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Pressure Equalization in Rainscreen Wall Systems

by M.Z. Rousseau, G.F. Poirier and W.C. Brown

A pressure-equalized rainscreen (PER) wall is a multiple-line-of-defence approach to rain penetration control. This Update defines pressure equalization and discusses the various elements that must be incorporated in a PER wall to minimize rain penetration due to air pressure differentials.

Rain can enter only if a combination of the following three conditions are present: rain water deposited on the wall, holes and cracks offering water leakage paths inwards and a force or a combination of forces to drive water inwards. Strategies for rain penetration control must entail the control of one or more of these contributing factors.

Various approaches to rain penetration control are currently used in the building industry. These range from single-line-of-defence assemblies (commonly called face-seal walls) to multiple-defence assemblies such as those that incorporate a rainscreen, a drained air space and a water-resistant membrane.[1] The pressure-equalized rain-screen (PER) wall design is one of these multi-defence approaches. It is based on the open rainscreen principle,[2] which aims to control *all* forces that can drive water into the wall assembly, i.e., air pressure difference, gravity, surface tension, capillary action, and rain drop momentum. Of these forces, air pressure difference is often a dominant one with the potential to drive a considerable amount of rainwater into the wall assembly. This Update therefore focuses on the control of air pressure difference across the rainscreen, and the particular elements of wall assemblies instrumental in obtaining such control.

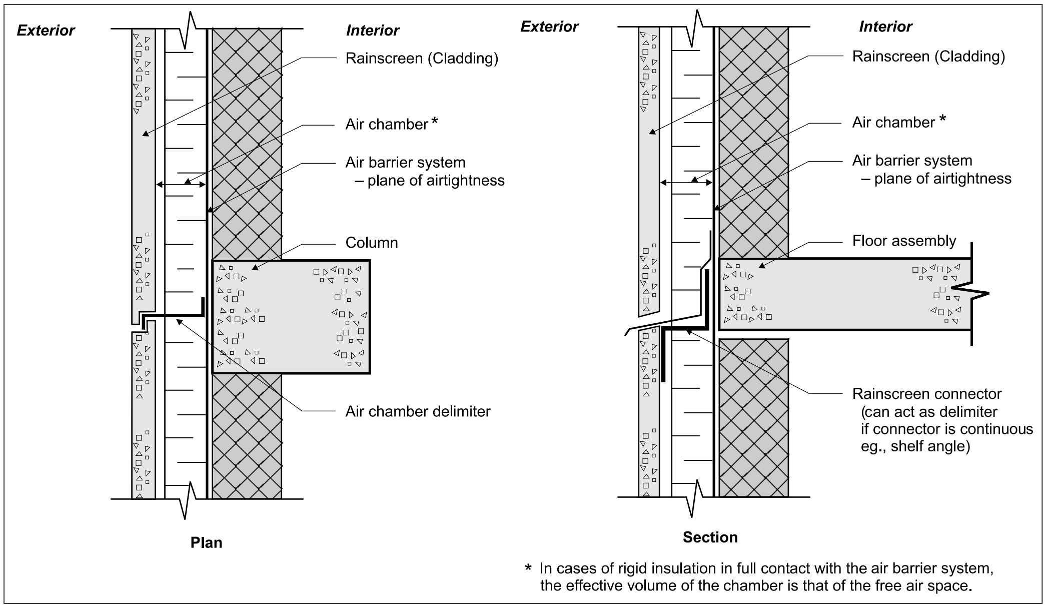

Figure 1. Components of a PER wall assembly

Defining Pressure Equalization

The pressure equalization concept is simple: when the outside air pressure is transferred to an air space behind the exterior cladding, the cladding is exposed to a near-zero pressure *differential*. In practice, the wall assembly must comprise three components (Figure 1): a rainscreen (i.e., vented cladding), a compart-mented air chamber and an air barrier system. The air chamber com-partments must be small enough, the air barrier system must be airtight

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enough, and the area of the venting through the rainscreen must be large enough to allow sufficient air to move in and out of the compartments under the applied air pressure. In a nutshell, the strategy lies in the control of airflow within and through the wall assembly.

