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Date September 1995

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REPRINT

No 134 (1995)

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From: Building and Environment,
Vol 30, No.3, 1995 pp.385-389

ISSN: 0111-7459

Pergamon

Building and Environment, Vol. 30, No. 3, pp. 385–389, 1995

0360–1323/95 $9.50+0.00

0360–1323(95)00003–8

Pressure Equalised Rainscreen Joint Modelling with the Numerical Model PERAM

J. C. BURGESS*

A process is developed to forecast cladding joint air pressure variations which affect rainscreen joint weathertightness in buildings, without recourse to experimental testing. A numerical model, PERAM, is presented to solve equations governing the pressure response of air within the cavity of a rainscreened joint in a building cladding when subjected to an external sinusoidal air pressure variation. A measure of the pressure equalisation performance of the joint as a percentage (the PEP) can then be calculated from the model waveforms derived, as a determination of the degree of weathertightness of the joint system. The PEPs calculated by PERAM are shown to fit the experimental data by incorporating two physically well-defined floating parameters into PERAM. This suggests that the model can be applied at the design stage of detailing weathertight pressure equalised cladding systems.

NOMENCLATURE

- A_e external joint opening area [mm^2]
- k_1 coefficient of flow through external cladding layer from equation (2)
- k_2 coefficient of flow through internal cladding layer from equation (3)
- n number of moles of substance [mol]
- 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]
- $P_e(t)$ instantaneous external air gauge pressure at time t [Pa]
- PEP Pressure Equalisation Percentage [%]
- PER Pressure Equalised Rainscreen joint [acronym]
- q_1 airflow rate through external cladding layer [mol s^{-1}]
- $\dot{q}_1$ differential with respect to time of q_1 [mol s^{-2}]
- q_2 airflow rate through internal cladding layer [mol s^{-1}]
- R gas constant [JK^{-1} mol^{-1}]
- Re Reynolds number
- s reciprocal of exponent to pressure difference
- t time [s]
- T period [s]
- T_c temperature [K]
- V_c volume of joint cavity [l]
- α constant
- β constant
- ω angular frequency of pressure variation [rad s^{-1}]

INTRODUCTION

TWO distinct methods are used to construct the outer layer of building claddings which are designed to impart weathertightness. These may be broadly classified as 'Sealed jointed' or 'Rainscreen jointed' systems. This distinction, although wide, effectively divides jointing methods into these two distinct groups, each possessing definite separate characteristics. A sealed jointed cladding must be formed of a skin impervious to water and air in order to be effective, as air pressure differences across claddings can cause water leaks. The joints in a sealed cladding also need to remain in perfect condition between building cladding maintenance intervals to remain weathertight. Both water and wind pressure are present at the same point in sealed jointed cladding systems, so the slightest imperfection in the integrity of the sealing can result in major leakage problems. In contrast, a rainscreen jointed cladding system seeks to physically separate two of the different weathertightness functions of a joint—wind exclusion and water exclusion—in order to achieve weathertightness, neither of which require perfection in construction to perform adequately.

This realisation by the early researchers Birkeland [1] and Garden [2] that an improved degree of weathertightness may be achieved within a jointing system if the two different physical requirements of the joint (being the prevention of water and air ingress) were physically separated, resulted in the development of the following jointing systems: the drained joint system [3], the two stage joint [4], the rainscreen joint [5], the pressure equalised joint [6], and the pressurised cavity joint [7], among others. All these jointing systems are variably capable of achieving a certain degree of pressure equalisation within themselves; however, the term 'Pressure Equalised Rainscreen' joint or PER joint has been coined by the Canadians [8] to refer to a construction of joint which, by design, specifically achieves a high degree of pressure equalisation through the compartmentalisation of joint cavities behind the facade, the provision of venting areas to the outside within each compartment to allow for the

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limited influx and efflux of air from variations in wind pressure such that rapid air pressure equalisation can occur, and for the drainage of water.

