The Rain Screen Principle

Introduction

The term "Rain Screen" is bantered about frequently and often misused. This paper is not intending to provide new research, to redefine what a rain screen is, or redefine what is meant by the rain screen principle. This paper is drawing the simple conclusion that a "rain screen assembly" should comply with the "rain screen principle" and that a "rain screen" is the exterior cladding of a rain screen assembly. A review of the literature since the rain screen principle was first clearly articulated suggests that many assemblies not complying with the rain screen principle are now being classified as rain screens. The result is that the primary barrier against rain water penetration shifts from the outer cladding to the inner air and water barrier. When the primary barrier shifts to the inner barrier then the attached glossary offers alternate terminology for these systems.

In this article we review the early literature, mechanisms of rain penetration, literature based on the rain screen principle as well as literature shifting away from the rain screen principle, and a review of the key elements of assemblies complying with the rain screen principle. We have also included a glossary of terms associated with the rain screen principle, and references.

The Technical Design for Building Performance Advisory Group is contemplating developing Best Practices which focus on building envelope performance, commissioning and other topics consistent with the goals of TDBP. The arguments within this paper could become the basis of one of these Best Practices. With that in mind we are seeking feedback and volunteers who would like to be a Peer Reviewer of this article.

Early History

The literature references a 1946 paper, Johansson, C.H. The influence of moisture of the heat conductance for bricks as being the first reference to a rain screen; the following is an excerpt:

> *"…it is clearly unwise to allow walls, whether of brick or porous cement, to be exposed to heavy rain. They absorb water like a blotting paper, and it would therefore be a great step forward if an outer, water-repelling screen could be fitted to brick walls, with satisfactory characteristics from the point of view of appearance, mechanical strength and cost. This screen could be applied so that water vapour coming from within is automatically removed by ventilation of the space between wall and screen."*

However, the foundational and prime reference paper setting out the rain screen principle is the 1963 G.K. Garden, Canadian Building Digest (40), Rain Penetration and its Control.**(NRC 40)** Garden utilizes the term "open rain screen":

> *"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."*

> *"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 positive pressure caused by stagnation of the wind down to suctions several times greater in magnitude. …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 suitable intervals to minimize lateral or vertical air movement."

The paper presented by Dr. John Straube, Pressure Moderation and Rain Penetration Control, **(S PM)** presented at the 2001 Ontario Building Envelope Council (OBEC) Pressure-Equalized Rainscreen (PER) Seminar includes a nice summary of the historical development of the pressure-equalized rainscreen wall concepts.

Mechanisms of Rain Penetration

G.K. Garden's paper **(NRC 40)** also provides a clear and often repeated synopsis of the mechanisms of rain penetration. In order for there to be rain penetration the following three conditions must exist:

1. Water on the wall,
2. Openings to permit its passage, and
3. Forces to drive or draw the water through the wall.

Garden's paper and many following papers review the forces involved which can be summarized as follows, the following is taken from AAMA Rain Penetration Control Applying Current Knowledge **(AAMA CK)**:

1. Kinetic - (wind)
2. Gravity
3. Surface tension
4. Capillary action
5. Pressure differences

Garden's paper does not mention surface tension but includes diagrams titled "air currents" and "wind pressure + capillarity". Air currents are a kinetic force related to wind and wind pressure + capillarity is clearly the sum of two forces.

The Rain Screen Principle - History Part 2- NRC 9, 17, 34

Designing Exterior Walls According to the Rainscreen Principle **(NRC 34)** summarizes the rainscreen principle as an approach; "*founded on the premise that multiple-element protection is necessary in most situations to achieve effective control, by means of*

1) a first line of defense that minimizes rainwater passage into the wall by minimizing the number and size of holes and managing the driving forces acting on the wall;

2) a second line of defense that intercepts all water that gets past the first line of defense and effectively dissipates it to the exterior.

