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Poirier, G. F.; Brown, W. C.

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Pressure Equalization and the Control of Rainwater Penetration Under Dynamic Wind Loading

By G. F. Poirier and W. C. Brown

Pressure-equalized rain-screen (PER) technology represents the most complete design approach to the control of rain penetration through walls. A PER wall system in its simplest form will contain three components: an air-barrier system, a cavity and a rain screen (Figure 1). Each of these components must contain properly designed features in order for the wall system to control water penetration through its fabric. This penetration is due to the kinetic energy of the raindrops, surface tension, gravity, capillarity and windinduced air-pressure differentials. The last force is significant and the pressure-equalization requirement of the system was developed to specifically address this driving force. Pressure-equalization performance of PER wall systems has been the subject of much research in recent years. Experimental work at the National Research Council's Institute for Research in Construction (IRC) has shown that if pressure equalization is achieved across the rain screen under static but not under dynamic air-pressure loads, then a significant amount of water may still find its way inside the wall fabric.

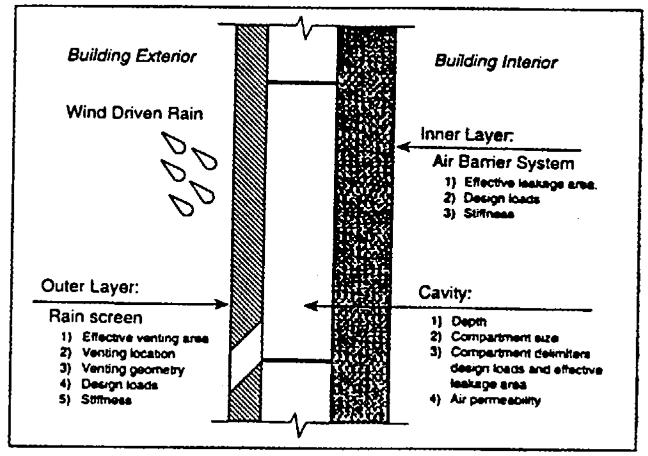

Figure 1. Principal components and features of a pressure-equalized rain-screen wall system.

Static and Dynamic Air-Pressure Loads

When dealing with the pressure-equalization performance of a PER wall system, it is important to distinguish between static and dynamic air-pressure loads since the wall system does not respond the same way to both. Air-pressure differences across the walls induced by mechanical ventilation and stack effect are static-pressure loads, i.e., the loads are relatively constant over time. Wind gusts, however, induce dynamic-pressure loads on walls, i.e., pressure that varies with time and location on the wall facade. Because wind gusts are time dependent, the time required for the cavity pressure to respond to the variable pressure induced by wind gusts may still result in a pressure differential across the rain screen (cladding). This is an important issue because this pressure differential will push water through openings and cracks in the rain screen. To reduce this pressure differential to nearly zero at all times, the features of PER wall-system components must be designed to keep the cavity pressure synchronized with induced dynamic air-pressure loads. The dilemma faced by designers is that very few guidelines are available to design PER wall sys-

G. F. Poirier *is a Senior Technical Officer in the Building Performance Laboratory of the National Research Council's Institute for Research in Construction.*

W. C. Brown *is a Senior Research Officer in the Building Performance Laboratory of the National Research Council's Institute for Research in Construction.*

