Canadian Building Digest CBD-40. Rain Penetration and its Control

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This is a classic seminal paper on rain penetration control in general but really focuses on "open rainscreen" approaches. Although it is now almost 60 years old, its compact presentation and clarity is still hard to beat. However, there are a few details that need comment to reflect some things we have learned and changes in how we build. Hence, I have added comments in italics throughout.

---- John Straube

[*JS: Summary. While much of the article remains correct and relevant, the most jarring omission in the document is any mentioned of what today is as the fundamental concept of drained rain penetration control strategies: that is a "second-line of defense" or drainage plane/ water resistant barrier integrated with flashing and weep holes. This is a serious limitation of the article. Today North Americans would always require a clearly defined water resistant layer behind the cladding and a drainage gap (not always a defined airspace) as fundamental to rain penetration control using the rainscreen principle. Remarkably, the importance of a WRB*[1] *was not singled out in the literature until the 1990s (although building paper and tar coatings had long been used in many buildings), and not integrated into North American building codes until the mid-2000's. Some European sales and scientific literature into the 2020's is still presented with this 60 year old back drop – they assume that an air gap behind the cladding is sufficient to stop rain penetration and the role of a water-resistant layer on the outer face of the wall support structure is assumed, implied, or mostly just ignored.*]

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.

[1] Water (not weather) Resistant Barrier, or WRB, is a term in common use that is descriptive and accurate. It appears only in the US I-codes. In Canada it is called a "sheathing membrane" in the NBCC. In other countries the term underlayment or sarking is also used.

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 considerable 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.

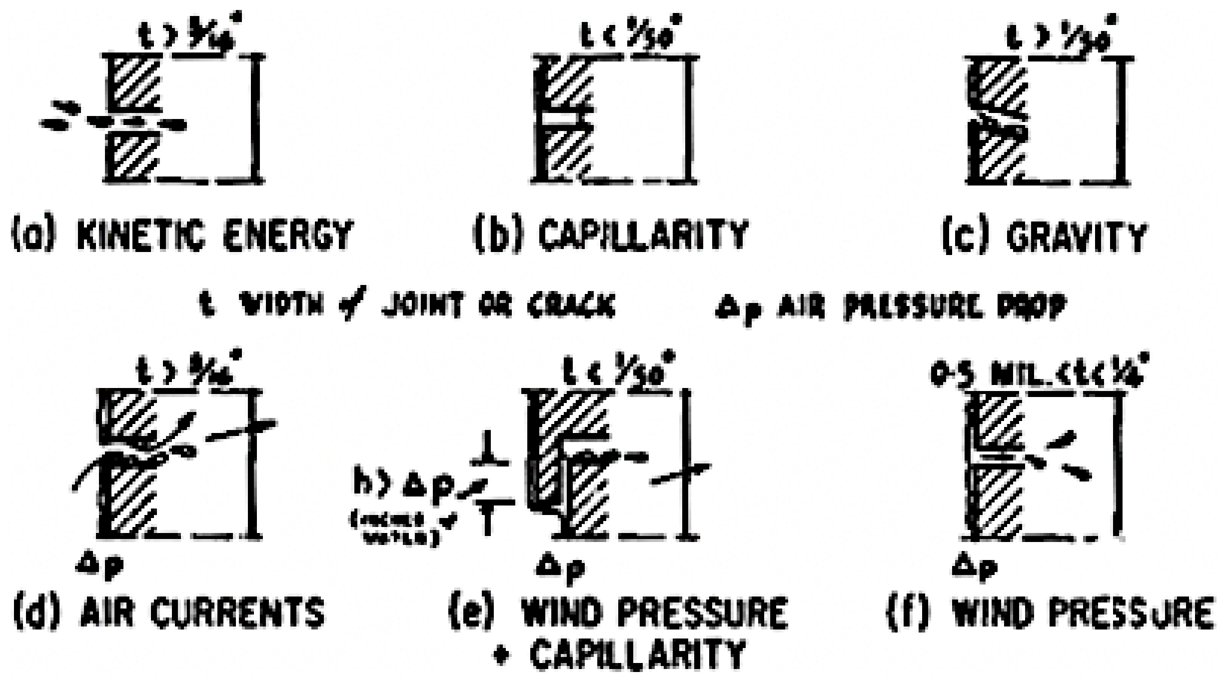

Figure 1 Forces producing rain penetration.

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. [*JS: In practise, gravity is the primary practical force driving water penetration. Field experience began to be documented in about the 1990s that gravity-drive leakage explains the overwhelming majority or field problems. Of course, water on the surface of the wall is critical, and this requires wind to drive rainfall onto* *the surface*]. 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. [*JS: water also can reach the inner layers of a wall because of water clinging to penetrations, such as windows, doors, ducts, pipes, balconies, cladding attachments, etc. We now know that water can cling to the inside surface of the space, and hence a secondary water resistant layer is critical to performance].*

