Facts and Fictions of Rain-Screen Walls

by M.Z. Rousseau

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Rain penetration through walls can damage the building envelope. Corrosion of anchors of exterior cladding, efflorescence on masonry, damage and staining of interior finishes are just a few examples of problems due to "mismanaged" rain. As if that is not enough, it can also affect the appearance, the function, and the comfort of the space, factors that translate into disruption of the occupants (loss of productivity), into loss of profit for the owner or manager of rented office and commercial space and probably decreased market value.

Proper control of rain penetration is easier and less costly to obtain at the design and construction stages than later on during occupancy. In the latter case symptoms showing up seemingly at random in many rooms (where expensive equipment can be located) of the twelfth floor of a 15-storey building can be distressing to the building owner/manager and to the users of the space. Designers and builders (and building owners) must understand what is required to control rain penetration through exterior walls.

Misunderstood Principles

Inquiries from builders, architects, and engineers suggest that drained cavity walls are often confused with rain-screen walls. Here is an example of how subtly this often appears. When possible causes of rain-leakage problems are discussed, the question eventually arises as to whether the design and construction of the walls apply the rain-screen principle. Quite often, the response is "Yes, they do: there is a drained cavity behind the cladding." Sorry... but this fits the description of a cavity wall, not a rain-screen wall. A "rain-screen wall" is designed and built according to what Kirby Garden referred to as the "open rain-screen principle,"[1] whose basic premise is the control of ALL forces that can carry rain to the inside.

Now a heated debate on terminology usually starts! It is clear in my mind that a "rain-screen wall" is a wall to which the "rain-screen principle" has been applied; this expression refers to a given package of requirements set out in Garden's published material twenty-five years ago. Others argue that any wall that uses the cladding as a screen for rain, such as a cavity wall, can be called a rain-screen wall. Usually the debate cools off when the expression "pressure-equalized rain-screen wall" is used. The term "pressure-equalized" rain screen is particularly useful in that it emphasizes what is ignored or confused, as well as what differentiates it from a drained cavity wall. Pressure equalization in the cavity behind the cladding: this is where the difference between a rain-screen wall and a cavity wall lies. In my view, it is a redundant expression, but at least it ends temporarily arguments on terms so that we can focus on how to build such a wall.

Cavity Walls

With respect to rain penetration, the concept of cavity walls is based upon the control of some of the forces acting on the cladding, i.e., gravity, surface tension, capillary action, and raindrop momentum. Decades ago it was used for masonry construction to reduce dampness of inside wall surfaces[2] (see Figure 1). To control rain entry by capillarity, a large cavity (50 to 75 mm wide) was introduced between the outer and inner layers of masonry: water entering the outer layer would not bridge the large gap to reach the inside layer. Water would then run down on a surface of the cavity to the bottom, and be collected by a flashing directing the water to little drains, the weep holes. At openings and interfaces with other components such as windows, raindrops can find their way deep into the joint, unless a shield (not airtight or watertight) is installed on the outside of the joint to "break" the momentum of the drop; this took care of the raindrop momentum. Surface tension, another manifestation of capillary force, can allow water to go up in a horizontal joint; to counteract this force, a sudden change in direction in the material allows the raindrop to detach from the surface. A groove in a thick material or a labyrinth in a thin one are examples of ways to reduce rain entry by surface tension. Horizontal joints should have a positive slope to drain outward so that gravity works for you. This "drained cavity" approach was later applied to other types of wall besides masonry walls, with varying details depending on the system. As impervious prefabricated cladding panel systems have entered the market, the proper detailing of joints has become critical to the control of all the forces by which rain enters exterior walls.

Even though an exterior wall includes a flashed and drained cavity behind the cladding as well as rain deflectors, it may not control rain penetration adequately because a significant force at play has been ignored: that is, a difference in air pressure across the cladding. This causes infiltration of air and water on windward facades through joints, small pores, gaps, cracks, poorly bonded surfaces, and openings that exist or develop during the life of the cladding.

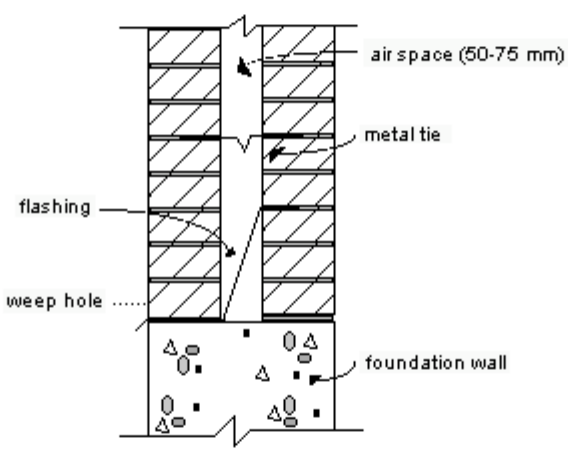

Figure 1. *Masonry cavity wall section, as designed 25 years ago*

Pressure-Equalized Rain-Screen Walls

The rain-screen principle entails the control of all the forces handled by a drained cavity wall plus the air pressure difference acting across the cladding. To many designers and contractors, believing that air-pressure difference across claddings causes water entry is hard to comprehend.

During a rain storm, air infiltration through porous cladding, its joints, cracks and gaps is a great vehicle for water to get a free ride into the enclosure. The rain-screen principle recognizes this harmful potential and addresses the control of air-pressure difference across exterior-cladding assemblies.

No one can stop the wind from blowing! But wall design should be such that the cladding experiences almost no net pressure difference due to wind. Imagine that wind pressure on cladding could practically cancel itself if the pressure is transferred to the back of the cladding... in the cavity (see Figure 2). For the cavity to respond quickly to fluctuations in wind pressure, and for proper management of wind in this cavity, air flow in the cavity must be minimal. Indeed all you want is to pump in a little volume of outside air to equalize the pressure across the cladding. For this to happen, you need a rigid air barrier; a cavity behind the cladding broken down vertically and horizontally into tight compartments of varying sizes; a large venting area connecting the cavity to the outside; and a somewhat impervious cladding. This is far from the myth spread in the industry which claims that simply venting a cavity (no matter how big the cavity behind the exterior cladding... no matter how leaky the inner wall) does the trick of applying the rain-screen principle.

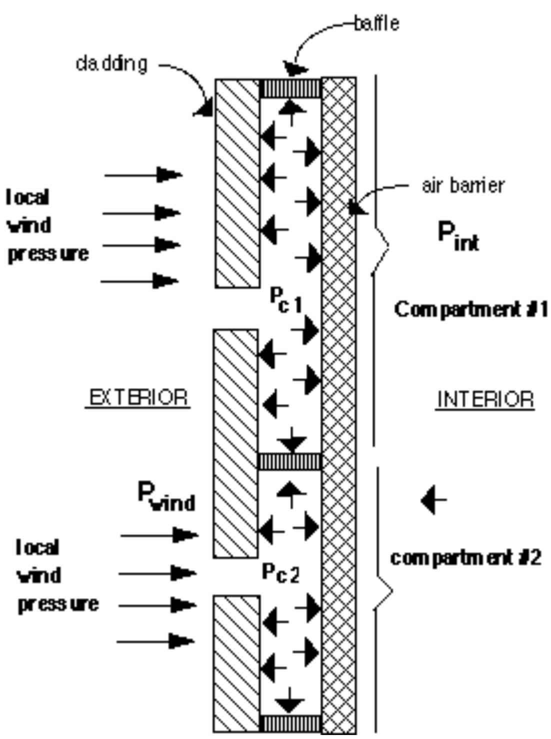

Figure 2. *Equalization of pressure across the cladding needs: a rigid air barrier; a cavity behind the cladding; cavity baffles; and exterior vents in the cladding*

Let's examine some of these needs:

A Rigid Air-Barrier System

Wind induces large air-pressure difference across exterior walls, especially during gusty wind conditions while mechanical ventilation and stack effect cause smaller but steady pressure differentials. Air leakage through a wall system prevents the outside pressure from equalizing across the cladding. This could be compared to trying to inflate a balloon also perforated at the other end: to increase the pressure in the balloon, the easiest way is to make a knot with the perforated end so it is sealed. In construction, this common sense action is called building an air-barrier system! An air-barrier system will control air flow through the wall system. The balloon example stops working here: the air barrier should be rigid to keep the volume of the cavity constant. A constant volume helps the cavity "bounce back" quickly in response to rapid pressure fluctuations (during wind gusting), e.g., reducing time lag for pressure equalization across the cladding. A flexible membrane deflecting in the cavity under wind pressure can promote some pumping in of outside air (and rain). Besides, the air-barrier system should be rigid for its own sake and durability: this way the pressure loads get uniformly distributed on its surface rather than concentrating fatigue stress at the supports.