In theory, pressure equalization means a zero air pressure differential at all times across the rainscreen, i.e., a complete elimination of the driving force for pressure-induced water penetration. In practice, however, perfect pressure equalization across the rainscreen at all times is neither achievable nor necessary for adequate rain penetration control (the wall assembly must be designed to tolerate the entry of a small amount of water without damage). Preliminary studies indicate that for practical purposes, "adequate pressure equalization" for rain penetration control may be defined as not more than 25 Pa pressure differential across the rainscreen.

Dynamic and static air pressures on the rainscreen

Static (steady over time) air pressures on wall assemblies are generated by mechanical systems and stack effect while dynamic pressures (fluctuating quickly with time and location) are caused by wind (Figure 2). Recent IRC research indicates that dynamic as well as static air pressures must be considered when addressing wind-driven rain and the pressure-equalization performance of a wall assembly for rain penetration control.[3] Under dynamic pressures, the ability of the assembly to respond *quickly* to the outside fluctuating pressure load is critical for adequate pressure equalization; this time constraint is not an issue under static loading. The IRC research showed that wall assemblies respond differently to dynamic and static loading, resulting in different design requirements for the wall components, particularly for the venting of the rainscreen and the compartmentalization of the air chamber.

Wall Components for Pressure Equalization

The following three basic components must be present in a wall assembly to minimize rain penetration due to air pressure differentials (Figure 1):

- an effective air barrier system,
- an air chamber and
- a rainscreen.

These components must have properly designed features such as vent holes in the

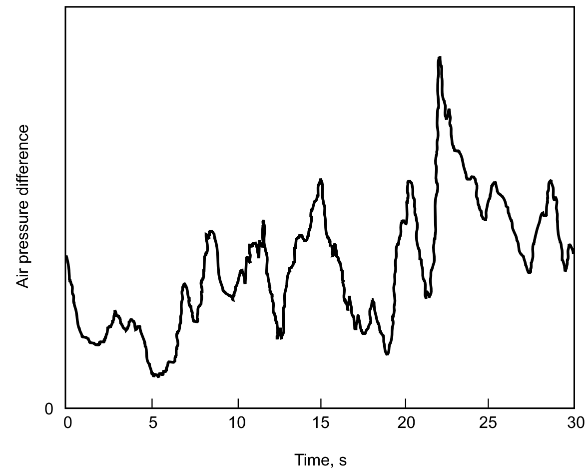

Figure 2. Example of wind-induced pressure differential measured across an exterior wall system (Brown et al. Field Testing of pressure-equalized rainscreen walls. ASTM. STP 1034, 1991.)

rainscreen and delimiters to divide the air chamber into a series of compartments.

Recently, IRC performed some experimental laboratory studies to characterize these features for various generic wall systems. In a project jointly sponsored by Canada Mortgage and Housing Corporation (CMHC) and several wall system manufacturers, IRC used its unique dynamic wall-testing facility to study the relationship between the three components (listed above) as a function of the physical characteristics of different wall assemblies subjected to static and dynamic air pressures. Specimens of precast concrete panels, brick veneer/stud wall assemblies and exterior insulation and finish systems (EIFS) were examined for their pressure-equalization performance. Some were also subjected to rain penetration tests.

