THE RAIN SCREEN WALL SYSTEM

ABSTRACT

Properly detailed and built, the rain screen wall is an effective envelope solution to external moisture penetration. This article reviews the various forces that move rain into buildings and suggests how they can be counteracted. Aspects of building geometry and aerodynamics are discussed as well as the components of wall assemblies. The rain screen principle and the process of pressure equalization are explained. Parameters are given for determining how to vent a rain screen properly. Sample details are shown for various rain screen wall and joint systems. Ten key features to look for in rain screen details are provided.

OBJECTIVES

After reading this article, you should :

1. Understand the forces that push rain into buildings, and know where rain causes most damage.
2. Understand the major ways building design influences rain penetration through the envelope.
3. Understand the concept of a rain screen.

Ontario Association of Architects

CMHC SCHL

HOME TO CANADIANS

Canada

4. Understand the concept of pressure equalization and how it reduces water penetration.
5. Know how to calculate required vent area, and determine vent locations and cavity compartmentalization for effective pressure equalization.
6. Know what to look for in window and joint design to reduce water entry.
7. Be able to determine when a rain screen design is an appropriate solution.

CONTENTS

HOW RAIN ENTERS WALLS

As all building professionals know, water is the most significant factor in the premature deterioration of buildings. It can cause corrosion of metals, rotting and mold in organic substances, dissolution of materials, reduction in effectiveness of insulation, efflorescence, and stresses, movement and breakage due to freeze/thaw cycling. While moisture can enter and cause damage to the building envelope from inside or outside, this article focuses on controlling rain penetration through vertical elements (walls and windows).

Three conditions are required to move water through the building envelope:

- A source of water;
- An opening or path for the water to follow; and
- A force to drive the water through the opening.

If one of these conditions is absent, moisture penetration cannot occur. The rain screen wall addresses the latter two, but aspects of building design influencing all three factors will be briefly discussed.

The first condition, the presence of water, cannot be eliminated. Water management strategies can reduce the frequency and intensity of moisture at critical points in the building envelope by diverting water away from these areas. Traditional features such as cornices and roof overhangs have long served this purpose at a larger scale, while flashings and copings protect joints and vulnerable materials.

Leakage paths exist at any opening in the wall surface, whether intended or unintended. Joints between materials and around windows and doors, vents, cracks, and porous surfaces are all potential entry points for water. Approaches to controlling rain penetration that rely on sealing openings without also dealing with the forces driving rain into buildings are often unreliable.

The forces that drive rain into buildings can be summarized as *kinetic, gravity, capillary action and surface tension, and pressure gradients*. In some circumstances only one or two of these forces may be present, but in a windy rainstorm they will probably all be acting to move water through any available leakage path. Each of these forces must be taken into consideration in designing buildings to prevent rain penetration. Of these forces, the most significant are gravity, capillary action and wind pressure differences. Materials, construction and orientation determine which force is dominant in a given situation.

Kinetic force refers to the momentum of wind-driven raindrops. This force will carry raindrops directly through openings of sufficient size. Cover battens, splines, and internal baffles can be used to protect intentional openings, such as drains and vents, from direct entry of rain. The design of these elements must recognize that rain does not simply fall straight down. Wind-driven rain can have a significant horizontal velocity, and near the top of a building this force may even have an upward component.

Dealing with water movement due to *gravity* may seem elementary, but leakage due to gravity action still occurs far too frequently in modern buildings. With near-horizontal or moderately sloped building elements, gravity is usually the main concern. These problems can usually be traced to errors in the design or construction of elements such as flashings, or to the restriction of drainage paths by dirt or ice, causing water to build up and follow an unintended path. Care is required in detailing and construction to avoid creating inward sloping leakage paths or areas where water can pond or overflow drainage paths. Gravity can be used to advantage in controlling rain penetration of vertical building elements. Flashings can intercept water coming from above and direct it to the outside and away from building surfaces. This also reduces the source of water that could be driven into the wall by other forces.

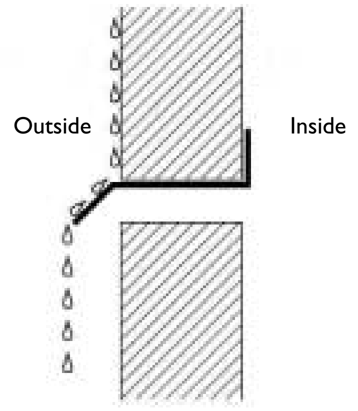


Figure 1. Example of a drip

Surface tension allows cohesion of water droplets, even against gravity and across small openings. Water movement due to this attraction of water droplets to one another is referred to as *capillary action*. These forces allow water to cling to and flow along horizontal surfaces, such as soffits, and to move against gravity through cracks and pores in building materials. The force with which capillary action can work against gravity is inversely proportional to the size of the openings (small cracks allow more capillary suction), and also depends on the attraction of the materials to water. At a critical distance, which depends on the materials, gravity overwhelms capillary forces and the water will drain. Smooth materials such as glass and aluminum show the strongest tendency to hold water against gravity, but a 10 mm gap is sufficient to disrupt capillarity in all common construction materials. Providing a drip (Figure 1) on the underside of projections and overhangs is a common detail to break surface tension and prevent water from collecting or reaching the building face.

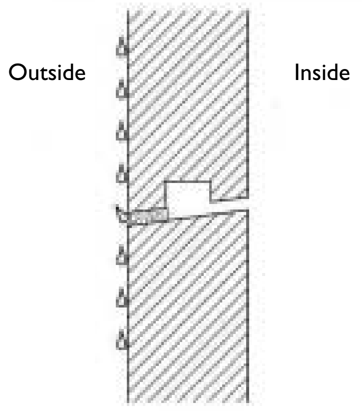


Figure 2. Example of a capillary trap

In porous materials, such as masonry, capillarity is usually the dominant force in water penetration and will tend to hold water in, drawing it through, even against gravity and an air pressure gradient, until the material is saturated. Other forces, such as wind pressure, gravity or kinetic energy may then drive this retained water further through the building envelope. While capillary forces can act all through brick, testing in brick walls shows most water penetration occurs at the mortar joints, primarily through cracks at the mortar/brick interface. With impervious claddings, capillarity is still a major concern at cracks and joints. Sealing exterior joints is typically unreliable in the long term without regular maintenance, as seals fail under stresses and due to weathering, creating ideal capillary paths. A more effective solution is detailing joints with a capillary trap, or drained air gap, of sufficient width to break *capillary action* (see Figure 2).

Air pressure differences across the building envelope can create suction drawing water through available leakage paths, while air movement due to pressure differences can carry water droplets directly. Pressure differences across the building envelope can result from wind, mechanical systems and stack effect. The latter two are referred to as static pressures, as they are relatively constant and act on all sides of the building in the same way at any given height (although they can vary over the height of the building). Mechanical and stack pressures are more significant in causing moisture exfiltration from indoor air than in causing rain penetration.

Of primary concern in controlling water infiltration is the pressure difference due to wind, as it is generally much higher and more variable. Even a steady wind does not create uniform pressures across a building, as airflow patterns around building edges create varying wind velocities and forces. Air pressures due to wind will be positive on the windward faces of a building, and negative (for example, suction or uplift) on the leeward side and, often, the roof (see Figure 3).

Cyclic pressures due to gusting winds, meanwhile, can create significant variations over very short time periods. Compensating for these variations in wind pressure is one of the key functions a properly designed rain screen wall can achieve, through providing pressure equalization in the wall cavity (see page 10). In wall systems with impervious outer cladding, such as curtain walls, pressure differences may be the most significant force driving rain into the building.

