BUILDINGENERGY BOSTON

Windows and Fenestration: Basics and Beyond

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Northeast Sustainable Energy Association (NESEA)
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Building Science Corporation

BUILDINGENERGY BOSTON
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Conference + Trade Show of the Northeast Sustainable Energy Association (NESEA)

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Course Description

Windows are a key part of the building enclosure, but they are also the costliest, most fragile, and worst thermally performing component. We will present on windows from our viewpoint as building enclosure consultants and forensic failure specialists. We will explore energy and comfort impacts of glazing and glazing ratios, and then move on to water control detailing and the window-to-wall interface. Covered topics will include sill pan and rough opening flashings, “innie” vs. “outie” windows in thick walls, two-stage joints and drainage, air barrier detailing, condensation problems, and window water leakage testing. We will also discuss storefront and curtain wall glazing systems and their associated detailing.

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Learning Objectives

At the end of this course, participants will be able to answer:

1. Weigh the energy impacts associated with glazing and glazing ratios.
2. Implement the concepts for sill pan designs and window-to-wall interface junctions.
3. Estimate the relative condensation risks associated with various window materials and designs.
4. Explain the water control and thermal detailing differences between storefront and curtain wall glazing.

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Housekeeping

- Slides will be available on website (https://www.buildingscience.com/past-events)
- Resources: list of links at end of presentation
- Questions—during plus reserved Q&A time at end

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Presentation Overview

- Windows and Energy
- Window Design and Detailing
  - General Concepts
  - Applied Concepts
    - Residential Windows
    - Commercial Windows
- Window Energy Performance
  - Alignment with insulation
  - Condensation
  - Comfort

- **NOT covering**
- Retrofits (renovation of existing windows, storm panels, etc.)
- Skylights (windows that face the sky)
- Unitized Curtain Walls
- Window Air/Water Testing In Depth (only overview)

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Windows and Energy

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Windows/Fenestration

- Functions: Same as wall - *plus*
  - transparent and allow ventilation (possibly)
  - not easy, hence expensive and compromise
- Structure - transfer loads
- Rain control
- Heat control
- Airflow control – tight / ventilation
- Solar control – gain / reject

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"Window Make for Lousy Walls"

	Window	Wall	Ratio
Conduction: $Q_c = U\,\Delta T$	**U=0.33 / R3**	**U=0.05 / R20**	
T_{in}=70 F **T_{out}=10 F**	**Q_c= 20** Btu/sf/hr	**Q_c= 3** Btu/sf/hr	**6.6**
Solar: Q_s = SHGC I	**SHGC=0.60**	**SHGC=0.015**	
I_s= 250 Btu/sf/hr (bright sun)	**Q_s= 150** Btu/sf/hr	**Q_s=3.5** Btu/sf/hr	**42**
Alternate: solar control glazing	SHGC=0.3 Q_s= 75 Btu/sf/hr	U=0.125 / R8 Q_c= 7.5	10

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So Of Course, We Usually Build These…


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So Of Course, We Usually Build These…

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Performance Issues and Metrics

- Primary Metrics
  - Heat Loss / Gain (R-value, U-factor)
  - Solar Heat Gain Coefficient (SHGC)
  - Visual Transmittance (VT)
- Other Important
  - Condensation resistance (CRI/CR)
  - Air Leakage (AL)
  - Water penetration (ΔP rating)
  - Impact and Blast

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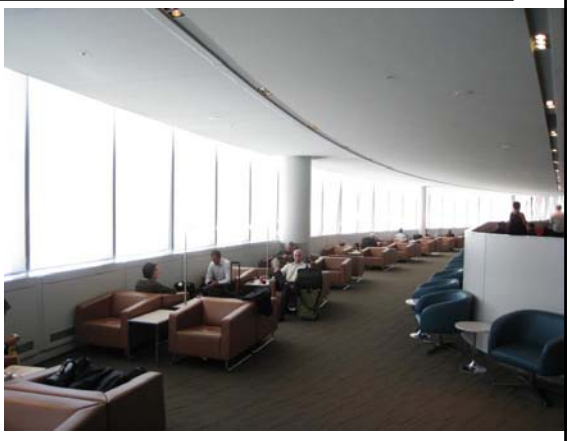
How Much Glass?

Daylighting

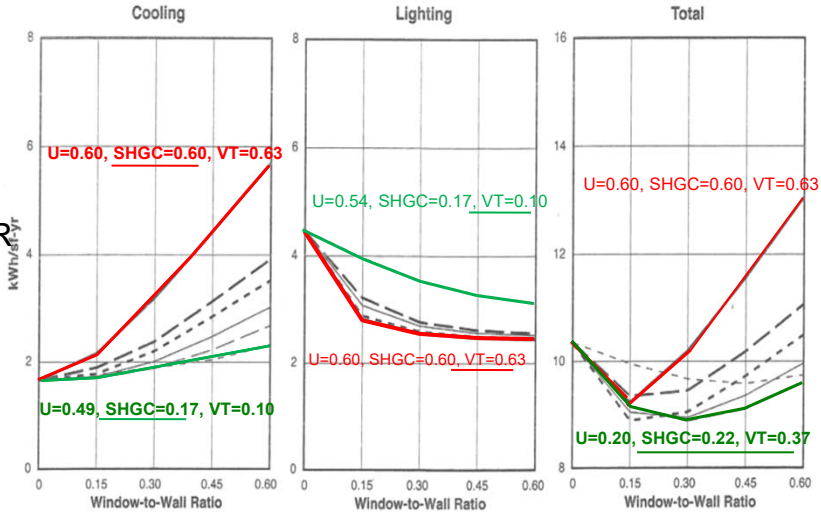
- Natural light can offset artificial lights
- Natural light almost always preferred
- BUT,
  - Must use daylight *controls* and sensors to capture energy savings
  - Need to control glare and solar heating caused by too much glass on sunny days
  - Cooling costs often overwhelm lighting savings
  - Over 60% WWR → glare problems



Balance Cooling & Lighting

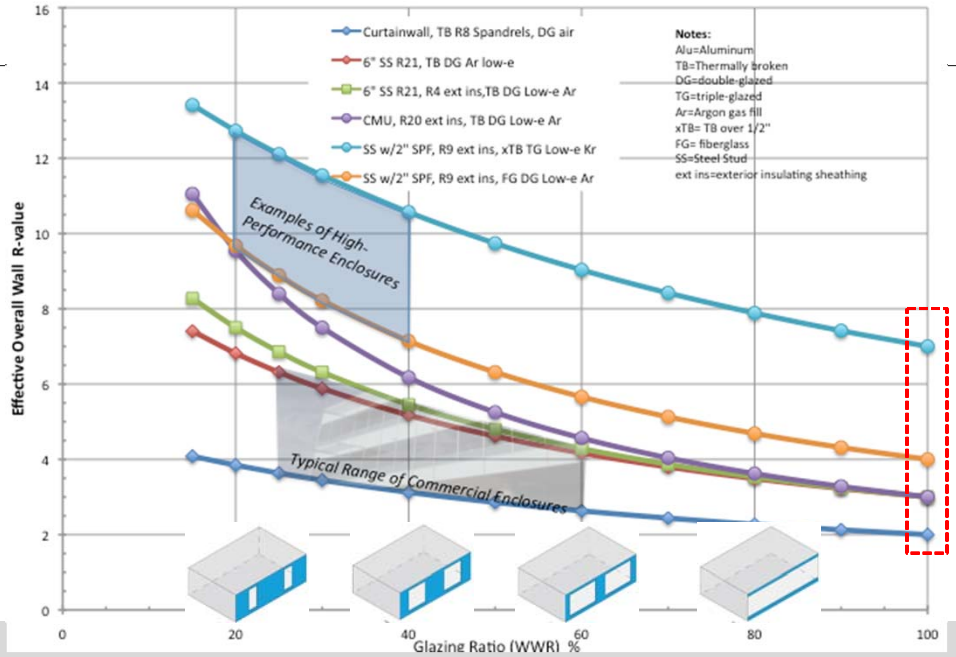
Chicago Illinois Office Building 15 ft (4.6 m perimeter zone)

- Cooling load vs. WWR
- Lighting load vs. WWR
- Combine cooling + lighting loads
  - Minima at 15-30% WWR
- Quantity is not quality!



Overall R-Values

Spandrels—high R-values defeated by frame thermal bridging



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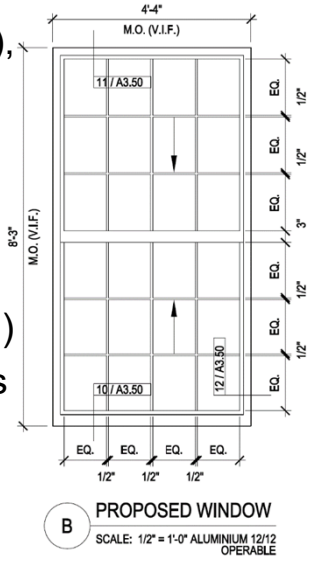
Window Heat Loss in Context (Masonry Mills)

- Large windows (4’ x 8’), high glass %
- Can’t change frame profile (historic)
- Aluminum, double, low E: U≈0.5 (center of glass U-0.30)
- R-2 holes in R-20 walls
- “Two faucets”



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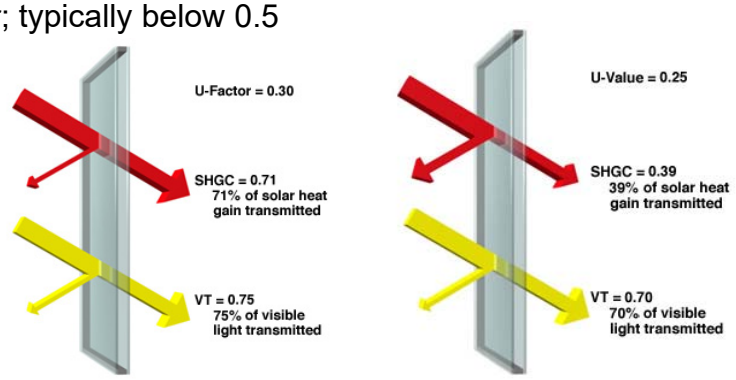
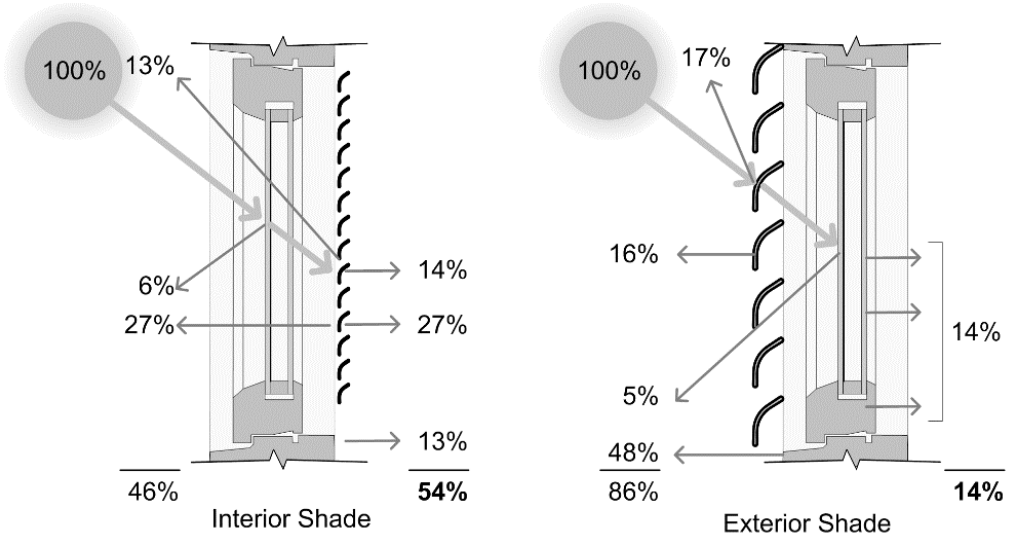
Solar Heat Gain