An air barrier system

The performance of the air barrier system affects the ability of the wall assembly to achieve pressure equalization across the rainscreen. The air barrier system in place within the wall significantly reduces the flow of air through the wall assembly, and therefore greatly contributes toward reducing the air pressure differential across the rainscreen. Under dynamic-pressure conditions, recent IRC studies indicate that excessive flexibility of the air barrier system will result in fluctuations in the volume of the air chamber compartment. These fluctuations adversely affect the potential for rapid pressure equalization across the rainscreen. Under static-pressure conditions, the leakage of the air barrier system is the determining factor for sizing the venting requirements. These findings emphasize the need for an air barrier system within the building envelope, as called for in the 1995 edition of the National Building Code of Canada.[4]

An effective air barrier system has low air permeance, structural strength, and continuity over gaps, joints and interfaces.[5] The air barrier system must be designed to resist air pressure induced by mechanical ventilation, stack effect and wind while still limiting air leakage. The system must also be rigid enough to sustain these air pressures with a resulting deflection that can be accommodated within the wall assembly. These air pressures must be transferred to the structure of the building.

IRC's Canadian Construction Materials Centre (CCMC) developed an evaluation protocol to assess the "effectiveness" of air barrier systems.[6] It covers requirements for maximum allowable air leakage rates for air barrier systems for walls of low-rise buildings, structural air pressures (static and dynamic) and material durability. CCMC's allowable air leakage requirements for air barrier systems are a function of the water vapour permeance of the outermost non-vented layer of the wall assembly. In any case, the maximum air leakage rate allowable by CCMC for the air barrier system in exterior walls of low-rise buildings is 0.20 $L/(s \cdot m^2)$ at 75 Pa pressure differential.

An air chamber

The air chamber is located between the rainscreen and the air barrier system. Wind pressures induced on the rainscreen are transferred to this space as air is displaced between the outside and the chamber through the vent holes located in the rainscreen. The air chamber can consist of a clear air space or other adequate options. As an example, in a recent IRC experimental study, one wall assembly with an air chamber made with a geosynthetic dimpled plastic sheet with a geotextile bonded to the dimples provided similar pressure equalization performance to that of the assembly with a clear air space. In some wall systems, specially designed insulation materials are intended to provide the required air chamber for pressure equalization purposes: the air chamber may be formed as a grid of narrow channels within the insulation material, or the air chamber can be housed within the insulation material itself when its physical properties provide the required "air permeability." In general, for dynamic pressure equalization, the volume of the air compartments and the rigidity of their boundaries (i.e., air barrier system, rainscreen and lateral delimiters) are the determining factors for estimating the venting requirement of the rainscreen. However, in wall systems without a clear air space, preliminary experimental work at IRC suggests that their pressure-equalization performance is very specific to their particular design, and that the data available cannot be extrapolated to generate guidelines.

The air chamber needs to be divided into smaller, separate compartments.[2] Remember that since wind pressure is dynamic, the pressure induced on the building façade varies not only with time, but also with its location on the façade. For example, the air pressure induced by wind can be fairly uniform near the centre of the walls, but steep gradients (variations) can develop towards the building edges and the roof line.[7] This spatial variation in pressure can induce lateral airflow within the chamber unless it is divided at suitable intervals. The compartmentation of the air chamber into smaller air compartments reduces the range of wind-induced pressures sustained by each of these compartments, resulting in a better potential for pressure equalization across the rainscreen.

In the 1960s, Garden[2] suggested that compartments be smaller at locations of large pressure variations (such as building edges and parapets) and larger in locations of smaller pressure gradients, such as in the central portion of the façade. Based on these premises, Garden suggested that compartment height should not exceed 6 m (about two stories) while compartment width could be up to 6 m in the central portion of the façade and about 1.2 m at building edges and parapets. Recently, Canadian research involving wind tunnel studies[8] has been initiated for the development of more definitive guidelines on compartment sizes over the building façade for PER wall systems. These studies confirm that Garden's rule-of-thumb about the locations on a façade that are most in need of of compartmentation is valid; the need for small compartments at parapet level is also stressed (Figure 3).[9,10]

The compartment delimiters close in the top, bottom and sides of the compartment. These delimiters need to be somewhat impervious to air and properly connected to the rainscreen and to the plane of airtightness of the air barrier system in order