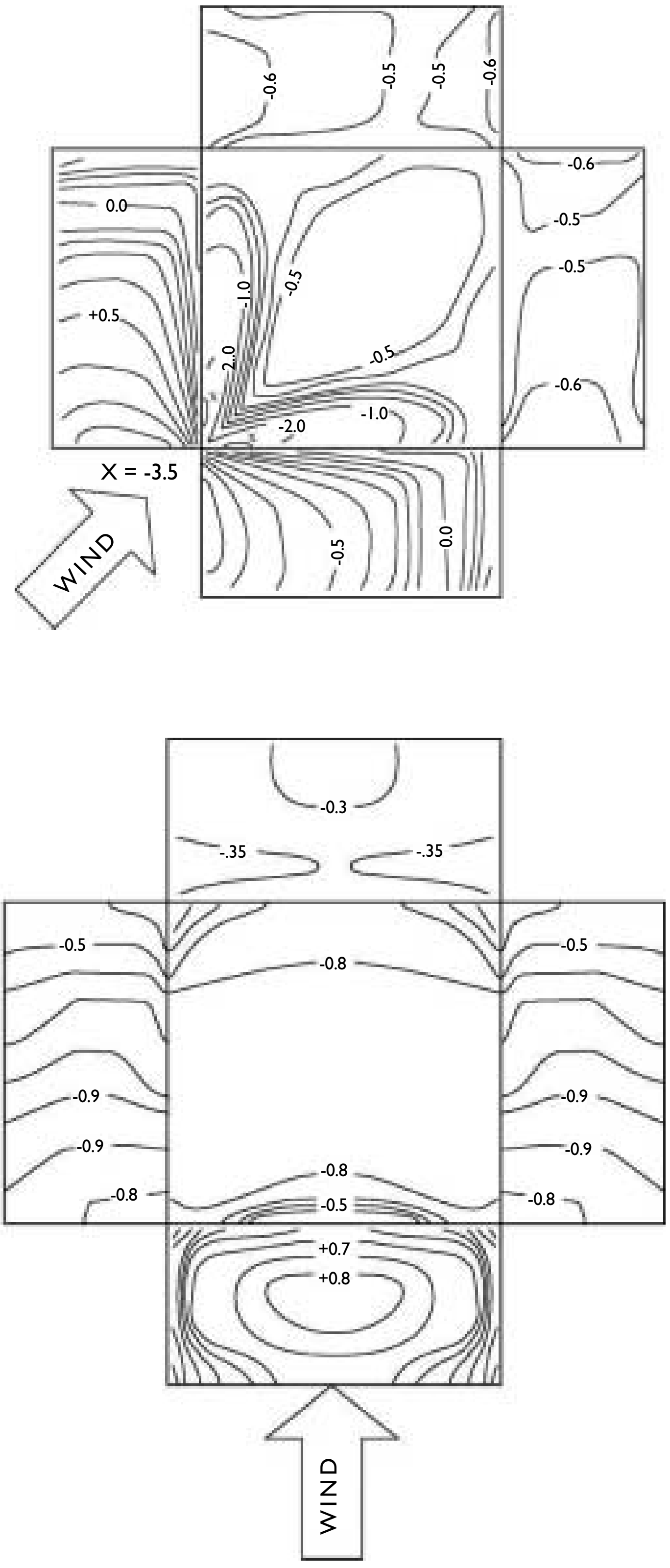
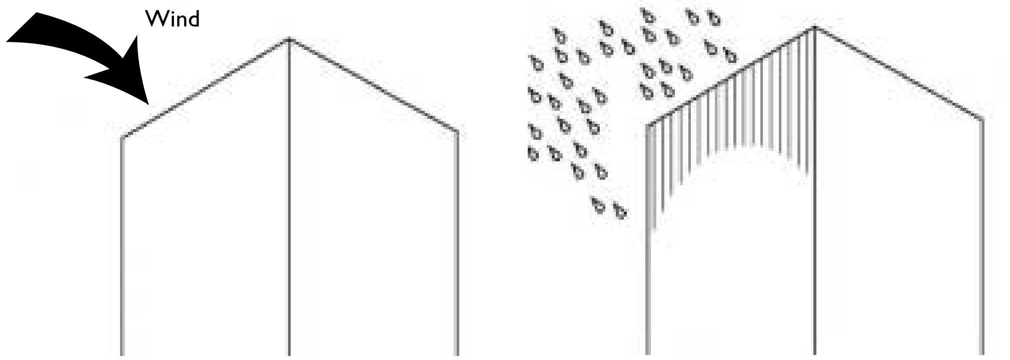


Figure 3. Wind pressures on building facades

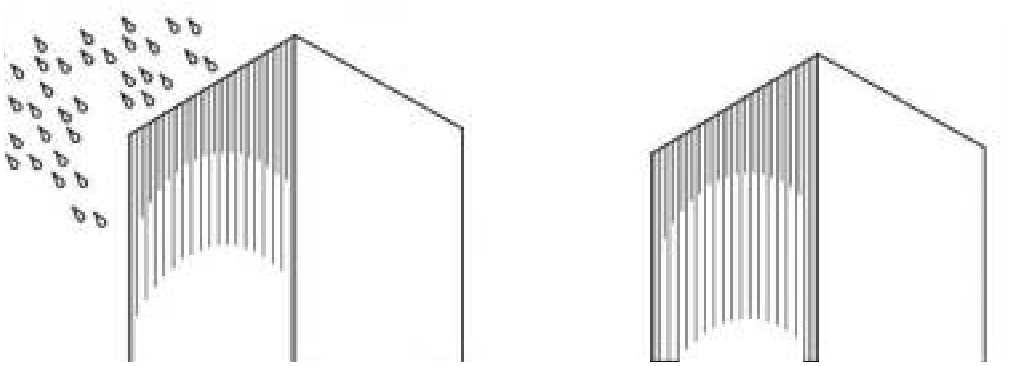
PATTERNS OF WIND AND RAIN EXPOSURE

Some areas of buildings are more vulnerable than others to rain penetration. As mentioned, all openings in the wall surface are potential entry paths for water. At a larger scale, wind flow patterns also affect how much rain hits various areas of a building. Wind direction is a factor, as windward-facing walls will be subject to more driving rain, while leeward walls will be protected. The aerodynamics of wind flow around buildings also mean that different areas of a single wall are subject to different wind forces, especially in larger buildings. As wind parts to flow around and over a building, a "cushion" of high-pressure, but relatively still, air is created at the centre of the wall. This "dead spot" protects this area of the wall from rain. Wind accelerates around the side and top edges of the building, driving rain more forcefully against these parts of the wall. The typical wetting pattern for a multi-storey building is shown in Figure 4. Studies have shown that these edges can receive more than 20–and as much as 50!–times the amount of rain at the centre of the wall. This discrepancy in wetting intensity is greater with taller and narrower buildings.



Dry building

After 10 minutes: migration begins



After 20 minutes: development of characteristic rain-wetting pattern

After 40 minutes: rain ends, wetting of windward faces by deposit and migration roughly proportional to directional exposure to driving rain

Figure 4. Wetting patterns on a tall building

Rain-wetting patterns on a building face also depend on the finishes used. Porous surfaces, such as masonry, absorb much of the water that strikes them and release this water more slowly, through diffusion. With impervious claddings, such as metal and glass curtain walls, water simply flows down the wall surface and the accumulated flow can be significant by the time it reaches the bottom of a tall building. Wind flow around corners and parapets can also draw water laterally and even upwards. This lateral flow can bring water to vertical joints, which are often quite vulnerable to leakage. Understanding wetting and wind patterns, therefore, suggests some design solutions and precautions regarding rain penetration.

Particular care can be paid to providing rain-resistant assemblies at the upper edge and corners of multi-storey buildings, and employing features such as cornices to direct rain off the building face. Roof overhangs have long been effective in reducing rain exposure of low buildings, as shown by a recent CMHC survey of building envelope failures in coastal British Columbia that found a strong relationship between the width of eave overhangs and decreased frequency of rain penetration. Sloped roofs also ease windward wall wetting by reducing lateral wind, and hence water, movement at the wall/roof intersection.

Driving rain wind pressure (DRWP) data are available for many locations in Canada. The DRWPs are estimates of the annual extreme mean hourly wind pressures (converted from wind speeds) associated with sufficient rain to cause leaks to occur. The 1/5 and 1/10 DRWP represents that storm which has a 20% and 10% chance, respectively, of occurrence in any given year. These data can be used to determine pressure equalization requirements. A height coefficient (the same as for structural calculations) is used to multiply the pressures for taller buildings. However, the DRWP data are for wind in combination with rain and do not necessarily correspond to peak wind speeds used for structural calculations. (In window and curtain wall performance standards, the American Architectural Manufacturers' Association (AAMA) recommends these assemblies be tested against water leakage at wind pressures approximately 20% of structural design wind pressures.)

DRWP data also are not indicative of frequency or duration of wind-driven rain exposure. For this purpose, the National Research Council has assembled an Annual Driving Rain Index (ADRI) for North America. The materials and construction of a building determine whether peak load or annual exposure is more important. For example, in systems where *any* water penetration may lead to problems, such as face-sealed walls or windows, or where water is controlled by barriers such as upstands, peak loading is the most relevant design consideration. For assemblies that tolerate some water penetration and rely on a balance between wetting and drying, for example, many masonry systems, annual exposure to rain is a more useful design parameter.

APPROACHES TO RAIN PENETRATION CONTROL

Traditional construction techniques have worked in various ways to counteract the forces bringing rainwater into building assemblies. Mass wall systems, such as solid brick, block or stone masonry, concrete, and solid timber or logs, rely on the wall surface to shed most rain, while the massiveness of the material allows it to absorb and hold remaining surface moisture. The absorbed water later evaporates during a dry period, with solar or indoor heating assisting the process.

Face-sealed systems, in contrast, try to eliminate leakage paths through which water can enter the wall. Water-resistant exterior surfaces are used and joints are sealed. This approach tends to be unreliable in modern, insulated veneer wall systems, especially in harsh climates, where without the tempering effect of the conditioned indoor air, the wall surface reacts quickly to changes in outdoor temperature and sun exposure. Thermal movement and cracking can result, with failures typically occurring at the joints, which are subject to additional stresses such as deterioration of sealants due to moisture contact, freezing and thawing, solar radiation, etc. The low permeability of the wall materials to water may exacerbate the problem, as water entering the wall assembly becomes trapped. The complete face-seal approach can work, but ongoing maintenance of the sealed joints is necessary. A better approach may be to provide water-resistant, sealed surfaces with rain screen joints. (See page 22, Rainscreen Principles Applied to Joints.)

