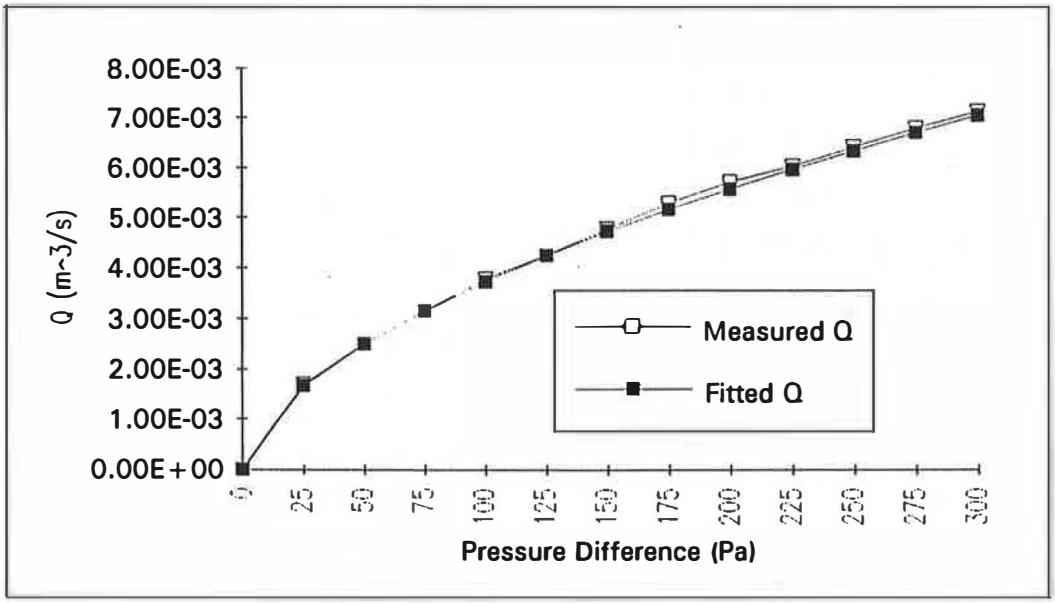
# GRAPH PF-4
# SPANDREL CAVITY PRESSURE-FLOW RELATIONSHIP

| Summary of Test Conditions | |
|---|---|
| Direction of Air Flow through Connected Source | Out of Cavity |
| Vision Unit Perimeter Seal | 1 |
| External Snap Caps | Off |
| Pressure Plate Openings | |
| Area | .000774 m^2 |
| Status | Closed |

**Notes to Vision Unit Perimeter Seal:**

1. **Pressure plates installed over bead of silicone sealant**
2. **Outer face of pressure plates sealed to outer side wall of mullion**

| Summary of Test Results | | | |
|---|---|---|---|
| Measured P (Pa) | Measured Q (m3/s) | Fitted Q (m3/s) | |
| 0 | 0.00E+00 | 0.00E+00 | |
| 25 | 1.70E-03 | 1.67E-03 | |
| 50 | 2.50E-03 | 2.49E-03 | Equation of fitted curve: |
| 75 | 3.16E-03 | 3.16E-03 | |
| 100 | 3.78E-03 | 3.73E-03 | |
| 125 | 4.25E-03 | 4.24E-03 | |
| 150 | 4.77E-03 | 4.72E-03 | Q = 2.58E-04 P^0.58 |
| 175 | 5.29E-03 | 5.16E-03 | |
| 200 | 5.71E-03 | 5.57E-03 | |
| 225 | 6.04E-03 | 5.97E-03 | |
| 250 | 6.42E-03 | 6.34E-03 | |
| 275 | 6.80E-03 | 6.71E-03 | |
| 300 | 7.13E-03 | 7.05E-03 | |

