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Features

The Rainscreen Principle

Micheal Lough, AIA

The term "Rain Screen" is bantered about frequently and often misused. This article is draws the simple conclusion that a "rain screen assembly" should comply with the "rain screen principle".
Full Article

Rain Screen—Getting Under the Skin of an Open Cladding Assembly

Mark Perepelitza, AIA

What is a rain screen? This article will examine the common misuse of the term "rain screen" in architectural design as applied to open cladding assemblies.
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Rainscreen and Back-Ventilated Drained Cavity Wall Systems: Practical Applications for High Performance Buildings

David Altenhofen, AIA

This paper provides recommendations for high performance exterior wall assemblies that are capable of providing the expected performance within current understandings of building science and practical application.
Full Article

Construction of Rainscreen Walls

Drake Wauters, AIA

Construction of successful building enclosures for high performance buildings including rainscreen walls require attention to some basics when creating bidding documents, during bidding, and throughout construction.
Full Article

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AIA TDBP Advisory Group: David Altenhofen, AIA, Michael Chelednik, AIA, Micheal Lough, AIA, Drake Wauters, AIA

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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. <u>The influence of moisture of the heat conductance for bricks</u> 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), <u>Rain Penetration and its Control</u>.**(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.

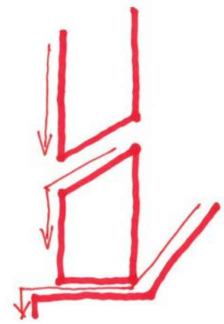
Components of Walls Designed According to the Rain Screen Principle

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.

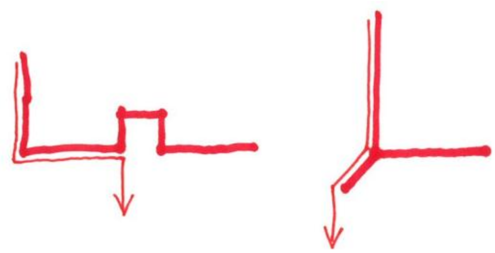
- **Rain Screen**

  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)**.

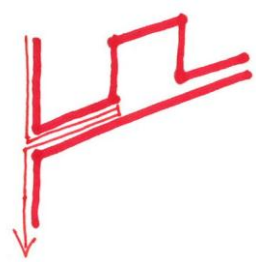
Gravity: "*The force of gravity pulls water down the face of the wall and into openings that lead inwards and downwards." **(SB BS)*** To resist water penetration due to gravity means to simply direct water on the face of the screen wall outwards and away from the cavity and the second line of defense.



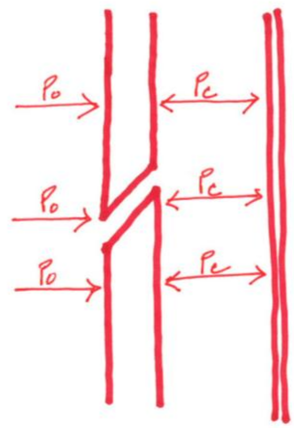
Surface Tension: "*Surface tension is a contractive tendency of the surface of a liquid that allows it to resist an external force"* **(W ST)***;* gravity and pressure differences are such forces. The introduction of drips, where the gravity force exceeds is the surface tension force, is typically how 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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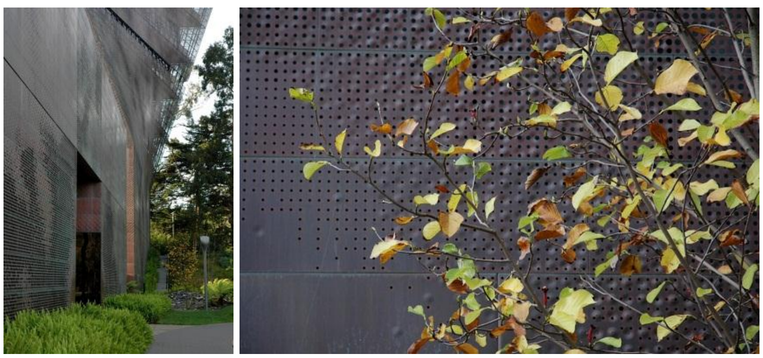
Rain Screen—Getting Under the Skin of an Open Cladding Assembly

What is a rain screen? In an effort to clarify the terminology and principles, Michael Lough's article in this newsletter digs into the research literature and identifies key elements and required functions. David Altenhofen offers practical applications of exterior wall systems for high performance buildings; and Drake Wauters addresses related aspects of construction. A common misuse of the term "rain screen" in architectural design applies it to open cladding assemblies, such as the open-joint stone cladding of the J. Paul Getty Museum in Los Angeles, or the perforated metal cladding of the De Young Museum in San Francisco.


J. Paul Getty Museum

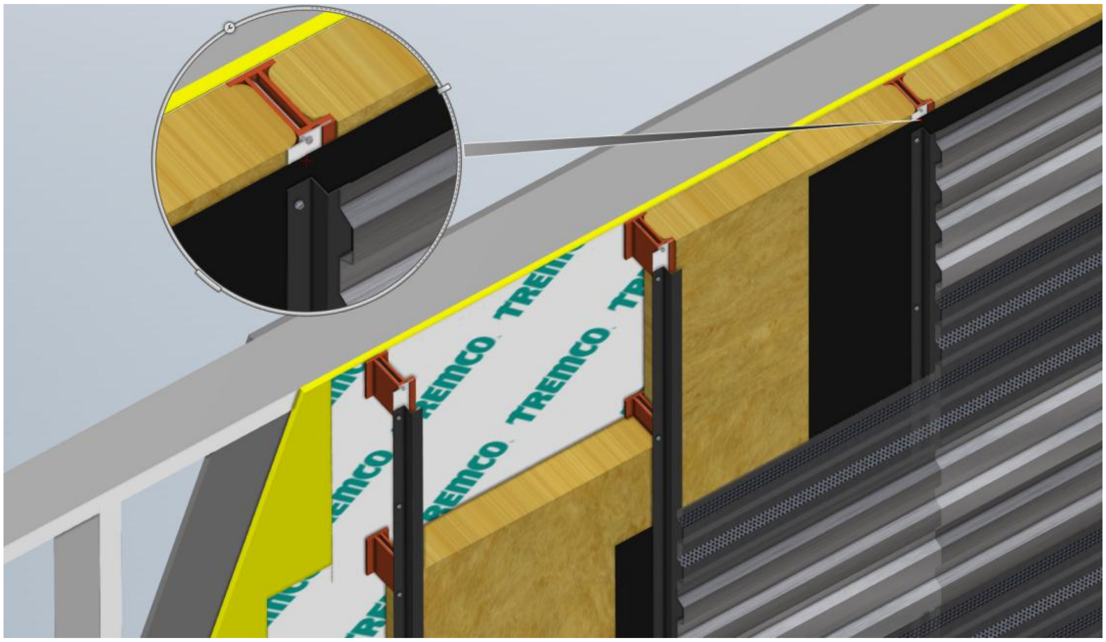

De Young Museum

Photos: Perepelitza

Although the complete wall assemblies of these buildings may incorporate the rain screen principle, it is clearly not achieved through their cladding surface. As Mike notes, to effectively manage water, a wall assembly needs a continuous water shedding surface, a cavity or drainage plane, and a water barrier to provide a second line of defense.

Is it possible for open-joint or perforated cladding to be components of a high performing exterior wall assembly? That's exactly what the team on a Portland project currently under construction set out to achieve. The project is the Collaborative Life Science Building (CLSB) and Skourtes Tower, a 650,000 sq. ft. laboratory, office, and classroom building. The Oregon University System (OUS) and Oregon Health & Science University (OHSU) are collaborating on the CLSB portion of the project, and OHSU is the client for the Skourtes Tower. SERA Architects is the executive architect, teamed with CO Architects as the design lead.

Due to the desired aesthetics and the intent to not rely on maintaining sealant joints for a water shedding surface, the CLSB exterior walls utilize perforated metal panels that have a corrugated profile and open joints between panels. This means that the outer cladding clearly does not provide a continuous water shedding surface. Because the materials immediately behind the panels and their joints are visible, a neutral background of black is also desirable. UV stability is required since the membrane is only partially covered by the cladding materials.



