RESEARCH REPORT

Rain Penetration Control: Applying Current Knowledge

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This report was prepared by Morrison Hershfield Limited with review and input from CMHC staff and members of the American Architectural Manufacturers Association (AAMA) Task Group on Rainscreen Principle and Pressure-Equalized Wall Design. Illustrations were prepared by David G. Anderson.

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Executive Summary

Water is the most significant factor in the premature deterioration of buildings. It can damage some materials directly and reduce the effectiveness of insulation. It is the major factor in the corrosion of metals, the chemical breakdown of many organic materials and the growth of mold and rot. Controlling water penetration, as well as its location, duration and phase (vapour, liquid or solid), is often the most critical factor in achieving long-term performance of a building envelope assembly.

This document focuses primarily on rain penetration control in walls and windows. Other wetting mechanisms include condensation and exposure to ground water. Moisture can be removed from a building assembly through drainage, by diffusion or venting (convective air change) to a drier indoor or outdoor environment. Most building assemblies and materials have some tolerance for infrequent and short duration wetting. Some infrequent passage of water to the inside is a minor inconvenience rather than a disaster. Determining how much effort and expense can be justified to minimize water penetration or evaluating what assembly types are appropriate for a particular building application and location is an exercise in judgment and risk management.

Following a discussion of several approaches to water penetration control in walls, including architectural design, there is a detailed explanation of the rain-screen principle and its application to contemporary buildings. Designers are further challenged to incorporate the Pressure Equilized Rain-screen (PER) principles. The PER system uses compartment seals to divide the cavity into a series of chambers in addition to the elements of a simple rainscreen. This limits lateral air flow in the cavity and increases pressure equilization, ultimately reducing the amount of water entering the interior wall. Remarkably, in pressure equalized rainscreen walls or joints, leakage is reduced by making bigger holes in the outside surface. This is counterintuitive.

To help design rainscreen curtain walls CMHC developed the ***RainScreen*** software. It allows designers to vary the parameters of their rain screen system and graphically see the resulting dynamic pressure distribution on cladding and air barrier (backpan) layers. Its mathematical engine is based on the CMHC report *Rainscreen* by Jacques Rousseau. ***RainScreen 2.1*** adds many new features and an easy GUI interface, using either Windows ***(3.1 or 95)*** or Macintosh systems.

The RainScreen v2.1 software may be downloaded free from CMHC at: ftp://ftp.cmhc-schl.gc.ca/highrise/rainscreen.html.

Résumé

L'eau est le facteur le plus important dans la détérioration prématurée des bâtiments. Elle peut endommager directement certains matériaux et réduire l'efficacité des isolants. Il s'agit de l'agent principal responsable de la corrosion des métaux, de la décomposition chimique de nombreux matériaux organiques, de la croissance des moisissures et de la pourriture. La maîtrise de la pénétration de la pluie ainsi que des endroits où elle se produit, de sa durée et de ses phases (vapeur, liquide et solide) constitue souvent l'élément critique devant assurer le rendement à long terme de l'enveloppe d'un bâtiment.

Le rapport traite principalement des moyens à prendre pour limiter la pénétration de la pluie dans les murs et les fenêtres. Les autres mécanismes de mouillage sont la condensation et l'exposition aux eaux souterraines. Il est possible d'évacuer l'humidité d'un bâtiment par le drainage, la diffusion ou la ventilation (renouvellement d'air par convection) vers un milieu intérieur plus sec ou vers l'extérieur. La plupart des assemblages et des matériaux possèdent une certaine tolérance au mouillage de courte durée et peu fréquent. Lorsque, à l'occasion, l'eau réussit à s'infiltrer, il s'agit plus d'un inconvénient mineur que d'un désastre. Si l'on veut déterminer le niveau d'effort et de dépenses à justifier pour réduire au minimum la pénétration de la pluie ou pour établir quels assemblages sont les plus appropriés en fonction d'un bâtiment donné ou de son emplacement, il faut faire appel à ses connaissances et gérer le risque.

Après avoir expliqué plusieurs méthodes susceptibles de limiter la pénétration de la pluie dans les murs, y compris la conception architecturale, le rapport décrit en détail le principe de l'écran pare-pluie et son application aux bâtiments modernes. On encourage fortement les concepteurs à incorporer dans leurs projets les principes de l'écran pare-pluie à pression équilibrée (ÉPPÉ). L'ÉPPÉ tire avantage du cloisonnement de la cavité en une série de compartiments qui s'ajoutent aux éléments du pare-pluie simple. Le déplacement latéral de l'air dans la cavité est ainsi réduit, ce qui tend à équilibrer les pressions plus rapidement, diminuant ultimement la quantité d'eau qui pénètre dans le mur de fond. Contre toute attente, ce qui est remarquable à propos des murs ou des joints pare-pluie à pression équilibrée, c'est qu'on diminue les infiltrations en pratiquant des ouvertures plus grandes dans la surface extérieure du mur.

La SCHL a mis au point le logiciel ***RainScreen*** pour faciliter la conception des murs-rideaux à écran pare-pluie. Il permet aux concepteurs de varier les paramètres de leur mur à écran pare-pluie et d'en visualiser graphiquement les effets sur la distribution des pressions à l'endroit du revêtement extérieur et du pare-air (plaque profilée). Son algorithme est fondé sur le rapport de la SCHL intitulé *Rainscreen* et rédigé par Jacques Rousseau. Le programme ***RainScreen 2.1*** comporte de nombreuses fonctions nouvelles dont une interface graphique conviviale, qui tourne aussi bien sous Windows (**3.1 ou 95**) que sous Macintosh.

Le logiciel RainScreen v2.1 peut-être téléchargé à partir de :
ftp://ftp.cmhc-schl.gc.ca/highrise/rainscreen.html

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Table of contents

Significance of Water Penetration

Water is the most significant factor in the premature deterioration of buildings. It can damage some materials directly and reduce the effectiveness of insulation. It is the major factor in the corrosion of metals, the chemical breakdown of many organic materials and the growth of mold and rot.

Water can dissolve materials and transport them to places where they are not wanted (for example, efflorescence). When water freezes, it expands by about 4%. Freeze-thaw cycling can displace materials or lead to spalling of materials where water fills pores or cracks.

Controlling water penetration, as well as its location, duration and phase (vapour, liquid or solid), is often the most critical factor in achieving long-term performance of a building envelope assembly.

Durability is the ability of a material or assembly to resist or accommodate agents and mechanisms of deterioration within a service environment and continue to do what it is required to do.

Since water is such a strong deteriorating mechanism, it is the dominant concern when it comes to the durability of many materials and building assemblies. The volume and duration of moisture in a building assembly is a function of the wetting and drying mechanisms within that assembly.

Moisture can enter the envelope assembly from the inside or the outside, or it can be trapped in the wall during construction. Water trapped during construction has been a source of problems early in the life of a building. Usually, it is the control of ongoing wetting and drying mechanisms that is most important for long-term performance.

Although this document focuses primarily on rain penetration control in walls and windows, it is necessary to understand the overall context of moisture control in building assemblies. (see Figure 1).

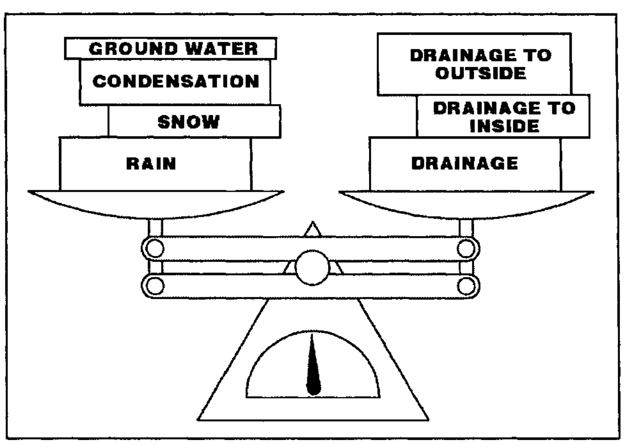


Figure 1: Moisture balance

Rain penetration is one wetting mechanism. Others include:

- Condensation on interior surfaces that are colder than the dew point temperature of the air to which they are exposed.
- Exposure to groundwater or snow melts.

Moisture can be removed from a building assembly through drainage, by diffusion or venting (convective air change) to a drier indoor or outdoor environment.

Most building assemblies and materials have some tolerance for infrequent and short duration wetting. Some infrequent passage of water to the inside is a minor inconvenience rather than a disaster.

Determining how much effort and expense can be justified to minimize water penetration or evaluating what assembly types are appropriate for a particular building application and location is an exercise in judgment and risk management. Several factors, other than the ability of the assembly to resist rain penetration, must be considered. All are important. They are:

- Climate, which governs the magnitude and frequency of most wetting, the forces and time available to dry out the wall and the potential for mechanisms such as freeze-thaw cycling. An assembly that proves to be very durable in a cold dry climate may not prove so in a warm wet one and vice versa.
- Exposure, since some walls will be more protected than others.
- The ability of the assembly to store, without adverse consequences, some moisture between wetting events until it can be drained or dried out.
- The ability of the assembly to dry out any water that has entered.
- The likelihood of other wetting mechanisms, such as condensation or groundwater transfer.
- How vulnerable are the building's materials to water damage .
- The planned use of the enclosed space.

This book deals with control of rainwater penetration, but the designer must also consider these other factors.

2 The physics involved

Three things are required to move water through an assembly:

- A source of water.
- An opening for the water to enter.
- A force to drive the water through the opening.

If any one of these items is absent, there cannot be a leak.

In most climates, eliminating exterior water sources to all areas of the building is impossible, but it is possible to greatly reduce the frequency and intensity of water penetration with a water management strategy. Chapter 3 discusses water management strategy.

Limiting or eliminating leakage paths is an obvious method of controlling leakage in building envelopes. This is the principle behind conventional flat roofs, which use a continuous waterproof membrane with limited interruptions and penetrations.

Providing a durable continuous plane of water tightness is much more difficult in walls with windows, doors, construction joints, variations in plane and different assemblies or finishes.

In the past, when uninsulated mass masonry construction was common, the ability of the masonry to soak up large quantities of water and the extra drying provided by indoor heat mitigated the problem. When solid bearing wall construction gave way to lighter, insulated, framed or veneer wall systems, these advantages were lost. Wall systems that rely solely on sealing leakage paths frequently deteriorate as a result of moisture entry.

In the last two or three decades, design approaches have focused on controlling the forces that drive rain penetration. These 'force control' approaches can be applied to a whole wall, or to individual joints. The principles involved are the same.

3 Assessing and reducing exposure to water sources

The amount of water falling on the face of a wall (the 'source') determines whether there will be water penetration, and how much. It is important to understand how rain water acts on a wall surface, and which parts of the wall are the most vulnerable.

The amount of water that actually hits a vertical surface, such as a wall or window, depends more on wind velocity than on rain intensity. Several factors have an impact on exposure.

- When rain falls straight down, very little touches a vertical surface. Wind must carry the raindrops to the surface. The greater the wind speed, the more raindrops hit the surface.

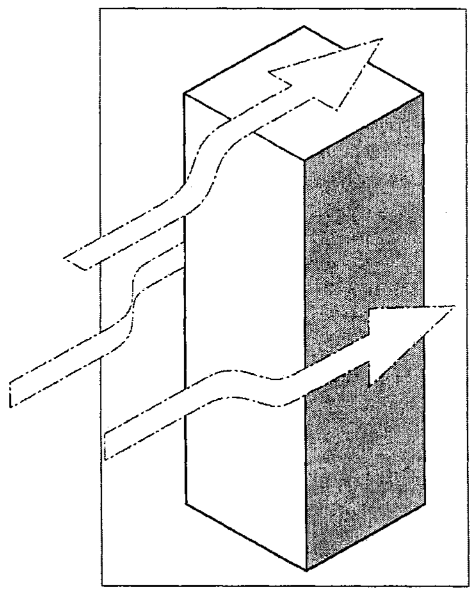


Figure 2: Wind Flow Pattern Around a Building

- The wind flow pattern affects how much rain is deposited at any location on the building. Figure 2 shows how the wind must part and flow around and over the building. A cushion of high pressure, but relatively still, air forms on the upwind, central part of the building. This dead spot protects the central portion of the wall from rain impact. At the edges of the facade, the wind accelerates around the building and raindrops are flung against the upper edge and corners.

  The typical wetting pattern in a multi-storey building is shown in Figure 3. Rain hits the roofline and corners and then runs down. Wind tunnel testing and field studies have shown that about 20 times more water is deposited at the upper edges than at the center of a wall.[1] This has been confirmed in field tests, which show that the taller the building and the higher the wind speed, the relatively narrower the band of high rain impact.

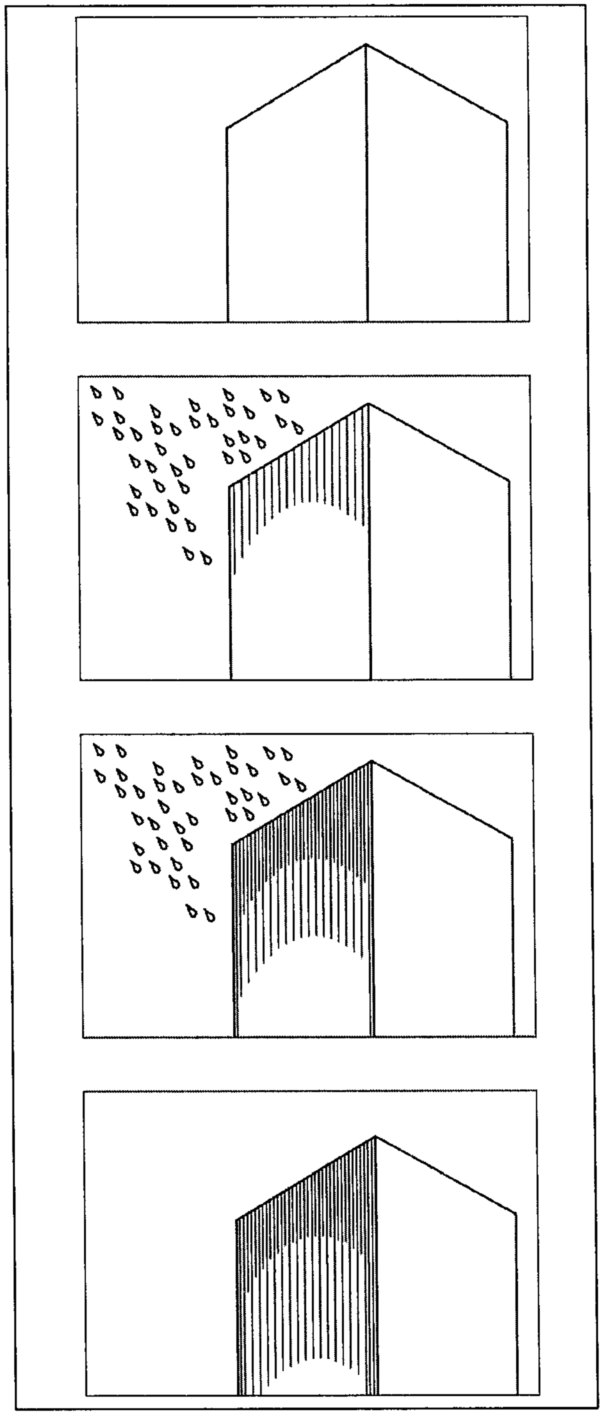


Figure 3: Wetting Pattern on a Tall Building

- The amount of water running down the face of a building depends on the absorbency of the exterior finish. On a porous surface such as masonry, much of the water hitting the wall is absorbed and held until after the rain stops. Walls with impervious claddings, such as metal and glass curtain walls, do not absorb any water. A substantial film of water flows down the wall surface, and the taller the building, the greater the accumulated flow over the lower parts of its walls.

Wind makes water flow laterally (particularly near the windward corners) and even upwards near the top of the building. The lateral flow can bring large quantities of water to vertical discontinuities, many of which are joints that are particularly susceptible to leakage.

Using knowledge of wetting patterns and appropriate architectural design, it is possible to reduce local rain exposure and the risk of rain penetration. A designer can incorporate rain resistant assemblies at the upper edge and corners of a multi-storey building, and use features such as cornices or overhangs to direct the water off the face of the building. Sloped roofs also reduce wetting in the wall, by reducing lateral acceleration at the wall–roof intersection. This means that raindrops hit the roof instead of the wall.

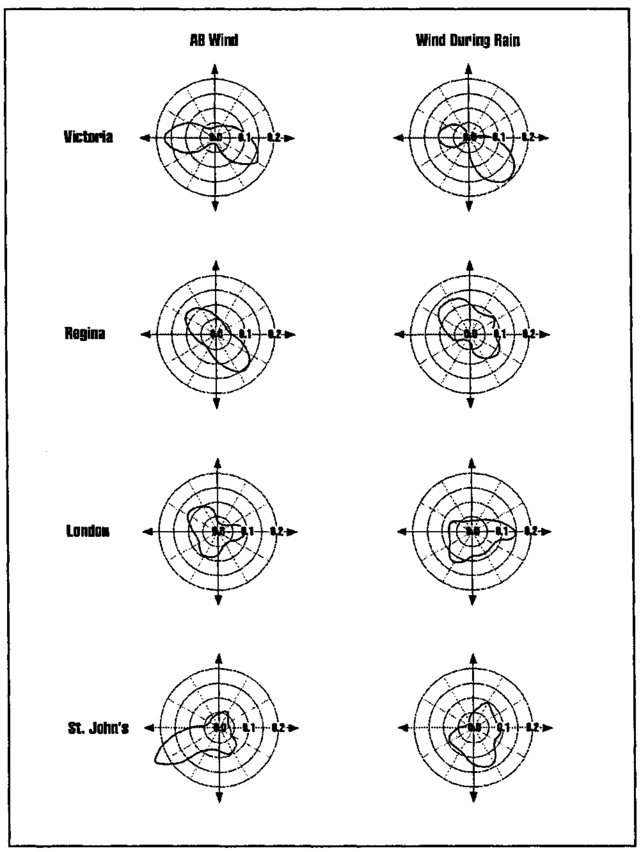


Figure 4: Wind Patterns During Rain

In low-rise buildings, eaves have a major effect on rain penetration. (A recent survey of envelope failures in the coastal climate of British Columbia found a very strong correlation between the frequency of rain penetration and the width of eave overhang.[2])

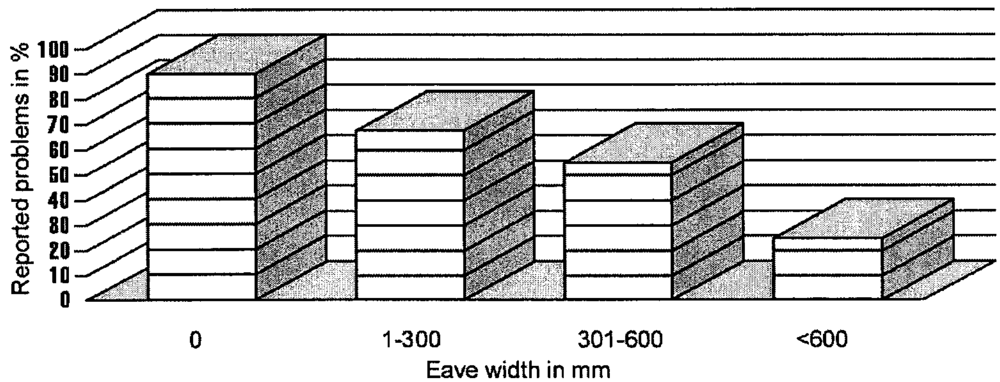


Figure 5: Frequency of Envelope Failures vs. Eave Width in B.C. Lower Mainland

The orientation of a building can also play a role. In most places in Canada, the predominant wind is westerly, but wind during rain comes from the east, as Figure 4 shows. It makes sense to use particularly rain- resistant assemblies and increase site supervision on the most exposed facades.

Wind governs the amount of water that may fall on a vertical surface and creates the differential air pressures which create water leakage, hence, window performance standards specify rain penetration resistance based on wind pressures expected during rain.

Climatic data for different locations in Canada is found in CAN/CSA-A440.1-*M90 User Selection Guide to CSA Standard CAN/CSA-A440 -M90, Windows.*[3] The Guide includes a Driving Rain Wind Pressure (DRWP) for five years and 10 years probabilities.

The listed DRWP is the pressure caused by the highest five-minute average wind speed (at 10 metres (32.8 ft.) above ground) during rain. This value can be adjusted for height using the same coefficients as used for structural calculations (Table 1).

Table 1— Height Coefficient for Wind Pressures

Height m ft.	10 30.4	13 39.6	18 54.8	25 76.2	32 102.4	41 124.9	51 155.4	64 195.1	78 237.7	94 286.5	113 344.4
Height Coefficient	1.0	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	2.0

Figure 6 shows how DRWP varies across Canada (the tables in standard A440.1, which provide climatic data for specific communities, are a better source of design information). The

DRWP is a measure of the expected peak load during a rain storm, not the amount of rain, or the frequency or duration of wind-driven rain. It does not necessarily correlate with how wet or dry a climate is. For example, Regina has a higher DRWP than Vancouver because it is subject to infrequent but intense thunderstorms with high winds.

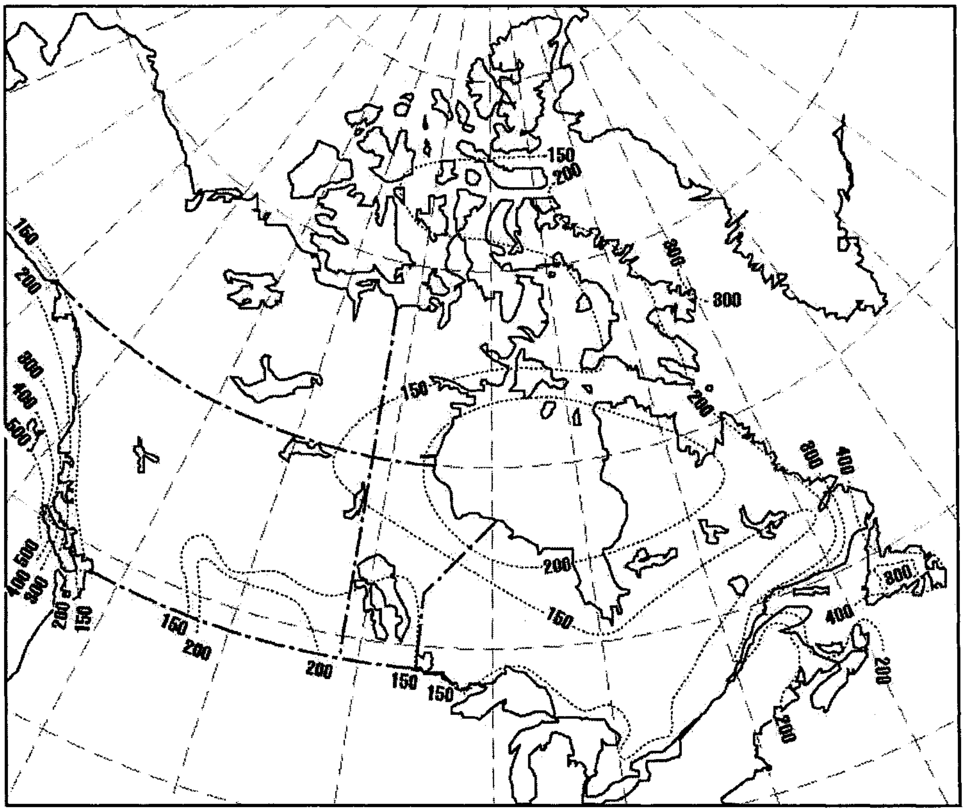


Figure 6: Map of DRWP

Consider both frequency and duration of exposure to fully evaluate the severity of a climate. The Annual Driving-Rain Index (ADRI) has been used to assess corrosion potential.[4] Figure 7 shows ADRI variations across Canada. There are many similarities but significant differences in the patterns shown on Figures 6 and 7. For example, Vancouver's ADRI is much higher than Regina's even though Vancouver has a lower DRWP.

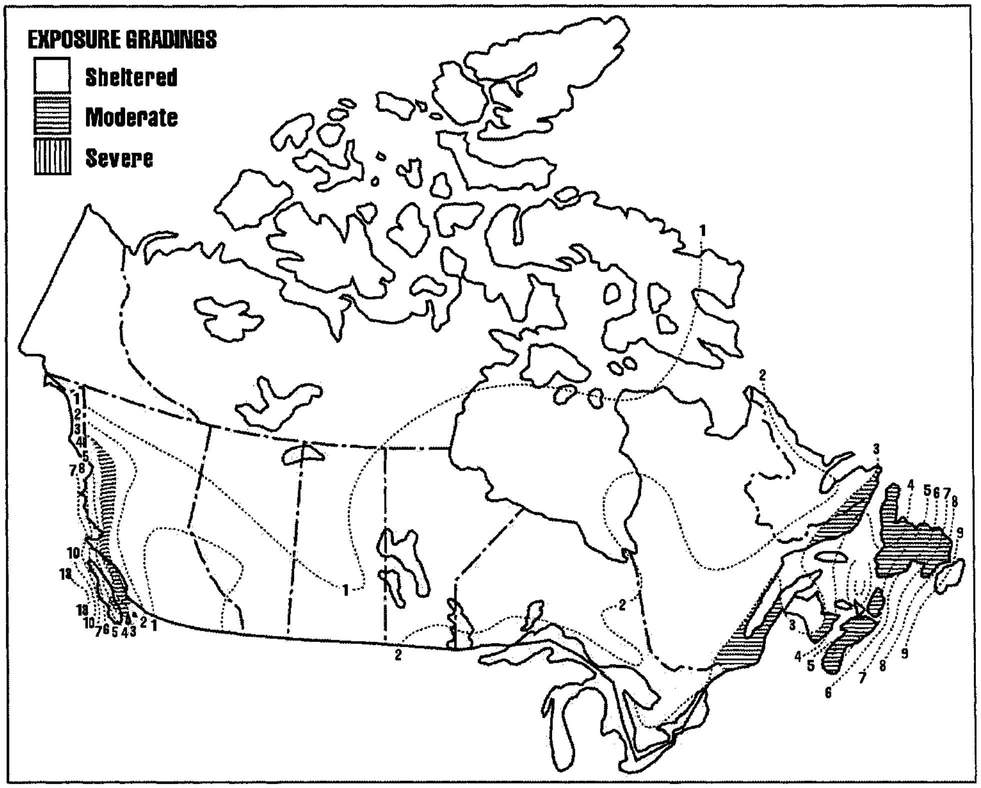


Figure 7: Map of annual driving rain index

The type of construction will determine which of these exposure assessment approaches is most relevant to a designer. Using DRWP to consider peak loading is most relevant for systems in which any water penetration must be avoided, or where it creates an immediate concern (such as rain leakage through a face sealed window or wall system) or in systems that rely on features such as upstands to avoid leakage.