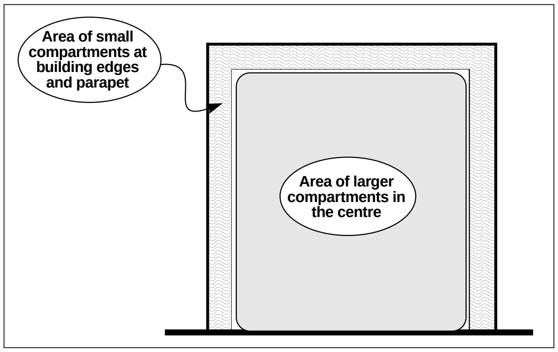

Figure 3. General pattern for façade compartmentation

to create the required lateral boundary. Information on the performance of any material and assembly for that purpose is scarce at the moment. In principle, wall components in place for other purposes, such as metal shelf angles, can act as delimiters. Rigid sheet metal and foam plastic insulation strips could likely be used as delimiters, as long as they can be made relatively airtight and can be installed to sustain the lateral air pressure loads.

> Any effective rain penetration control strategy should assume that some rain will enter the wall at some time during the service life of the wall assembly; that water must be disposed of quickly. The inner surface of the compartments must be water-resistant, and the compartment must be drained at the bottom with the use of a flashing.

A rainscreen

A rainscreen is the first line of defence against wind-driven rain, and as such is subjected to all forces leading to rain penetration through its openings and imperfections. Pressure equalization across the rainscreen minimizes water entry into the wall due to one force, air pressure differential. For pressure equalization to take place, the rainscreen must be vented; that is, holes must be present in the rainscreen so that enough air can be exchanged between the outside and each compartment of the air chamber. Two major issues arise concerning the venting requirements: the amount of venting needed for adequate pressure equalization under static and dynamic pressures, and the placement of the venting for each compartment.

How much venting

Under *dynamic-pressure* conditions, the rainscreen venting requirements are mainly driven by the volume of air in the chamber compartment, the resistance to airflow at the vent holes, within the chamber as well as between the compartments, and the rigidity of the wall assembly. Indeed, the larger the volume of air in the compartment, the larger the volume of air that has to be displaced in and out of the compartment to obtain adequate pressure equalization across the rainscreen; hence, the larger the total area of venting. The more rigid the assembly, the smaller the venting area required. The *volume/venting ratio* of the wall assembly, i.e., the volume of the compartment divided by the effective cross-sectional area of the vent holes, is a critical characteristic of the assembly for achieving dynamic-pressure equalization. Again, IRC's limited experimental work suggests that chamber compartments of small volume and high rigidity (such as the specimen illustrated in Figure 4) should have a volume/venting ratio of 50 m or less (i.e., $\text{venting}_{RS} \geq \text{volume}_{COMPARTMENT}/50$ m). Chamber compartments larger in volume and less rigid (see specimen in Figure 5) should have a volume/venting ratio of 25 m or less (i.e., $\text{venting}_{RS} \geq \text{volume}_{COMPARTMENT}/25$ m). In other words, the smaller the volume of the compartment and the more rigid it is, the less venting required.

For *static-pressure equalization* across the rainscreen, the effective venting needed depends on the leakage characteristics of the air barrier system and, to a lesser extent, of the compartment delimiters: the larger the total leakage openings of the air barrier system, the larger the venting area has to be. This pressure equalization design characteristic is generally referred to as the *venting/leakage ratio* of the wall assembly, i.e., the effective total cross-sectional area of the vent holes divided by the equivalent leakage area (ELA) of the air barrier system. Limited laboratory experimentation at IRC suggests that, for static loading, the effective total cross-sectional area of openings in the rainscreen should be at least 20 times that of the air leakage area of the air barrier system (i.e., $\text{venting}_{RS} \geq 20 \times \text{ELA}_{ABS}$).

The vent holes must be designed to let in air, not water; i.e., the openings must be shielded from direct rain entry. This shielding reduces the free area of the venting openings and needs to be accounted for in the estimation of the effectiveness of the venting provided.