- Glazing ratio dominates size of AC equipment and ducts
- Solar Heat Gain Coefficient: SHGC
  - Ratio of solar gain on window that enters room as heat
  - Lower controls better; typically below 0.5



Interior vs. Exterior Shading



Low Energy-Use All-Glass Box? (UW Solar Decathlon)

- Operable exterior shading to control solar heat gain

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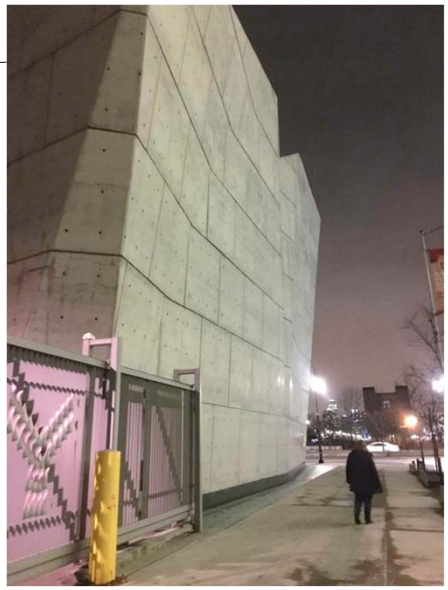
Windows and Energy

- "Engineers want architects to build windowless bunkers."
- Glazing ratios have consequences
- Bacon triple cheeseburgers
- Triple/quad glazing as "tax" on large amounts of glazing?
- Vacuum insulated glazing can't get here soon enough…



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Window Design and Detailing

Windows Leakage & Damage

- "All windows leak…"

Windows Design and Detailing

- Exposure and loads
- Building/Window Type
- Enclosure Design
  - Water management of elements and systems
  - Window Water Management
    - The window product
    - The window interface
- Construction Sequence

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Window Design - General Concepts

- Barrier vs. Drained
- Two-stage joints
- Three-stage joints
- Pressure moderation

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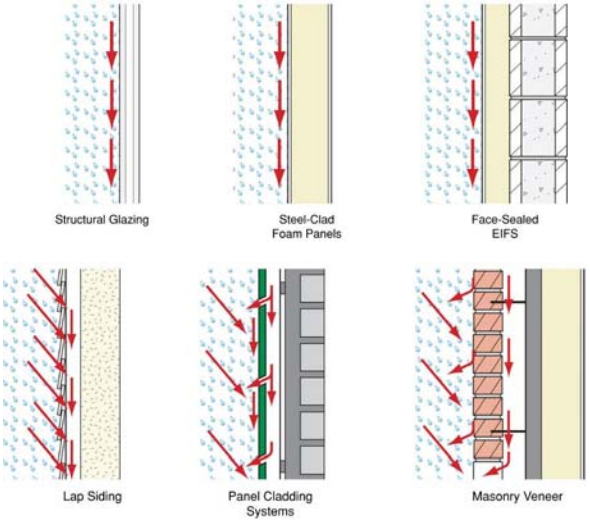
Barrier vs. Drained



Barrier
- All of the water is controlled on the outer surface
- No provision to manage water that gets past the outer layer
- The continuity of the outer surface must be "perfect"

Drained
- Most of the water is controlled on the outer surface
- Secondary drainage is provided behind the outer layer
- The outer surface can have "holes" (both intentional and unintentional)

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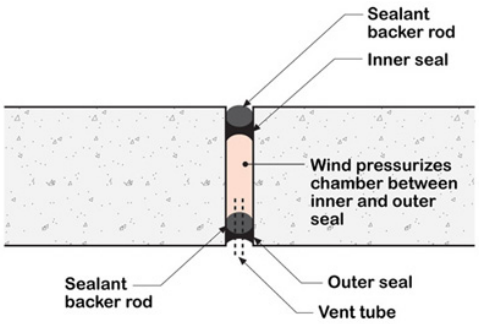
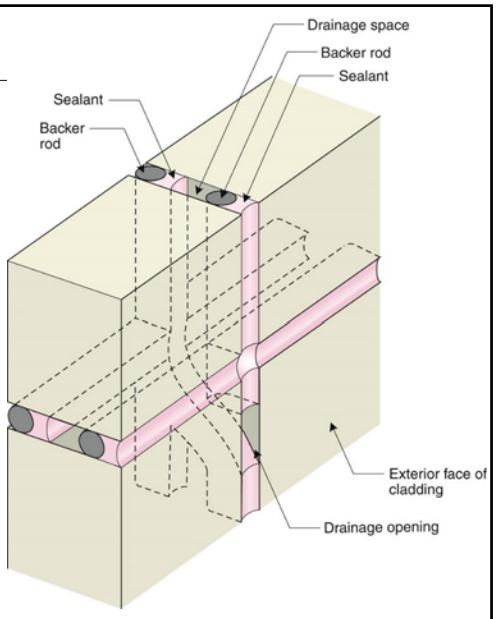
Two-Stage Joints (Precast)

- Interior needs to be the airtight layer; outer joint is weeped





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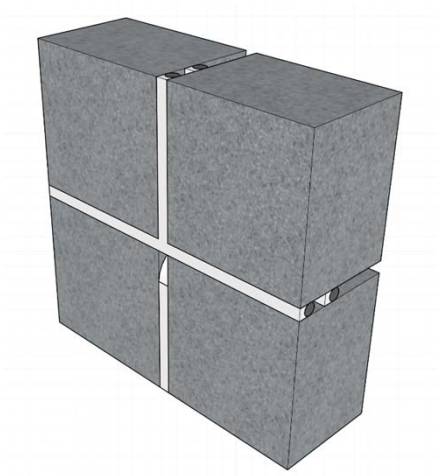
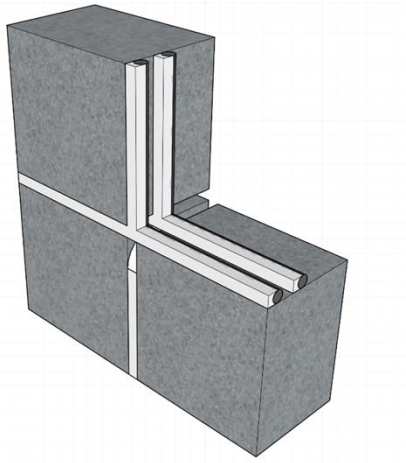
Two-Stage Joints





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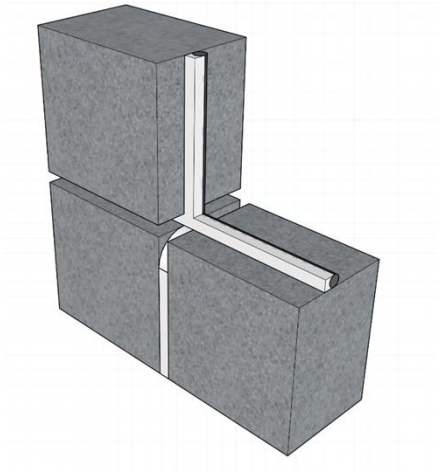
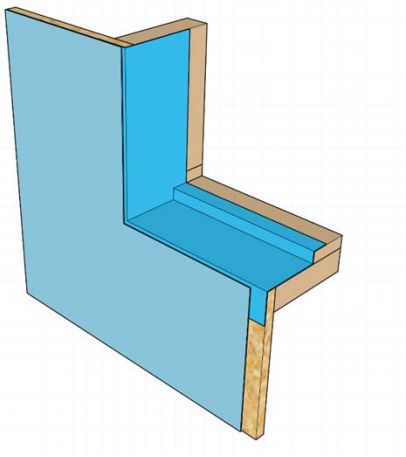
Two-Stage Joints





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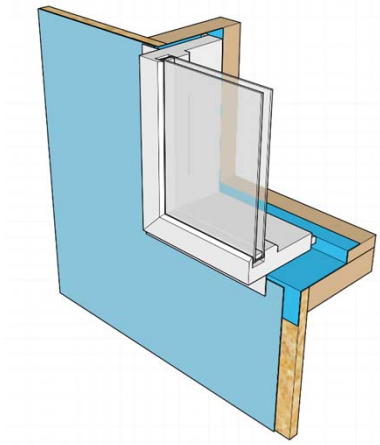
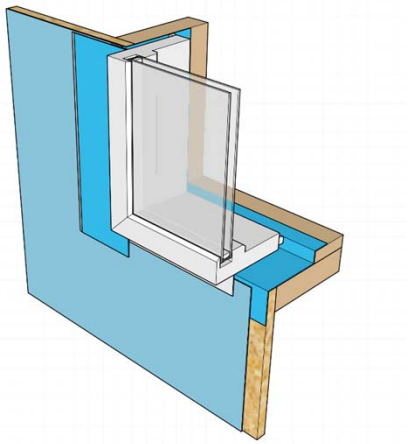
Two-Stage Joints





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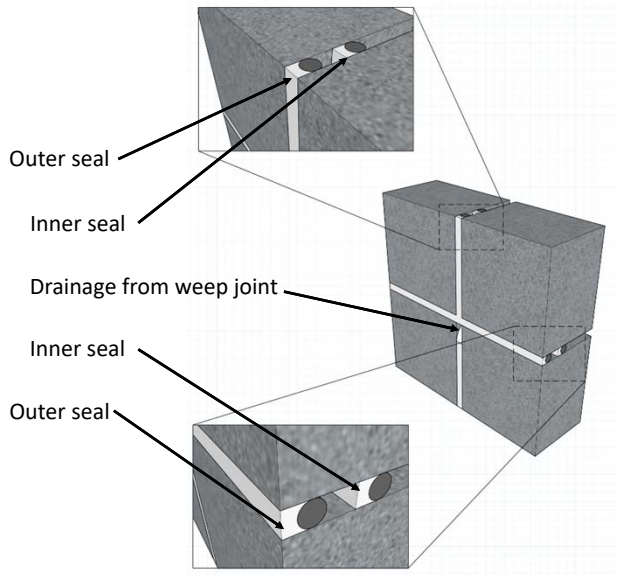

