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Building cladding air pressure equalisation investigations—comparison between field results and a numerical model

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Abstract

Experimental measurements of the air pressure differentials across the outer cladding layers on four buildings have been made, to assess the likely weathertightness performance of the cladding systems due to the mechanism of pressure equalisation. Results for two of these four buildings verify the pressure equalisation percentages predicted through the use of the numerical model PERAM. © 2000 Elsevier Science Ltd. All rights reserved.

1. Introduction

One of the major requirements of the external cladding of a building is to prevent the ingress of water under all climatic conditions.

Two disparate ideologies within the commercial cladding industry have developed to address this issue of achieving weathertightness in high-rise construction. These techniques may be broadly classified as 'Sealed jointed' or 'Rainscreen jointed' methods. A sealed jointed cladding must be formed of a 'skin' impervious to water and air. As both the environmental fluids (water and air) are present at the same point in sealed jointed cladding systems in the form of rain and wind, the slightest imperfection in the skin can result in weathertightness failure. In contrast, a rainscreen jointed cladding system separates the weathertightness functions of joints in order to achieve weathertightness. Neither of these functions, wind exclusion and water exclusion, require perfection in construction to perform adequately.

Birkeland [1] and Garden [2] first reported on the rainscreen principle in the early 1960's. This resulted in detailed investigation of the new realms opened up to the cladding designer and the development of the following jointing systems: the drained joint system [3], the two stage joint [4], the rainscreen joint [5,6], the pressure-equalised joint [7,8], and the pressurised cavity joint [9] systems. These joint types all, to some degree, implement the rainscreen principle propounded by Garden and Birkeland in the early 1960's. Other researchers [10] have developed these ideas to allow reduction in cladding design loadings [11], as well as cross-cladding differential pressure reductions [12], with Kerr providing a good bibliographic database [13].

1.1. Rainscreen cladding

The operational aim of a rainscreen cladding is to allow the passage of air through a restricted opening into a cavity between the building interior and the exterior cladding. Horizontal and vertical compartmentalisation of joint cavities behind the facade is necessary to restrict transverse flows of air behind the cladding, and cavity venting is through (ideally) a single opening such that the joint cavity is subject to a single isobaric field at any one time.

This imparts a high PEP (pressure equalisation percentage—see Eq. (1)) such that the differential pressure across the potentially wet exterior face of the joint is maintained too low to form a significant driving force

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Nomenclature

A_e	external joint opening area [mm^2]
k_1	coefficient of flow through external cladding layer
k_2	coefficient of flow through internal cladding layer
P	amplitude of external air gauge pressure [Pa]
p_b	gauge air pressure in building interior [Pa]
$P_c(t)$	gauge air pressure within joint cavity at time t [Pa]
$P_e(t)$	gauge air pressure outside joint cavity at time t [Pa]
PEP	Pressure Equalisation Percentage [%]
PER	Pressure Equalised Rainscreen joint [acronym]
T	period [s]
V_c	volume of joint cavity [l]
f	frequency [Hz]

to transport liquid water to the interior of the joint, and the weathertightness of the joint is increased.

The quantitative determination of the weathertightness of a PER (Pressure Equalised Rainscreen) construction joint through the action of air pressure equalisation was not possible prior to the development of equations describing this behaviour [14] and the consequent numerical models [12]. However, experimental verification of these numerical processes has been instigated by Baskaran [15]. This paper describes the experimental determination of the PEP of three cladding types and presents an investigation into cladding cavity compartmentalisation. It also reveals the deficiency in knowledge of raindrop trajectory response to air pressure fluctuation frequency.