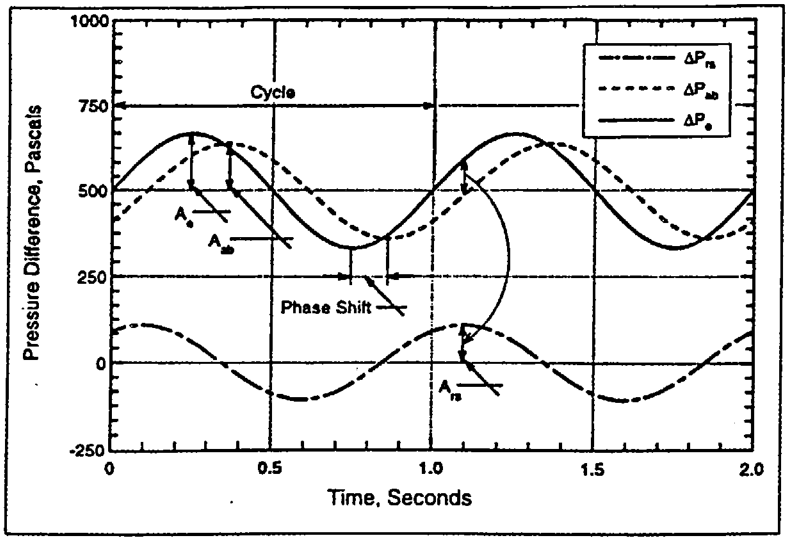

Figure 2. Dynamic-pressure response of a PER wall system under a sinusoidally varying air-pressure differential

tems, especially for dynamic response. A recent literature review by NRC has shown that the guidelines available are not at all comprehensive. In fact, they are based on static theory and may not be sufficient to design a wall with a dynamic-pressure response fast enough to minimize the pressure differential across the rain screen in wind-driven rain conditions.

Research Project

In light of the designer's dilemma, a research project has been initiated to develop perfomnance-evaluation procedures and systematic design guidelines for PER wall systems. The project is a collaborative effort between the Institute for Research in Construction and Canada Mortgage and Housing Corporation (CMHC). Several wall-system manufacturers are also contributing by providing test specimens and advice on practical details of construction.

The project is divided into three tasks:

1) computer modelling,
2) experimental evaluation, and
3) development of design guidelines.

A test procedure to evaluate the pressure-equalization and water-penetration control performance of a PER wall system was developed in the preliminary stage of task 2. The test procedure is being improved by evaluating the pressure-equalization and water-penetration control performance of innovative wall designs using IRC's unique dynamic wall-testing facility. This facility contains hydraulic equipment and a data acquisition/control computer system that simulates air-pressure dynamics typically experienced by

Side Bar

What does the dynamic-pressure response of a PER wall system mean? It is easier to explain with a graph of the resultant pressure differential across the air-barrier system (ΔP_{ab}) and the rain screen (ΔP_{rs}) over time when a sinusoidally variable air-pressure differential is induced across the wall (ΔP_e) as shown in Figure 2. When the pressure across a wall system and its components vary sinusoidally, the wave form of the pressure-differentials can be described by their average pressure, their amplitude, and their frequency. The maximum magnitude of the dynamic pressure-differential cycles is the amplitude, i.e., A_e, A_{ab} and A_{rs}, measured in Pascals (Pa). The number of times a cycle repeats itself in a specified time is the frequency; it is measured in Hertz (Hz). If the cavity pressure responds instantaneously to the induced pressure, then A_{ab} will be equal to A_e and, consequently, A_{rs} (A_e-A_{ab}) will be zero. If the cavity pressure does not respond instantaneously to the induced pressure, then A_{ab} will be less than Ae and will occur at a later time, i.e., will be delayed (see Figure 2). The delay that occurs between ΔP_e and ΔP_{ab} is the phase shift and it is generally expressed in degrees or radians. (The larger the number of degrees, the longer the delay for a specific frequency.) Because of the delay, the amplitude of the pressure cycle across the rain screen (A_{rs}) will not be equal to the arithmetic difference between A_e and A_{ab}. The phase shift between ΔP_e and ΔP_{ab} increases as the frequency of ΔP_e increases.

The amplitude and the phase shift of the ΔP_{ab} cycle is governed by the ability of the cavity pressure to equalize over time with the variable induced pressure, i.e., the cavity pressure response. This ability is controlled by the physical characteristics of the wall system such as:

- the cavity volume,
- size and geometry of the vent holes,
- the air tightness of the air-barrier system and of the delimiters of the cavity compartment
- the flexibility of its components.

