RESEARCH REPORT

Monitoring of Cavity Humidity Levels at Canada Life Building

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Monitoring of Cavity Humidity Levels at Canada Life Building

Prepared for:

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CMHC MANDATE

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

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This publication is one of the many items of information published by CMHC with the assistance of federal funds.

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ACKNOWLEDGEMENTS

This research project was funded by Canada Mortgage and Housing Corporation in collaboration with Adason Properties Limited.

The author wishes to thank CMHC Project Managers, Jacques Rousseau and Pierre-Michel Busque for their interest in this work. Many thanks to David House and Hugh Kerr for allowing this work to be carried out on Canada Life Building and for providing valuable details of its envelope.

EXECUTIVE SUMMARY

Canadian Building Envelope Science and Technology (CAN-BEST) was retained by Canada Mortgage and Housing Corporation (CMHC) to carry out field monitoring of humidity levels in the rainscreen wall cavity at the Canada Life's new headquarters building in Toronto during and following a rainstorm. The objective of the performed work was to assess the wall's moisture intake and drying potential when subjected to rain.

Two west-facing wall panels, located on the 12th floor (top floor), were selected for this investigation. These panels were instrumented for measuring rainfall intensity, relative humidity, temperature and barometric pressure. The first panel was located near the centre of the building, while the second was located at approximately quarter building width from the north corner.

During a monitoring period of four weeks, one significant rainstorm occurred. The amount of rainfall intercepted by the two test panels varied significantly. The centre panel received less rain than the one closer to the building corner. In a 15 minute rain period, the centre panel rain gauge registered 124 mm of rainfall compared to 205 mm registered by the other gauge.

Based on the collected data of relative humidity, temperature and barometric pressure, the Humidity Ratio (HR) curves for each wall cavity and for both the exterior and interior ambient environments were plotted prior to, during and following rainfall. The obtained HR curves revealed that a Maximum Vapour Contribution (MVC) limit to the cavity's air moisture content was established prior to rainfall. The MVC concept is introduced in this report as a potential means of determining the wetting characteristic and drying time of a rainscreen wall.

Based on the HR/MVC concept, it was possible to detect the presence of free water which penetrated the wall panels. It was also possible to estimate each panel's drying time. The predicted minimum drying time was 2.25 hours for the centre panel and 10.0 hours for the other.

In addition to predicting the cavity's drying time, this report presents a simple approach for estimating the quantity of residual rain water which penetrated the rainscreen cladding. However, this approach needs to be validated through further research and field monitoring before an effective method can be developed.

RÉSUMÉ

La Société canadienne d'hypothèques et de logement (SCHL) a engagé la firme Canadian Building Envelope Science and Technology (CAN-BEST) pour étudier, avant et après une pluie torrentielle, les taux d'humidité de la cavité de l'écran pare-pluie du nouveau siège social de la compagnie Canada Vie situé à Toronto. L'objectif visé était d'évaluer l'accumulation d'humidité et le potentiel de séchage d'un écran pare-pluie soumis à la pluie.

Deux panneaux muraux donnant sur l'ouest et situés au 12e étage de l'immeuble (dernier étage) ont été choisis en vue de cette étude. Ces panneaux ont été équipés d'instruments destinés à mesurer l'intensité des chutes de pluie, l'humidité relative, la température et la pression barométrique. Le premier panneau était situé près du centre de l'immeuble, tandis que le second se trouvait au quart environ de la largeur du bâtiment à partir de l'angle nord.

Il est survenu un épisode important de pluies torrentielles pendant une période de contrôle de quatre semaines. La quantité de pluie interceptée par les deux panneaux d'essai a varié considérablement. Le panneau du centre a reçu moins de pluie que le panneau situé plus près de l'angle de l'immeuble. Durant une période de pluie de 15 minutes, le pluviomètre affecté au panneau du centre a enregistré 124 mm de précipitations comparativement à 205 mm pour l'autre pluviomètre.

À partir des données recueillies sur l'humidité relative, la température et la pression barométrique, on a pu tracer sur graphique des courbes d'humidité spécifique (HS) pour chaque cavité murale et pour le milieu ambiant intérieur et extérieur avant, pendant et après la chute de pluie. Les courbes d'HS ainsi obtenues ont fait ressortir que la limite d'apport maximal de l'humidité (AMH) à la teneur en humidité de l'air de la cavité avait été atteinte avant la chute de pluie. Le concept de l'AMH est présenté dans ce rapport comme un moyen possible de déterminer les caractéristiques de mouillage et le temps de séchage d'un écran pare-pluie.

Grâce au tandem HS et AMH, il a été possible de détecter la présence d'eau libre ayant pénétré dans les panneaux muraux. On a également pu estimer le temps de séchage de chaque panneau. Le temps de séchage minimal ainsi prévu a été de 2,25 heures pour le panneau du centre et de 10,0 heures pour l'autre panneau.

En plus de prévoir le temps de séchage de la cavité, ce rapport présente une façon simple d'estimer la quantité d'eau de pluie résiduelle qui traverse le parement d'un écran pare-pluie. Toutefois, cette méthode devra être validée au moyen de recherches et de contrôles sur le terrain plus poussés avant qu'une méthode efficace puisse être mise au point.

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1. INTRODUCTION

Canadian Building Envelope Science and Technology (CAN-BEST) was retained by Canada Mortgage and Housing Corporation (CMHC) to carry out field monitoring of humidity levels in the rainscreen wall cavity at the Canada Life's new headquarters building, 181 University Avenue, Toronto, during and following a rainfall.

The Canada Life Building is of special interest since its envelope incorporates specific design and construction details intended to promote cavity pressure equalization. Furthermore, the wall system itself was the subject of considerable laboratory and field testing, particularly on rainscreen performance. Figure (1) shows a general view of the building.

The objective of the performed work was to assess the wall's moisture intake and drying potential when subjected to rain.

This report presents the findings of a monitoring project carried out in order to answer the following questions:

- *How much rain is the surface of the panel being exposed to?*
- *Is rain penetrating into the cavity?*
- *If the cavity gets wet, how quickly does it dry?*

2. GENERAL APPROACH

Two wall panels were selected for this investigation. They were instrumented for measuring rainfall intensity, relative humidity, temperature and barometric pressure. The intention was to monitor the relative intensities of the rain intercepted by the two wall panels, and to monitor the moisture conditions inside and outside the wall cavity prior to, during and following the rainfall.

In order to provide answers to the questions cited earlier, the following approach was adopted:

How much rain is the surface of the panel being exposed to?

The relative magnitude of rainfall intensity on the two wall panels was established by direct measurement of the surface water run-off. This water was collected at the bottom of each panel using two horizontal troughs which directed the collected water to two identical rain gauges.

Is rain penetrating into the cavity?

Since direct inspection of wall cavity was not practical to perform, a non-destructive method of predicting the presence of rain water and its duration inside the wall cavity was sought. The presence of rain water, whether penetrated or absorbed into the wall materials, causes a corresponding increase in the cavity's air moisture content. The approach was then to detect any increase in the cavity's air moisture content occurring **immediately** following the commencement of rain. This immediate increase in moisture content can be attributed to the evaporation of free water which may be present at the bottom of the cavity. Due to the various sorption capacities of the wetted wall materials, any increase associated with the evaporation of absorbed water will cause a **delayed** increase in cavity moisture content.