A Cavity

A cavity behind the cladding acts as a site for the outside pressure to be transferred, a capillary break and a channel for drainage. The net width of the cavity should be about 25 mm. Allowances for site tolerances and possible blockage of the cavity with debris and (mortar for masonry cladding) should be made. The larger the cavity, the more venting needed to obtain an equalization of pressure in it.

A Compartmented Cavity

Lateral air flow within the cavity can occur without air passing through the wall. This air flow is due to variations in wind pressures over the height, width, and geometry of the facade: outside air (and rain, remember) flows into the cavity through vents in locations of high pressure, and out of the cavity through vents in areas of low pressure, messing around in the cavity (and insulation possibly) on its way out. Corners and tops of buildings are usually exposed to extremely sharp pressure gradients, where the windward side is exposed to high positive pressure and the other side is subjected to high negative pressure. Pressure equalization across the exterior cladding cannot be achieved without proper control of lateral air flow within the cavity.[3] It should be divided into a series of tight compartments; then the range of pressure variations that each compartment senses is reduced, and chances of getting a quick equalization of pressure in each compartment will increase.

How large should the compartments be? Their size should be based on the pressure ranges they are likely to experience. Since wind pressures are usually more uniform in the centre of a flat facade than at the corners, compartments can be larger in the centre and should be smaller at the corners (a wind tunnel study stressed the importance of compartmenting corners[3]). Garden[1] suggested compartments every 1.2 m (4 ft) at the ends and tops of walls in a 6-m (20-ft) wide perimeter zone, and on 3- to 6-m (10- to 20-ft) centres in both directions over the central portion (see Figure 3). Existing components of walls can act as cavity baffles: windows, flashings, shelf angles, balconies, furring strips, etc. At this stage no guidelines exist on the airtightness, the strength and the connections of these cavity baffles. Field monitoring of a precast-concrete sandwich-panel wall designed as a pressure-equalized rain-screen wall system indicated that mechanically attached extruded-polystyrene foam strips suited this wall system in providing the features required to reduce lateral air flow and in remaining in place. It may be that strips of wood, sheet metal and rigid plastic may also prove suitable as long as they do not interfere with other requirements for the wall such as fire and heat-flow controls. In 1989, Canada Mortgage and Housing Corporation initiated a project to define better the features required for rain-penetration control using the rain-screen principle as applied to typical claddings (masonry, stucco, clapboard) used for wood-frame construction. The project involves laboratory experiments under steady-state and some dynamic wind-loading conditions.

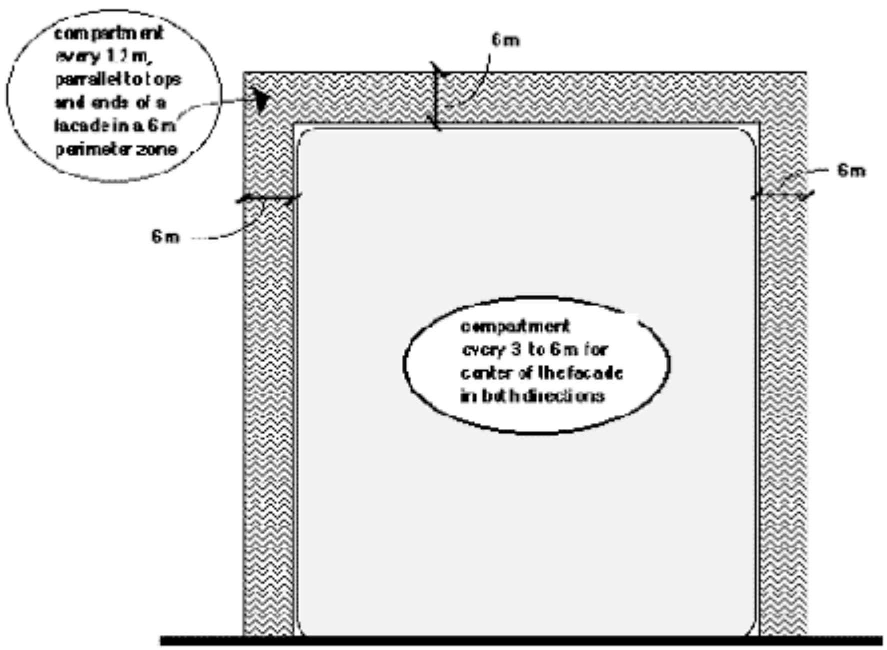

Figure 3. *Compartmentation over a flat facade due to wind pressure variations*

Venting

To equalize the pressure between two environments, these must be connected somehow: venting holes connect the cavity to the outside. Vents should preferably be located at the bottom of the compartment so that they also drain it. All vents of a compartment should be placed at the same height to avoid air-flow loops. The vents holes should be at least 10 mm in diameter to prevent formation of a film of water over the holes, which would reduce the useful venting size.

The amount of venting required in the cladding depends upon the tightness of other components of the cavity, i.e., the air-barrier system and the baffles. The cladding should be much leakier than the other layers of the compartment (air barrier + baffles) so that the cavity pressure is closer to outside pressure than to inside pressure, and pressure drop across the cladding is minimized (see Figure 4).

Latta[4] calculated that a 10:1 ratio for cladding leakage/air-barrier leakage could be satisfactory. Recently IRC laboratory experiments involving tight curtain-wall systems confirmed this figure.[5] However, a quite small, tight, and rigid compartment was used in the experiments, and other types of wall design may call for different ratios. Another study suggests 25 to 40 times more venting than leakage.[6] Most often the cavity baffles will not be that airtight and to account for this, the cladding venting should be even larger than those figures. This approach to venting is quite different from that used for cavity walls, where venting is rather small.

Therefore the tighter the compartment, the less venting of the cladding required for a rapid equalization of pressure. The reverse statement is also technically correct by itself: the leakier the air barrier, the leakier the cladding has to be; but misinterpreted, this statement can be hazardous to your health! Indeed you may end up with a leaky wall and its associated array of potential problems, e.g., uncontrolled flows of moisture, dust, noise, and heat. So don't neglect provision of a proper air barrier on the basis that all you need is to open the tap on the cladding venting because this could cause problems. The air-barrier system should be as tight as possible, whether it is for the control of rain, condensation, or noise. After having evaluated the air-barrier tightness, the venting of the cladding should be established to fit the recommended ratio. To obtain the airtightness value of the air-barrier component proposed, testing of a mock-up wall compartment may be required, since little information on the range of airtightness of generic as-built wall air-barrier components is available.