In systems that accept some water entry and work by relying on a balance of wetting and drying mechanisms (including many masonry systems), the ADRI is a better measure of this balance.

4 Controlling the Forces

The forces that can drive leakage are:

- Kinetic forces
- Gravity
- Surface tension
- Capillarity
- Pressure differentials

In some circumstances only one or two of these forces may be present. In a windy rainstorm all will likely be acting to move water through any available leakage path. Design must counteract or accommodate them.

Kinetic forces

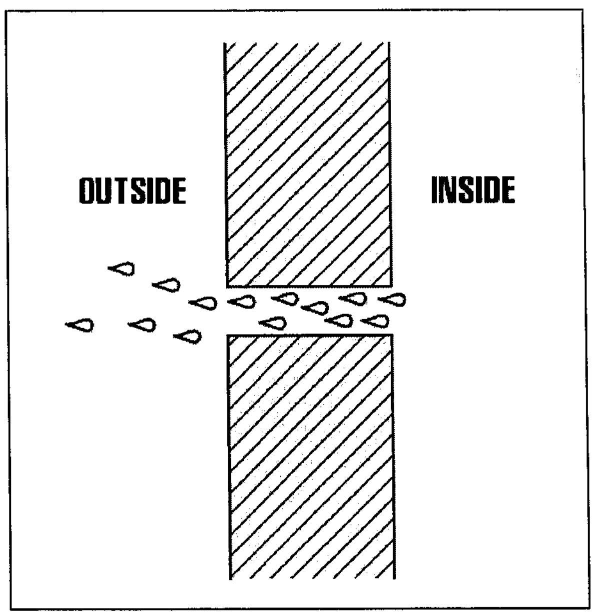


Figure 8: Kinetic energy

Wind-driven raindrops can have a significant horizontal velocity. Near the top of the building there can even be an upward component. Their momentum can carry raindrops directly through openings of sufficient size.

Intentional openings such as drains and vents can be protected from direct rain entry by cover battens, splines, or internal baffles. Their design must recognize that raindrop motion can have a lateral and even upward component.

Gravity

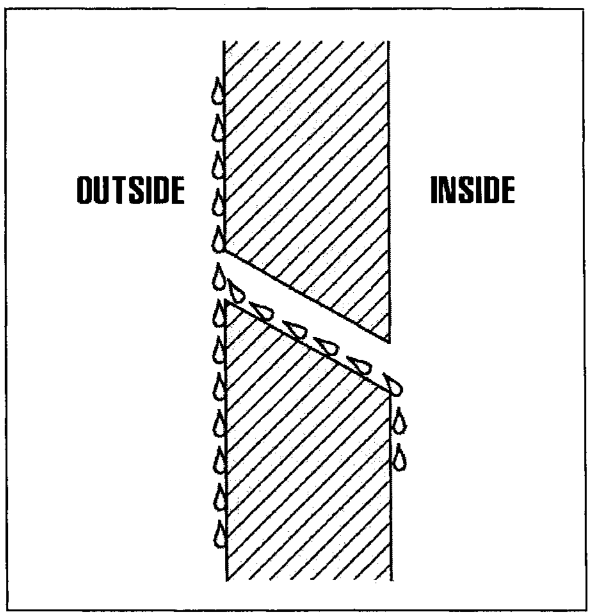


Figure 9: Gravity

Gravity's importance has long been recognized in wall design and dealing with it seems elementary. Unfortunately, leakage due to gravity still occurs too frequently in modern buildings.

The cause is usually faulty design or construction of elements such as flashings, or clogging of intended drainage paths by dirt or ice. If there is flow restriction, water builds up a head and finds a new, unintended path.

There are two things to remember about gravity: it always acts downward, and it acts all the time. This makes it relatively easy to deal with gravity in vertical elements, a challenge in sloped elements and difficult in horizontal elements.

Designers can use gravity to their advantage in vertical elements. Flashings can intercept water coming from above (either on the face of the wall or in an internal cavity), and direct it to the outside and off the face of the wall (by using extended flashings and drips). This reduces the potential source of water that could be driven into the wall by other forces.

If water is allowed to pond on horizontal surfaces, or back-up on sloped ones because of a drainage restriction, hydrostatic forces will force water through any imperfection. The ponded water also provides a constant source of water that capillary forces can move through cracks or pores. In addition, acid in the ponded water can quickly corrode metal flashings at the top of parapets. Leakage due to gravity forces is most often associated with horizontal elements. Some of the elements which are commonly associated with failures include:

- Failed or open joints in horizontal elements such as parapets and window sills.
- Porous materials in horizontal applications.
- Flashings installed with a reverse slope, or that develop one, so that water can collect at joints.
- Horizontal structures, such as balconies, with insufficient slope.
- Low slope flashings that have their drainage paths to the outside restricted by design features, poor installation, dirt, ice or improperly applied sealants.
- Flashing designs that do not stop the lateral flow off the end of the flashing to adjacent sections (in cases where the designer did not think in three dimensions).
- Gaps in corner gaskets of glazing.
- Poor drainage provisions for any water that penetrates the seals on or around windows.

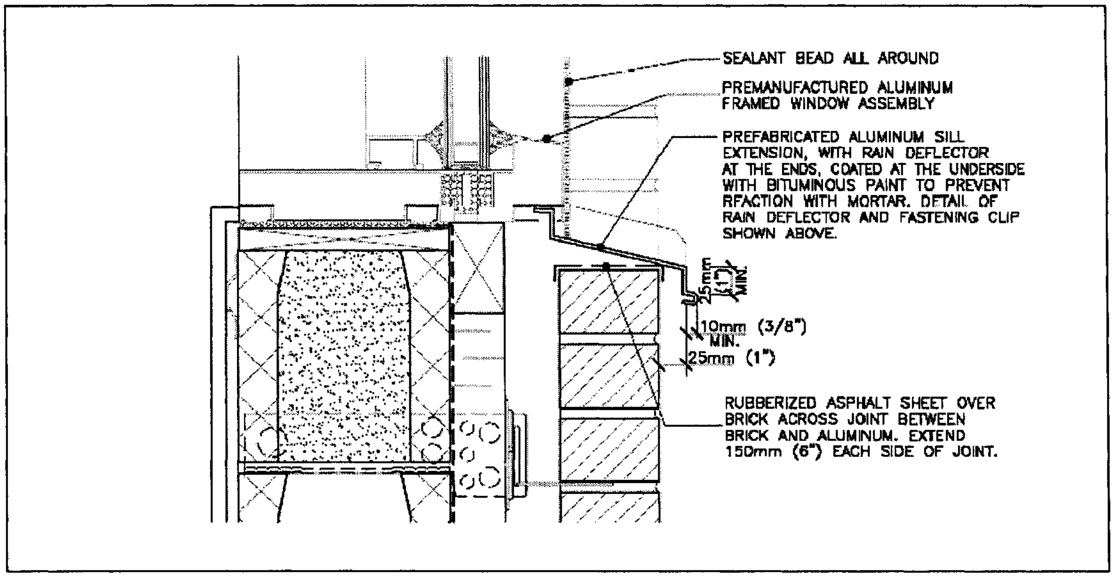


Figure 10: Metal Window Sill

Design principles that should be included in flashings include:

- Limiting the number of joints in horizontal elements where possible. Where joints are required, the element should have a positive slope (6 to 8 per cent).
- Sloping (6 to 8 per cent or more) all flashing and sills, extending them past the face of the wall, and providing a firm drip edge.
- Providing any low slope elements with an impervious, continuous cladding or sub-flashing.
- Providing end dams for all flashing (Figure 11) and for elements which may act as flashings (such as shelf angles for brick).

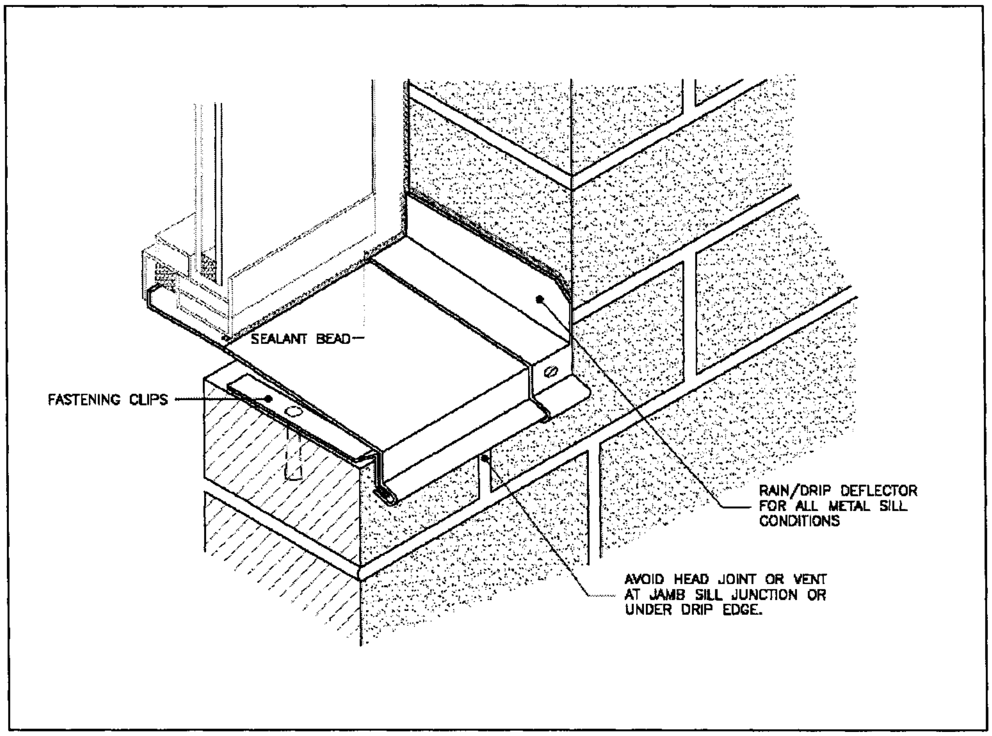


Figure 11: Sub-sill flashing with end dam

- Sizing drainage paths so they can handle significant blockage and designing them, if possible, to be the first to thaw rather than the last. Make it obvious which openings are intentional drains so that they are not sealed by mistake.
- Avoiding mortar droppings to clog weep holes by cleaning out the cavity as bricks are laid.

Surface tension and capillarity

Surface tension allows water to cling to and flow along the underside of horizontal surfaces such as soffits. This is usually prevented by a drip at the outer edge of the overhang, as shown in Figure 14.

If the space separating two surfaces is small, surface tension can pull water into the gap, even against gravity. Capillarity will draw water into thin cracks and pores and restrict drainage from the space between closely spaced layers of material. Capillarity will draw water through a layer of porous material until the layer is saturated. On its own, capillarity will tend to hold water in the material, but other forces, such as wind pressure, kinetic energy and gravity, can drive the retained water past the inside face.

The "suction" that capillarity uses to pull water in and up against gravity is inversely proportional to crack width—the thinner the crack, the stronger the suction. It also depends on the attraction of surface finish materials to water (joints between glass and/or aluminum have the greatest tendency to hold water against gravity). At a critical width, which depends on the materials used, gravity overwhelms the capillarity and water will drain from the space.

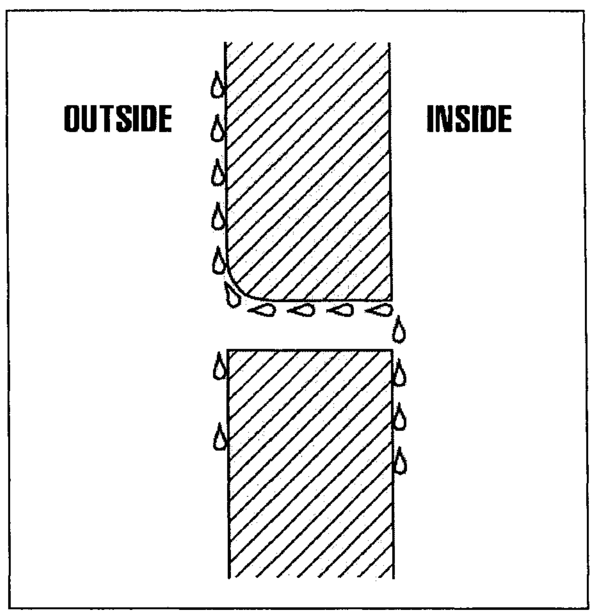


Figure 12: Surface tension

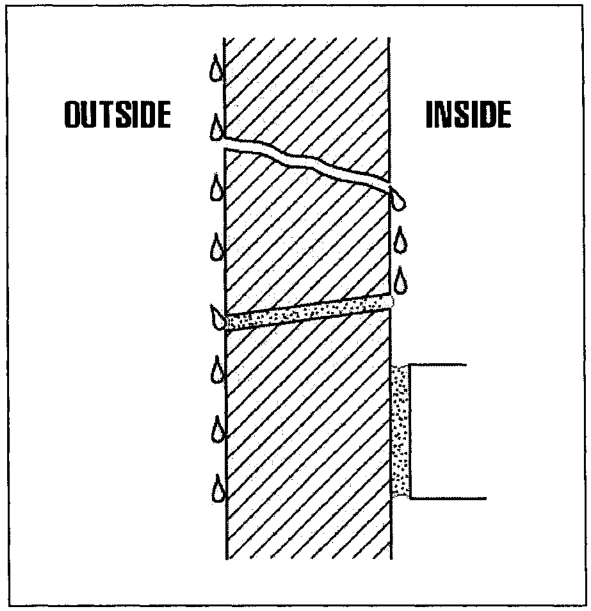


Figure 13: Capillarity

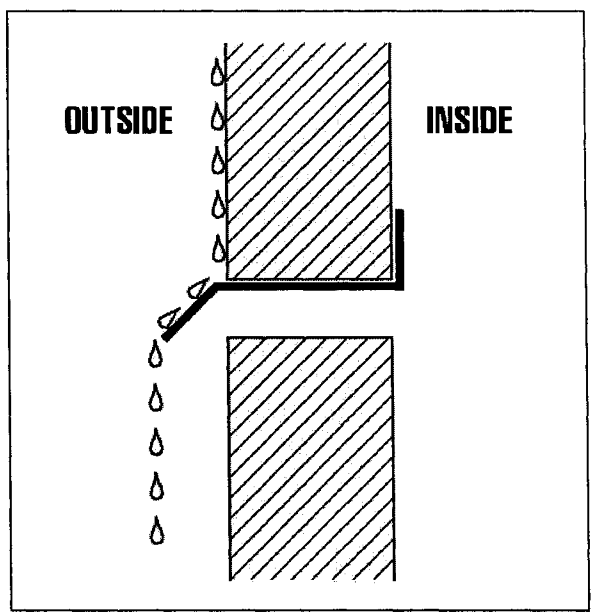


Figure 14: Drip Edge

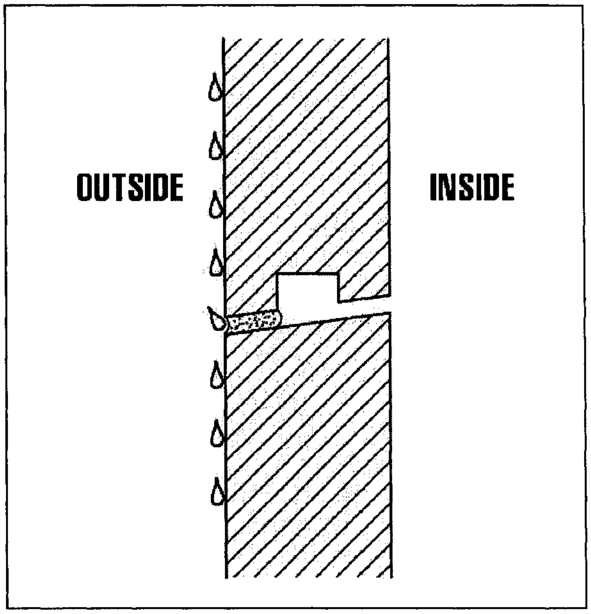


Figure 15: Joint with capillary trap

There are two general approaches to controlling capillarity. One is to seal cracks and pores in a material (make surfaces impervious). The second is to provide gaps or voids large enough to drain by gravity. If fine joints are unavoidable, a broader chamber (capillary trap) can be placed inside the joint. A 10-mm (3/8") gap interrupts capillarity in all common construction materials.[5]

In masonry and other porous materials, capillarity is usually the leading force drawing water into the material. Treating surfaces to make them less permeable will reduce water entry but may cause problems related to vapour migration. The most effective control is a drained cavity behind the cladding.

Tests of brick walls show that most water penetration occurs at the mortar joints, primarily through cracks at the mortar/brick interface, and that there is substantial water penetration even with outward air pressure differential.[6] Pressure equalization cannot substitute for drainage.

Capillarity is still a major concern at cracks and joints in impervious claddings. Sealing the joints is the usual way to deal with the problem. Sealing does not often last very long. The thin cracks that form as joint seals fail are ideal capillary paths. A more effective way to control capillary water flow in joints is to introduce an air gap in the joint that is wide enough so capillary action can't span it.

Pressure differences

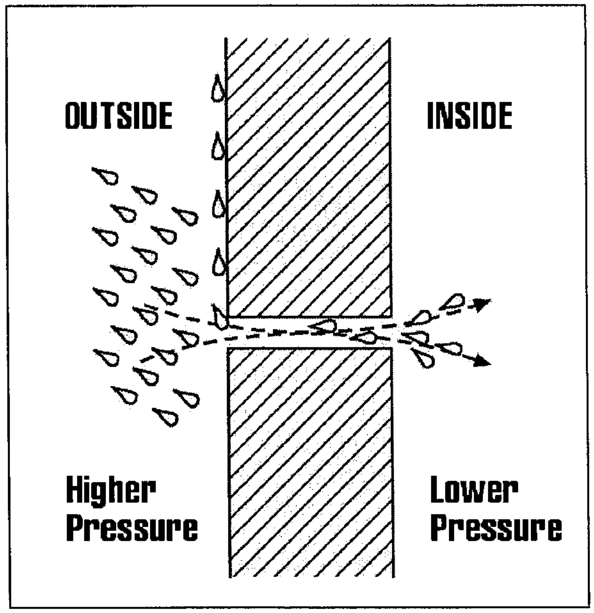


Figure 16: Air pressure difference

Air pressure differences across the envelope can be generated by mechanical systems, stack effect and wind. A pressure difference can drive water through small leakage paths, even those having a limited upward slope. Air movement driven by pressure differences can also carry droplets directly through larger openings.

In controlling water penetration, the greatest concern are pressures created by strong winds because they are generally much higher than those caused by stack effect or mechanical systems. They vary with both the location on the building (see Chapter 3, page 4) and duration (gusts).

This does not mean that stack or mechanically induced pressures do not contribute to rain penetration, but that a system that minimizes the effect of wind forces also minimizes the more limited—and stable—stack and mechanically induced pressures.

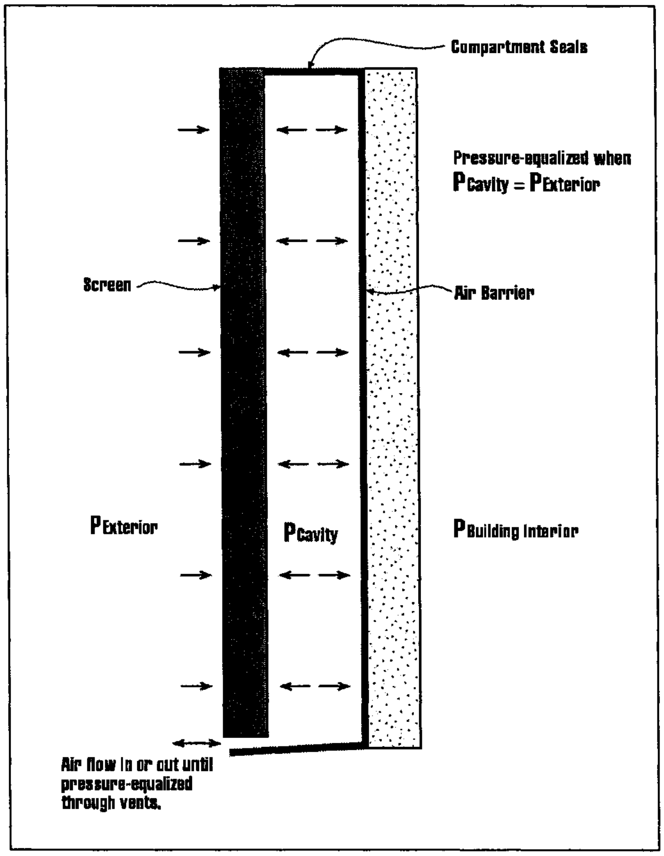


Figure 17: Rainscreen principle

Envelope assemblies must resist the pressures they are exposed to. It is possible to design a wall, window or joint assembly so that certain layers carry most of the pressure and others carry little. Most of any steady pressure across the assembly is carried by the most airtight continuous surface. This is the basis of the pressure equalized rainscreen principle.

The air pressure difference across the outer surface or cladding that is exposed to rain is minimized by making it much less airtight than the surfaces further in the assembly. A pressure difference across the wall or joint is carried by the inner surfaces and the pressure in the cavity or chamber is almost the same as outside (Figure 17). There is little pressure difference to drive air or water though the rainscreen. A simple analogy is trying to blow into a pop bottle.

There is a higher level of design sophistication needed to achieve pressure equalization (or at least moderation) as the designer considers static pressures and pressures that vary by location and time.

Dealing with the static pressure induced by stack effect and mechanical systems is relatively easy. The pressure is fairly constant and acts on all faces of the envelope in the same direction (inward or outward) at any particular height. The inner surfaces only need to be substantially more airtight than the outer rainscreen surface.

Steady wind pressures complicate matters because there is great variation in pressures across a facade and around a building. Unless the cavity is divided into chambers to stop lateral flow of air in the cavity pressure, equalization cannot occur.

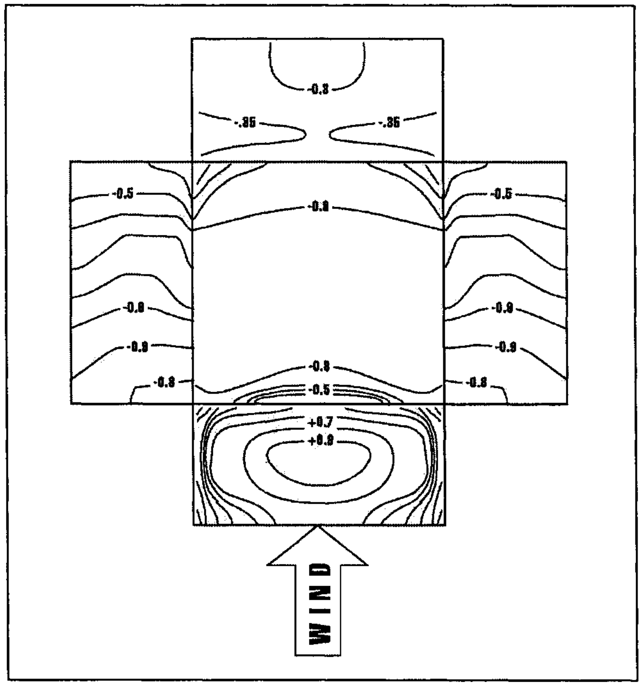


Figure 18: Pressure on the faces of a building with wind normal to facade

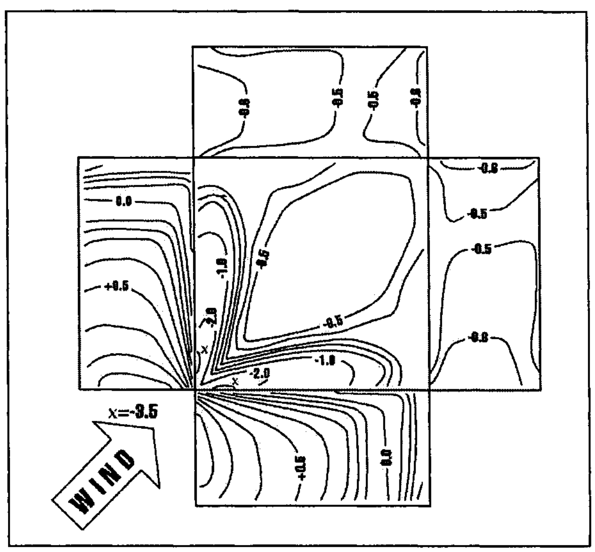


Figure 19: Pressure on the faces of a building with wind 45° to facade

Figures 18 and 19 show how mean wind pressure varies over the faces of a tall building when the wind is at 90° and 45° to one face, respectively. Pressure can be fairly uniform near the center of the walls but steep gradients develop towards the corners and the roof line. At the corners, there can be a strong positive pressure on one side and a strong negative pressure on the other.