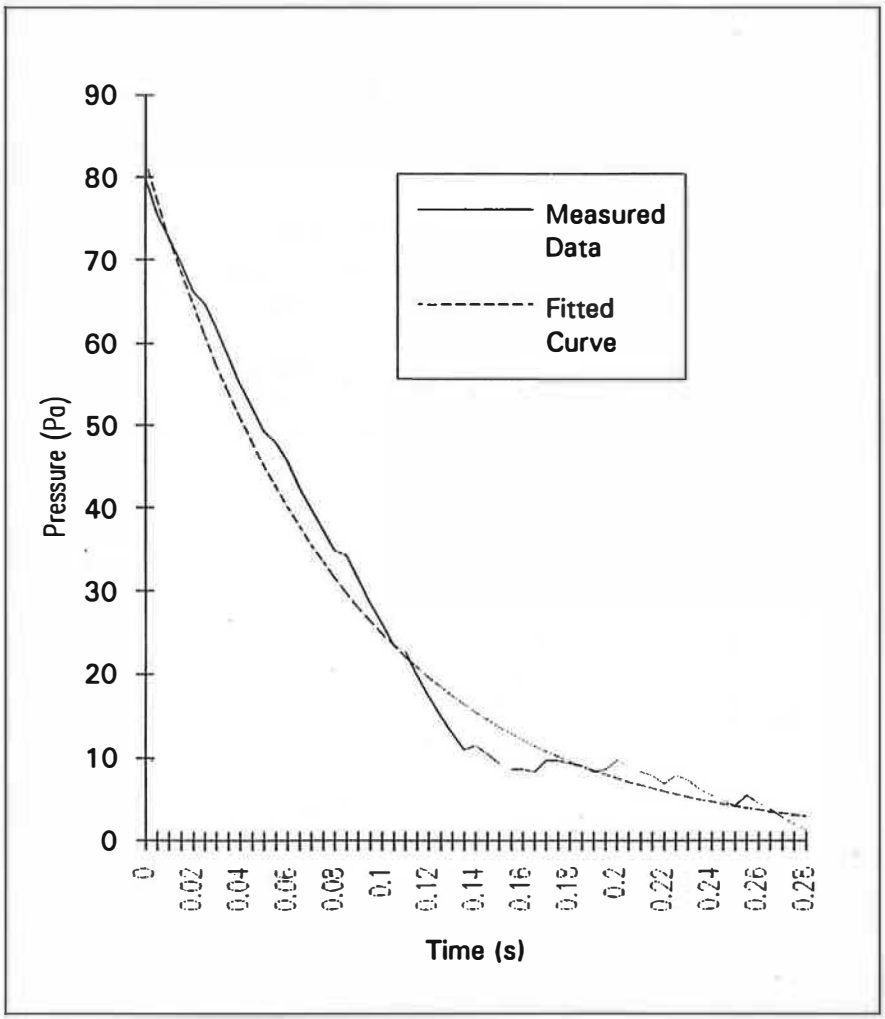


# GRAPH PD-1
# SPANDREL CAVITY PRESSURE DECAY

| Summary of Test Conditions | |
|---|---|
| Direction of Air Flow through Connected Source | Into Cavity |
| Vision Unit Perimeter Seal | 1 |
| External Snap Caps | Off |
| Pressure Plate Openings | |
| Area | .000774 m^2 |
| Status | Open |

**Notes to Vision Unit Perimeter Seal:**

1. **Pressure plates installed over bead of silicone sealant**
2. **Outer face of pressure plates sealed to outer side wall of mullion**



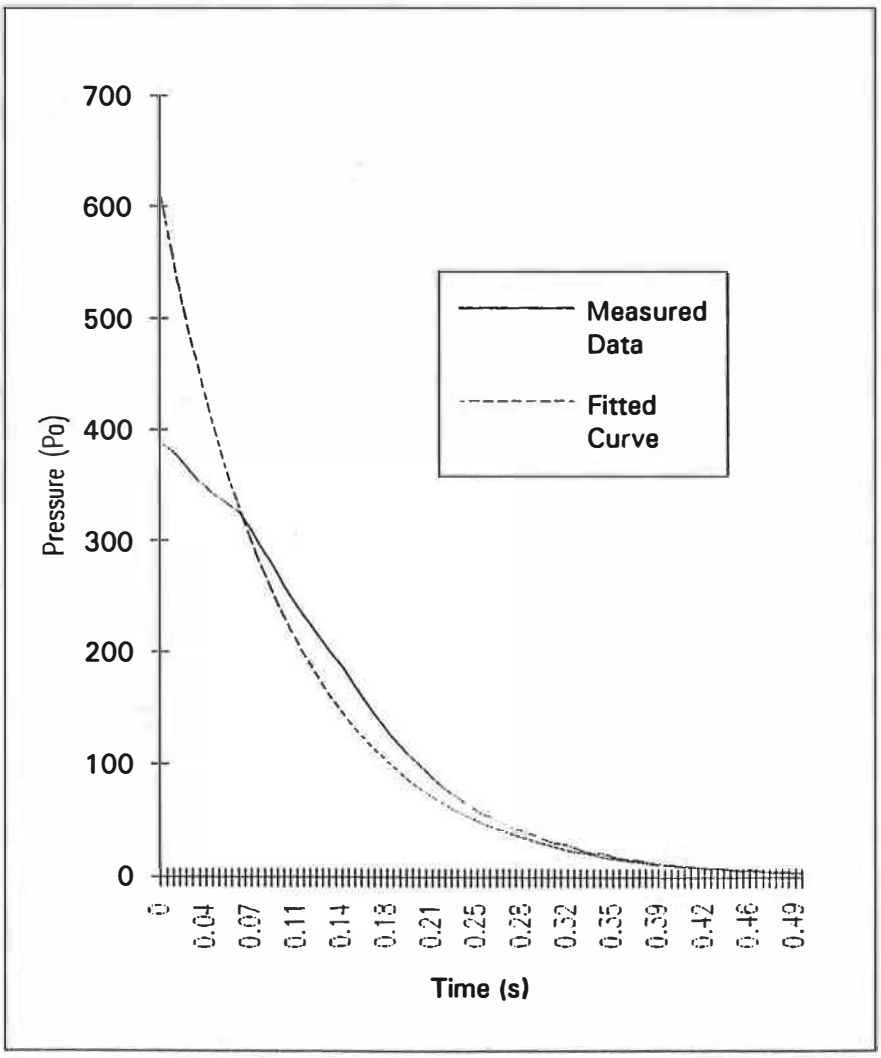

Equation of fitted curve: P = 82e^(-11.9t)

# GRAPH PD-2
# SPANDREL CAVITY PRESSURE DECAY

| Summary of Test Conditions | |
|---|---|
| Direction of Air Flow through Connected Source | Into Cavity |
| Vision Unit Perimeter Seal | 1 |
| External Snap Caps | Off |
| Pressure Plate Openings | |
| Area | .000774 m^2 |
| Status | Open |

Notes to Vision Unit Perimeter Seal:

1. Pressure plates installed over bead of silicone sealant
2. Outer face of pressure plates sealed to outer side wall of mullion