Wind Loading on the Cladding

The proper application of the rain-screen principle reduces not only the water loads on the cladding but also wind loads. Indeed, the foundation of the principle is the achievement of the same pressure on both sides of the cladding. In theory, a well-performing rain-screen wall should have all wind loads sustained by the air-barrier system; and consequently, the structural requirement for the exterior cladding and its anchorage could be greatly reduced. In practice, this may happen under sustained pressure in a well-designed rain-screen wall. However, under gusty wind conditions, the cladding does sustain some wind loading because of time lag in getting pressure equalization across the wall, as proven by monitoring two buildings for a year and a half,[7] while a wind tunnel investigation was performed on similar walls.[3]

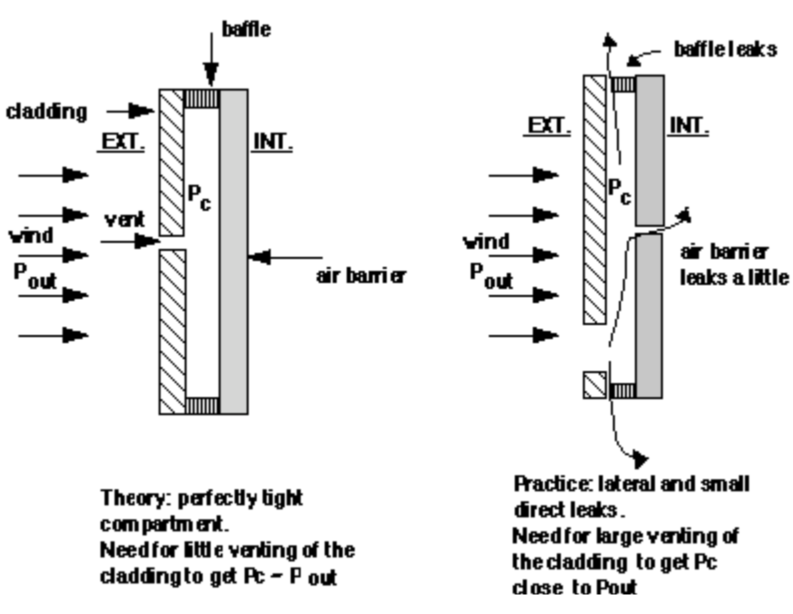

Figure 4. *Need for venting of the cladding vs leakage of the compartment*

Building A, a high-rise structure, had precast-concrete sandwich walls with a very rigid air barrier [(115-mm cast concrete, very small compartments, tight baffles, and large venting (see Figure 5)].[8] A static pressure test using the HVAC equipment on a calm day indicated that all the pressure drop could occur across the air barrier; so this implies the air-barrier system was well designed and built. In general, under sustained (several seconds or more) wind loading, the loads on the cladding were small (up to 50 to 60 Pa); this indicated that the potential for rain entry is minimized. However, rapid changes in outside air pressure, especially under negative loading (suction), resulted in a pressure difference of at least 150 Pa across the cladding due to the time-lag response of the cavity. The largest transient pressure measured across the cladding was 285 Pa. This negative load on the cladding does not affect the rain-penetration potential in the walls but the peak short-lived pressures to be sustained by the cladding and its anchors do affect their structural design. The measurements indicate that the rain screen and its attachments may have to withstand as much as 75% of the design pressure for the whole wall assembly. The results of the wind-tunnel investigations of this wall system brought similar figures, indicating the cladding of a "well-designed and built" rain screen wall could be designed for 70% of the design load.

Figure 5. *Building A. Isometric view of a compartment*

The qualification "well designed and built" is very critical to the wind loading on the cladding as found out by monitoring Building B. Building B has a masonry cladding, unusually large compartments, little venting, and a flexible air barrier unsupported on one side (see Figure 6). What might look at a glance like a pressure-equalized rain-screen wall did not perform as such, and the negative wind-pressure loads did not get transferred to the air barrier. In positive pressure, the cavity pressure followed the outside pressure but without ever equalizing it. In this case, the cladding should be designed to sustain 100% of the design wind loads.

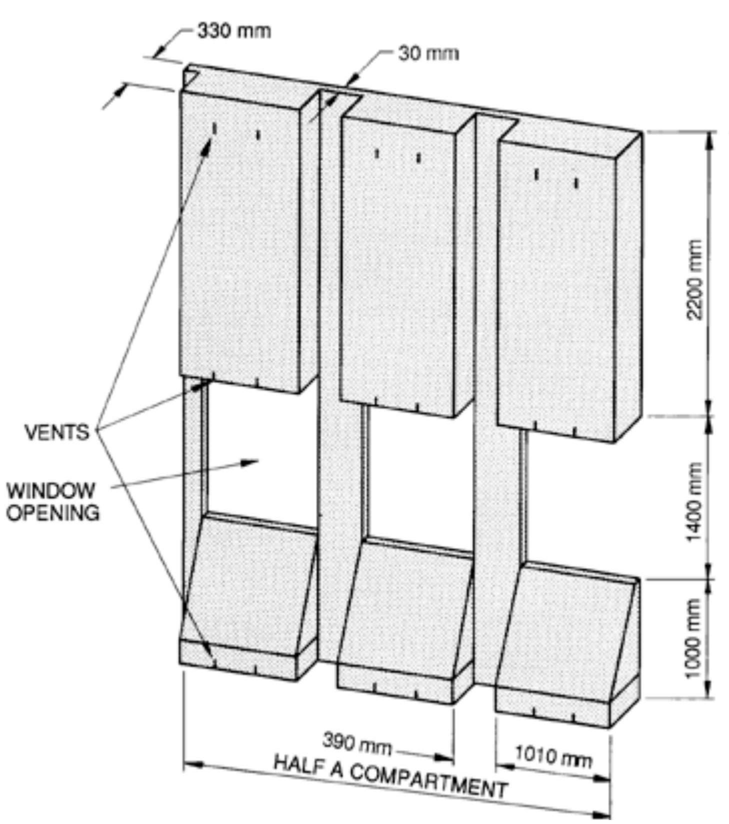

Figure 6. *Building B. Geometry of the compartment*

These are fairly serious implications for the structural design of cladding systems. At this stage wind-tunnel studies should be performed on the proposed design, if relief of wind-loading pressure on cladding is sought by applying the pressure-equalized rain-screen principle.

Need for guidelines

Many questions are still pending about the practical considerations to design a pressure-equalized rain-screen wall. The maximum sizes of compartments should be the object of further laboratory and field work since Garden came out with rough figures twenty-five years ago. The types of baffles, their attachment and tightness should be tested for their efficiency, ease of installation, and possible trade-off with other criteria of performance. Joints between large, prefabricated panels and their interface with other components, such as windows, can also apply the rain-screen principle; guidelines on their design should be developed. A laboratory testing procedure using dynamic wind loading and water sprays would allow the evaluation of a mock-up design; IRC is presently working on a project that requires the development of such a procedure. The rigidity of the air barrier in relation to that of the cladding could be investigated. The best way to provide large venting without causing direct rain entry should also be looked at.

Conclusion

The application of the pressure-equalized rain-screen principle requires more attention, detailing, and care from the designer and builder, but is likely to require less maintenance and care from the owner/manager during the service life of the building.

Compared to traditional practice, the proper application of the rain-screen principle can result in a reduction in strength required for the cladding and its anchorage system, which must go hand-to-hand with an increase in strength in the air-barrier system and its anchorage system. One may ask, why bother switching the loads from one component to the other? Only a systematic and consistent approach to air and rain flows will produce durable exterior walls that can meet harmoniously all criteria of performance set by designers for the benefits of building owners and users. This systematic approach calls for a continuous air-barrier system that not only sustains wind loads, but controls air leakage moisture flow, noise, pollutants, etc. in a durable fashion; it is practically a prerequisite for rain-penetration control.

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CBD-40. Rain Penetration and its Control

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G. K. Garden

Rain penetration of building walls occurs all too frequently despite advances in building technology. Through-wall or complete penetration may damage building contents as well as cause stains and deterioration of interior finishes; uncontrolled partial penetration, which is less frequently recognized, can permit undesirable quantities of water within the wall. Water, in excess, is a key factor in most cases of deterioration of walls or wall materials (CBD 30) and one source of this water is rain. Although a number of traditional wall systems have had a measure of success, it is only recently that scientific studies have been undertaken to explain the mechanisms of rain penetration. Through better understanding of these mechanisms it should be possible to design and construct walls from which the problem is virtually eliminated.

Mechanisms of Rain Penetration

Rain penetration results from a combination of water on a wall, openings to permit its passage and forces to drive or draw it inwards. It can be prevented by eliminating any one of these three conditions.