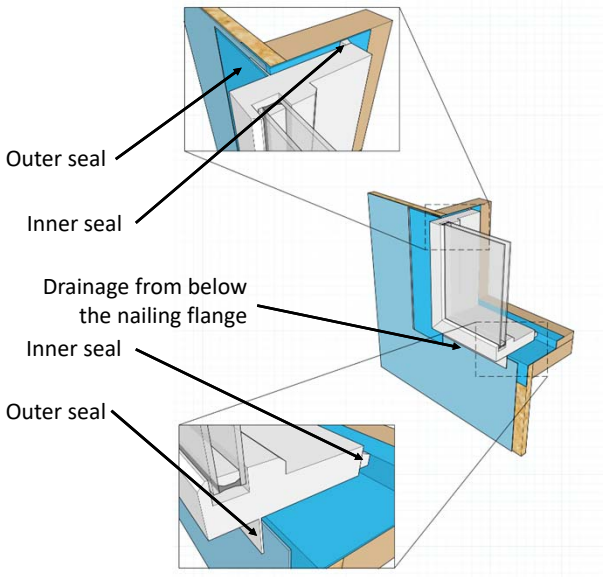

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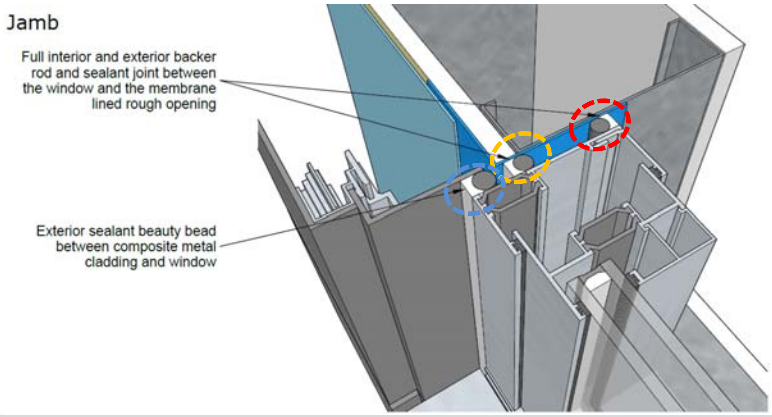
Three-Stage Joints

- This might not actually be a thing*
- Concept is to provide protection over the more critical seals and water control layers
- Load reduction (water, wind, UV)
  - Prolonged service life
  - Reduced risk

* OK, it is a “thing”, but it might not be called the “thing” I just called it, but it falls very nicely in the order of “things” for this presentation.

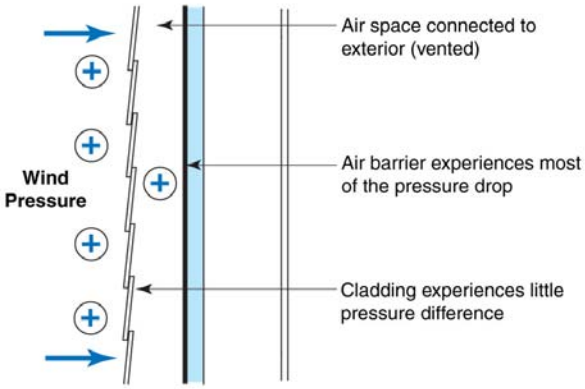
Three-Stage Joints

- Seal window to rough opening water control layers and cladding
- Air seal, weather seal, and rain screen seal



Pressure Moderation

- Sometimes called “Pressure Equalization”
- Increased pressure drop over interior seals, reduces pressure on exterior elements
- Reduced pressure on exterior elements, reduces the risk of water leakage through those elements



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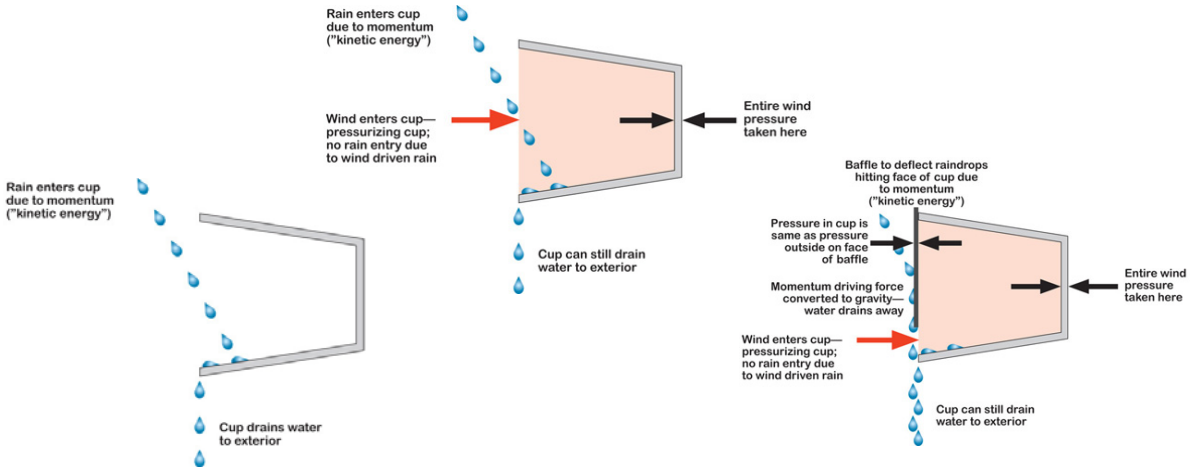
Pressure Moderation – “Cup in the wind”



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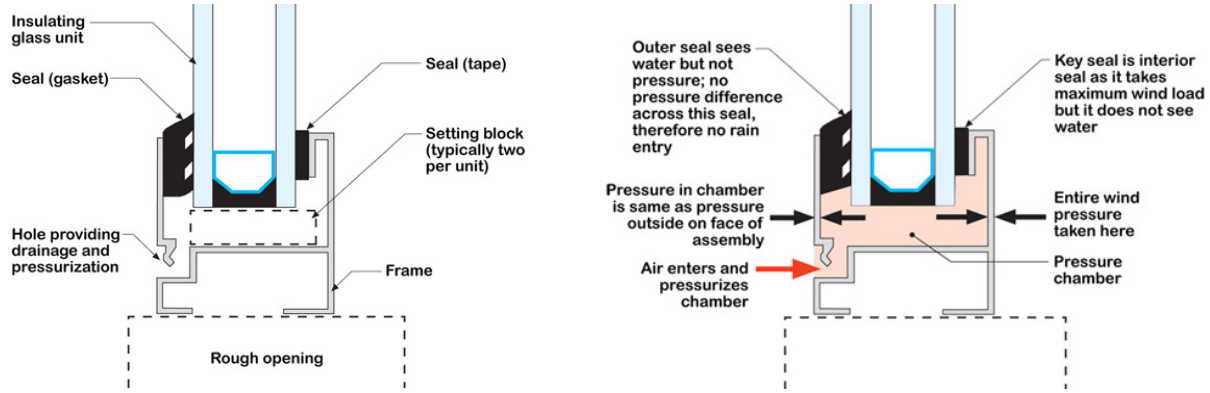
Pressure Moderation



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Window Design – Applied Concepts

- Residential Windows
- Commercial Windows
  - Storefront
  - AW Window/Window Wall
  - Curtain Wall*

* Unitized curtain walls are not included in this presentation

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Residential Windows

- Performance ratings are described under the ***North American Fenestration Standard/Specification for windows, doors, and skylights AAMA/WDMA/CSA 101/I.S.2/A440***
- Flanged windows are most common for new residential wood frame construction, though non-flanged window products are used
- Considerations:
  - The flange is typically used as part of the water control
  - Watch out for discontinuous flanges at the corner
  - The window flange dictates the position of the window in the wall

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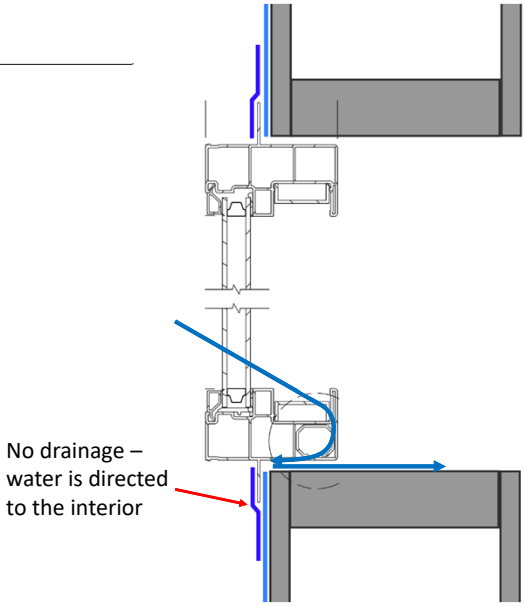
Residential Windows

- 4-sided sealing



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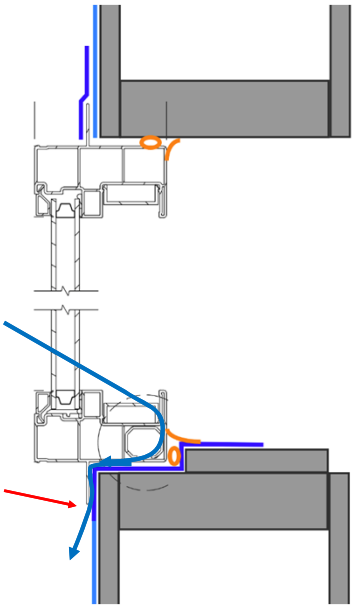
Residential Windows

- 3-sided sealing with a pan flashing

Drainage out below the nailing flange at the sill



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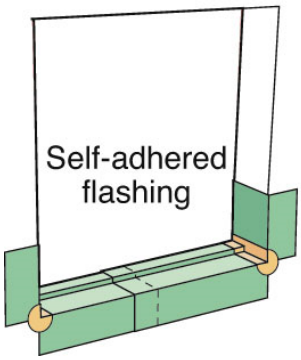
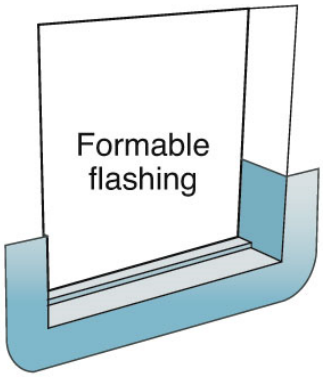
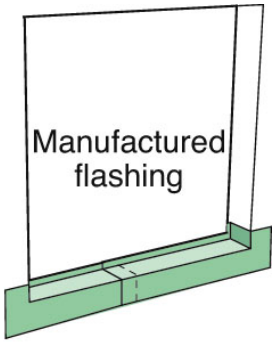
Sill Pan Flashings







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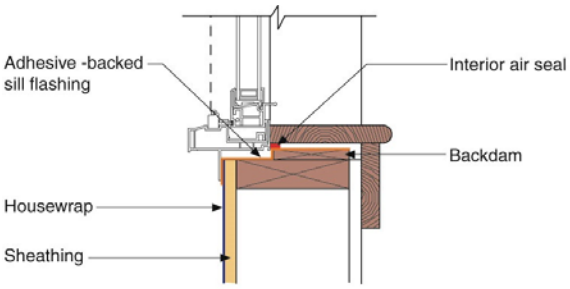
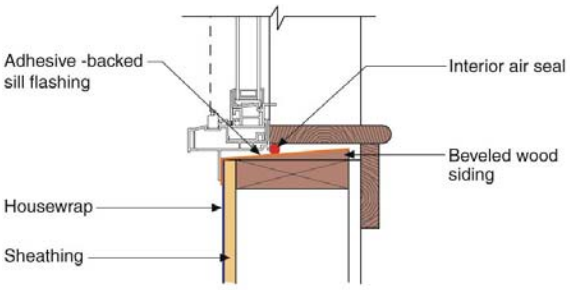
Backdams and Sloped Sills

- Prevents inward water entry from sill pan
- Left open at bottom to allow for drainage