Given that the cavity-pressure response is a function of time, ΔP_{rs} is obtained by taking the difference between ΔP_e and ΔPab at a given time or by measuring the pressure difference directly across the rain screen. The amplitude of the ΔP_{rs} cycle is governed by both the amplitude and the phase shift of ΔP_{ab} (see A_{rs} arrow on Figure 2). Because of this time dependence, ΔP_{rs} cannot be evaluated by looking only at the average pressure differential (static pressure) across the air-barrier system and the rain screen. (In Figure 2 the average ΔP_{ab} and ΔP_{rs} are 500 Pa and 0 Pa respectively) Average pressure differences are mainly a function of the cavity venting/leakage ratio of the wall system, whereas the time taken to dynamically equalize the pressure across the rain screen is more closely related to the factors mentioned above. (The cavity venting/leakage ratio of the wall system is the ratio of the cross-sectional area of the cavity venting and of the leakage opening in the air-barrier system.)

a building-envelope system in the field.

Preliminary Experimental Evaluation

A specially designed brick-veneer, steel-stud wall system was used to examine qualitative trends on the parameters of some of the features of PER wall systems. The pressure-equalization performance of the wall system was measured under dynamic air-pressure loads for cases of:

- a flexible air-barrier system and a rigid air-barrier system
- the cavity being unfilled or filled with mineral fibre insulation
- various cavity venting/leakage ratios.

These were evaluated by sinusoidally varying the air pressure across the test wall and monitoring the resultant pressure across the air-barrier system at frequencies from 0.1 to 2.0 Hz. (This frequency range covers a significant portion of the frequency spectrum of the wind.)

Test Results

Preliminary experimentation has shown that the pressure-equalization performance of a PER wall system is a function of the frequency of the induced dynamic air pressure and of the physical characteristics of the wall system. It was also noted that:

- pressure equalization across the rain screen can probably still be achieved when the cavity is filled with certain fibrous materials; however, this type of design needs to be investigated further.
- the dynamic-pressure response of the wall system can be degraded significantly when the elements that delimit the cavity are flexible. This translates into a pressure differential across the rain screen.
- the amplitude of the pressure difference across the rain screen can be minimized under dynamic conditions with proper design of cavity venting.
- the pressure difference experienced by the rain screen will depend on both the leakage of the air-barrier system and on the dynamic-pressure response of the wall system.

The importance of the dynamic-pressure response of a PER wall system cannot be underestimated. For example, when the test wall was built with an airtight air-barrier system and its cavity was vented through the brick veneer with 10 holes of 10-mm diameter, it responded as follows:

- at 0.5 Hz the air-barrier system experienced 94% of the amplitude of the induced pressure differential with a phase shift of 22°.
- at 1.0 Hz the air-barrier system experienced 83% of the amplitude of the induced pressure differential with a phase shift of 40°.

In the dynamic stage of the water penetration test, the wall system was subjected to a dynamic-pressure differential (ΔP_e) that had an amplitude of 167 Pa (see side bar). The dynamic-pressure response across the air-barrier system (ΔP_{ab}) had an amplitude of 157 Pa at 0.5 Hz and 139 Pa at 1.0 Hz. The arithmetic difference between the amplitude of ΔP_e and ΔP_{ab} seems to indicate that the rain screen would have been exposed to a maximum air-pressure differential of 10 Pa at 0.5 Hz and 28 Pa at 1.0 Hz. Because the dynamic-pressure response across the air-barrier system was not in synchronization with ΔP_e, the rainscreen was actually exposed to a maximum dynamic air-pressure differential of 63 Pa at 0.5 Hz and 108 Pa at 1.0 Hz. These levels of pressure differential will cause water penetration. At 0.5 Hz, water was accumulating inside the cavity through the vent holes at approximately 0.02 L/min. However, at 1.0 Hz, water was accumulating inside the cavity at an estimated rate of 0.11 L/min.

Conclusion

As mentioned above, the pressure-equalization performance of a PER wall system is a function of the dynamic air-pressure differential across the wall and of the physical characteristics of the wall system. More details on this preliminary study can be found in the Proceedings of the 6th Conference on Building Science and Technology, Toronto, 1992. Another source of information on the preliminary work is 'Review of Design Guidelines for Pressure Equalized Rainscreen Walls' by Dr. A. Baskaran (IRC Internal Report No. 629). Much work is still required to truly understand the dynamic behaviour of PER wall systems so that proper design guidelines can be developed.❖