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J.C. Burgess

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Air Pressure Equalization in Rainscreened Joints by Geometric Alteration

J. C. BURGESS*

Weather penetration through rainscreened building claddings is dependent on the air pressure differences existing across joints in the cladding. Apparatus has been built to model the degree of air pressure equalization that can occur across rainscreened joints and its variation through geometric alteration of the joint opening area and joint cavity volume. The results obtained using this equipment predict that a ratio of joint opening area to cavity volume of over 0.05 m^{-1} *will give a pressure equalization percentage greater than 96% for all pressure variation frequencies. The pressure equalization percentage can fall to 77% for lower ratios of joint opening area to cavity volume at high pressure variation frequencies.*

NOMENCLATURE

P Amplitude of external air gauge pressure [Pa]
P_e Instantaneous external air gauge pressure $= P \sin \omega t$ [Pa]
P_c Gauge pressure of joint cavity $= AP \sin(\omega t + \phi)$ [Pa]
A Constant
ϕ Phase change [rad]
V_c Volume of internal joint cavity [m^3]
f Frequency [Hz]
T Period [sec]
ω Angular frequency [rad.sec^{-1}]
t Time [sec]
$PEP(f)$ Dynamic air pressure equalization percentage [%]
PER Air pressure equalized rainscreened joint
A_e External joint opening area [m^2]
A_c Internal joint leakage area [m^2]
$\neq$ Not equal to

1. INTRODUCTION

AIR pressure equalized jointing systems in the exterior cladding of buildings have been used in some form to prevent weather penetration for many years, for example the ventilated-board cladding systems prevalent in Norway in the 19th century [1]. However, it is only in the last twenty years that the reasons why such systems prevent weather penetration to the building interior have been studied analytically. The concept of enabling the air pressure inside a joint to continually (and rapidly) equalize with fluctuations in the exterior air pressure, has been known since 1963 [2], and utilized in work such as [3]. However the parameters influencing the degree of this air pressure equalization and how it influences weathertightness have not been fully investigated.

The degree of weathertightness in a building cladding system is always a prime concern, and many different methods have been devised to increase this; one example is the use of weathergrooves [4]. However the common face-sealed cladding systems (where joint gaps are filled with a sealant or otherwise blocked off) are notoriously susceptible to workmanship faults, as little can be done at the design stage to avert potential weathertightness problems following construction. Air pressure equalized, rainscreened (PER) jointing systems can however be relatively immune to workmanship errors causing weathertightness failure of cladding systems, if designed so as to allow a large degree of pressure equalization to occur. This may be achieved by modifying geometric features as in [5], and as expounded in this paper.

PER joints have a lower maintenance requirement than face-sealed joints, and, by separating the functions of wind barrier and rain barrier, can result in the rainscreen supporting only a fraction of the design wind pressure of the cladding system, with obvious cost advantages. This has been indicated in [6] following a comprehensive introduction to pressure equalization and the performance of rainscreened joints, which will not be duplicated here. An extensive set of references to publications dealing with PER joint design (among other topics) has been published in [7], and information on the construction and performance of rainscreened walls is found in [8] and [9].

It has been shown [10] that particular joint geometry will determine whether air pressure equalization is possible within a given joint type by modifying the joint opening area (A_e) to joint leakage area (A_c) ratio A_e/A_c, as illustrated in Fig. 1. This ratio is required to be at least 10, and preferably over 25 (as found in [5]), to ensure a large degree of air pressure equalization, and hence cause a reduction in one of the forces causing weather penetration. This paper introduces a mathematical expression for the experimentally measured dynamic air pressure equalization percentage (PEP) of a joint, as a measure to determine the specific weathertightness performance of a PER jointing system. The changes to the PEP that can be obtained purely through geometric alteration of the joint opening area and cavity volume are presented along with the PEP variation due to frequency,

*Weathertightness Physicist, Building Research Association of New Zealand, Private Bag 50908, Porirua, New Zealand.

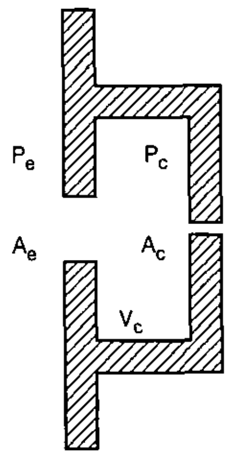

Fig. 1. Air pressure equalized joint.

and it is shown that a joint opening area to cavity volume ratio (A_e/V_c) of more than 0.05 m^{-1} is desirable.

2. THEORY

Air pressure equalization of building cladding joints relates to the situation where the instantaneous air pressures on each side of a restricted orifice (the joint opening area—A_e) are equivalent at all times. As a result the differential air pressure across A_e is reduced to zero, which eliminates the pressure difference across a joint opening as a cause of water penetration.