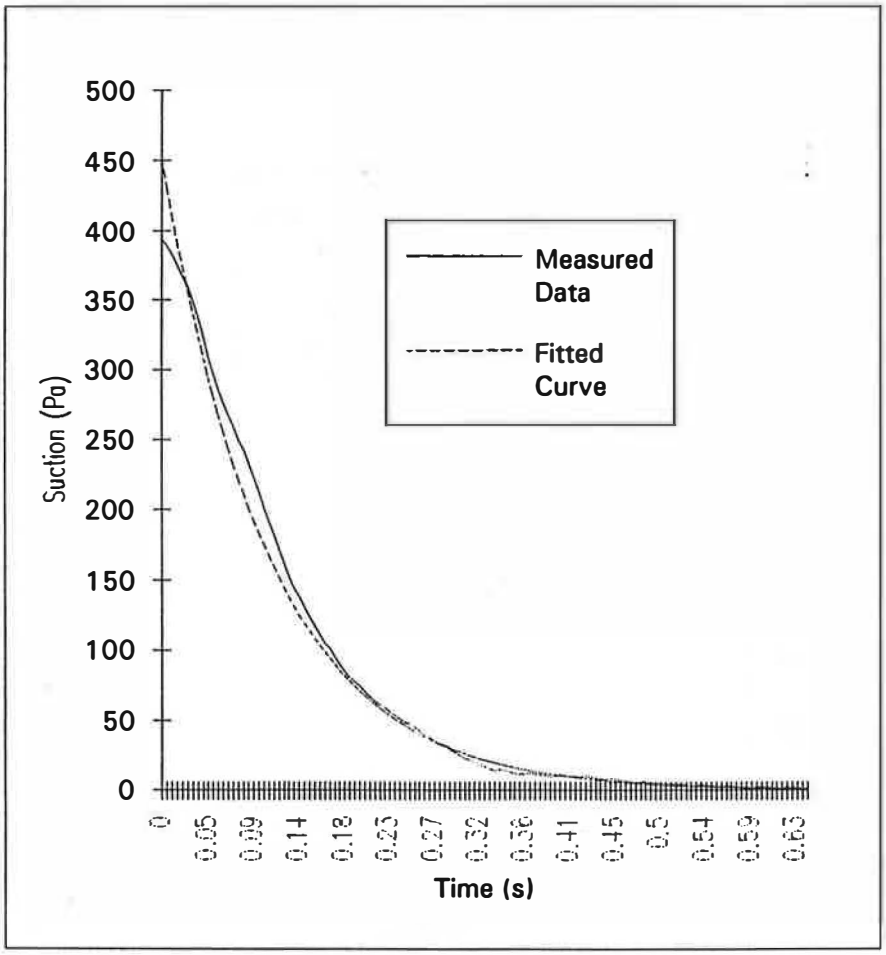

Equation of fitted curve: P = 618e^(-10.3t)

# GRAPH PD-3
# SPANDREL CAVITY PRESSURE DECAY

| Summary of Test Conditions | |
|---|---|
| Direction of Air Flow through Connected Source | Out of Cavity |
| Vision Unit Perimeter Seal | 1 |
| External Snap Caps | Off |
| Pressure Plate Openings | |
| Area | .000774 m^2 |
| Status | Open |

**Notes to Vision Unit Perimeter Seal:**

1. **Pressure plates installed over bead of silicone sealant**
2. **Outer face of pressure plates sealed to outer side wall of mullion**



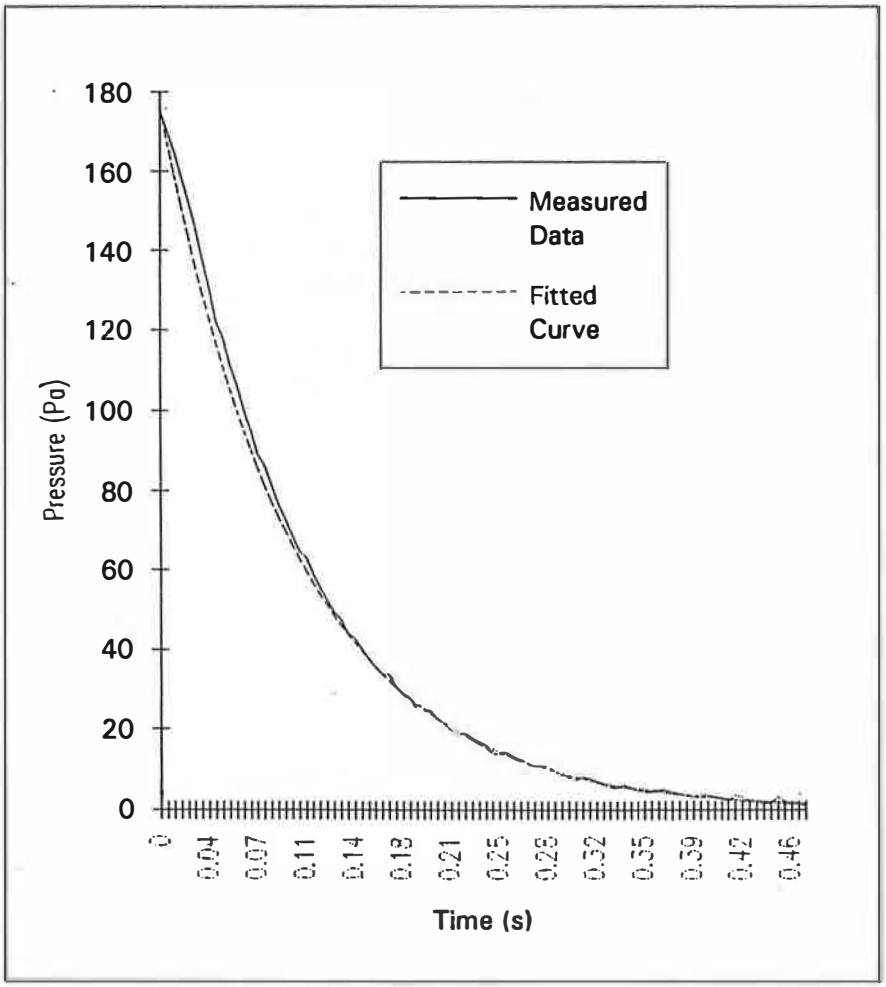

**Equation of fitted curve:** $P = 450e^{(-9.5t)}$

# GRAPH PD-4
# GLAZING CAVITY PRESSURE DECAY

| Summary of Test Conditions | |
|---|---|
| Direction of Air Flow through Connected Source | Into Cavity |
| Vision Unit Perimeter Seal | 1 |
| External Snap Caps | Off |
| Pressure Plate Openings | |
| Area | .000452 m^2 |
| Status | Open |

**Notes to Vision Unit Perimeter Seal:**

1. **Pressure plates installed over bead of silicone sealant**
2. **Outer face of pressure plates sealed to outer side wall of mullion**