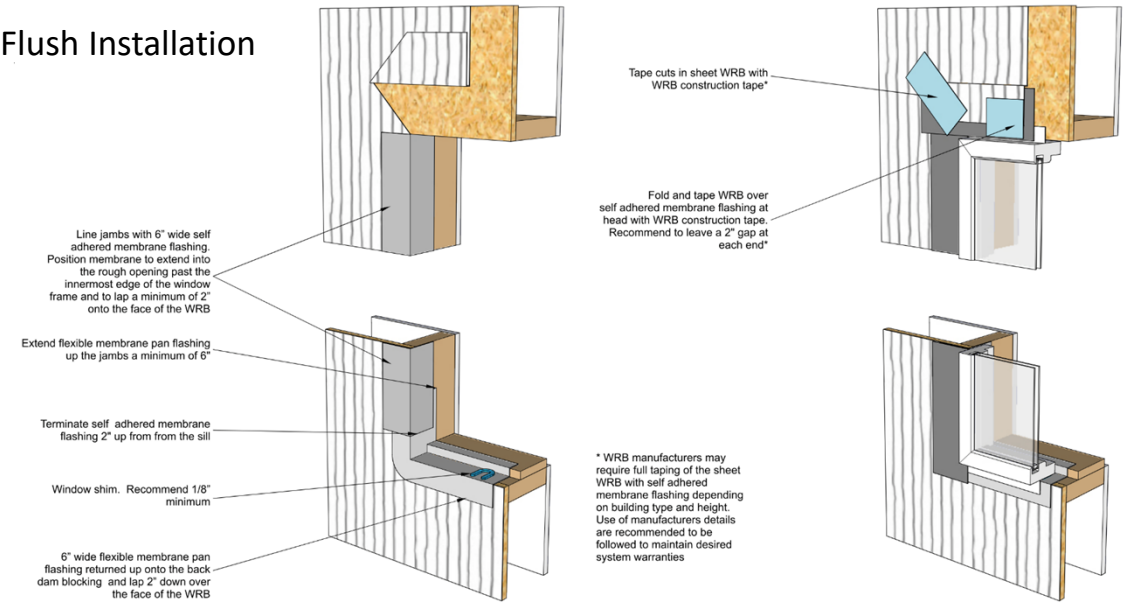


A strip of wood nailed at the back of the rough opening sill forms a dam to prevent water from draining into the interior.



A piece of wood bevel siding nailed over the sill to create positive drainage toward the exterior is even better. Note that the rough opening needs to be enlarged to account for this and tapered shims in the opposite direction of the slope may be required.

Flush Installation



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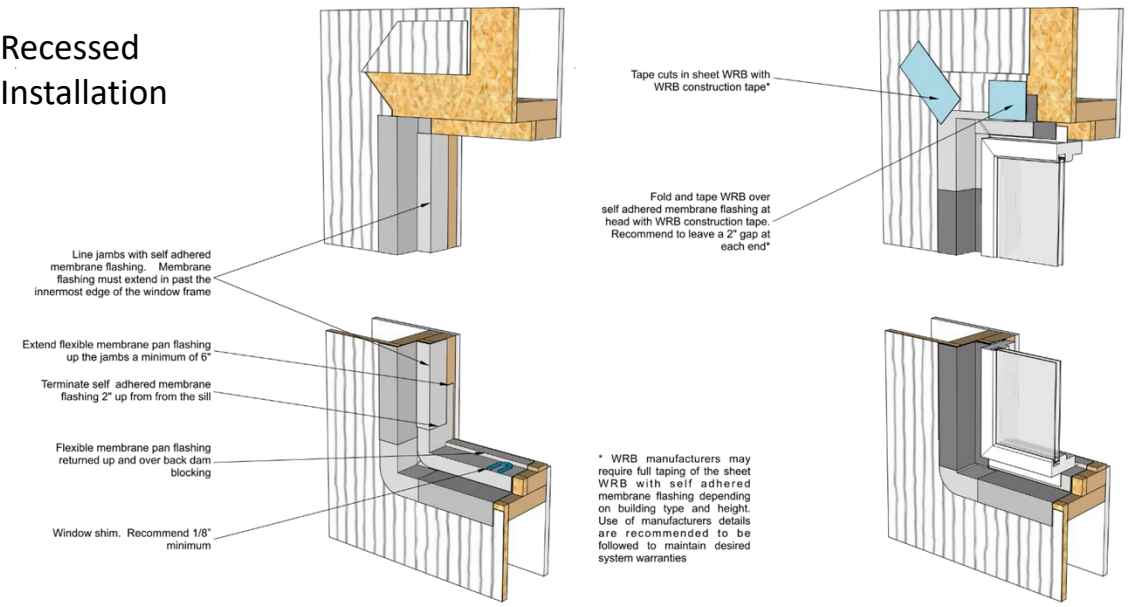
Recessed Installation



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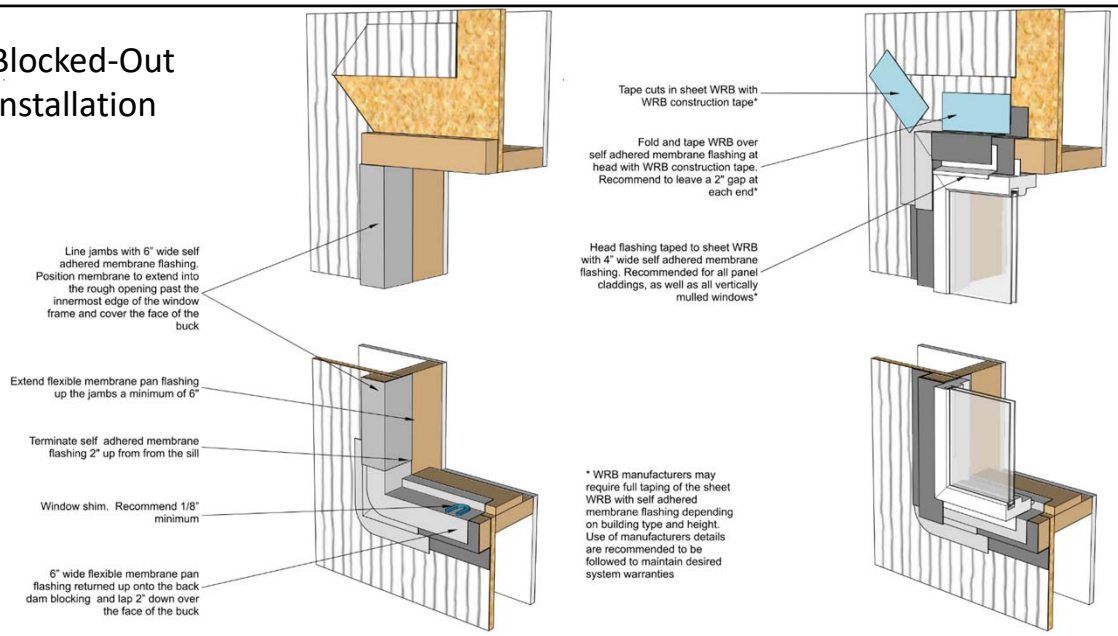
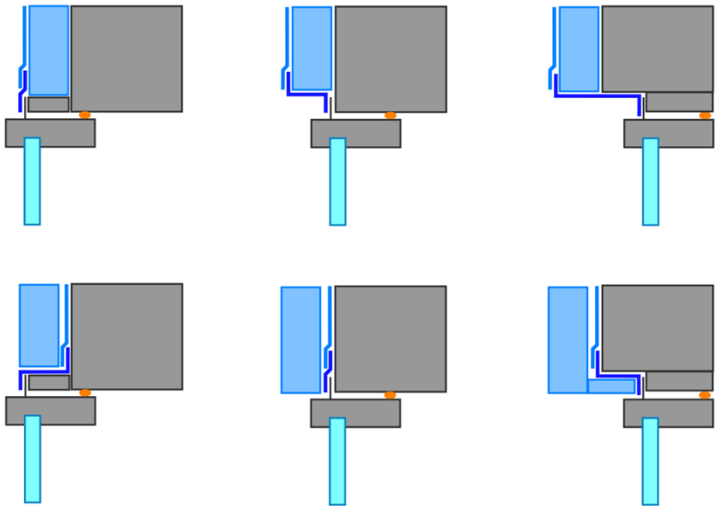
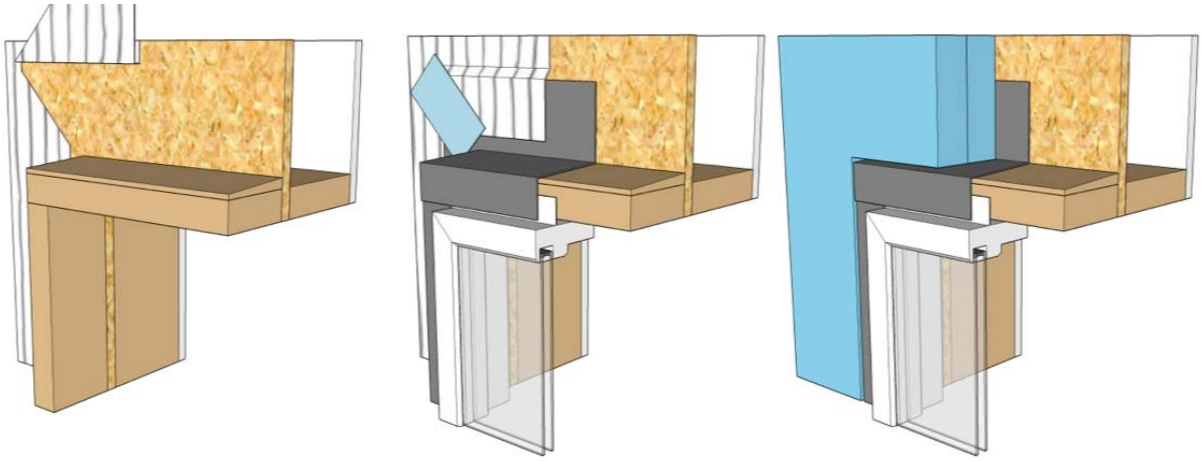
Blocked-Out Installation



WRB location with respect to the window location



Blocked out window with exterior insulation



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Mock-Up Installation

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Mock-Up Installation

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In-Situ Performance Testing

- Field verification performance testing is commonly covered under ***AAMA 502 – Voluntary Specification for Field Testing of Newly Installed Fenestration Products***
- Test Methods:
  - ASTM E783 for air leakage
  - ASTM E1105 Method B for water infiltration
- Testing is related back to the laboratory tests that are used to determine the Performance Grade of the window - but are de-rated to account for field conditions
  - Acceptable air leakage rates are 1.5 times the laboratory rates
  - Water infiltration test pressure is 0.667 times the laboratory test pressure

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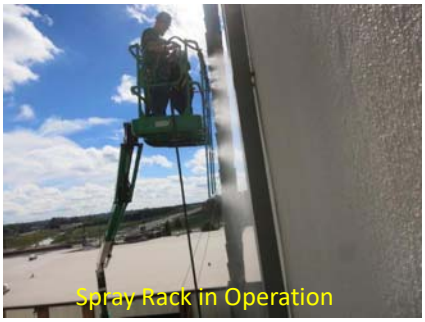
AAMA 502 Water Testing