CLSB wall assembly rendering


CLSB construction photos of wall assembly

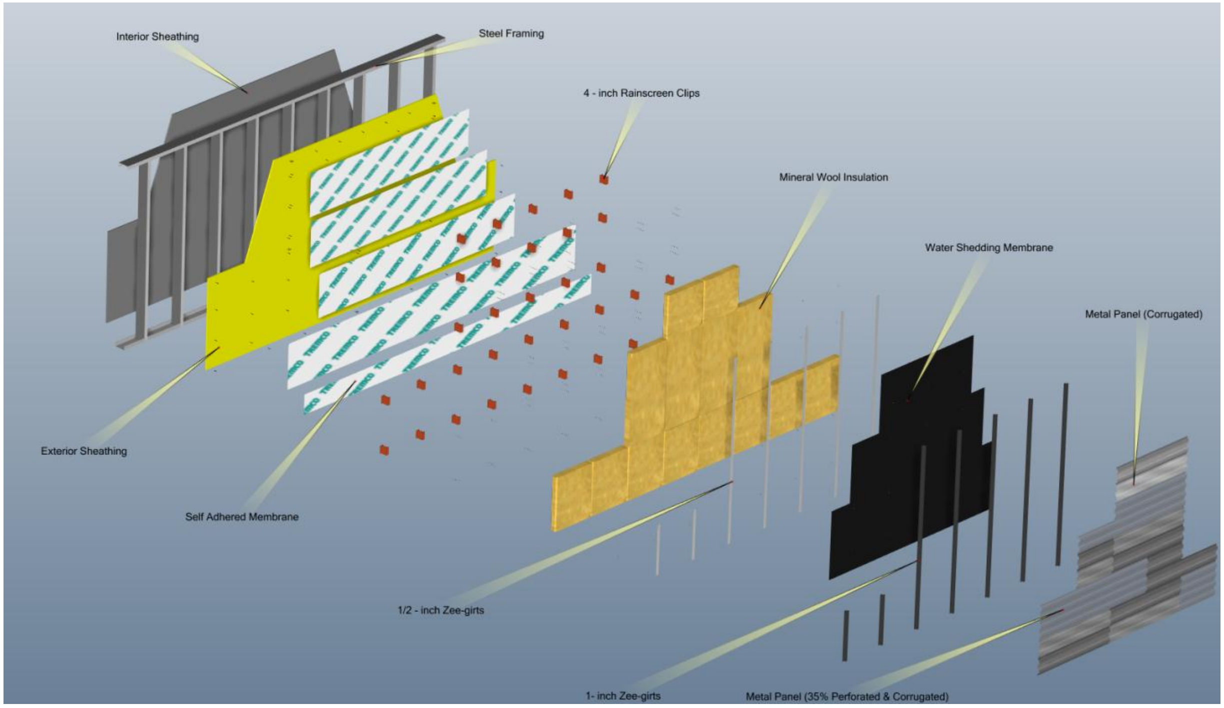
To meet these challenges, the team researched, tested, and ultimately utilized a water shedding membrane material that is vapor permeable to allow drying toward the exterior, black to address the desire for a neutral background, and that provides the necessary continuous water shedding surface.

Note how the water shedding membrane is separated from the self-adhered membrane that provides the second line of defense, as a water resistive barrier. The water shedding membrane fulfills the control layer function while still allowing a perforated cladding with open joints. An additional payoff is an experience of visual depth when the observer is within about 20' of the material (for example from the stair towers and at the lower levels of the south tower) or when the same cladding is incorporated over the glazing as back-lighting shows the transparency of the metal panel perforations.

The water shedding membrane that is being utilized is most frequently installed directly on sheathing as a water resistive barrier. In this application, it is fully supported by semi-rigid mineral wool and ½" z-girts, however wind-cycling was something the team wanted to verify would not cause any issues. Although the team did not have funding or time to do thorough lab testing, the sub-contractor, testing agency, membrane manufacturer, and SERA teamed to design, build, and test a small mock-up. Not only did the material and assembly pass at the specified air pressure, it did not fail until the air pressure reached the maximum level capable of being produced by the test equipment.

Because the water shedding membrane has been tested and has a warranty based on a UV exposure of up to 40%, the team limited all open joints and perforations to a maximum openness of 35%. Anecdotal evidence shows the assembly has lasted for several years in 100% UV exposure, but the warranty was the governing factor on the degree of opacity.

All together, the assembly meets the project's aesthetic goals and offers a high performing exterior wall with respect to durability, drainage, wind-cycling, and UV exposure. Does this assembly meet the definition of a pressure-equalized rainscreen as described by other articles in this newsletter? No—although it adheres to the "rainscreen principle" it is actually a hybrid assembly that would come closer to fitting the definition of a "back-ventilated drained cavity wall system." Is this the perfect solution for all North American climates and cladding assemblies? No—obviously cladding assemblies should designed for local climate conditions. In the relatively mild Pacific Northwest climate extended freezing periods are not an issue, whereas in colder northern and high-elevation climates this can be a significant concern. Freeze-thaw would particularly be an issue in those colder climates with an open-joint masonry assembly. In addition to its role as a water-shedding surface, the outer membrane in the CLSB wall assembly also protects the other control layers from environmental damage, dust, and insects. Although open joint and perforated assemblies have an additional cost for the separate water-shedding membrane, in the right applications such as this, they can offer the desired aesthetics without compromising functional long-term performance.



CLSB wall assembly rendering

Sean Scott is an Enclosure Specialist at SERA Architects and the CLSB Enclosure Project Architect. Mark Perepelitza manages the Sustainability Resources Group at SERA and is a member of the TDBP Advisory Group.

RAINSCREEN and BACK-VENTILATED DRAINED CAVITY WALL SYSTEMS: PRACTICAL APPLICATIONS for HIGH PERFORMANCE BUILDINGS

David Altenhofen, The Facade Group

INTRODUCTION:

High performance buildings must have exterior wall assemblies that provide a superior level of control and performance. Unfortunately, there is little quantifiable data to establish the performance of the enclosure. This paper provides recommendations for high performance exterior wall assemblies that are capable of providing the expected performance within current understandings of building science and practical application. It is the intent of the paper to assist Architects to understand the underlying building science and the practical application of that science to the design and detailing of exterior walls to deliver high performance. Proven, redundant, watertight, air tight, highly reliable, energy efficient walls are targeted. While many other wall assemblies may provide completely acceptable performance under normal expectations, this paper is intended to address the elevated expectations for high performance buildings. The concepts and features included apply to all building types, but the article is focused primarily on commercial construction. The wall assemblies included herein are generally more expensive than lower performing assemblies and the value decisions for performance versus cost must be made by project teams.

The recommendations in this paper are based on the experience and knowledge of the members of the AIA Technical Design for Building Performance Knowledge Community. This article uses “The Rain Screen Principle” by Mike Lough, also published by the TDBP for a foundational description of the principles for how these wall assemblies resist the passage of air and water. It is recommended to read “The Rain Screen Principle” before this article. The articles “Construction of Rainscreen Walls” by Drake Wauters and “Rain Screen—Getting Under the Skin of an Open Cladding Assembly” by Mark Perepelitza and Sean Scott covers issues related to actual construction of these wall assemblies. As a group, these articles by the TDBP KC represent one path for high performance enclosures.

Please see “The Rain Screen Principle” for a glossary of terms used in this article. The TDBP KC hopes that this glossary can bring clarity to the confusing lack of conformity now present in the industry.

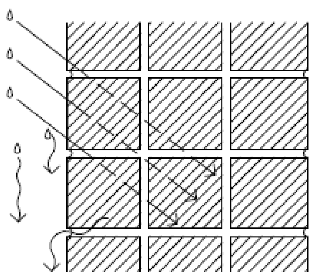
Illustrations used in this article are taken from AIA Architectural Graphic Standards, 11th edition, Element B – Shell and maintain that numbering system. AGS provides additional information on this subject and additional illustrations that may be helpful.

SELECTION OF THE EXTERIOR WALL SYSTEM:

Wall assemblies are classified into 5 major types related to the methodology to resist water penetration. (See AIA Architectural Graphic Standards, 11th edition, Element B, Shell, page 128 John Wiley and Sons, 2007 and “Designing the Exterior Wall” by Linda Brock, John Wiley and Sons, 2005 for additional information).

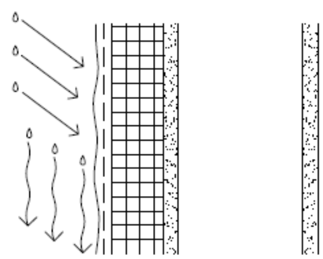
- Mass Barrier Wall Assemblies, figure 2.233.a.

- Face Sealed Barrier Wall Assemblies, figure 2.233.b.
- Drainage Plane Wall Assemblies, figure 2.234.a.
- Drained Cavity Wall Assemblies (DC) further defined as Back-Ventilated Drained Cavity Wall Assemblies (BVDC), figure 2.234.b.
- Pressure-Equalized Rainscreen Wall Assemblies (PER), figure 2.235.



MASS WALL

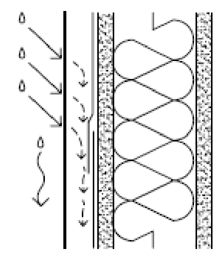
Figure 2.233.a



FACE SEALED

2.4_82

Figure 2.233.b



DRAINAGE PLANE

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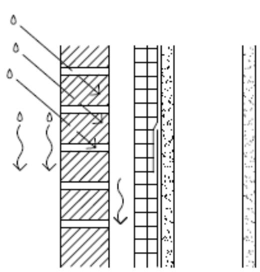
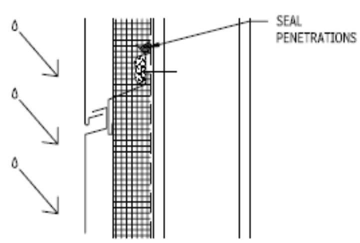
Figure 2.234.a



DRAINAGE CAVITY

2.4_83

Figure 2.234b



PRESSURE EQUALIZED RAINSCREEN

Figure 2.235

Current descriptions and definitions of high performance buildings do not provide quantifiable criteria for wall performance. In order to meet with the spirit and intent of the goals for high performance buildings, wall assemblies of high-performance building should possess the following attributes: Other performance characteristics are necessary to fulfill the basic functions of walls and are not included here.