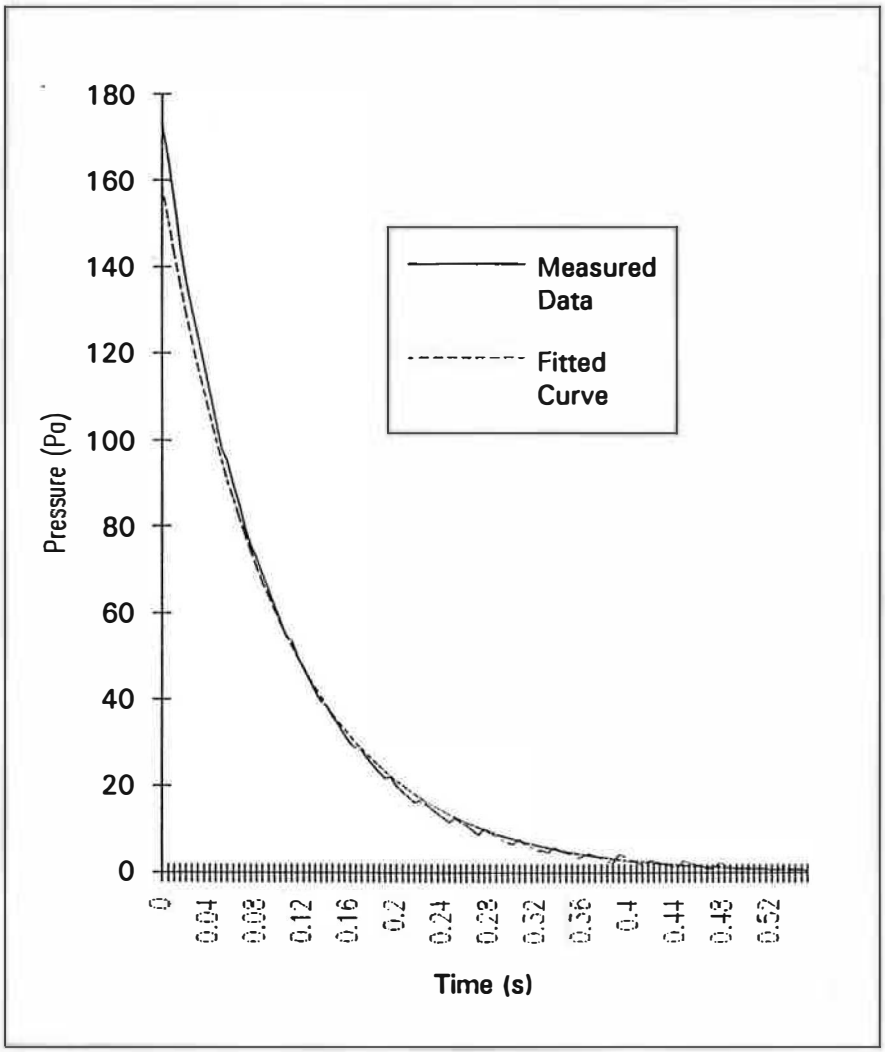

**Equation of fitted curve:** P = 176e^(-10.3t)

# GRAPH PD-5
# GLAZING CAVITY PRESSURE DECAY

| Summary of Test Conditions | |
|---|---|
| Direction of Air Flow through Connected Source | Into Cavity |
| Vision Unit Perimeter Seal | 1 and 2 |
| External Snap Caps | Off |
| Pressure Plate Openings | |
| Area | .000452 m^2 |
| Status | Open |

**Notes to Vision Unit Perimeter Seal:**

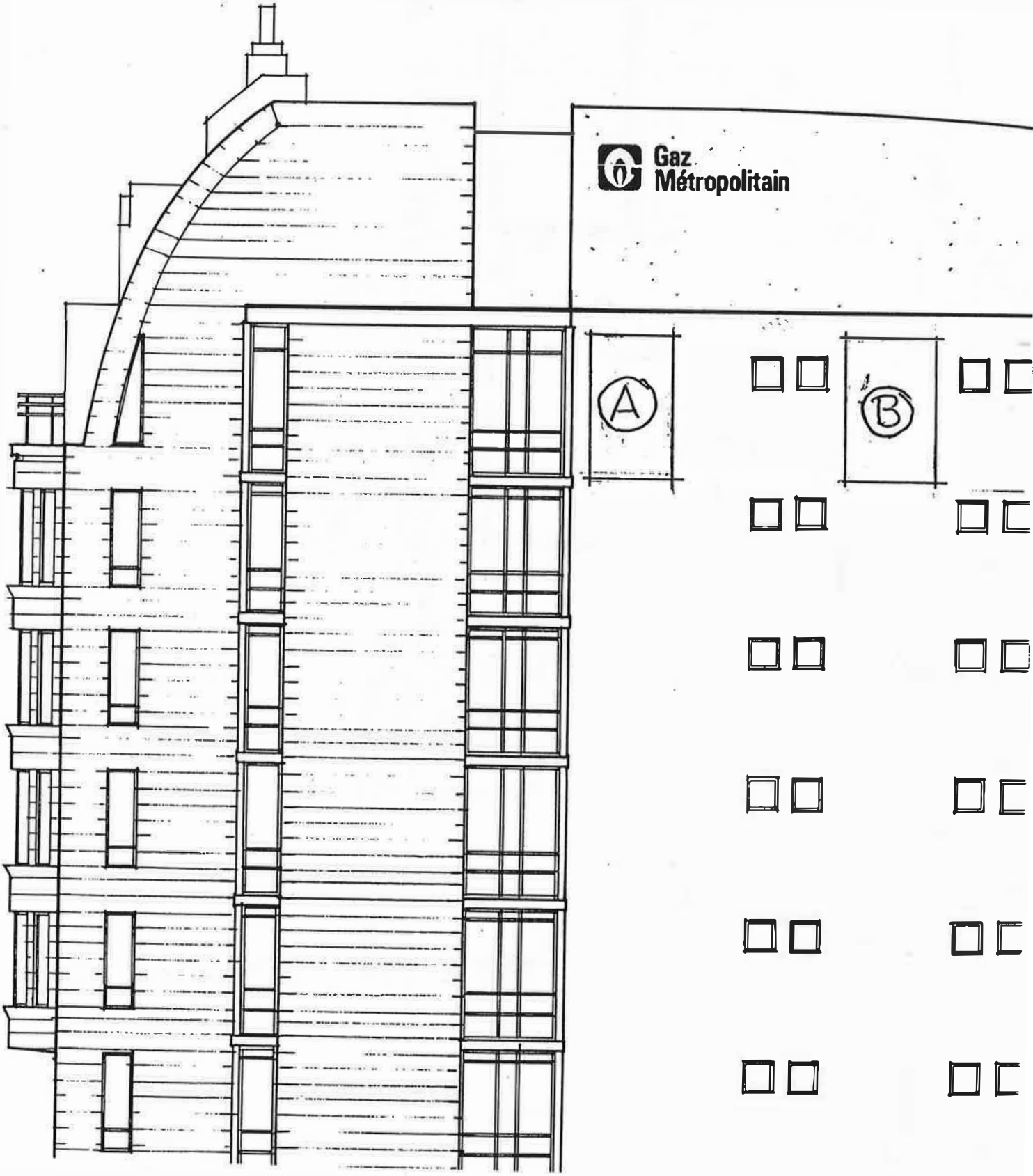
1. **Pressure plates installed over bead of silicone sealant**
2. **Outer face of pressure plates sealed to outer side wall of mullion**