If the cavity gets wet, how quickly does it dry?
In addition to detecting the presence of free water, monitoring the time rate of change in the cavity's air humidity ratio relative to the time of rainfall occurrence can provide a reliable indication of the magnitude and duration of water penetration, and a potential means of estimating the cavity's drying potential. High cavity air humidity ratios (higher than ambient's) persisting long after the passage of rainfall suggest a wet cavity with possibly long drying time.

3. DESCRIPTION OF WALL PANELS

The building's exterior walls comprise of stone-veneered precast concrete curtainwall panels. A typical panel is composed of the following (from interior to exterior):

- *125 mm thick precast concrete panel which includes a cast-in-place aluminum window frame glazed with vision and spandrel glass*
- *89 mm thick rigid glass insulation*
- *6 mm thick plastic Terra drain mesh sheets*
- *75 mm thick stone*

Cavity compartmentalization is accomplished horizontally by installing a membrane head closure. The closure, also serving as a drainage gutter for the cavity of the panel above, is returned upward in front of the concrete slab and sealed to its upperside. Vertical compartmentalization is accomplished through the inclusion of a full height EPDM foam gasket positioned between the stone veneer and the precast concrete panel along the window's left jamb and sill.

Panel pressure equalization is promoted by leaving open the joints located along the window's right jamb and head. Panel drainage is accomplished by the open bottom end of wall cavity. Further details of panel construction is provided in Appendix (A).

4. INSTRUMENTATION

Measuring rainfall intensity, relative humidity, temperature and barometric pressure was accomplished by using the following instruments:

- Two rain gauges (1 mm resolution)
- Four relative humidity transducers (±2% and 1% resolution)
- Four temperature transducers (±0.5°C and 0.1°C resolution)
- One barometric pressure transducer (±5% and 0.1 mbar resolution)

The instruments were connected to a computer-based data acquisition system programmed for unattended data collection and storage. Data was sampled at the rate of one sample per second, continuously averaged, and logged every 15 minutes.

4.1 Rainfall Intensity

The surface water run-off was measured using two identical tipping-bucket rain gauges. As shown in Figure (3), a 1500 mm wide horizontal water collection trough was installed at the window sill of panels 90 and 91 located directly below the panels under investigation. The collected water was directed to the corresponding rain gauge through a down-spout located at the end of the trough.

4.2 Cavity Humidity/Temperature

Monitoring of the cavity's relative humidity and temperature was carried out on two west-facing panels, both located on the 12th floor (top floor). The first panel, #101, was located near the centre of the building. The second panel, #99, was located at approximately quarter building width from the north corner. Panel locations are shown in Figure (2) and indicated on the west elevation drawing included in Appendix (B).

One relative humidity/temperature transducer was placed at the bottom of each wall cavity. The wall cavity was accessed through one of the anchor pockets in the precast concrete panel by cutting through the interior drywall and the airseal membrane. Once the transducer was positioned at the bottom of the panel cavity, the membrane and the drywall were properly sealed and restored to their original condition. A typical wall cross section indicating the sensor location is found in Appendix (A).

4.3 Ambient Environment

The exterior ambient relative humidity, temperature and barometric pressure were monitored outside the building at one location on the 11th floor. The 11th floor was chosen, instead of the 12th, for practical accessibility to the building's exterior side. As shown in Figure (3), the narrow perimeter balcony of the 11th floor was used to gain access to the building's facade and to mount the exterior instruments. An access door to the balcony was temporarily created by removing the sealed glazing unit of panel #91 which was centrally located between the two monitored panels.

Monitoring of the interior ambient relative humidity and temperature was carried out on the 11th floor. The instruments were mounted at a central location above the dropped ceiling panels.

5. MONITORING RESULTS

During a monitoring period of four weeks, one significant rainstorm occurred. Figures (4) and (5) show rainfall occurrence, magnitude, duration and the associated changes in temperature and relative humidity levels inside and outside the panel cavity measured over a period of 48 hours during and following the rain storm.

The amount of rainfall intercepted by the two monitored panels varied significantly. The centre panel (#101) received less rain than the one closer to the building corner (panel #99). In a 15 minute period, the centre rain gauge registered 124 mm of collected rain water compared to 205 mm registered by the other rain gauge.

6. DISCUSSION OF RESULTS

The relative humidity measurements shown in Figures (4) and (5) do not reflect the true changes in the air's absolute moisture content. For presentation of absolute moisture contents (independent of air temperature), it would be more appropriate to discuss the results in terms of humidity ratios.

6.1 Humidity Ratio

The "Humidity Ratio" (HR) of an air-vapour mixture is used whenever the absolute moisture content of air is of interest. It is defined as the mass ratio of water-vapour to dry air present in an air mixture. HR is measured in kg of water-vapour per kg of dry air. The humidity ratio of an air-vapour mixture can be derived directly from a standard psychrometric chart for any given state of air temperature and relative humidity. Alternatively, it can be calculated using the measured values of relative humidity, temperature and barometric pressure. A calculation method is presented in Appendix (C).

Figures (6) and (7) show the humidity ratios of the cavity's air of both panels and the exterior and interior environments as calculated from the collected data. As indicated by the three curves, the cavity's humidity ratio is determined by changes in the ambient exterior and interior humidity ratios and, as we will explain later, by the evaporation of the free water which may be present in the wall cavity.

The HR curves presented in Figures (6) and (7) may be used to detect the presence and possibly estimate the amount of free water residing in the wall cavity. By analyzing the HR curves before, during and after the rainfall, the cavity's drying time can also be estimated.

6.2 Pre-Rainfall Stage

Prior to rainfall, water is present in the environment and in the cavity air only be in vapour form (assuming air temperatures are above the dew point). At this stage, the cavity's HR is established by a moisture balance based solely on the exchange of water vapour with the surrounding environments. The cavity's HR level is determined by the interior and exterior environment HR's and the rates of air movement and vapour diffusion through the wall's components.

Given enough time with the exterior air being maintained at or near saturation (a general condition of ambient air immediately prior to rainfall), the cavity HR reaches a plateau of maximum vapour contribution limit (indicated on the HR curves by a dashed horizontal line). Since the exterior air is nearly saturated with water vapour, this limit is the cavity's absolute maximum water intake in vapour form. In other words, this maximum limit represents nature's **Maximum Vapour Contribution (MVC)** to the cavity's air moisture content. As shown in Figures (6) and (7), the MVC limits were established at 9.5 and 10.0 x 10^{-3} kg water vapour per kg dry air for panels #101 and #99 respectively.

Any increase in the cavity's HR beyond the MVC limit can **only** occur during or following a rainfall as a result of water penetration and/or absorption. Such increase may be attributed to the evaporation of either free water which may be present in the wall cavity (due to leakage) or water which may be absorbed in the wetted wall materials.

The timing of HR incremental increase above MVC can be used to determine the wetting nature of the wall cavity (penetrated versus absorbed water). The evaporation of free water inside the cavity causes an **immediate** HR increase above the MVC limit. While a **delayed** increase in HR above the MVC limit can be attributed to the evaporation of water absorbed in the wall materials. In order for the absorbed water to increase the cavity HR, absorption of rain water must continue until the water sorption capacities of the various wall materials are reached at which time water vapour molecules are released to the cavity air.

6.3 During-Rainfall Stage

The curves presented in Figures (6) and (7) indicate that the HR of both cavities increased to beyond the MVC limit within 15 minutes of rainfall. This "immediate" increase in HR can be attributed to the evaporation of water present in the cavity. These HR curves indicate that the rate of water intake of panel #99 during a rainfall was higher than that of the centre panel #101.

Towards the end of rainfall, the cavity's HR dropped momentarily to the level delineated by the MVC limit line. This suggests that the free-running water has drained to the outside. Once validated, this information can be used for estimating the amount of water penetration.