This spatial variation will cause lateral air flow within the cavity unless it is interrupted at suitable intervals. If the air flow through the cavity is not controlled, the air-pressure difference across the rainscreen can be very high, particularly at corners. In order to provide some control, compartmentalization seals should be installed at corners and parapets to isolate each face from the dramatic difference in pressure between adjacent faces. Additional control can be provided by breaking up the cavity on each facade into compartments to address the differences in wind pressure across the facade.

To deal with changes in pressure from gusts (the **cyclic pressures**) the size of vents must be based on the working volume of each pressurization chamber as well as the leakiness of the internal air barrier and compartment seals. In a high volume pressurization chamber, more air must move through the vents to achieve pressure equalization. The stiffness of the internal air barrier and the rainscreen must also be considered because this affects the working volume of the chamber.

Chapter 6 (page 34) provides guidance on designing for pressure equalization.

Relative significance of forces

Wind pressure differences, gravity and capillarity are generally the most significant in driving rain into the fabric of building assemblies. Which is the dominant force depends on the application and construction.

On near-horizontal or moderately sloped building elements, gravity is usually more important than pressure differentials. Striving for pressure equalization may be unwarranted and even counterproductive if the horizontal compartment seals interfere with drainage.

A successful approach on sloped roof systems or rafter joints on sloped glazing systems has been a simple rainscreen with the double protection of an outer shedding surface and an inner air and water barrier. Adding the horizontal compartment seals needed to equalize pressure may actually compromise drainage from the glazing cavity and increase the potential for leakage.

In vertical elements such as walls, it is usually easier to deal with gravity, because gravity does not have an overall inward component. Inward sloping leakage paths or ponding can change this locally, requiring design attention.

In porous claddings, capillarity will move water whether or not there are pressure differentials. Pressure equalization does not eliminate the need for drainage and drying capacity.

In lightweight wall systems with impervious exterior finishes, such as curtain walls, pressure differentials may be the main force driving rain into the envelope.

5 Approaches to water penetration control in walls

Over the thousands of years that humans have constructed buildings, they have developed several ways of preventing rain penetration. This Chapter discusses the evolution of the principles set out in Chapter 4.

There is much debate about definitions and classifying some of the wall systems. This book uses consistent nomenclature based on the following descriptions, but recognizing that there are other definitions.

Solid walls

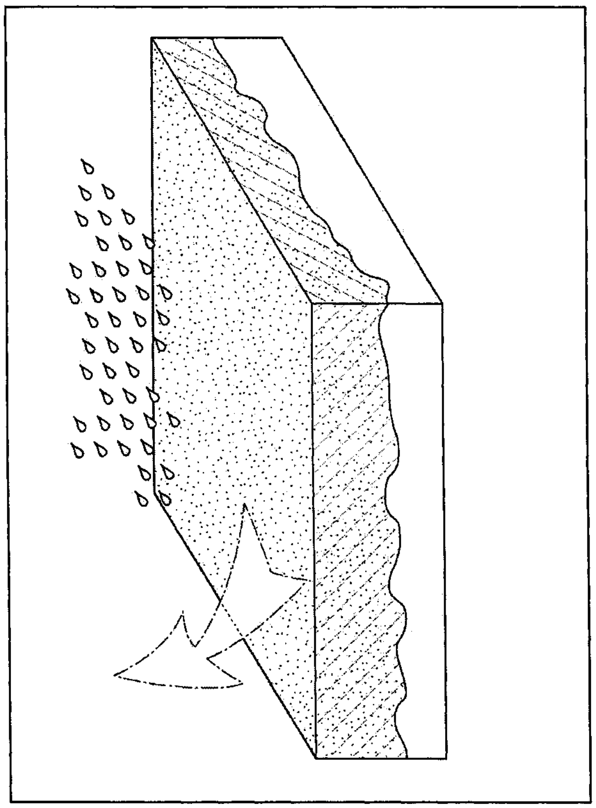


Figure 20: Solid wall

Often load-bearing, these walls include most traditional construction, such as solid brick, block, stone, concrete, solid timber and log construction. They prevent penetration by shedding most of the rain deposited on them and absorbing and holding the rest. The absorbed water is released during drier periods. In colder climates, mass wall systems often rely on indoor heat to help drying.

Face-seal approach

Typical Face Seal

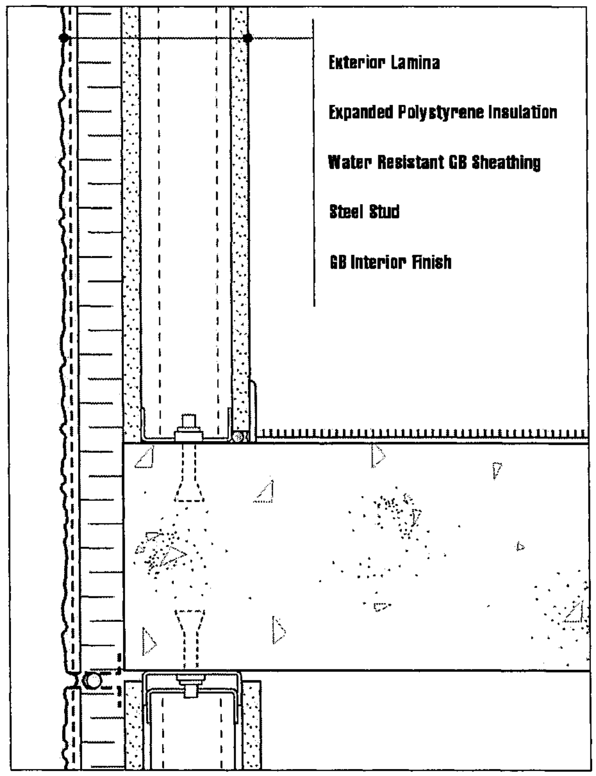


Figure 21: Face-sealed wall

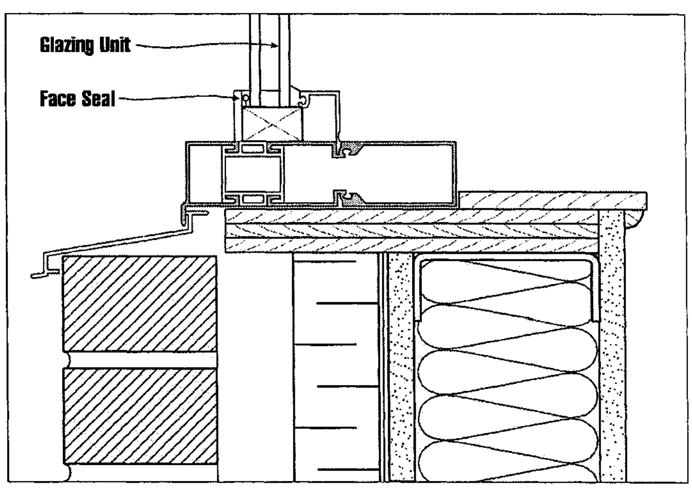


Figure 22: Face-sealed glazing joint

The face-seal approach uses water-resistant exterior surfaces sealed together to control air leakage and water penetration. The concept is to eliminate leakage paths rather than control the forces that drive leakage. The outer surface is exposed and must counteract all the forces discussed in Chapter 4 (page 10)

The exterior surfaces of these walls are exposed to the full effects of climate without the tempering effect of thermal contact with the interior environment. This makes the system less reliable than modern, insulated veneer wall systems.

Exterior surfaces of the walls react quickly to changes in temperature and solar radiation, creating significant stress on the joints. The durability of sealants used to seal the joints is limited by these stresses and the exposure to water. Inevitably, the seal fails and water can be driven into the wall by any of the forces discussed earlier. The water can be trapped for long periods, as the low permeability of the exterior materials means there is limited capacity to dry, and because of the complete lack of drainage.

Assemblies using the face-seal approach can and have been used to provide adequate air leakage and water penetration control in many climates. They need frequent maintenance to sustain the performance of the exterior sealants.

Internal Drainage Plane (Concealed Barrier Approach)

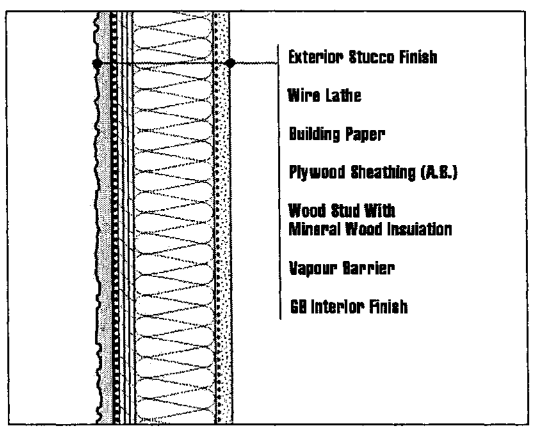


Figure 23: Stucco wall

Some wall systems have an internal barrier to leakage. For example, the exterior cladding of a stucco-finished wall can be quite porous but behind the stucco there is a water-resistant layer, such as building paper.

The water-resistant layer can (but does not always) include flashing at the base of the wall to direct draining water out. Whether these systems actually drain is debatable, and is probably dependent on how the stucco was applied. If a tight-meshed, furred-out lath was installed, a series of small, interconnected cavities may be formed between the stucco and building paper. If welded-wire lath is used, the stucco will be forced fully against the building paper with no gaps. Capillarity would restrict drainage.

It is perhaps better to consider these assemblies as face-sealed walls, with the combination of stucco and building paper acting as the air and water barrier. The stucco will absorb water until it is saturated and will release the water during dry periods. The building paper provides the resistance to capillary flow.

Stucco walls work well in many climates. Recent history shows a disconcertingly high frequency of moisture problems with stucco in rainy, windy climates and few drying periods.[2]

Many of these problems are apparently related to water entry at penetrations and joints rather than through the stucco. This suggests that lack of drainage and restricted drying are important. Most research in stucco wall systems focuses on improving draining and drying by including a drained cavity.

Drained-cavity approach

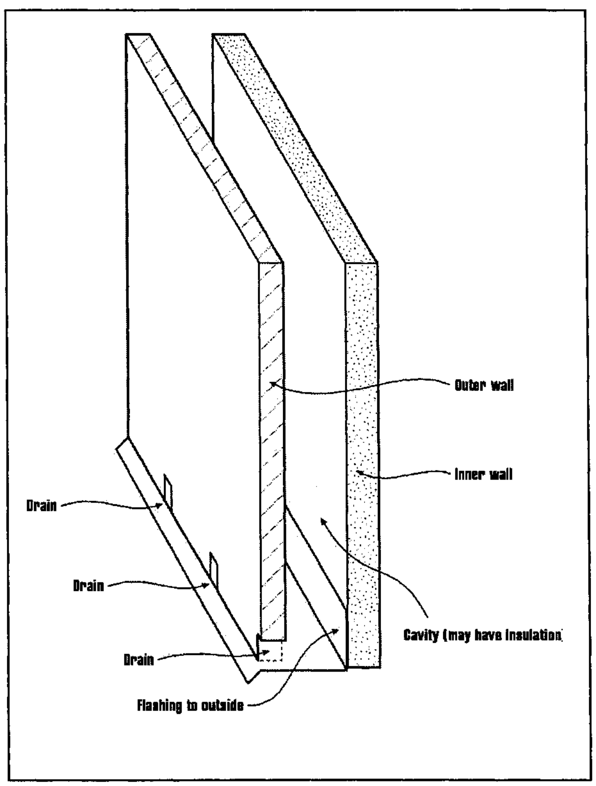


Figure 24: Drained-cavity wall

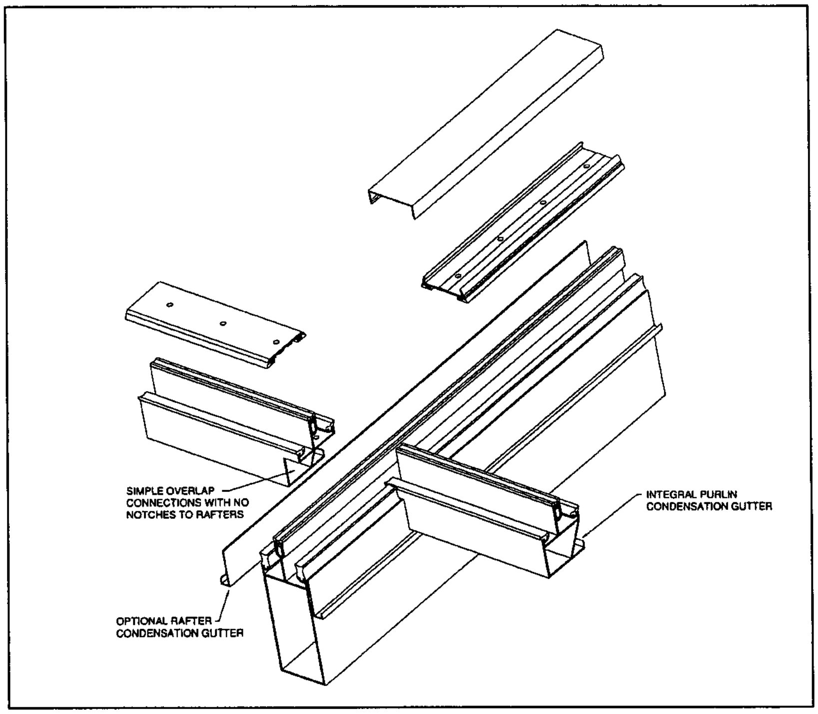


Figure 25: Drained joint on sloped glazing

Drained-cavity designs address some of the forces contributing to rain-water penetration. The key elements of this design are two layers of material separated by a cavity or free-draining material.

Either the outer or inner layer may be the most airtight and provide the resistance to air leakage. The outer layer takes the raindrop momentum (kinetic force). The cavity between the outer and inner layers prevents any water passing through the outer layer (by capillarity or gravity) from contacting the inner layer (which carries the interior finish, insulation and a water-resistant surface facing the cavity).

Some water is expected to pass through the outer layer but the amount and frequency is limited. The penetrating water must be collected and directed out of the cavity by flashing and drainage paths at the bottom of the cavity.

Even if a design includes a flashed and drained cavity behind a rainscreen, it may not control rainwater penetration because the design does not account for air pressure differentials across the wall. Air pressure increases infiltration of water on windward facades through joints, small pores, gaps, cracks, poorly bonded surfaces and openings that exist or develop during the wall's life. The water that can penetrate may be too much for the drainage to handle, or the water may be retained for long periods, degrading any moisture-sensitive materials.

Open or simple rainscreens

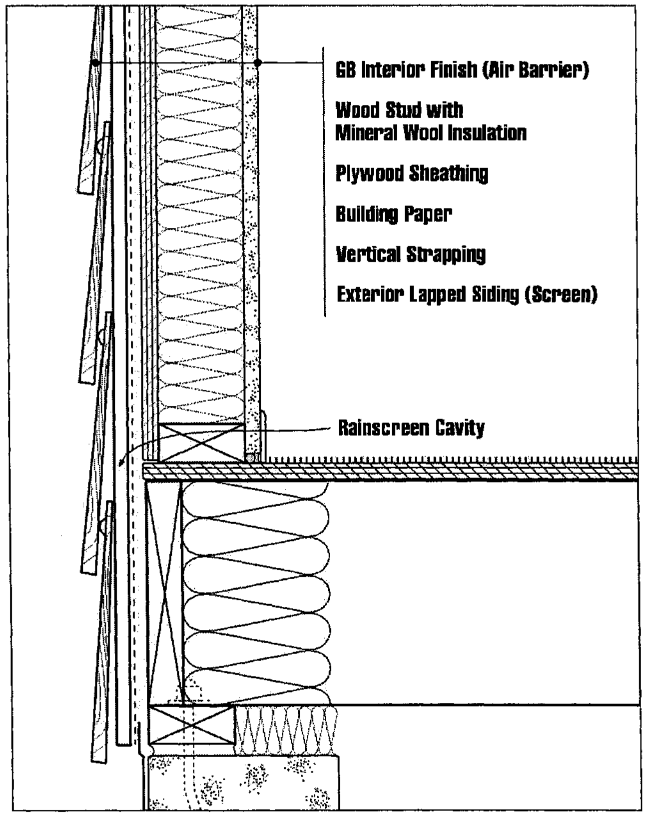


Figure 26: Siding Acting as Rainscreen

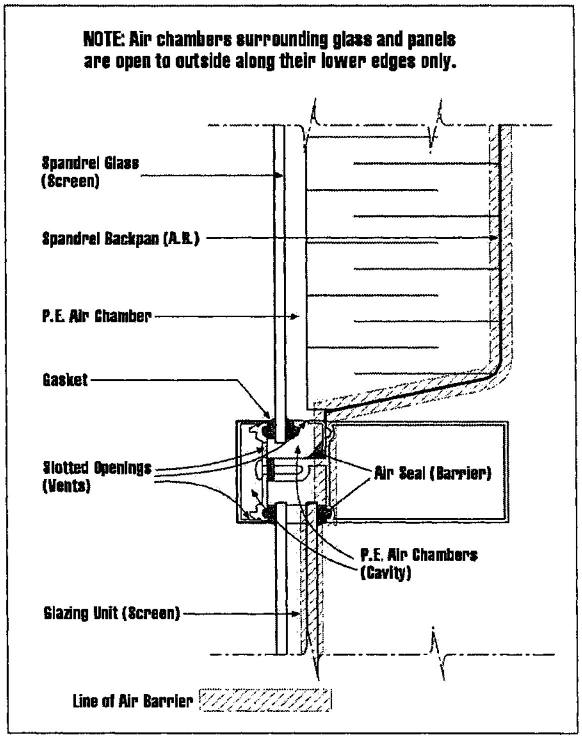


Figure 27: Rainscreen Glazing Joint and Spandrel Section

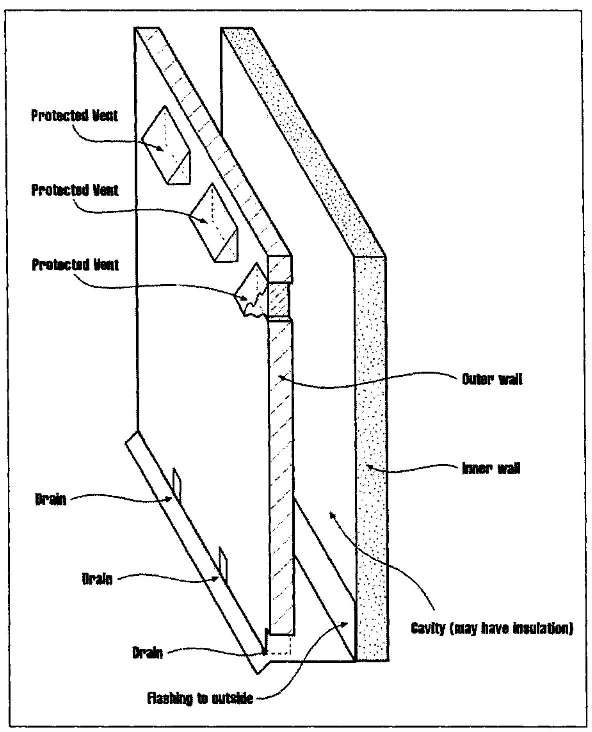


Figure 28: Back-ventilated cavity wall

Most modern cavity walls and walls clad with siding act as open rainscreens. There is also a design approach popular in Europe, sometimes called the "drained and back-ventilated cavity" which is a variation of the simple rainscreen.

The key elements of a simple rainscreen design are two layers of material separated by a cavity or free-draining material. The difference between a simple rainscreen and a drained cavity approach is that the inner layer, or back-up wall, is designed as the **air barrier** and the outer layer or rainscreen is purposely vented to the exterior. The rainscreen takes the raindrop momentum. The cavity addresses capillarity, surface tension and gravity.

Since the inner surface is the most airtight, it carries most of the air pressure load, which minimizes static pressure differences across the rainscreen.

Some water is expected to pass, so the back-up wall should have a **second line of defence against moisture**. This second line of defence consists of a layer of water-resistant material that can shed water down to a flashing and drain at the base of the wall. This defence can be made of water-resistant sheathing materials, building paper or, in severe climates, waterproof membranes (placed considering the insulation to avoid potential condensation).

The back ventilation concept (Figure 28, page 30) concentrates the venting through the rainscreen into relatively large vents (screened and protected from raindrop momentum) at the top and bottom of the wall. Temperature differences caused by the sun and wind-pressure differences at the top and bottom of a building create an airflow pattern. The pattern goes in through the bottom drains and out through the top vents. This pattern can help dry out moisture that penetrates the rainscreen.

Simple rainscreens achieve limited pressure control. Without dividing the cavity into compartments, air that passes through the rainscreen vents can flow laterally in the cavity to areas of low pressure at corners and the top of the building so equalization cannot occur. Rapid changes of wind pressures with time (that is, gust effects) also limit pressure equalization.

Pressure-Equalized Rainscreens (PER)

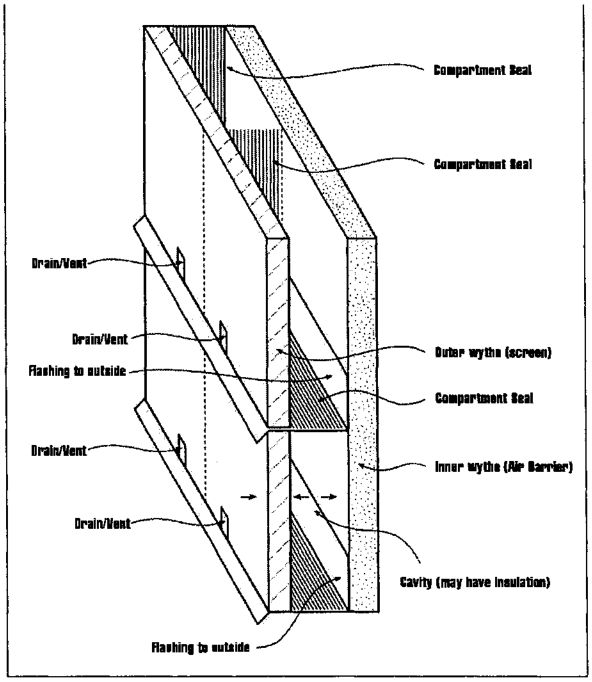


Figure 29: PER wall

A Pressure-Equalized Rainscreen (PER) wall is designed to control the pressure difference across the rainscreen.

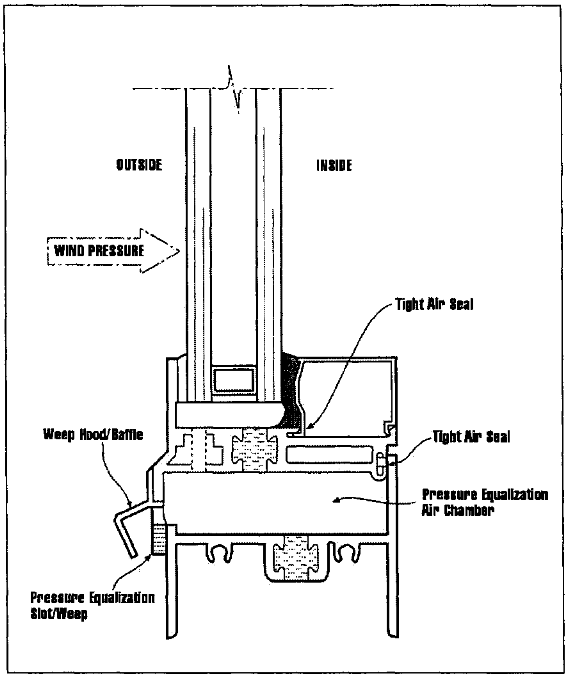


Figure 30: PER glazing joint

The PER system uses compartment seals to divide the cavity into a series of chambers in addition to the elements of a simple rainscreen. This limits lateral air flow in the cavity. The area and volume of each chamber should be such that the variation of air pressure across the face of a compartment is minimized.

The chamber must be closed at all corners of the building, since wind flowing around the building will produce very high pressure variations at corners. Compartmentalizing within the facade of the building provides additional pressure equalization. The size of the compartments can vary over the face of the wall, with larger compartments at the center of the facade and (relatively) smaller compartments near the edge of the wall.

To achieve pressure equalization at all times, select the size, number and geometry of vent holes based on the air leakage of the air barrier system and compartment seals and the volume of the chamber. The stiffness of the rainscreen and air barrier system will affect the volume of the chamber under changing pressures, and must be taken into account when designing venting requirements.

Remarkably, in pressure equalized rainscreen walls or joints, leakage is reduced by making bigger holes in the outside surface. This is counterintuitive.

6 Design of rainscreen walls

Applying the rainscreen principle

The goals of designing for rain penetration control are:

- Reduce the premature deterioration of building components.
- Prevent water from entering the interior space.

These goals do not necessarily require the application of rainscreen principles.

In some climates and in some applications, solid walls, face-sealed walls, and concealed barrier wall systems are adequate. This is particularly true for low-rise buildings with walls protected by features such as eaves and overhangs.

There has been a history of failures with face-sealed approaches used in more severe applications, such as lightweight frame construction of taller buildings, or in climates with high exposure to wind-driven rain and limited drying periods.

In these more severe applications, walls using the rainscreen concept seem to be more reliable. There are a number of reasons for this greater reliability.

Rainscreen walls generally have two layers of protection against rain entry (the rainscreen and a second line of defence). They incorporate drainage and venting to accelerate the removal of water that does pass by the rainscreen. Also, they are designed to minimize the forces that drive water past the rainscreen.