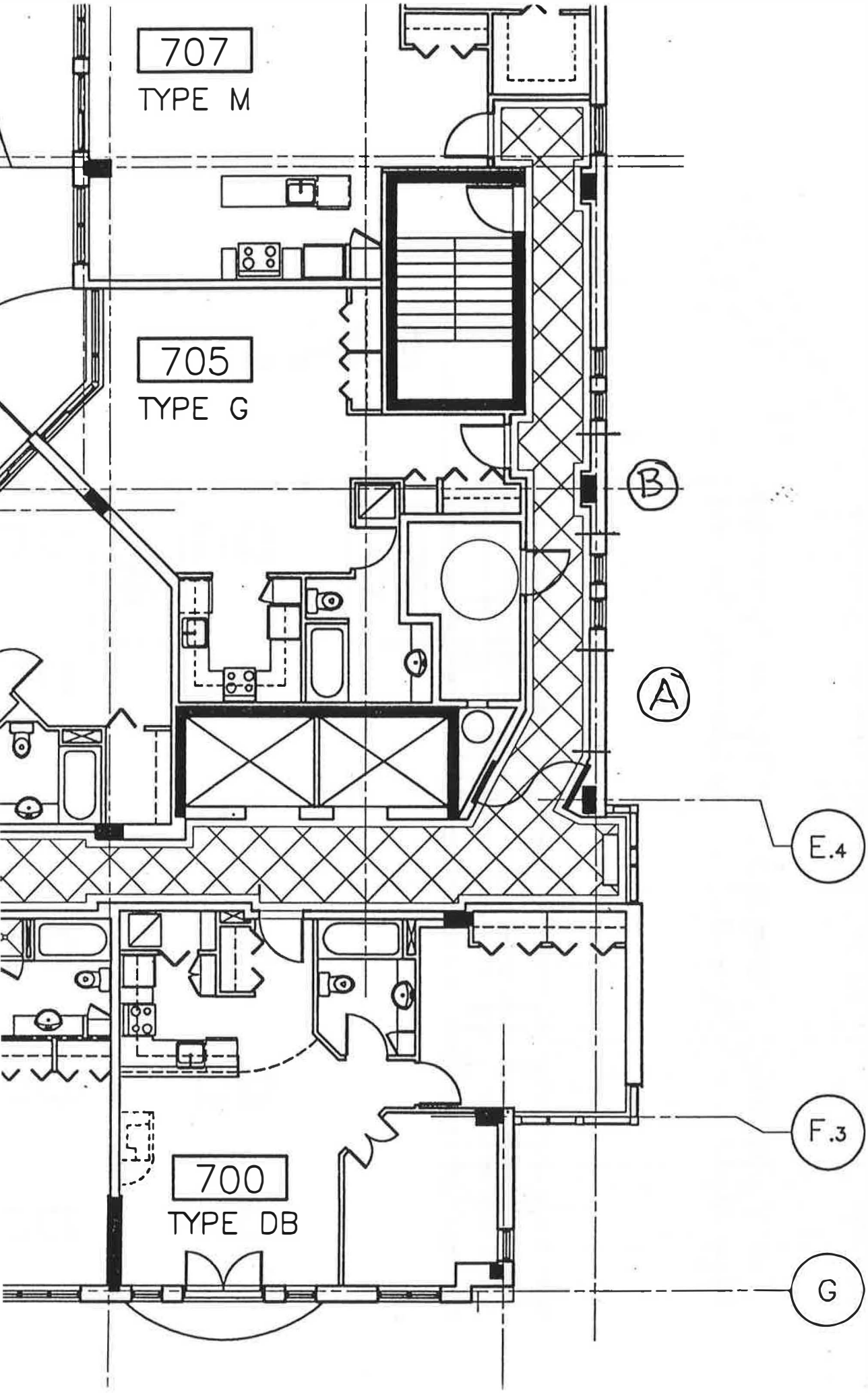


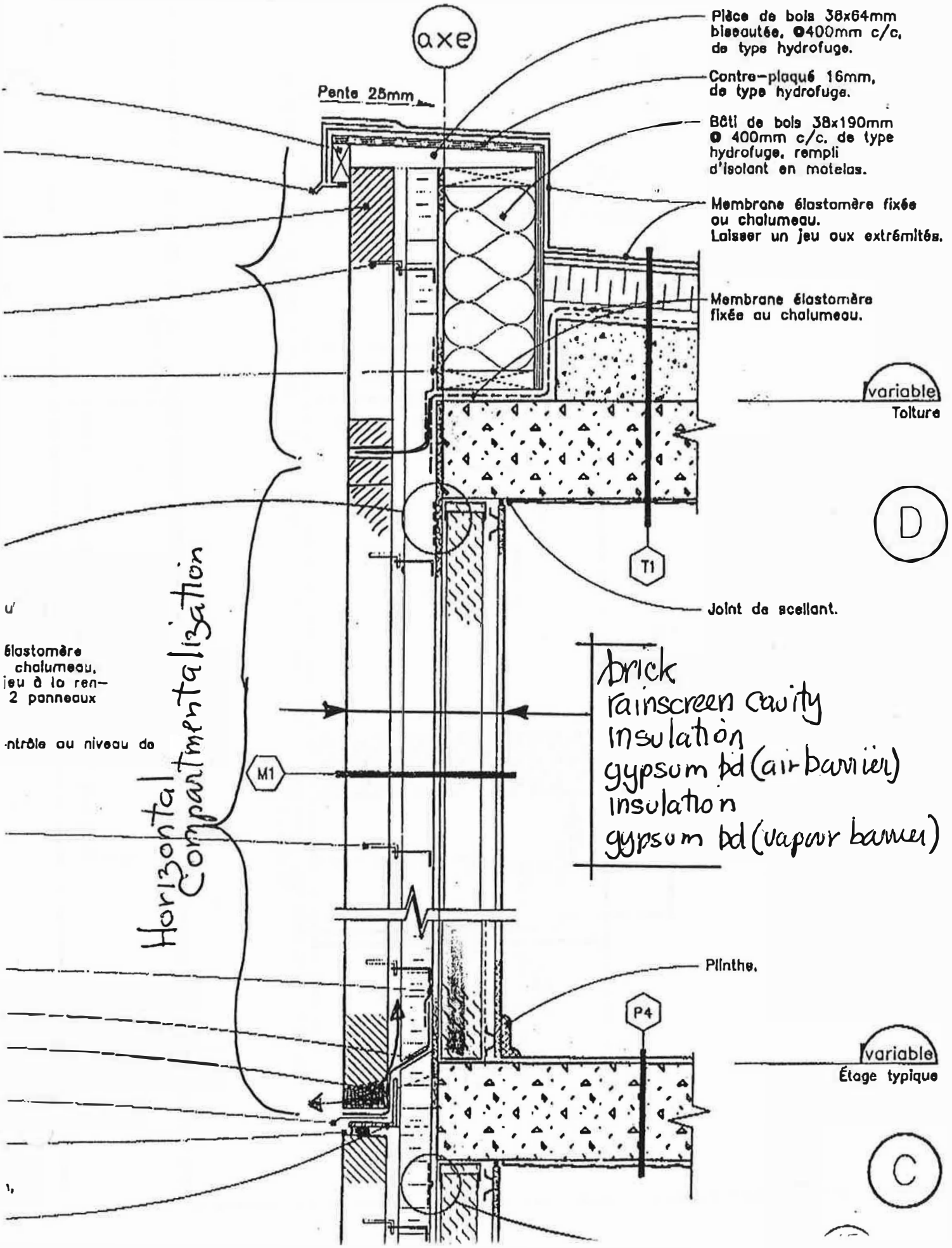

Equation of fitted curve: P = 158e^(-10.1t)