It has been demonstrated [11] how a pressure equalized jointing system is able to achieve an air pressure within a joint that rapidly equalizes to the air pressure outside a joint, however no dynamic expression for the degree of air pressure equalization has been defined. This paper addresses this situation, and presents two geometric parameters that influence the degree of pressure equalization achievable in a PER joint.

2.1. *The pressure equalization percentage of a rainscreened joint*

The degree to which the internal joint cavity air pressure can equalize with fluctuations in the external air pressure at a particular frequency can be measured experimentally, and has been termed the dynamic air pressure equalization percentage (PEP). The PEP is derived from the differential pressure across a PER joint, and is a function of frequency as pressures will take a certain time to equalize, as has been found indirectly in [12]. This dependence on frequency indicates that the differential air pressure across a joint opening will be least at low frequencies, which results in a lower force available to drive water leaks, and gives a higher degree of pressure equalization. The converse of this is also true. The PEP can be defined at a specific frequency by equation (1).

$$PEP(f) = 100\left(1 - \frac{1}{2PT}\int_0^T |P_e - P_c|\,dt\right). \quad (1)$$

This definition has been chosen in order that the following equations will hold true for all time.

$$P_e = P\sin\omega t = P_c, P_e \neq 0 \Rightarrow PEP = 100\% \quad (2)$$

$$P_e = P\sin\omega t, P_c = 0, P_e \neq 0 \Rightarrow PEP = 50\% \quad (3)$$

$$P_e = P\sin\omega t = -P_c, \quad P_e \neq 0 \Rightarrow PEP = 0\%. \quad (4)$$

These equations allow a sensible range for pressure equalization to exist within, being dependent on the phase and amplitude of the exciting sinusoidal air pressure fluctuations and avoiding the generation of physically meaningless negatively-valued PEPs.

This definition of the PEP determines that a PER cladding may have a PEP of 100% if the pressure response is in phase with, and equal to, the driving pressure, or a PEP of 50% if the internal air leakage through A_c coupled with the external air leakage through A_e is able to maintain a pressure of 0 Pa in the joint cavity. A poorly designed PER joint may have a PEP of less than 50% at low wind pressure frequencies, and the PEP could approach 0% [as in equation (4)] at high wind frequencies if the internal and external air pressure fluctuations are significantly out of phase, implying high differential air pressures across the cladding. This could lead to poor weathertightness performance, which can be prevented: a situation which this paper addresses. The ultimate goal for PER claddings, however, is a PEP of 100% so as to eliminate one of the factors responsible for weather penetration.

2.2. *Natural conditions*

In the natural world, chaotic gusting wind is incident on PER building cladding joints, commonly with pressures in the range of ± 1 kPa, and with air pressure fluctuation frequencies from effectively zero to 6 Hz, although little wind energy is contained in gusts above a frequency of 2 Hz [13]. In severe climatic events, air pressure and frequency peaks may exceed these arbitrary values, but simulation of this range of conditions will cover a large range of the climate-driven air pressure fluctuations that a PER joint in a building cladding will be subject to. A time sequence of the chaotic air pressure fluctuations incident on a joint (mainly due to wind), may be decomposed through Fourier analysis into a set of sinusoidal waveforms differing in phase, amplitude and frequency. Use of one of these sinusoidal waveforms will determine the PEP response of a PER joint to a single component of such a frequency stimulus, as is performed here. The actual response of a PER joint to a chaotic climatic stimulus may then be theoretically determined, with a mathematical combination of the responses from each single frequency component. This may be done with Fourier methods if it is assumed that the system has a linear response function: as is implied from the results. However, no attempt is made here to combine the individual PEPs from each frequency response.

3. EXPERIMENTAL

A sinusoidally oscillating air pressure was generated with frequencies varying from D.C. to 6 Hz with air pressure amplitudes (P_e) maintained in the range of ± 1 kPa from atmospheric pressure. This allowed a varying air pressure to be applied to a PER joint, modelled as a system of chambers, with the experimental arrangement depicted in Fig. 2. This meant that air pressure change rates of up to 12 kPa/sec could be generated, as measured with a pair of MKS bi-directional, differential pressure

