Understanding Moisture Penetration of the Drainage Plane: A Building Science Principle
Why is this relevant to the IAQ professional?

- The fundamental role of any structure is to keep water out.
- The drainage plane constitutes the elements that protect the structure and prevent water penetration.
- Understanding how water penetrates a structure is necessary to identify why indoor air quality may be impaired.
The Four Basic Rules of Water Damage

• Porous materials “suck” via capillary action
• Water vapor diffuses from a higher to a lower concentration gradient
• Air carrying water vapor moves from high pressure to low pressure
• Water runs downhill by gravity
Basic Rule of Water Damage No. 4

- Water runs downhill by gravity (i.e., roof and flashing leaks, attic condensation)
Five Forces of Rainwater Penetration

- Gravity
- Surface Tension
- Capillary Action
- Momentum (Kinetic Energy)
- Air Pressure Differences
Which forces of drainage are shown?

1. Drip Edge
2. Stucco Cracks
3. Failed vent cover

Gravity
Surface Tension
Capillary Action
Momentum (Kinetic Energy)
Air Pressure Differences

QUIZ Question
Four Strategies to Prevent Rainwater Penetration: 4 D’s

• Deflection
• Drainage
• Drying
• Durable Materials

Stave Church at Urnes, Norway – Norway’s oldest stave church that dates back to the early 12th century in its present form. Wooden components of an even older church were used to build it.
Deflection

• Deflection is the first principal in water management.

• The intent is to keep rain off the building façade and minimize penetration of the building envelope.

• This part of a building system sheds water away from roofing and siding finishes, as well as any sheathing panels or water resistant membranes.

• Pitched roofs, deep eaves or overhangs that deflect water away from the walls, proper flashing around windows and doors, and sealants applied to penetrations and joints.

![Bar chart showing percent of all walls with problems based on overhang width.](chart.png)
**Recommended Minimum Roof Overhang for 1 & 2 Story Buildings**

<table>
<thead>
<tr>
<th>Rainfall</th>
<th>Eve Overhang</th>
<th>Rake Overhang</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;20 inches</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>12 to 40</td>
<td>12</td>
<td>12</td>
</tr>
<tr>
<td>41 to 70</td>
<td>18</td>
<td>12</td>
</tr>
<tr>
<td>71 and above</td>
<td>24 or more</td>
<td>12 or more</td>
</tr>
</tbody>
</table>


What do these homes share in common?
Outside New: Surface water drainage

• Poor drainage & high water table conditions threaten slab-on-grade homes
• Landscape irrigation and water reuse programs can exacerbate drainage problems
• This phenomenon is known as “Damp Rising”

Developer discretion
Wicked water evaporates inside the building.

Forces of attraction pull the water up the concrete wall.

Water wicks in top of footing.

Poorly installed drain tile enables water ponding.

Lumber-formed footing.

Water ponding.

Poorly sloped excavation enables water ponding.

Water wicks in bottom & sides of footing.

Impermeable soil.
A damp proof or water proof membrane must be attached to the outside. A vertical drainage layer can be added to provide a pathway for the water to the drain tile.
Drainage

• This part of a building system sheds water away from roofing and siding finishes, as well as any sheathing panels or water resistant membranes.

• Pitched roofs, deep eaves or overhangs that deflect water away from the walls, proper flashing around windows and doors, and sealants applied to penetrations and joints.

Diagram from J.F. Straube, Ph.D., PE
Wood Materials Exposed to Moisture
Solid Pine: Repeated Wetting and Drying
Exterior Grade Plywood: Repeated Wetting and Drying
OSB: Repeated Wetting and Drying
Bad Marriage
Case History 5417

Owners of newly purchased home experience musty odors and respiratory irritation.

Examination of home reveals no apparent plumbing leaks or water infiltration from irrigation sources.

Windows reveal exterior separation of drainage plane and burglar installation methods that breach the window sill drainage plane.
Bad Marriage
Case History 8209

Water damage and microbial growth were observed in first floor Kitchen window

Water damage was beneath windows on both first and second floors

Aluminum windows were positioned inset from the exterior drainage plane to give the appearance of a CMU wall

Second floor windows were installed without flashing. Repair required replacement of all windows on second floor

Original window installation (face seal) converted to concealed
Paint

- Moisture penetrates the exterior wall in both directions
- In the heating season, water vapor moves inside to outside
- In the cooling season, water vapor moves from outside to inside
- When is the temperature gradient most severe?
Permeance Ratings*

- Vapor impermeable: 0.1 perm or less (Class 1)
- Vapor semi-impermeable: 1.0 perm or less and > than 0.1 perm (vapor retarder) (Class II)
- Vapor semi-permeable: 10 perms or less and > 1 perm (Class III)
- Vapor permeable: > than 10 perms