6.4 Post-Rainfall Stage

Following the "drainage dip" in the cavity's HR observed at the end of rainfall, the cavity's HR rises once again above the MVC limit. This indicates that additional moisture is released due to evaporation of absorbed water. The level and duration of HR rise above MVC are determined by the rate of evaporation of absorbed water and the rate of drainage of free water.

6.5 Wall Drying Potential

The information presented in the HR curves can also be used to establish the cavity's drying time. The drying time may be defined as the time required for the cavity's HR to return to below the MVC limit line. Therefore, the minimum drying time can be estimated as the interval between the end of a rainfall and the last intersection point of the cavity's HR curve with the MVC limit line. As shown in Figures (6) and (7), the predicted minimum drying time is 2.25 hours (20.0 - 17.75) for the centre panel, and 10.0 hours (27.75 - 17.75) for the other.

Method for Estimating Cavity Drying Time:

1. *Establish the cavity's Maximum Vapour Contribution (MVC) limit line from the Humidity Ratio (HR) curves obtained prior to rainfall.*
2. *Identify the last intersection point of the cavity's HR curve and the MVC limit line following rainfall. Calculate the time interval between the end of rainfall and the intersection point.*

7. FURTHER RESEARCH

The Humidity Ratio/Maximum Vapour Contribution (HR/MVC) concept holds a promising possibility for determining the amount of water penetration and drying potential of an existing rainscreen wall. This non-destructive/non-intrusive method of evaluating a wall's wetting characteristics and drying time can be developed for widespread use as a investigation and research tool.

Further monitoring of various buildings is needed to validate the concept of MVC and to provide answers to the following questions:

- *Is the MVC limit a real parameter associated with every rainfall?*
- *Can the MVC limit be determined with acceptable accuracy and repeatability for a given wall?*
- *Can the MVC limit be used to characterize and rate the rainscreen performance of wall systems?*
- *Can it be applied to predict moisture problems in face-sealed walls?*

8. CONCLUSIONS

The Humidity Ratio/Maximum Vapour Contribution (HR/MVC) concept can be used to determine the wetting characteristics and drying time of a rainscreen wall. Based on this concept, and on the collected rain/humidity data, the following conclusions can be made:

1. *The amount of rainfall intercepted by the centre panel was less than that of the panel closer to the building's corner.*
2. *Water penetrated into the cavity of the panel closer to the building's corner during rainfall at a higher rate than it did at the centre panel.*
3. *The predicted minimum cavity drying time was 2.25 hours for the centre panel and 10.0 hours for the panel closer to the building's corner.*