A fully pressure-equalized rainscreen wall attempts to maximize the benefits of all these factors, and may be the approach with the lowest risk for the most severe applications. There are, though, many different ways of achieving durability without striving for full pressure equalization. Some well-proven methods based on the simple rainscreen approach include:

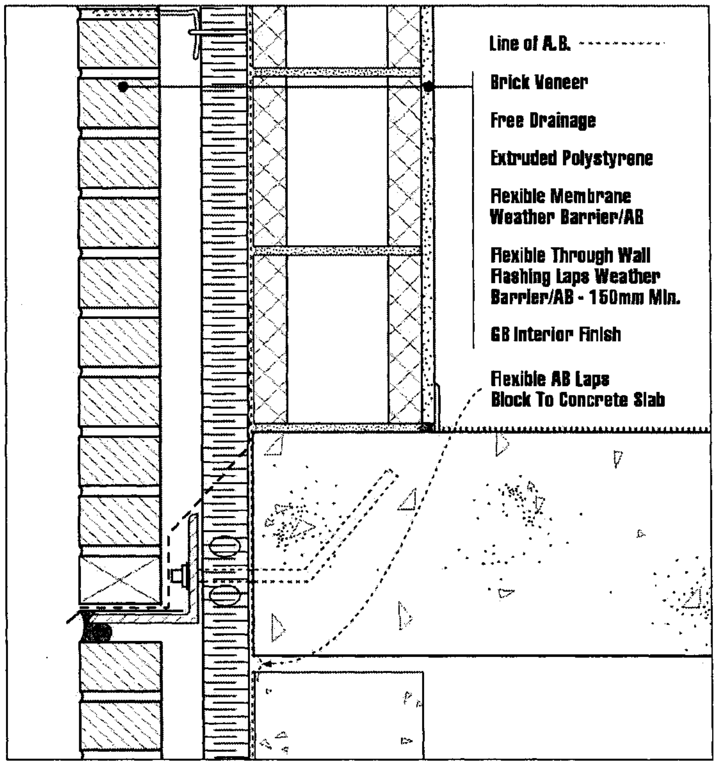


Figure 31: Masonry cavity wall

- Using only materials for the wall assembly that do not deteriorate in moist environments, such as concrete, masonry, stainless steel ties).
- Using solid panels of relatively impervious materials, such as concrete, for the exterior, and using rainscreen joints to seal between them (see Figure 55, page 66).

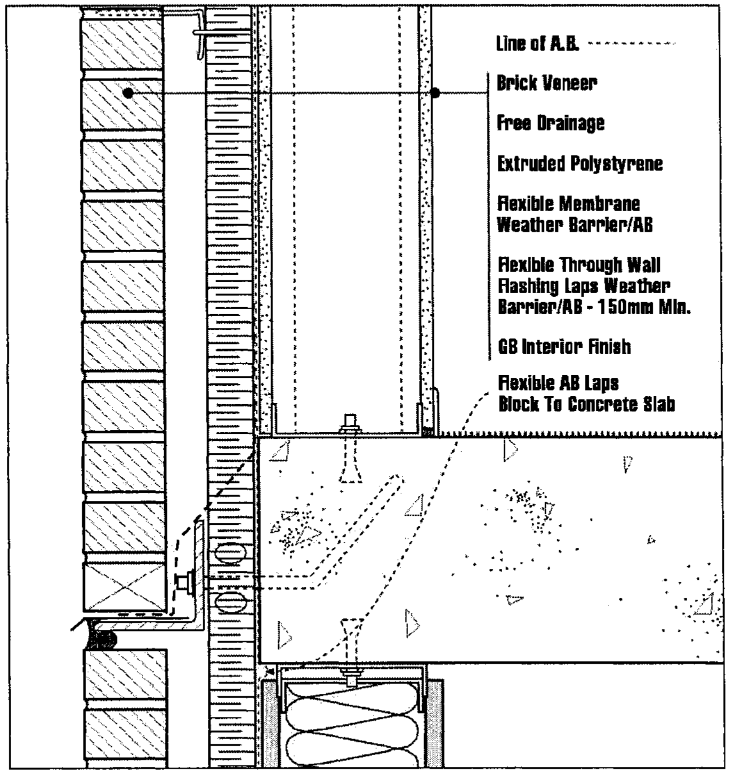


Figure 32: Metal stud wall with membrane air barrier

- Using a very impermeable, tough, well-sealed material (such as a waterproof membrane) as the second line of defence against moisture entry and air barrier, and using only materials that do not deteriorate in moist environments outside this layer. The membrane must be located where its vapour impermeability will not lead to condensation—that is, with most of the insulation on the cold side.

- Providing a good second line of defence against moisture entry; enhancing draining and drying mechanisms by careful flashing and venting design and minimizing rain entry by using impervious materials for the rainscreen cladding with joints protected from direct or capillary water entry.

- Using any of the approaches above and designing to achieve partial pressure equalization by compartmentalizing at corners and—where practical—in the facade.

Even when giving specific design consideration for pressure equalization, the designer can focus on addressing the steady or average wind pressures during rainfalls or attempt to minimize the cyclic pressures resulting from gusts. There is also the question of what is the appropriate degree of equalization for a particular application and climate.

Test results

Recent tests by the National Research Council on two different types of walls give some insight of the effectiveness of pressure equalization.[7, 8] In all the results reported in this section, 2.43 m x 2.43 m (8 ft. x 8 ft.) sections of wall were tested for water leakage with a calibrated water spray with no pressure differential, with static pressure differentials of up to 500 Pa (10.4 lb/ft^2) and under a cyclic pressure load of $\pm$1000 Pa (20.8 lb/ft^2) at 0.5 Hz (one cycle every 2 seconds).

Precast Concrete Wall

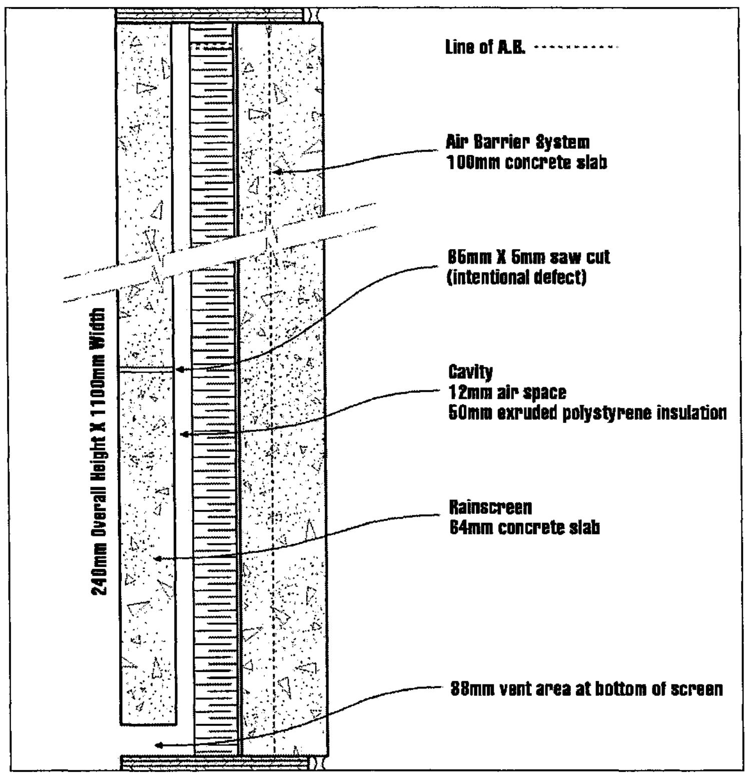


Figure 33: Precast test wall

Some of the most comprehensive NRC testing was on a precast concrete wall system.[7] Figure 33 shows a cross-section of the test wall. It consists of a very rigid precast inner concrete wall and an outer precast concrete cladding that was effectively impervious to water. The cladding had an intentional defect in the form of a 64 mm x 5 mm (2.5" x 3/16") horizontal saw cut through the cladding. The airtightness of the inner wall and the venting of the cladding could be adjusted by opening or closing holes in the inner wall or cladding vents.

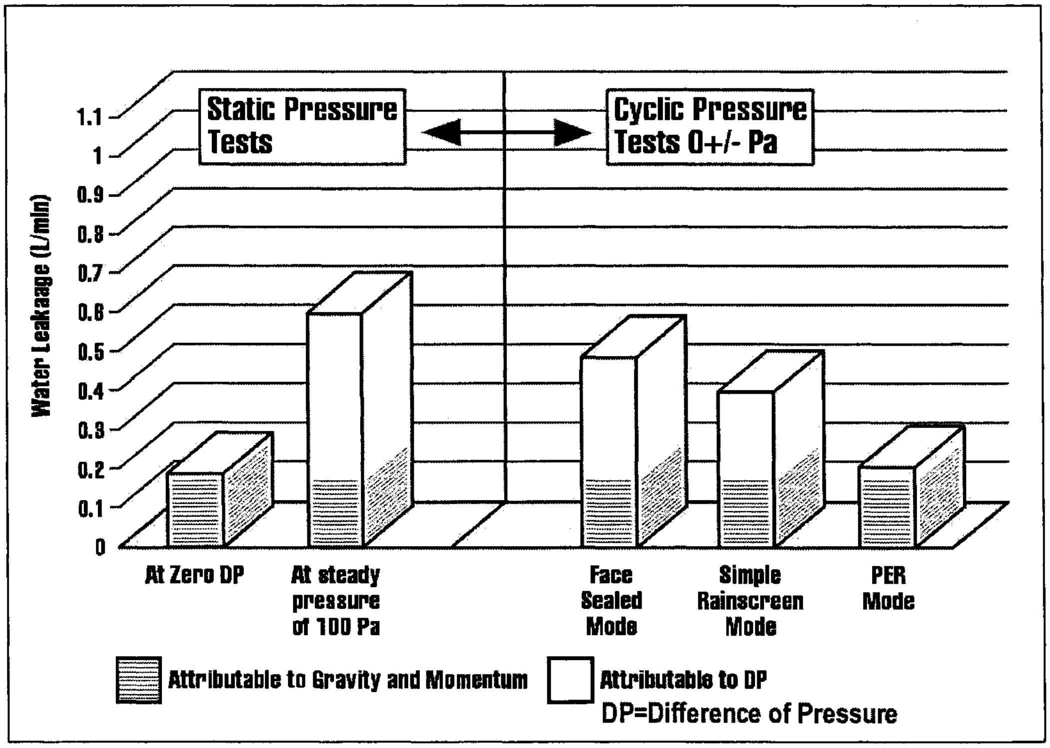


Figure 34: Water penetration test results—precast test wall

- Under zero pressure difference, just under 0.2 L/min (6.75 US oz/min) of water entered into the wall. Virtually no water entered the wall when the defect was closed, so it is assumed that the water entered through the defect by kinetic, capillary and gravity forces (the defect had a slight inward slope).
- With the vents sealed, and under a static pressure of 100 Pa (2.08 lb/ft^2) or higher, the entry rate was about 0.6 L/min. (17.76 US oz/min). This matches the total amount of water that hits the wall above the defect. In other words, all the water that ran down the wall to the defect went in. If there had been more water running down the surface, more would have entered under high static pressure loads.
- When the defect was sealed but the vents opened, very little water (<0.07 L/min)(2.07 US oz/min) entered the vents, even under 500 Pa (10 lb/ft^2) of static pressure.

The test results with the cyclic load are shown in the three bars in the middle of Figure 34. Note that in this test, the average pressure on the wall was zero but the peaks were $\pm$1000 Pa. (20 lb/ft^2)

- In the face-seal mode, with the vents sealed and an air leakage rate for the interior wall set at about 0.3 L/sec/m^2 (0.44 US gal/min/sq.ft.) at 75 Pa (1.5 lb/ft^2), 0.48 L/min (16.2 US fl.oz/min) of water entered the defect.

When the interior wall was made airtight (which equalized static pressures), the entry rate dropped to 0.40 L/min.

- When venting of the cavity was increased by opening five, 13-mm vent holes in the cladding, the water entry rate dropped to 0.21 L/min — very close to the value with no pressure differential at all (that is, water entering by gravity, kinetic and capillary forces). The difference can be attributed to equalizing cyclic pressures.

Brick Wall

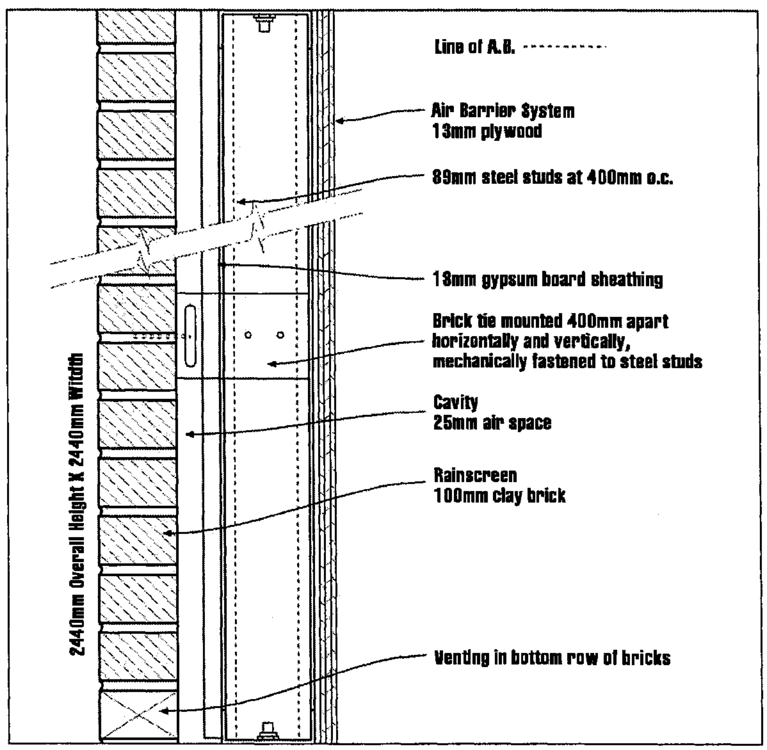


Figure 35: Brick test wall

Figure 36 (page 40) summarizes the test results for a brick veneer/steel stud system. Figure 35 shows the system in section.[8] There was no intentional defect in the brick and the volume of the chamber is large because the air barrier was the interior finish.

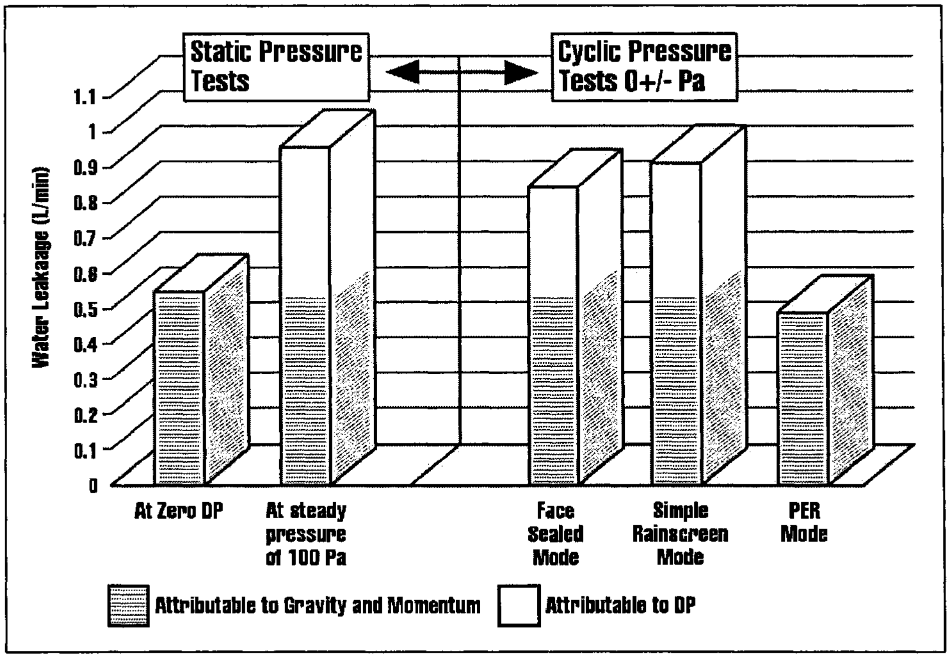


Figure 36: Water penetration test results—brick veneer wall

- Under zero pressure difference, the water entry rate attributable to entry by capillarity, gravity and kinetic forces was approximately 0.6 L/min for the test specimen

- The water entry rates through the brick with static test pressures of 100 Pa was about 50 per cent higher than with no pressure. At 500 Pa static pressure, the entry rate was four times that at zero pressure. These measurements where taken with all vents sealed and the air barrier's air leakage rate set to about 0.3 L/s/m^2 at 75 Pa.

Under the $\pm$1000 Pa at 0.5 Hz cyclic pressure :

- With all vents sealed and the air barrier air leakage rate set to about 0.3 L/s/m^2 at 75 Pa, the water entry rate was about 0.8 L/min for the test specimen. This is only 40 per cent higher than with no pressure difference.

- With an airtight air barrier and vents sealed, the tested water entry rate was about the same.

- With vents consisting of eight open head joints in the 2.44 m x 2.44 m (8 ft. x 8 ft.) sample, water entry fell to 0.5 L/min, which was about the same rate as with no pressure difference

Lessons

From these results, it is clear that if pressure equalization is achieved, rain penetration is reduced, but this only addresses the portion of leakage that can be attributed to pressure forces.

In wall systems with porous cladding or joints open to gravity and kinetic or capillary forces, the relative improvement in rain penetration resistance may be modest because water still enters by these other forces. With such walls good drainage is critical.

With impervious cladding materials, the relative performance gain afforded by pressure equalization can be very significant because capillarity is controlled.

The application of pressure-equalized rainscreen technology to a wall or joint requires great attention and care, in both detailing and construction, on the part of the designer and the builder. However, a PER wall is more tolerant of common construction defects than either a cavity wall or a face-seal wall because a major driving force is reduced. In general, although designing and building a performing PER wall is more expensive and complex, there are benefits for the owner/manager since its performance is better and requires less maintenance.

If pressure across the rainscreen is controlled at all times, so are the structural loads. This is another potential advantage of pressure equalization. Some manufacturers are working on assemblies that exploit this factor to reduce the thickness of cladding panels. This requires great care and testing because, unlike dealing with rain penetration, which is a function of average pressure differences, structural requirements must address instantaneous peak loads. The designer must be assured that the cladding loads are controlled at all times in all conditions before reducing structural capabilities.

Designing for pressure equalization in walls

Steady Pressure Differences and Mean Wind Pressures

Air Barrier Requirements

A wall need an effective air barrier for moisture control and thermal efficiency. To achieve pressure equalization, the air barrier must be inside the cavity. Parts 5 and 9 of the National Building Code (NBC) give the requirements for air barrier systems. Air barrier materials shall have a leakage rate of less than 0.02 L/s/m^2 at 75 Pa. There is explanatory material and recommendations in the Code's appendices. The NBC recommendations, and the requirements in the Canadian Construction Materials Centre (CCMC) technical guide for air barrier systems, are that air leakage rates through the air barrier system in insulated walls should range from 0.1 to 0.2 L/s/m^2 at 75 Pa.[9]

This is equivalent to a leakage area of 10 to 20 mm^2 for each m^2 of wall area. Many walls have a higher air leakage rate than the NBC recommendation. When considering static pressure equalization performance, the absolute number is not important. It is the ratio of the air barrier leakage area to vent area that is important.

Since the air barrier system will carry most of the wind load, the Code requires that the air barrier system withstand 100 per cent of the wind load for which the wall structure is designed and that it transfer that load to the structure. Any deflection caused by wind loads must be accommodated without compromising other wall functional elements.

Compartmentalization

The basic purpose of compartmentalization is to divide the wall so that all parts of a particular pressurization chamber face similar wind pressures. If there is a large change in the pressures across the face of the chamber, as there can be at the corners and the top of a building (Figure 19, page 20), and the vents are evenly spaced, the pressure in the chamber caused by a steady wind will be somewhere between the high and low external pressure.

Some parts of the rainscreen will be subject to an inward pressure difference and some parts exposed to an outward pressure difference. Air, and perhaps water, will enter any cracks or vents exposed to the inward pressure difference. The air, perhaps carrying water, will move laterally through the cavity to the low pressure zone, where it will go out the vents. The location of the cavity seals affects the pressures driving these effects.

It is important to take into account the sharp pressure gradients at corners and tops of buildings. One way to do this is to design smaller compartments at these edges.

There is an analytical approach to compartment sizing.

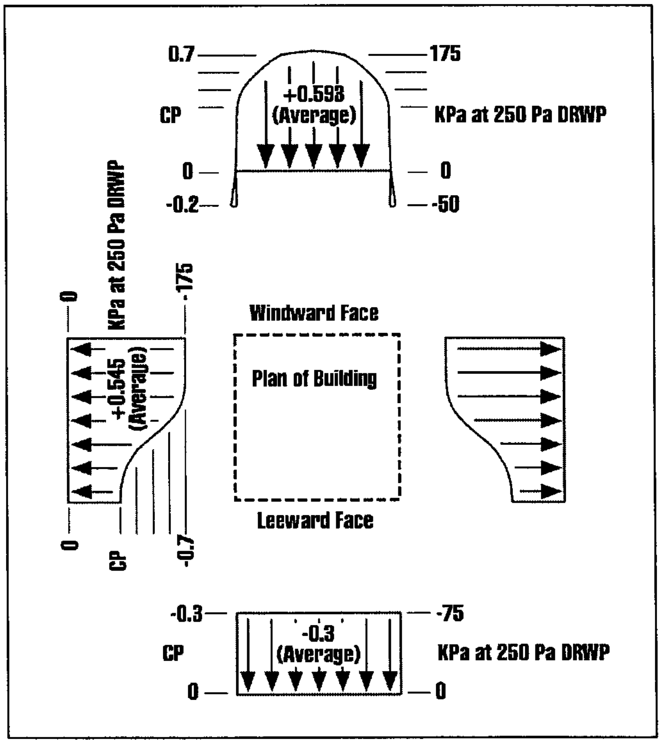


Figure 37: Distribution of average wind pressure on the faces a building

Figures 18 and 19 (page 20) show the results of wind studies of distribution of average wind pressure around a building.. [10, 11, 12] Figure 37 shows a plan section of a square building with the wind direction normal to one face. For this discussion, the pressure graphs have been scaled to a wind pressure of 250 Pa. This is a Driving Rain Wind Pressure appropriate for most areas of Canada. For example, the one-in-five year DRWP in Vancouver is 160 Pa at 10 m. At 40 m, this increases by a factor of 1.5 (see Table 1, page 8) to 240 Pa.

In the center of the windward face, the mean pressure on the building wall acts inward and is about 175 Pa (C_p = 0.7). This tails off rapidly near the corners and roof line, and, in fact, acts outward at the edge. At the sides and leeward face, the pressure acts outward.

No Compartmentalization

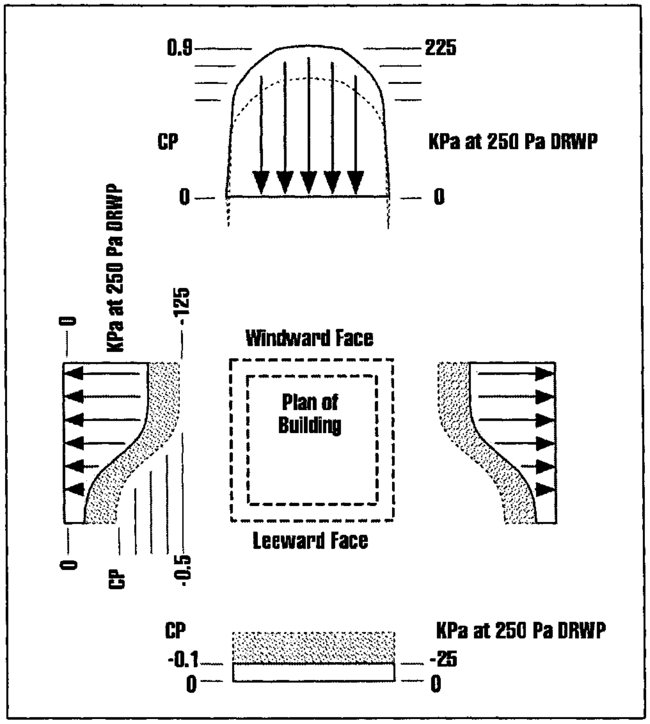


Figure 38: Wind pressure on uncompartmentalized rainscreen wall

For an idealized, simple rainscreen wall (in which the inner wall is much more airtight than the rainscreen) with a wide open cavity all around the building, the pressure in the cavity is an area-weighted average of the pressures around the building. In our example, this is -50 Pa. The pressure across the rainscreen, as shown in Figure 38, is the difference between the wind pressure and cavity pressure at that point.

Note that the inward pressure at the center of the windward face is now about 225 Pa. This high pressure can drive moisture though openings in the rainscreen and drive air flow and entrained water from the center, to and around the corner.

Effect of Sealing the Corners

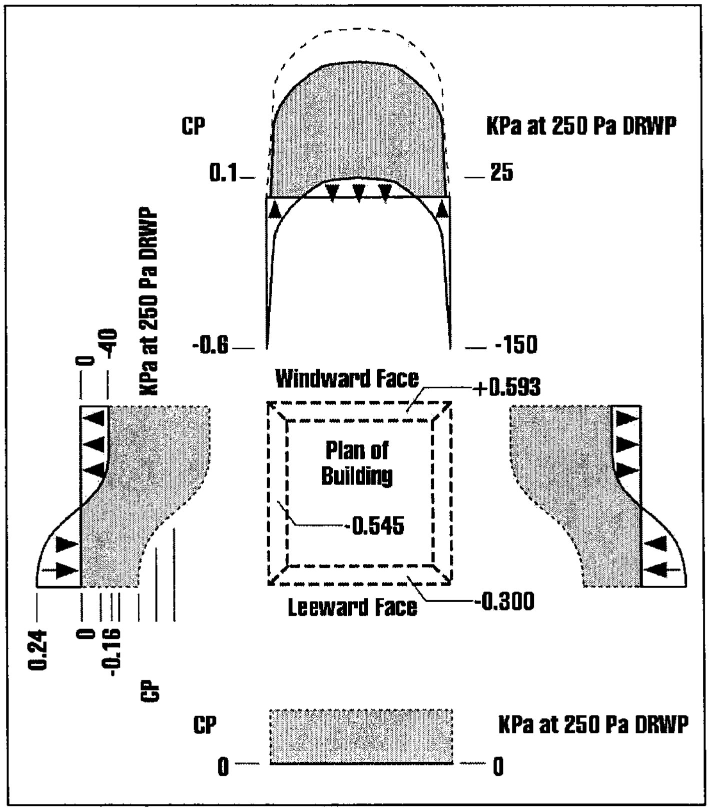


Figure 39: Distribution of wind pressure with facades isolated

If each facade is isolated by sealing at the corners, the pressure relationships are dramatically changed. On the windward facade the cavity pressure would be about 150 Pa and on a side facade about -135 Pa. Figure 39 shows that the pressures available to drive water though the rainscreen and air flow in the cavity are much reduced.