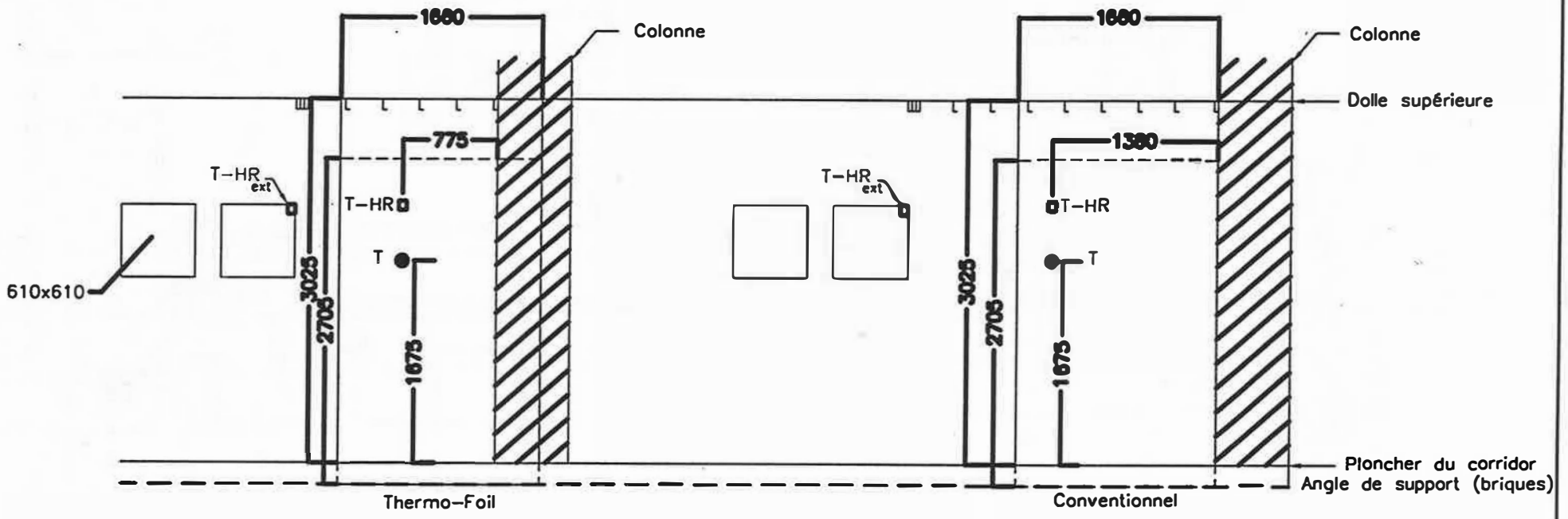
# Appendix
# "B"

CEM Field Testing
"Le Clos St-André"