- Redundant protection against air and water infiltration.
- Control of water infiltration without dependence on absorption and drying to the interior.
- A continuous and easily installed air barrier (AB) and water resistant barrier (WRB).
- Continuous thermal insulation without major thermal breaks (approximately 1% of surface area).
- High levels of thermal insulation.
- Water vapor control with any potential condensation outside of the water control line.
- An installation process that allows for progressive quality management inspection and testing before covering by subsequent layers.
- A vented drainage cavity large enough to overcome water surface tension for a high drying capacity
- Ventilation towards the exterior side of the continuous insulation rather than behind.

- UV and thermal protection of sensitive membranes and seals.
- Shingling of layers of membranes, sheets, and flashing in the direction of water flow or mechanically anchored terminations at negative shingling.
- Accommodation of building structural movement.
- Durability for dependable service after years of in-situ service.
- The ability to effectively construct joints between the various wall systems and other enclosure components such as roofs, waterproofing and fenestration incorporating all of the criteria listed above.

Of the 5 wall assemblies listed, only Back-Ventilated Drained Cavity Wall Assemblies and Pressure-Equalized Rainscreen Wall Assemblies meet these heightened performance attributes.

In practical terms the difference between a BVDC wall assembly and a PER wall assembly is compartmentalization of the air cavity to provide for heightened control of water infiltration at the cladding by eliminating air pressure differential. In low-rise and smaller scale construction, the air pressure differentials between ambient and inside the cavity will frequently be low enough that a simple upturned leg in the cladding design can resist water penetration. As buildings get larger and in particular taller, the pressure-differentials are larger and present for much longer durations. Up turned legs would need to exceed 2 or more inches to control water penetration under common wind loads on tall buildings. Compartmentilization moderates the pressure differential, and allows for more consistent water infiltration control at the cladding without the large upturned leg. Compartmentilization can also help reduce air washing over the thermal insulation, improving the actual performance.

The most common credible method to verify that a wall assembly functions as a PER Wall Assembly is through successful testing according to AAMA 508-07, Voluntary Test Method and Specification for Pressure Equalized Rain Screen Wall Cladding Systems. It is recommended that only wall assemblies that have passed this test (or some similarly rigorous impartial test) be labeled as a “Pressure Equalized Rainscreen” or “Rainscreen”.

Unfortunately, the equivalent test method for a BVDC wall assembly, AAMA 509-09, Voluntary Test and Classification Method for Drained and Back Ventilated Rain Screen Wall Cladding Systems, has a pass threshold too low to establish an appropriate performance value. The test method places too much reliance on a near perfect waterproof air barrier.

There is great confusion within the industry over the term “rainscreen” and it can be difficult to determine the actual performance mechanisms claimed for materials and products. Clarity can be gained by studying the performance attributes of a product independent of any terminology and determining if the functional aspects are met. Some common clarifications:

- Simple open-jointed cladding that does not incorporate upturned legs, sloped surfaces, drips, and capillary breaks does provide for all necessary cladding functions in BVDC or PER assemblies. Such cladding is more properly called “Open Cladding” (see “Rain Screen—Getting Under the Skin of an Open Cladding Assembly”). Without an additional layer for water shedding under the open cladding, the WRB must be nearly perfect as it is exposed to relatively large amounts of water.
- Cladding systems without a method to compartmentalize the air cavity are BVDC wall assemblies, not PER.

- Some cladding systems utilize BVDC or PER joints, but the panels themselves are a type of barrier wall. Common examples are insulated metal panels and precast concrete panels.
- Some cladding assemblies provide ventilation between the insulation layer and the interior, which degrades thermal performance even if truly a BVDC or PER.

MATERIAL SELECTION

Proper selection of materials for each component of a BVDC or PER wall assembly requires an understanding of the idealized function and the realities of practical applications. For example, in a perfect laboratory test, the air barrier need not be waterproof as all water penetration is stopped at the cladding. However, real-world experience proves this to not be true due to the vagaries of construction tolerances, quality control and unforeseen conditions. Therefore passing the single lab test for an air barrier is not enough to determine actual in-situ performance. Laboratory tests of products are also frequently based on new samples. UV exposure, heat, substrate movement, and chemical decay can all seriously degrade performance. Realistic performance may also be difficult to obtain if installation instructions require a level of care in the field that cannot be realistically performed. Architects are cautioned to carefully examine performance claims based only on lab tests.

Air Control and Water Control Layers: At the interior cavity face of BVDC and PER wall assemblies is the most important material for long-term performance (figure 2.236). This layer is the plane to control air infiltration and is the final limit to water penetration. It is not uncommon for this layer to also control vapor diffusion. Finally, this layer is deeply embedded in the wall assembly and will likely not be exposed for many years. Therefore the selection of the AB/WRB is crucial. While other methods can be used to provide for air and water control, such as sealed sheathing or rigid insulation, utilization of a membrane to provide this function is typically more durable and reliable. In order to perform long term the AB/WRB should be; thick enough to cover rough substrates when applied in the field, robust enough to resist damage from subsequent construction activities, fully adhered to the substrate to resist wind pressures, able to readily self-seal around penetrations for anchoring/supporting the cladding or be easily patched waterproof, shingled to drain or incorporate termination bars to mechanically anchor “uphill” edges. In parts of the country such as the Pacific northwest, where there is seldom a week without rain, the ability to apply the AB/WRB to damp substrates will be important. With the 2012 ICC there will a requirement for the AB/WRB to also comply with NFPA 285 testing for combustibility. Under earlier ICC codes the AB/WRB will have to match the NFPA tested assembly for most commercial buildings if there is foam plastic insulation in the air cavity.

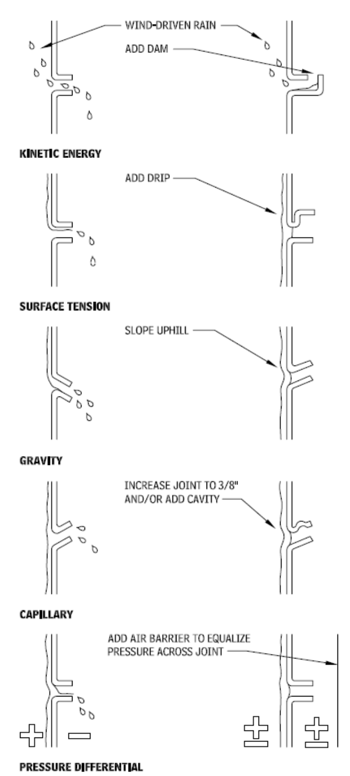


Figure 2.236

Insulation: A portion of the air cavity will be filled with insulation to provide a continuous line of thermal control outside of the wall supports and main structure (figure 2.272 and figure 1a, 1b, and 1c). The insulation is typically either a rigid foam plastic or semi-rigid mineral wool. Rigid foam plastic typically extruded polystyrene, polyisocyanurate or spray polyurethane foam provides the highest R-value for the cost but introduces a flammable material into a concealed cavity. The ICC has requirements that limit the use of foam plastic or requires compliance with a very restrictive and expensive large scale assembly test, NFPA 285. Note that the NFPA 285 test requires that the entire wall assembly be constructed in compliance with the test report, which restricts the selection of all other materials and influences detailing, particularly at window heads. The joints between rigid boards should be sealed with compatible spray foam or mastic for maximum performance. Spray polyurethane foam can be used as for the insulation and perhaps also for the AB/WRB and it solves the jointing problem. There are some questions about long term watertight sealing of the spray foam to all necessary penetrations. Carefully consider the qualifications of the applicator and the source of the raw products as the SPF is highly sensitive to numerous variables in the field. Semi-rigid mineral wool for cavity insulation has a lower embodied energy, is completely non-combustible and dries readily in the cavity, but typically requires a 50% increase in thickness for a comparable R-value. Because of its compressible nature, it is typically friction fit tightly together at joints.

In addition to the insulation in the air cavity, insulation may be added between the stud spaces of the back-up wall.

Girts and Shelf Angles: The cladding is always spaced away from the back-up wall to create the requisite cavity. To support the cavity a system of clips, girts, and shelf angles must be detailed. Unfortunately, these must penetrate the insulation layer and create thermal bridges. The cross-sectional area of the bridges should be minimized for optimum thermal performance.

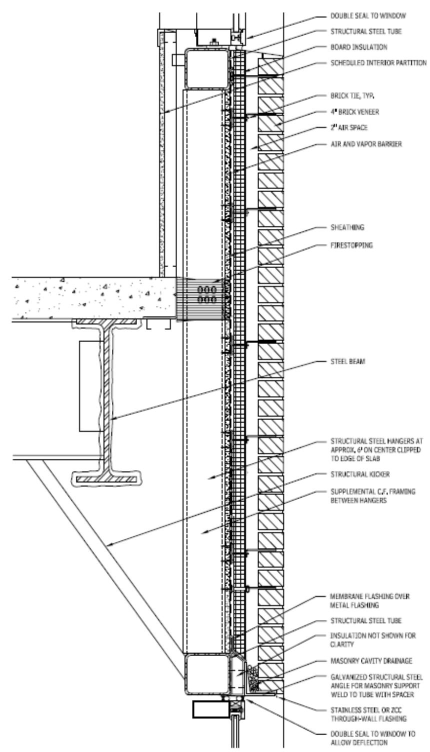


Figure 2.272

Shelf angles if needed for heavy cladding should be spaced off of the supporting structure to allow the insulation to pass behind. (figure 2.272) (See Thermal Bridging Solutions: Minimizing Structural Steel's Impact on Building Envelope Energy Transfer published by Structural Engineering Institute (SEI) /American Institute of Steel Construction (AISC)).