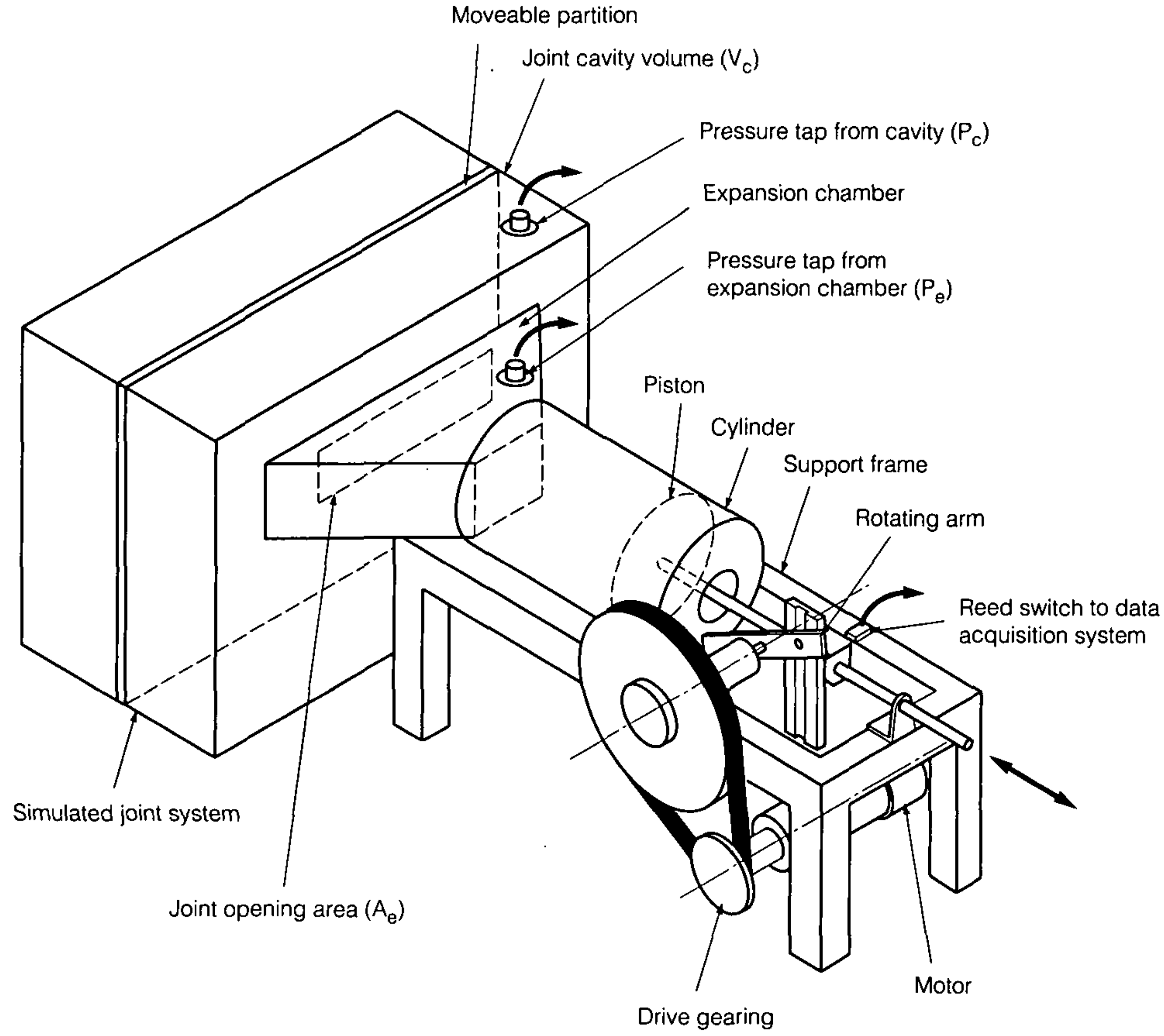

Fig. 2. Sinusoidal air pressure generation equipment and joint simulation.

transducers tapping from the expansion chamber, where P_e was generated, and the joint cavity, where P_c was measured. This air pressure is incident on a specific joint opening area A_e, the geometry of which could be varied from 0 mm × 0 mm, to 500 mm × 200 mm, although the smallest opening size was arbitrarily limited to 400 mm × 5 mm to mimic a realistic joint opening area. The sizes of A_e and V_c were chosen to mimic the sizes of these parameters that are commonly found in concrete panel rainscreen cladding systems, where there is a slot opening at the bottom of each panel, and an interior volume behind the exterior facade. Air could then flow from A_e into the volume of the pressure equalization cavity V_c, which could be varied in size from 0 mm × 0 mm × 0 mm, to 635 mm × 750 mm × 960 mm (450 litres), before air flows could continue through the internal leakage area A_c. The size of A_c was maintained at a set value chosen to satisfy the condition that A_e/A_c was greater than 25. Upon P_e becoming negative, air flows were free to reverse their flow direction and exit the PER joint system through A_e. Pressures P_e and P_c were logged for a time, t, greater than $10/f$, with an EXP-RES signal conditioning multiplexer. This was connected to a PC which was automated to allow sampling frequencies in excess of 400 Hz, enabling accurate representation and determination of signals to at least 30 Hz.