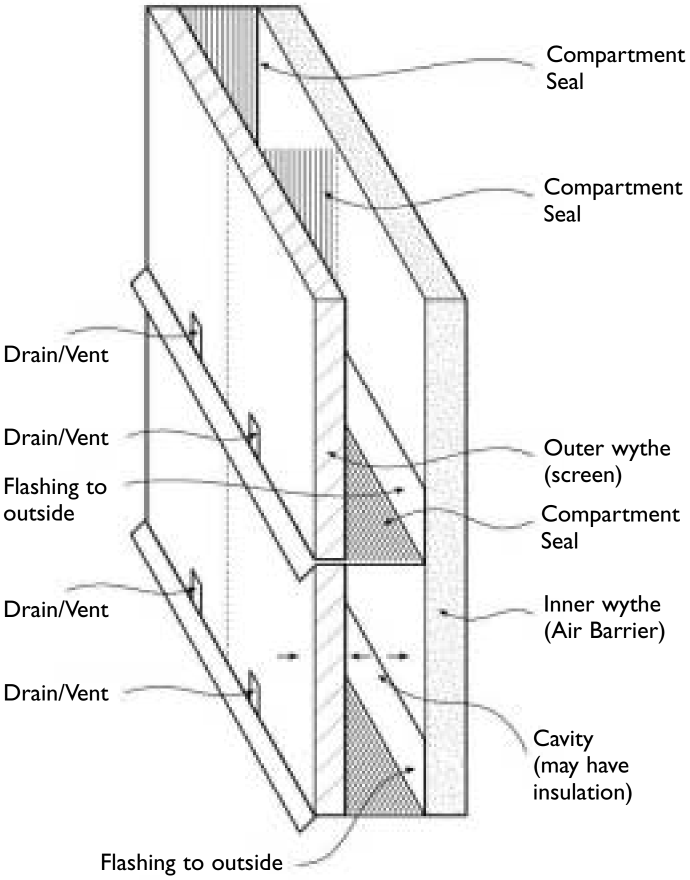


Figure 5. Pressure-equalized rain screen wall.

The rain screen wall addresses all of the forces we have described that move rain into the wall. The basic configuration, incorporating two layers, or wythes, separated by an air space, has variations that provide different levels of rain protection effectiveness. A distinction should be made between the drained cavity wall, the simple or open rain screen, and the pressure-equalized rain screen wall. What is usually meant by a "rain screen wall" is generally the latter: an exterior cladding, a cavity behind the cladding, drained and vented to the outside; an inner wall plane incorporating an air barrier; and a set of compartment seals limiting the cavity size. (See Figure 5.) The outer "screen" layer of cladding deflects the kinetic force of the rain, while the inner wythe remains protected. The vented cavity uses gravity and flashings to drain water that penetrates the outer wall, away from vulnerable surfaces and joints. The cavity is sufficiently wide that surface tension and capillary action are not able to move water across the cavity.

Figure 6 shows in diagram form how the rain screen concept addresses air pressure differences. Exterior wind pressure (P_e) causes air to flow through the cladding vents into the cavity, increasing cavity pressure (P_c) until P_c = Pe and the pressure difference across the cladding (ΔP_e) equals zero. At this point, pressure equalization has occurred, and the entire wind pressure has been transferred to the air barrier. When $P_c = P_e$, moisture is no longer drawn through the outer wall into the cavity by a difference in air pressure. The pressure gradient now exists between the cavity and the interior of the building (ΔP_i), but the source of water has been removed, as water is unable to cross the cavity.

Figure 7 shows the situation when the exterior wind load decreases. Now $P_c > P_e$ and there is a net negative load on the cladding. Air will flow outwards from the cavity until pressure equalization is again achieved.

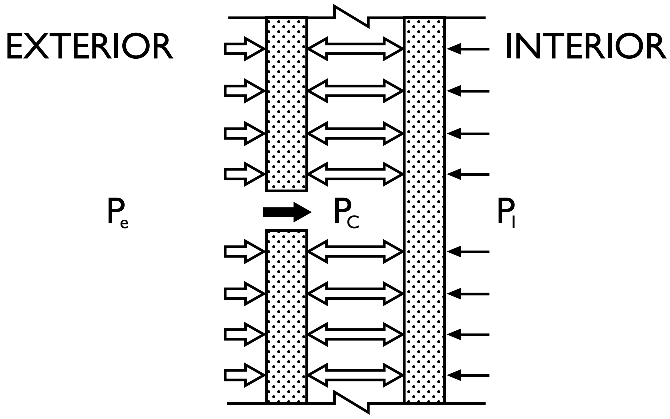


Figure 6.

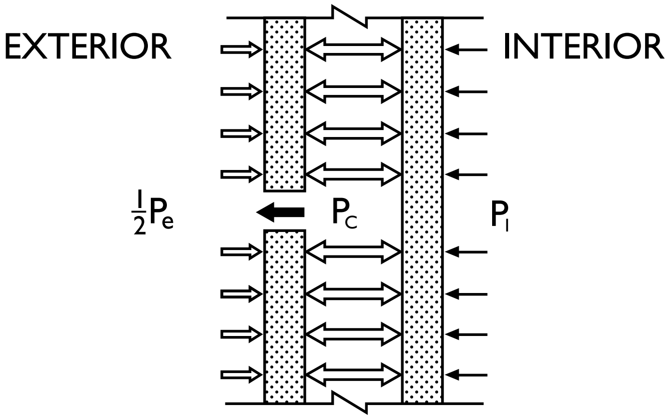


Figure 7.

The Drained Cavity Wall

The drained cavity wall (Figure 8) has aspects of the rain screen approach and addresses some of the forces that cause rain penetration, but should not properly be called a rain screen wall. Two layers are separated by a cavity. An internal layer of free draining material installed in the cavity (the concealed barrier approach) will work in effectively the same way. The outer layer receives the kinetic force of the rain, while the cavity or drainage layer prevents the capillary action of water from reaching the materials of the inner wall. Water penetrating the outer wall must be collected and directed out of the cavity with flashing and weep holes. In this type of wall, either the outer or the inner layer may act as the air barrier to provide resistance to air leakage.

However, the major flaw in this wall design–and what prevents it from acting as a true rain screen–is its failure to address air pressure gradients. If the outer layer of the wall is most airtight, the wall surface will be subject to significant wind forces. The lower air pressure in the cavity will create suction, causing rainwater to infiltrate through any tiny opening in the wall surface, whether joints, pores, gaps, cracks, or poorly bonded surfaces. Rainwater that penetrates may exceed the volume that the wall can drain internally, or it may be retained in the wall and cause materials to deteriorate over time.

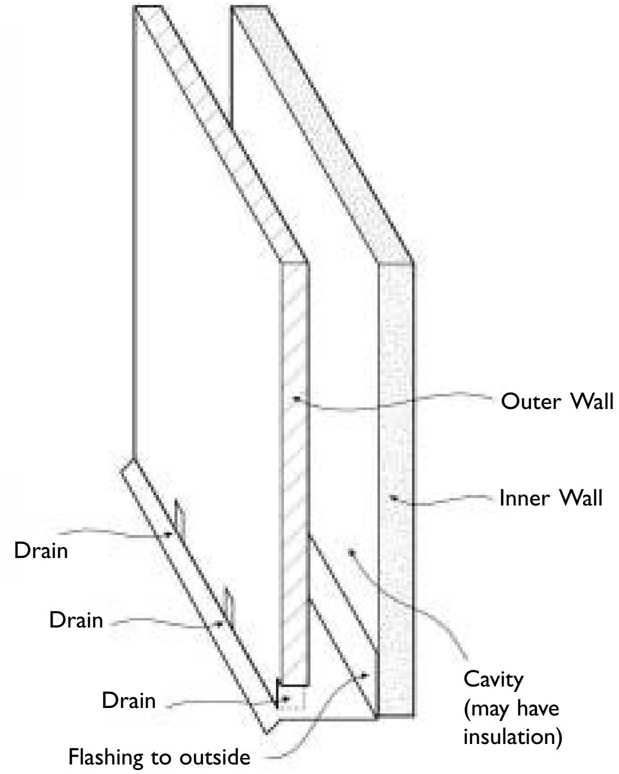


Figure 8. Drained cavity wall

The Open (or Simple) Rain Screen

The open, or simple, rain screen wall differs from the drained cavity wall in the placement of the air barrier. Most modern cavity walls and walls clad with siding act as open rain screens. In fact, the name "rain screen" is somewhat misleading in that it implies deflecting rain is the only problem. The term "two-stage weathertightening" has been used in Europe for several decades, and is a more accurate description as it acknowledges that most water entry is controlled at the first stage, the outer wall, while air leakage is prevented at a second, inner layer.

In this wall type the outer or "screen" layer is intentionally vented to the exterior, while the air barrier is located at the inner layer or backup wall. Since the inner surface is the most airtight, it bears the brunt of wind pressure loads. This relieves the pressure gradient across the outer wall, which would otherwise tend to draw moisture inward. However, since the air pressure difference now exists at the backup wall, and since some water should still be expected to pass through the vented outer layer, the inner wall requires a second line of defense against moisture. This should be a layer of water-shedding material, such as sheathing, building paper, or a waterproof membrane, and a flashing and drain at the base of the wall. The waterproof material should be located on the "warm" side of the insulation to avoid condensation (for example, on the inside in cool climates with a long heating season; on the outside in climates in which indoor air cooling is a more important consideration). Note that an advantage of moving the air barrier to the inner layer is that it is often easier to seal the inner face than the outer cladding–and the seal will last longer as it is not exposed to the exterior environment (rain, ultraviolet radiation, etc.).

Common simple rain screen wall types include brick or stone veneer on concrete block backup, stucco or vinyl siding on wood or steel frame construction, etc. Wood claddings of overlapping shingles and shakes are an example from traditional construction of what is effectively a simple rainscreen wall: small air spaces exist between the lapped shingles and the backup board or strapping to which they are fixed, with the effect of a rain screen and cavity (Figure 9). Figure 10 shows a simple rain screen wall assembly incorporating brick veneer on steel stud framing. The rain screen concept can also be applied effectively to curtain walls, and the particulars of this wall type are discussed in the section, "Rain screen Principles in Curtain Wall" (page 20).