Note that the peak inward pressure is about 25 Pa, or about 11 per cent of that without sealing at corners. Note also that the pressure difference across the corner seal is 285 Pa, which is higher than the total wind pressure on which the scale was based. Under the design structural wind loads, the pressure across the seals will also be higher than the wind load. These pressure relationships with corner seals have been confirmed in wind tunnel testing.[13]

Two design principles come out of this analysis:

- Isolating facades by sealing the corners dramatically reduces driving pressures across the rainscreen, reducing the potential for, and magnitude of, water entry. Incorporating corner seals into other desirable design features at corners (that is, expansion joints in masonry or panel corner closures) can be a very cost-effective method of reducing the risk of rain-entry problems .

- Corner seals must be strong. They should be designed to withstand twice the structural wind load.

Seals at corners make such a dramatic reduction in the pressures across the rainscreen that they are probably all that is needed in smaller buildings. In larger and taller buildings, compartmentalizing within the facade gives further control of pressures.

Compartmentalizing within a facade

Deciding on a desirable compartment size within a facade is a judgement call. The judgment is deciding what is the desirable limit to the variation of pressure differences over the face of a compartment. When considering rain penetration only, not structural design, the designer only has to be concerned about facades facing into the wind.

A designer can decide, based on experience or test results, that the pressure across the rainscreen caused by a steady wind should be no more than of five per cent of the DRWP (12.5 Pa in our example). This is half of what would occur with only the corners sealed (see Figure 39, page 45). Choosing a cavity width based on a 25 Pa difference in wind pressure from the inside to outside edge of the cavity meets this criteria because the cavity pressure will be about halfway between the mean wind pressures at the two edges.

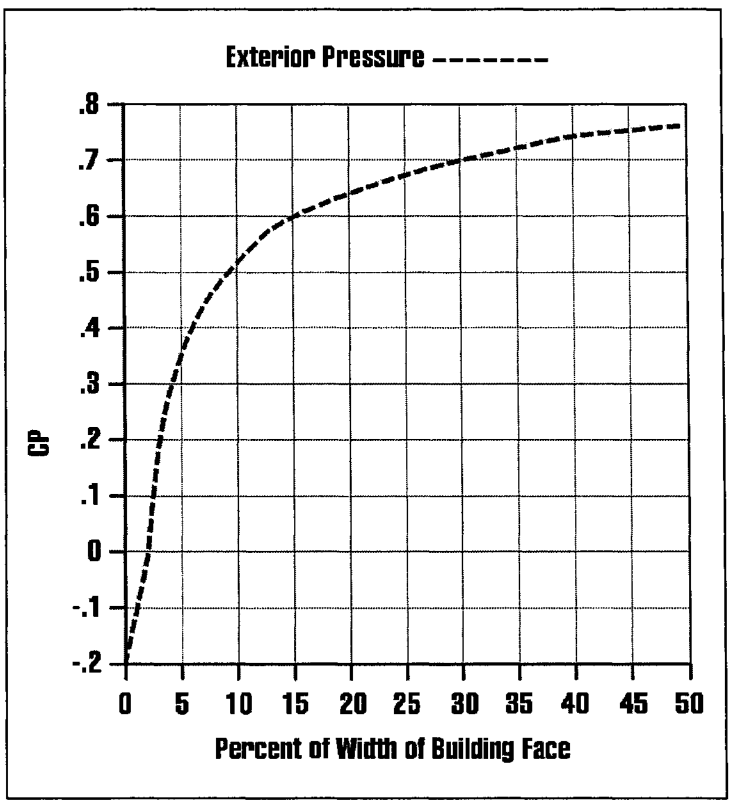


Figure 40: Horizontal pressure distribution at building edge

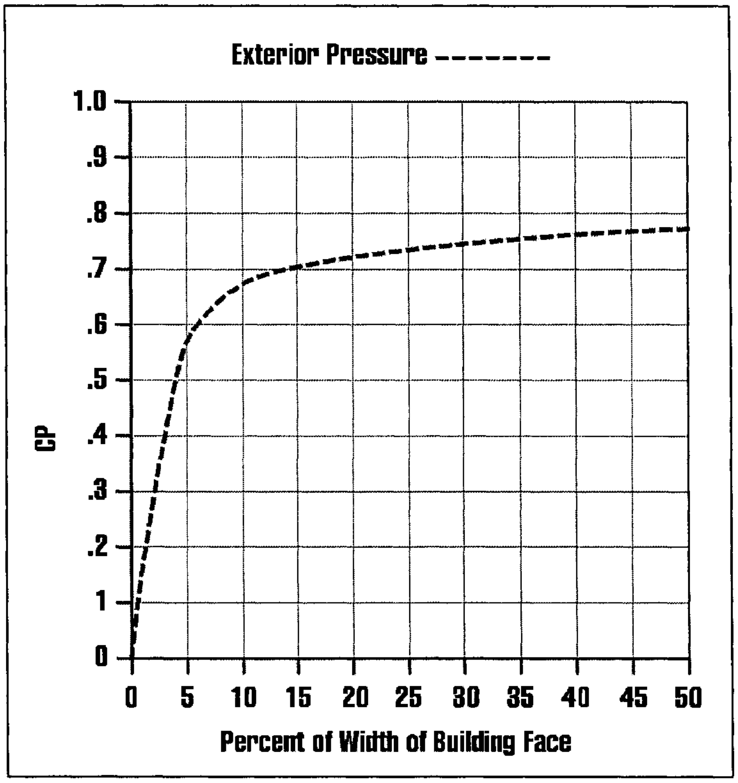


Figure 41: Vertical pressure distribution at top of building

Example 1

The criteria for this example is that the variation in mean wind pressure across the face of a compartment must be less that 25 Pa when assuming a DRWP of 250 Pa.

The width of the cavity is then related to the slope of the wind pressure line. Figure 40 (page 46) is a larger-scale graph of a typical horizontal wind pressure gradient on the windward face of a tall building. Figure 41 is a graph of a typical vertical wind pressure gradient. Figure 40 is used in this exercise.. There are two pressure scales: C_p, and C_p times the assumed 250 Pa DRWP. There are also width scales: per cent of width of building face and distance from the edge assuming a 40 m (131 ft.) wide building.

Meeting the criteria of 25 Pa variation across the face of the compartment at the building corner, requires very narrow compartments. The designer could decide that it is more practical to detail the corner so that durability requires less pressure equalization—that is, use a rainscreen design with a sealed waterproof membrane as the second line of defence and provide good drainage or use asymmetrical venting as discussed below. Assume that this is the approach taken for the outer 1.5 m, or 3.75% of the width of the facade.

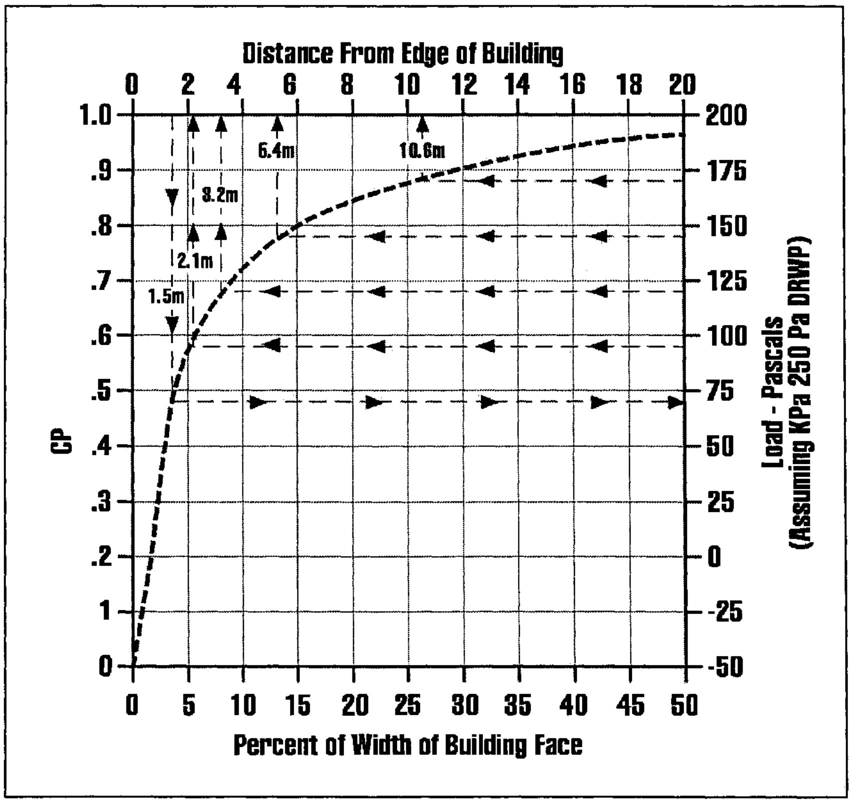


Figure 42: Compartment sizing

Figure 42 shows that the expected average wind pressure 1.5 m (5 ft.) from the edge is about 70 Pa, and that 95 Pa (70 plus the criteria value of 25) can be expected at 2.1 m (6.8 ft.) from the edge. A compartment width of 60 cm (23.4 in) or less, meets the selected criteria.

The next compartment's seal should be placed where an average wind pressure of 120 Pa can be expected—about 3.2 m (10.4 ft.) from the edge—so the next cavity could be up to 1.1 m (3.6 ft.) wide.

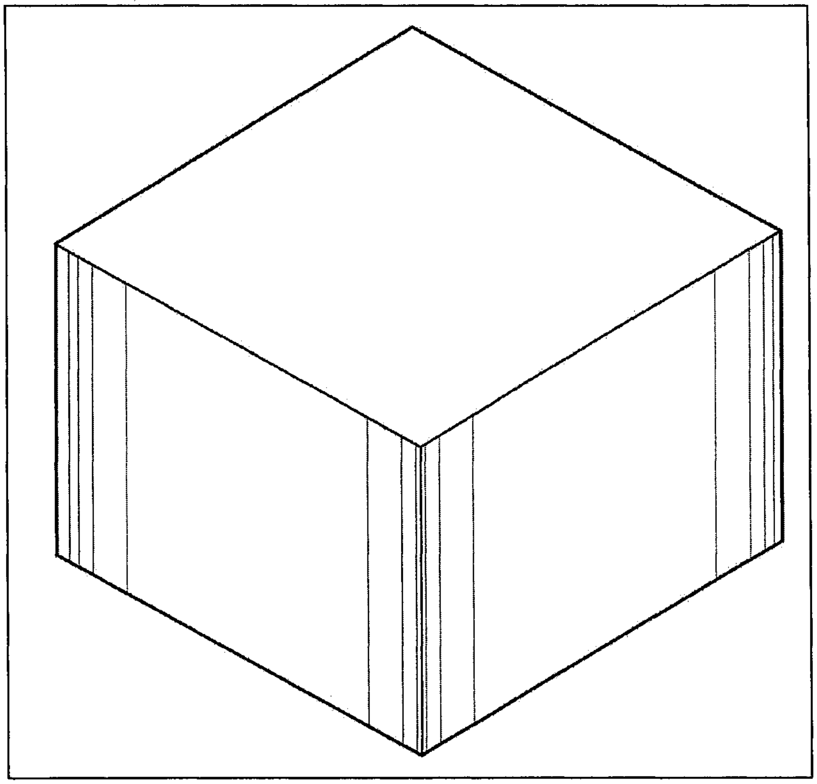


Figure 43: Developed compartmentalization plan

The next seal is required at 5.4 m (17.7 ft.) or 2.2 m (7.2 ft.) further in. The next after that is at 10.6 m (34.7 ft.) or 5.1 (16.7 ft.) m further in. In the remainder of the building, a single compartment would meet the criteria.

If it is more convenient to locate any seal at a lesser distance than the calculated width, determine the width of the next compartment in by locating the outer seal on the graph, moving the pressure line up by 25 Pa, and finding the location of the next required seal.

The same approach can be used to define vertical dimensions of compartments. For most buildings the evaluation is very simple. Figure 41 (page 47) shows that the average pressure goes from zero at the top of the building to 90% of the highest expected pressure at about 10% of the building height below the roof.

A very high variation in pressure can be expected over the top floor and parapet of most buildings, so compartmentalization heights would have to be impractically small to maintain the criteria we selected. Below that, compartment heights could be several storeys high. However, providing for drainage every one or two storeys is advisable in any case. Figure 43 shows the compartmentalization plan.

Note that the maximum inward pressure allowed by the design criteria in our example is only 50% of what would have occurred with seals at the corners only.

There may be another way of eliminating the need for small compartments at the edges of a building. If the objective of all this effort is to decrease rain penetration (not pressure equalization for structural reasons), the pressure gradients at the edge may actually be used to improve rain penetration resistance.

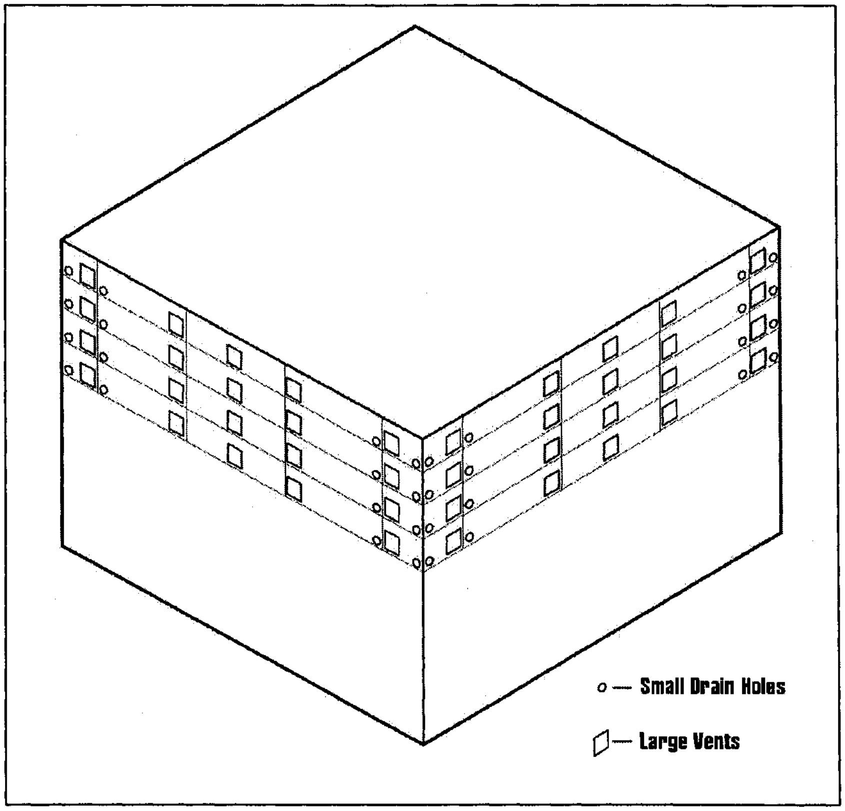


Figure 44: Asymmetrical venting

If the vent area is concentrated on places with the highest pressure on the face of the compartment, is the highest (see Figure 44), the cavity pressure can be raised so that most of the rainscreen sees an outward pressure. The raised cavity pressure pushes water out of leakage paths rather than in. We suggest concentrating the required vent area on the side of the compartment closest to the center of the facade. If the compartment is well sealed at the corner and top, and the intentional vent is the major area of leakage to the outside (the leakage area of the rainscreen material is small compared to the vents), the pressure difference across the rainscreen will be outward exactly where exposure to water is the highest. The wider the compartment, the higher the outward pressure difference.

At wind angles which make the facade a leeward face, the vent could create inward forces, but this isn't a problem since the face is protected from the rain. An asymmetric venting pattern should work to protect exactly the part of the wall that is most exposed to wetting. This concept may be particularly valuable for top storeys and parapets because the cavity drains are in exactly the right place to pressurize the cavity. At corners, vents could be concentrated to the inner edge but drainage should still be provided farther out.

Wind tunnel testing at the Boundary Layer Wind Tunnel Laboratory of the University of Western Ontario has demonstrated the concept. [14] The tests showed that for wind angles that are most important in terms of wetting from wind-driven rain, asymmetrical venting resulted in near zero or outward acting pressures across the rainscreen at the roofline and edges. The tests modeled cavities 2 m and 4 m wide. They found relatively low inward pressures at the top corner of the roof line and edge. There are indications that this could be reduced further with different vent locations.

There is a caution about using asymmetric venting in very wide or high compartments. It can increase structural loads.

In discussing vent locations, it is important to recognize that it is the location of the holes connecting a closed space to the outside that governs the pressure in the enclosed space. A common example is snap caps over curtain wall joints.

A snap cap creates a confined space over the vents for the glazing cavities and spandrel sections. These cavities can span the full height or width of a facade and may even go around corners. This can create an uncompartmentalized cavity over the main cavity vents. If a significant fraction of the drainage and venting area of the snap cap is at the corner or top of the building, the pressure in the cavity enclosed by the snap cap will be sucked below the pressure on the center of the wall. This suction will in turn reduce the cavity pressure (and increase pressure across the cladding) of the rainscreen compartments that vent behind the snap cap. Achieving good pressure equalization probably requires compartmentalizing the snap cap cavities.

Vent location could also have a negative effect when vents are located on a protrusion from the face of the building. Under some wind conditions, these protrusions can be in a local area of high negative pressures which would also suck the compartment below the outdoor pressure.

Summary of compartment design principles

- Good compartment seals are required at all corners and at the top of the building to isolate each facade from the adjacent facades.
- If intentional and unintentional venting through the rainscreen and its joints is fairly evenly spaced, compartments within 10% of the width to the edge should be small, perhaps 1 m (3.2 ft.) to 1.2 m (3.9 ft.) wide.
- If the rainscreen and its joints are intrinsically tight and most of the venting is through intentional vents, the compartments can be wider if the vents are placed at the edge closest to the center. More research is needed to define the limits to this

approach but it appears that such an asymmetric venting approach can be used with compartments 10% of facade width or larger (subject to structural considerations).

- Vents should not be placed close to the outside edge.

- In the middle of the facade, compartments of up to 1 to 15 m (3.2 to 49 ft.) wide and 6 m (19 ½ ft.) high appear acceptable.

- Compartment seals must be tight enough to limit air leakage and strong enough to resist the pressure. At building corners, the pressure across the seals can be more than twice the wind pressure. Towards the center of the facades, pressures will be lower.

Venting requirements

Static pressure loads or mean wind pressures can be controlled by sizing the effective area of the vent holes in relation to the leakage of the air barrier system and compartment seals. If the seals between compartments are airtight, and the leakage area of the rainscreen is five times the leakage area of the air barrier, the rainscreen will only carry 4% to 15% of any steady pressure to which the wall is subjected, depending on the pressure/flow relationships of leakage paths through the air barrier and vents. At a 10 to 1 ratio, the rainscreen would carry between 1% and 9% of the steady load.

In the absence of specific test data or a more detailed analysis such as an evaluation with ***Rainscreen 2.1*** (see Chapter 10, page 75), we recommend designing to achieve the performance of the 5 to 1 ratio between rainscreen vent area and air barrier leakage area.

If the compartment seals are airtight, this translates to quite small vents. As a useful rule of thumb, a 100 mm^2 (0.15 in^2) hole allows about one l/s (0.26 US gal/sec) of flow at 75 Pa (1.5 lb/ft^2). The air barrier system leakage recommendations in the National Building Code (< 0.2 $l/s/m^2$ at 75 Pa) translate to less than 20 mm^2 (0.03 in^2.) of leakage area for each m^2 (10.76 sq. ft.) of wall area in the cavity. This is only 0.002% of the wall area. Following the 5 to 1 ratio recommendation, vents of 100 mm^2 per m^2 of facade area (0.014 sq. in. per sq. ft.) or 0.01% of wall area are adequate for air barrier leakage.

The real question is the airtightness of compartment seals, or at least those at corners that have a high pressure difference across them. It is necessary to compensate for this leakage area between compartments (as opposed to leakage from the compartment to outside). Leakage though a hole in a corner seal can be expected to be up to twice that of the same size hole in the air barrier because the pressure across the corner seal is twice as high. There will be less leakage through the compartment seals within a facade, because pressure differences are controlled and in many cases will act inward into the compartment.

While a more complex analysis based on the pressures calculated in Example 1 (page 47) can be put forward, we suggest that vents be sized so that the effective vent area for a compartment be the sum of:

- 5 times the estimated leakage area of the air barrier in the compartment
- 10 times the estimated leakage area of any corner seals in the compartment
- 1 times the estimated leakage area of the intermediate compartment seals

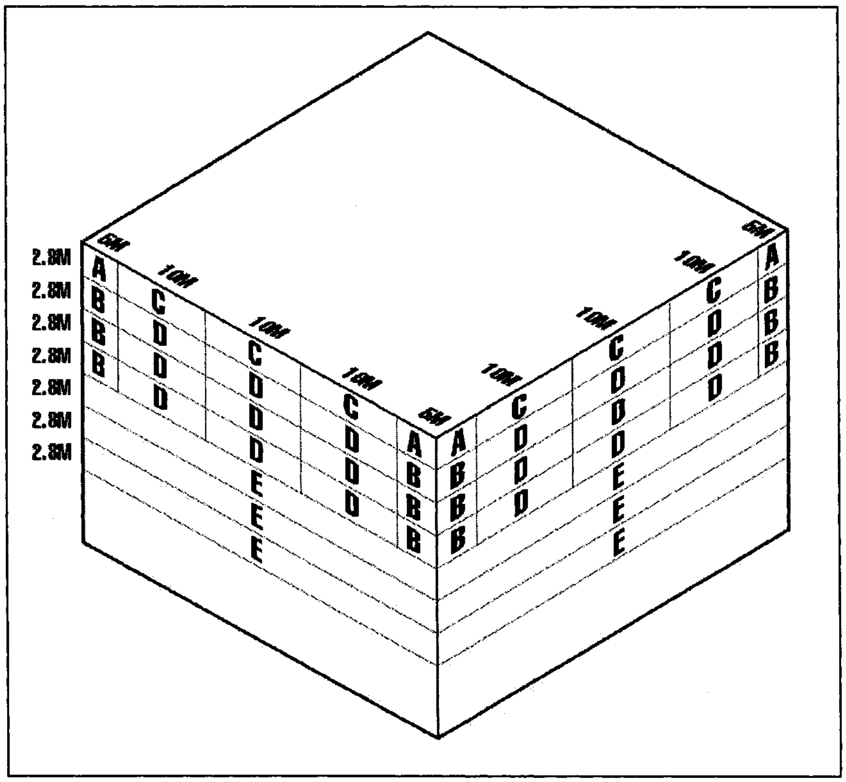


Figure 45: Compartments for example 2

Example 2

This example calculates vent sizing to address static pressures for a series of 2.8 m (9.1 ft.) high compartments, as shown in Figure 45, assuming the following:

- The air barrier has the airtightness recommended in *Air Barrier Systems for Walls of Low-Rise Buildings: Performance and Assessment* [15] and of 20 mm^2/m^2 (0.002 sq. in./ sq. ft.).
- The average crack width of compartment seals is 0.1 mm (0.0039 in.).

The effective area of the vents could be sized as shown Table 2 (page 54).

Table 2—Vent Area Determination for example 2

Compartment	A	B	C	D	E
Area of compartment (m^2)	14	14	28	28	112
Leakage area of air barrier (mm^2)	280	280	560	560	2,240
Vent area to cover for air barrier leakage 5 times above (mm^2)	**1,400**	**1,400**	**2,800**	**2,800**	**11,200**
Length of corner seal (m)	7.8	2.8	10	0	5.6
Leakage area of corner seal (mm^2)	780	280	1,000	0	560
Vent area to cover for corner seal leakage (10 times above—mm^2	**7,800**	**2,800**	**10,000**	**0**	**5,600**
Length of intermediate seal (m)	7.8	12.8	15.6	25.6	80
Leakage area of intermediate seal (mm^2)	780	1,280	1,560	2,560	8,000
Vent area to cover for intermediate seal leakage (1 times above—mm^2)	**780**	**1,280**	**1,560**	**2,560**	**8,000**
Total effective vent area required (mm^2)	**9,980**	**5,480**	**14,360**	**5,360**	**24,800**
Percentage of compartment area	0.071%	0.039%	0.051%	0.019%	0.022%

The example clearly shows the importance of obtaining an airtight seal at the corners.

In sizing vents, the flow resistance along the entire flow path must be considered. If there is a restricted flow path before or after the designed vent hole, the effective vent area will be less than the hole size.

One common example of this is windows and curtain walls in which the vent/drains from glazing cavities and spandrel sections are hidden behind a snap cap. The small holes provided for drainage through the snap caps can have less free area than the vent of the glazing and spandrel cavities. Where the vents are covered by a snap cap, the holes in the snap cap must be larger than the vents.