Data manipulation, mathematical and graphical analysis was continued through the SAS programming language on a micro-Vax cluster where an FFT (fast Fourier transform) routine was used to calculate a cross correlation between P_e and P_c, determine the phase shift, and calculate the PEP values. Equation (1) was computed on an IBM-clone PC, running a routine in the C^{++} language. Parameters investigated were the dependence of the PEP on frequency (f), joint opening area (A_e), joint cavity volume (V_c), and their combination (A_e/V_c). It was expected that the combination of low frequency, small V_c and large A_e, would result in a PEP that would approach 100%, as the air pressure equalization would be rapid. It was also expected that the combination of high f, large V_c and small A_e, would result in a small PEP, indicating large differential pressures across the joint opening which could lead to poor weathertightness performance. This is due to restriction in the communication of the air pressure through a small A_e, and retardation of the air pressure change in a large V_c due to the volume of air required to alter P_c.

4. RESULTS

Figure 3 illustrates a typical experimental run where P_e and P_c are logged, showing that both the amplitude and phase of the response waveform (P_c) in the joint cavity vary from the external driving air pressure (P_e). The results of all experimental runs were converted to PEPs by equation (1), and are presented in Tables 1, 2, and 3, so the dependency of the PEP on the joint opening area, joint cavity volume, and the driving frequency of the external air pressure can be determined. Each table portrays the PEPs measured at nine different frequencies for ten different joint opening areas. The frequencies

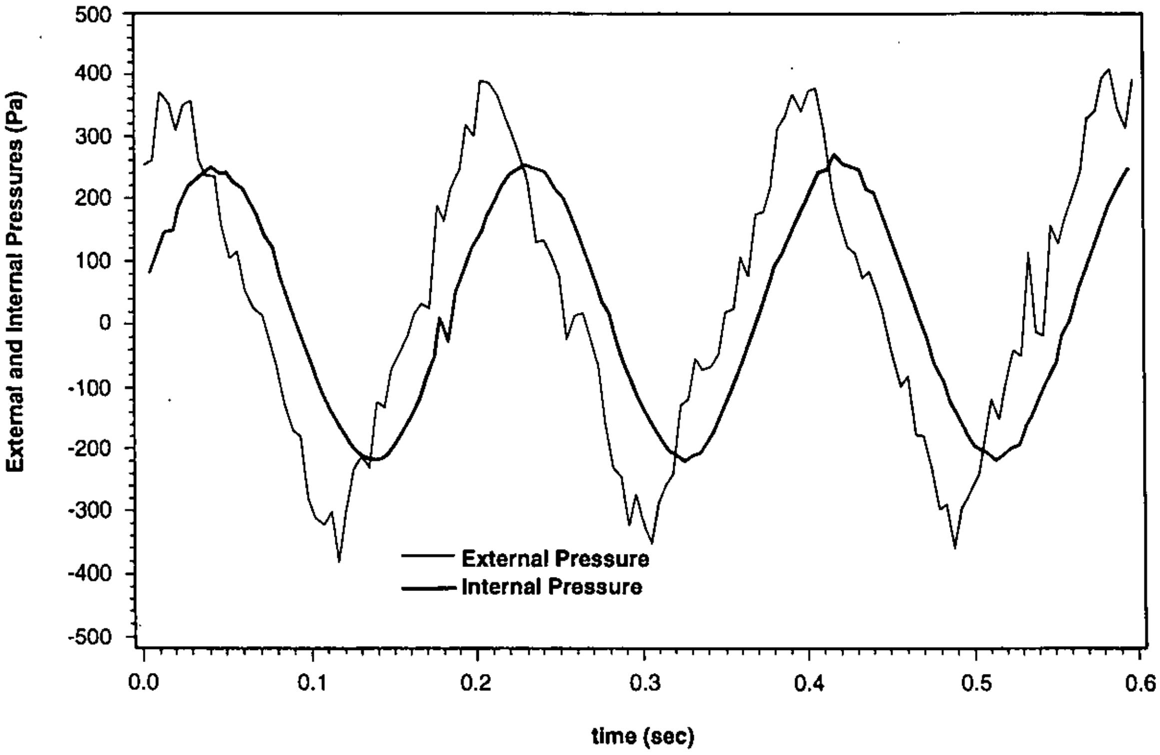

Fig. 3. Air pressures logged for a single experimental run, where the sinusoidal fluctuations in the external air pressure drive the sinusoidal air pressure fluctuations in the cavity.

are termed 'Nominal' as they were indirectly controlled, varying by up to 7%.

4.1. *The relation between the pressure equalization percentage, frequency, and geometric parameters*

The variation in the PEP which is introduced due to the frequency variation of P_e is illustrated in Fig. 4, as derived directly from the experimental measured data. Here, the driving frequency of P_c varies from 0.96 Hz to 5.6 Hz. The PEP is expected to reduce with increasing frequency, as pressures have less time to equalize, resulting in larger differential pressures in the integration of equation (1), as is indeed observed.