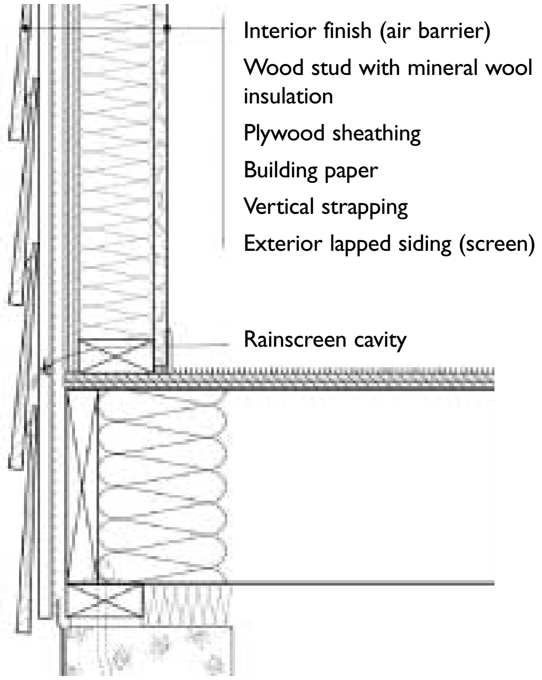


Figure 9. Example of a simple rain screen wall

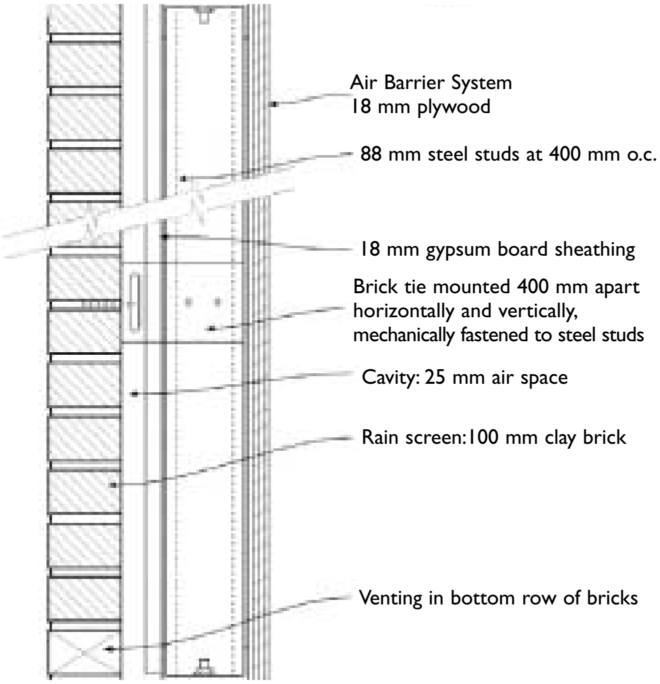


Figure 10. A simple rain screen wall incorporating brick veneer on steel studs

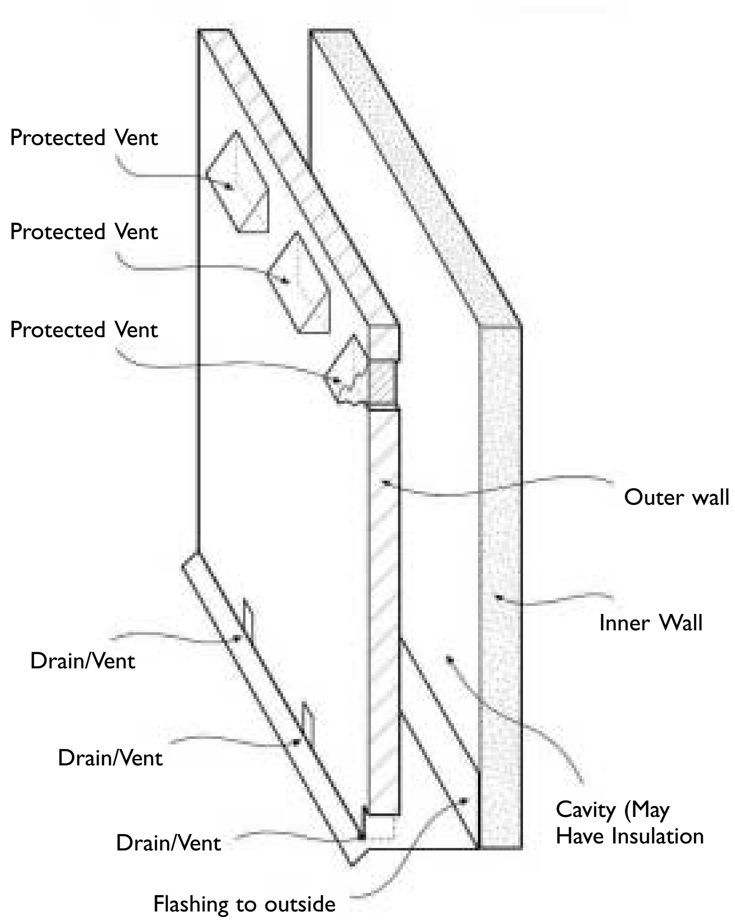


Figure 11. Back ventilated cavity wall

A variation of the open rain screen popular in Europe is the "back ventilated cavity" wall (Figure 11). The vents provided in the outer screen layer are relatively large and are concentrated at the top and bottom of the wall. This configuration takes advantage of the differences in air pressure (due to wind), and temperature (due to solar warming), between the base and roof of a building. The resulting airflow pattern in the cavity moves air in through the bottom vents and out the top vents, helping to dry out any moisture that penetrates the wall.

The simple rain screen wall still provides only limited air pressure control. In principle, venting the outer wall to the exterior transfers wind forces to the air barrier at the backup wall; as air flows into the cavity, the pressure in the cavity increases until it equals the applied wind pressure. This is referred to as pressure equalization. However, airflow through the entire wall cavity cannot respond to rapid local changes of pressure during gusts of wind. As wind pressures are distributed unevenly over walls, air will also flow laterally in the cavity to areas of low pressure at the corners and top of the building. Therefore, air pressure gradients will still exist across the outer wall, drawing moisture inside. More control over pressure differences can be achieved with a pressure-equalized rain screen (PER) wall.

The Pressure Equalized Rain Screen

The Pressure-equalized rain screen wall employs additional features in the design of the cavity to improve performance over a simple rain screen wall design. Theoretically, the outer cladding of a pressure-equalized rain screen wall is not subject to any wind load, as wind forces are transferred to the air barrier at the backup wall. This would allow design of the cladding to be as light as possible. In reality, wind forces are dynamic and variable, and pressures applied to the wall are constantly changing.

The pressure equalization strategy is sometimes referred to as "pressure modification", as no wall system achieves immediate and constant equalization when subject to dynamic wind pressures. An ideal rain screen wall would pressure equalize instantly, but research has shown that a time lag always exists between applied wind loads and pressure equalization in the cavity. Until equalization occurs, the cladding is subject to wind pressure, requiring it to perform structurally. And as long as the pressure difference exists between the cladding and the cavity, this force will drive moisture through the outer wall. "Time to equalization" and "peak cladding load" are therefore both measurements of the effectiveness of a PER wall.

Several parameters have been shown to affect both of these quantities. These include:

- Magnitude of the applied wind load
- Airtightness of the air barrier
- Leakage area of the cladding
- Compartmentalization of the cavity
- Cavity volume
- Stiffness of the air barrier
- Stiffness of the cladding

FACTORS AFFECTING PRESSURE EQUALIZATION

Magnitude of the Applied Wind Load

Analysis of these factors has been carried out under steady-state wind pressure conditions, and so our understanding of their response to rapidly changing wind loads–gusts–is fairly speculative. Wind loading creates complex situations; for example, as the force of wind impacts a rain screen wall, airflow into the wall cavity causes the cavity air pressure to increase. The mass of air required to achieve equalization depends on the cavity volume, while the time to reach equalization depends on the rate at which air can enter the cavity. The pressure difference across the cladding is the force driving air into the cavity, and the rate of air flow is proportional to the pressure difference. Therefore, the rate of air movement will decrease as air flows into the cavity and the pressure gradient diminishes. Consider, as well, that the wind loads may be varying from one second to another, and it is clear that a very complex balance of forces is at work.

The effect of decreases in wind pressure must also be taken into consideration. In gusting wind conditions, the cavity pressure will periodically exceed the outdoor air pressure. This occurs when wind loads suddenly decrease, after the cavity pressure has increased to match that of a high wind. The higher cavity pressure will create a negative (outward) load on the rain screen, which will tend to force water out of openings in the cladding, providing a further defense against rain penetration.

To take advantage of this benefit, perhaps the "ideal" rain screen wall would pressure equalize instantly when exposed to wind gusts, but would restrict airflow leaving the cavity to delay equalization when external wind load decreased. While such a construction might be possible–for example, using one-way baffles on the vent openings–nothing of the sort is currently tested or commonly used.

It is important to remember that pressure equalization counteracts only that portion of air leakage due to air pressure differences. Depending on the wall construction and orientation, this may or may not be the major factor in water penetration. For example, in wall systems where the cladding is a porous material or has open joints, improvements in wall performance achieved by pressure equalization may be relatively small, as water will still enter via capillary, gravity or kinetic forces. Therefore, pressure equalization does not eliminate the need for drainage and drying capacity. In contrast, pressure equalization may work to greatest effect in walls using impervious cladding materials. Attempting pressure equalization may also be pointless in near-horizontal or moderately sloped building elements, for example, (as airflow dynamics typically create negative pressures, or uplift, on horizontal elements); it can even be counterproductive if creating sealed compartments interferes with drainage. However, a simple rain screen approach can be used for sloped roof systems and rafter joints in sloped glazing (Figure 12), providing the dual protection of an outer shedding layer and an inner air and water barrier.