Water blown against a windward wall and thrown by air turbulence onto side walls produces an accumulation of water on the building exterior. Wide roof overhangs and cornices, although successful in minimizing rain wetting of low buildings, are usually incapable of keeping walls dry on tall buildings or of giving protection during rainstorms accompanied by high winds. Some designs for solar shading can be effective in minimizing wetting, but there is little likelihood that a building can be designed so that walls will never be wet.

Depending upon the absorptivity and moisture storage capacity of surface materials and upon the rate of rainfall, a substantial film of water can form and flow on a wall face. Surfaces of low absorptivity and low moisture storage capacity readily become covered with a film of water that increases in thickness or volume flow toward the lower levels of multi-storey buildings. The flow of this film is influenced by surface texture, gravity and air movements along the wall face. Normally, the net result is a lateral migration of water, with downward flow concentrated at vertical irregularities in the wall surface. Experiments have shown that the flow in narrow vertical depressions (i.e. joints) in a wall face can be many times greater than the average over the wall.

Openings that permit the passage of water are quite numerous on the face of a building in the form of pores, cracks, poorly bonded interfaces and joints between elements or materials. Very small pores and cracks can be covered with impermeable or semi-impermeable coatings or treated with surface waterproofing compounds, but these treatments are less likely to be effective for larger pores and cracks. Joints between elements or materials can be sealed with gaskets or sealants. If they are located where they can be wetted by rain, however, the seal must be perfect, and this is difficult to achieve because of fabrication or job site inaccuracies. Even more difficult is the maintenance of a perfect joint over a reasonable period of time, because of aging of the sealant, and because differential movements between the elements constantly flex and stress the joint material. Skill and new sealing materials can all be employed, but it is seldom possible to guarantee that no openings will develop to permit the passage of water.

Even when water is available and an opening exists, leakage will not occur unless a force or combination of forces is available to move the water through the opening. The forces contributing to rain penetration are kinetic energy of the rain drop, capillary suction, gravity and air pressure differences.

Under the influence of wind rain drops may approach the wall of a building with considerably velocity so that their momentum or kinetic energy carries them through large openings (Figure 1a). If an opening is small, the rain drop will be shattered upon impact, but small droplets will continue inwards. If there is no through path, however, water cannot pass deeply into the wall by this means alone. Thus, battens, splines, baffles, interlocks or labyrinths can be used to advantage at joints to control rain penetration from kinetic energy.

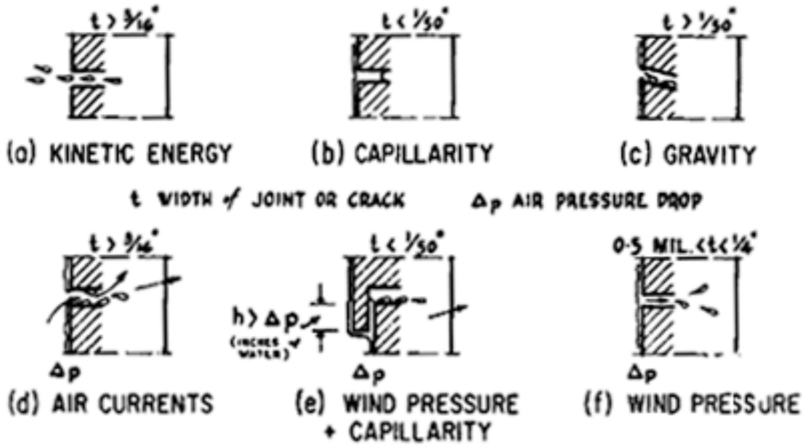

Figure 1 Forces producing rain penetration.

Capillary suction acts only to draw or hold water in a space bound by wettable surfaces. When a material approaches saturation the capillary suction approaches zero, but the water it holds will have no tendency to exude from it unless an external differential force is introduced (Figure 1b). Gravity or an air pressure difference can cause a certain amount of water to flow through or out of this saturated material at a rate limited by the size of the capillaries. Fine capillaries of less than about 0.01 millimetre (normal hard-fired clay brick or concrete) draw and hold a small volume of water with such high suction that they seldom contribute to rain penetration. A greater volume of water, however, is held by the lower suction in large capillaries such as cracks and unbonded interfaces. Large capillaries are important contributors to the problem when an additional force of even low magnitude is added. If the exterior and interior faces of a wall are connected by capillary passages, severe wetting at the interior finish may occur because of capillarity alone, but only after the moisture storage capacity of the materials of the wall has been filled. Partial water penetration of a wall by capillarity is difficult to overcome, but complete penetration can be controlled by introducing a discontinuity or air gap in the capillary, the joint, or the wall.

Gravity acting on water on the wall surface or in large capillaries will pull it through any passages that lead downwards and inwards (Figure 1c). Water running down the sides of vertical cracks or joints can also be diverted inwards by surface irregularities. Rain penetration as a result of gravity alone seldom occurs through intentional openings; this mechanism is generally well understood and control methods are well developed. Cracks or other openings that develop after construction, however, often allow water to enter. An air space or discontinuity in the joint or wall immediately behind the wetted face will prevent further flow of water inwards. Water reaching this space will cling to the surface and will flow down the outer face of the space so that it can be led out of the wall by flashings at suitable locations.

A pressure drop through a wall is produced by wind pressure on the face of a building. At a point where a high rate of inward air flow occurs as a result of an opening and an air pressure drop, water can be dragged along the walls of the opening and cause rain penetration (Figure 1d). A relatively low velocity air flow can also carry fine water droplets or snow into the wall to create the same problem. Water can be raised a considerable distance and caused to flow into a wall when an air pressure difference is added to capillary suction (Figure 1e). An even more serious situation can occur when, as a result of a large amount of water at the surface, openings up to 3/8 inch or more are bridged with water, which is readily forced through the passage by even small differences in air pressure (Figure 1f).

As with capillary suction and gravity, water entry resulting from an air pressure difference can be controlled by the introduction of an air space in the joint or wall; but the air pressure in the space must always be equal to that on the wall face. This can be accomplished by providing sufficient free area of opening to the exterior to allow the wind pressure to maintain equalization. When the air pressures both outside and inside a wetted plane are equal, there is no air pressure difference to move the water inward. It is important to note that the infiltration air barrier of the building must be located inward of this air space. The air barrier, regardless of its position, is the point at which the air pressure difference between outside and inside the building occurs and must resist wind loads. Provided the air barrier does not get wet, minor air leakage through it will not be accompanied by rain penetration.

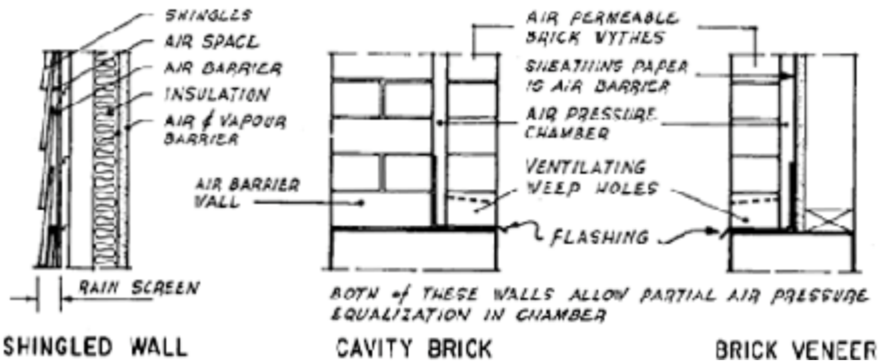

Figure 2. Traditional walls that resist rain penetration.