Pressure Equalization in Rainscreen Wall Systems **(NRC 17)** states:

"The pressure-equalized rainscreen (PER) wall design is one of these multi-defense approaches. It is based on the open rainscreen principle, which aims to control all forces that can drive water into the wall assembly, i.e., air pressure difference, gravity, surface tension, capillary action, and rain drop momentum."

Garden **(NRC 40)** clearly states that pressure-equalization is fundamental to the rainscreen principle. NRC 34 does not make the distinction between a rainscreen and a pressure-equalized rainscreen. The cladding is the first line of defense bearing "the full brunt of the weather" and the function of this cladding is to manage the driving forces acting on the wall. NRC 17 utilizes the term "pressure-equalized rainscreen (PER) but does not suggest that there are other types of rainscreens; Rousseau, one of the authors of this paper, states in another paper **(NRC R)** that the phrase "pressure-equalized" is redundant.

Evolution of Wall Design for Controlling Rain Penetration **(NRC 9)** provides a summary of various rain penetration control strategies including mass, face-sealed, cavity walls, and rainscreen walls.

This paper suggests that the rain screen concepts evolved and that under the term rainscreen there are those where pressure equalization is not required as well as those where pressure equalization is utilized. A synopsis of the evolution of the concept and terms summarized as follows:

> ***The Original Concept -*** *This references the 1946 Johansson, C.H. paper.*
>
> ***Open Rainscreen Walls -*** *This references the 1963 Garden paper which includes pressure equalization and compartmentalization.*
>
> ***Conventional or Basic Rainscreen Walls -*** *(1997) The commentary seems to imply compartmentalization is not required and pressure equalization is not a necessary requirement.*
>
> ***Pressure-equalized rainscreen walls -*** *(1997) with the adjective added this equivalent to the 1963 Garden Open Rainscreen Wall.*

Other Sources

AAMA's Rain Penetration Contol: Applying Current Knowledge **(AAMA CK)** follows NRC 9 and defines an Open or Simple Rainscreen similarly to NRC 9's Conventional or Basic Rainscreen and defines a Pressure Equalized Rainscreen (PER) wall as one designed to control the pressure difference across the rainscreen. However, AAMA's The Rain Screen Principle and Pressure-Equalized Wall Design **(AAMA PEW)** states that the terms "rain screen principle" and "pressure-equalized design" are interdependent, but not strictly synonymous.

> *The "rain screen" is only the outer skin or surface of a wall or wall element - the part exposed to the weather. The "rain screen principle" is a principle of design which prescribes how penetration of this screen by rain water may be prevented. Thus the use of the rain screen principle is essential to achieving a pressure-equalized design, and conversely, a pressure-equalized design depends on this principle.*

So I would argue that AAMA CK and AAMA PEW are not consistent. AAMA PEW is consistent with Garden and Rousseau, whereas AAMA CK is consistent with NRC 9. However, AAMA CK is not totally clear; the paper states that in choosing to apply the rainscreen principle partial pressure equalization is achieved by compartmentalizing at corners and where practical in the façade.

In 2005 AAMA developed a Voluntary Test Method and Specification for Pressure Equalized Rain Screen Wall Cladding Systems, this test method and specification was updated in 2007 **(AAMA 508)**. A test sample must pass four primary performance characteristics to be compliant:

- Air Leakage of the air and water barrier which below is inner or secondary line of defense.
- Structural performance of the assembly by uniform static air pressure difference.
- Water penetration under both static and dynamic pressures.
- Pressure equalization behavior. Pressure equalization is defined when the lag time between the cavity and cyclic wind pressure does not exceed 0.08 sec^2 and when the maximum differential between the cavity and cyclic wind pressure does not exceed 50% of the maximum test pressure.