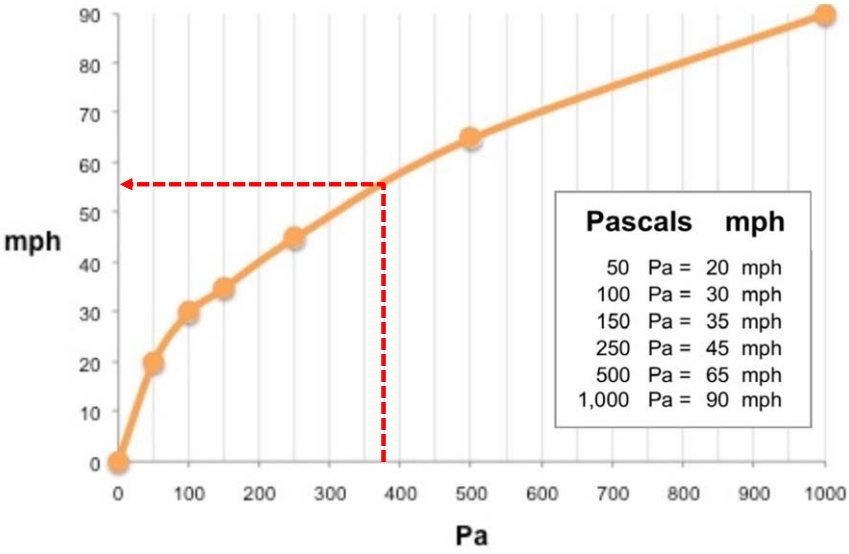
- Specialized equipment that is calibrated to deliver a specific flow rate of water
- Specialized contractors
- Typical for new construction QC testing


Spray Rack in Operation


Interior Negative Pressure Rig

Wind Speed vs. Stagnation Pressure

- 8 PSF window test = 383 Pa = 55 mph
- Rain + continuous 55 mph = hurricane
- Leaky buildings often leak without ΔP



Simple Water Testing (Diagnostics)

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Simple Water Testing (Diagnostics)

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Commercial Windows

- Commonly fabricated out of aluminum
- Frames require a thermal break to achieve even some degree of energy efficiency
- Common products would be classified as:
  - Storefront
  - AW windows/Window Wall
  - Curtain Wall
- Each product type manages water in a different manner

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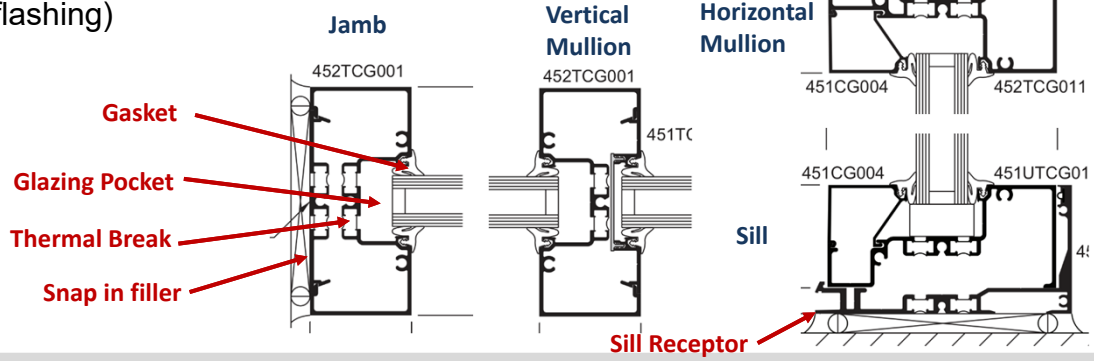
Commercial Windows

- Storefront Frames
  - Used primarily at ground level and entrances
  - Limited to single story heights
  - Manage water with a sill receptor (or sill flashing)



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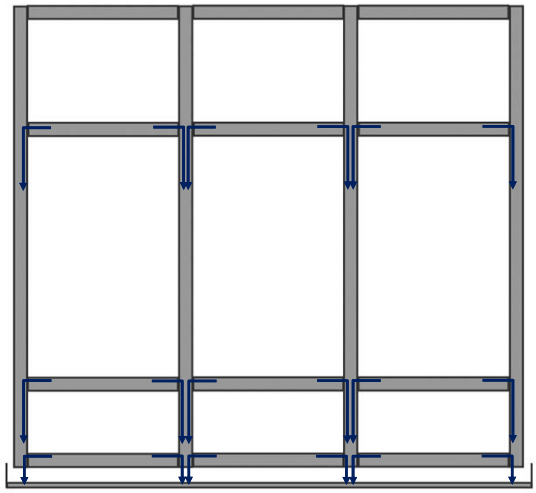
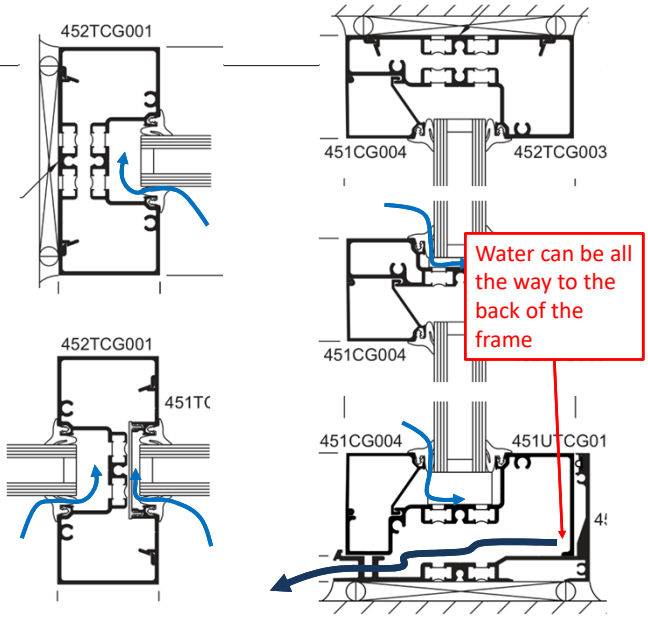
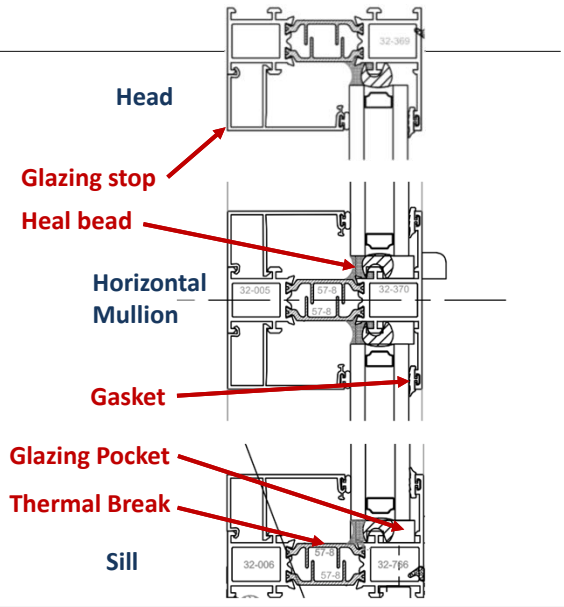
Storefront



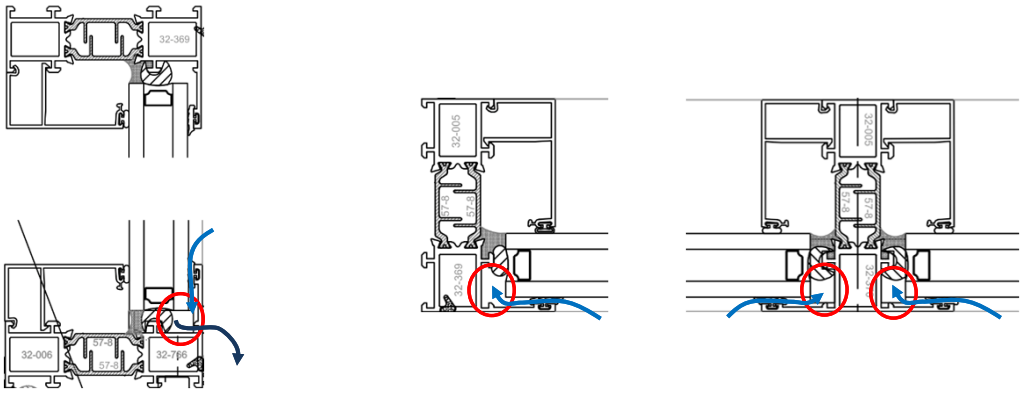


Commercial Windows

- AW Windows/Window Wall
  - Common glazing for mid-rise to high-rise buildings
  - Used for:
    - Punched windows
    - Ribbon windows
    - Full height slab to slab windows
  - Manage water through both direct drainage of the glazing pocket as well as a sill receiver
  - Limited to single story (floor to floor)

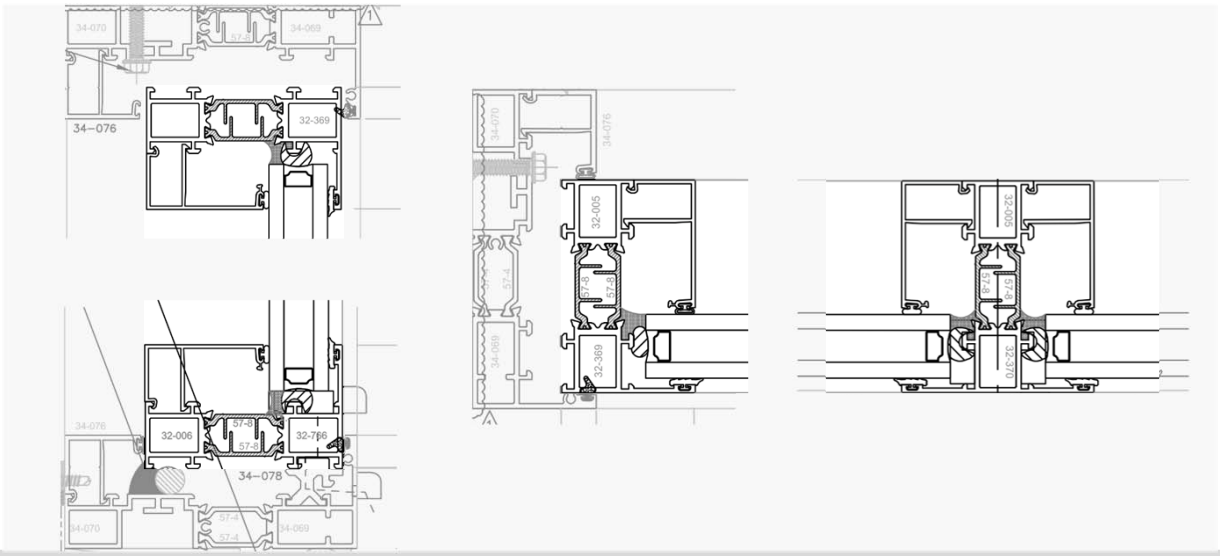


AW Window/Window Wall



61

AW Window/Window Wall



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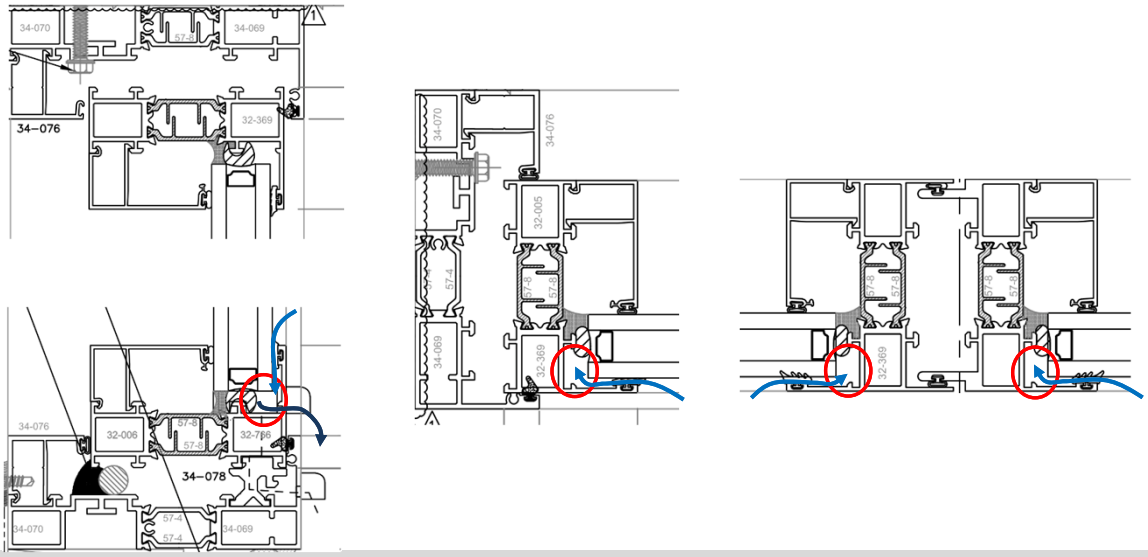
AW Window/Window Wall