It is not conceivable that a building designer can prevent the exterior surface of a wall from getting wet nor that he can guarantee that no openings will develop to permit the passage of water. It has, however, been shown that through-wall penetration of rain can be prevented by incorporating an air chamber into the joint or wall where the air pressure is always equal to that on the outside. In essence the outer layer is then an "open rain screen" that prevents wetting of the actual wall or air barrier of the building. The success of the traditional walls shown in Figure 2 is explained by this principle. Partial rain penetration or the wetting of the rain screen materials can be minimized by reducing the surface porosity and absorptivity or by control of the forces necessary to produce it. It should be emphasized that the open rain screen principle of rain penetration control can be employed for any situation where rain penetration of walls and wall components can occur, especially at joints between prefabricated components (Figure 3).

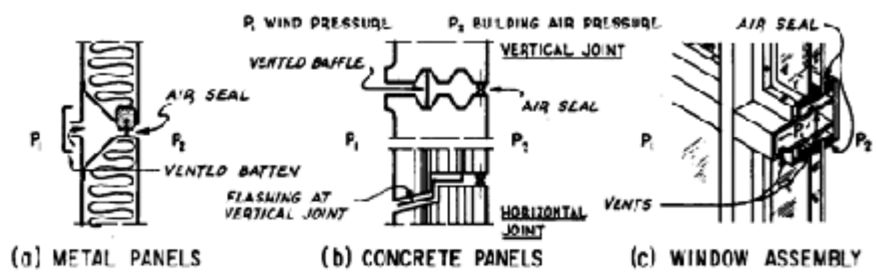

Figure 3. Joints between prefabricated components.

Special Considerations

A building designer employing this principle must assume that water may enter a joint and gain partial penetration of a wall. The water must then be led out of the joints or wall by flashings at horizontal joints of panels or at the bearing planes of multilayer walls (ventilated cavity masonry walls). Openings such as windows, doors and grilles in multilayer wall must be sealed to the air barrier portion of the wall with projections or overhangs connecting with the rain screen. The air barrier must prevent major air leakage and resist wind loads on the building.

A most important special consideration in the application of the open rain screen principle is related to the fact that air pressures on the exterior of a building vary from the positive pressure caused by stagnation of the wind down to suctions several times greater in magnitude (CBD 34). Because of this variation an air pressure drop occurs that causes air to flow from a point of high pressure through the wall and along the air chamber to come out at a point of lower pressure. As this air flow could move a large amount of water or snow into the chamber, with the risk of rain penetration, the air chamber should be interrupted at suit able intervals to minimize lateral or vertical air movement. The frequency of the chamber closures should be such that the variation of air pressure outside any compartment is at an acceptable minimum. Thus the size of the compartments could vary over the face of the building, being relatively small near the extremities of walls where the rate of wind pressure change is the greatest, and quite large over the central portion where there will usually be only slight wind pressure variation. The space must, however, be closed at all corners of the building to prevent air from going around the corner to feed the high suctions that occur on the adjacent wall face. In the absence of more specific information it is suggested that the closures occur at not more than 4-foot centres parallel to ends and tops of walls in a 20-foot wide perimeter zone, and at 10- to 20-foot centres in both directions over the central portion.

The advantages inherent in designs based on the open rain screen principle go far beyond those associated with rain penetration control. Movements and minor imperfections of the joint seal between prefabricated components become less critical, and the life of sealants is extended by shading from solar radiation. Although there may be problems regarding adequate ties and support of the rain screen when this principle is applied to the total wall covering, it should be noted that the exterior cladding is relieved of much of the normal wind load. It must be resisted by the remainder of the wall. A complete rain screen approach can result in easy handling of cladding movements and cracks after construction, and in reduced air conditioning loads, and permits rapid drying of cladding material. It also permits the better positioning of insulation and minimizes the risk of condensation within the wall. With the many advantages of the open rain screen, its full development should be pursued by all building designers.

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Elements of a Rain-Managed Wall

There are four fundamental requirements for watermanaged assemblies:

- ***Drainage plane***: some water-repellent material that's continuous over the whole building exterior and overlapped to drain downward. "Continuous" is the key word here. All it means is that you should connect your windows and doors to the drainage plane, as well as connect your deck, your roof-wall intersections, any service penetrations — everything. Every single flashing must tie into the drainage plane and dump on top of it, not behind it. There are no exceptions: One reverse lap or unflashed penetration can ruin your whole wall.
- ***Drainage space*** between the cladding and the drainage plane (the space can be very narrow, but it must be there). Water needs space to move.
- ***Flashings*** at every opening, penetration, or intersection, designed to kick water out and down.
- ***Weep holes***: openings to allow water to escape to the outside.

If you have those four elements, you have a watermanaged system. If you're missing any one, or you do any of them incorrectly, you can expect trouble.

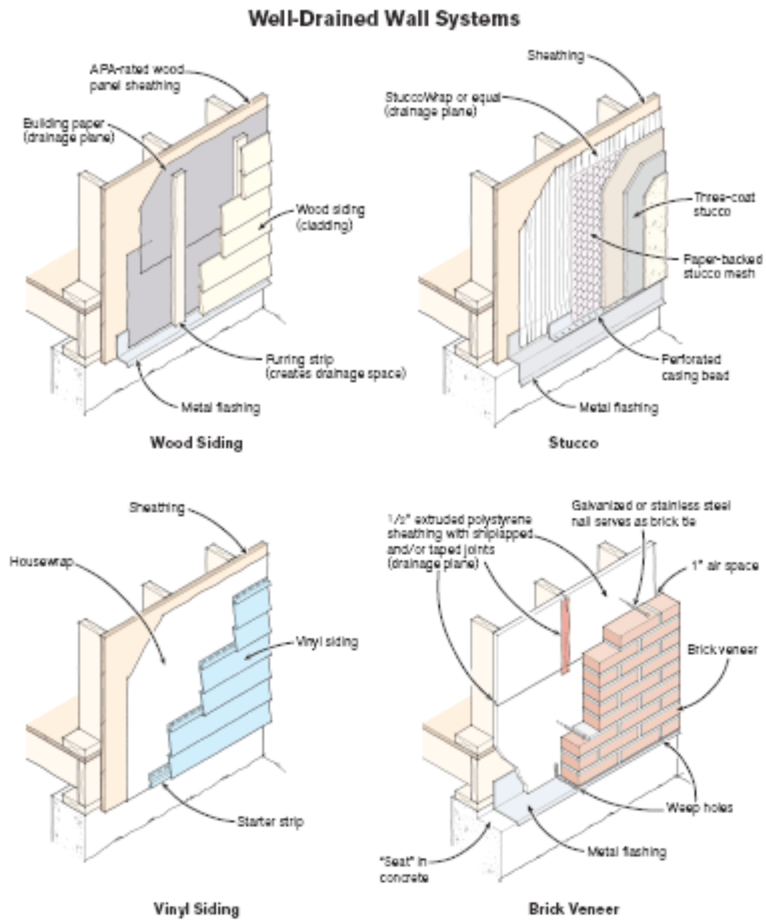

Figure 2. The key elements in rain control are a drainage plane, a drainage space under the cladding, flashings that integrate with the drainage plane, and weep holes to allow water to escape. These principles can be applied with any cladding system and with many different drainage plane and flashing materials.

Evolution of Wall Design for Controlling Rain Penetration

Construction Technology Update No. 9, Dec. 1997

by G.A. Chown, W.C. Brown and G.F. Poirier

The design of walls to control rain penetration has changed considerably over the years. This Update describes the evolution of walls from massive masonry construction through to pressure-equalized curtain-wall assemblies, focusing on developments in rainscreen walls.

The penetration of rainwater through walls depends on the following combination of conditions:

- the presence of water
- openings in the assembly that permit water to enter
- forces that can move water through the assembly.

The control of rainwater penetration depends on being able to control any one or all of these conditions.

Rain penetration creates problems ranging from damage to interior finishes and furnishings, to the growth of mold and mildew, to premature structural deterioration. Over time, rain penetration has been controlled in various ways ranging from massive masonry construction to pressureequalized rainscreen (PER) curtain-wall assemblies.