In 2009 AAMA published AAMA 509-09, Voluntary Test and Classification Method for Drained and Back Ventilated Rain Screen Wall Cladding Systems (**AAMA 509)**. For this test there are no criteria associated with pressure equalization. The introduction notes that the primary weather seal is the inner air and water barrier and that rain water which passes through the cladding shall be drained back out and the cavity is allowed to dry via venting.

Building Science for Building Enclosures **(SB BS)** states that the "term rain screen has been rather loosely applied" and does reference pressure-equalized rainscreens as very special cases of drain systems which moderate wind pressure. This book shies away from taking a position what constitutes a rain screen and chooses to adopt a category system of rainwater control strategies where the PER would follow a classification; Imperfect Barrier: Drained or Screened Types: Cavity: Pressure moderated: ventilated and pressure moderated.

Rainscreen Cladding **(AG)**, Anderson and Gill, is generally consistent with NRC 9:

> *First there is the drained and back-ventilated rainscreen which involves draining off most of the rainwater at the outermost surface of the wall and providing for cavity drainage and evaporation of the remainder. Second there is the pressure-equalized rainscreen.*

Water Penetration Resistance - Design and Detailing, **(BIA 7)** states that there are two primary wall types when addressing water penetration, drainage wall systems which are cavity walls and barrier walls which are mass walls. There are those who would argue that the drainage wall type would be a conventional or basic rainscreen, however, the BIA is not making such a claim. Brick Masonry Rain Screen Walls **(BIA 27)** is consistent with Garden with pressure equalization fundamental to the rain screen principle. Brick Masonry Cavity Walls **(BIA 21)** does reference cavity walls designed as pressure-equalized rain screens by referencing BIA 27.

The Rain Screen Principle and the Foundation leading to the Glossary

Facts and Fictions of Rain-Screen Walls by M.Z. Rousseau make a clear case that "A rain-screen wall" is designed and built according to what Kirby Garden referred to as the "open rain-screen principle," whose basic premise is the control of ALL forces that can carry rain to the inside." He does not distinguish between a Conventional or Basic Rainscreen Wall and a Pressure-equalized rainscreen wall. This paper pre-dates the referenced NRC papers #9, #17 and #34. Rousseau was one of the authors of #17 and #34 but not of #9. The clear implication is that a Conventional or Basic Rainscreen Wall **(NRC 9)** does not address ALL forces that can carry rain to the inside whereas a Pressure-equalized rainscreen wall can.

Currently one can easily find claims by design professionals, some system manufacturers and others of "rain screen" systems with open joints or other conditions where the "rain screen" is not necessarily even preventing rain water penetration from the simpler forces to address such as gravity, surface tension and capillary action. None of the historic literature would support calling such a cladding system a rain screen.

The AIA Technical Design for Building Performance Advisory Group is taking the position consistent with the Rousseau and Garden where the cladding, the "open rain screen", of the Pressure-Moderated Rainscreen Assembly is intended to be the primary barrier preventing rain water penetration and the inner wall is the secondary line of defense. The term Rainscreen Assembly is synonymous with Pressure-Moderated Rainscreen Assembly. The glossary offers other terms for drained and for cavity walls which are not pressure-moderated.

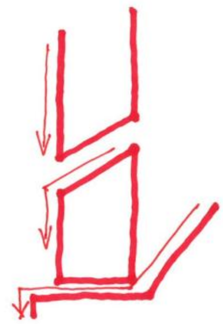
Components of Walls Designed According to the Rain Screen Principle

The component parts of a Pressure-Moderated Rainscreen Assembly include the first line of defense which is the "rain screen", the second line of defense which dissipates any water that gets past the first line of defense, and the compartmentalized cavity between the first line of defense and the second line of defense.