1.2. Pressure Equalised Rainscreen joints

The differential air pressure acting across an opening of a PER joint can be a cause of weathertightness failure for the joint, so the PEP was designed to provide a measure of this pressure differential. The PEP, as defined by Burgess [14], is a specific value between 0 and 100% which measures the rapidity and degree to which the internal air pressure within a joint cavity can equalise with the external air pressure, when the joint is subjected to sinusoidal air pressure fluctuations at a specific frequency. A PEP can be calculated from a time history of the air pressures within and outside a PER joint with the equation given below, as derived by Burgess [12].

$$\mathrm{PEP} = 100\left(1 - \frac{1}{2PT}\int_0^T \mid P_e(t) - P_c(t) \mid \,\mathrm{d}t\right). \tag{1}$$

A PEP value of 100% implies that the internal cavity pressure is completely in phase with, and of an identical amplitude to, the driving air pressure, so that at all times the differential pressure across the interface is zero.

The PEP is frequency dependent, and although there is yet no study linking the PEP at different driving frequencies with rain water leakage rates through openings in joints, a figure of PEP = 95% at 3 Hz has been selected as an appropriate benchmark for PER joints [12].

2. Experimental

Two different cladding forms with three different approaches to pressure equalisation were identified on four high-rise buildings within the city of Wellington, New Zealand. The cladding types were as follows.

1. Vented pre-cast concrete panel, hung over a backing wall, Building A—Fig. 1.
2. Pre-cast concrete panels with baffled joints over a backing wall, Building B—Figs. 2 and 3.
3. Ceramic tiles hung over a galvanised steel backpan, Buildings C&D—Fig. 4.

The experimental procedure involved positioning air pressure tappings at several locations around each cladding to measure the static and dynamic external

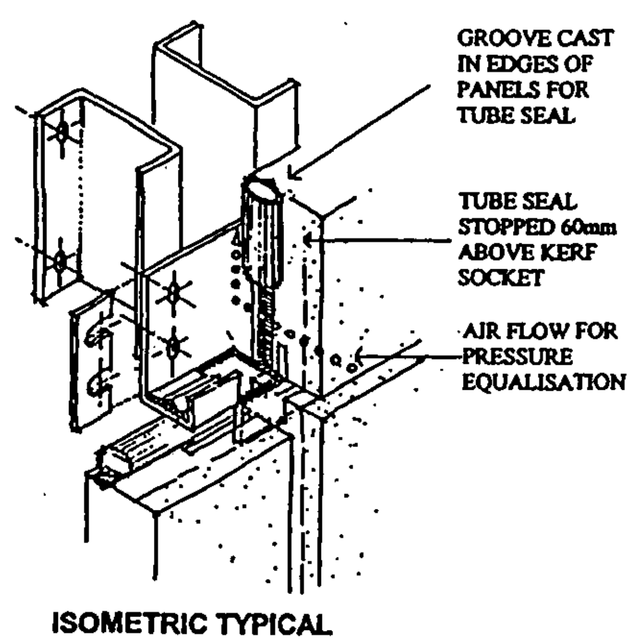

Fig. 1. Isothermic typical double kerf bracket.