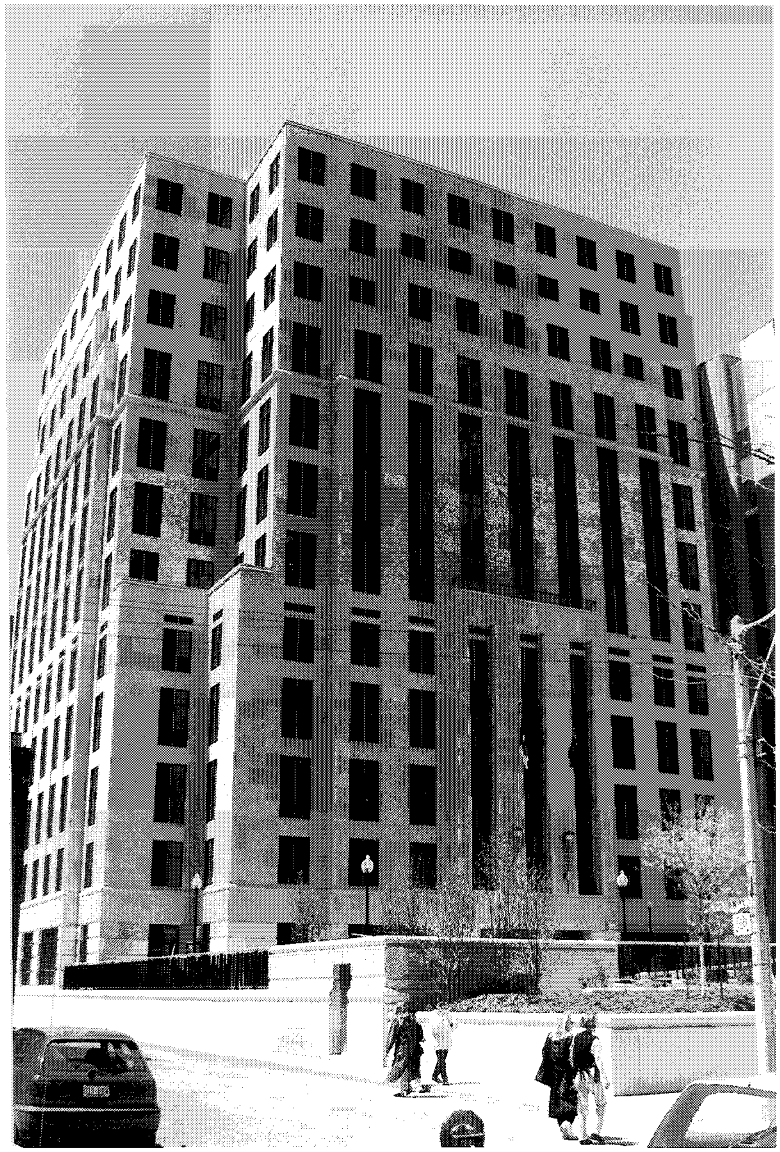

Figure (1): General View of Canada Life New Headquarters Building

Figure (2): West Building Elevation Showing location of Monitoring

Figure (3): Arrangement of Rain Water Collection Trough and Rain Gauges

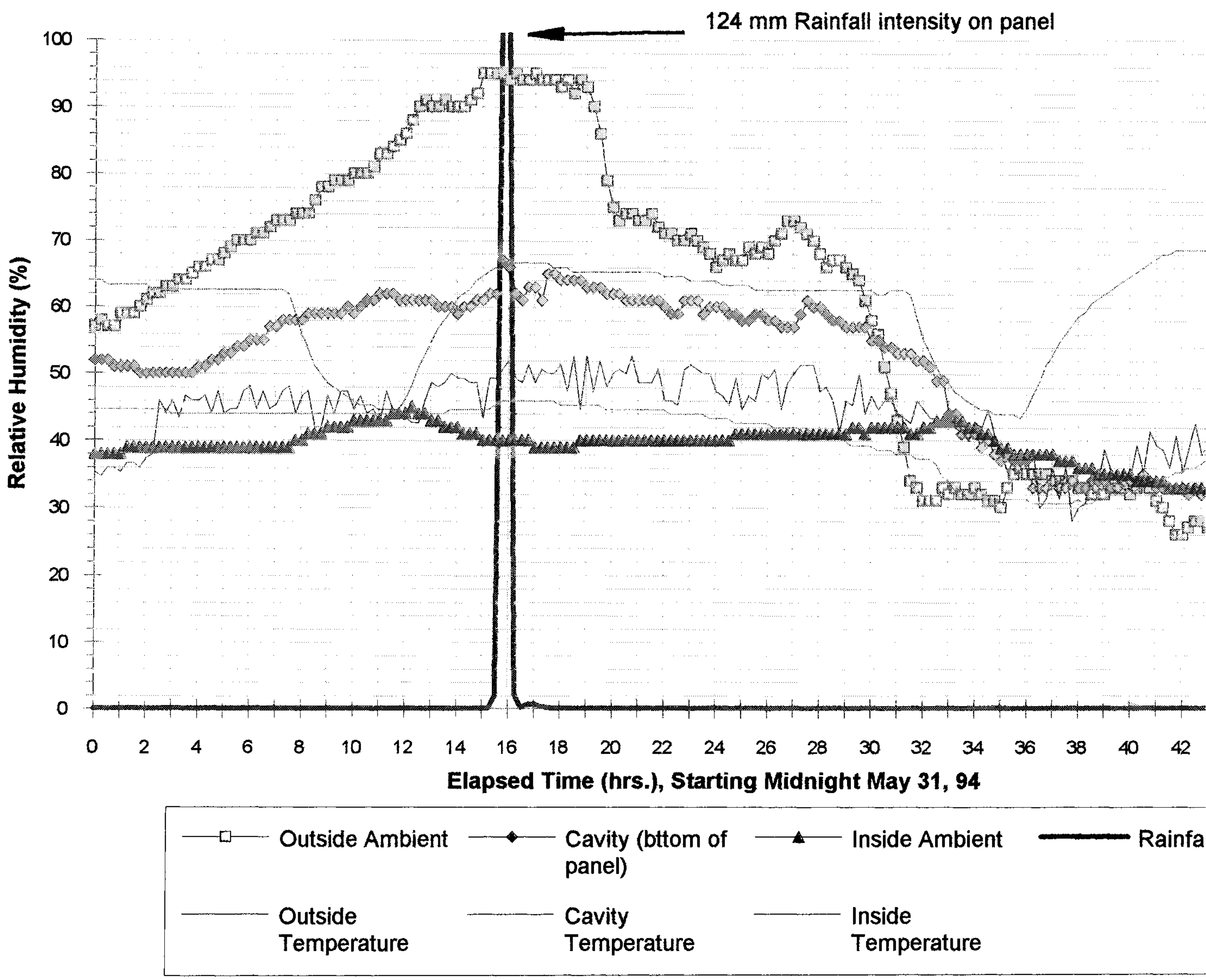

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Figure (4): Relative Humidity Inside and Outside Wall Cavity - Panel 99

CMHC.XLS Chart 6

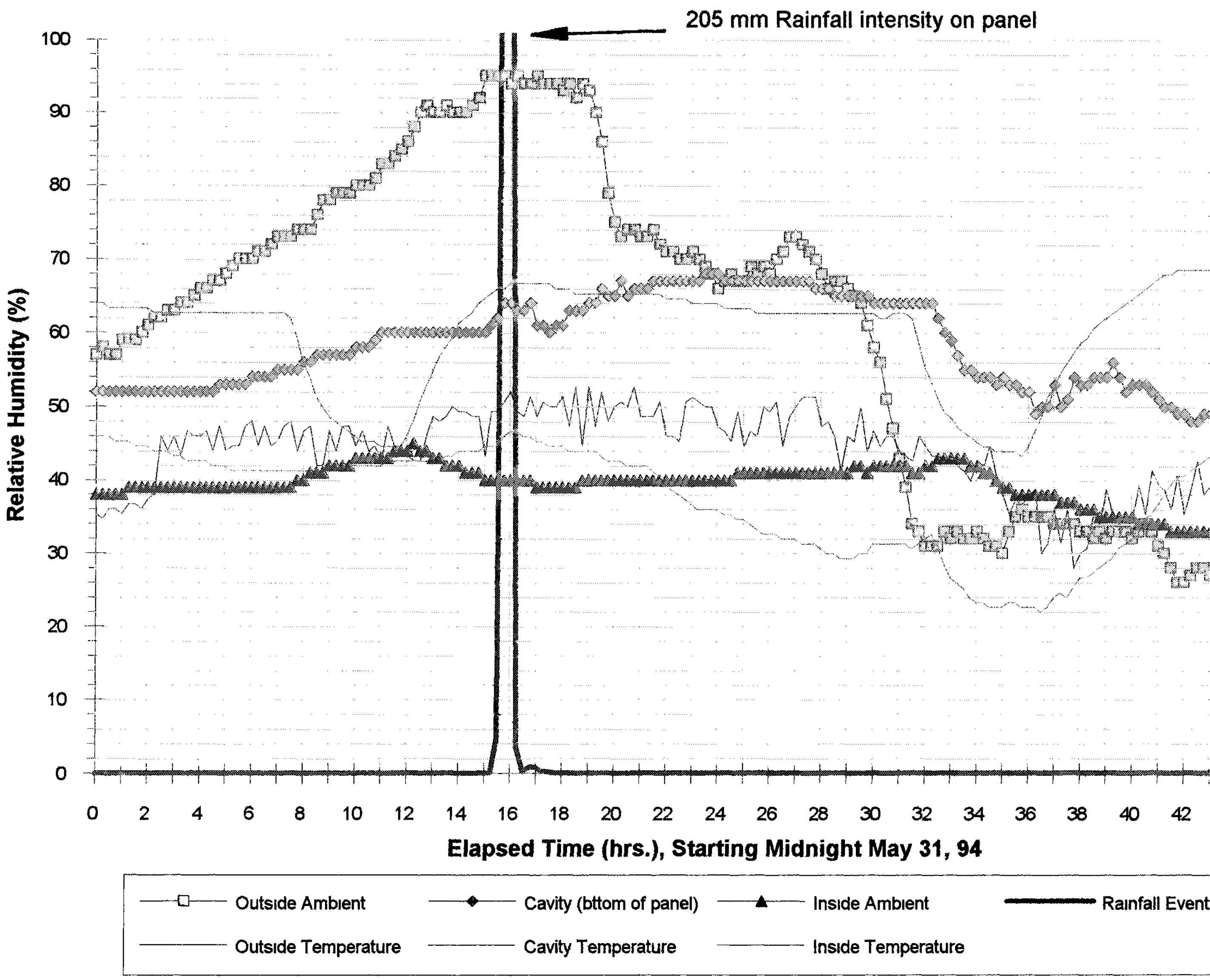

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Figure (5): Relative Humidity Inside and Outside Cavity - Panel 101