Gaz
Métropolitain
A
B

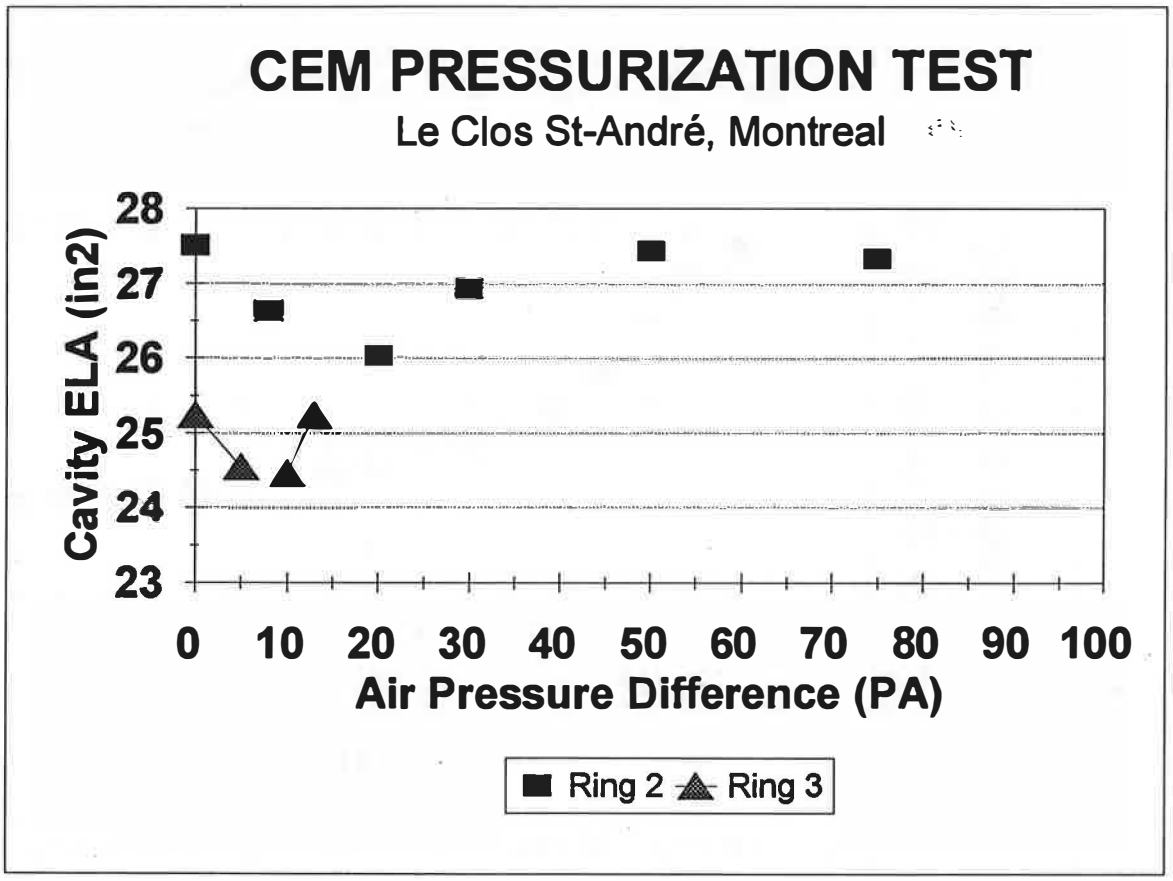

707
TYPE M
705
TYPE G
700
TYPE DB
B
A
E.4
F.3
G

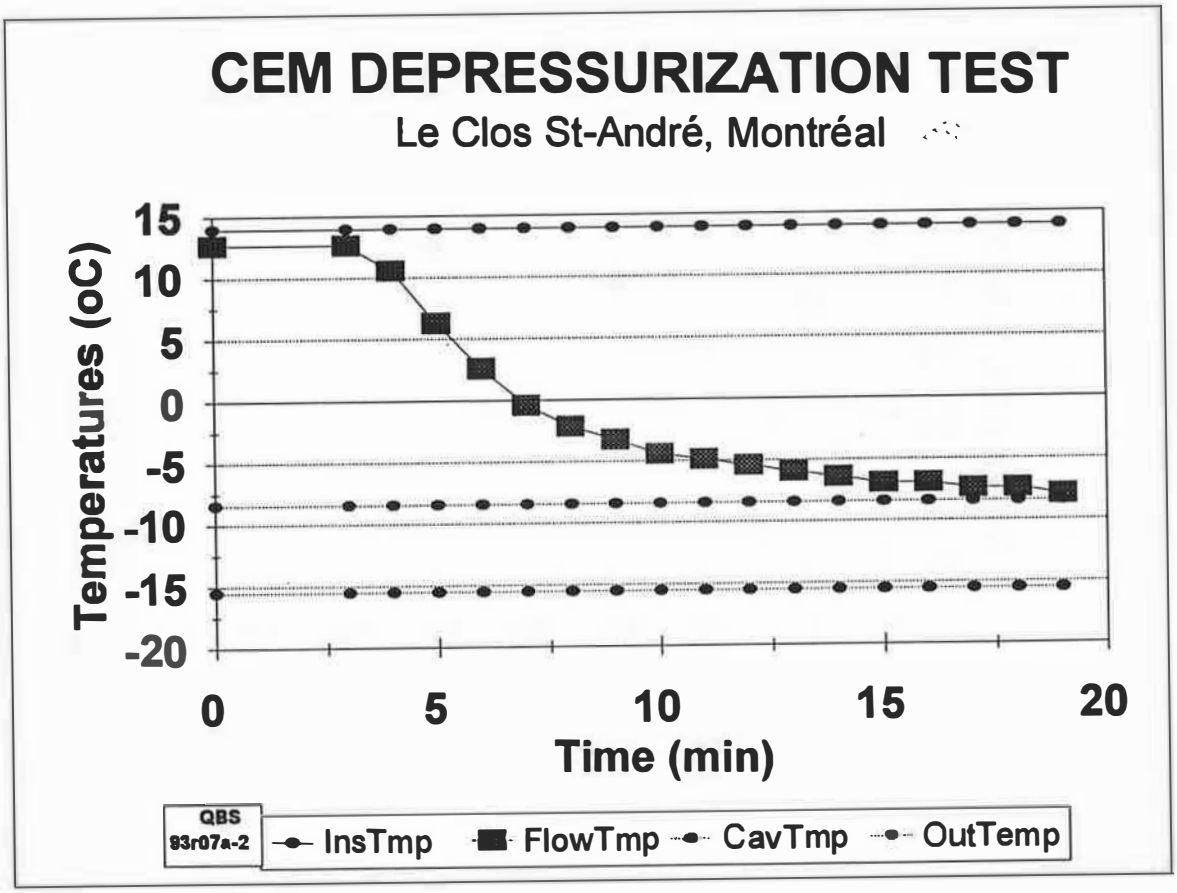

axe
Pente 25mm
Pièce de bois 38x64mm biseautée, @400mm c/c, de type hydrofuge.
Contre-plaqué 16mm, de type hydrofuge.
Bâti de bois 38x190mm @ 400mm c/c. de type hydrofuge, rempli d'isolant en matelas.
Membrane élastomère fixée au chalumeau. Laisser un jeu aux extrémités.
Membrane élastomère fixée au chalumeau.
variable
Toiture
D
T1
Joint de scellant.
élastomère
chalumeau,
jeu à la ren-
2 panneaux
ntrôle au niveau de
Horizontal Compartmentalization
M1
brick
rainscreen cavity
insulation
gypsum bd (air barrier)