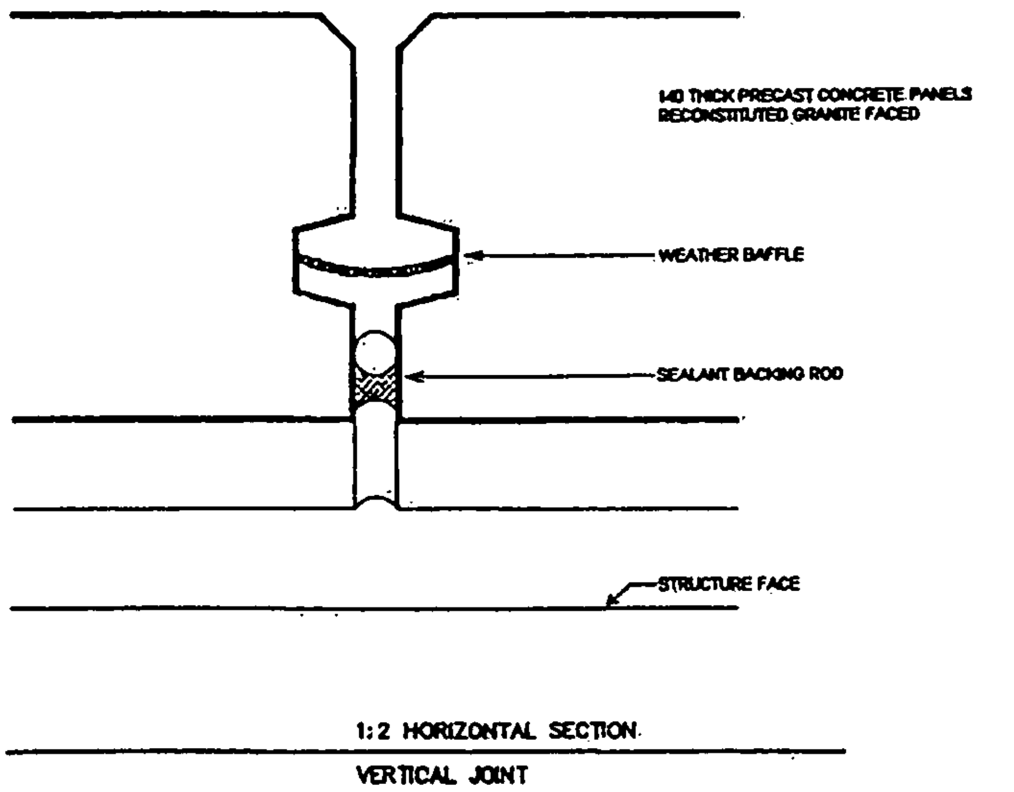

Fig. 2. Horizontal section, vertical joint.

air pressure, the building internal air pressure, and the joint cavity air pressure. To take the external and cavity air pressure measurements P_e and P_c, an air pressure logging head was connected to a pair of bi-directional differential pressure transducers, interfaced to a METRABYTE EXP-RES signal conditioning multiplexer and pc-based data acquisition system, with the pressures referenced to the internal building air pressure, P_b. This static air pressure measurement, P_b was made with a device described by Bassett [16] which performs an averaging over the air pressure environment surrounding the device. A PC-based data-logging system running data acquisition routines in BASIC, was utilised to record data sets logging high wind pressure events over a certain threshold, such that the variables within Eq. (1) could be recorded, to enable an experimental determination of the degree of air pressure equalisation to be made. The data acquisition rate was set at 1 kHz, although phase differences between measurement locations were introduced with this approach, so that only data acquired at below 10 Hz was utilised in this work.

Logging of the air pressure environment around the cladding of these buildings, and the air pressure fluctuations due to wind incidence and resultant air pressure equalisation, was undertaken intermittently over a three year period to obtain a variety of weather conditions, with at least 90 data sets per building.

2.1. Building A

This building has pre-cast concrete cladding panels which are hung (see Fig. 1) over a concrete block backup wall with seals along the extent of the panel horizontal joints, and down the vertical joints, cut 60 mm short of the cruciform joint to provide a slot for the air pressure equalisation of the cladding. However, the cladding cavity is not compartmentalised, and the foot and jambs of termination panels are open, such that air flows are unrestricted within the cladding cavity.

Four pressure measurement sites were chosen in August–December 1995 on the 4-level western elevation of this site on the waterfront in Wellington, New Zealand. There was considerable exposure to the north and west, with the prevailing wind pattern at this site from the north. Sites 1 and 2 were at the third and second levels of the cladding facade, respectively, where logging was performed before the joint cavity, which extends the full length and height of the facade, had been sealed at all its horizontal joints, and at its head, foot and ends. Sites 3 and 4 were at adjacent locations to sites 1 and 2, with logging performed after the cladding cavity had been sealed at all its joints, head and foot in November 1995.