CMHC.XLS Chart 7

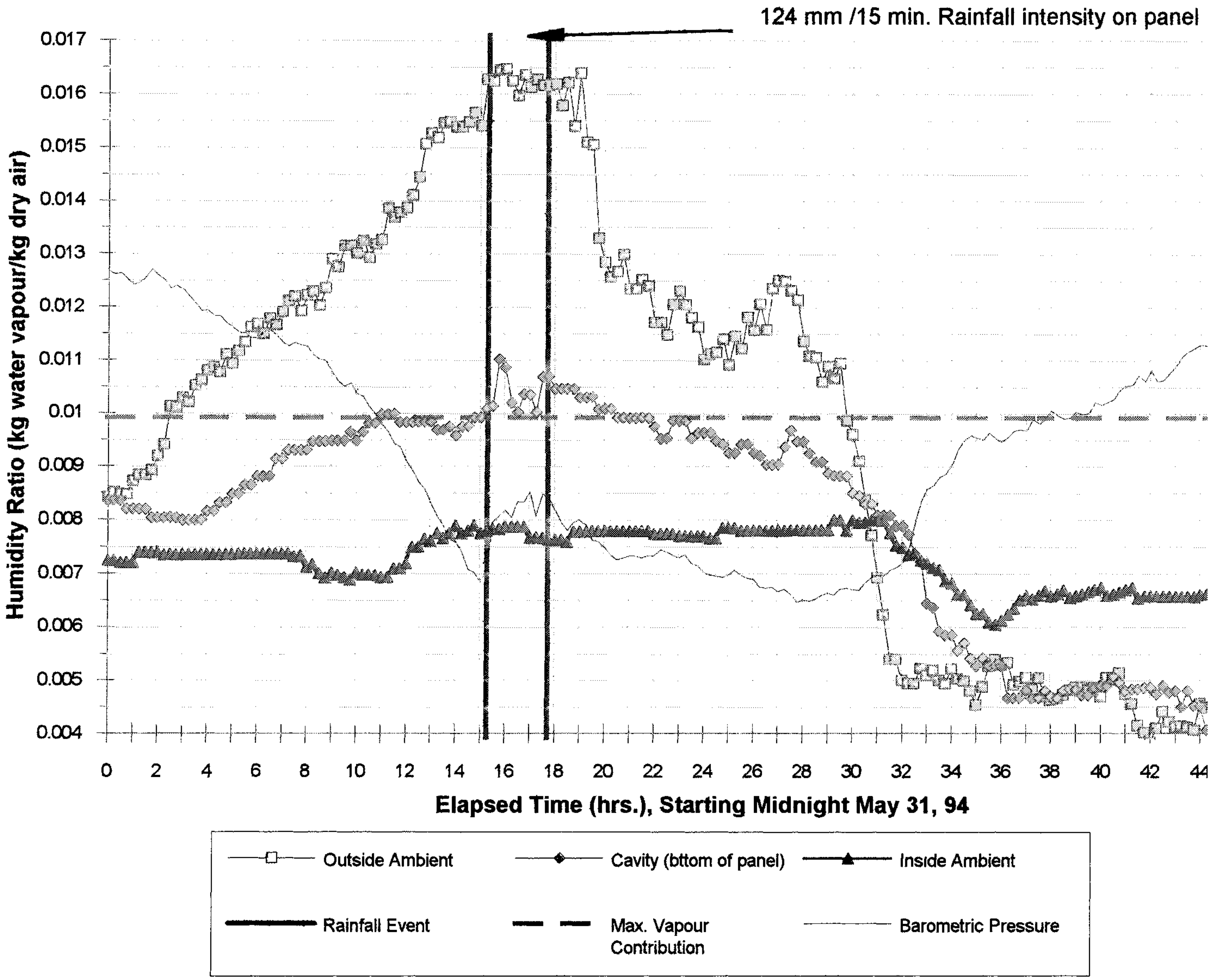

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Figure (6): Air Humidity Ratio Inside and Outside Wall Cavity - Panel 99

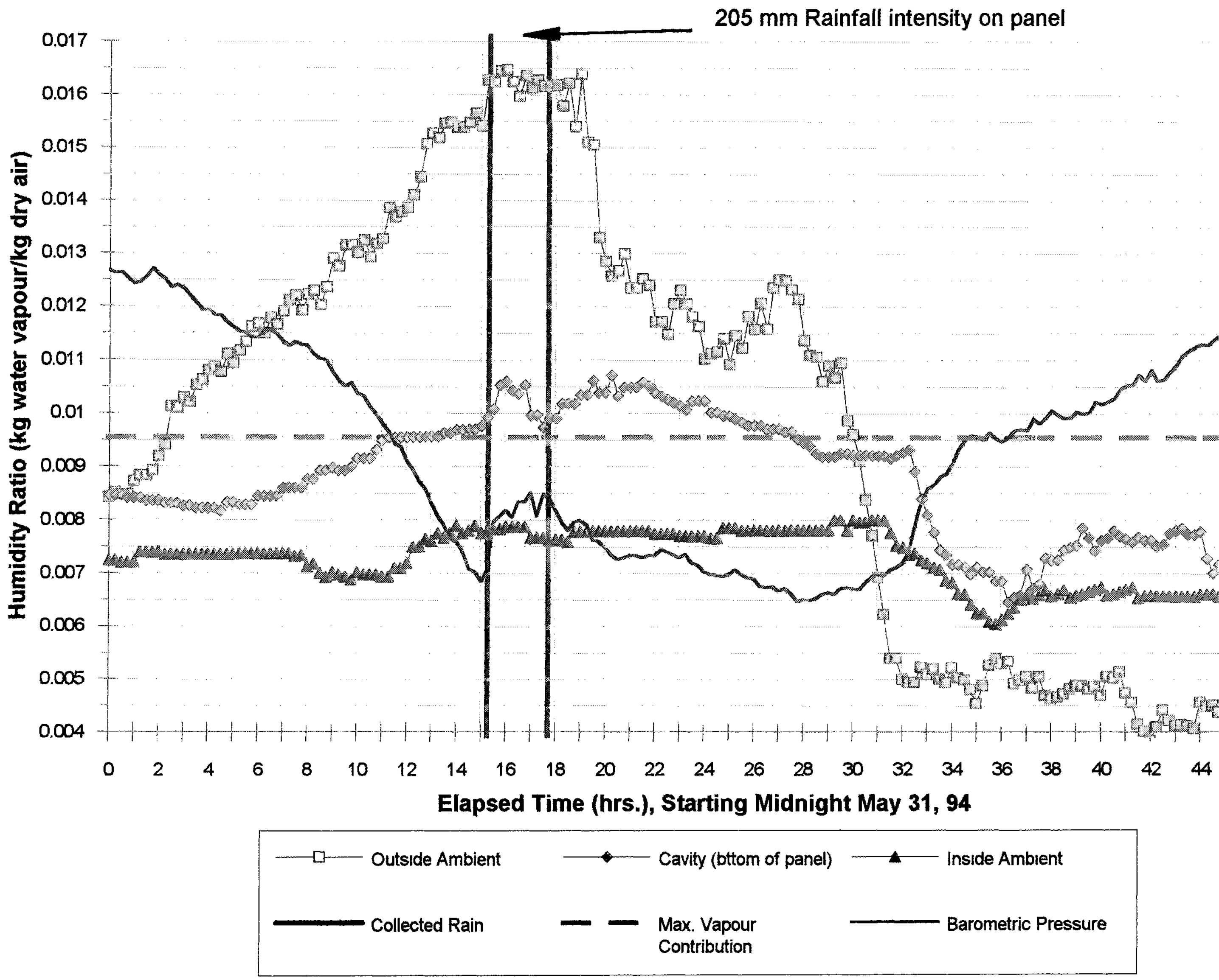
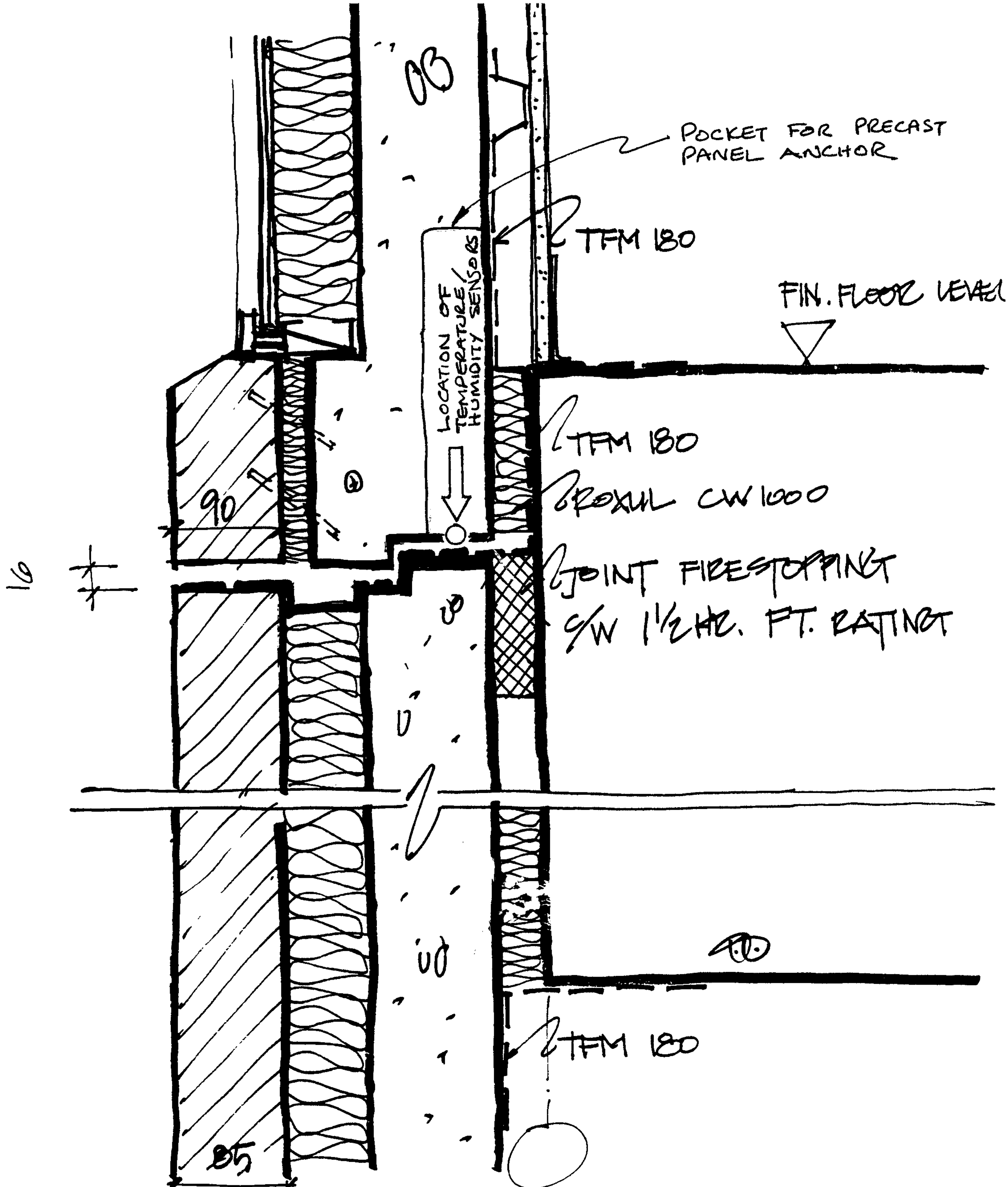