In general, for a wall with a properly functioning air barrier system, the venting required for dynamic pressure equalization across the rainscreen will likely be larger than that for static pressure loading. In any event, after estimating both venting requirements, the larger of them should be selected for the design of the vent holes

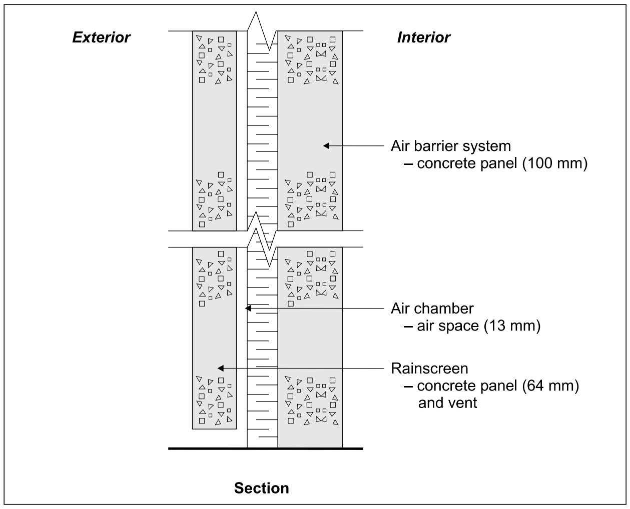

Figure 4. Example of a rigid assembly with a chamber of small volume

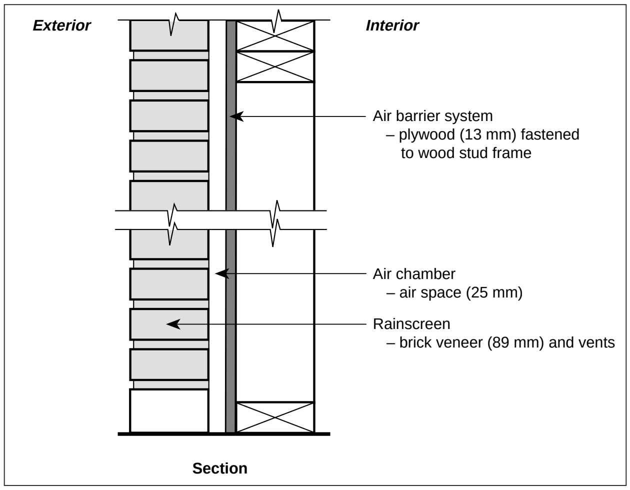

Figure 5. Example of a flexible assembly

Estimating required venting

Here is a simplified example to illustrate the steps for estimating the effective venting required for static and dynamic pressure equalization across the rainscreen:

Let us assume a rigid assembly (such as the wall assembly of Figure 4), with an air leakage rate of 0.1 L/s/m^2 at 75 Pa corresponding to an Equivalent Leakage Area (ELA) of 28 mm^2. The compartment volume is estimated to be 0.04 m^3.

For static loads:

Venting $_{RS}$ (m^2) ≥ 20 x ELA$_{ABS}$ (m^2)

Venting $_{RS}$ (mm^2) ≥ 20 x 28 mm^2, that is, 560 mm^2

For dynamic loads:

Venting $_{RS}$ (m^2) ≥ volume $_{COMPARTMENT}$ (m^3)/50 m

Venting $_{RS}$ (m^2) ≥ 0.04 m^3/50 m, that is, 800 mm^2

Compare the static and dynamic requirements, and select the larger value; in this particular example, that is the dynamic venting requirement of 800 mm^2 for that compartment.

(see box "Estimating required venting"). These guidelines do not provide an absolute figure for the venting requirements for all situations but rather an order of magnitude to aim for during the design of prototype wall assemblies.