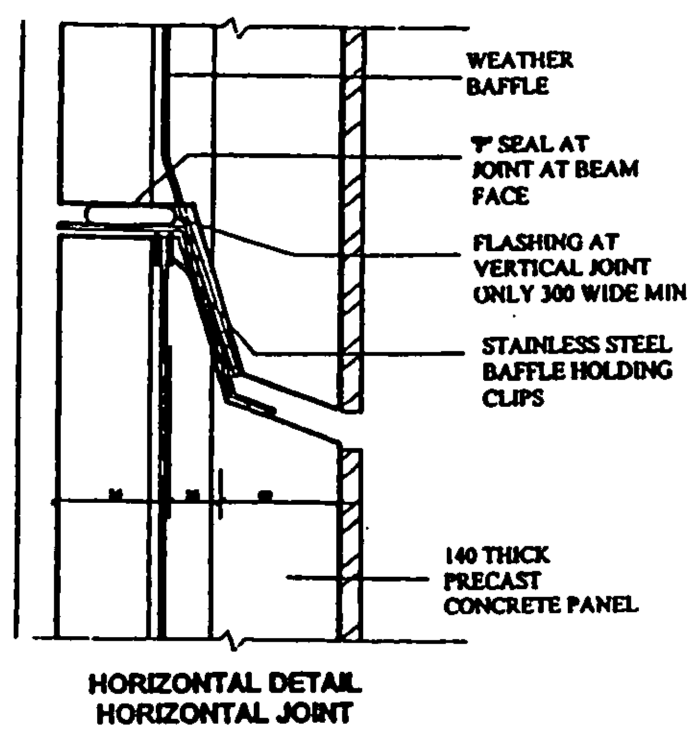

Fig. 3. Horizontal detail, vertical joint.

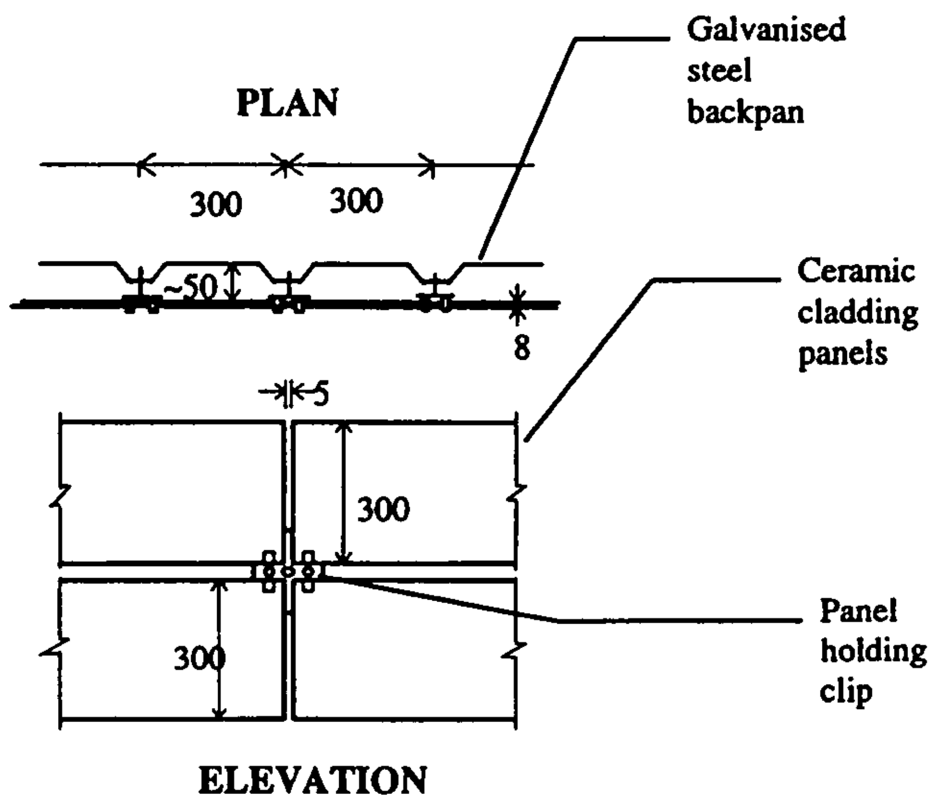

Fig. 4. Plan and elevation of joint.