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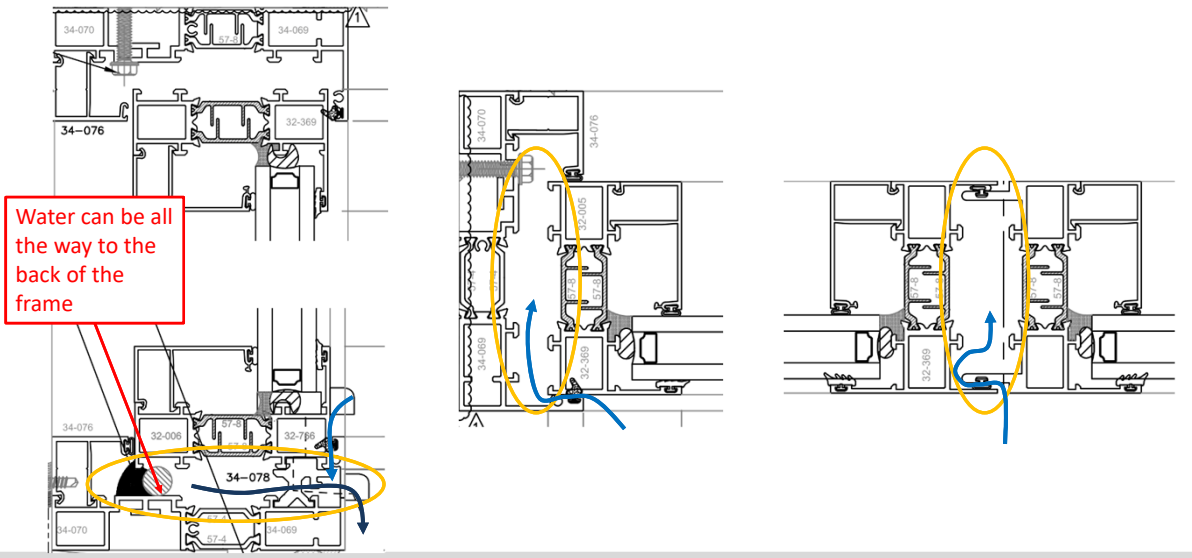
AW Window/Window Wall



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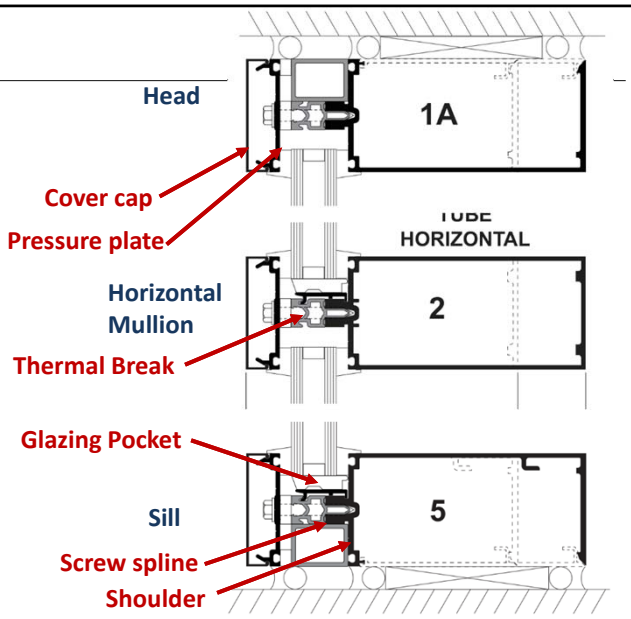
Commercial Windows

- Curtain Wall
  - Commonly used for larger glass areas
  - Can be used for:
    - Punched openings
    - Ribbon windows
    - Full height floor to floor
    - Multi-story glazing
    - Full enclosure system
  - Manages water by compartmentalizing each glazing pocket and drains water out the front face through weep holes



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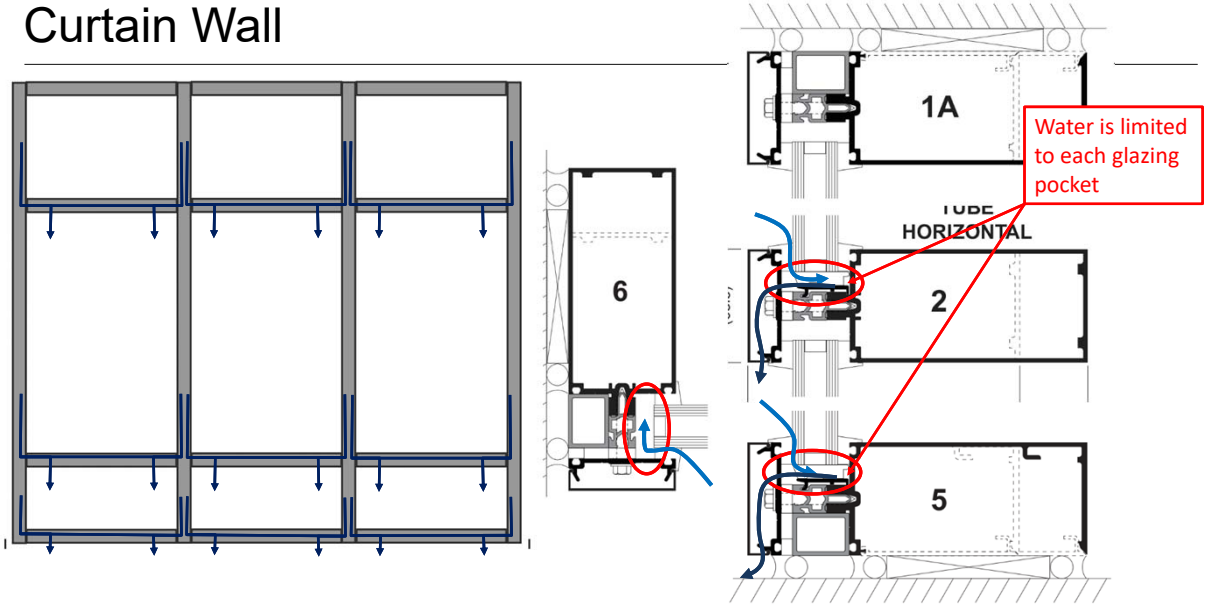
Curtain Wall



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Commercial Windows – Interface with the wall

- Some commercial windows are specifically designed for integration with a rain screen
- Many windows appear to be specifically designed to be used in a barrier application (or at least that is the interpretation)
- Recommend designing the interface detail to mitigate risk of window system leakage
  - align the seals and flashing with the location of water within the window system

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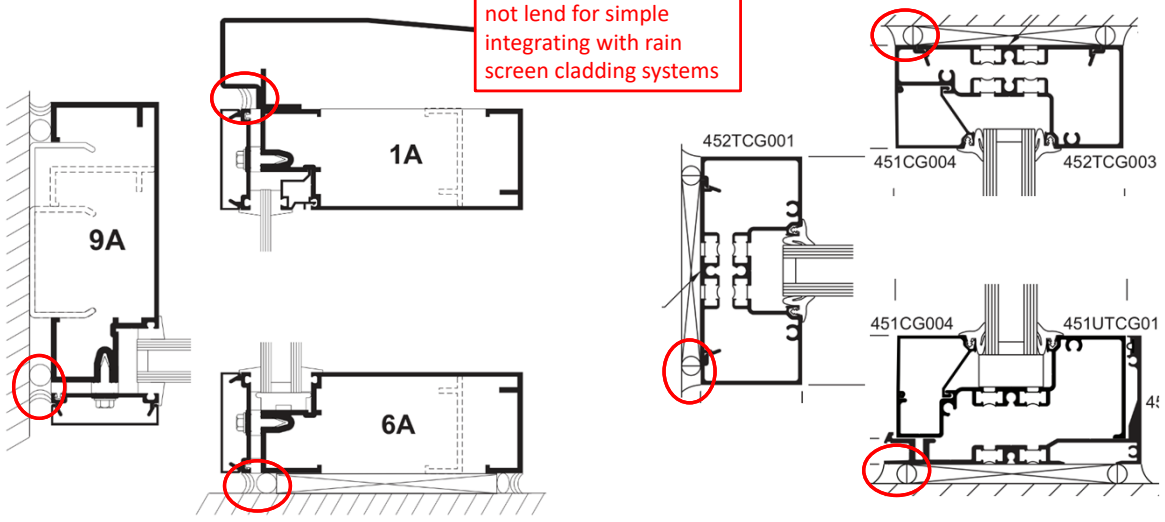
Barrier Seals

Single exterior seals do not lend for simple integrating with rain screen cladding systems



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Commercial Windows – Interface with the wall

- Barrier Seals
  - Resistance from subcontractors to allow for the exterior seal to be weeped to the exterior
  - Claim “it is part of how the system is tested”
  - Window manufacturer is concerned with ensuring water does not leak “through” their system – They do not design the interface with the wall
  - This can lead to difficult scope issues on projects

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Commercial Windows – Interface with the wall

- Recommend to use a 3-seal approach (Curtain wall might be an exception)
  - Interior air seal
  - Middle primary seal to water control layer
  - Exterior rain screen seal to the cladding
- Include a membrane pan flashing extending at least to the innermost location that water would be expected in the frame