For lighter cladding use a network of girts, preferably aluminum or stainless steel as the penetrations and ends of galvanized material is subject to corrosion. Continuous zee girts should be avoided, instead provide small clips spaced approximately 4 feet apart which in turn support girts outside of the insulation (figure 1a, b, and c). The clips can be stainless or plastic to limit thermal bridging or can include a thermal break detail within the thickness of the insulation. Proprietary systems are available with the advantage of extensive engineering, but perhaps a loss of customization. Coordinate the location of the clips with the framing of the back-up wall framing to accommodate the more widely spaced and larger point loads. Note that every penetration of the AB/WRB should be detailed so that it can be properly sealed and inspected before installing the insulation. Be wary of anchors that supposedly seal through rigid insulation, the seal is frequently a gasket at the cavity face of the insulation, not at the proper location at the surface of the AB/WRB.

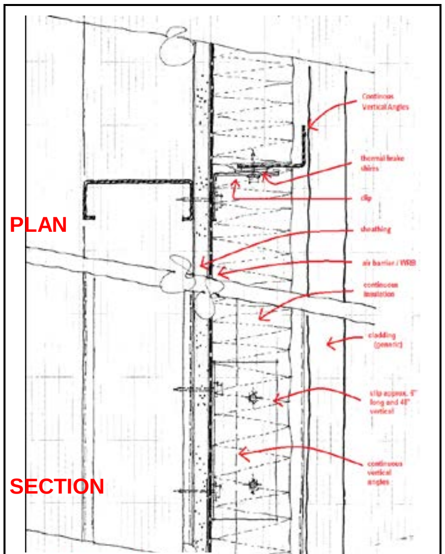


Figure 1a

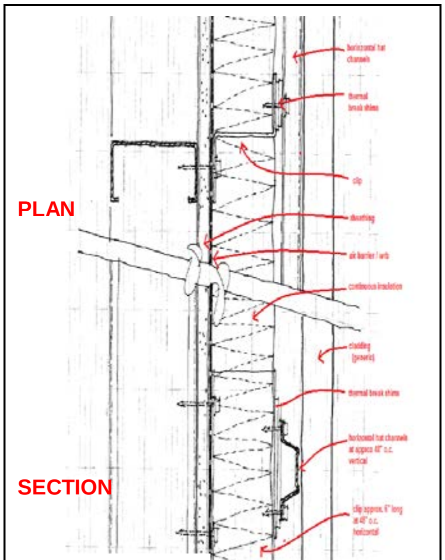


Figure 1b

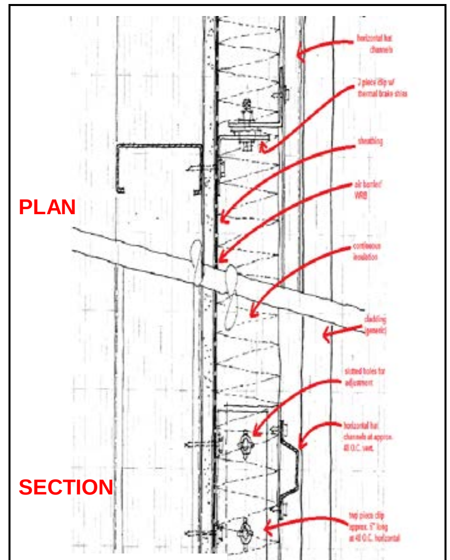


Figure 1c

Cladding: The outer cladding of the wall assembly can be a wide variety of materials. For the sake of clarity this layer is not referred to as the “rainscreen”. This name has created confusion and seemingly led to the idea that the cladding can be nearly anything, including open jointed systems, perforated materials, and literally screens. The cladding must be detailed to attempt to stop ALL water intrusion to qualify as a proper BVDC or PER system.

Masonry cladding may be stone, brick or CMU. Frequently mortar or sealant provides the primary sealing function of the cladding joints, and thus masonry cladding is rarely detailed as a true PER. Square jointed stone panels without joint fillers are open cladding and should be detailed as such. (figure 2.272).

Panel type cladding comes in nearly endless materials; wood, phenolic, cementitious, plastic, ceramics, metal composite materials, porcelain coated steel, sheet metal (aluminum, galvanized steel, zinc, titanium, etc.), metal plate (aluminum, steel), and more (figures 2.294, 2.341, 2.349. 2.350, 2.351 and 2.352).

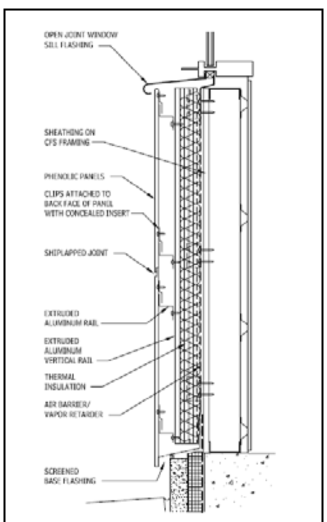


Figure 2.294

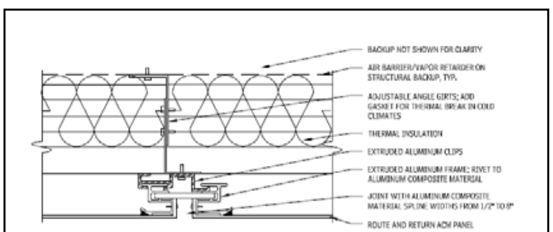


Figure 2.349

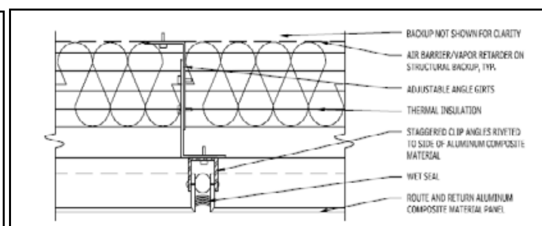


Figure 2.350

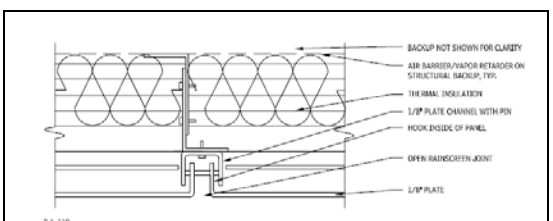


Figure 2.351

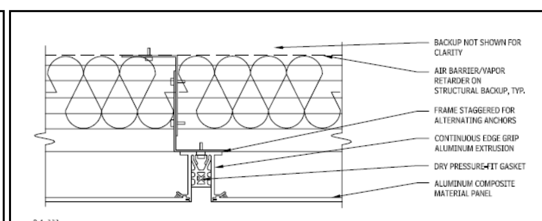


Figure 2.352

Mounting typically falls into either exposed or concealed fastener types. Whichever fastener type, ensure that the system will accommodate differential movement without distortion or degradation. Many of the cladding products can expand and contract more than ¼" in common panel sizes with normal seasonal temperature changes. Systems that are rigidly screwed onto girts may fail very quickly. The jointing of the panels has to be detailed to stop water penetration. For thin panels that cannot provide sufficient ship-lapped edge profiles then metal zee flashing at horizontals and channels at vertical joints may be required. For any panel not inherently non-combustible verify if it is allowed on commercial projects. For any manufactured panel, verify long-term successful in-place service of the exact color and chemical make-up. Many variables can determine if the product will perform, simply changing to a very dark panel can change temperatures sufficiently to cause failure.

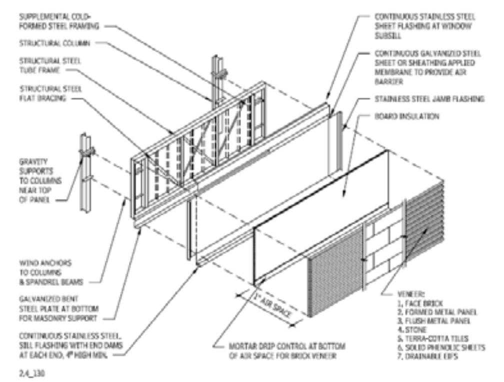


Figure 2.341

Terra Cotta, ductile concrete, glass fiber reinforced concrete, fiberglass, and other products all have been used successfully if properly detailed. Again, open -joint systems such as terra cotta baguettes do not meet the requirements for cladding of a BVDC or PER wall assembly. Note that many aluminum and glass curtain wall systems are designed as pressure-equalized rainscreens. However, those systems are not included in the scope of this article.

DOCUMENTATION

Once the architectural team has properly selected a BVDC or PER wall assembly, the design must be fully described in the drawings and specs.

For the drawings, build from the most generic to the most specific in a logical fashion. It is recommended that the set of drawings include an assembly diagram of each individual system required to enclose the entire building. Think of these assembly diagrams as exterior partition types. By showing every single layer of the assembly clearly defined and annotated with material callouts that exactly match the specs there is little room for mis-interpretation. These assemblies should be started early in Design Development and finalized BEFORE starting construction documents. It is also desirable to develop large scale details of the most common head/jamb/sill, parapet and base of wall conditions during DD phase (figure 2). During CDs the detailing can proceed from these typical assemblies into all of the special conditions. This rigor not only allows for proper time to complete the necessary details, it also helps offices maintain schedule and profitability.