2.2. Building B

Building B is a 32 level construction completed in 1990 on an elevated site within the Wellington CBD. A very similar approach was taken for the data acquisition on Building B as was performed on the Building A cladding. Two datalogging sites were selected on the 16th level of the facade, with the joint detail shown in Figs. 2 and 3. The cladding type is similar to that of Building A and the jointing is composed of loose fitting baffles within the panel edge joints, without designed joint opening areas. This differs significantly from the Building A example, which has tube seals and designed opening areas. The joint cavity is taken to extend between cruciform joints for the height of the 800 mm wide panel behind the baffle. The joint opening area is a 20 mm wide slit the height of the panel, which varied from 1.2 to 1.8 m high.

2.3. Building C

This is a 14 level building located within the Wellington CBD. Datalogging operations were undertaken in early 1997 on the ceramic cladding panels hung over a galvanised steel backpan. The general joint details are shown in Fig. 4, (same as Building D) where the cavity was compartmentalised into 1.8 m high, 0.3 m wide sections, formed by the ribs of the trough-section galvanised steel backpan. The 600 mm wide tiles span two of these compartments, with the joint opening area around the periphery of the tiles. There is considerable air leakage between the cavities of adjacent panels.

2.4. Building D

This is a four level building on the seafront outside the Wellington CBD, exposed to a considerable catchment to the north, with restricted wind exposure through the city to the west. The north-west facade was utilised to obtain air pressure fluctuation records in late 1997, including some severe storm conditions. The ceramic cladding panels of 600 × 300 mm and attachment detail was the same as that applied to Building C, except that both the cladding cavity volume and joint opening area were three times larger. The general joint details conform to Fig 4.

Table 1
Experimental data: PEP values for the four buildings

Building name	A	B	C	D
No. of runs	820	515	94	1221
Mean	69	65	59	59
Standard deviation	12	12	15	14

2.5. Data analysis

The experimental data was fed to a purpose-built C program running on a PC incorporating a suite of 'Numerical Recipes' [17] FFT methods to filter and correlate the data.

As the PEP is frequency dependent, Fourier methods were used to filter the data and obtain information at single air pressure driving frequencies for analysis. The main frequency of interest was 3 Hz, (as this is a suitable representative frequency for a PEP measurement—see [12]) although frequencies over an order of magnitude from 0.5 to 5 Hz were analysed, being within the range of expected air pressure fluctuation frequencies [13]. An FFT cross correlation is used to determine the phase shift and amplitude modification between the spectral element of the driving signal chosen, and its response. Further C code yields the PEP of each of the data sets pertinent to the system, with the results displayed below.