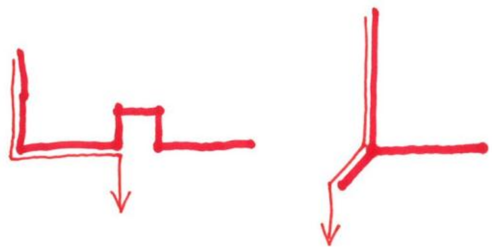
- **Rain Screen**

  The "*rain screen"* is the cladding which provides the first line of defense against rain penetration in a "*Pressure-Moderated Rainscreen Assembly*". Per Garden, "*In essence the outer layer is then an "open rain screen" that prevents wetting of the actual wall or air barrier of the building."* **(NRC 40)** In order to prevent the wetting of the actual wall the "rain screen" and then entire assembly need to control ALL forces that can carry rain to the inside as argued by Rousseau **(NRC R)**.

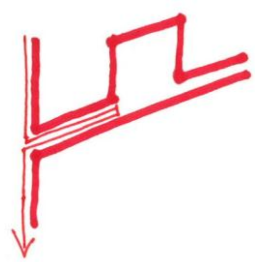
Gravity: “*The force of gravity pulls water down the face of the wall and into openings that lead inwards and downwards.”* **(SB BS)** To resist water penetration due to gravity means to simply direct water on the face of the screen wall outwards and away from the cavity and the second line of defense.



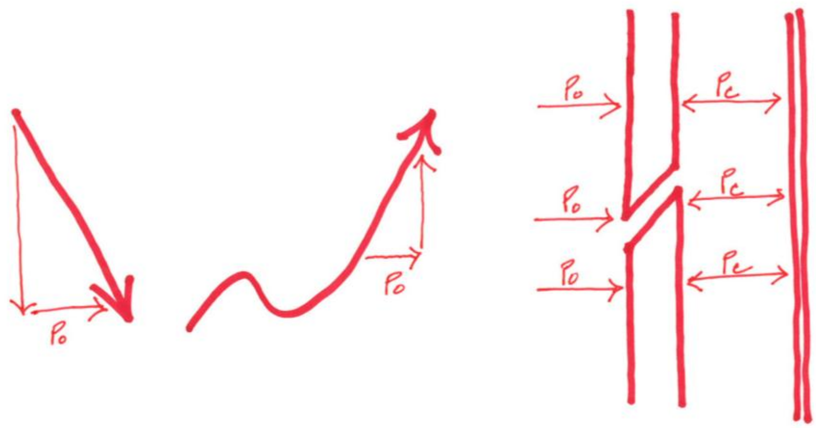
Surface Tension: “*Surface tension is a contractive tendency of the surface of a liquid that allows it to resist an external force”* **(W ST)***;* gravity and pressure differences are such forces. The introduction of drips, where the gravity force exceeds is the surface tension force, is typically how surface tension is broken.



Capillary Action: Capillarity “is the ability of a liquid to flow in narrow spaces without the assistance of, and in opposition to external forces like gravity” **(W CA)**. The forces involves are a combination of the surface tension of the water and the adhesive forces between the water and the adjacent materials. Where such narrow spaces are intended joints one solution is to provide a gap, void or a capillary trap in the joint. Where the rain screen material is masonry, precast concrete or other material where there may be unintended cracks through the material the best solution would be to seal the cracks.



Kinetic Energy: By kinetic energy we are generally referring to wind-driven rain. Wind loads on buildings are subject to many variables including wind direction, gusts, building geometry, and surrounding conditions. This force is also that most associated with air pressure differences. These forces are not consistent on the building or on a wall of a building and there are generally substantially different pressures on a wall of a building with higher pressures at the corners and top. Wind at any particular point can be viewed as the horizontal force or pressure being applied to the wall ($\mathbf{P}_o$). Of all the forces the kinetic energy associated with wind-driven rain and wind gusts is often the most dominate. If the pressure within the cavity ($\mathbf{P}_c$) were equal to the pressure applied to the wall that would cancel out the force component due to the wind; in that case rain water would not reach the second line of defense and the inner part of the wall would be kept dry. Not only would this pressure-equalization prevent wind-driven rain from entering the wall system but it would also reduce the intrusion forces from surface tension and capillary action. Even with a well-conceived design it would be unrealistic to think that the pressure within the cavity is equal to the pressure applied to the wall which is why we are adopting the terminology “*pressure-moderated rainscreen assembly”*.