Single-Element Protection

A variety of constructions have been used that rely essentially on a single element for rain-penetration control. Where the construction material is relatively porous, the wall relies on mass to absorb and re-release the moisture. Solid masonry walls typically depend on this mechanism (see Figure 1). Where the construction material has low porosity (e.g., cast-in-place concrete or masonry walls made of dense stone), the wall may rely on the low water permeance of the material for rain-penetration control. However, this may not be sufficient as any cracks in the wall will allow direct penetration. Traditionally, many of these walls have provided acceptable performance because of the protection afforded by building details that direct water away from the walls. Such details include wide roof overhangs, cornices, and drips on window sills.

Moisture transfer forces

- kinetic energy of raindrops
- surface tension
- capillarity
- gravity
- air-pressure difference

With increased understanding of structural design, and the eventual transition from load-bearing walls to curtain walls, thinner assemblies became possible, making more efficient use of structural material and space. The loss of mass and thickness, however, often led to rain penetration.

Figure 1. Massive masonry construction

Relatively thin, single-wythe walls continue to be used in buildings in milder service environments, or in commercial or industrial buildings that need provide only limited environmental separation. In such situations, buildings can be designed to tolerate some moisture penetration from rainwater without adversely affecting the building fabric, the health or safety of the occupants, the intended use of the space, or the operation of building services.

Face-Sealed Walls

Face-sealed walls rely on single-element protection and require the exterior surface of the wall to be essentially impermeable to water and air. Because these walls are insulated on the interior of the sealed surface, the surface is exposed to extreme changes in temperature and solar radiation, both of which impose large stresses on the joints between cladding components, and on the junctions between the cladding and other components. The durability of sealants under these conditions is significantly less than in more protected environments, and is also considerably less than that of other components in the cladding assembly. Without timely maintenance and replacement of the sealant, the walls lose their water and air tightness, which can affect the performance of all their intended functions. Because of its relatively low initial cost, the face-sealed approach continues to be used. To sustain performance, however, significant resources must be allocated for on-going maintenance.[1]

Multiple-Element Protection

The preferred approach for rain-penetration control is to design multiple-element protection into a wall. Many assemblies incorporate more than one element to control rain penetration. Historically, such elements include an air space or drainage plane and a water-resistant layer as well as joint and junction details that also incorporate multiple elements of protection. Such features have been observed in both masonry and wood-frame constructions.

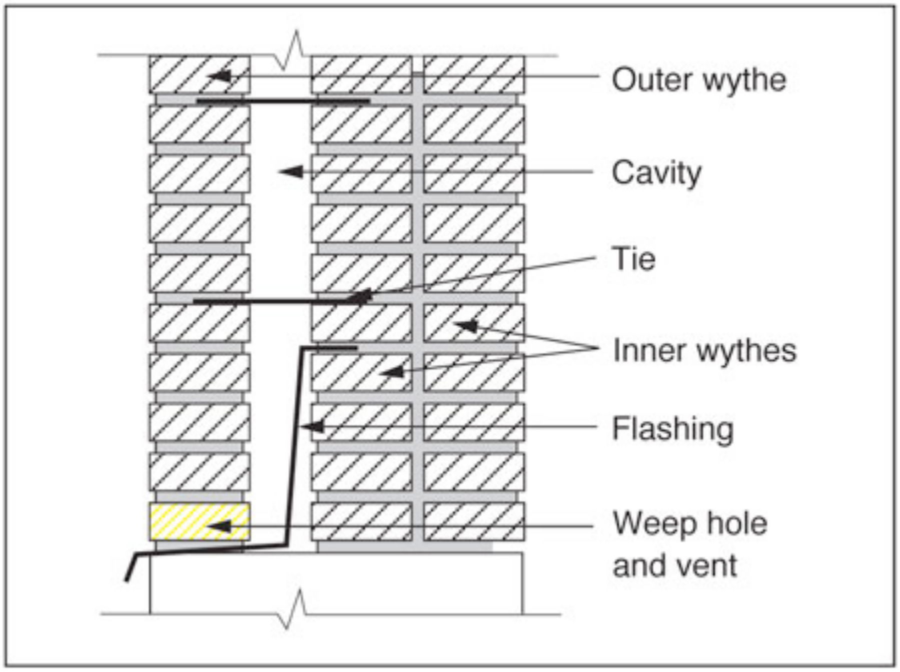

Figure 2. Drained and vented cavity wall

Cavity Walls

The masonry cavity wall evolved in response to a need to control rain penetration through masonry walls that had become thinner. It is defined as "a construction of masonry units laid with a cavity between the wythes. The wythes are tied together with metal ties or bonding units and are relied upon to act together in resisting lateral loads."[2] Both the inner and outer wythes, and the bonding units or ties, have structural functions beyond self-support under gravity. The cavity prevents water from reaching the inner wythe by means of capillary action; it also allows water to dissipate through the capillary action of the outer wythe during dry spells.

The drainage of cavity walls was advocated in the early 1900s, although it was not common practice at the time.[3] Today, however, it is a well-known fact that when drainage holes and flashing are provided at the bottom of the cavity (as required by the National Building Code since 1953), any water that penetrates the outer wythe is able to drain back to the outside (see Figure 2).[4],[5],[6] The drain holes may in some cases also act as vents, allowing vapour in the cavity to dissipate. Although the drained cavity wall can provide considerable protection against water ingress caused by capillarity, surface tension and gravity, this type of assembly cannot address water transfer due to air-pressure difference without the addition of other elements to the wall.

The current edition of the National Building Code (NBC) requires cavity walls to have a minimum cavity width of 50 mm.[5] This relatively wide cavity helps prevent mortar dropped in the cavity from forming bridges between the outer and inner wythes.

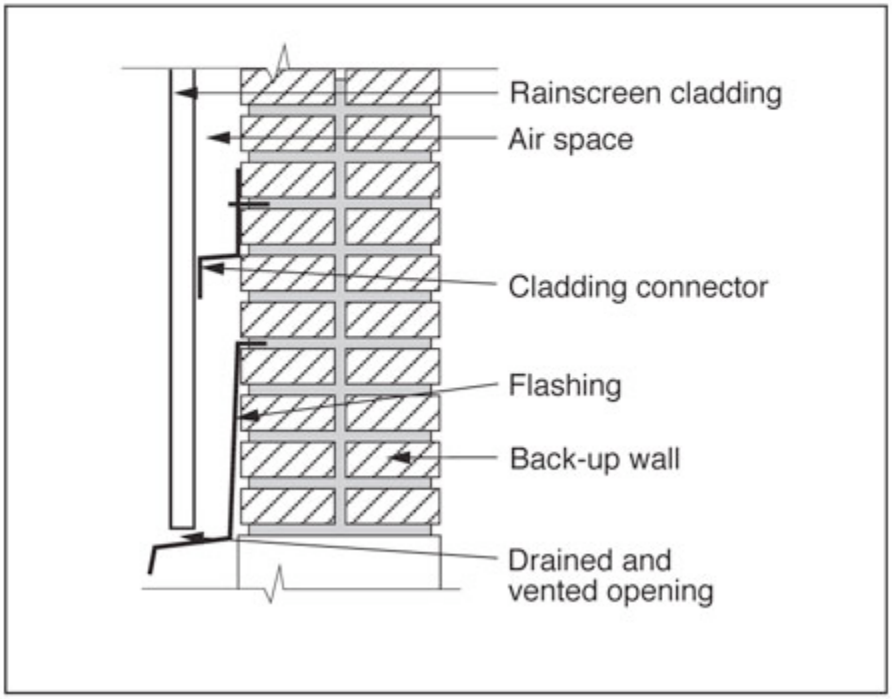

Figure 3. Rainscreen concept applied to solid loadbearing brick wall

Early Wood Constructions
At least as early as 1604 in Canada, walls of buildings that required enhanced protection against rainwater ingress incorporated multiple control elements.[7] By the 1920s, standard wood-frame residential wall assemblies typically consisted of cladding layered over building paper which was, in turn, layered over exterior sheathing. In many cases, an air space between the cladding and the building paper was incorporated into the wall system.