PER JOINTS

The outer rainscreen of a PER joint (see Fig. 1) sheds most of the water from rain and surface runoff, while the joint is composed of a sealed cavity beyond this point, formed with an airseal, which prevents air current-entrained water from passing into the joint. The intent of such a construction is to eliminate the pressure differential that may act across any wet orifice, by providing for the rapid equalisation of the joint cavity air pressure with that externally applied air pressure which impacts on the joint from natural wind. In so doing, the differential pressure is too low to form a driving potential for the transport of liquid water to the interior of the joint, and the weathertightness of the joint is increased. Transverse flows of air behind the cladding are eliminated by the horizontal and vertical compartmentalisation of the cladding, and cavity venting is through a single opening such that the interior of the joint is subject to only one exterior air pressure region at any one time.

The PER system has been shown, e.g. by Ganguli and Dalgliesh [9], to be an effective method of weathertightening the external facades of high rise buildings. Further elucidation concerning PER joints, and the problems raised through the spatial and time variation in wind-generated air pressures, are dealt with by Baskaran and Brown [10], with information and many useful references also coming from Kerr [11].

WEATHERTIGHTNESS THROUGH THE 'PEP' OF A JOINT

Until recently there has been no method of quantitatively determining the weathertightness of a PER construction joint as imparted through the action of air pressure equalisation, and designers could rely only on the qualitative means of extensive laboratory simulation of a range of environmental conditions, or observation of the system in place, by which time it was too late for design solutions to be built in.

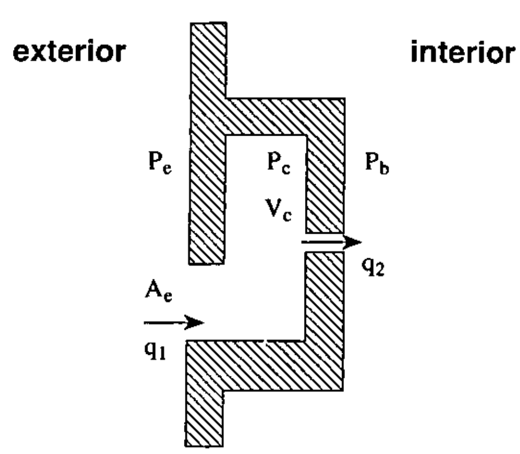

Fig. 1. Section through an idealised pressure equalised joint, showing the joint opening area A_e, cavity volume V_c, and joint leakage as the airflow q_2.

However, independently in 1993–94, both the present author [12] and Baskaran [13] implemented a quantitative measure of the degree of pressure equalisation that is able to be achieved in a particular joint construction from experimental measurements. This was termed the PEP—the pressure equalisation percentage (Burgess)—or the PEI—the pressure equalisation index (Baskaran).

THE PEP

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 (pressure equalisation percentage) was designed to provide a measure of this pressure differential. The PEP, as defined in Burgess [12], is a specific value between 0 and 100% that 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].

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

A PEP value of 100% implies that the internal cavity pressure is completely in phase with, and of an identical amplitude to, the driving sinusoidal air pressure, so that at all times the differential pressure across the interface is zero. A PEP of 50% implies an identical magnitude air pressure response wave (P_c) of phase lag $\pi/2$; an in-phase amplitude damping between the driving and response air pressures; a combination of the two; or, more commonly, a DC level constant response pressure (possibly $P_c = 0$ Pa, for a face sealed joint). A very improbable PEP of 0% is derived from a response air pressure wave P_c of identical magnitude to the driving air pressure, but at a phase lag of π, meaning that the differential pressure across the interface is always at a maximum of twice the imposed air pressure P_e.

The PEP required to ensure that the air pressure variation across an open orifice of a PER joint is maintained low enough so that water is unlikely to be entrained into air flows, or be driven into the joint through water bridging a small joint, is independent of the external pressure environment. A suitable generic PEP value required to ensure the existence of such an air pressure environment may be taken arbitrarily from the results of [12] as 95%. This figure is obtained at a sinusoidal external pressure fluctuation frequency of 3 Hz, as is accepted practice when quoting PEPs due to the variation of the PEP with frequency.