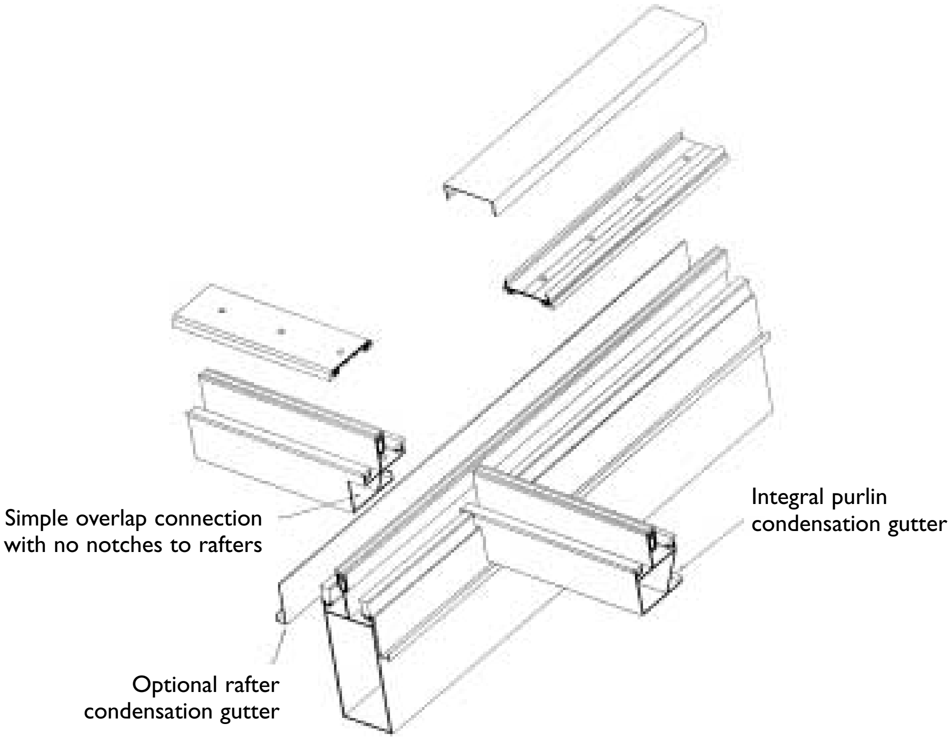


Figure 12. Drained joint on sloped glazing

Airtightness of the Air Barrier

In order for wind loads to be effectively transferred to the air barrier (and in order for the air barrier to perform its function), the air barrier must be as airtight as possible. The National Building Code provides recommended maximum air leakage rates for air barriers in insulated walls, ranging from 0.1 to 0.2 L/s/m^2 when subject to a 75 Pa pressure difference. AAMA suggests a maximum leakage rate of 0.3 L/s/m^2 at 75 Pa for curtain walls, and many walls are less airtight. For Canadian climate conditions, a rate not exceeding 0.1 L/s/m^2–equivalent to a leakage area of 10 mm^2 per m^2–should be the objective. Of course, performance of the air barrier has other implications, affecting energy utilization, condensation from exfiltration of indoor air, etc. (See the CMHC article, "Design Considerations for an Air Barrier System".)

In addition to the actual airtightness of the air barrier, its *relative* airtightness with respect to that of the cladding determines how quickly pressure equalization can be achieved. As the air barrier is made more airtight than the cladding, it will be subject to a greater pressure difference as air flows more easily across the cladding and meets more resistance at the air barrier. Ideally, the air barrier would be completely airtight and wind loads would be entirely transferred to it, achieving complete pressure equalization in the cavity and zero wind load on the cladding. For practical purposes, complete airtightness is not possible to achieve.

Leakage Area of the Cladding

The cladding should be made less airtight than the air barrier by incorporating intentional openings, or vents.

The recommended area of the cladding vents is at least **five times greater** than the leakage area of the air barrier. In other words, if the air barrier leaks 0.1 litres of air per second, per square metre (the recommended maximum and equivalent to a leakage area of 10 mm^2/m^2), the vent area in the cladding should be at least 50 mm^2 per m^2. This should transfer between 80 and 95% of the wind load to the air barrier; at a 10:1 ratio, the air barrier should carry 90 to 99% of the wind load.

The larger the vent area, the shorter the time to pressure equalization. Individual vent openings should be at least 8 mm in width to eliminate the possibility of capillary water bridging, and edges should be detailed with drips. Vents should be sloped downwards and outwards and be shielded from direct exposure to the kinetic force of rain.

Some research advocates providing vents at the top and bottom of the cavity to promote drying through convective air movement. Another approach recommends vents be combined with drainage openings at the base of the cavity only, on the grounds that locating vents at different heights in the cavity may lead to suction forces drawing moisture into the airspace. The strategy of "asymmetrical vent spacing" (see following text), in contrast, exploits the potential for pressure differences along on the cladding face to cause air movement in the cavity.

Compartmentalization of the Cavity

A key aspect of PER wall design takes into account the unequal distribution of wind pressures over building surfaces. Figure 3 shows how wind pressure varies over a building when the wind is at 90° and 45° to one face. As the spacing of contours shows, wind pressure can be fairly uniform at the centre of walls, but steep gradients develop toward edges and at the roofline. A single wall may experience positive wind forces in one area and negative (suction) forces elsewhere, while corners may be subject to strong positive pressure on one side and strong negative pressure on the other. These pressure differences become greater as building height increases. If the cavity of a rain screen wall has vents open to the outside in areas of unequal pressure, air will flow laterally through the cavity along the pressure gradient. Pressure equalization will not occur in the cavity, and the pressure difference across the rain screen can be very high–in fact, higher than if no vents were provided–especially at the corners.

To prevent this lateral air flow, the cavity is divided into compartments. Fig. 5 shows this concept incorporated into the rain screen system. At a minimum, the wall cavity must be sealed at all corners of the building and at the roofline, to prevent air from the windward face being drawn through to the negative pressure areas on the other faces. This approach should be adequate for small buildings. Corner compartment seals must be designed to resist high loads, as wind tunnel tests show they are subject to pressures up to two or three times the structural wind load. Seals can be incorporated into other design features at corners, such as expansion joints or panel edge closures. Materials that could provide effective compartment seals include elastomeric membranes, sheet steel angles, or foamed in urethane insulation, or extruded polystyrene cut to fit precisely and mechanically fastened. Note that compartment seals are not merely baffles, and solutions such as fiberglass batt or glued rigid foam strips do not provide sufficient airtightness and strength.

In larger buildings, additional compartmentalization within a façade can address differences in pressure across the building face. The size of the compartments should be based on the extent of pressure variation across a given area. Therefore, smaller compartments are required at the edges of walls, while toward the centre of a building face, where pressure is more uniform, the compartments could be larger. When the concern is only rain penetration, not structural loading, only facades subject to positive wind pressures (for example, facing into the wind) need be considered. Of course, the direction of the prevailing rain must be considered; it may not always rain from the same direction.

Determining compartment size requires a judgment by the designer as to acceptable pressure variations over a compartment. If a building's performance under expected wind conditions can be modelled, compartment spacing can be calculated based on parameters set by the designer. For example, one might decide that the variation in wind pressure across the face of a compartment should be less than 10% of the maximum wind pressure on that compartment area. Such a restriction might, however, demand very small compartment sizes at building extremities. A better solution might be to detail corners to require less pressure equalization–through increased durability, a sealed waterproof membrane, good drainage, etc.

Some basic principles can be used to size compartments in the absence of calculations based on specific wind loads. Assuming vents in the cladding are evenly spaced, compartments located close to the edges (within 10% of the building's width) should be small, around 1-1.2 m wide. The same dimensions apply to the height of compartments located within 10% of building height from the roofline. For the rest of the building, compartments could be up to 10-15 m wide and one or two storeys high (up to around 6 m). Flashing and drainage are required at horizontal compartment divisions (the vent openings at the base of each cavity can serve the drainage function).

A 1995 CMHC study (Reference 7) provides more detailed recommendations on compartment sizing, shown in Table 1. These recommended dimensions are more conservative than the above and are intended to provide pressure equalization–within 25 Pa–under instantaneous gusting wind pressures, which can be significantly higher than average maximum wind loads. Since rain penetration control has more to do with average, cumulative moisture penetration than single or momentary events–unlike load calculations for structural design–to determine whether the cavity warrants design to gust pressure levels, the designer must consider various factors, such as: local wind behaviour and exposure of the building to gusts; vulnerability of the wall materials to moisture damage with limited wetting; etc.

Table 1. Design guidelines for compartment sizing to achieve gust pressure equalization

(From "A Study of the Characteristic Shapes of Mean Pressures and Their Gradients on Buildings in Realistic Surroundings." P.F. Skerlj and D. Surry for CMHC, 1995.)