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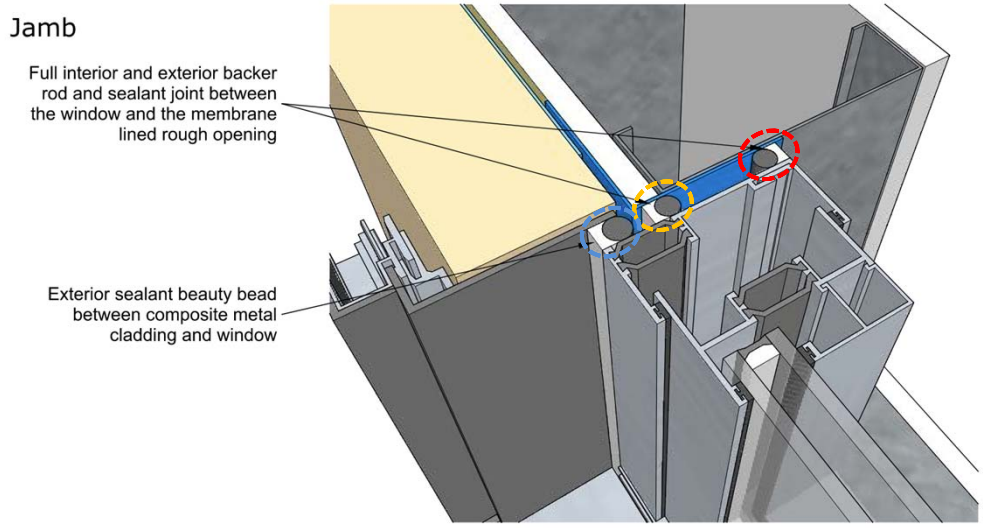
AW Window – Interface with the wall



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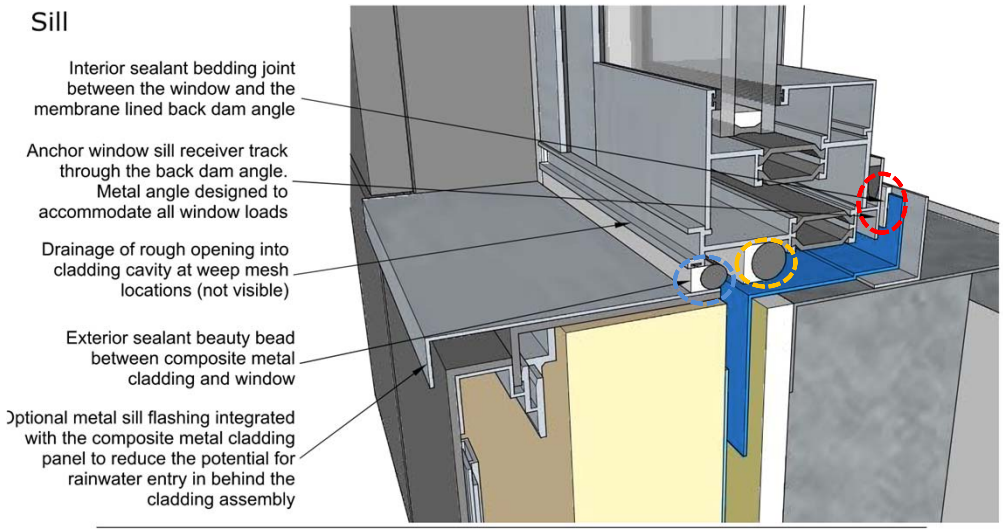
AW Window – Interface with the wall



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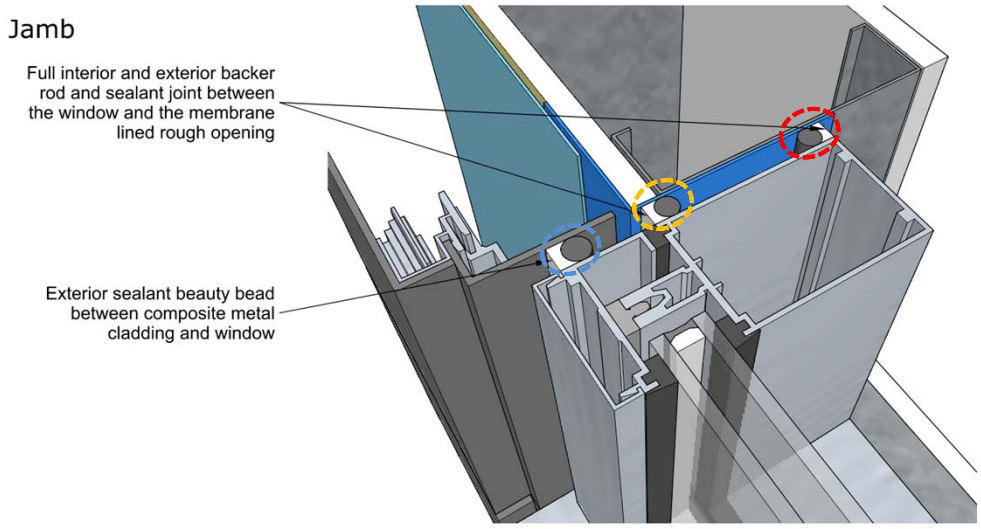
Curtain Wall – Interface with the wall



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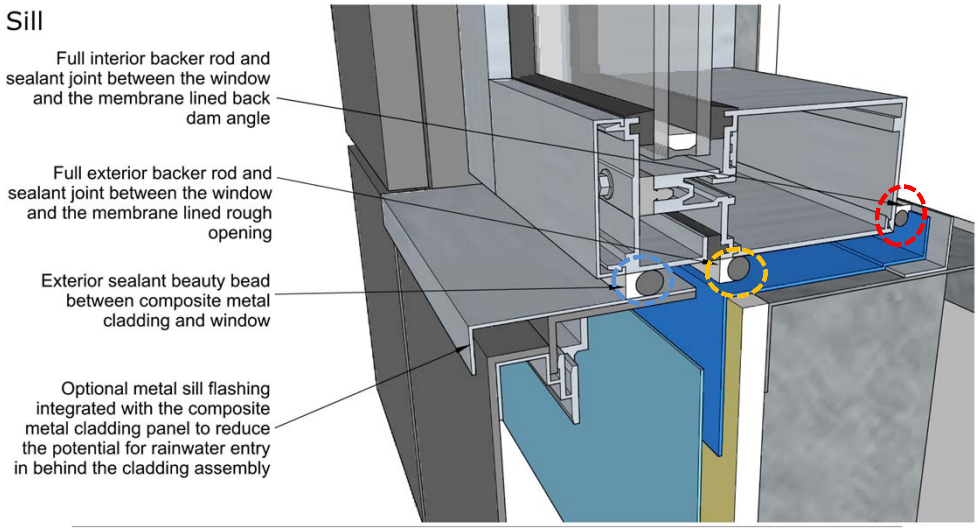
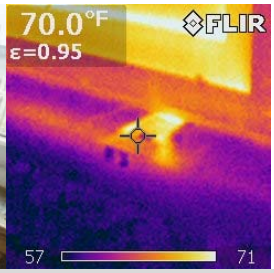
Curtain Wall – Interface with the wall



Window Air Sealing with Strap Anchors

- Window attachment clips common on commercial windows, walls with exterior insulation
- Commonly a “miss” in detailing of interior air seal



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Window Air Sealing with Clips

- Detailing interior air seal with tape; cover up window clip
- Detailing interior air seal with sealant—“bury” clip perimeter in sealant




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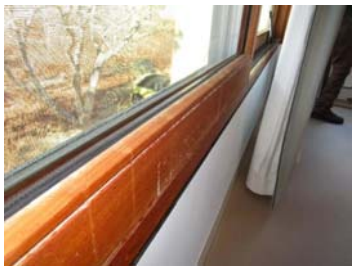
Window Condensation & Comfort

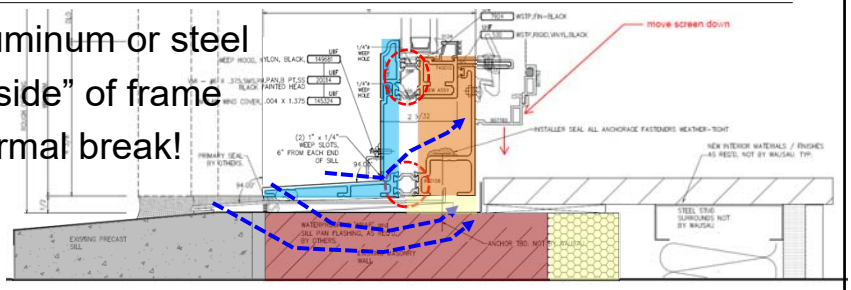
Window Condensation Problems

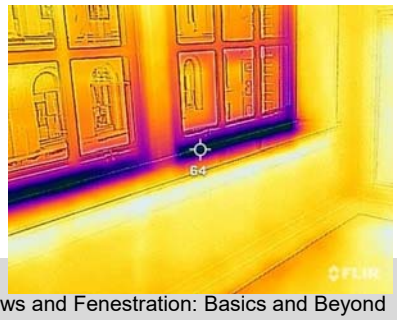
- Outdoor temperature
- Indoor humidity
- Indoor temperature
- Interior shading
- Heating directed at windows
- Geometry e.g. “tunnel”
- Window frame materials & design (aluminum, steel)
- Single-glazed windows



Window Condensation Problems

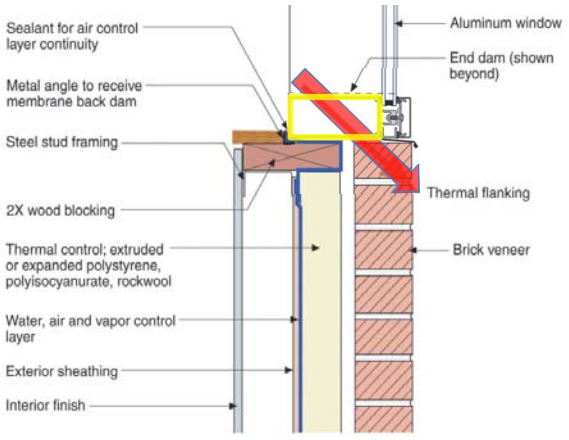
- Thermally broken aluminum or steel
- “Warm side” & “cold side” of frame
- Don’t bypass the thermal break!
- “Infill” insulation?
- Vent hole air leak?