Two NRC publications suggest that the vent holes do not need to be uniformly distributed over the width of the pressure equalization chamber, as long as the holes are not further than 3 m (9.8 ft.) from the vertical seals of the chamber. [16, 17] The publications suggest that all vent holes should be at the bottom of the compartments, where they also act as drains. This location along the same horizontal line avoids any pressure difference over the height of the compartment that might induce air flow and water penetration into the cavity. Not all researchers agree with this recommendation. Advocates of the back-ventilated approach believe that vents at the top and bottom of a wall increase drying by promoting venting in the chamber. [18]

It may be possible to locate the vents in a pressure equalization chamber in a zone exposed to higher average wind pressures (towards the middle of the building). This would tend to pressurize the chamber relative to the average outside pressure and could reduce rain penetration.

Further experimentation with vent location is needed. Regardless, the vent holes should be a minimum of 8 mm (1/16 in.) in diameter or width to eliminate the possibility of capillary plugs. They should be shielded from direct exposure to rain drop momentum, be sloped down and out, and provided with appropriate drips to prevent bridging by water and surface tension effects.

Requirements for Equalizing Cyclic Pressure

The previous section dealt only with steady or mean wind pressures. To achieve pressure equalization at all times, the impact of wind gusts must be considered. No wind is truly steady, so wind pressure imposed on a wall varies with time. As the wind pressure changes on a PER wall system, air has to flow through the vents into the equalization chamber to equalize the chamber pressure with the outside. The relationship between the rate of change in wind pressure and the time it takes to move the volume of air required for equalization through the vents, affects the pressure across the rainscreen elements. Determining this relationship, and the "cyclic load" it leaves on the rainscreen, is a fairly complex calculation that depends on:

- assumed wind gust frequency
- assumed mean and peak wind pressures

- working volume of the pressurization chamber (this is, the open air volume of the chamber: a chamber with foam insulation will have a significantly smaller working volume than a chamber filled with fibrous insulation)
- rigidity of the cladding and air barrier (because this affects the working volume)
- area of vents through the rainscreen
- leakage area of the air barrier
- leakage to adjacent chambers through compartment seals, if they are at a different pressure
- harmonic effects that depend on cavity shape, vent geometry, air density and other factors.

CMHC has developed a simple program, ***RainScreen 2.1***, that can help assess the impact of variations in the above parameters.

RainScreen 2.1 takes user values for wind loads and pattern, cavity dimensions, rainscreen venting and air barrier leakage area, and air barrier and cladding flexibility. It uses those values to estimate the static and cyclic loads carried by the rainscreen cladding. It assumes zero leakage into adjacent cavities (that is, assuming either perfect seals or no pressure difference to adjacent cavities).

RainScreen 2.1's "Results" window provides a graph of how cavity pressure reacts to the changing wind pressure (see Figures 46 to 53 pages 57 to 61). Note that the peak of the cavity pressure generally does not match the peak of the exterior wind pressure, either in amplitude or in time. The difference between the two at any time is the pressure across the rainscreen cladding. The "Results" window also gives the percentage of the pressure carried by the rainscreen cladding under static loads and the percentage of peak pressures carried by the rainscreen assuming the input cyclic wind load.

There is much debate in the research and design community about the importance of designing to minimize cyclic pressures across a rainscreen cladding. From the perspective of rain penetration resistance, addressing cyclic loads would appear to be a lower priority than designing to minimize the pressure across the rainscreen caused by steady or average wind pressures. However, from the perspective of structural design of rainscreen walls, it is very important, since it is the gusts that impose the peak structural loads. A designer should at least have an understanding of how various design parameters affect the cyclic pressure across the rainscreen cladding.

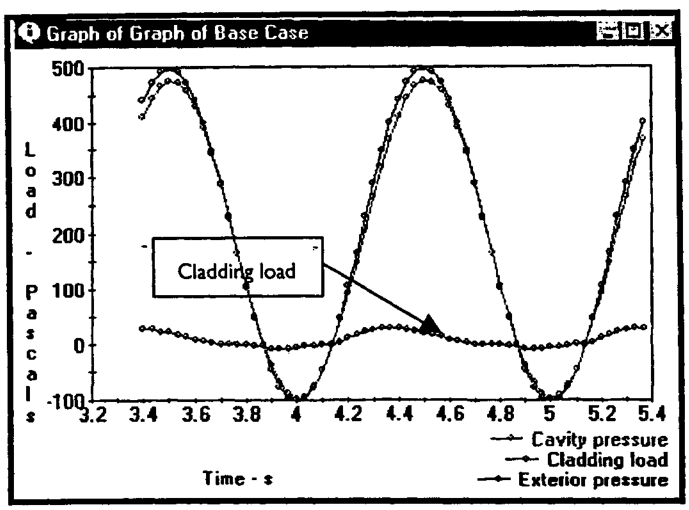
In Figures 46 to 53, ***RainScreen 2.1*** is used to show how the pressure across a rainscreen changes as some of the parameters noted above are modified. Each figure shows the

RainScreen 2.1 output as one parameter at a time is changed. Table 3 summarizes the runs. All runs are based on a 2.7 m (8.8 ft.) high, by 2 m (6.5 ft.) wide compartment.

Table 3—Summary of RainScreen 2.1 runs

Input Parameter	Base Case (Figure 46)	Changed Parameter	Shown in
Mean DRWP	200 Pa	400 Pa	Figure 47
Frequency of cycle	1 Hz	5 Hz	Figure 48
Air barrier leakage area	60 mm^2/m^2 (same as 0.1 l/s/m2 at 75 Pa)	500 mm^2/m^2	Figure 49
Vent area	300 mm^2/m^2	2000 mm^2/m^2	Figure 50
Cavity depth	25 mm/xx in.	100 mm/xx in.	Figure 51
Air barrier flexibility	equivalent to 75 mm concrete	equivalent to 8 mm glass	Figure 52
Rainscreen flexibility	equivalent to 75 mm concrete	equivalent to 8 mm glass	Figure 53

Figure 46- Base case output



Loads on Cladding

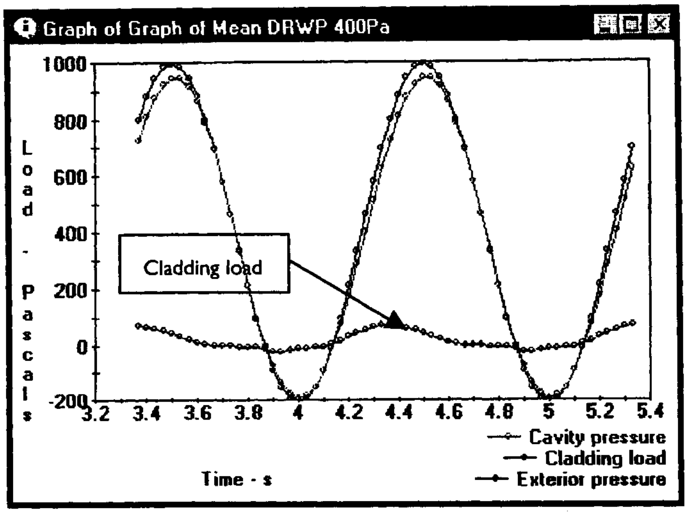
Static Load: 3.8 %

Cyclic Load: 6 %

Comments:

With the base case, RainScreen 2.0 shows that, with the cladding having 5 times the leakage area of the air barrier, it carries only 3.8% of the average wind load (at a DRWP of 200 Pa). However, there is a small Time lag in the cavity pressure. Equalization allows the peak pressures on the cladding to reach 6% of the peak wind gust load.

Figure 47 - Impact of doubling wind load



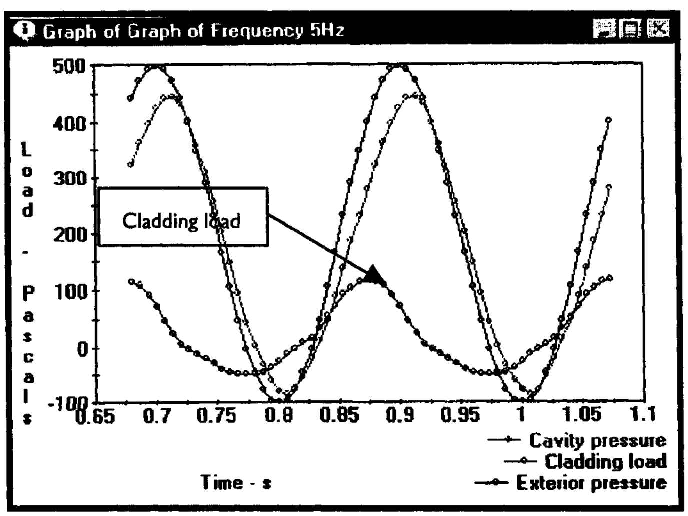
Loads on Cladding

Static Load: 3.8 %
Cyclic Load 7.4 %

Comments:

When the assumed base load is doubled to 400 Pa, there is a slight increase in the % peak load carried by the cladding but the output is very similar to the base case.

Figure 48 - Impact of higher gust cycle frequency



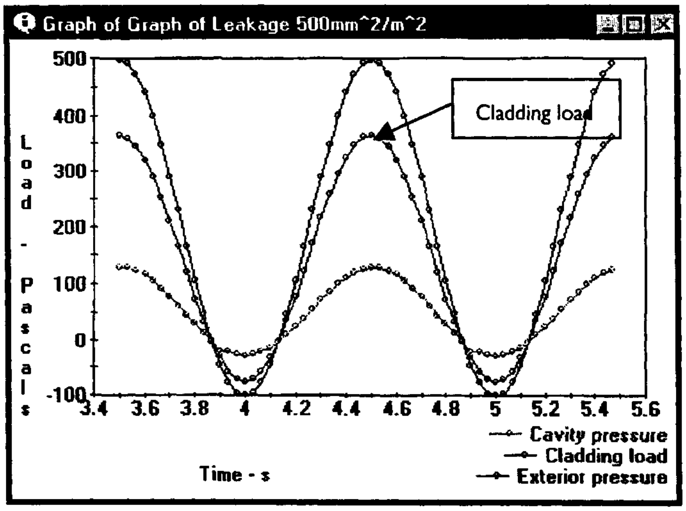
Loads on Cladding

Static Load: 3.8 %
Cyclic Load: 24 %

Comments:

In this run the base case wall is assumed, but the gust frequency is increased from 1 to 5 Hz. Since the cavity pressure lags even further behind the applied cyclic pressure, the peak load carried by the cladding increases to 24% of the assumed peak load.

Figure 49 - Impact of higher Air Barrier leakage



Loads on Cladding

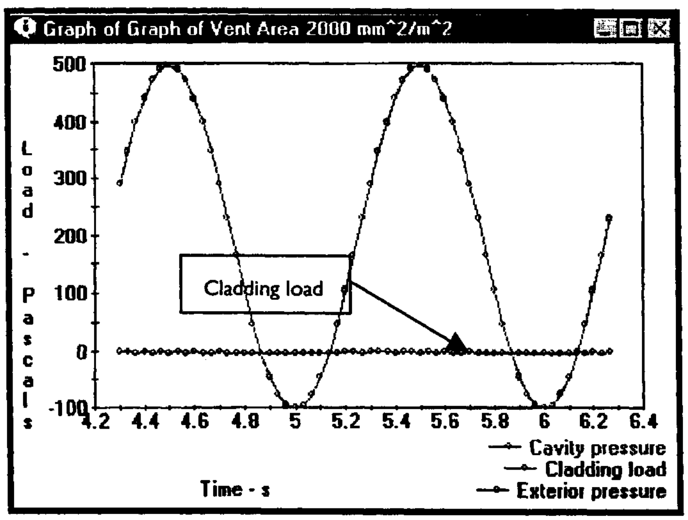
Static Load: 74 %

Cyclic Load: 73 %

Comments:

If the inner wall of the base case is made 'leakier' than the cladding, the cladding carries the majority of static and cyclic load.

Figure 50 - Impact of Greater Venting



Loads on Cladding

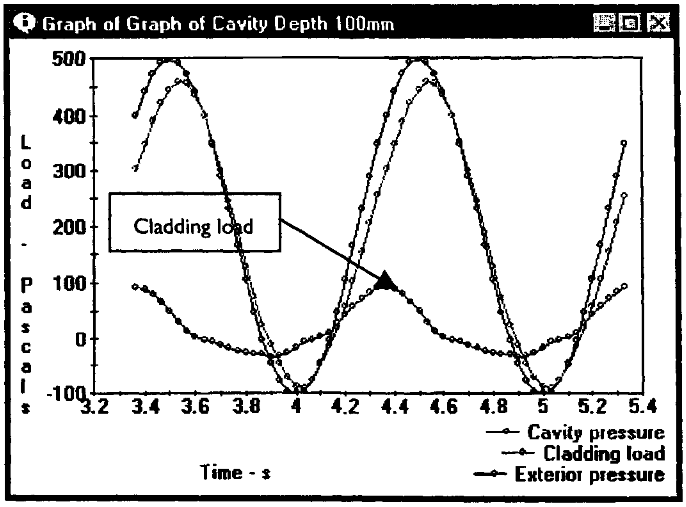
Static Load: 0.0 %

Cyclic Load: 0.5 %

Comments:

In this run the vent area of the base case was increased to 2,000 mm^2/m^2 from 300 mm^2/m^2. Pressure equalization is nearly complete at the 1 Hz frequency.

Figure 51 - Impact of Greater Cavity Depth



Loads on Cladding

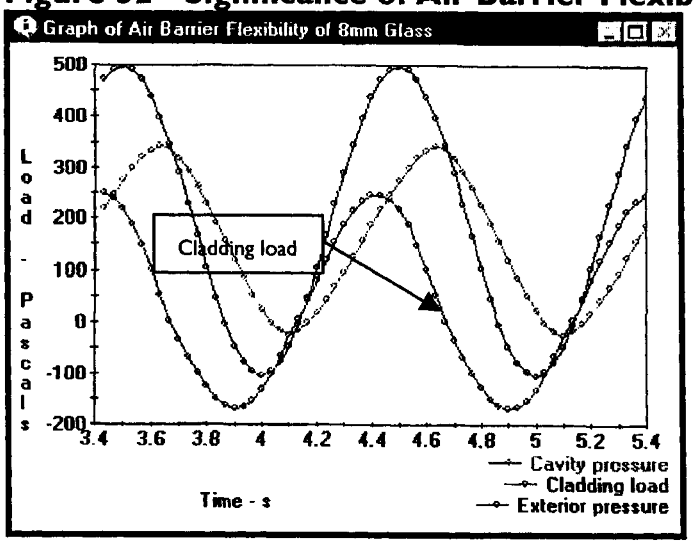
Static Load: 3.8 %
Cyclic Load: 19 %

Comments:

The only difference in this run from the base case is that the cavity volume was increased by a factor of four.

Since a greater volume of air must pass through the vents to achieve equalization, cavity pressure lags further behind the applied pressure. The load on the cladding increases from 6 to 19%. As the vent / leakage ratio is unchanged, the proportion of static pressure carried by the cladding is unchanged.

Figure 52 - Significance of Air Barrier Flexibility



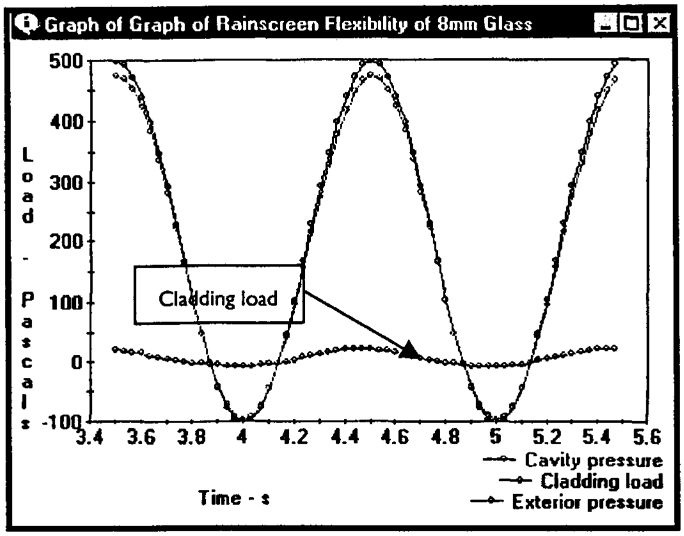
Loads on Cladding

Static Load: 3.8 %
Cyclic Load: 50 %

Comments:

A flexible back up wall deflects under load, increasing cavity volume and so reduces cyclic response. The cyclic load on the cladding is increased.

Figure 53 - Significance of Rainscreen flexibility



Loads on Cladding

Static Load:	**3.8 %**
Cyclic Load:	**4.8 %**

Comments:

A flexible cladding deflects under load, reducing cavity volume and so improves cyclic response. The cyclic load on the cladding is reduced.

In practice, perfect cyclic pressure equalization is not possible. Design can only minimize the proportion of the total load which will be carried by the rainscreen cladding. A target of 25% of the peak pressure being carried by rainscreen cladding has been suggested by some researchers.

A key design parameter for cyclic pressure equalization is the chamber volume to vent area ratio. Testing indicated that a chamber volume to vent area ratio of less than 50 to 1 (m^3/m^2—cubic feet to square feet)) should be acceptable for PER walls with rigid elements, such as the precast concrete panel system they tested.[16, 17] For a variable chamber volume such as the flexible brick veneer wall tested, the preliminary results indicate that a chamber volume to vent area ratio as low as 25 to 1(m^3/m^2—cubic feet to square feet) is required.[8] As Table 4 shows, this requires large vents for deep chambers These values can be compared to those developed in Example 1 (page 47).

Table 4—Recommended Vent Size Expressed as a percentage of Chamber Area

Cavity Depth	25 mm (1 in.)	100 mm (4 in.)	200 mm (8 in.)
Rigid Walls	0.05%	0.20%	0.40%
More Flexible Walls	0.10%	0.40%	0.8%

Table 4 shows the importance of designing a rigid air barrier system and supporting structure to achieve adequate pressure equalization with limited venting.

Brown et al. found that the cyclic pressure response of rigid compartments was directly proportional to the amplitude of the applied pressure difference.[7] This means that most PER walls only need to be evaluated under one amplitude in order to establish their pressure-equalization characteristics. They suggest that most of the wind's energy is carried in gust variations that have a frequency of less that 2 Hz, so that evaluating performance at frequencies of 1 or 2 Hz is appropriate.

Compartment sizing must consider that the wind pressures created by gusts are higher than the average pressures used in Example 1 and can act on part of a facade. Since there can be great variation in pressure across the face of a compartment, small compartments may be required. Inculet and Surry developed a guideline for compartment sizing based on limiting differences in gust pressures across the face of compartments to 25 Pa.[10] The guidelines are reproduced in Table 5. Figure 54 shows how this would look on a 30 m high by 40 m wide building.

Table 5—Design guidelines for compartmentalization of PER walls[10]

Region	**Compartment Size (W x H)** as a percentage of building width (w) and height (h)	
	Width	**Height**
3% to 10% of building width from corner	2% w or 1 m (3.2 ft.)	5% h or 1 m (3.2 ft.)
10% to 20% of building width from corner	4% w or 1 m (3.2 ft.)	5% h or 1 m (3.2 ft.)
20% to 50% of building width from corner	8% w or 1 m (3.2 ft.)	10% h or 1 m (3.2 ft.)
3% to 10% of building height from top	5% w or 1 m (3.2 ft.)	2% h or 1 m (3.2 ft.)
10% to 20% of building height from top	5% w or 1 m (3.2 ft.)	4% h or 1 m (3.2 ft.)
20% to 100% of building height from top	10% w or 1 m (3.2 ft.)	8% h or 1 m (3.2 ft.)

Inculet and Surry stated that within 3% of the width of the building, pressure equalization was unlikely to be achieved.[10]

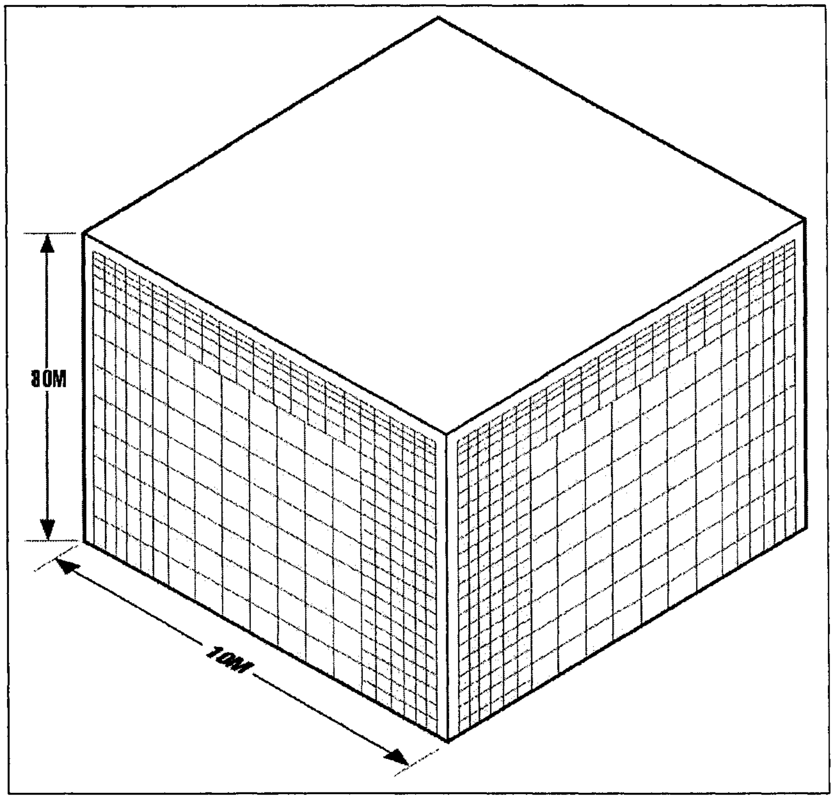


Figure 54: Compartmentalization recommended in Inculet and Surry

Comment on Structural Issues

Because cladding systems are exposed to wind, they are subject to stringent wind load design criteria. Part 4 of the National Building Code requires that cladding elements be designed to accommodate the 1-in-10-year reference wind pressure for the location and exposure assuming a gust factor of 2.5. Since the pressure across the exterior rainscreen surface is reduced, it may be possible to reduce the structure of pressure equalized rainscreen walls.

Great caution is required in accepting that there will be a reduced cladding load for the purpose of structural design.

Peak structural loads are caused by cyclic wind loads. It is only appropriate to assume reduced structural loads in a PER wall system that was designed and tested to show a reduction in cyclic loads. Considering all the variables that can affect performance under cyclic wind loads, this is a major design challenge.

We do not recommend assuming less than full structural loads for any elements attaching the rainscreen to the structure or where full load deflections could lead to detachment of elements from the wall. There is some scope for assuming reduced structural loads where load limits are based on serviceable criteria such as appearance, noise or non-catastrophic deterioration.

7 Design of Rainscreen Joints

In most wall designs, joints are—or become—the major water entry path. Applying rainscreen principles to limit water entry at joints is particularly relevant and valuable. This applies to joints between assemblies that are themselves designed with rainscreen principles and those such as precast and Exterior Insulated Finish System (EIFS) panels that are sometimes face-sealed assemblies.

An effective rainscreen joint requires the same functional elements as rainscreen walls:

- A cavity that is drained and vented to the outside.
- An outer weather seal (the rainscreen).
- An inner seal which is the primary air seal (the air barrier) and has some resistance to water (the second line of defence against moisture).

The effectiveness of rainscreen joint designs was shown in a study evaluating the performance of EIFS joint materials and designs.[19] Test panels containing a horizontal and a vertical joint were subjected to accelerated aging and cyclic joint movement. Eight sealing methods were evaluated: four relied on a face-seal, three used an inner air seal and outer screen and one used a recessed inner seal. After the aging and loading procedures, the length of the failed joint was determined and the test sections were subjected to air and water leakage testing. As shown in Table 6, only the joints using rainscreen principles prevented water leakage.

The same concepts discussed for walls can be applied to joints with a cavity:

- The inner seal must be the most airtight one.
- Drainage must be provided from the cavity.
- Compartmentalization of the cavity should be incorporated, especially near corners of the building.
- The outer weather seal should have a vent area that is about five or ten times the leakage area of the inner air seal (with the limited volume of most joints, this will usually be adequate to provide good equalization even during wind gusts).

Addressing the requirement for drainage can be a challenge. Figure 55 (page 66) illustrates one approach that has been applied to joints in precast concrete panels.