Figure (7): Air Humidity Ratio Inside and Outside Wall Cavity - Panel 101

CMHC.XLS Chart 10

APPENDIX (A): Details of Wall Construction



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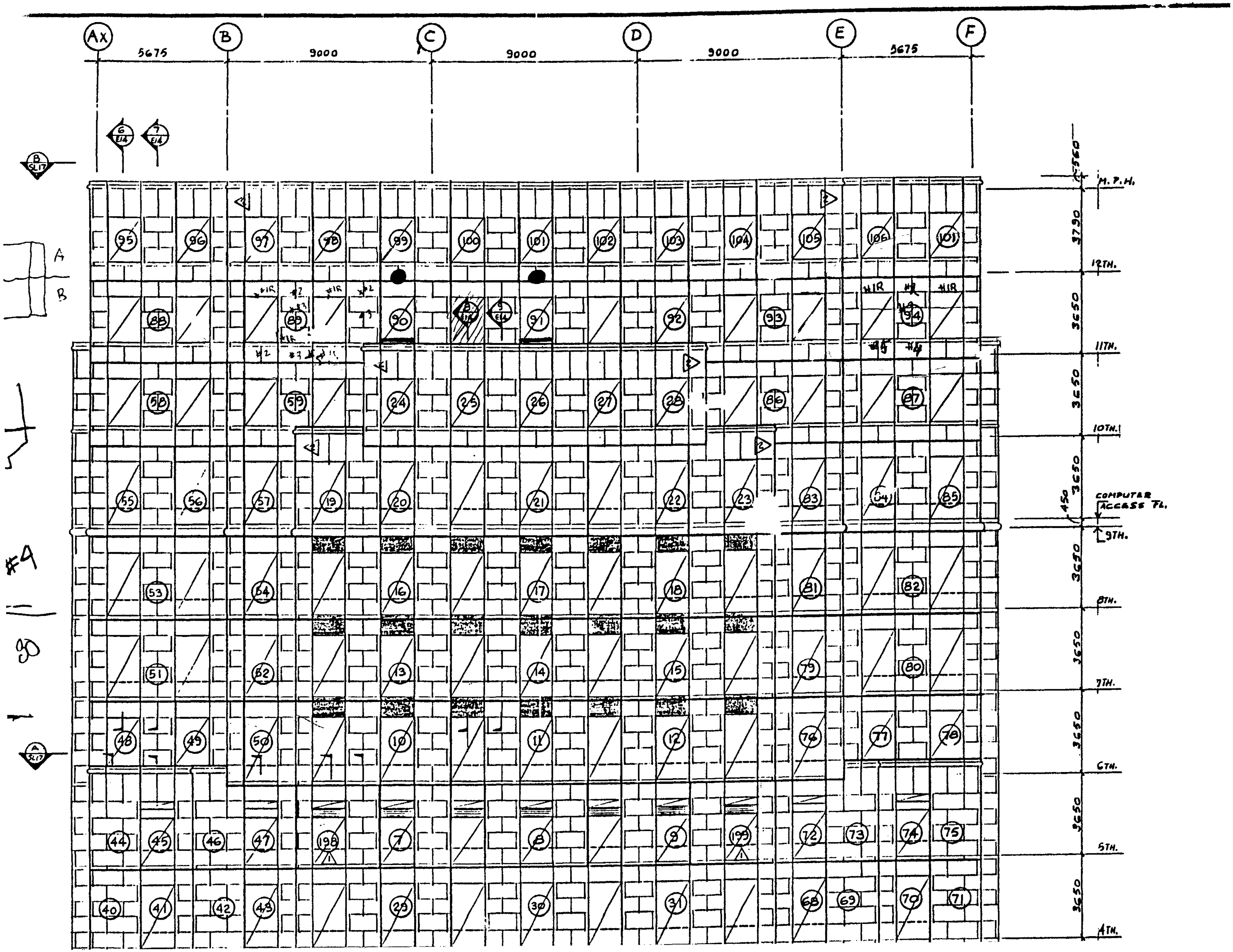
APPENDIX (B): Details of Monitoring Location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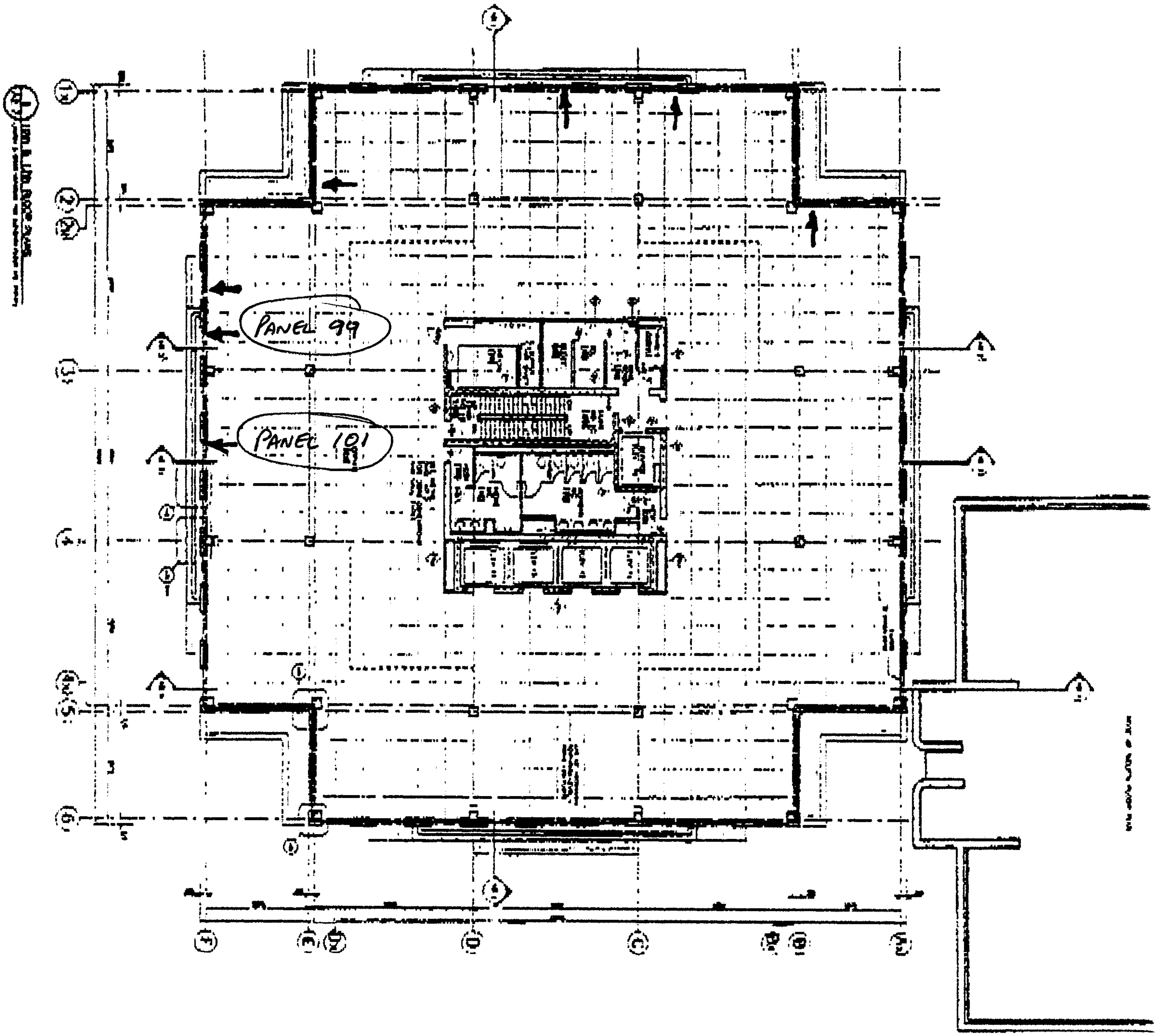