“Perm” is a unit of measurement used to characterize permeability
General Classes of Permeance

Impermeable
- Rubber membranes
- Polyethylene film
- Glass
- Aluminum foil
- Foil-faced insulated sheathing
- Vapor semi-impermeable
- Oil-based paints
- Vinyl wall coverings

Vapor semi-permeable
- Plywood
- Bitumen impregnated Kraft paper
- OSB
- Elastomeric paints
- Most latex-based paints

Permeable
- Unpainted gypsum board and plaster
- Some latex-based paints
- Housewraps
Caulking

CAULK TYPES
• High performance silicone
• Polyurethane
• Polysulphide
• Thermo-plastic elastomeric
• Acetoxy silicones
• Mildew resi
• Acrylic
• Butyl
• Acoustical
• Oil-based

• Choosing the right caulk requires an understanding of its limitations

• Movement capacity is one of the most important factors when selecting a caulking product, especially if the joint moves in response to solar heating, changes in moisture or structural movement

UV light resistance, compatibility, life expectancy, joint design also affect this decision
<table>
<thead>
<tr>
<th></th>
<th>Low Movement Caulking</th>
<th>Medium Movement Caulking</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Application:</strong></td>
<td>Slight or infrequent joint movement</td>
<td>slow moving joints <em>i.e.</em>, masonry control joints</td>
</tr>
<tr>
<td><strong>Types:</strong></td>
<td>bituminous rubber, oleoresinous and butyl rubber</td>
<td>Plasto-elastic caulking including acrylic latex, acrylic solvent and butyl and thermoplastic elastomerics (kreytons)</td>
</tr>
<tr>
<td><strong>Restrictions:</strong></td>
<td>should not be applied to joints in constant movement cycles or large deflections and protected from the weather</td>
<td>Maximum Joint Movement: below 25% of joint width</td>
</tr>
<tr>
<td><strong>Maximum Joint Movement:</strong></td>
<td>below 5% of the joint width</td>
<td>Service life: 5-15 years for plasto-elastic and 10-20 years for elasto-plastic material</td>
</tr>
<tr>
<td><strong>Service life:</strong></td>
<td>2-5 years when used in exposed exterior applications</td>
<td></td>
</tr>
</tbody>
</table>
Improper application of Bituminous sealant on medium
To high movement joint, Orlando

Mark Meshulam, Chicago Window Expert, Window Sealant Failure
High Movement Caulking

Application: Large or fast moving joints between metals and window frames

Types: One and two part polyurethanes, acetoxy and neutral cure silicones

Service Life: 10-25 years
## Caulking Use Summary

<table>
<thead>
<tr>
<th>Caulking</th>
<th>Durability</th>
<th>Application</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low Movement</td>
<td>Low</td>
<td>Suitable when low movement is expected</td>
<td>Butyl rubber</td>
</tr>
<tr>
<td>Caulking</td>
<td></td>
<td></td>
<td>Synthetic rubber</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Oil based</td>
</tr>
<tr>
<td></td>
<td>High</td>
<td>Indoor application suitable for small joints with limited movement</td>
<td>Acrylic latex</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Thermoplastic</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>elastomerics</td>
</tr>
<tr>
<td>High Movement</td>
<td>High</td>
<td>Suitable for indoor and outdoor applications</td>
<td>Neutral cure silicones</td>
</tr>
<tr>
<td>Caulking</td>
<td></td>
<td>Long service life expected</td>
<td>Acetoxy silicone</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Polyurethanes</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Polysulphides</td>
</tr>
</tbody>
</table>

Air Leakage Control Manual, Existing Multi-Unit Residential Buildings, CMHC, 2007
1. Face-Sealed Barrier Walls

- Face-sealed walls are essentially impermeable to water and air
- The surface is exposed to extreme temperatures and solar radiation that impose stress on joints between cladding and other components
- Sealant durability is diminished requiring regular maintenance and replacement
- Relatively low costs encourage face-sealed construction; however, ongoing maintenance will be costly

Examples
- Stucco on block
- EIFS
- Log cabins
2. Drainage Cavity Wall

• Drainage cavity represents a typical brick veneer wall and many cladding systems that use stone or metal panels

• Drain holes serve as vents and protect against water penetration by capillarity, surface tension and gravity

• This strategy is intended to collect and control rainwater that passes through the exterior cladding
3. Internal Drainage Plane Wall

- This is common with stucco applications that use building paper or a non-perforated building wrap as a water barrier.
- A drainage screed is located at the base to increase drainage and improve drying.
Drainage Plane: Stucco Cracking

- Stucco systems vary in construction sequence
- 3 layer (scratch, brown, final) requires uniform application of wire mesh
- Stucco must not dry too quickly
- Intimate contact between the stucco and drainage plane allows penetration
- Corrosive substances threaten the wire mesh in stucco

*Construction Skill Level*
4. Pressure-Equalized Rain-Screen Wall

- A pressure-equalized rain screen (PER) is a drainage cavity wall that is designed so that the air pressure behind the cladding is similar to the exterior pressure.