As a result of the work of Burgess [12] and Baskaran [13], a method now exists that is capable of comparing the pressure equalisation performance of PER joints through the experimental calculation of the PEP. However, extensive experimentation is still required to determine a PEP for a specific joint in a PER wall.

This issue is addressed in this paper through the development of a numerical model, PERAM, which is able to calculate the response of a PER joint to a sinusoidally fluctuating exterior pressure. These pressure amplitudes are then able to be converted into a PEP through equation (1). Previous work [12] has experimentally determined the PEP of a range of joint geometries of varying frequencies, and the PEP results derived from PERAM are matched to these.

ANALYSIS

Taking the boundary condition of wind modelled as a sinusoidal air pressure fluctuation, $P_e = P \sin \omega t$ impacting upon the exterior of a PER joint, and assuming that air is incompressible, we will attempt to model the air pressure response of the cladding joint cavity of volume V_c and solve for the airflow rate q_1. As can be seen from Fig. 1, air from natural wind gusts must first flow through a designed joint opening area (A_e) in the cladding to gain access to the internal joint cavity. From here the air flows may continue only through cracks in the air barrier formed around the compartmentalisation of the cladding, or back out through A_e. The contribution to air leakage from all the cracks in the air barrier is attributed to the air flow q_2 through only one crack, with the crack flow coefficient k_2. The governing equations of airflow through such cracks and joints are given respectively by equations (2) and (3) from Kimura [14].

$$q_1 = k_1(P_e - P_c)^{1/s} \tag{2}$$

$$q_2 = k_2(P_c - P_b). \tag{3}$$

If we differentiate the ideal gas law with respect to time, and substitute equations (2) and (3) for q_1 and q_2 after assuming that $dn/dt = q_1 - q_2$ and that $dV_c/dt = 0$, we obtain equation (4).

$$\frac{dP_c}{dt} = \frac{RT_e}{V_c}[k_1(P_e - P_c)^{1/s} - k_2(P_c - P_b)]. \tag{4}$$

Then, making P_c the subject of equation (2), we substitute for P_c into equation (4), and equate this to the time differential of P_c (dP_c/dt) from equation (2), and with some re-arrangement we obtain equation (5), where $\alpha = RT_e k_2^s / V_c s$, and $\beta = k_2^s / s$.

$$q'_1 q_1^{s-1} + \frac{k_1}{k_2^s}\alpha q_1^s + \alpha q_1 = \beta P \cos \omega t + k_1 \alpha P \sin \omega t - \alpha k_1 P_b. \tag{5}$$

The above assumes an incompressible flow regime, while $dV_c/dt = 0$ effectively means that the cavity has totally inflexible walls. P_b is taken as a constant, meaning that the air pressure beyond the extent of the sealed joint system is maintained constant (by the air handling system of the building), and we also use the boundary condition $P_e = P \sin \omega t$. Equation (5) is unfortunately not analytically solvable in the region of interest, and so has to be solved numerically.

NUMERICAL MODEL

The numerical model that has been written to find the solution to equation (5) is based on a finite difference modelling technique, with a variable stepsize in time, and is named PERAM (Pressure Equalised Rainscreen Airflow Modelling). This routine has been implemented on a DEC Micro Vax cluster in C, and on a PC in C^{++}.

PERAM requires the input of the geometric parameters of joint cavity volume V_c, the joint opening (or venting) area A_e, the two physical parameters s and k_2, the boundary conditions of the amplitude P, and the frequency ω of the sinusoidal impulse. This information is sufficient to simulate a response wave form from a chosen wind pressure driving force, P_e. The value of k_1 (which is a function of Re) is approximated as a constant [15], being the discharge coefficient when the opening to be modelled is larger than 10 mm in width.

The model was run with the following range of variable values: 2000 mm$^2 \leqslant A_e \leqslant$ 40,000 mm^2, 50 l $\leqslant V_c \leqslant$ 450 l, and 1.0 Hz $\leqslant f \leqslant$ 5.6 Hz, to match the range of experimental values used by Burgess [12].