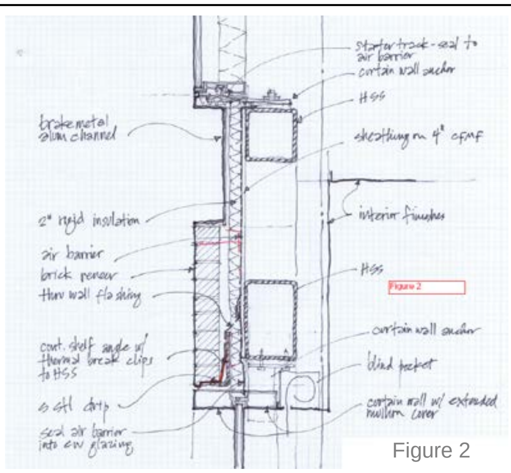


Figure 2

Evaluate the details using the simple "pencil" test (figure 3). Trace the continuity of every control function; air, water, vapor, cladding, insulation, etc, around the entire perimeter of the building in plan and section without lifting the pencil. Gaps show areas that require study.

In particular for BVDC and PER wall assemblies, the drawings need to show the location of all movement joints, especially those in the back-up wall. These joints can get lost in panelization lines, so a separate diagram or larger line symbol is necessary. The extent should be shown on elevations with details for each condition. Make sure that no movement joints dead end.

For PER wall assemblies, the drawings should show the compartmentalization of the air cavity. Elevations should show extent with details showing methodology.

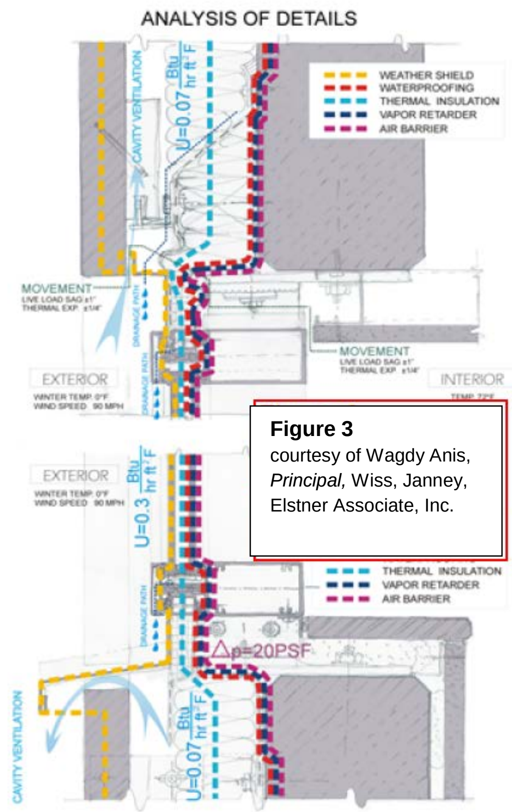


Figure 3
courtesy of Wagdy Anis, *Principal*, Wiss, Janney, Elstner Associate, Inc.

Detailing the BVDC or Rainscreen: Depending on the type of BVDC or PER Wall Assembly desired; the amount of detail required for compartmentalization, drainage, joints, weeping, ventilation and support varies. Some systems can be specified as a nearly complete assembly with relatively few details, others require that the architect detail every condition. Understand what the supplier or manufacture will provide and then detail missing elements accordingly. It is very rare that a product or system includes the full back-up wall, insulation and AB/WRB. Those layers of the wall assembly will need to be detailed by the architect.

Detailing Joints: The joint where a BVDC or PER wall assembly meets adjacent construction is crucial, especially at the interface to a different type of wall assembly or to barrier type fenestration. One must remember that water will likely be present some of the time in the cavity and the cavity is always open to ambient air conditions. At transitions the cavity must be blocked off.

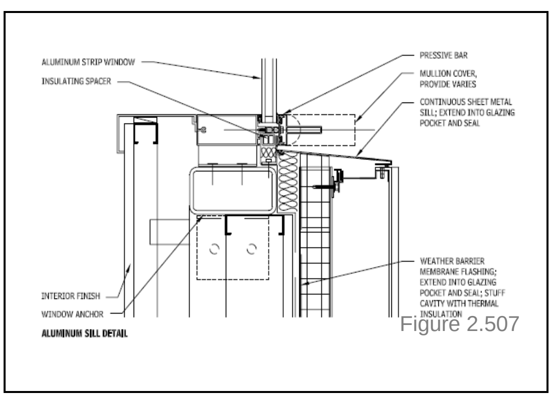


Figure 2.507

PER curtain wall: Bridge the AB/WRB line across to the back of the glazing pocket and maintain the thermal control layer. Connect the cladding to the curtain wall mullion covers. (figure 2.507)

Storefront: It is very difficult to seal cavity walls to storefront and many storefront systems do not provide strong thermal performance or water control. If possible, avoid using storefront framing on high performance walls. If unavoidable, it is important that there be a primary watertight seal from the storefront frame to the AB/WRB. An inner line of sealant can help provide some redundancy and reduce air pressure differences across any gaps in the outer sealant.

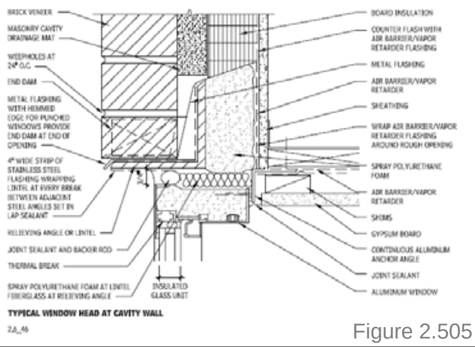


Figure 2.505

Windows: Similar to storefront, many older technology windows function as a face-sealed barrier and should be avoided or treated as listed above for storefront. If required provide a double line of sealant with inner air seals and outer weather seals (figure 2.505). More current window systems include provisions for sealing of the AB/WRB to the window frame itself. An outer seal at the cladding line should be provided.

Hollow metal doors: Hollow metal doors are extremely difficult to properly seal into cavity walls. A flashing should close off the cavity to the exterior face of the hollow metal frame (figure 2.557). It is preferable to use aluminum curtain wall frames with aluminum doors and avoid the problem all together.

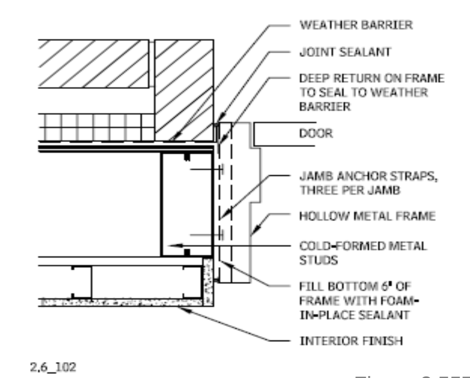


Figure 2.557

Barrier walls: At the joint between the BVDC/PER wall assembly, close the cavity with flashing, connecting the AB/WRB to the cladding. Seal the barrier wall to this closure. Note that the use of barrier walls in high-performance buildings is not recommended.

Roof Edge/Parapet: Detail a connection between the roofing membrane and the AB/WRB. At parapets it must be decided if the air barrier is to run up and over the parapet wall or if the air barrier is detailed to bridge the base of the parapet wall (figure 2.421). At gravel stop roof edges the roof membrane must extend to the air barrier (figure 2.424). If possible, utilize a protected membrane roof assembly, which more closely matches the layering of the BVDC or PER wall assembly. See Building Science Corp, "The Perfect Wall" for further explanation.

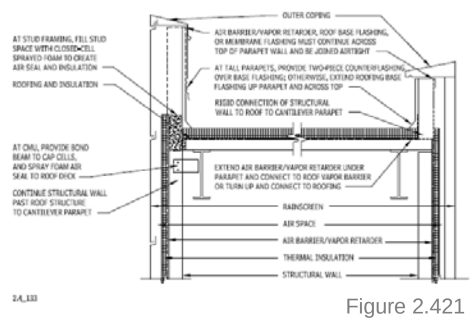


Figure 2.421

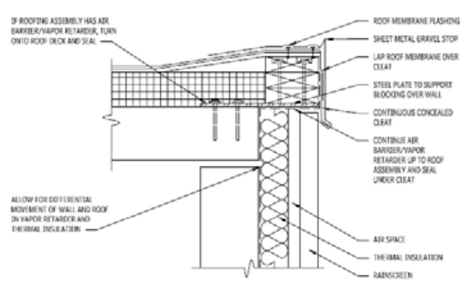


Figure 2.424

Overhangs and Soffits: The continuity of the double line of defense should be maintained across the soffits (figure 2.425a). Vented soffits are not recommended (figure 2.425b).

Foundation wall: Detail a connection of the AB/WRB to the foundation waterproofing system. Maintain continuity of the thermal control layer. For high performance buildings, true waterproofing is preferred over dampproofing. (figures 2.123, 2.294 and 2.328)

Slab-on-Grade condition: Provide a strip of waterproofing along the base of the wall, extending a short distance below grade. Maintain continuity of the thermal control layer if possible. Connect the below slab vapor barrier with to the AB/WRB if possible. (figure 2.294 and 2.328)

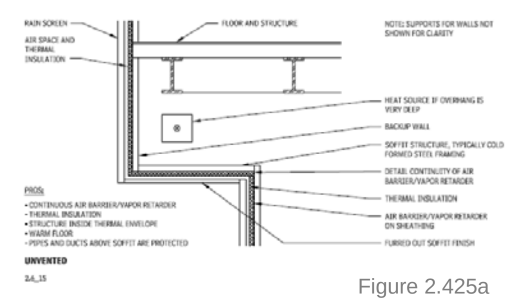


Figure 2.425a

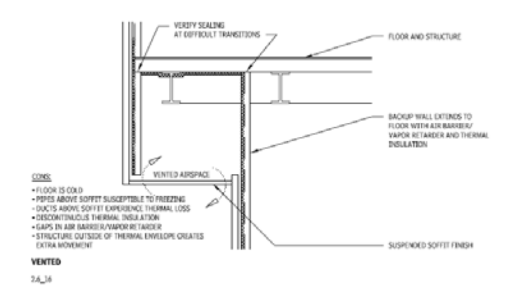


Figure 2.425b

Specifications:

Complete and coordinated specs will help deliver a functioning enclosure. The specs must be highly tailored to the specific project requirements, boilerplate will not do.