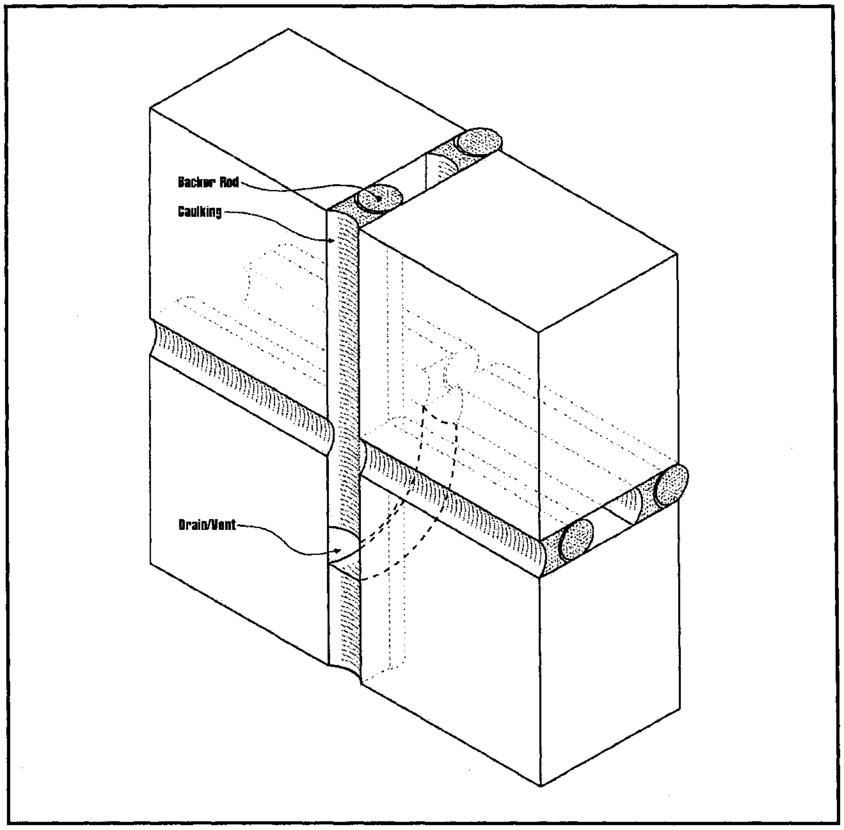


Figure 55: Rainscreen joint between face-sealed elements

Table 6—Air and water leakage of weathered joints

	Sealing method	Per cent of joint length failed after testing	Air leakage (m^3/min)	Time to Water Infiltration (min)
Rainscreen joints	Urethane sealant over backer rod on outside, expanded acrylic impregnated foam internal seal, vented cavity	46	0.0142	N/A
	Urethane sealant over backer rod on outside, elastomeric membrane inner seal, vented cavity	19	0.0057	N/A
	Elastomeric membrane inner seal with vented metal flashing	0	0.0057	N/A
Face-sealed joints	Conventional face seal with urethane sealant over backer rod. Sealed to base coat	44	0.0028	1.5
	Conventional face seal with urethane sealant over backer rod. Sealed to finish coat	58	0.0142	1
	Conventional face seal with urethane sealant over backer rod. Sealed to base coat and aluminum window	40	0.0057	?
	Silicone sealant on expanded acrylic impregnated foam. Sealed to base coat	37	0.0142	12
Joint with recessed seal	Urethane sealant over backer rod on inside edge	49	0.0036	0.5

8 Evaluation and Verification of Rainscreen Performance

CMHC has done preliminary development of a commissioning protocol for rainscreen wall systems.[20, 21, 22] The suggested commissioning protocol calls for a process that covers design through construction as follows:

1. Definition of performance criteria for walls that could include pressure equalization performance required under static and cyclic conditions (that is, 10% static pressure and 25% cyclic pressure at 2 Hz that is supported by the cladding).

2. Use of ***RainScreen 2.1*** to define system requirements such as air barrier leakage rate required by the National Building Code, vent area, rigidity of air barrier, and cladding.

3. Design of system and confirmation of design performance with ***RainScreen 2.1***.

4. If possible, laboratory mock-up testing under static and cyclic loads, and modification of system if necessary.

5. Establishment of field test criteria and compliance values which could include standards for airborne/compartment seal leakage, vent area, decay curve using the cavity excitation method or deflections of rainscreen and air barrier.[20]

6. Field testing of site mock-up to original performance criteria.

7. Periodic testing of some parameters through construction.

The key to steps 5 through 7 of this approach is the ability to evaluate performance criteria in the field. The ability to perform useful field tests is often dependent on site conditions and circumstances. The following notes are suggested approaches that can be used to address specific questions about basic performance parameters of rainscreen systems. Agencies with expertise in testing building components should be able to use these principles to develop appropriate test methods for a specific case and site.

1. **What is the ratio of vent area of the rainscreen to leakage area of the internal air barrier?**

i. Create a steady state pressure across the wall system (or at least the compartment being tested and the adjacent compartment) using natural forces (stack effect), the building mechanical system, or an ancillary fan. Measure the pressure difference from outside to inside (DP_{Total}) and across the rainscreen (DP_{RS}). The ratio of the leakage areas of the rainscreen and air barrier can be estimated by the ratio of pressures carried by the two elements.

Pressure difference across air barrier (DP_{AB}) = (DP_{Total}) - (DP_{RS})
Ratio of rainscreen leakage area (A_{RS}) to air barrier leakage area (A_{AB}) can be estimated as

$$\text{Total vent/leakage ratio} = \frac{A_{RS}}{A_{AB}} = \sqrt{\frac{DP_{AB}}{DP_{RS}}}$$

This calculation gives the ratio but not the values for leakage areas.

2. How can I estimate air barrier leakage without an airtight chamber?

i. If leakage of compartment seals is reasonably small and the vents can be sealed with an estimated leakage area (A_{Vent}), we can estimate air barrier leakage area by doing a second test with the vents sealed. The ratio of pressures should change (if not, vents are not a major portion of the total leakage of the rainscreen and compartment seals).

ii. Under the new condition, the total vent/leakage ratio is

$$\sqrt{\frac{DP_{AB}}{DP_{RS}}} = \frac{A_{RS} - A_{Vent}}{A_{AB}}$$

With the two equations, we can solve for A_{AB} (see Example 3, page 70).

It should be noted that the value for (A_{RS} - A_{Vent}) in the calculation includes all leakage from the chamber including compartment seals. This can create a limited error in the result but if leakage through compartment seals is very high, the pressure ratio will not change when the vents are sealed.

3. How can I check compartment seal integrity?

i. (a) Use some sort of blower to pressurize the cavity and inject smoke and observe where it exits the cavity.

ii. (b) Connect a vacuum pump to a vent (a shopvac works well for smaller cavities). Stick a tube in another vent and connect to a manometer. Turn on vacuum and seal vents until a good suction pressure in the cavity is created (30-100 Pa). Use a smoke pencil to see if air is sucked into vents of adjacent cavities. Do this with vacuum on and off.

4. How can I check equalization performance?

(a) CMHC commissioned the development of a method for testing the cyclic response of a pressure equalization chamber.[20] The cavity excitation method is still in an early stage of development but it holds some promise for evaluating rainscreen performance in a section of wall prior to completion of the building.

(b) In an operating building, the indoor to outdoor pressures and pressures across the rainscreen can be monitored and the degree of equalization can be assessed as in Question 1. Equipment to monitor average pressures is reasonably available. Monitoring cyclic performance requires high speed data acquisition equipment which is more specialized and hard to obtain and use.

Example 3

Test 1

$DP_{T1} = 30$

$DP_{RS1} = 3$

Therefore, $DP_{AB1} = 30 - 3 = 27$

Vent/ Leakage Area Ratio = $A_{RS}/A_{AB} = Ö(27/3) = 3.00$

rearranging terms $A_{RS} = 3.00\ A_{AB}$

Test 2 with 200 mm^2 of vent sealed:

$DP_{T2} = 32$

$DP_{RS2} = 9$

Therefore, $DP_{AB2} = 32 - 9 = 23$

Vent/ Leakage Area Ratio = $(A_{RS} - 200\ mm^2)/A_{AB} = Ö(23/9) = 1.56$

rearranging terms $A_{RS} = 1.56\ A_{AB} + 200$

A_{RS} and A_{AB} are the same for both tests, so

$$3.00\ A_{AB} = 1.56\ A_{AB} + 200$$

$$A_{AB} = 200/(3.00-1.56) = 139\ mm$$

9 Designing for Pressure Equalization in Metal and Glass Curtain Walls

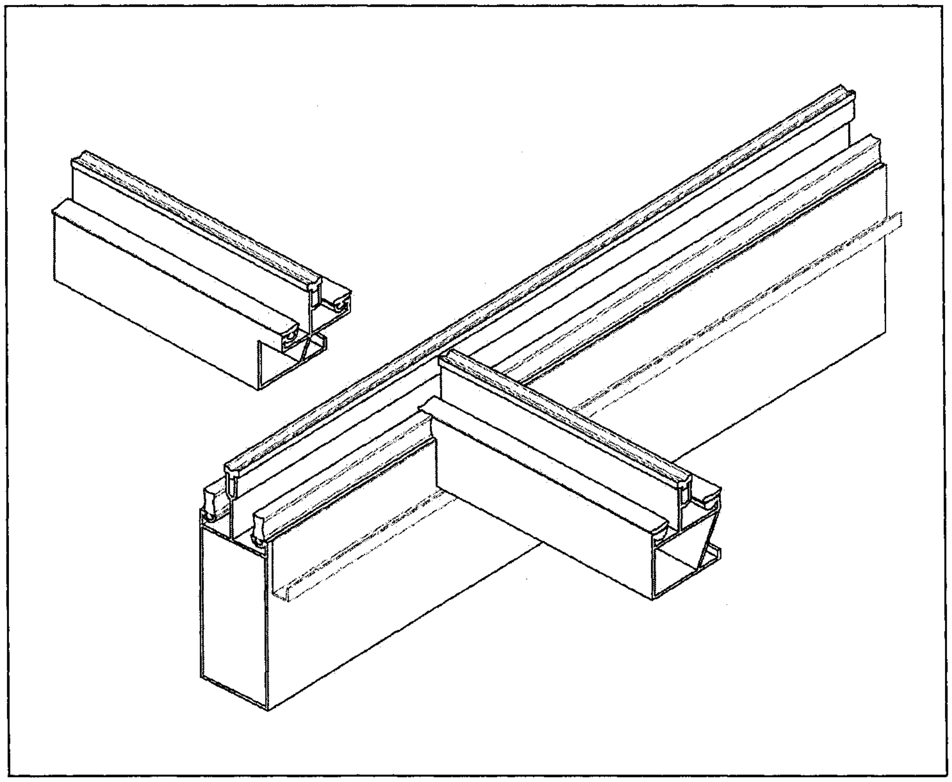


Figure 56: Curtain wall section

Example 4

This example shows how to design for pressure equalization in a metal and glass curtain wall. Figure 56 is a cross-section of a fairly conventional curtain wall with sealed, double glazing and a metal backpan insulated with glass fiber insulation. The following assumptions are used :

- Bay width: 2 m (6.5 ft.)
- Height of spandrel and vision sections: 1.5 m (4.9 ft.)
- Depth of spandrel cavity: 125 mm (4.87 in.)
- Air leakage specification: 0.3 $l/s/m^2$ at 75 Pa.

Rainscreen principles are incorporated by providing for drainage and venting of the glazing cavity spandrel cavity. Note that many exterior glazed curtain walls operate quite successfully with drained cavities (small drains at the base of glazing and spandrel cavities). The object of this example is to show what other features are needed to achieve significant pressure equalization.

Air Barrier Location

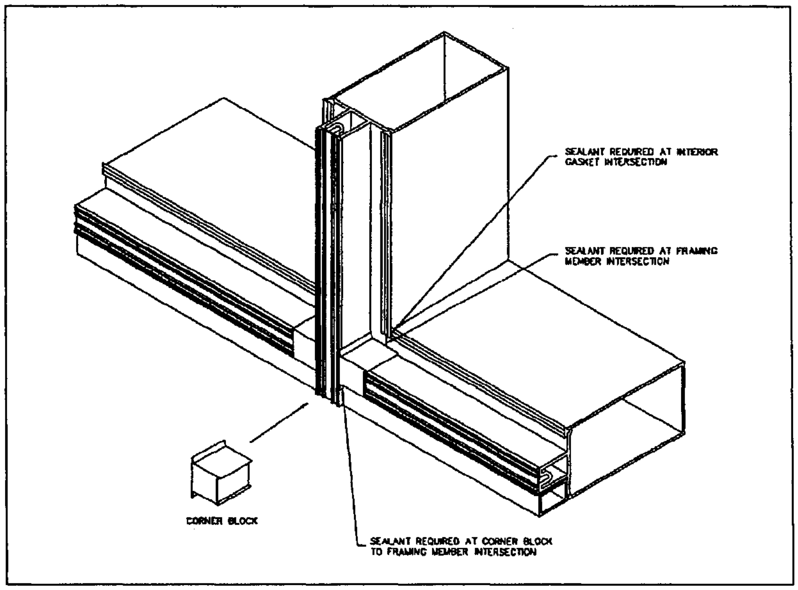


Figure 57: Corner block

With a drained design, the inner seal is the primary air seal.. In the example, the inner seal is formed at the shoulder of the mullion. For the glazing section, the seal can be achieved using a wet sealant (typically shimmed glazing tape) or a gasket. In the spandrel section, the backpan is usually sealed with glazing tape or sealant applied to the joint between the backpan and shoulder of the mullion. We can assume that all leakage is through joints (that is, that the glass and backpan are airtight).

Compartmentalization

The designer must consider how to compartmentalize the cavities. The necks of the mullions (glazing splines) are a good separation for the most part, but two major leakage paths past them must be addressed:

- The gap left at the intersection of vertical and horizontal mullions, and
- the gap between the pressure plate and spline.

Corner blocks sealed to the mullions (Figure 57) can address the gap left at the intersection of vertical and horizontal mullions. A soft thermal break acting as a gasket between the pressure plate and spline can address the gap between the pressure plate and spline if the space under the intersecting pressure plates (over the corner block) is addressed. There may also be a need to consider compartmentalization of the cavity under the snap caps. This is discussed in Chapter xx) .

Vent sizing

The size of the vents/drains is based on the expected air leakage areas of the air seals and compartment seals. We will use the approach to vent sizing given in Example 1 (page 47).

Our assumed air leakage of 0.3 l/s/m^2 (convert) at 75 Pa is equivalent to 30 mm^2/m^2. If we assume that the compartment seals have a leakage area no greater than 10 mm^2/m of compartment seal, the vent area required to address steady or mean wind pressures for bays other than those at corners can be estimated as shown in Table 7.

Table 7—Effective Vent Area

Compartment	Glazing cavity	Spandrel cavity
Area of compartment (m^2)	3	3
Volume of Cavity (m^3)	0.0023	0.380
Leakage area of air barrier (mm^2)	90	90
Vent area to cover for air barrier leakage (5 times above)	**450**	**450**
Length of compartment seal (m)	7	7
Leakage area of intermediate seal (mm^2)	70	70
Vent area to cover for intermediate seal leakage (1 times above)	**70**	**70**
Total effective vent area required (mm^2)	**520**	**520**

Assuming that 10 mm (3/8 in.) wide vent/drain slots are cut through the pressure plates into each cavity, we will require about 50 mm (2 in.) of slot to equalize steady pressures.

The difference between the glazing and spandrel cavities becomes evident when considering venting to achieve equalization of dynamic pressures. The glazing cavity has a low volume and is made of rigid elements. It has been suggested that for rigid compartments, vents be sized to achieve a cavity volume to vent area ratio of less than 50 to 1 m^3/m^2 (cu. ft. to sq. ft.) to address dynamic pressures.[16, 17] For less rigid compartments, the ratio should be lower.

The ratio with 0.0023 m^3 (0.0812 cu. ft.) of volume for the glazing cavity divided by 520/1,000,000 m^2 of vent is only 4.42 to 1. We can expect good dynamic pressure equalization in the glazing cavity.

The same calculation for the spandrel yields a ratio of more than 700 to 1, which is clearly inadequate to achieve dynamic pressure equalization even if the backpan were rigid. In reality, backpans are not rigid and achieving significant pressure equalization of dynamic pressures may not be a reasonable objective with this design of spandrel section.

One approach to improving dynamic response would be to use 100 mm foam insulation instead of glass fibre since this reduces the volume of the cavity. This would reduce the volume to vent area ratio to about 145 to 1 and would probably stiffen the backpan. Increasing drain/vent slots at each spandrel to a total of 300 mm would then provide a ratio close to 25 to 1 which should allow for reasonably good dynamic response.

Placement of Vent/Drain Slots

Drainage must be provided at the bottom of the cavities and it is normal practice to size these to provide the required venting. However, additional vent areas can be provided at the top and sides of the cavity. Some people believe that having vents at the top as well as the bottom increases the ability to dry water in the cavity that gets there from outside or by condensation. This has not been conclusively proven. Vents at the side would be under the vertical snap caps. This may not be the best place because it is difficult to provide the same vent area through the snap caps. The designer then has to consider compartmentalization of the cavity under the snap cap. Vents at the top of the cavity have been shown to increase the amount of water that enters the cavity and do not increase the intended drying.

There is an advantage to locating most of the vent area towards the side of the cavity furthest away from the corner or roofline of the building, since this tends to pressurize the cavity. We can specify that a 50 mm drain slot through the bottom pressure plate be located 50 mm from the vertical mullion furthest away from the corner, and that additional 10 mm drain holes be placed at the centre and outer side of the bay to ensure drainage.

Snap cap issues

All the effort in sizing and locating vents is wasted if vents are covered by snap caps that have small drain holes. To maintain the pressure equalization characteristics that we have designed into the cavities, the vent area of the snap caps should be two times larger than the vents they cover.

Snap caps spanning compartment seals compromise the compartmentalization plan. This can be avoided simply by arranging to have the vertical snap caps continuous and the horizontal snap caps interrupted at mullion intersections (assuming that there are no vents under the vertical snap caps).

10 End notes

1 Surry, D. *Simulation of Wind-Driven Rain and Wetting Patterns on Buildings*, Boundary Layer Wind Tunnel report BLT-SS30-1994 for Canada Mortgage and Housing Corporation, 1995

2 Morrison Hershfield Limited, *Survey of Building Envelope Failures in the Coastal Climate of British Columbia*, Canada Mortgage and Housing Corporation, Burnaby, B.C., 1996.

3 CAN/CSA-A440.1-M90, *User Selection Guide to CSA Standard CAN/CSA-A440-M90, Windows*, Canadian Standards Association, 1990.

4 CAN/CSA-A370-M94, *Connectors for Masonry*, Canadian Standards Association, 1994.

5 Patenaude, Armand, Migration de l'eau par capillarité, Canada Mortgage and Housing Corporation, 1993.

6 Drysdale, Robert G., Wilson, Michael J., Tests of Full Scale Brick Veneer Steel Stud Walls to Determine Strength and Rain Penetration Characteristics, Canada Mortgage and Housing Corporation, 1990.

7 Brown, William C., Dalgliesh, W. Alan, Ullett, James M., *Progress Report #3, Measured Pressure Equalized Performance of Two Precast Concrete Panels, Performance of Pressure Equalized Rainscreen Walls: A Collaborative Research and Development Project*, National Research Council Canada, Ottawa, 1995

8 Brown, William C., Ullett, James M., *Progress Report #4, Measured Pressure Equalized Performance of a Brick Veneer/Steel Stud Assembly, Performance of Pressure Equalized Rainscreen Walls: A Collaborative Research and Development Project*, National Research Council Canada, Ottawa, 1995.

9 *Technical Guide for Air Barrier Systems for Exterior Walls of Low-Rise Buildings*, Canadian Construction Materials Centre, 1996.

10 Inculet, D., Surry, D., *The Influence of Unsteady Pressure Gradients on Compartmentalization Requirements for Pressure-Equalized Rainscreens*, University of Western Ontario, 1996.

11 Lin, J.X., Inculet, D.R., Surry, D., *A Study of the Characteristic Shapes of Mean Pressures and Their Gradients on Buildings in Realistic Surroundings*, Part 2 & Part 6, Canada Mortgage and Housing Corporation, 1995.

12 Skerlj, P.F., Surry, D., *A Study of Mean Pressure Gradients, Mean Cavity Pressures, and Resulting Residual Mean Pressures Across a Rainscreen for a Representative Building*, Canada Mortgage and Housing Corporation, 1994.

13 Morrison Hershfield Limited, *A Study of the Rainscreen Concept Applied to Cladding Systems on Wood Frame Walls*, Canada Mortgage and Housing Corporation, 1990.

14 Inculet, D., Surry, D., *Optimum Vent Locations for Partially-Pressurized Rainscreens*, University of Western Ontario for Canada Mortgage and Housing, 1996

15 Morrison Hershfield Limited, *Air Barrier Systems for Walls of Low-Rise Buildings*, National Research Council of Canada, 1997.

16 Brunett, Eric, Straube, John, *Vents, Ventilation Drying, and Pressure Moderation*, Canada Mortgage and Housing Corporation, 1995.

17 *Proceedings of Building Science Insight*, National Research Council of Canada.

18 Rousseau, Madeleine, Poirier, Gilles and Brown, William C., *Pressure Equalization in Rainscreen Wall Systems*, Construction Technology Update No. 17, National Research Council of Canada, 1998.

19 Gibson, Lawrence, *Exterior Insulation Finish Systems, Laboratory Evaluation of Materials and Joints Subject to Artificial Conditioning*, Canada Mortgage and Housing Corporation, Ottawa, 1995

20 Quirouette, Richard, *Testing Rainscreen Wall and Window Systems: The Cavity Excitation Method*, Canada Mortgage and Housing Corporation, Ottawa, 1996.

21 Quirouette, Richard, *Laboratory Investigation and Field Monitoring of Pressure Equalized Rainscreen Walls*, Canada Mortgage and Housing Corporation, Ottawa, 1996.

22 Quirouette, Richard, *The Rainscreen Wall: A Commissioning Protocol*, Canada Mortgage and Housing Corporation, Ottawa, 1996.

23 Rousseau, Jacques, "*RAINSCREEN*," Canada Mortgage and Housing Corporation.

Conversion Table

1mm = 0.039 in

1 cm = 0.393 in

1 m = 3.27 ft

1 ft = .3048m

1 m2= 10.76 sq.ft.

1 sq.ft = 0.092 m^2

1 US fl oz = 29.57 mL

1 US gallon = 3.785 L

1 L = 33.87 US fl oz

1 g = 0.0353 oz

1 oz = 28.35 g

1 lb = 16 oz = .4536 kg

500 Pa = 10.4 lb/ft^2

1 Pa = 0.0208 lb/ft^2

1 L/min = 33.87 US fl oz/min

1 $L/sec/m^2$ = 1.46 US gal/min/sq.ft.

RainScreen 2.1 User's Guide

Prepared by RWDI for CMHC

June 13, 1998

Table of Contents

0

Introduction

RainScreen was created as a tool to help design rain screen curtain walls. RainScreen 2.1 allows designers to vary the parameters of their rain screen system and graphically see the resulting dynamic pressure distribution on cladding and air barrier (back-pan) layers. Its mathematical engine is based on the CMHC report entitled 'RAINSCREEN' by Jacques Rousseau. RainScreen 2.1 adds many new features and an easy GUI interface under either Windows or Macintosh operating systems which were not available under its predecessor, RAIN 1.1.

1

Getting Started

Hardware Requirements

The Windows version of RainScreen 2.1 can be run on any Windows PC. For good performance, a 486/33 or better processor with colour graphics resolution of 800x600 or better and a mouse, are recommended. At least 8MB of RAM is required.

The Macintosh version can be run on either a conventional Macintosh(Motorola 68000 based) or a Power Macintosh (Power PC based). At least 8MB of RAM is required.

Software Requirements

Microsoft Windows 3.1 or greater, or for Macintosh, the System 7 operating system.

Installation

Windows

From the DOS prompt, go to your RainScreen install disk and run INSTALL. You will be presented with an important disclaimer screen. Press 'OK' when you are ready to begin the installation. Enter the name of the directory where you would like to install the RainScreen program, and click on the 'Continue' button. To view the on-line User's Guide, you will need to install Adobe Acrobat Reader if you do not already have it on your machine.

Macintosh

On the RainScreen 2.1 Installation disk, double-click on the 'Install RainScreen 2.1' icon. After clicking past the splash screen, you will be presented with an important disclaimer screen. Press 'Continue' to go on to the next screen. Click the 'Install' button when you are ready to continue - the rest of the installation procedure is automatic. To view the on-line User's Guide, you will need to install Adobe Acrobat Reader if you do not already have it on your machine.

2

Tutorial

Exploring RainScreen

Launching RainScreen 2.1

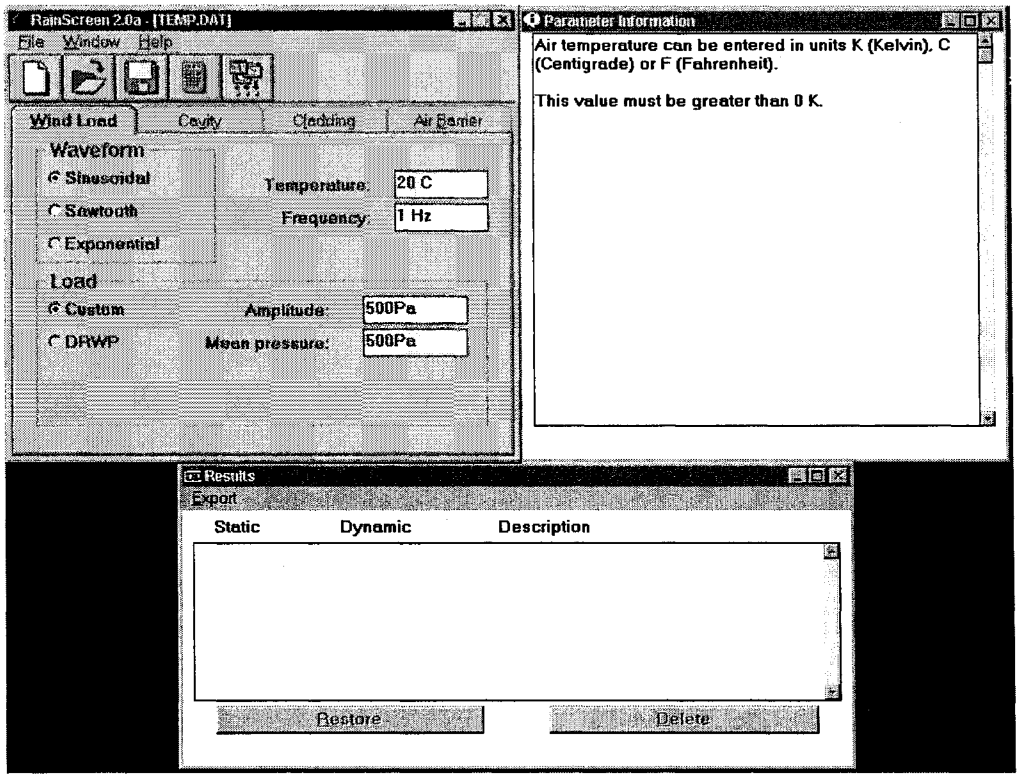
Windows
From Windows, enter the RainScreen program group and click on the RainScreen icon to launch the program. Now skip the following 'Macintosh' section and continue reading under the 'Common' section.