	Compartment Size as % of Building Width (w) and Height (h)	
Region of Building	**Width**	**Height**
3%* to 10% of width from corner	2% w or 1m	5% h or 1m
10% to 20% of width from corner	4% w or 1m	5% h or 1m
20% to 50% of width from corner	8% w or 1m	10% w or 1m
3% to 10% of height from top	5% w or 1m	2% h or 1m
10% to 20% of height from top	5% w or 1m	4% h or 1m
20% to 100% of height from top	10% w or 1m	8% h or 1m

* *The study states that pressure equalization is unlikely to be achieved in the 3% of building width and height closest to the edges.*

When the cavity is compartmentalized to achieve pressure equalization, additional vent area should be provided to compensate for air leakage through compartment seals. Corner seals are especially subject to high pressure differences. Therefore, in addition to providing **five** times the air barrier leakage area as noted above, effective vent area for a compartment should include **10** times the estimated leakage area of corner seals, and **once** the estimated leakage area of any intermediate compartment seals.

Compartments may be made wider if vent position is adjusted to take advantage of the steep pressure gradients at the building edges. Instead of spacing vents evenly across the face of a compartment, vents are concentrated in areas of highest wind pressure. Rather than pressure equalization, this approach employs a positive pressurization of the cavity. Providing the compartment is well sealed and the vent is the major area of air leakage in the cladding (for example, the leakage of the cladding material is small compared to the vents), cavity pressure will rise to match the wind pressure at the vents. This will create an *outward* pressure on the cladding over most of the compartment width, which will drive water out of leakage paths rather than in. The wider the compartment (and the larger the pressure variations over the cladding face), the higher the resulting outward pressure difference. As a rule, vents should be placed at the edge of the compartment closest to the centre (where wind pressures are highest on a windward face). This area remains insufficiently researched, but this approach seems viable with compartments 10% of façade width or larger. Note that asymmetrical vent spacing in very wide or high compartments may increase structural loads due to the pressure differences created, and this possibility should be taken into consideration. This venting strategy could create inward forces when the façade is subject to significant negative pressures–that is when wind direction makes it a leeward face–but in this case the wall would be protected from rain. The virtue of asymmetric vent spacing is that it should work to protect precisely those areas of the building that are most exposed to rain-wetting. In fact, wind tunnel testing of this vent strategy has shown near zero or outward pressures across the cladding at the roofline and edges, areas of heaviest rain-wetting.

Asymmetrical vent spacing relies on the fact that it is the location of the vents that connect the sealed compartment to the outside, and the specific air pressures at those locations, that determine the air pressure in the entire enclosed compartment. Care must be taken to use this strategy effectively, as common construction practices may compromise its effectiveness. (For example, using snap caps over curtainwall joints may cover the vent openings for the glazing cavities and spandrel sections; see page 20, "Rain screen Principles in Curtain Wall".) As well, for the most part, vents should not be located on protrusions from the face of the building, as wind flow around protrusions may create local suction pressures which would act against compartment pressure equalization. For this reason, cladding vents should not be located close to the building edges, though drainage should be provided at extremities.

Cavity Volume

As mentioned above, gusting or cyclic wind pressures create complex conditions for achieving pressure equalization. Walls can experience air pressures due to gusting winds that are more than double the average or mean wind pressures. While the influence of the relative airtightness of the cladding and the air barrier on achieving pressure equalization was explained, the volume of the air cavity is also a factor in this equation. If the cavity is large, more air must move through the vents to achieve equalization. Therefore cavity volume, as well as the leakiness of the air barrier, determines the vent area required in the cladding.

Minimum cavity volume is governed by minimum cavity width. A minimum cavity width is required, sufficient to provide a capillary break, permit drainage of any water that enters the cavity, and allow unobstructed air movement (including convective air movement to enhance drying, if vents are provided at top and bottom of the cavity). A cavity width of about 25 mm is suitable–and remember to make allowances for construction tolerances.

In determining *maximum cavity volume*, tests carried out by the National Research Council of Canada [INSERT REFERENCE] showed that the ratio of cavity volume to vent area should be less than 50 m^3 to 1 m^2 for a PER wall with rigid components (the wall tested was a precast concrete panel system).

Stiffness of the Air Barrier and Cladding

The stiffness of the cladding and of the air barrier must also be considered, as their deflection under wind loads affects the working volume of the cavity. Increasing the flexibility of the cladding reduces wind pressure loads on the cladding, but will affect cavity volume. Increasing the flexibility of the air barrier, in contrast, will increase wind loads on the cladding, as these pressures will not be transferred to the air barrier as quickly. Variations in cavity volume resulting from deflection of the cladding or air barrier may promote suction of wind and rain into the cavity, which is undesirable. A constant cavity volume helps the cavity respond faster to rapid changes in applied wind pressure. Rigidity of the air barrier is also desirable as it maintains a uniform distribution of loads, rather than causing stress at the supports. The more flexible the assembly, the more variable the cavity volume, and the lower the ratio of cavity volume to vent area should be. For example, a somewhat flexible assembly, such as brick veneer, requires a ratio of 25:1 or lower.

MODELLING CYCLIC WIND PRESSURES

CMHC has developed a software program, RainScreen 2.0, which can model a wall assembly's performance under cyclic wind pressures. The user provides input on wind loading (mean and peak pressures, and gust frequency), cavity dimensions, cladding vent area and flexibility, and air barrier leakage and flexibility. The program estimates static and cyclic loads carried by the rain screen cladding and models how cavity pressure responds (in magnitude and time) to changes in wind pressure. The software can thus show the impact of varying any of the design parameters– for example, how increasing cavity volume slows time to pressure equalization, while increasing vent area speeds it. The effects of varying the flexibility of the cladding or the air barrier can also be seen.

REDUCED CLADDING LOADS DUE TO PRESSURE EQUALIZATION

In theory, if wind pressure across the rain screen can be controlled at all times, so can the structural load on the cladding. Future wall assemblies, some currently being developed by manufacturers, may take advantage of pressure equalization to allow lighter cladding panels. Here, however, the instantaneous peak loads presented by gusting winds are the limiting factor: structure must be designed for these loads, while water penetration control is more concerned with average pressure differences. Tests have shown that rapid changes in wind loading, such as produced by gusting winds, result in higher loads on the cladding. While a basic understanding of the factors affecting peak cladding load exists, any reduction of structural capacity in the cladding and its anchors would have to be certain of cladding behaviour in all conditions. The National Building Code requires that cladding elements be designed to the 10-year maximum wind pressures for their location and assuming a gust factor of 2.5. Some researchers have suggested a target of 25% of peak wind pressure being carried by rain screen cladding, but there is currently little scope for assuming reduced structural loads in the design of rain screen cladding systems. An exception could be instances where cladding load limits are based on serviceable criteria such as appearance, noise, or non-catastrophic deterioration.

RAIN SCREEN PRINCIPLES IN CURTAIN WALLS

Figure 13 shows a curtain wall detailed as a partial rain screen. The rain screen concept can be applied to curtain wall, to create a wall assembly that is essentially a combination of a face-sealed system (the glazing unit), portions of rain screen wall (the spandrel panels), and a set of rain screen joints. The wall section shows how the spandrel works as a rain screen wall. The glass spandrel panel is the cladding, and the cavity is between the panel and the metal backpan. The air barrier incorporates the back of the sealed glazing unit, the shoulder of the sill mullion, the backpan, the shoulder of the header mullion, the back of the next glazing unit, and so on. Seals are required to maintain air barrier continuity, typically wet sealant (glazing tape) or a gasket between the window face and the mullion shoulder, and glazing tape or sealant at the joint between the backpan and the mullion.

Note: Air chambers surrounding glass and panels are open to outside along their lower edges only.

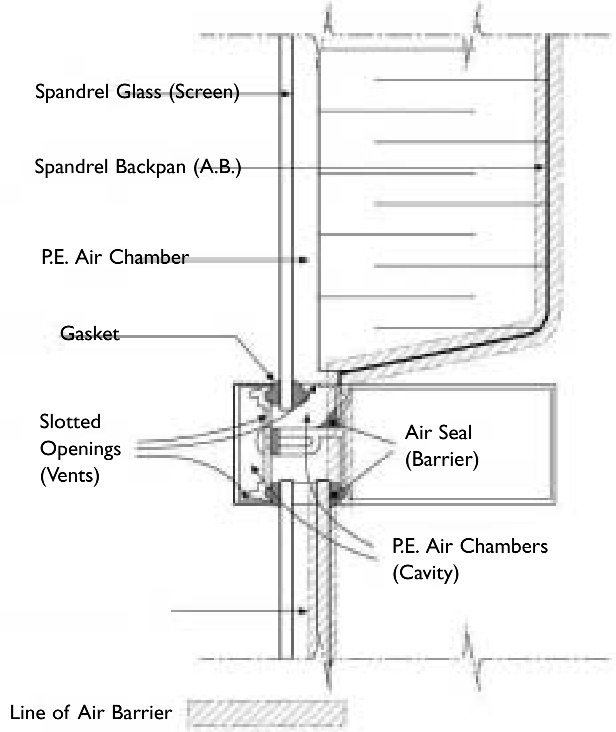


Figure 13. Rain screen concept applied to a curtain wall

Many curtain walls work effectively with drained cavities only, but designing for pressure equalization requires additional considerations. Remember that in assessing maximum cavity volume, the ratio of cavity volume to vent area should be less than 50 m^3 to 1 m^2 for a PER wall with rigid components, while a more flexible assembly requires a lower ratio. Here, the sheet metal backpan acting as the air barrier at the spandrel panels would typically be relatively flexible, perhaps 20 or 22 gauge sheet metal. Especially given the large volume of the airspace at the spandrel panel (compared to the window panels), this could significantly decrease the potential for pressure equalization.