PERAM uses the boundary condition of $P_e = P \sin \omega t$ as the starting point for the numerical solution, then equation (2) to calculate q_1, followed by equation (6) to calculate P_c and equation (3) for q_2, but first requires the values of s and k_2 to be fitted to it. The values of these parameters can be approximated analytically, as $s = 1.5$ for orifice flow through a sharp-edged opening [6] and $k_2 < 1$ for 'crack flow' which is a function of the width, length and depth of the crack [15]. A value of k_2 more accurate than this is difficult to estimate, as many unintentional cracks contributed to the value of k_2 through leakage from the cavity, so little could be known about them. Extensive numerical trials were performed to suitably fit the results of PERAM to the experimental data obtained previously [12]. There were several pairings of s and k_2 which gave reasonable agreement with experiment, so the best choices of the two coefficients in equations (1) and (2) were determined from a simple matching algorithm 'CAV4' written in C^{++}, as $s = 1.40$ and $k_2 = 0.001$. CAV4 collated the number of numerical results from PERAM which fell within an acceptable target band for each value of s and k_2, determining the values of these parameters that were most frequently utilised. The value of s is close to the analytically approximated value of 1.5, which is appropriate. Given that the value of k_2 should be zero for the case of q_2 being zero (no flow), it is acceptable for k_2 to be 0.001 in this case, as q_2 was very small in the experimental analysis [12].

PERAM is then able, stepwise, to solve the equations above, with the step size (in time) being varied to maximise the CPU time efficiency while maintaining adequate accuracy. From the resulting periodic waveform record of pressure amplitude data, a PEP can be calculated for each joint type as defined by equation (1).

RESULTS

The full range of values for the geometric parameters used in the experimental investigation of [12] were successively input to the numerical model PERAM and the