insulation
gypsum bd (vapour barrier)
Plinthe.
P4
variable
Étage typique
C

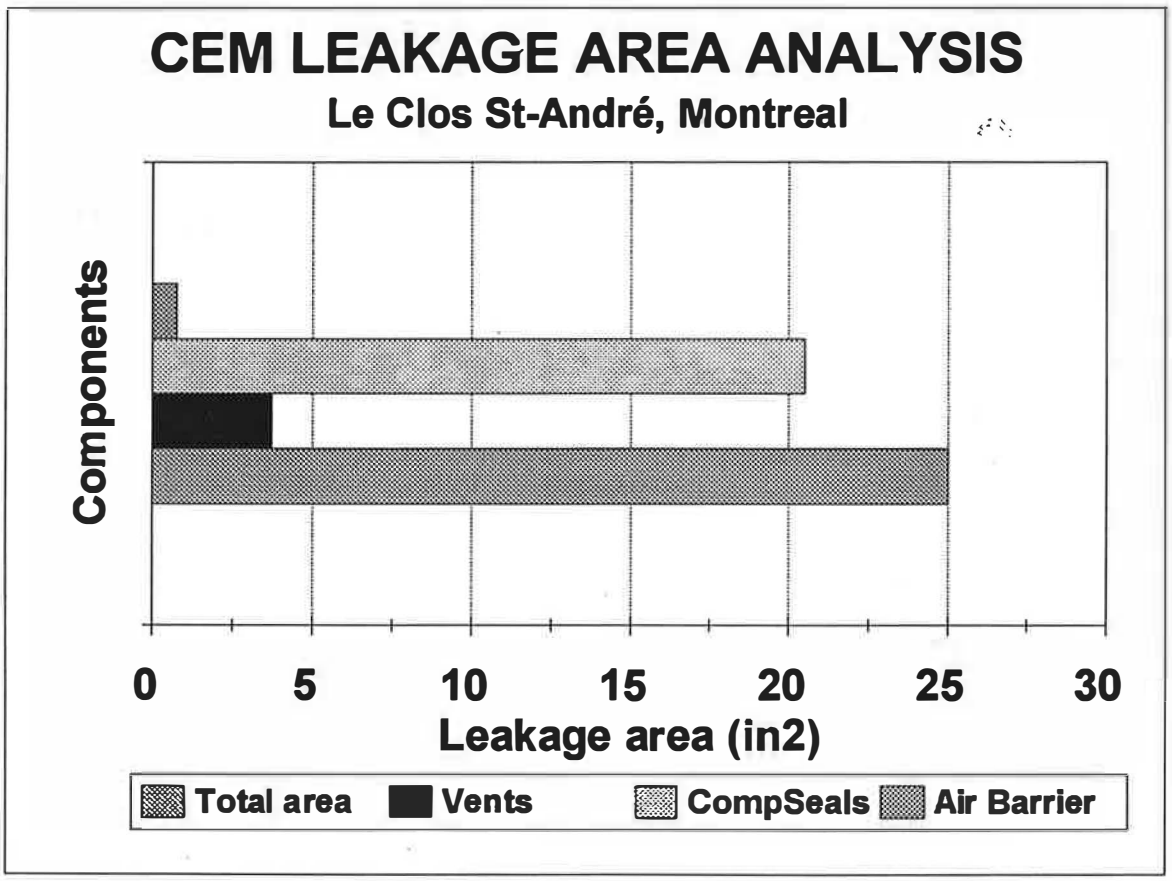



Notes:

| Dessinateur: | Échelle: 1 : 50 | Date: |
|---|---|---|


CEM PRESSURIZATION TEST
Le Clos St-André, Montreal
Cavity ELA (in2)
28
27
26
25
24
23
0
10
20
30
40
50
60
70
80
90
100
Air Pressure Difference (PA)
Ring 2
Ring 3


CEM DEPRESSURIZATION TEST
Le Clos St-André, Montréal
Temperatures (oC)
15
10
5
0
-5
-10
-15
-20
0
5
10
15
20
Time (min)
QBS
93r07a-2
InsTmp
FlowTmp
CavTmp
OutTemp


CEM LEAKAGE AREA ANALYSIS
Le Clos St-André, Montreal
Components
0
5
10
15
20
25
30
Leakage area (in2)
Total area
Vents
CompSeals
Air Barrier