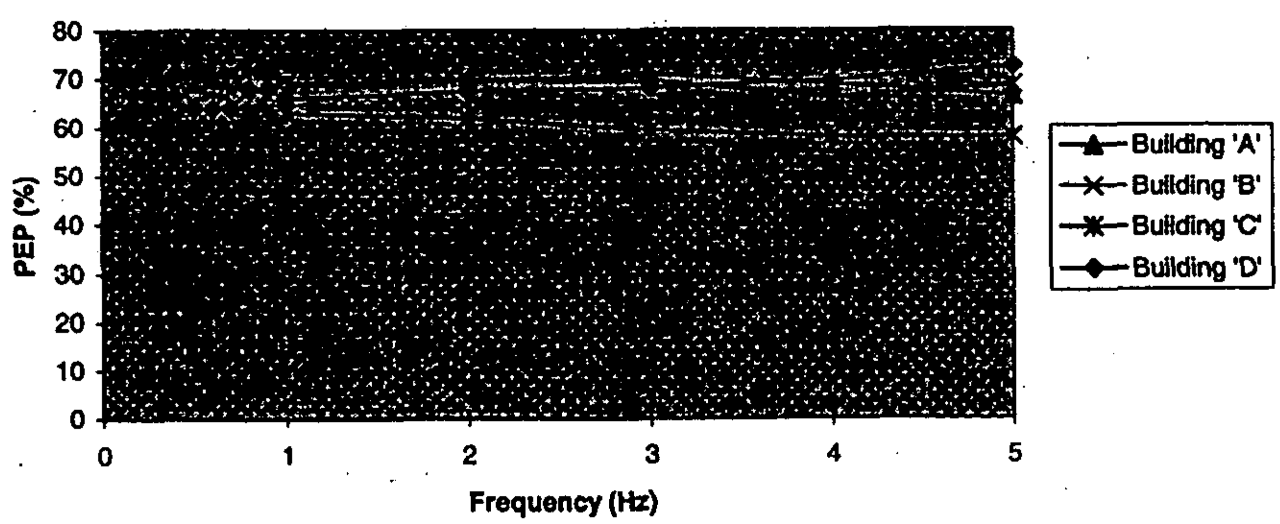

Fig. 5. PEP values by air pressure fluctuation frequency for four Wellington buildings.

Table 2
Comparison of experimental and numeric model data for four buildings

Building	PERAM PEP (3)	Mean experimental PEP (3)
Building A	71	69
Building B	70	65
Building C	83	59
Building D	85	59

3. Results

The range of PEPs at 3 Hz—PEP(3), calculated from the experimental data at the four buildings is shown in Table 1, where each individual experimental run of 200–1000 points yields a PEP for each of the four buildings.

It was observed that there was no noticeable difference at this frequency between the cladding locations chosen on any of the buildings, and no difference between the results from Building A before the cavity was closed and after it was closed. This indicates that the volume of air contained in the cavity of Building A has sufficient inertia that compartmentalisation is effectively achieved without physical barriers at this frequency of 3 Hz.

Fig. 5 portrays the PEP's for the four Wellington buildings at the frequencies investigated in this work.

3.1. Comparison of experimental vs numerical model results

The numerical model PERAM [14] for calculating PEPs was fed the relevant design information for the claddings, including joint opening area, A_e, cavity volume, V_c, and flow coefficients, k_1 and k_2, together with parameters relevant to the phase, amplitude and frequency of the driving air pressure wave. Due to the non-compartmentalised nature of the cladding cavity at Building A, and the linkage between cavities at Building D and Building C, a value of $k_2 = 0.2$ (airflow coefficient through leakage openings) was chosen, as discussed by Burgess [14], as an input parameter to PERAM.

The correlation between the experimental and algorithmic representations of the PEP(3) is given in Table 2.

While the comparison between the experimental and PERAM-numerical PEP's is within 3% for Building A, and 7% for Building B, the performance of the numerical model PERAM at modelling the ceramic tile cladding systems of Buildings C and D is 29% and 28% too high, respectively.

4. Discussion

The numerical model PERAM is shown to predict well the PEP at 3 Hz for Buildings A and B. However, the PERAM predicted results for Buildings C and D with the ceramic cladding panels do not agree well with experiment. Theoretically it is expected that the PEP of these cladding systems would be high, as they incorporate incomplete PER joint design concepts [6].

Upon analysis of the experimental data acquisition from the two buildings C and D, it was realised that the datalogging tap locations were (in both buildings) near to the edge of a bluff face, such that rather than the expected low velocity air flow environment, the data logged could well have included a sizeable component of airflow parallel to the plane of the cladding. The method of pressure measurement included an assumption that there would not be sizeable air flows parallel to the cladding, as parallel airflows would tend to erroneously contribute to the measurement of the local static air pressure environment. It appears that the placement of air pressure tappings near to the edge of the cladding system in Buildings C and D, makes it uncertain how well the results reflect uncorrupted data from parallel air flow contamination, such that the PERAM predictions cannot be well verified for these buildings.