The Rainscreen Principle

The Original Concept
The rainscreen principle, introduced in 1946, was the next refinement of rain-penetration-control strategies for walls.[8] Wall assemblies built according to this principle consisted of a cladding, made of a lightweight, low water-permeance and low water-capacity material, installed on the exterior of a solid load-bearing brick wall, with a drained and vented air space between the cladding and the load-bearing wall. The idea was to reduce the moisture load on the back-up wall and, by providing this space, to permit the removal of moisture transferred from both the exterior and the interior (see Figure 3). When properly detailed, this type of wall prevented water ingress due to

raindrop kinetic energy, gravity, capillarity and surface tension. It performed like a drained and vented cavity wall; however, like the cavity wall, it did not explicitly address the issue of air-pressure difference as a driving force for rain penetration.

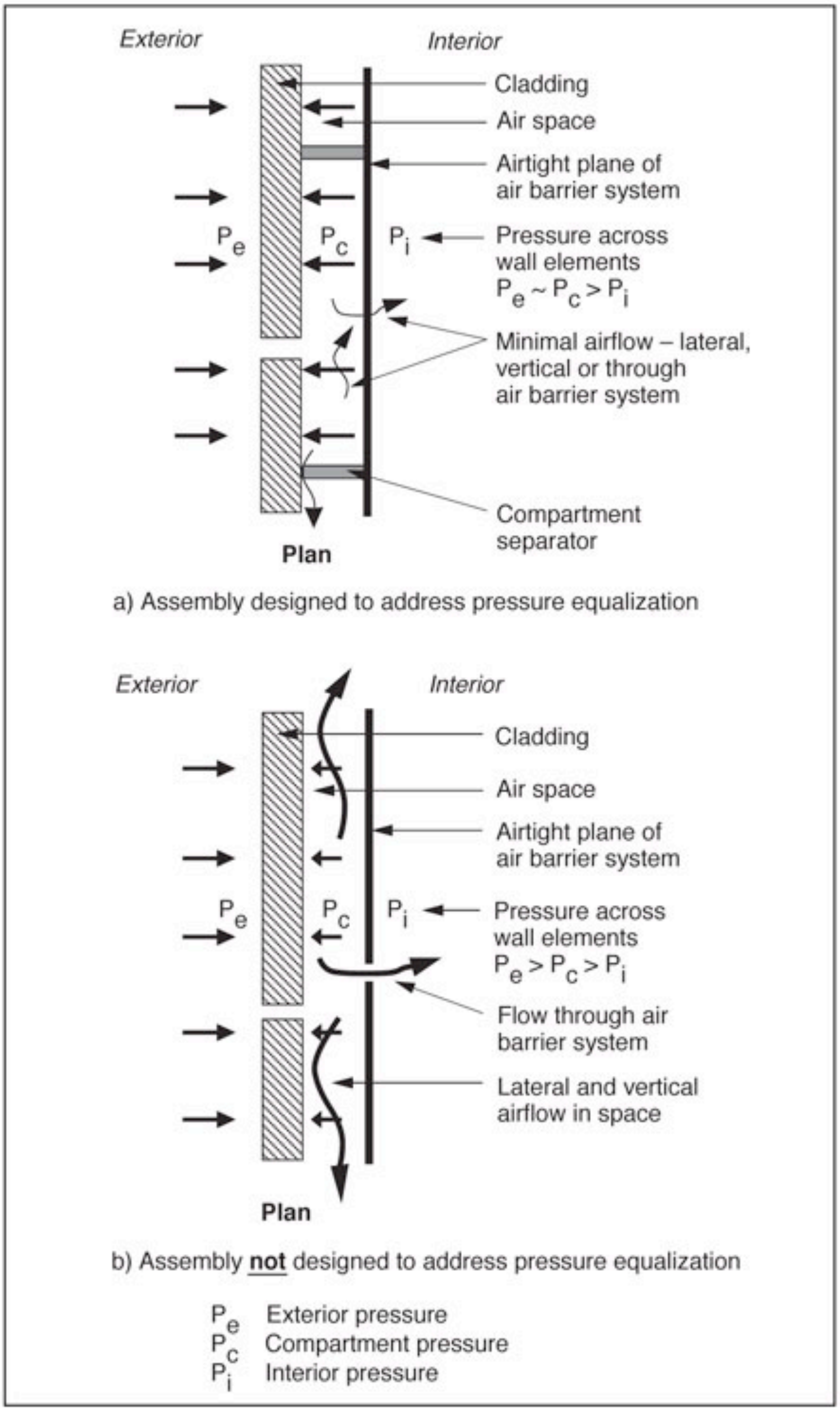

Figure 4. Air flows through and within rainscreen wall assemblies

How much ingress control is needed?

Different wall assemblies can accommodate different amounts of water penetration before damage occurs. The permissible quantity of water depends on the materials used and on the ability of the assembly to dry out. The latter, in turn, is dependent on the configuration of the assembly and on the climate.

Open Rainscreen Walls

The rainscreen concept evolved in the 1960s through the work of the National Research Council's (NRC) Division of Building Research. This further evolution, known as the "open rainscreen wall," addressed all of the forces that can lead to rainwater ingress, including the control of airflow through and within the wall, in order to minimize air-pressure differences across the cladding (see Figure 4).[9] The research demonstrated that by

- adding holes
- controlling the size and distribution of vent holes
- providing an air space
- dividing the air space into compartments, and
- incorporating an air barrier system in the back-up wall

the pressure across the rainscreen assembly can be reduced, thus significantly reducing one of the forces responsible for driving the rain through the wall (see Figure 5). This consideration of pressure equalization across the wall assembly differentiated the open rainscreen wall from its predecessors.