- This strategy is commonly used metal and glass curtain walls.
Pressure-Equalized Rain Screen

• Rainscreen systems allow air to flow into the base and out the top
• Water that enters the system is removed by ventilation and by gravity down the rear face
Western Red Cedar Siding: Cooler Climates

- This wall assembly is well suited to high interior humidity
- Water vapor migrates through the wall assembly from the warm interior to cold exterior: note the location of the vapor barrier
Face Seal/Barrier-Type Systems: Problems

- Ineffective exterior seals from improper installation or ageing of materials
- Odd shaped, custom or EIFS windows are often sealed to form a barrier against water penetration
Water Penetration Resistance Strategy: 2. Drainage

• This strategy assumes water penetration will occur through the primary exterior glazing seal and joints of the window assembly; however, its design collects the water and directs it to the exterior.

• This is a preferred strategy because the design is redundant and is not dependent on exterior seal maintenance because water penetration is assumed to occur.

Commercial Windows

• Weep holes that were used, blocked or drilled?
Drainage: Problems

- Interior water penetration from poorly functioning internal system seals or water overflowing horizontal members, such as sills.
- Sill members should be designed to accommodate anticipated water height within the system, which is based on design wind pressures.
- Defects may also contribute to interior leakage.
Water Penetration Resistance Strategy:
3. Concealed Barrier

- Exterior surface and joints of windows are sealed or the curtain wall is sealed permanently to prevent water penetration.
- This strategy uses exterior gaskets and sealants.
- Failure results in water accumulation within the framing and penetration into the building.
- This design strategy accepts the idea that some water may pass behind the face of the window (or cladding). These windows and walls incorporate a drainage plane within the window (or wall) assembly.
Water Penetration Resistance Strategy: Concealed Barrier

- Strategy for rain penetration where the water shedding surface is behind the cladding rather than the exterior moisture.
Water Penetration Resistance Strategy: Improved Concealed Barrier
Water Penetration Resistance Strategy:
4. Rain Screen/Curtain Window

- **Curtain Wall/Window:** Typically used for high performance aluminum framed wall systems.
- Less condensation; cavity breathes and dries
- Outer panel purely esthetic
Rain Screen/Curtain Wall: Problems

- The lack of a sealant can pose challenges
- There may be a lack of responsibility for water penetration between the manufacturer and installer
- The A/E’s depth of knowledge may be limited

R. Keleher, AIA CSI LEED, Rainscreen Cladding Systems, North Clad Rainscreen Solutions, 2009
Residential Foundations: Basement, Crawl Space, Pier Foundation, Concrete Slab
Basement Foundation

- Common throughout the country
- Built using concrete perimeter of pillars that support structure
- Usually dug to a minimum depth of 8 feet
- Pros: added space, storage, natural ventilation, cooling mechanism
- Cons: Cost, moisture penetration, mold, often attains dew point temperatures

IAQA Investigation Perspective

Finished Basements

- Obscured identification of leaks
- May contribute to air quality concerns

Unfinished Basements

- Easy identification of leaks above and adjacent to basement
- Facilitates access to repair plumbing leaks

IAQA
Crawlspace Foundation

- Three to four feet high and are used when water table conditions are high or soils are difficult to dig
- Supported by concrete pillars or poured wall systems
- Pros: Best for high water take conditions, may facilitate cooling in summer
- Cons: Heat sink in winter, prone the moisture accumulation when poorly ventilated, may accumulate water, should be sealed
Pier and Beam Foundation
• Constructed using circular or square pads of concrete positioned around the outer perimeter.
• The pads are inserted and secured into the ground with treated lumber or steel rods
• Pros: Ideal where a traditional foundation may not be possible
• Cons: may leak to creaking and sagging floors as well as issues of poor ventilation
Concrete Slab Foundation

• Most common foundation
• Slabs are four to eight inches thick and reinforced with steel rods
• Pros: Inexpensive and quick foundation to build, no air space beneath
• Cons: difficult to repair plumbing leaks, limited protection from flooding, absorbent
What is the reoccurring theme of this presentation?

A. All components of drainage plane are in motion

B. Buildings that integrate materials that move together . . . will last longer

C. The most important attribute of a building is to keep it dry

D. The principles of effective construction have been known for centuries

E. Air quality consulting requires a comprehensive understanding of building construction and moisture management
Questions?

Ralph Moon
Ralph.Moon@ghd.com