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) [*JS: this can be an important mechanism, but modern buildings have or should have good air barriers which limit the rate of airflow to much lower levels than 1963, and hence this mechanism is only important if significant defects in an air barrier occur]*. 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) [*JS: but this is only valid for gaps of 1-2 mm width, as capillary suction in smaller gaps is strong enough that wind pressures can only rarely overcome them*]. 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. [*JS: subsequent research in the 1980s and 1990s showed that equalization was rarely achieved in the field, but pressure differences could be* moderated*, sometimes significantly. The average pressure difference (say over 1 minute or so) is mostly equalized but peak gusts (of say a few seconds duration) are not.*]. 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. [*JS: many modern wall assemblies violate this recommendation, as the water resistant barrier / second line of defense is commonly also the air barrier]*

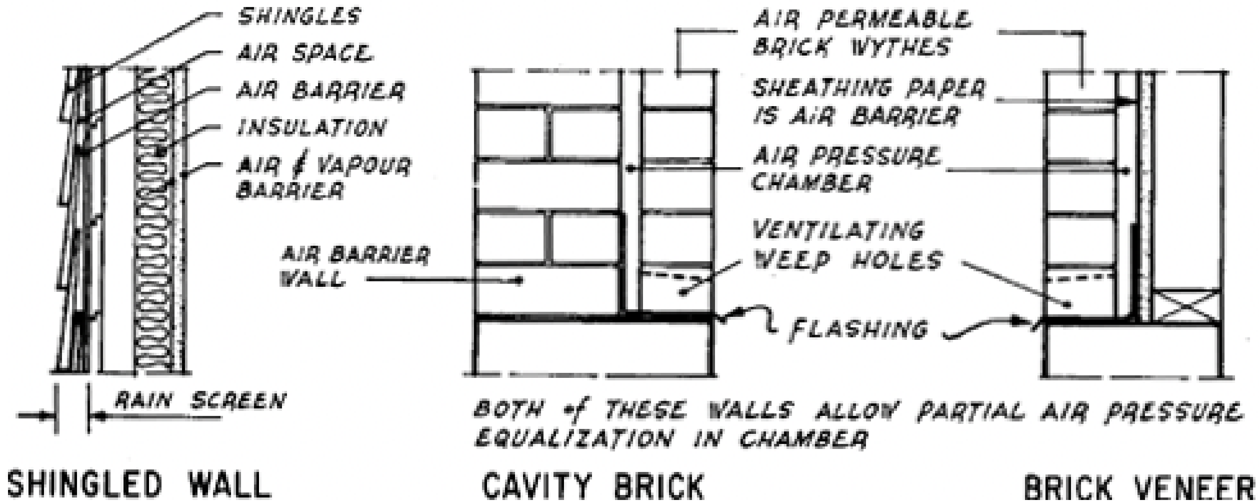

Figure 2. Traditional walls that resist rain penetration.

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. *[JS: Here CBD 40 really shows its age. The air barrier in the figure is labelled as the building paper in the shingled wall, the masonry in the cavity and the sheathing paper in the brick veneer wall. None of these would be considered sufficiently airtight to provide an air barrier today. Just as striking, there is no water resistant barrier /drainage plane labelled anywhere!]* 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).

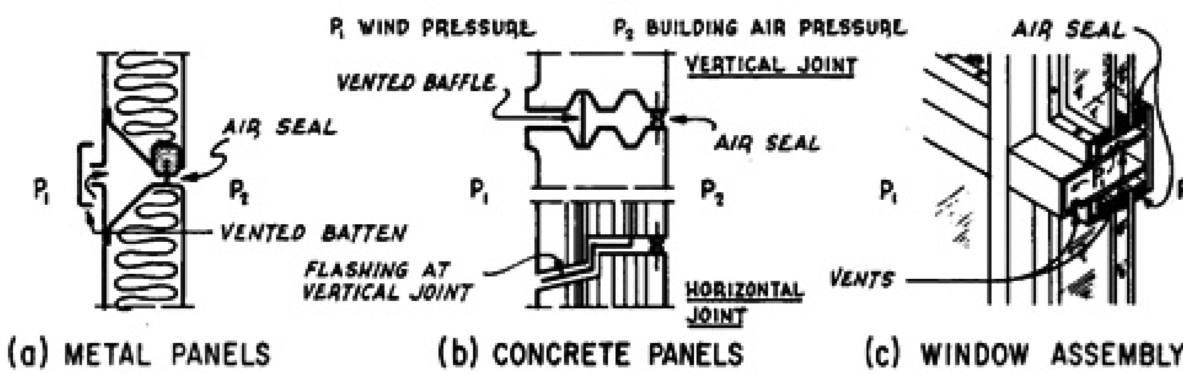

Figure 3. Joints between prefabricated components.

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) [JS: *this "most important" consideration is widely ignored in practise today. Technically this has been shown to be true by field measurements, and in fact is the primary factor limiting pressure equalization. Perhaps because the shift to a focus on drainage, not pressure equalization, has been so successful in practise the spatial pressure variations discussed have largely been ignored]*. 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. *[JS: spatial pressure variations over the face of the building have subsequently been shown as a primary reason why field pressure equalization does not occur, even with the compartmentalization 10-20 ft spacing. Joints (including window frames) are usually inherently compartmentalized (by friction and blocakge) and hence achieve higher levels of moderation in practise*].

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.