For the rain screen to function, deflection limits should be established in consideration of cavity volume, especially for larger panels. The larger the spandrel area, the larger the potential change in cavity volume caused by deflection of the backpan. Since vent area is provided at the mullions and will not usually be significantly adjusted for different panel sizes, deflection limits should perhaps be proportionately less for larger panels than for smaller areas. In conventional construction, the backpan may be backed with rigid insulation or provided with metal stiffeners, but limiting deflection is usually not considered except with respect to noise or firestopping issues. In this case, if 100 mm foam insulation is used instead of fiberglass batt, this will reduce the volume of the airspace significantly and help to stiffen the backpan. A cavity-volume-to-vent-area ratio of around 25:1 should be acceptable. Vents should be provided at the bottom, or at top and bottom of the cavity, through slots in the pressure plate as shown. Vents along the side are impractical as they would be under the vertical mullion cap.

Cavity compartmentalization must be taken into account. The glazing splines at the necks of mullions provide a good separation, except for two air leakage paths: the intersection of horizontal and vertical mullions, and the gap between the pressure plate and the mullion. Corner blocks can be sealed to the mullions to address the first problem (see Figure 14). A compressible thermal break can act as a gasket between the pressure plate and spline, to solve the second problem.

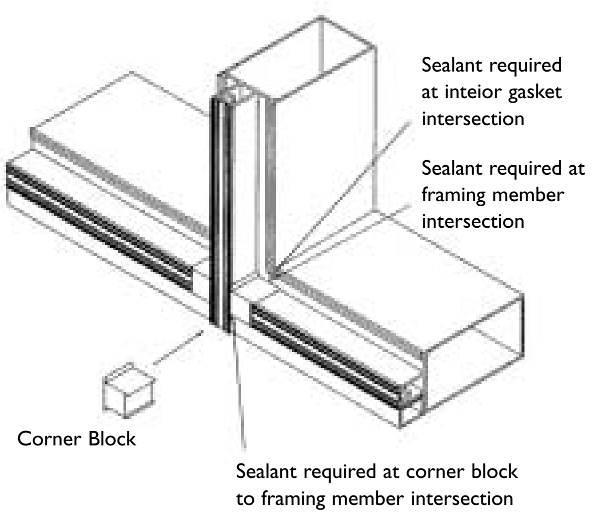


Figure 14. Corner block

Snap caps used over curtainwall joints are a potential concern, as these may cover the vent openings for the glazing cavities and spandrel sections. The snap caps thus create another, continuous cavity into which the pressure equalization vents open. We noted that asymmetrical vent spacing relies on the location of the vents that connect the sealed compartment to the outside, and the specific air pressures at those locations, that determine the air pressure in the entire enclosed compartment. The locations of the drainage and venting openings of the snap caps thus determine the *effective* locations of the pressure equalization vents on the wall face. These locations may be less than ideal–for example, at negative pressure areas–and will impede the rain screen performance. As well, the openings in the snap caps must be at least as large as the vent open area, otherwise effective vent area is reduced– twice the area is recommended. Compartmentalizing the snap cap cavities can be achieved if horizontal caps are interrupted at mullion intersections and vertical snap caps are continuous (and no vents are under the vertical caps). This will effectively restrict the snap cap cavities to the size of the glazing or spandrel panel.

To take advantage of asymmetrical vent spacing, the design could specify, for example, a 50-mm drain slot, located 50 mm from the vertical mullion at one edge, with 10-mm drain holes provided at the centre and the other side of the compartment.

Manufactured window units can incorporate a similar strategy to use the rain screen concept in the window frame. Figure 16 shows an aluminum, awning window sill detail (from the 1988 NRC publication "Window Performance and New Technology"). Note the airtight heel bead, which research shows is essential to pressure equalized performance.

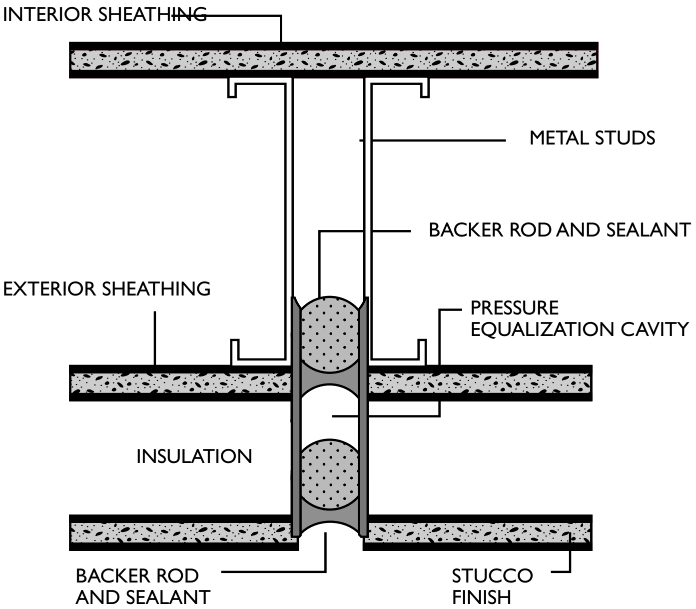


Figure 15. Sections of a stick-build curtain wall showing pressure equalized design.

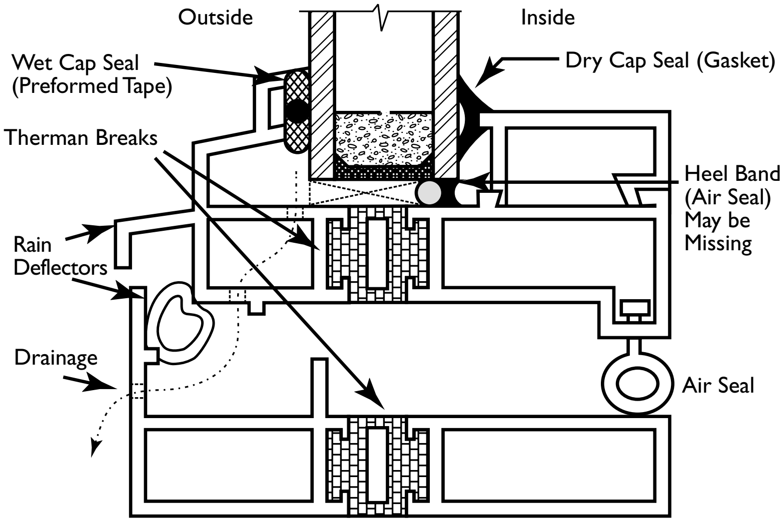


Figure 16. Application of pressure equalization principle to an aluminum awning window.

RAIN SCREEN PRINCIPLES APPLIED TO JOINTS

Joints are typically the most vulnerable point of water entry in all kinds of wall construction, due to differential movement, sealant deterioration, etc. Rain screen principles can be applied to joints whether the wall is itself a rains creen, or a face-sealed assembly, such as EIFS or precast panels. A rain screen joint incorporates the same elements as a rain screen wall:

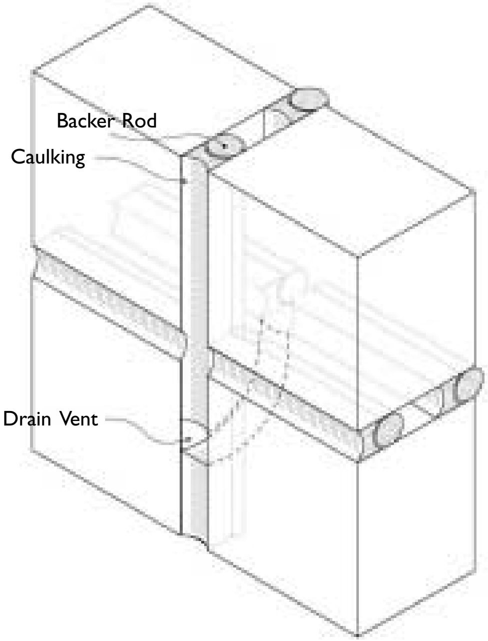
1. A cavity which is drained and vented to the outside
2. An outer weather seal
3. An inner seal which is the primary air seal (the air barrier)

And the same considerations apply to detailing the rain screen joint:

- The inner seal should be water-resistant to provide a second line of defense against moisture
- The outer seal should have a vent area equal to at least five times the leakage area of the inner air seal
- The cavity should be compartmentalized, especially near edges of the building.

A ratio of 5:1 or 10:1 between vent area and air seal leakage should be adequate to achieve pressure equalization even during gusting winds, as the cavity volume of most joints is small.

A 1995 CMHC study of EIFS panel joints (Measured Pressure Equalized Performance of Two Precast Concrete Panels, Performance of Pressure Equalized Rainscreen Walls) showed that rain screen joints performed much better than face-sealed and recessed joint designs in preventing moisture penetration. Figure 17 shows an example of a two-stage EIFS panel joint functioning as a rain screen. Note that the outer seal must be open and drained at the base of the panel, with flashing provided along the horizontal joint.