The variation in the PEP introduced due to variation in the joint opening area (A_e) is seen in Fig. 5. A_e varies over an order of magnitude from 2000 mm^2 to 40,000 mm^2. The PEP is expected to reduce with reducing A_e as is observed.

The variation in the PEP introduced due to cavity volume variation (V_c) is seen in Fig. 6. Here, V_c varies over a factor of 3 from 150 litres to 450 litres. Here again, the PEP is expected to reduce with increasing V_c as can be verified from the figure.

4.2. *Geometric combinatorial effects*

The two geometric parameters of A_e and V_c individually affect the values of the PEP at all frequencies. However, if the combination of A_e/V_c is graphed versus the PEP as in Fig. 7, the variation in the PEP may be

Table 1. Pressure equalization percentages for a joint cavity volume $V_c = 450$ l for various frequencies and joint opening areas

PEPs	Nominal frequency (Hz)								
A_e (mm^2)	1	1.7	2.4	3	3.8	4.3	4.7	5.2	5.6
5×400	98	94	86	84	80	81	82	80	77
5×500	94	93	91	87	86	86	84	82	80
10×400	99	96	92	88	85	86	84	86	84
10×500	97	94	92	90	89	85	83	80	77
20×400	100	99	98	97	96	94	93	94	93
20×500	98	98	98	98	97	96	96	95	95
40×400	100	100	100	99	99	99	99	99	99
40×500	98	98	98	98	97	97	97	96	96
80×400	100	100	99	99	99	99	98	98	98
80×500	100	100	99	99	99	99	98	98	98

Table 2. Pressure equalization percentages for a joint cavity volume of $V_c = 225$ l for various frequencies and joint opening areas

PEPs	Nominal frequency (Hz)								
A_e (mm^2)	1	1.7	2.4	3	3.8	4.3	4.7	5.2	5.6
5×400	99	98	97	95	92	90	88	91	90
5×500	97	97	96	95	93	93	92	90	89
10×400	100	99	99	98	96	96	94	94	93
10×500	98	97	97	97	97	97	97	97	97
20×400	100	100	99	99	99	99	99	99	99
20×500	98	97	97	97	97	97	97	97	97
40×400	100	99	99	99	99	99	98	98	98
40×500	97	97	97	97	97	97	97	97	97
80×400	100	99	99	99	99	98	98	98	98
80×500	100	99	99	99	99	98	98	98	98

Table 3. Pressure equalization percentages for a joint cavity volume of $V_c = 150$ l for various frequencies and joint opening areas

PEPs	Nominal frequency (Hz)								
A_e (mm^2)	1	1.7	2.4	3	3.8	4.3	4.7	5.2	5.6
5×400	100	99	98	96	94	92	94	93	92
5×500	100	99	99	98	97	96	95	95	94
10×400	100	100	99	99	98	98	97	97	98
10×500	100	100	99	99	99	99	99	99	98
20×400	100	100	99	99	99	99	99	99	98
20×500	100	99	99	99	99	98	99	98	98
40×400	100	100	99	99	99	99	98	98	98
40×500	100	99	99	99	99	98	98	98	98
80×400	100	100	99	99	99	99	98	98	98
80×500	100	99	99	99	99	98	98	98	98