Macintosh
After running the installation program, the RainScreen files will be located in the folder 'RainScreen 2.1' within your hard-drive folder. Open the program folder and double-click on the 'RainScreen 2.1' program icon. Continue reading under the 'Common' section below.

Common
You will now be presented with a title screen showing the CMHC logo and a choice of operating in English or French. (**Note:** system menus and file dialogue windows are controlled by the operating system, and will always be displayed in the language of the operating system you are using).

Once you have chosen a language, three windows will appear on the screen. Depending on the resolution of your screen, you may notice the windows overlapping. It's recommended that you use a resolution of 800x600 or higher.

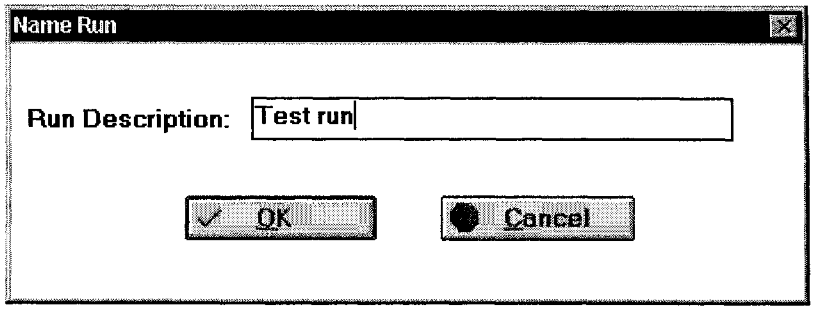
The three windows



Take a look at the window on the top left corner of the screen. From now on we'll refer to it as the **main window**. This window is where you will enter the simulation parameters for your rainscreen wall. Also, using the menus on this window you can also save or re-load your work (from the **File** menu) and access the help system (from the **Help** menu). There are short-cut buttons below the menu bar for the commands in the File menu; as the icons indicate you can use these buttons to start a new session, open an existing session, save the current session to disk, run a simulation, or (on the Windows version only) minimize all windows.

Below the menus and buttons are the simulation parameters. The parameters are divided into four pages; to change pages, click on the tab showing the page title you want to switch to.

Running the simulation
To start with, let's try running the simulation using the default parameters. From the File menu, select the **Calculate** item. A **Name Run** window will appear in the middle of the screen asking you to name this run. Enter a description and then click OK.



You will notice a couple things happening: The window in the top right corner now displays a graph of simulated pressures. In addition, the run description you entered appears in the window labelled **Results** at the bottom of the screen. To the left of the run description is a summary of the effects of the rainscreen wall on the cladding: the static and dynamic pressure ratios. A dynamic pressure ratio of 61.5% means that the pressure experienced by the cladding is 61.5% of the exterior load. This ratio is also apparent from the graph, where you can see the cladding load is lower than the exterior pressure - 38.5% lower at the peak.

Now let's change the simulation parameters to see how they change the results. Click on the tab for the Cladding page, and then add a vent by clicking on the 'Add to Total' button. Now run the simulation again and enter a different run description, or leave the default enumerated run description if you like. ***Note***: It's important that each run description is unique, because you will use these descriptions later to distinguish the runs from one another.

Multiple runs: the Session

You will notice this run description has been added to the results window, and the Dynamic ratio for this run is different. The old graph has been replaced by the new sawtooth one, but we can get the previous graph back - just click on the previous run description in the results window and it will re-appear. In this way we can build up a number of different simulation runs representing different cases on the same rainscreen cavity. The list of runs you have created is referred to as a ***session***. Sessions can be saved and restored from the File menu - and also from the SpeedButtons below the File menu.

We can recall the parameters used to create a previous run - to do this, click on the desired run description in the Results window, and then click the Restore button at the bottom of the window. All of the parameters for that run will then be restored into the main window for you to view.

Simulation parameters

Now let's take a look at the various parameters used to control the simulation on each of the four pages.

Wind Load page

Since Wind Load is the active page when RainScreen first loads, we'll start there. First choose a waveform for the wind load you would like to apply to your rainscreen cavity. **Sinusoidal** and **Sawtooth** are both periodic external wind loads. Choose **exponential** if you would like to set the cavity to a given pressure and see how quickly that pressure decays.

Exponential Wind Loading
Click on the **temperature** field and enter the air temperature to use in the simulation, if you would like to change the default value. The **duration** field specifies the amount of time you would like to run the simulation for. The rainscreen cavity will be set to the **Starting pressure** and allowed to decay for the given duration. When using exponential wind loading, external pressure remains at constant barometric pressure.

Sinusoidal/Sawtooth Wind Loading
Notice that when you click on the field, text appears on the window entitled **Parameter Information** in the top right corner of the screen. This window will give you information on the currently selected field when available. Values in RainScreen can usually be entered in a number of different units - whenever you are entering a value in a data field, look at the Parameter Information window to see what units RainScreen will accept.

Next you can change the gust **frequency**. Then we need to specify the magnitude of the gusts at this frequency. This is the purpose of the **Load** group of fields at the bottom of the main window. There are two methods you can use to specify the magnitude of gusts: **Custom** or **DRWP**. Custom allows you to entering the exact peak and mean pressures that will occur. DRWP (Driving Rain Wind Pressure) allows you to use the A440 building code to specify these pressures.

Custom
Simply enter an amplitude and a mean pressure about which the pressure will oscillate. For example, if you want the external pressure to vary from 200Pa above barometric to 800Pa above barometric, enter a mean of 500Pa and an amplitude of 300 Pa.

DRWP

The DRWP code uses four values you supply to calculate an amplitude and a mean wind pressure using the equation shown in the sidebar.

The code supplies a **reference pressure** for many locations. To make things easier, RainScreen supplies these **preset values** for you. For more information on preset value lists, see the *Preset Value Lists* sidebar below.

Now enter a value for **exposure**. This value depends on the height of the cavity above ground and the surrounding terrain, and is usually greater than or equal to 1. A preset value list is supplied for this parameter.

> **DRWP Calculations**
>
> $$P_{mean}=P_{ref}\cdot C_e\cdot C_p$$
>
> $$P_{amp}=(C_{gust}-1)\cdot P_{mean}$$
>
> P_{mean} = mean exterior pressure
> P_{amp} = amplitude of exterior pressure
> P_{ref} = reference pressure
> C_e = exposure factor
> C_p = pressure coefficient
> C_{gust} = gust factor

Next is the **pressure coefficient**. This expresses how the location of the cavity on the wall affects the pressure it experiences. For example, a cavity on the very edge of a wall will usually experience greater pressures than one in the middle of a wall face.

The last field is the **gust factor**. The peak pressure of the varying wind pressure will be the mean pressure (calculated from the values above) multiplied by this factor. The amplitude will be [gust factor-1] multiplied by the mean pressure.

Cavity page

On this page you define the dimensions of the rainscreen cavity.

Cladding page

Here you describe flexibility and vent area for the cladding (exterior wall) of the cavity. You can enter a total cladding vent area directly, or use the built-in calculator. Select a vent shape, enter dimensions for individual vents and the number of vents. Then click **Add Vent** to add these vents to the total at the top. To set the total to zero, click on the **Clear Total** button. Note that RainScreen assumes cladding vents are large enough to permit turbulent air flow.

Flexibility

The fields in the Flexibility group describe cladding panel dimensions, mechanical properties, and the way the cladding is fixed to the wall. RainScreen uses these to calculate how much the cladding will deflect under loading conditions. Horiz span and Vert span are the horizontal and vertical distances between studs under the cladding. RainScreen assumes that the cladding surface is attached to horizontal and vertical studs, which divide the area of the cavity face into individual panels. If there are no studs sub-dividing the outer frame of the cavity, just use the cavity width and height (from the cavity page) for the horizontal and vertical spans.

Once the shape of the panels has been specified, enter the material properties E (modulus of elasticity), I/Width (moment of inertia per unit width) and Poisson's ratio. Sample values for these parameters are available in the parameter information window. Specify the way in which the cladding is fixed to the wall in the 'Edge cond' field - this will determine the deflection shape and volume. For more details on deflection, see the chapter entitled **Mathematical Model**.

Edge Condition	Explanation
All Simple	All sides of the cladding panels are attached but allowed to rotate freely
V Simple	The vertical sides of the cladding panels are attached and allowed to rotate, the horizontal sides are not attached
H Simple	The horizontal sides of the cladding panels are attached and allowed to rotate, the vertical sides are not attached
All Clamped	All sides of the cladding panels are attached and **not** allowed to rotate
V Clamped	The vertical sides of the cladding panels are attached and **not** allowed to rotate, the horizontal sides are not attached
H Clamped	The horizontal sides of the cladding panels are attached and **not** allowed to rotate, the vertical sides are not attached

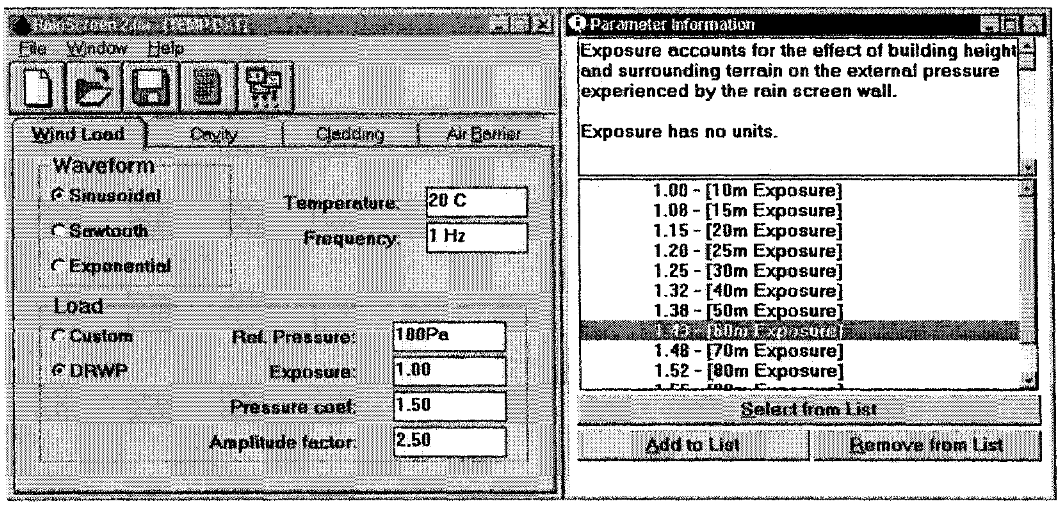
Air Barrier page

Here you describe the leakage properties and flexibility of the air barrier (the cavity's internal wall). Leakage can be defined either directly as the total area of holes and leaks in the air barrier, or as a rate of volume flow at a pressure gradient of 75 Pascals. As with cladding vents, RainScreen assumes air barrier leaks are large enough to permit turbulent air flow. Air barrier flexibility works exactly like cladding flexibility.

Preset value lists

Some parameters in RainScreen 2.1 have lists of saved values. Instead of having to come up with values for these parameters, a user can simply click on one of the items on the list to have the appropriate value inserted into the input box.

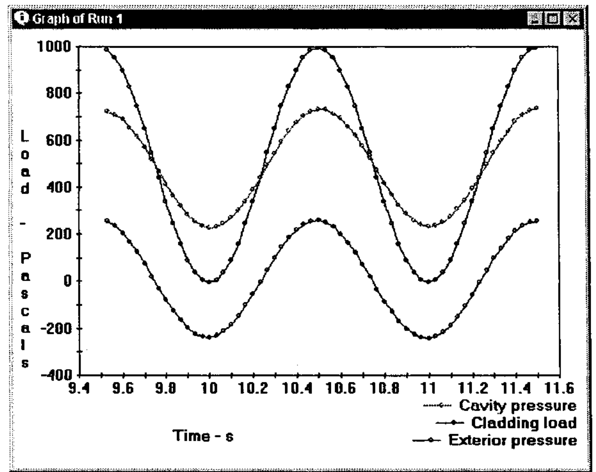
To see a preset value list, click on the DRWP button on the Wind Load page. Now select the **exposure** input box. The bottom half of the Parameter Information window will now display the preset value list for this parameter. To select one of the exposures listed, click on the item in the list and then click the **Select from List** button.



As well as using the default values on these preset value lists, you can add your own values by clicking on the **Add to List** button. You will then be prompted for a description and value - remember to use appropriate units when you enter the value. RainScreen will automatically save your lists and restore them for you next time.

Using your results

The Graph



The graph display shows instantaneous values for three pressures: the exterior (wind) pressure relative to barometric, the pressure within the cavity relative to barometric, and cladding load (the difference between cavity pressure and external pressure).

When displaying a periodic waveform (sinusoidal or sawtooth), a fixed number of cycles are displayed. Often the graph begins at a point past time=0; this is because RainScreen only begins displaying simulation results after steady state has been reached. This eliminates the unrealistic transient effects that would otherwise occur at the beginning of the simulation.

Numerical output

Once you have created a session, you will probably want to use your results in a report of some sort. The parameters and results from a simulation can be exported to text files in four different ways. These text files can then be imported into other programs, for example a spreadsheet or word-processor, to be included with a report.

To export data, chose the type of data you wish to export from the **Export** menu on the Results window.

Summary run listing

Creates a file with one line for each run in your session. For each run, only the run description and cladding ratios are given. This summary could be used in the body of a report.

Detailed run listing

Similar to **Summary run listing**, but all input parameters are given. This could be useful for the appendix of a report.

Selected run only

Cladding ratios and input parameters for the currently selected run only are stored to a text file. The selected run is the run which is displayed in the Graph Window. This menu item is grayed-out if no run is selected.

Time series data

A table of the data used to plot the graph for the selected run is saved to a text file. Values such as cavity volume, cavity pressure, and air flow are given for each sampled moment in time. This would be useful for a detailed investigation of the simulation results.

3

Error Messages

... is not a valid unit for this field.
RainScreen does not recognise this unit. Click on the field and use one of the valid units shown in the information window.

Cannot save an empty session.
You cannot save a data file if your session does not yet contain any runs

Error opening/writing/closing file ...
RainScreen may be unable to find a required file in its current directory. Other possible reasons for this error message could include:
-no disk in the disk drive
-a physical error on the disk media
-insufficient free space on the disk

... is not a RainScreen session file.
The file you have attempted to load is not a RainScreen file, even though it may have the .DAT extension.

... was not created with this version of RainScreen.
The file format for the file you have attempted to load is different from the format used by your version of RainScreen. This file should be re-loaded with the version of RainScreen that was used to create it.

Note: ... is above/below this parameter's recommended upper/lower bound of ...
The value you have entered for this parameter is outside the recommended value. This value may be unrealistic and cause your results to be incorrect. Continue only if you are certain this value is correct, otherwise use a value within the given range.

Note: ... is above/below this parameter's upper/lower bound of .... Please use a lower/higher value.
This value is outside the allowed range for this parameter. RainScreen will force the parameter

back to the last valid value. Boundaries are set on parameter values to avoid mathematical errors such as division by zero.

Too many iterations without convergence. This is usually caused by flexibility being too high or cavity volume being too low. Results for this run may be incorrect.

Often when this error message is displayed, the results will show wildly fluctuating pressures and loads. When this message is displayed, the results cannot be trusted. Check your values for flexibility and cavity dimensions. The mathematical model on which RainScreen is based breaks down when flexibility is too high or cavity volume is too low.

Steady-state has not been reached after 100 cycles. Giving up the search for steady-state conditions.

This message is displayed when cycles are still significantly changing after 100 cycles. This usually means the parameters used have produced chaotic (and thus incorrect) results.

During the simulation, cavity volume has fallen below zero....

Due to high flexibility values, a low cavity volume, or a combination of the two, the simulation has calculated that the cavity volume will reduce to zero or to a negative volume - a physical impossibility. This usually means the results of this run will be chaotic and unreliable. To correct this problem, reduce the flexibility or increase the cavity volume.

Cavity volume has been reduced to zero....

Due to high flexibility values, a low cavity volume, or a combination of the two, the simulation has calculated that the cavity volume will reduce to zero or to a negative volume - a physical impossibility.

4

Mathematical model

Terms of the RainScreen Equation

The equation used in RainScreen is derived from the elementary gas law:

$$P=\frac{nRT}{V}$$

substituting mass over molar mass for n, the number of moles:

$$n=\frac{m}{M}$$

We now have:

$$P=\frac{m}{M}\cdot\frac{R\cdot T}{V}$$

This is the same form taken by the final RainScreen equation:

$$\Delta P_{cavity}=[\frac{R\cdot T_{abs}}{M_{air}}]\cdot\frac{m_{air}}{V_{cavity}}$$

The terms in the braces should need no explanation. Expanding m:

$$m = m_{previous} + \delta m_{cladding} + \delta m_{barrier}$$

$$= m_{previous} + C_d \cdot t_s \cdot [A_{cladding} \cdot \sqrt{2 \cdot \rho_{air} \cdot (P_{extern} - P_{cav_{est}})} + A_{barrier} \cdot \sqrt{2 \cdot \rho_{air} \cdot (P_{intern} - P_{cav_{est}})}]$$

where C = discharge coefficient (unitless), assumed to be 0.61
ρ = density of air (kg/m^3)
t = time interval (s)
A = area of vents or leaks (m^2)
P_{intern} = pressure within building (Pa) (constant)
P_{extern} = external pressure (Pa) (varying)
P_{cav_est} = estimated pressure within cavity (Pa)

Note: To use a discharge coefficient other than 0.61, multiply your vent area or your air barrier leakage area by the appropriate factor. For example, to use a coefficient of 0.35, multiply the vent area by 0.35/0.61.

Expanding the volume term (V), we have:

$$V_{cavity} = V_{initial} + \Delta V_{flex_{cladding}} + \Delta V_{flex_{barrier}}$$

Flexibility

The equations for flexibility depend upon what edge conditions were chosen; there are four groups of equations for the four groups of edge conditions.. The common terms of all four equations have been grouped together in the term Y:

$$Y = \frac{q \cdot a^4 \cdot (1 - v^2)}{E \cdot I/b}$$

where: q = applied pressure
a = short length or beam length
v = Poisson's ratio
E = modulus of elasticity

I/b = moment of inertia per unit width

Equations for the four different classes of edge conditions follow:

1) Simply supported on two sides

Based on equations for deflection of a simply supported beam:

$$w_{max} = \frac{5}{384} \cdot Y \qquad V = \frac{1}{120} \cdot ab \cdot Y$$

where w_{max} = maximum deflection
V = deflected volume

2) Clamped on two sides

Based on equations for deflection of a clamped beam:

$$w_{max} = \frac{1}{384} \cdot Y \qquad V = \frac{1}{720} \cdot ab \cdot Y$$

3) Simply supported on four sides:

Theoretical solution:

$$w_{max} = \frac{16}{\pi^6} \cdot Z(a/b) \cdot Y \qquad V = \frac{16}{\pi^6} \cdot X(a/b) \cdot Y$$

where:

$$Z(a/b) = \sum_m \sum_n \frac{\sin(m \cdot \frac{\pi}{2}) \cdot \sin(n \cdot \frac{\pi}{2})}{m \cdot n \cdot (m^2 + \frac{a}{b} \cdot n^2)^2} \qquad X(a/b) = \sum_m \sum_n \frac{1}{m \cdot n \cdot (m^2 + \frac{a}{b} \cdot n^2)^2}$$

m and n are odd natural numbers (1,3,5,7...)

4) Clamped on four sides:

Approximation based on a numerical solution:

$$w_{max}=\frac{1}{791}\cdot P(a/b)\cdot Y \qquad V=0.71\cdot\frac{4}{\pi^2}\cdot ab\cdot w_{max}$$

where:

$$P(a/b)=1.674+2.782[\frac{a}{b}]-5.234[\frac{a}{b}]^2+1.772[\frac{a}{b}]^3$$

Iterating the equation

Returning to the original pressure equalization equation:

$$P_{cav_{calc}}=[\frac{R\cdot T_{abs}}{M_{air}}]\cdot\frac{m}{V_{cavity}}$$

Calculating the terms Δm and V_{cavity} requires that we know P_{cavity}. Since we obviously don't know P_{cavity}, this equation cannot be used directly - we have to use numerical methods as summarized below:

1. An initial value for P_{cavity} is selected, let's call it $P_{cav\text{-}est}$ (estimated). This value should be close the what we expect the final value to be in order to reduce the number of iterations required for convergence.
2. This value is used to calculate new tentative values for V (changes due to flexibility) and m (changes dues to air vents and leakages). These values are used in the right side of the pressure equalization equation to produce another distinct cavity pressure, let's call this one $P_{cav\text{-}calc}$ (calculated).
3. We now compare these two values. If our estimation was correct, then $P_{cav\text{-}calc}$ should be equal to, or very close to, $P_{cav\text{-}est}$, and we use our tentative mass value m for the next time step. If not, we adjust $P_{cav\text{-}est}$ in the appropriate direction and return to step 1. How much we adjust $P_{cav\text{-}est}$ depends on whether we have overshot or not; if we have, then the adjustment amount is divided by 2, if not, we continue with the same pressure adjustment. This is effectively a binary search algorithm.

5

Technical Notes

Time intervals and the graph

The way the pressure graph is displayed depends on what waveform you are using. In all cases the number of data points displayed is constant.

Exponential

Cavity pressure will be displayed from time 0 to the time specified in the duration field.

Sinusoidal and Sawtooth

Pressures are calculated from time 0. However, the initial conditions are somewhat unrealistic - constant cavity and external pressures before time 0, instantaneously changing to a varying pressure after time 0. RainScreen attempts to eliminate the effect of these abrupt initial conditions by continuing its calculations until a cycle is found which is identical (or nearly identical) to the previous cycle, and displaying two cycles after this point is reached. This means that the time axis on the graph will usually not start at time 0. The number of cycles that must be calculated before this condition is reached depends on the input parameters - mostly the cladding vent area and air barrier leakage area.

Limitations

The mathematical model is limited to dealing with a certain range of flexibilities for the cladding and air barrier systems. The upper limit for flexibility depends on the wind loading and cavity volume. Essentially, the mathematical model cannot account for the case where the cladding flexes inwards to the extent that the cavity volume is reduced to zero. This case will only occur when RainScreen is supplied with unrealistic input parameters.

Comparing simulation vs. real-world results

The results of two full-scale curtain-wall experiments were compared with RainScreen's calculations. The results of this comparison were favourable:

Experiment 1

NRC Report #A3028.4

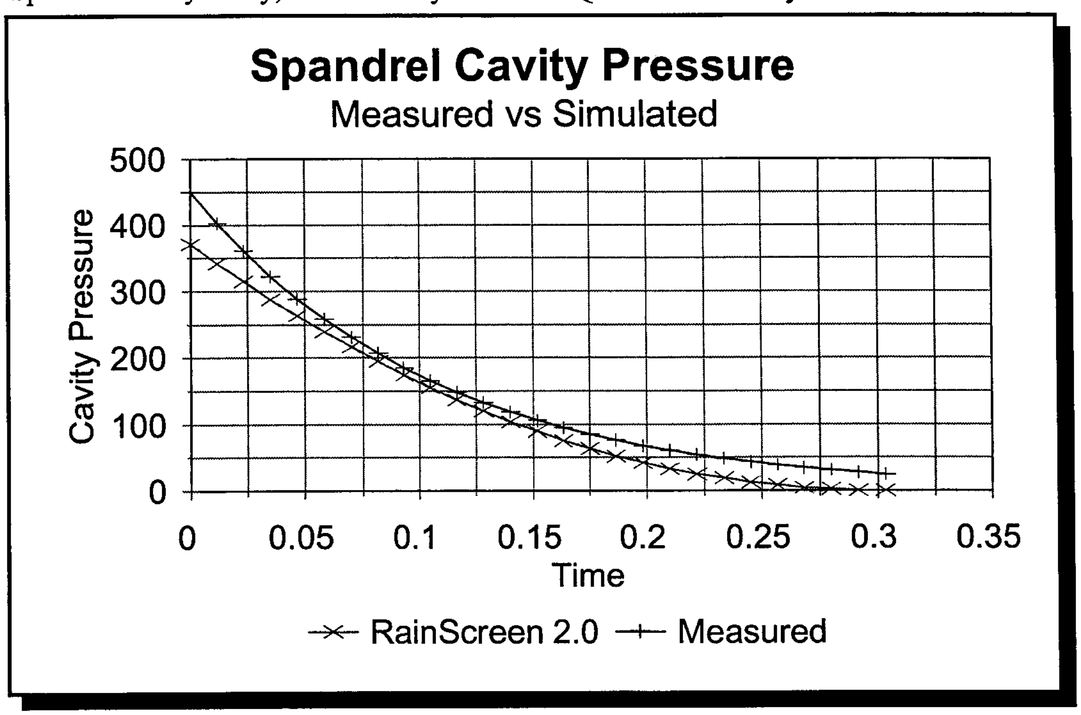
Reported results				
	No air barrier leaks		With air barrier leaks	
	0.5 Hz	2 Hz	0.5 Hz	2 Hz
Vent area 1	60	480	60	460
Vent area 2	20	230	20	220

RainScreen results				
	No air barrier leaks		With air barrier leaks	
	0.5 Hz	2 Hz	0.5 Hz	2 Hz
Vent area 1	55	508	62	495
Vent area 2	14	194	17	195

Difference (% of wind load)				
	No air barrier leaks		With air barrier leaks	
	0.5 Hz	2 Hz	0.5 Hz	2 Hz
Vent area 1	-0.50%	2.80%	0.20%	3.50%
Vent area 2	-0.60%	-3.60%	-0.30%	-2.50%

Experiment 2

Spandrel Cavity decay, conducted by Brooks at Queen's University



6
References

- Rousseau, Jacques "RAINSCREEN"
- Richard Quirouette (1996), "Laboratory Investigation, Field Performance and Commissioning of Pressure Equalized Rainscreen Walls"
- CAN/CSA-A440-1-M1990, June 1990