In many projects the BVDC or PER wall assembly is made up of many products specified in many technical sections. It is advisable to add an “Enclosure General Requirements” section in Division 1 or perhaps at the beginning of Division 7 that brings together all of the elements of the enclosure. Include a statement that the wall system is designed to function as a BVDC or PER wall along with a definition of that performance. Include performance criteria that is necessary for the entire assembly versus criteria that applies to only one layer such as air infiltration and water penetration. Include a rigorous quality process from the builders including requirements for coordinated enclosure drawings, coordination meetings, mock-ups, special testing, and site observations.

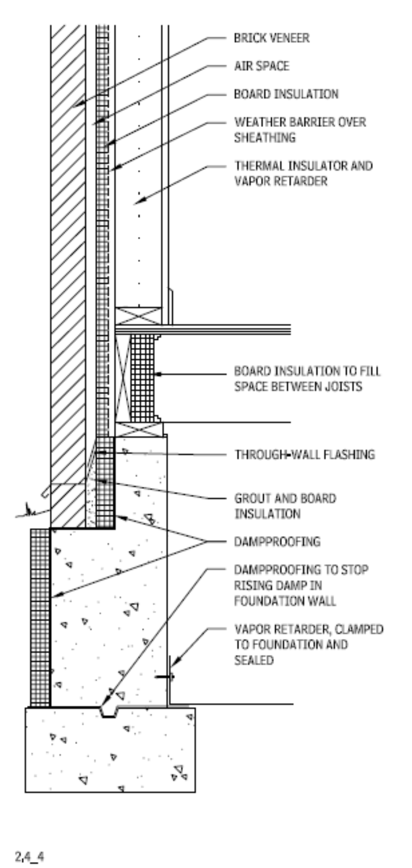


Figure 2.123

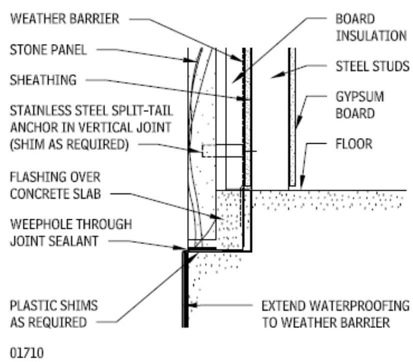


Figure 2.328

It is desirable for a single source to provide most if not all of the components required for the enclosure (most commonly available with all curtain wall buildings). Unfortunately, the construction industry is not prepared to address that desire when there are multiple trades involved. Work with local trade groups and CMs to establish if it is possible to find a contractor or sub-contractor who will provide all of the components of a BVDC or PER Wall Assembly before issuing a specification that includes a single source requirement.

Specify performance criteria with the product providing the performance, e.g. ACM panels frequently do not provide air tightness but it is common to see air tightness criteria included in the ACM panel spec section. This inconsistency causes confusion with the construction team.

Specify each product with a unique name tied to the drawings so there is no question of what material is desired. For example, instead of “FLASHING” which can be specified in a dozen sections, use something more specific such as “AIR BARRIER TRANSITION FLASHING”.

Coordinate between the various technical spec sections, especially for products that bridge the cavity. For example, wall flashing speced in one section has to be connected to the AB/WRB speced elsewhere. Girts and girt anchorage must be coordinated with the cold formed metal framing spec to ensure proper structural support.

Ensure that outdated construction technology instructions, such as thru wall flashing embedded into CMU back-up wythes, are edited out for the more current AB/WRB membrane.

It is common for some aspects of a BVDC or PER wall assembly to be specified using delegated design. It is crucial that the documents clearly describe the extent of the delegated design (e.g. just the stud back-up wall or the entire wall) and must include all performance criteria and the method to validate compliance with the criteria (e.g. signed and sealed shop drawings with calcs and/or mock-ups with testing). If delegated design is utilized, then the drawings must represent a realistic solution to the delegated design in order for the architect to maintain sufficient control (e.g. the space allowed for internal girts must be deep enough for the required span conditions).

CONSTRUCTION

The drawings and specs are completed and a good team of contractor’s, subs and suppliers has been selected. Now it is time to actually get these high performance walls built. Please refer to “Construction of Rainscreen Walls” by Drake Wauters, part of this series of articles, for the next steps.

CONSTRUCTION OF RAINSCREEN WALLS

By Drake Wauters, AIA

Construction of successful building enclosures for high performance buildings including rainscreen walls require attention to some basics when creating bidding documents, during bidding, and throughout construction. Construction is arguably where the Owner's Project Requirements (OPR) and the architect's design cross from vision to execution. This crossing point between what has been designed and what is being offered and delivered by the construction team requires clear design intentions, attention to the bidding process, confirmation of compliance throughout construction, and attention to close-out documentation.

Regardless of the specific systems proposed, construction delivery method employed by the owner, testing and inspection required, or whether building enclosure commissioning services are provided on a given project, the best results are more likely when information at each step is as complete and coordinated as possible. The desired level of quality needs to be pursued throughout the entire process. A baseline to help assure high quality exterior building enclosures will likely include peer review during design, quality reviews and backchecks during creation of the bid documents, analysis of bids and qualifications, and inspection and testing during construction.

The two types of multilayer exterior wall approaches in greatest use in the US today are Pressure-Equalized Rainscreen Wall Assemblies (PER) compliant with AAMA 508-07[1] and Back-Ventilated Drained Cavity Wall Assemblies (BVDC) compliant with AAMA 509-09[2]. While a PER is arguably the best approach for most projects, the following discussion points may be applied to PER and BVDC walls assemblies. Note also that use of the last three less commonly used wall types of the five primary exterior wall types listed in the Eleventh Edition of the Architectural Graphic Standards may also benefit from this discussion. These include Mass Barrier Wall Assemblies, Face Sealed Barrier Wall Assemblies, and Drainage Plane Wall Assemblies. Refer to David Altenhofen's article in this issue for further description of the five basic exterior wall types.

Since multilayer exterior wall assemblies are comprised of performance rated control barriers concealed in the final construction, great care may be warranted during construction to assure that documentation of concealed work is clear and performance is verified through inspection and testing to assure systems are built correctly and perform at the levels specified before they are enclosed. This applies as equally to wall systems that use mortared brick and/or stone veneers as to mechanically removable panels because disassembly of any multilayer wall to access air or water leaks or thermal insulation failures is costly and may lead to new complications. Removing wall systems considered removable or accessible such as cassette metal panels or extruded terra cotta should only be a last resort as components of the wall system may be damaged during access, storage, and reinstallation. Such damage may not be discovered or effectively remedied when the disturbance occurs, which may lead to additional challenges to performance and reliability down the road. Further, reinstallation of shiplapped or interlocked panels may require modification to panels or supports from original installed conditions that could lead to future complications or the creation of undocumented conditions.

Special attention to photography during construction of the exterior building enclosure may be helpful. This could include routine progress photos as well as additional photos during critical periods and of important conditions such as construction of flashing, expansion joints, air barriers, point connections, and during in-place testing. Besides initial construction, rework may also be photographed. Whether part of the commissioning process, the lender's progress verification, the architect's construction phase services, the contractor's own record keeping, or professional contract photography, the photography may be most useful if accessible to the entire project team as soon as possible after the shots are taken. Image files may be posted to a secure database and kept for project closeout documentation and project archives.

As with all building enclosure systems, PER walls need to be built correctly to perform as planned. This often includes testing for air and moisture barrier continuity and leakage prevention before these control barriers are concealed behind insulation, enclosure supports, or the final rain screen. Insulation barriers may also be tested for installed continuity and u-values with thermography or other methods. Actual installed insulation values are critical particularly where condensation damage risks are high due to the local climate and use of the building. However, reaching the OPR energy use goals suggests that we understand the walls as-built and whether our actual building enclosure u-values and air leakage rates meet the conditions assumed in creating the project energy model.

Institutional owners such as the US Army Corps of Engineers (USACE) have been leading owner-driven improvements for some time by requiring building enclosure air leakage testing and assurance of compliance with standards such as ASTM[1] E2178-11, E2029-11, E1827-11, E1677-11, E1424-91, E1186-03, E779-10, and E283-04. Additionally, the USACE and the Air Barrier Association of America (ABAA) have issued the "Air Leakage Test Protocol for Building Envelopes" (Version 3) which lays out clear protocols as well as low whole-building air leakage benchmarks. The US General Services Administration (GSA) has also included whole building air leakage testing in the latest version of their general specification P100 "Facilities Standards for the Public Buildings Service." This elevating level of attention to building enclosure performance is becoming more common each year we move closer to meeting nationwide goals such as the AIA 2030 Challenge to deliver energy neutral buildings.