PANEL 99
PANEL 101

APPENDIX (C): Calculation of Humidity Ratio

Calculation of Humidity Ratio

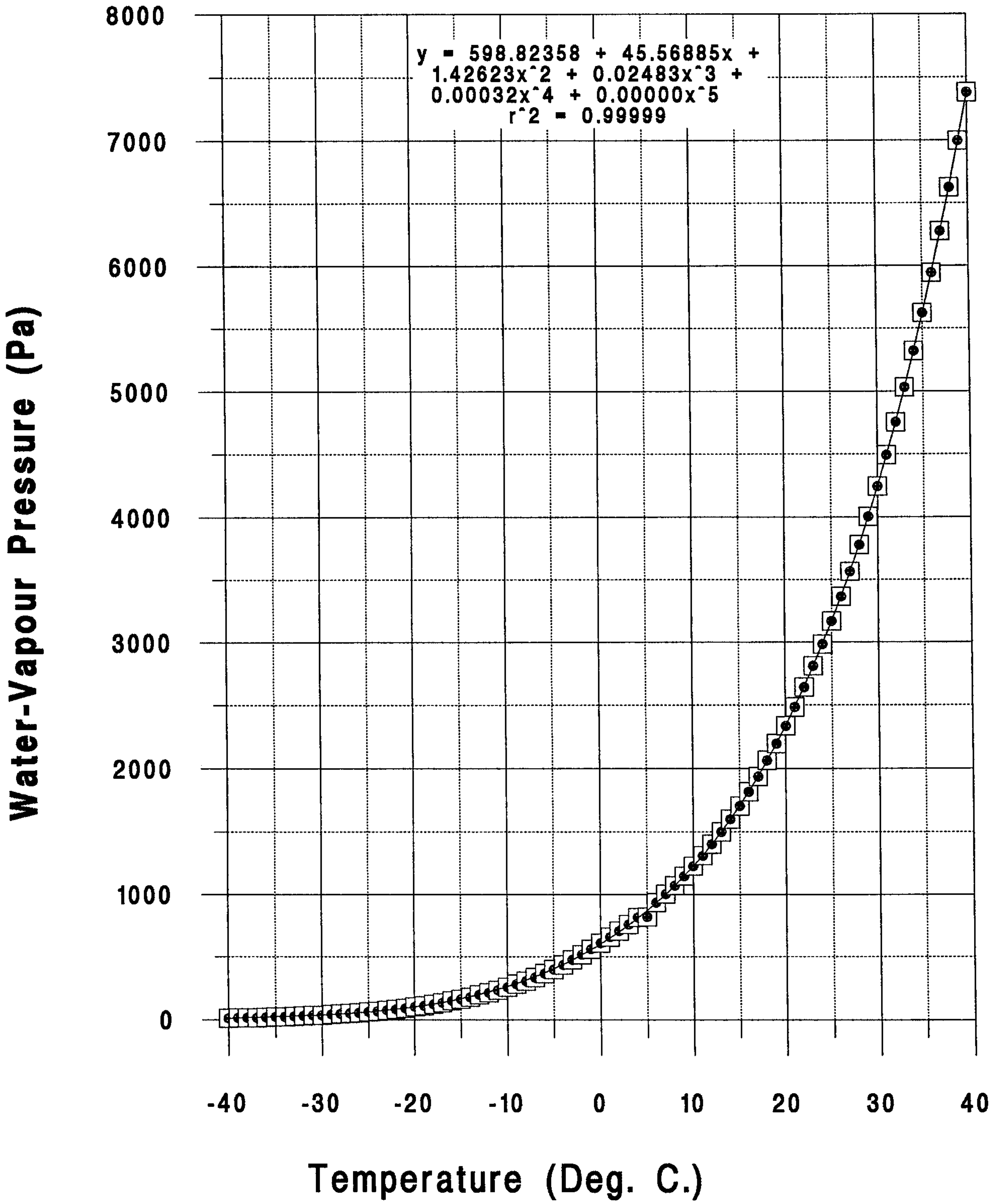
The relative humidity (rh) of a mass of air is the ratio of its actual water-vapour partial pressure (p_w) to its saturation water-vapour partial pressure (p_{ws}). Since the saturation partial pressure is temperature dependent, then using relative humidity to compare the moisture conditions of two masses of air having different temperatures is not appropriate. Instead, the humidity ratio is used. The humidity ratio (W) is defined as the mass ratio of water-vapour to dry air, and measured in kg of water-vapour per kg of dry air. The humidity ratio can be read directly from a standard psychrometric chart for any given state of temperature and relative humidity. Alternatively, once the temperature, relative humidity and barometric pressure are known, the humidity ratio can be calculated as follows:

1. Given the measured temperature, find the saturation vapour pressure (p_{ws}) in Pascals from the chart and equation provided.