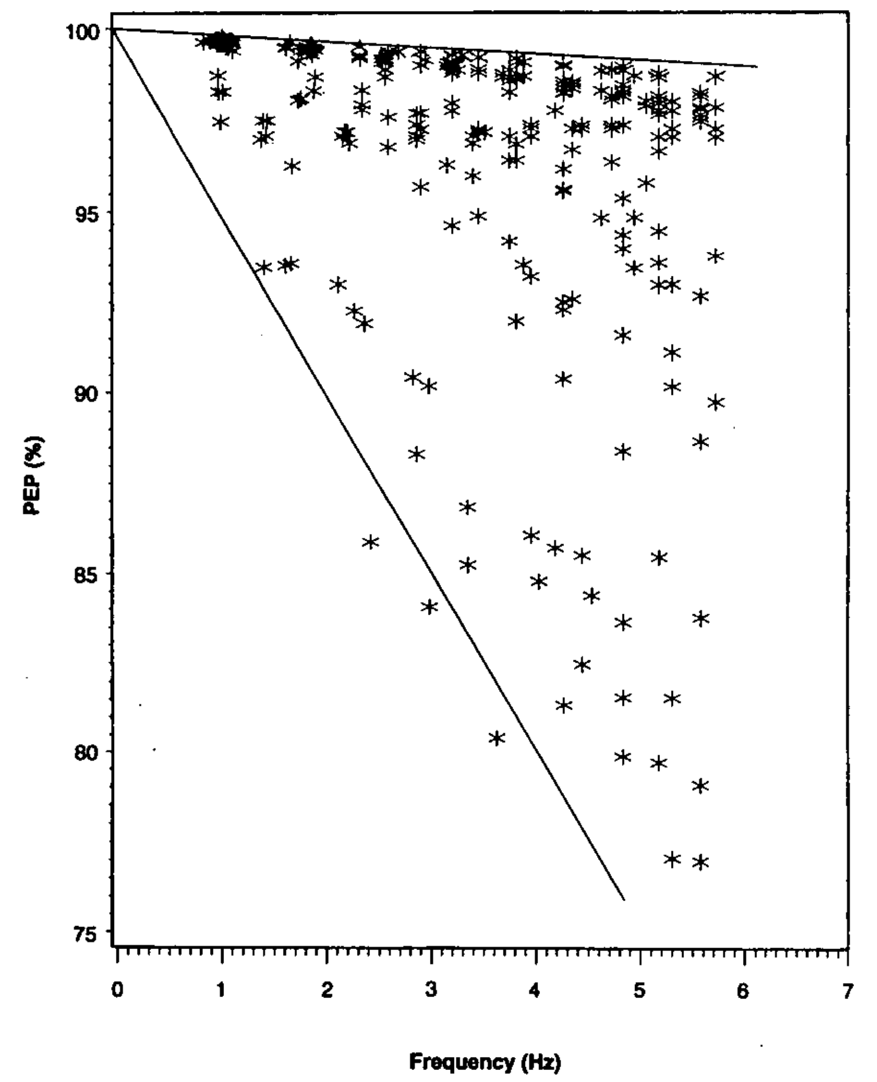

Fig. 4. Variation in the air pressure equalization percentage with frequency of the external air pressure fluctuation. Two of a family of curves for all values of the joint opening area and cavity volume are shown. Frequency varies from 0.96 to 5.6 Hz.

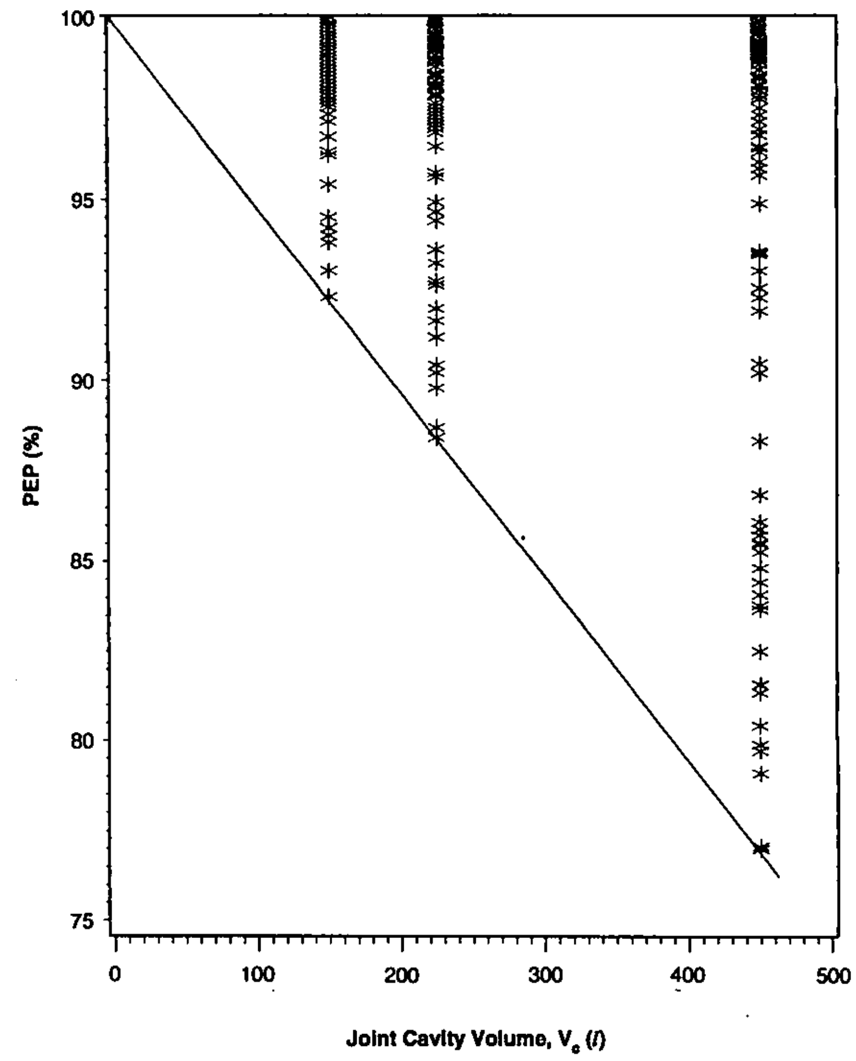

Fig. 6. Effect of variation in the joint cavity volume. One member of a family of curves for all the tested frequency values and joint opening area values is shown. Volume varies from 150 l to 450 l.