Where to vent

Within a compartment, all the vent holes should be at the same height. The common approach has been to distribute the openings uniformly across the bottom of the compartment in order to obtain a mean pressure in the compartment close enough to the outside pressure anywhere on the outside face of the corresponding rainscreen. Placing the vent holes at the bottom of the compartment provides the added benefit that the vent holes can also provide uniform drainage of the compartment.

Wind tunnel studies at the Boundary Layer Wind Tunnel Laboratory at the University of Western Ontario have shown that gathering all the openings horizontally on the corner of the compartment furthest from the edge of the building tends to pressurize the compartment. This approach may offer an extra margin of safety with respect to rain penetration control, particularly at building edges and parapets exposed to steep pressure gradients. Further investigation of this new development and its practical applications is warranted.[11]

In PER walls, vent holes are installed in the rainscreen to allow air to move in and out of the air chamber under the applied air pressure load so that the air pressure differential across the rainscreen is minimized. These openings are not intended to induce the "ventilation" of the chamber, that is, to get a flow of air coming in at the bottom of the compartment and coming out at the top, or vice versa. In fact, it is quite the opposite: in order to control rain penetration due to pressure differential across the rainscreen, there must be little airflow through the chamber. For this reason, all vent holes should be located at the same height level of the compartment.

Summary

Control the airflow. An effective PER wall minimizes the amount of water that can enter the wall assembly, limits how far water can get into the assembly and provides a drainage route back outside to reduce the length of time the water remains in building materials. A PER wall design aims to control all forces acting on a wetted cladding surface. Air pressure difference across the exterior cladding is considered a significant force in driving rain into the wall. To control this force, the air barrier system, the air chamber and the rainscreen must be designed and built to work together to control airflow.

Achieve dynamic and static pressure equalization. Dynamic pressure equalization across the rainscreen requires different wall characteristics than static pressure equalization. For dynamic pressure equalization, the rigidity of the compartment boundaries, the volume of the compartment and the area of rainscreen venting are the determining factors. For static pressure equalization, the airtightness of the air barrier system and the area of rainscreen venting are important.

Build an effective air barrier system. A good air barrier system is a key component of a durable, functioning wall system in more than one way. The tighter and the more rigid the air barrier system, the less venting required to obtain dynamic and static pressure equalization across the rainscreen.

Compartmentalize the air chamber. The locations on a building façade exposed to wind-driven rain that require pressure equalization to achieve rain penetration control include building edges, parapets and architectural projections. Consequently the air chamber needs to be divided into smaller compartments at these locations while larger compartments are usually sufficient in the centre of the façade.

Introduce sufficient venting in the rainscreen at the bottom of the compartment. Traditional drainage openings in current wall systems may not be sufficient to provide the necessary venting for pressure equalization. Dynamic pressure equalization likely requires more venting of the rainscreen than static pressure equalization. The vent holes must be designed to let in only air, not water, so they must be shielded from direct water entry.

At this stage of knowledge advancement, the comprehensive design of specific pressure-equalized rainscreen wall systems for a given building configuration and climatic exposure should be supported by additional research and testing. At the design stage, a prototype wall assembly can be tested under environmental conditions representative of those that the building envelope is expected to experience. Laboratory studies under controlled static and dynamic pressures and wind tunnel studies can be performed to evaluate the pressure equalization response of compartments, and assist in finalizing the design in that respect.

Remember: PER walls ≠ pressure equalization. PER walls are not *only* about pressure equalization across the rainscreen. Other forces are at work as well, not the least of which is gravity; their control is part of the PER wall strategy for rain penetration control in exterior walls. One should assume that some rain will enter at some time during the service life of any wall assembly; that water must be disposed of quickly. Drainage of the air compartment is an important feature; properly detailed and sloped flashings and drainage channels are necessary for that reason.

__M.Z. Rousseau__ is a research officer and __W.C. Brown__ is a senior research officer in the Building Envelope and Structure Program of the National Research Council's Institute for Research in Construction.
__G.F. Poirier__ is an evaluation officer with IRC's Canadian Construction Materials Centre.

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