On the other hand, the PERAM predictions are good where we can be confident of the integrity of the data for Buildings A and B. On these buildings, the logging locations used were within a central portion of a bluff face, such that stagnation pressures were expected from wind at normal incidence, that could be isolated from parallel cross flow through the directional external air pressure measurement method.

4.1. Compartmentalisation

The data obtained from Building A, with a non-compartmentalised cladding cavity, reveals that cavity compartmentalisation is in this case, not essential to achieve a *degree* of pressure equalisation at an external air pressure fluctuation frequency of 3 Hz. Of course, a PEP of 65 or 69% at 3 Hz is still not high enough to impart ensured weathertightness through this mechanism, as the target is over 95% [12]. However, the reduction in the wind pressure differential across the wet cladding area and consequent reduction in design load of cladding fixings does impart an advantage over the sealed cladding approach, where a PEP of 50% is expected. Typically [12] the PEP is expected to increase inversely with frequency, although this is not shown in the results, since it is likely that the non-compartmentalisation of the cladding of Building A has reduced the experimentally determined PEP.

5. Conclusions

The numerical model PERAM models the pressure equalisation behaviour of air movement around the cladding systems constructed on Building A and Building B at 3 Hz, to within 3 and 7%, respectively, of that measured experimentally.

Until further work is performed linking the critical air pressure fluctuation frequencies at which rain drops will be imparted with sufficient momentum to re-direct them into cladding cavities, the contribution of the PEP at 3 Hz (or any other frequency) to the weathertightness of cladding systems cannot be effectively measured.

It is recognised that work to determine the critical frequencies at which the trajectories of rain drops of varying sizes will be altered by air pressure fluctuations, will form an important extension to this work.

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References

[1] Birkeland, Curtain Walls. Norwegian Building Research Institute Handbook 11b. Oslo, 1962.

[2] Garden GK. Rain penetration and its control. Canadian Building Digest 40, NRCC, 1963.

[3] Bassett MR. Drained joints, case studies. BRANZ (Building Research Association of New Zealand), 1991.

[4] Brown, Ballantyne ER. Watertight or Weatherproof—application of drained joint principles. Build Forum 1973;23(1):2–8.

[5] Ganguli U, Quirouette RL. Pressure equalization performance of a metal and glass curtain wall. IRC Paper No. 1542, NRCC, Ottawa, Ontario, Canada, 1988.

[6] Killip IR, Cheetham DD. The prevention of rain penetration through external walls and joints by means of pressure equalisation. Build Env 1984;19(2):81–91.

[7] Baskaran A. Extraction of design guidelines for pressure equalised rainscreen walls, Internal Report No. 629, Institute for Research in Construction, National Research Council of Ottawa, 1992.

[8] Fazio P, Kontopidis T. Cavity pressure in rain screen walls. Build Env 1988;23(2):137–43.

[9] Kontopidis T, et al. Potential of rain screen walls to prevent rain penetration: pressurised cavity principle. Building Research and Information 1993;21(3).

[10] Ganguli U, Dalgliesh WA. Wind pressure on open rain screen walls: place air Canada. J Struct Engng 1988;114(3).

[11] Baskaran A, Brown WC. Performance of pressure equalised rainscreen walls under cyclic loading. J Thermal Insul Bldg Envs 1992;16.

[12] Burgess JC. Air pressure equalisation in rainscreened joints by geometric alteration. Build Env 1995;30(1):13–8.

[13] Kerr DD. Annotated bibliography on the rain screen principle. NRCC Bibliography No. 45, 1985.

[14] Burgess JC. Pressure equalised rainscreen joint modelling with the numerical model PERAM. Build Env 1995;30(3):385–9.

[15] Baskaran A. A numerical model to elevate the performance of pressure equalised rainscreen walls. Accepted for publication in Build Env 1994.

[16] Bassett MR A static air pressure measurement device. BRANZ (Building Research Association of New Zealand) Internal report 1985.

[17] Press, Flannery, Teukolsky, Vetterling. Numerical recipes in C: the art of scientific computing. Cambridge: Cambridge University Press, 1992.

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