The following series of questions may help project teams, especially during peer review and the construction phase of building enclosures, avoid issues before they occur and, if they arise, resolve them during construction. These may seem obvious however, it is often and ironically, the simplest ideas that elude even the brightest professionals in their pursuit of high performance or perfection.

Are the PER walls described adequately in the bid documents? If information cross-linked between drawings, details, and specification sections is not coordinated and complete then misunderstandings may occur and affect the bidding phase or may surface later during the construction phase. Through delegated design, is the contractor being asked to design systems and components or is the very intent of the building enclosure open to their interpretations? Contractors require clarity to earnestly bid any set of documents. Asking competitive bidders to over interpret design intent may lead to deficiencies. In seeking the lowest price to win a project, contractors should not be expected to assume systems are more costly or complex than indicated in drawings and/or mandated in the specifications. If the contractor did not include something in their price, the last stage the design team or owner wants to find this out is when they have received a time-critical construction phase submittal, yet this is not an uncommon event.

Are the control barriers for air, moisture, vapor, thermal loss, and sunlight defined clearly in elevations, wall sections, and details? Is nomenclature clear and consistent throughout the specifications and drawings notes? For instance, flashing can act as an air barrier, a waterproof membrane, or a weather resistive barrier or all three. Is this defined in each instance? Barriers can be vapor impermeable (less than 1 US perm), vapor semi-permeable (1-10 US perms), or vapor permeable (more than 10 US perms) based on rates of water vapor transmission (WVT) as defined in ASTM E96[4]. These are often grouped in to breathable and non-breathable control barriers by materials vendors that may lead to confusion. Use of a WVT perm range for each material in the bid documents may help clarify requirements. Is it clear in the bid documents which systems are required at each location in the design? If used, are the terms "vapor retarder" and "vapor barrier" clearly defined and not used interchangeably? Is the term "rainscreen" correctly used as an external control barrier that excludes liquid water from the concealed barriers of the PER as defined by AAMA 508?

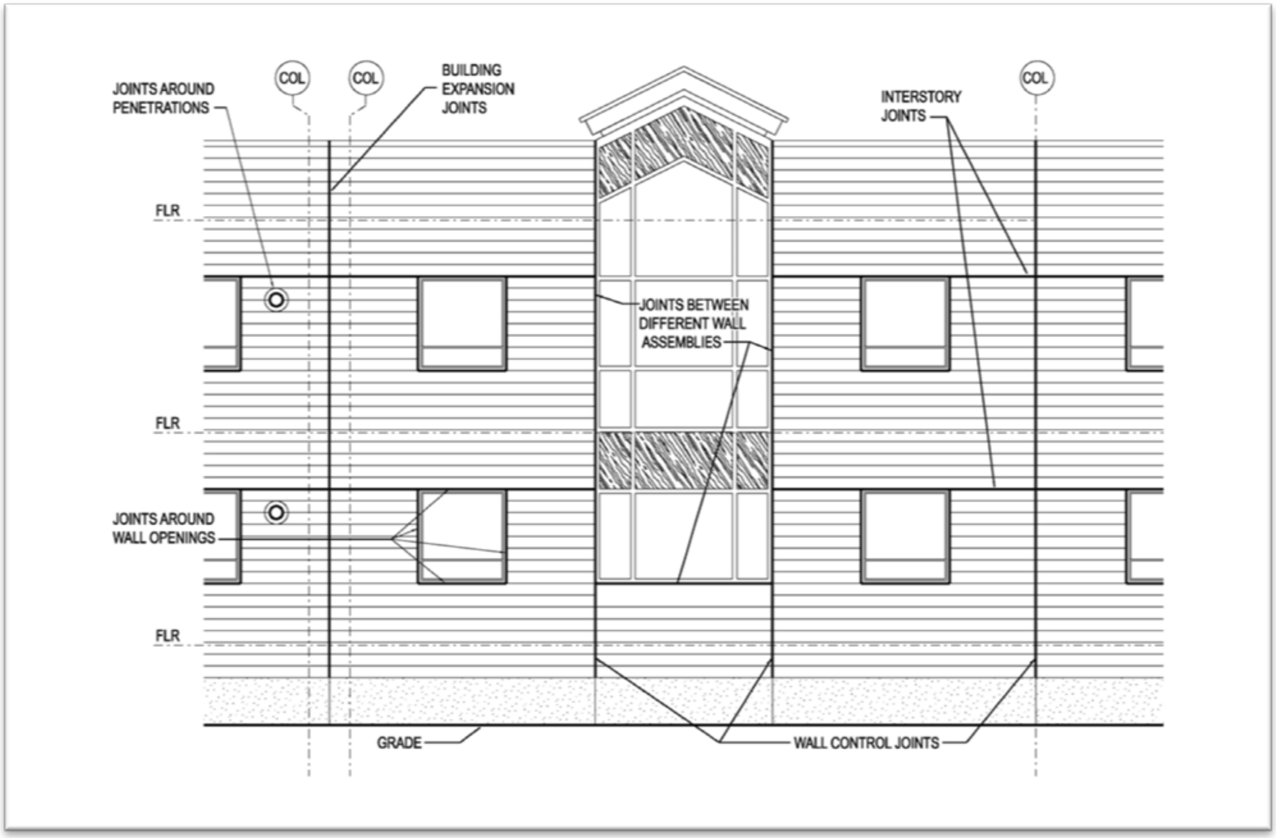
Is a published glossary of terms cited as a basis for definitions or are the terms defined in the contract documents? What seems like a simple misunderstanding may result in troublesome mistakes and lead to significant claims. Such misunderstandings may be even greater if the work is international. For instance, those who created the bidding documents are from one country, the bidders may be from many countries, and the project will be permitted and constructed in still another country. Definitions for terms in each nation involved may differ dramatically.

Have the PER walls been described as a system or as systems and is the demarcation between delegated design for systems and other non-delegated design work clear? For instance, it is common for distinct delegated design such as glazed curtainwalls, cold formed wall framing, enclosure panels, and subframes to be intertwined with design work not delegated such as masonry, sheathing, air/moisture barriers, sealants, insulation, and flashing. Responsibilities and work points between delegated design systems and other assemblies may need to be well defined in the drawings and specifications. In doing so, the architect may avoid misunderstanding by setting a clear basis for bids and the scope of construction phase submittals such as shop drawings, calculations, and tests. For instance, is the inter-story slip-connection in a PER in effect one vendor's subframe sliding up and down directly against another vendor's self-adhering air barrier in direct contradiction to the approved published use for that air barrier? To help address these challenges, all aspects of the building enclosure, or at least the PER walls, may be assigned to a specialty contractor to create a single source of responsibility for the work. If this is not possible due to the nature of local trades and vendors or the bidding climate, electing to use enhanced commissioning may help assure that the different parties work together as seamlessly as possible.

Is coordination clearly called for in the specifications under the summary and related sections and under description of shop drawing requirements? Are related submittals identified and specifically required to be coordinated in applicable specifications? Are regular exterior building enclosure coordination meetings required in the specifications throughout the submittal, installation, and testing periods? Are the minutes of coordination meetings detailed and inclusive of all matters discussed and agreed to?

Have bidding instructions, bid phase RFI answers, or qualifications issued by the Contractor changed the scope or design intent of the PER walls? For instance, the architect may have called for complete shop drawings to detail the air/moisture barrier but during bidding, the contractor qualified that the air barrier would be detailed completely on the construction drawings and the owner may have agreed. A detailed air/moisture barrier with enough information to explain to the trades how to build the air barrier at every single condition could add dozens of details to a typical drawing package. Has the architect expanded their drawing package to capture this assumption? Have the specifications been amended to clarify this change in direction? Did the owner perhaps inadvertently expand the architect's scope of services?

Has the delegated design been assigned to an engineer registered in the state where the project is located? If not, has the design work in fact been successfully delegated? For instance, a local product reseller may hire a drafting firm to prepare shop drawings. Does the authority having jurisdiction accept those shop drawings as a delegated design package? Most likely not if the preparer or certifier of the shop drawings is required to be an engineer in the same state as the project. If the detailed design has not been effectively delegated then the architect may in fact be responsible for detailed information reviewed such as selection of metal gages and alloys, travel distances on slip connections, and sizes and types of anchors shown. A blanket assumption that contractor's means and methods protect the architect from liability in such instances may not be founded. Means and methods as to how work is planned and sequenced or how safety is addressed may have little bearing on delegating design responsibility. For instance, if the drawings show a PER with ribbed sixteen-ounce copper panels without backup or stiffeners and the specification does not call for engineering of the cladding by the contractor, the architect in fact has not likely delegated this work. The ounce weight, alloy, panel size, anchors, and rib profiles as defined by the architect could be considered the final detailed design regardless of whether it can resist deforming under wind loading or when impacted by maintenance craft using a boson's chair or swing stage.



Have the building facades been mapped during design to show active joints that address differential movement (see illustrated example above)? Have these joints and the related transitions been captured in both delegated and non-delegated design submittals from the contractor? Have they been expressed clearly on the bid drawings? Are all modes of movement defined and is joint movement predicated on the correct thermal swings above and below the installed temperature range, differential structural deflection, and building drift affecting the assemblies? For instance, white colored wall panels will expand and contract less than black wall panels as high temperature in summer sun in many regions can be 40-50 degrees F greater for black materials than white materials. Simply assuming bidders will account for the complexity of providing these active joints without some design intent direction may lead to confusion during construction. Complete mapping of all insulated air/moisture barrier active joints may lead to more accurate bids as assumptions made during the bidding phase without information could differ greatly between bidders. The bidder who seeks to win a project on lowest cost may not have assumed more active joints or transitions are required than indicated on the bid drawings.