Materials and Properties of a Rain Screen:

- The rain screen cladding needs to be a material which is designed to resist deterioration under regional climatic conditions.
- It is intended to prevent rain water penetration but it also vented and permits air infiltration (see venting below).
- It does not necessarily need to be an impervious material such as metal or glass. It could be a relatively impervious material such as precast concrete or face brick but if that is the case then the design needs to take into account air infiltration through the material and dissipating stored water within the material. The more pervious the material the more likely capillary action will be a force to be mitigated.

- **Compartmented Cavities**

Between the "*rain screen*" and the "*second line of defense against moisture*" there are compartmented cavities. These compartmented cavities can take several forms including:

- A "*Back-Ventilated Drained Cavity Wall Assembly".*
- Precast sandwich panels with interconnected air space channels within a layer of polystyrene insulation.
- Chambers within aluminum curtain wall framing.
- Double line joint systems between precast panels.

The cavity addresses capillarity, surface tension and gravity **(AAMA CK)**. The cavity also needs to pick up any moisture within the cavity or is shed at the second line of defense and drain at the base of each compartment to the exterior.

Garden **(NRC 40)** was the first in the know literature to propose parameters for compartmentalization; "*In the absence of more specific information it is suggested that the closures occur at not more than 4-foot centers parallel to ends and tops of walls in a 20-foot wide perimeter zone, and at 10- to 20-foot centers in both direction over the central portion."*

AAMA's The Rain Screen Principle and Pressure-Equalized Wall Design (2004) **(AAMA PEW)** references the work of Garden and Dalgliesh and cites the perimeter at outside corners and top having the 4-foot compartments for the 20-foot zone but calls for 30-foot horizontal and vertical divisions in the central zone.

Brick Masonry Rain Screen Walls (1994) **(BIA 27)** has compartment sizing requirements based on Garden.

NRC 17 confirms "that Garden's rule-of-thumb about the locations on a façade that are most in need of compartments is valid".

AAMA's Rain Penetration Control Applying Current Knowledge (2000) **(AAMA CK)** references research conducted by the National Research Council Canada and Canada

Mortgage and Housing Corporation conducted in the 1990's. Their conclusions are based upon the following:

- The second line of defense is required to be a high performance air barrier
- Compartmentalization "must recognize the sharp pressure gradients that occur at corners and tops of the buildings"; the recommendations are similar to the recommendations by Garden nearly 40 years earlier. These recommendations are based upon research that had been done in the intervening years.
  - Compartments within 10% of the edge of the wall should be small; less than 4 feet.
  - In the middle of the façade the compartments can be much larger; 32 feet to 49 feet wide and nearly 20 feet high.
  - Vent locations can impact compartment sizes and vents should not be placed close to the outside edge.
  - Compartment seals must be tight and can be subject to high loads at the corners of the building.
- Vent sizes and locations are important considerations in addressing compartmentalization. Effective Vent Area for a compartment the sum of **(AAMA RS)**:
  - 5 times the estimated leakage area of the air barrier
  - 10 times the estimated leakage area of any corner seals
  - 1 times estimated leakage area of intermediate compartment seals

The natural vent locations are at the bottom of the cavities since the cavities are required to be drained. There is no conclusive evidence to date which supports the opinion that providing vents at the top as well as at the bottom improve the ability to dry the cavity; more research is required.

The Rain Screen Wall System, **(RSWS)** CMHC SCHL, Ontario Association of Architects, provides an excellent summary of The Rain Screen Wall System and summarizes venting and compartmentalization similarly to AAMA RP.