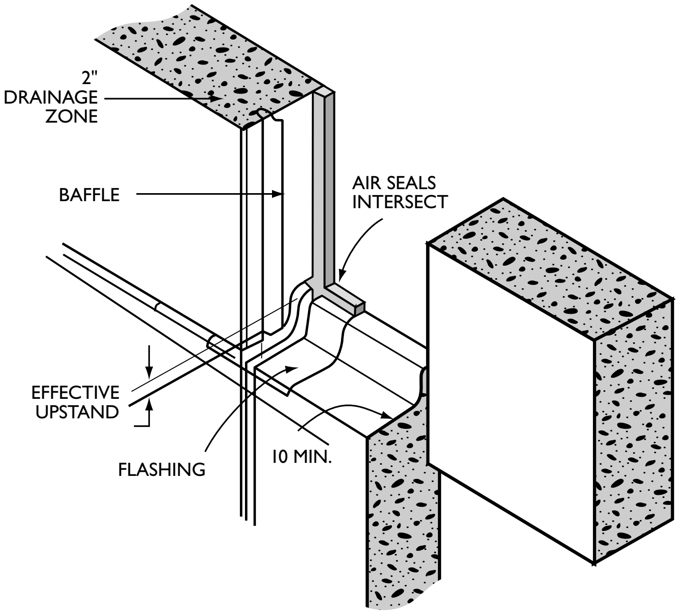


Figure 17. Example of a two-Stage EIFS panel joint.

Figure 18. Example of a two-stage precast panel joint.

WHEN TO USE A RAIN SCREEN WALL

Rain screen walls have become the most reliable choice for applications exposed to significant rain and wind. As we have seen, a fully pressure equalized rain screen wall incorporates several strategies for minimizing rain penetration: rain shedding by the cladding; drainage and venting to speed removal of water that passes through the rain screen; air pressure equalization in the cavity to minimize forces drawing water through the cladding, with the cavity also providing a capillary break; and a second layer of moisture protection at the backup wall.

The greater care required in detailing and construction to achieve a pressure-equalized rain screen wall or joint may add complexity and expense compared to other wall systems. However, because a major driving force of water entry is reduced, a PER wall is more tolerant of common construction defects and should require less maintenance over its service life. This wall system is, therefore, probably the most conservative approach for the most severe applications. However, a rain screen wall is not necessarily the best solution in every instance. In some climates and some applications, face-sealed walls perform well, and rain screen construction might be unsuitable due to expense, space, structural considerations or other factors.

As well, there are types of wall construction with proven durability that incorporate features of the simple rain screen and are worth considering in less demanding applications. For example:

- Walls incorporating only materials which are not subject to moisture damage or deterioration.

- Combining solid panels of a relatively impervious material, such as concrete, with rain screen joints to seal between them (using a face-sealed strategy for most of the wall, with rain screen joints).

- Using an air barrier made of a very impermeable, tough and well-sealed material (such as a waterproof membrane), and using only materials not subject to moisture damage outside of this layer. Note that the membrane must be located on the warm side of most insulation to prevent condensation at its surface.

- Walls clad in impervious materials, with joints protected from direct or capillary water entry, provided with careful flashing and venting to promote draining and drying, and with a good second line of defense against moisture entry.

- Any of the above, designed to achieve partial pressure equalization by compartmentalizing vents at corners, and to the extent it is practical, in the façade.

PERFORMANCE STANDARDS FOR RAIN SCREEN WALLS

There are no universally adopted standards in Canada for measuring performance of a rain screen wall. If a wall system is to be designed and built to performance criteria, however, the design and building process must be expanded to include engineering and commissioning procedures to verify design levels and construction compliance. Recent studies commissioned by CMHC have looked at establishing quantitative criteria and developing field tests of rain screen performance. (See References 4 and 5: "Testing Rain screen Wall and Window Systems: The Cavity Excitation Method" and "The Rain screen Wall: A Commissioning Protocol".) These studies propose a minimum of 80% pressure equalization at steady wind pressure and 50% under dynamic conditions as provisional performance standards. Criteria would ideally also include an allowable ratio of rain penetration to rain loading, but establishing this standard requires further research.

Performance criteria should be established before envelope detailing. A modelling tool such as CMHC's RainScreen 2.0 should be used during the design process to analyze and refine iterations of the envelope design until the above criteria are achieved. Working drawings and specifications could then follow. The design would be validated before construction with tests of a mockup built to drawings and specifications. Testing would ideally be in a laboratory, or else a mockup could be built on site as part of the construction contract with some budget allowance for redesign. Research commissioned by CMHC has developed a test method, the "Cavity Excitation Method" (CEM), suitable for laboratory and field testing. The rain screen cavity is subjected to various levels of air pressure (positive and negative) and flow (steady state and dynamic) to obtain basic leakage data. The measured rate of pressure change in the cavity is also an indicator of performance, reflecting the combined effect of attributes such as cavity volume, flexibility of components, and leakage and vent area.

Upon construction, attributes to be measured for compliance could include the following: leakage area of air barrier and compartment seals not exceeding a specified maximum; rain screen vent area not less than a specified minimum; and deflection of the cladding and air barrier within specified limits. A water test comparable to ASTM E547, "Standard Test Method for Water Penetration of Exterior Windows, Skylights, Doors, and Curtain Walls by Cyclic Static Air Pressure Difference", is also recommended to test for control of kinetic, capillary and gravity forces, to ensure that water in the cavity is not excessive, and that no water infiltrates the building interior.

REVIEW: CHECKLIST OF 10 CRITICAL POINTS IN RAIN SCREEN DETAILS

In summary, to achieve rain penetration control, an effective rain screen wall depends on certain key features. These are:

- Provision for water shedding at the outer cladding, away from joints, with drips under any projections to prevent water collecting at the building face.
- A cavity of appropriate width to allow pressure equalization across the cladding system and prevent capillary movement (allow for construction tolerances!).
- A continuous and effective (for example, airtight to a maximum air leakage of 0.1 L/s/m^2) air barrier within the backup wall.
- Drainage of the cavity through continuous flashings and weep openings, and proper management of drained water.
- Adequate venting of the cavity provided through properly located openings in the cladding (appropriate ratio achieved between vent area and leakage of air barrier and seals).
- Additional provision for drainage at the backup wall (located on the "warm" side of the insulation to avoid condensation problems).
- Effective compartmentalization of the cavity at each building face with airtight seals, and additionally across the width of the façade as required (refer to calculations).
- Sufficient rigidity and/or structural support of the air barrier to resist wind loads and limit deflection.
- Sufficient rigidity of the cladding to limit deflection and resist wind loads as required.
- Special attention paid to water-resistance and drainage at building edges and parapets (areas subject to heaviest rain-wetting and wind pressure differences, where pressure equalization may not be achievable).

QUESTIONS

1. What areas of a wall are subject to heaviest rain-wetting?
2. Why should a wall cavity be compartmentalized?
3. What must be considered in determining cavity width when designing a rain screen wall?
4. Is a PER suitable for a near-horizontal or low-sloped surface?
5. If a wall is designed as a PER, the cladding does not have to be designed to resist wind loads …True or false?
6. In a curtain wall system designed as a PER, why should care be exercised when using snap caps on the mullions?
7. A wall consists of brick veneer on concrete block backup, with a 25 mm airspace and semi-rigid insulation. If the brick incorporates sufficient vents to achieve pressure equalization in the cavity, no other measures are required to prevent rain from penetrating the wall … True or false?
8. A rain screen wall assembly employs interior gypsum board as the air barrier, with an air leakage rate of 0.02 L/s/m^2. How much open vent area should be provided in the cladding, per m^2?
9. Now assume the wall cavity is compartmentalized to improve pressure equalization. A single compartment at the edge of the building and halfway up the building face is 3 m high x 1.2 m wide. The compartment is closed along the outside edge and on the other three sides, leaving an opening of 0.1 mm (average). What is the leakage area of the compartment seals? How much vent area does the compartment require?
10. The west facade of a six-storey building faces prevailing winds and is 21 m high x 36 m wide. The wall is a PER incorporating masonry veneer cladding. Suggest a compartmentalization plan for the wall cavity to enhance pressure equalization.

For the answers to these questions, please refer to your professional association's Web page.

REFERENCES

1. "Rain Penetration Control: Applying Current Knowledge", Morrison Hershfield Limited, 2001.
2. "Pressure-Equalized Rainscreen Walls", Luis de Miguel for Canada Mortgage and Housing Corporation, 1998.
3. "Laboratory Investigation and Field Monitoring of Pressure Equalized Rain screen Walls", Quirouette Building Specialists Ltd. for CMHC, 1996.
4. "Testing Rainscreen Wall and Window Systems: The Cavity Excitation Method", Quirouette Building Specialists Ltd. for CMHC, 1996.
5. "The Rainscreen Wall: A Commissioning Protocol", Quirouette Building Specialists Ltd. for CMHC, 1996.
6. "Simulation of Wind-Driven Rain and Wetting Patterns on Buildings", D. Inculet and D. Surry for CMHC, 1995.
7. "A Study of the Characteristic Shapes of Mean Pressures and Their Gradients on Buildings in Realistic Surroundings", P.F. Skerlj and D. Surry for CMHC, 1995.
8. "Measured Pressure Equalized Performance of Two Precast Concrete Panels, Performance of Pressure Equalized Rainscreen Walls." William C. Brown, , W. Alan Dalgliesh, James M. Ullett, A Collaborative Research and Development Project for the National Research Council Canada, Ottawa, 1995.
9. Exterior Insulation Finish Systems, Laboratory Evaluation of Materials and Joints Subject to Artificial Conditioning, Gibson, Lawrence,Canada Mortgage and Housing Corporation, Ottawa, 1995.
10. "The Rainscreen Wall", Dale D. Kerr, Progressive Architect August, 1990.
11. "Facts and Fictions of Rain-Screen Walls", M.Z. Rousseau, *Construction Canada* 32(2), 1990.

CREDITS

Photo page 2: Canadian Precast/Prestressed Concrete Institute