Are transitions between building components accurately addressed in both design intent and in the construction phase submittals for PER walls? For instance, a three-story curtainwall forms a parapet yet the wall parapets flanking this condition are directly supported on the roof framing and faced with PER while the curtainwall is supported at least a floor below with fixed connections. Interstory deflection plus the story or more thermal swings of the curtainwall have created the need for active joints such as insulated air/moisture barrier bellows assembly conditions through the coping and down the parapet. Is this clear in the bid documents or are the various trades and vendors to assume and bid such complicated work when competitors may overlook such costs and win the project?

Has completion of all material compatibility tests been called for prior to approval of each material proposed for use in the construction? Specifications should be clear with regard to the level of preconstruction testing and validation required and that testing needs to accurately address expected conditions specific to the project. The responsibility of the contractor to provide compatible materials should be both product and use specific. For instance, adhesion between materials may be predicated on certain thermal conditions and limits on shearing movement that are in fact exceeded at certain conditions in the building.

When required, has the wall assembly combustibility test NFPA 285, the "Standard Fire Test Method for Evaluation of Fire Propagation Characteristics of Exterior Non-Load-Bearing Wall Assemblies Containing Combustible Components," been referenced correctly in the design and in the submittals as a tested assembly? Do the wall assemblies submitted comply in all regard to the complete wall assemblies tested including specific products included in the test? If variations to previous NFPA 285 test assemblies are proposed have project specific tests been included in the price and schedule? If engineering judgments are proposed to address variations between previous successful NFPA 285 tests, has the authority having jurisdiction approved the use of such judgments? The scope of 285 as written on the NFPA site reads: "This test provides a method of determining the flammability characteristics of exterior, non-load-bearing wall assemblies/panels. The test method described is intended to evaluate the inclusion of combustible components within wall assembled/panels of buildings that are required to be of non-combustible construction. It is intended to simulate the tested wall assemblies' fire performance." NFPA 285 should not be referred to out of context, such as describing a single product or material, as it only applies to complete wall assemblies.

Have the bidders successfully proposed substitutions during bidding as required in most specifications? Are the proposed substitutions accompanied with complete information as to how the alternate product and details will meet the specifications and detailed intent and the project performance criteria? Are ramifications such as additional testing and acceptability of engineering judgments addressed in the request? If not requested during bidding but after project award, are established grounds for considering substitutions after award fully addressed in the request? Has the owner been included in the decision process to review and possibly accept substitutions or were substitutions incorrectly included in construction submittals without prior approval by the owner and architect? Are change orders required to address the substitution and insure that cost reductions are passed through to the owner while schedules are not impacted? Will the substitution result in cost shifting and lead to change orders from other impacted trades or redesign and drawings and specification bulletins? Does the substitution require modifications to the permit documents on file?

Are mockups detailed in the bid documents and do the mock-up designs capture the important features and transitions expected in and around the PER wall construction. If mockups are not defined clearly, bidders are unlikely to include the level of detail the owner and architect may require. Are mockups to be tested and if so are they to be tested as installed or at a test facility? Have the contract documents been conformed to the decisions made during the mockup review? Do the construction phase submittals include the decisions made based on the mockup? For instance, if an air/moisture barrier of sealant on backer rod indicated in design drawings is changed to a bellows assembly during the mock up review or any point during the construction administration, it may be best to capture this in the as-built drawings. We often speak to the importance of BIM (Building Information Modeling) but where design intent is graphically or materially changed during construction, it should be reflected in the as-built model and documents to help eliminate confusion during operation of the facility.

Has the design package been peer reviewed before being issued for bid? AIA best practices call for design peer review but skipping this critical stage of the design may be tempting when aggressive schedules or contracts are faced. Where does one imagine the conversation is headed during the tense discovery process after claims are made and the architect admits that design peer review was skipped despite it being called for in accepted best practices? Once it is established that best practices were overlooked, the momentum against the architect may make almost any claim harder to dispute. Have the bid documents been checked for clarity and completeness and have backchecks assured all comments were incorporated in the manner the reviewer intended?

Is Building Enclosure Commissioning (BECx) provided on the project? ASTM E2813-12 the “Standard Practice for Building Enclosure Commissioning” is one established standard for the provision of building enclosure commissioning. If commissioning is not to be provided, how will the many important tasks be completed and tracked such as verifying and tracking compliance with the OPR; assuring construction testing and inspection are completed, timely, and successfully recorded; assuring mock-ups are completed and issues are resolved and tracked; and assuring that training and close-out documentation is completed? If commissioning is not provided, the entire team from the owner, to the architect and consultants, to the contractor need to essentially fill the roles of the commissioning agent themselves in one way or another. This may be easier said than done in most cases particularly since most owners do not have the dedicated or trained staff to meet the many challenges of managing the detailed information and confirmations required in creating high performance buildings.

How are construction phase submittal requirements being scheduled and tracked? Are submittals scheduled in a manner that allows for critical review, correction, and resubmission or are submittals being scheduled for late submission when the pressure to approve incomplete and uncoordinated package may be very high? How are required close-out documents being tracked and verified such as completed test results, completed warranties, completed operations and training manuals, owner training sessions, coordinated BIM files, and complete and well documented as-builts? Again, if commissioning is not provided, are the architect and owner otherwise providing the detailed services necessary to manage the construction phase services and assure compliance with every requirement?

Has construction inspection been provided for the PER walls? Is inspection required by the authority having jurisdiction, the lender, and/or underwriter? Were air/moisture barriers including active joints and transitions inspected? Were both fixed- and slip-connections for PER cladding systems inspected? Were fire barriers such as at floor lines or above wall openings inspected? Was application of insulation in cavities inspected for continuity, support, and anchorage? Are means to prevent air washing of PER wall cavity insulation comprehensive and well installed?

Do the building expansion joint construction submittals integrate clearly with the PER wall submittals? Are transitions at parapets, roof edges, terrace edges, and rainwater overflow conditions clearly detailed including expected differential movement accommodations? Differential movement of assemblies, rainwater flow at normal and overflow conditions, and materials compatibility need to be confirmed prior to fabrication and installation of the impacted work. Misunderstandings may be especially likely where the PER walls meet the roof or foundation and subsurface work.

Have the insurers for either the architect or contractor issued advisement on building enclosures and in particular PER walls? Insurers may have advised that exterior walls for new buildings use PER techniques in response to moisture damage claims due to failures of mass walls or face-sealed walls. In doing so, their terms may include requiring compliance with critical rainscreen principles such as pressure equalization. As with best practices, not following insurer advisements may be cited as poor professional performance during a legal challenge.

Are construction phase submittal certifications from the contractor issued by the correct party and are they applicable to the project at hand? For instance, if the local reseller or product representative agency state that products and systems meet project requirements this may not meet the requirements in the specification that the manufacturer directly certify compliance of their product or system. A certified testing agency authorized by the manufacturer or an officer of the manufacturer may be the only parties authorized to issue certifications on behalf of the manufacturer. Short of that, statements submitted as certifications may in fact only be marketing language. Owners and architects should be vigilant where certification is required. Similarly, certification may be valid for only a limited time or only when the product is used in specific locations and applications. If used outside these conditions the certification may have no validity.

In closing, avoiding misunderstandings is a pillar of success in any undertaking but where exterior building enclosures are concerned all parties may need to participate[5] in helping assure that what has been planned is bid correctly and what has been bought is in fact built correctly.

Footnotes:

1. AAMA 508-07 “Voluntary Test Method and Specification for Pressure Equalized Rain Screen Wall Cladding Systems.”

2. AAMA 509-09 “Voluntary Test and Classification Method for Drained and Back Ventilated Rain Screen Wall Cladding Systems” - Refer to David Altenhofen’s article in this issue “Rainscreen and Back-Ventilated Drained Cavity Wall Systems - Practical Applications for High Performance Buildings” for discussion of AAMA 509-09 applicability and limitations regarding Back-Ventilated Drained Cavity (BVDC) walls.

3. ASTM E2178-11 “Standard Test Method for Air Permeance of Building Materials”

ASTM E2029-11 “Standard Test Method for Volumetric and Mass Flow Rate Measurement in a Duct Using Tracer Gas Dilution”

ASTM E1827-11 “Standard Test Methods for Determining Airtightness of Buildings Using an Orifice Blower Door”

ASTM E1677-11 “Standard Specification for Air Barrier (AB) Material or System for Low-Rise Framed Building Walls”

ASTM E1424-91(2008) “Standard Test Method for Determining the Rate of Air Leakage Through Exterior Windows, Curtain Walls, and Doors Under Specified Pressure and Temperature Differences Across the Specimen”

ASTM E1186-03(2009) “Standard Practices for Air Leakage Site Detection in Building Envelopes and Air Barrier Systems”

ASTM E779-10 “Standard Test Method for Determining Air Leakage Rate by Fan Pressurization”

ASTM E283-04(2012) “Standard Test Method for Determining Rate of Air Leakage Through Exterior Windows, Curtain Walls, and Doors Under Specified Pressure Differences Across the Specimen”

4. ASTM E96-12 “Standard Test Methods for Water Vapor Transmission of Materials”

5. Link to a sample proposed checklist based on this article