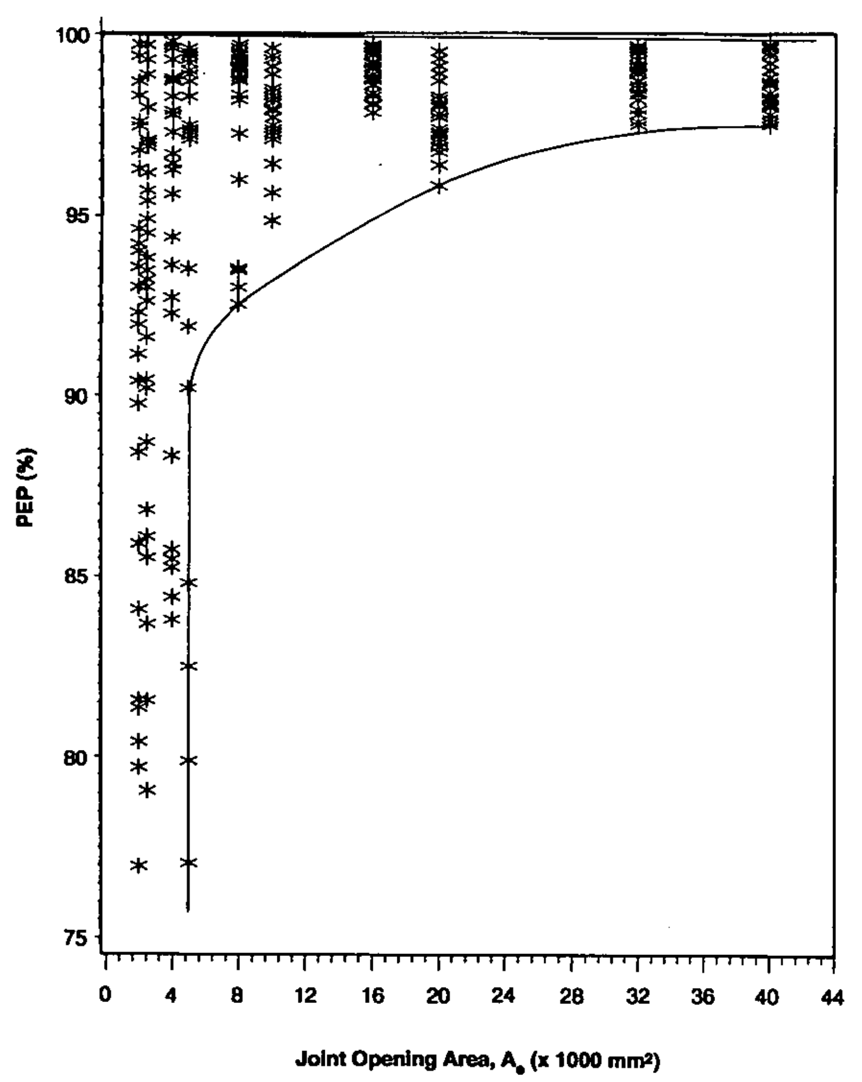

Fig. 5. Effect of variation in the external joint opening area. Two of a family of curves for all values of frequency and joint cavity volume are shown. Joint opening area varies from 2000 mm^2 to 40,000 mm^2.