2. Given the measured relative humidity, find the partial pressure (p_w) in Pascals from the relationship: $rh = 100 \times p_w/p_{ws}$

3. Given the measured barometric pressure (p_t) in Pascals, find the humidity ratio (W) from the relationship: $W = 0.622 \times p_w/(p_t - p_w)$

Water-Vapour Pressure at Saturation at Various Temperatures over Plane Surfaces of Pure Water and Pure Ice



Appendix D

Pressure Equalization Monitoring of Panel 89

The information contained in this appendix was supplied to CMHC by CAN-BEST for the purpose of illustrating the in-situ pressure equalization characteristics of a typical panel on the Canada Life building exposed to natural wind conditions. This data was obtained from a previous contract executed by CAN-BEST and is being reprinted with permission from Adason Properties Ltd., property managers of the Canada Life building.

The results included in this section are those produced by monitoring panel #89 for pressure equalization. While data from panels #101 and #99 would have preferable, budget constraints involved in the monitoring of these locations forced us to settle for the results of panel #89. Though CAN-BEST expressed reservations about including this information in the final report because the pressure equalization characteristics panels #101 and #99 may not be identical to that of panel #89, CMHC felt that this information was a useful record of the performance of these panels.

The graph outlining the pressure equalization performance of panel #89 in this section shows that a leeward wind causing a stagnation pressure of -110 Pa can account for a pressure of -55 Pa across the cladding (i.e. 50% pressure equalization for this precise loading scenario at this location). If one considers that the cavity sensor was placed in the Roxul™ insulation and not between the geotextile membrane and the limestone cladding, where cavity pressures would no doubt be greater, one can postulate that the pressure equalization performance of panel #89 is better than shown on the graph contained in this appendix.

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CAN-BEST

April 3, 1995

CMHC
700 Montreal Road, 7th floor
Ottawa, Ontario
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Attention: Mr. Pierre-Michel Busque

Dear Mr. Busque,

Re: Pressure Equalization Monitoring - Canada Life Building

A record of pressure equalization monitoring for Panel #89 was sent to you in our first submission of September 8, 1994. Two spreadsheet data files (Excel format) were sent. These, entitled CMHC2.XLS and CMHC3.XLS, provided pressure measurements taken under dry and wet conditions, and the corresponding graphs in time and frequency domains.

The exterior pressure was measured at the bottom of the panel. The pressure tube was positioned in the open horizontal joint directly below the window. The cavity pressure tap was located at the panel's centre between the insulation and the plastic drainage mesh. The pressure tubes used were flexible PVC, 2000 mm in length having an interior diameter of 3 mm and wall thickness 1.5 mm. The enclosed drawing provides the location of the exterior and cavity pressure taps.

The accuracy specifications of the pressure transducers used in the monitoring were as follows:

Full Scale	*±0.5" W.C. (125 Pa)*
Accuracy	*The combined non-linearity, hysteresis, and non-repeatability <±1.0% full scale (best straight line)*
Resolution	*Infinite*
Dynamic Response	*1 kHz*
Repeatability	*< 0.3% full scale*
Thermal Effects	*< 0.033% FS/°F over 40°F to 100°F range, calibrated at 70°F*

I trust the above is to your entire satisfaction. Should you have any questions, please call me at your convenience.

Sincerely yours,

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Science and Technology

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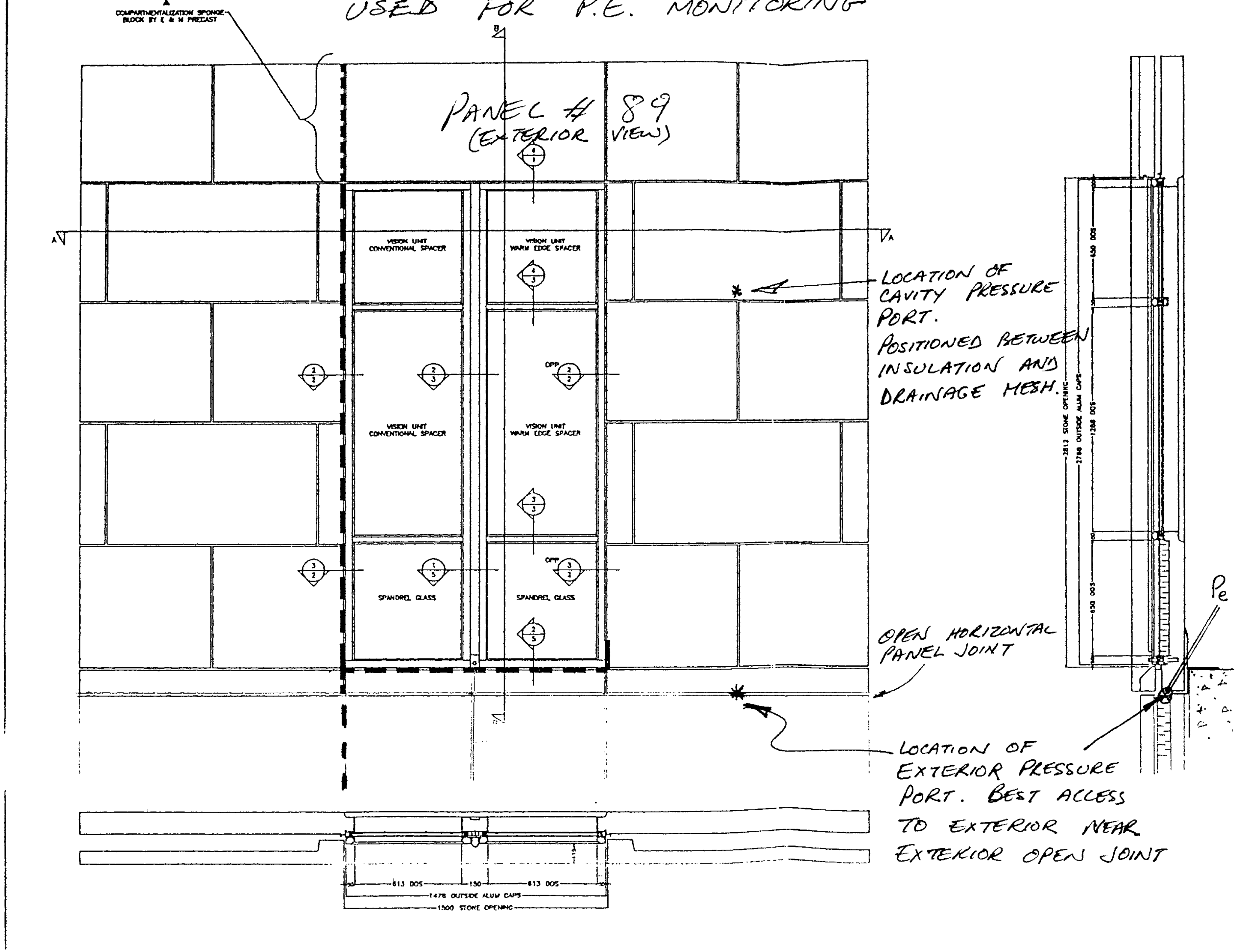
CMHC3.RPT

LOCATION OF PRESSURE PORTS USED FOR P.E. MONITORING



Pressure Equalization at Canada Life Panel 89