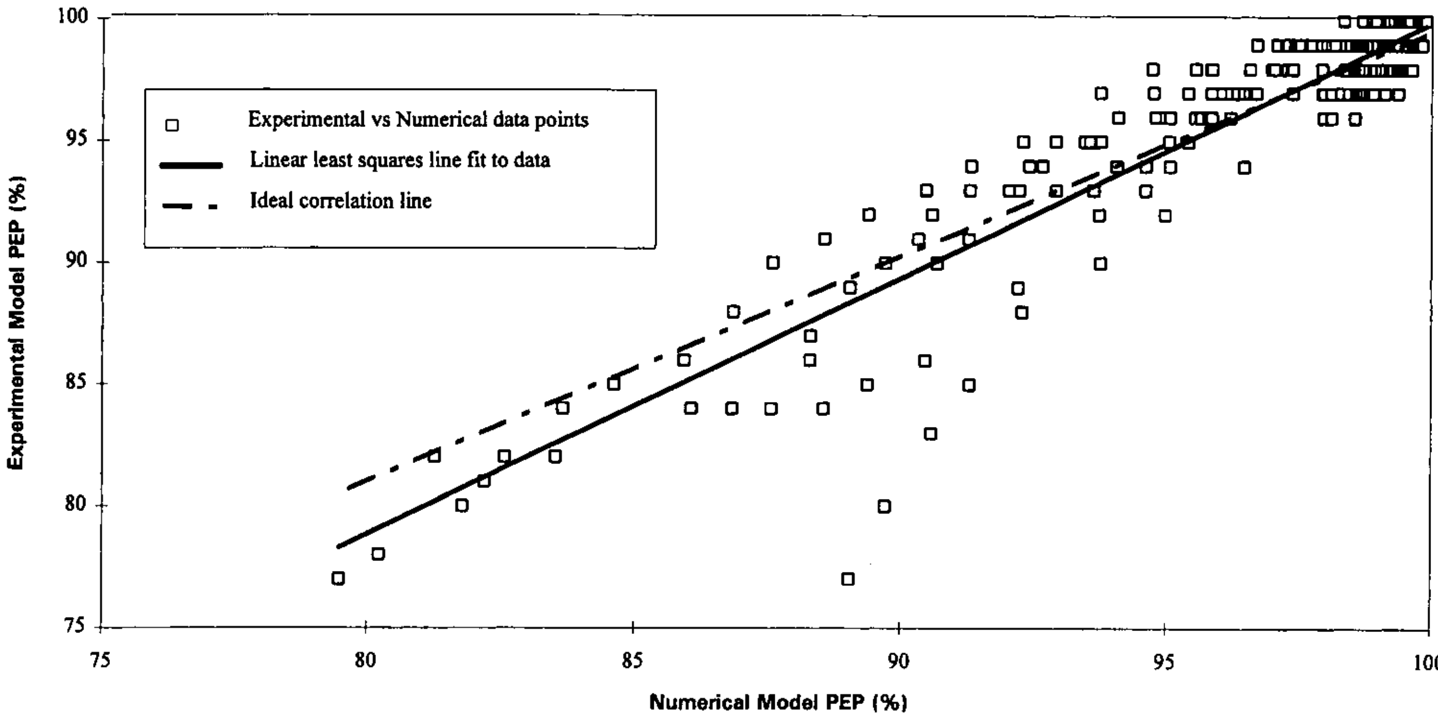

Fig. 2. Comparison of experimental with PERAM-generated numerical data.

output files analysed. Then all of these PERAM results of the discretised pressure records of the air pressure response waves P_c within the cavity volume V_c were input to equation (1). This produced an individual PEP value for each of the 270 PEPs generated for the range of geometric parameters investigated in [12]. These PEP values are presented graphically, plotted against the experimental data in Fig. 2, to show the correlation between the experimental results and PERAM, following the fitting of the parameters s and k_2.

The effects on the PEP of varying the geometric parameters of a PER joint are dealt with in [12] and will not be further investigated here.

DISCUSSION

Two lines are drawn on Fig. 2, being the 'ideal' which would be expected from a perfectly fitting model, and the 'best fit' line which represents a least-squares linear regression fit line through the numerical data points. As can be seen from these lines the agreement is very good. The four data points which appear as significant aberrations from the general trend at the lower right of the fit-lines may result from a systematic error in the experimental analysis, as data both directly above and below these points indicate a problem exists only with these four points, which has no obvious physical explanation. Unfortunately, subsequent modifications to the testing system rendered it impossible to re-do these experimental runs, after the apparent trend change was noticed, as it was initially believed this trend did have a physical explanation.

The range of applicability of the model remains unknown at this stage as, without correlation of PERAM with experimental data, the model validity has only been checked within the limits 2000 mm^2 < A_c < 40,000 mm^2, 50 l < V_c < 450 l, and 1.0 Hz < f < 5.6 Hz, for the situation of the laboratory experimental simulation. However, this range has been chosen to overlap with the ideal geometric parameters desired to achieve a high level of pressure equalisation within a rainscreen joint, and matches the data from the 270 experimental points gathered from the previous analysis [12].

CONCLUSIONS

The weathertightness of pressure equalised jointing systems within a range of realistic geometric and wind pressure environments can now be assessed prior to construction, by the use of a numerical model PERAM. This numerical model has been developed to solve equations governing the pressure response of air within the cavity of a rainscreened joint in a building cladding when subjected to an external sinusoidal air pressure variation. Two numeric parameters are fitted to PERAM to allow the model to predict acceptably the performance of pressure equalised jointing systems that have previously been examined in an experimental study on an idealised model joint system in the laboratory. A measure of the pressure equalisation performance of joints (the PEP) is calculated from the model waveforms as a determination of the degree of weathertightness of the joint system. Results show that PERAM is able to predict acceptably the air pressure responses of air within building cladding joint cavities for the experimental cases investigated. Numerically generated PEPs can be made to fit well with the experimental PEPs, which suggests that the model may be successfully applied to detail weathertight pressure equalised cladding systems. This will allow use of the model at the design stage in specifying the geometric parameters of a pressure equalised jointing system, and will serve to impart greater confidence in the levels of weathertightness of the cladding of commercial, industrial and domestic buildings.

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