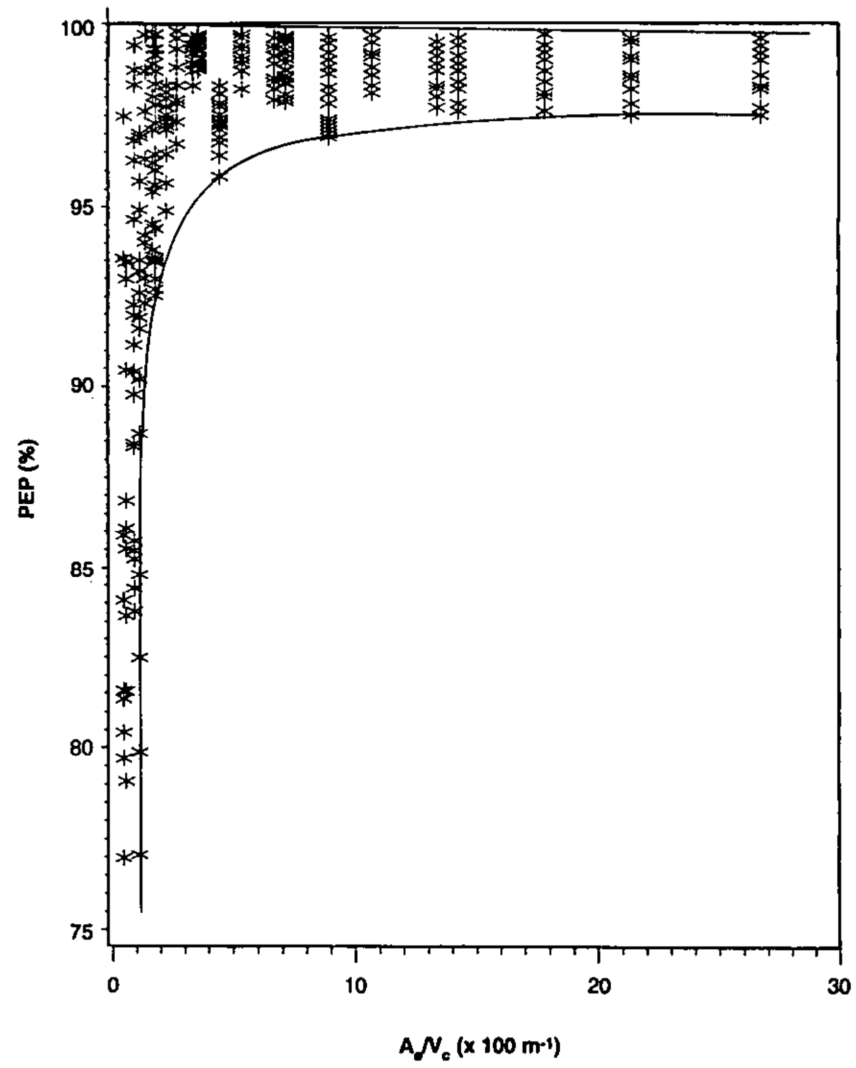

Fig. 7. Pressure equalization percentage versus joint opening area/cavity volume. Two of a family of curves for all values of frequency are shown. The ratio varies from 0.005 m^{-1} to 0.26 m^{-1}.

seen to be related more closely to this ratio. From this graph it can be stated that a value for A_e/V_c of more than 0.05 m^{-1} is required at all frequencies in order to achieve a PEP of at least 96%, thereby reducing the differential pressure available to drive weather penetration through PER joints.

5. DISCUSSION

There is a distinct PEP value for the same joint system at every frequency, however, if any 'total' PEP was calculated by averaging the individual PEPs measured over many frequencies, it would require an arbitrary limit to be set on the maximum measurement frequency utilized, a procedure of debatable merit. Rather, the PEP for a particular joint can be quoted at a specific frequency, say 3 Hz, so as to allow comparisons to be made between jointing systems. The PEP at any frequency may then be interpolated from Fig. 4 if desired, as all rainscreened joints must have a PEP of 100% at a frequency of 0 Hz, but may have a PEP anywhere between 0 and 100% at other frequencies. From this fact, the PEPs for a range of joint opening area sizes, joint cavity volumes, and sinusoidal air pressure frequencies may be read off from the 3 Hz column in Tables 1, 2 and 3.

Experimental measurements may still be used to generate a PEP for a PER joint if desired, yet this work in conjunction with previous results from [5] and [10] has shown that the influence of geometric alteration on the pressure equalization of PER joints (and therefore their weathertightness) may be calculated.

6. CONCLUSIONS

Geometric alteration of the joint opening area and the joint cavity volume of a rainscreened joint has been shown to affect the degree to which air pressures can equalize across the joint opening areas of pressure equalized rainscreened joints. This reduces the magnitude of one of the factors causing weather penetration, and so geometric alteration of pressure equalized rainscreened joints can result in improved weathertightness. A measure of the degree of air pressure equalization in a pressure equalized rainscreened joint has been defined as the dynamic air pressure equalization percentage (PEP), which is able to be obtained from experimentation. Results obtained show that the ratio of joint opening area to joint cavity volume is required to be more than 0.05 m^{-1} to generate a pressure equalization percentage of over 96%. Joints at the other geometric extreme with a ratio of less than 0.05 m^{-1} have pressure equalization percentages as low as 77% at high frequencies. The frequency of sinusoidal air pressure fluctuations has also been shown to affect the air pressure equalization of a given jointing system.

As a result of this work it can be seen that air pressure equalization percentages of 100% are readily achievable purely through geometric alteration of the dimensions of pressure equalized, rainscreened joints. As weathertightness is partially dependent on the magnitude of the differential pressure across a joint, this information will allow air pressure equalized, rainscreened, exterior cladding systems to be designed for favourable weathertightness behaviour without necessary recourse to experimentation.

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