- **Second line of defense against moisture**

The inner most portion of the rain control assembly which at minimum is an air control layer and layer which is at least water resistant and water shedding; it may be a waterproof membrane. The air barrier component is critical to the system because it is necessary to achieve pressure-moderation. The components of this second line of defense should be resistant to moisture deterioration and the assembly should be designed to resist the wind loads required of the exterior envelope.

Associated with the second line of defense could be a vapor control layer and a thermal control layer. The thermal control layer may be within the cavity applied to this layer, inside of this layer or a combination. The relationship of the thermal control, air control and vapor control layers introduce other design considerations such as condensation control and climatic considerations not within the scope of this article.

Glossary

The majority of this glossary was submitted by David Altenhofen, The Façade Group. The "control layer" terminology is used in the literature by Joseph Lstiburek, Building Science Corporation; he may have coined this terminology.

- Barrier: something material that blocks or is intended to block passage (Merriam-Webster)
- Control: to exercise restraining or directing influence over: regulate
- Control layer: This is a generic term that assigns a function to each layer without naming a product.

  - Air Control Layer: The layer which addresses the performance criteria associated with air leakage; this may or may not be a single material designed as an air barrier.
  - Vapor Control Layer: Only to be used when one actually adds a layer that is purposely designed to control vapor transmission. Otherwise we should be controlling vapor with progressively more open vapor permeable materials towards the edges of the wall assembly.
  - Water Control Layer: This used to be the old WRB by code and is now the final line of water intrusion allowed before it is directed to the exterior.
  - Thermal Control Layer: Insulation and thermal breaks.
  - Watershed: The outer layer of the wall that faces the exterior.   This control layer has to resist the penetration of water across openings and joints by controlling capillarity, wind driven rain, gravity, and surface tension.
  - Weather Grille: An open outer layer that only blocks bulk water penetration but does not otherwise control water penetration across the joints.
- Layer: One thickness, course, or fold laid or lying over or under another
- Mass Wall Assembly: A wall assembly that controls by having sufficient capacity to absorb water and then dry before water reaches the interior.
- Moderate: To lessen intensity or extremeness of (Merriam-Webster)
- Retard: to slow up especially by preventing or hindering advance or accomplishment: Impede (Merriam-Webster)
- Surface: a two-dimensional, topological manifold; about each point, there is a coordinate patch on which a two-dimensional coordinate system is defined. (Mathematics) This implies continuity; there are no holes.
- Barrier Wall Assembly: A wall assembly that controls with a continuous and perfect membrane.
- Drainage Plane Wall Assembly: A wall assembly with a small open plane 3/8” wide or less over the Water Control Layer to allow limited drainage, typically without any ventilation.
- Drained Cavity Wall Assembly: A wall assembly with a continuous cavity larger than 3/8” over the Water Control Layer.
- Back-Ventilated Drained Cavity Wall Assembly: A Drained Cavity Wall Assembly with opening distributed from bottom to top to allow for air movement between the Water Control Layer and the Water Shedding Layer.
- Pressure-Equalized Rainscreen Assembly (PER): We are suggesting adopting the term Pressure-Moderated Rainscreen Assembly because pressure-equalized assumes no pressure difference between the cavity and the pressures across the cladding.
- Pressure-Moderated Rainscreen Assembly: A back-ventilated drained cavity wall assembly, with the air cavity compartmentalized so air pressures between the exterior and air cavity are approximately equal to control the final force that causes water to move through an opening in the Watershed layer.
- Rainscreen: The cladding layer which provides the first line of defense against rain penetration in a Pressure-Moderated Rainscreen Assembly.
- Rainscreen Assembly: See Pressure-Moderated Rainscreen Assembly; this glossary does not differentiate between a Conventional or Basic Rainscreen (NRC 9) and a Pressure-Moderated or Pressure-equalized rainscreen.
- Grilled Barrier Wall Assembly: A wall assembly with a cavity and a grille over a barrier type water control layer.

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