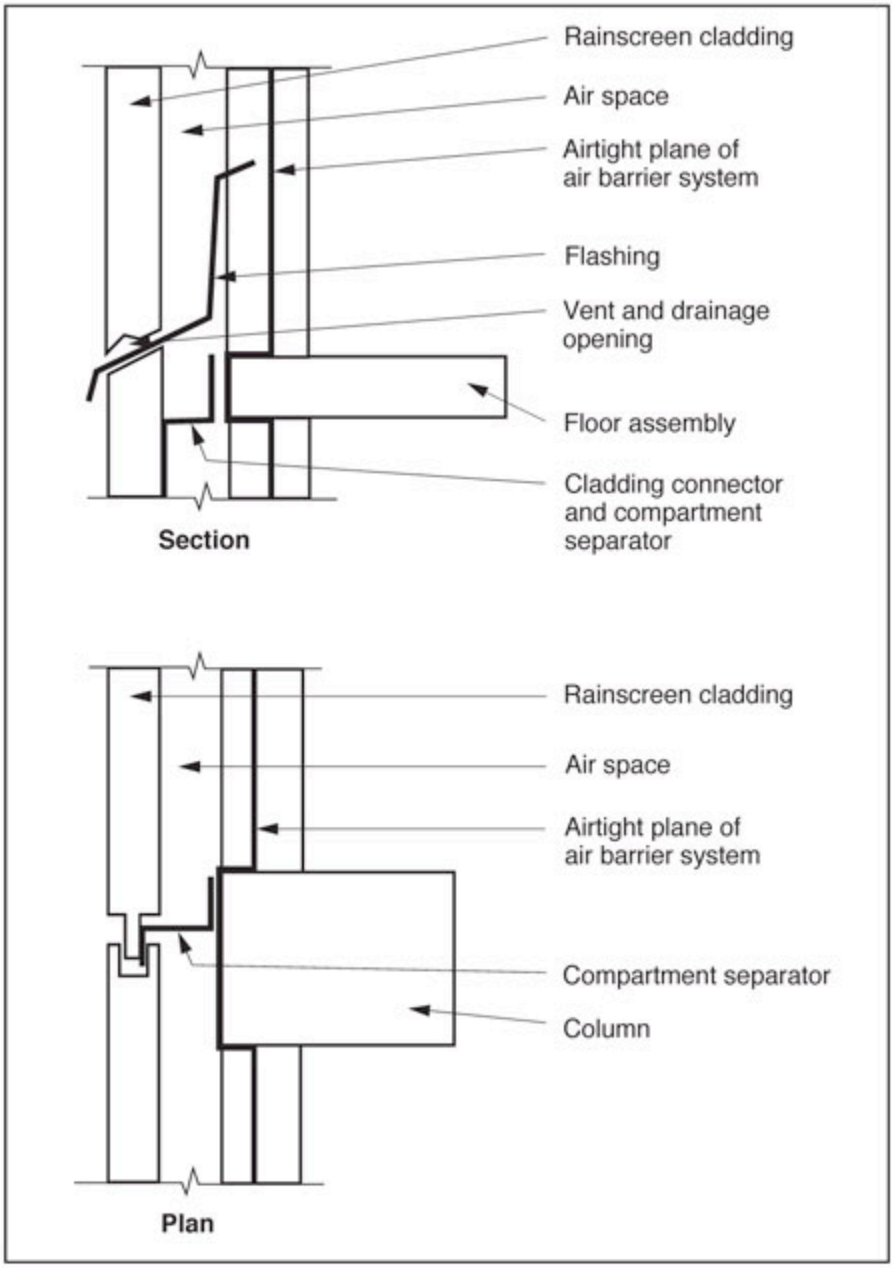

Figure 5. Open rainscreen wall

Current Applications of the Rainscreen Principle

Conventional or Basic Rainscreen Walls

The application of the rainscreen principle that first saw widespread use in the 1970s consists of:

- a cladding (rainscreen)
- a second line of defence, and
- an air barrier system in the back-up wall.

These are considered to be the essential elements of a viable rainscreen wall assembly.

Cladding. The cladding, which is the first line of defence, provides a rain-shedding screen. The rainscreen material is not necessarily lightweight and may or may not have low water permeance or low water capacity. In fact, rainscreen walls with brick veneer cladding are very common. One of the important features of the cladding is that the rainscreen material is assembled so that it minimizes rainwater passage both through and around the cladding.

Joints in the cladding must be detailed to control raindrop kinetic energy, surface tension and gravity. Openings in the rainscreen have an impact on reducing the airpressure difference across the cladding, but pressure equalization has to be addressed in conjunction with the other elements of the wall, particularly the air barrier system. The elements that connect the cladding to the back-up wall should be designed to control moisture transfer by surface tension, capillarity and gravity. Components such as windows and doors that penetrate through the rainscreen, and the junctions between these components and the rainscreen, should also be designed in accordance with the rainscreen principle in order to control moisture transport forces. The incorporation of air spaces that drain to the exterior is one example of this comprehensive approach.

Second line of defence. This comprises a flashed, drained and vented air space, and a material installed on the exterior of the back-up wall to protect moisture- susceptible components (or, in other words, a water-resistant membrane). The role of the second line of defence is to ensure that any water penetration through the cladding will not affect the rest of the wall assembly. For houses and small buildings, the NBC requires a wall assembly to have two layers of sheathing membrane if not supported by sheathing, one layer if supported by sheathing or, alternatively, sheathing that is either not moisture susceptible or that incorporates a sheathing membrane.[5] As with the cladding, the second line of defence should be applied to all components of the wall assembly in order to provide the necessary continuity.

The minimum allowable width of the air space depends on the cladding material and on the material used to create the air space. For brick veneer walls, the minimum width is 25 mm. (It is important to ensure the cavity is kept reasonably clear of mortar.) Where wood furring is used, there must be sufficient material thickness for structural attachment of the cladding: the NBC calls for 19 mm for wood furring installed in houses and small buildings.[5] In any case, the width should not be less than 10 mm to allow for variations in construction.

Adequate performance is provided in many low-rise residential assemblies clad with materials such as stucco, or vinyl, metal or wood siding, even though the air space is less than the generally accepted minimum width and may be discontinuous between flashing levels. These assemblies reflect a long tradition of wood-frame construction with multiple protective elements. The first level of protection is provided by the cladding system which, when properly designed, greatly limits the moisture load on the second line of defence. In addition, roof overhangs may be used to limit the quantity of rainwater on the cladding. Because these assemblies have reduced drainage capacity, the sheathing membrane, or other material installed to protect moisture-susceptible materials in the back-up wall, may need to be upgraded to provide greater water resistance and thus ensure an effective second line of defence.

Air barrier system. For most types of buildings, the NBC requires a back-up wall to have an air barrier system, i.e., a continuous barrier for the purpose of controlling airflow through the wall.[5],[10]

This also reduces the static air-pressure difference across the cladding. The air barrier system allows the rainscreen cladding and the second line of defence to perform effectively.

When is a rainscreen wall no longer a rainscreen wall?

The original rainscreen wall consisted of a lightweight protective cladding installed on the outside of a drained and vented air space on the exterior of a structural wall. In many of today's wall assemblies, the cladding may not be lightweight, and the drained and vented air space may not exist, but a second line of defence against rain ingress is provided. Such walls are considered to be rainscreen walls.

Modifications to the Basic Rainscreen Wall

As wall designs, construction methods, and building materials have developed, the application of the basic rainscreen wall concept (as described above) has been modified to respond to different service environments, durability requirements and (construction) cost constraints. Whenever a modification is made, the overall performance of the assembly must be assessed to ensure that the individual components and the assembly as a whole are capable of handling the water to which they will be exposed in their service environments over their design service lives.

Recently, the construction industry has been experimenting with assemblies that incorporate a self-draining material in the air space, providing an alternative to the combination of a simple air space and a protective membrane as the second line of defence. These materials include semirigid glass fibre panels with oriented fibres and self-furring materials such as profiled plastic sheet. Assemblies that have incorporated these materials are sometimes referred to as "drainscreen" walls. Many recent building envelope failures have occurred because they were designed with very limited or no drainage capacity behind the cladding. In these cases, an inadequate assessment of the water resistance required in the second line of defence has led to the premature deterioration of the wall as a consequence of the moisture load imposed on it. A wall design that works well in one climate may not perform adequately in another because of differences in the intensity and frequency of rainfall, average relative humidity and temperature, and wetting and drying cycles.

Pressure-equalized rainscreen walls are the most sophisticated version of the rainscreen wall.[11] In these assemblies, the openings in the rainscreen are specifically designed to allow both static and dynamic pressure equalization to take place across the rainscreen. The number and geometry of the vent holes are determined on the basis of allowing sufficient air to flow in and out of the air space quickly enough to respond to wind gusts so that the pressure difference across the cladding and within the compartments of the air space can be minimized, thus reducing the rain-driving force. The effective area of the vent holes depends on the airtightness of the air barrier system, on the stiffness of the rainscreen and of the air barrier system, and on the volume of the individual compartments that make up the air space. The air space behind the cladding is divided into separate drained and vented compartments to control vertical and lateral airflow within it. Since air pressure induced by wind varies over the height and width of the building, the size of the compartments, which are designed to minimize the difference in air pressure within each compartment, varies over the face of the wall. Compartments must be closed at all corners of the building to prevent the wind from affecting the wind pressures on adjacent building faces.

Guidelines for the Design of Rainscreen Walls

Both conventional and modified rainscreen walls have become the norm for low-rise residential construction. Consequently, numerous publications provide information on their design and construction.[12,13,14] However, design guidelines currently available for PER walls are very limited and do not sufficiently deal with the issue of controlling rain penetration under wind-driven conditions.[15,16]

Summary

Over time, the rainscreen principle for wall design has evolved and a number of variations have been developed. The performance of these assemblies depends on:

- the materials and construction details used
- the moisture loading on the wall
- the drying forces in the service environment.

Virtually any assembly can provide acceptable performance under certain conditions; however, where an assembly varies from the conventional rainscreen, a careful assessment must be made to ensure that it can handle the moisture to which it will be exposed.

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