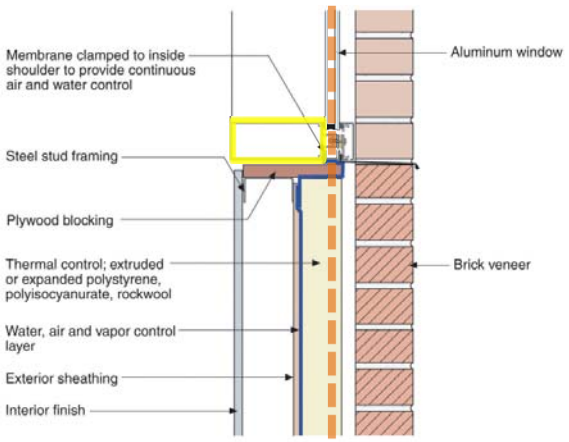




Aligning Window Thermal Break w. Wall/Insulation

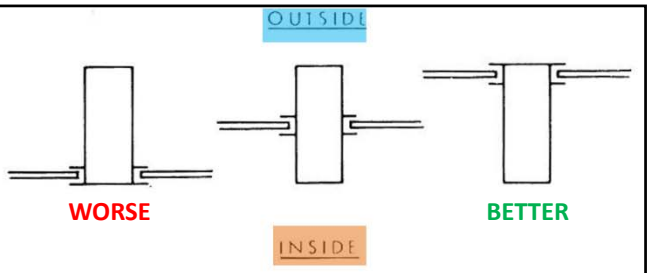
- Misalignment = thermal loss, condensation risks

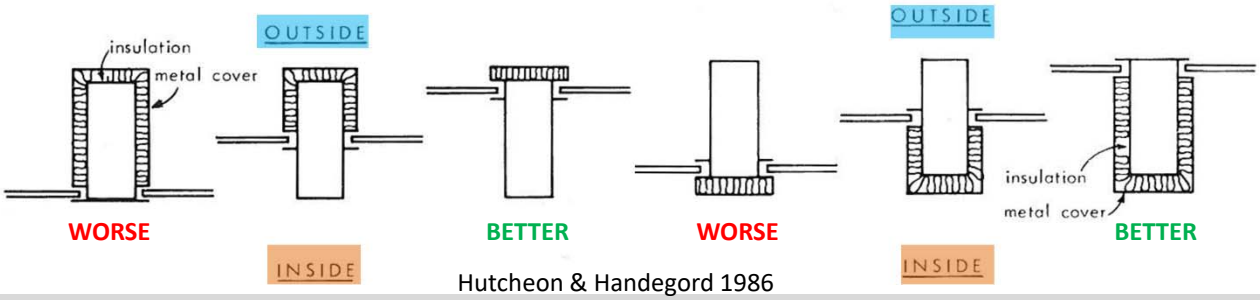




"Inside" vs. "Outside Metal"

- "More metal to outside" worse
- Insulating on inside of metal → condensation risks underneath
- Insulating on outside of metal → warmer metal, less risk (BEST)

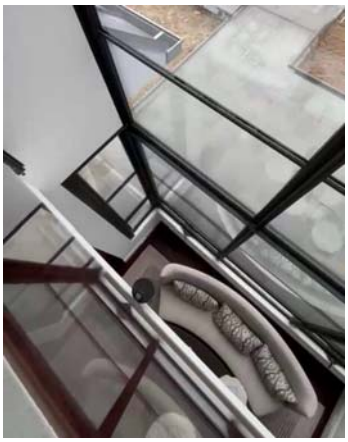


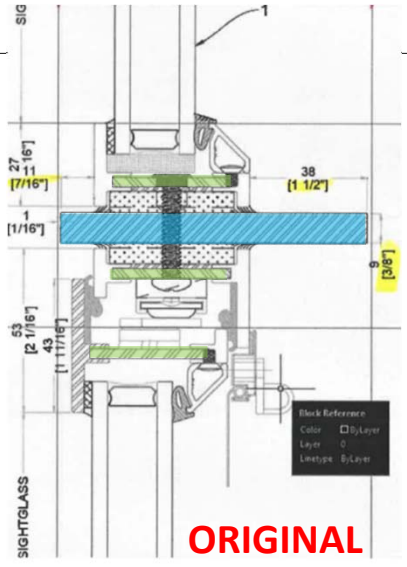


Hutcheon & Handegord 1986

"Inside" vs. "Outside Metal"

- Structural element: "bar" to "tee"





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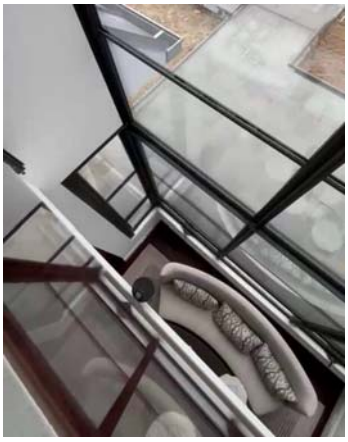
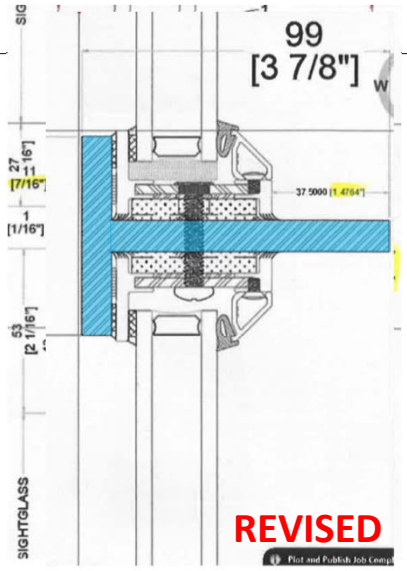
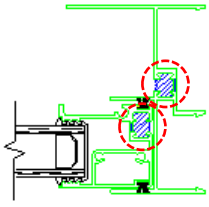
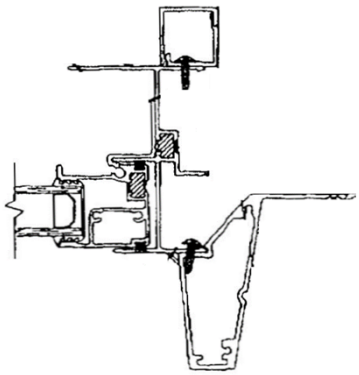




“Inside” vs. “Outside Metal”

- Exterior “shadow box” profile





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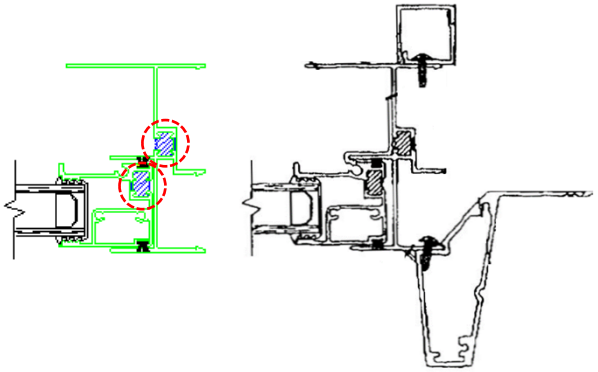
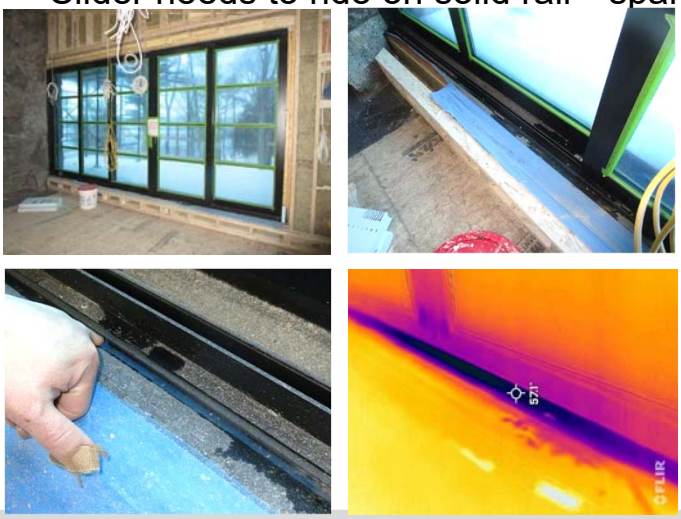
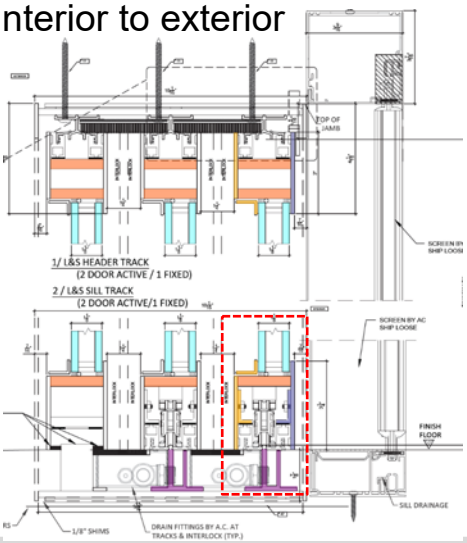


Multi-Leaf Lift/Slide Doors

- Slider needs to ride on solid rail—spans interior to exterior





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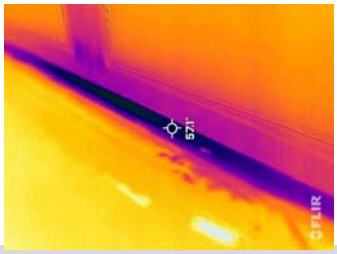
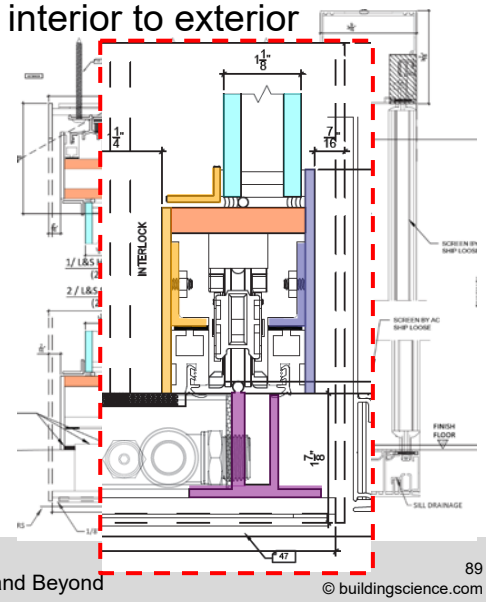
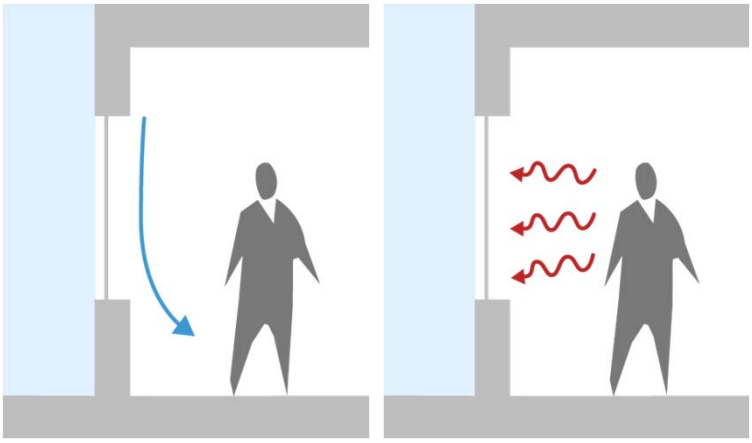




Window Condensation and Comfort

- "Downdraft discomfort"
- "Radiative discomfort"
- Problems worse with larger & taller windows
- Problems worse if less clothed
- Consider triple glazing?
  - Energy
  - Condensation
  - Comfort



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Questions?

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Presentation will be available at:
https://buildingscience.com/past-events

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Document Resources

- BSD-006: Can Highly Glazed Building Façades Be Green?
  https://buildingscience.com/documents/insights/bsi-006-can-fully-glazed-curtainwalls-be-green
- BSI-004: Drainage, Holes and Moderation
  https://buildingscience.com/documents/insights/bsi-004-drainage-holes-and-moderation
- BSI-022: The Star-Crossed Lovers of Building Science
  https://buildingscience.com/documents/building-science-insights-newsletters/bsi-022-star-crossed-lovers-building-science
- Info-302: Pan Flashing for Exterior Wall Openings
  https://buildingscience.com/documents/information-sheets/pan-flashing-for-exterior-wall-openings
- BA-1203: Measure Guideline—Wood Window Repair, Rehabilitation, and Replacement
  https://buildingscience.com/documents/bareports/ba-1203-wood-window-repair-rehabilitation-replacement/view
- BA-1406: Final Measure Guideline: Incorporating Thick Layers of Exterior Rigid Insulation on Walls
  https://buildingscience.com/documents/bareports/ba-1406-final-measure-guideline-incorporating-thick-layers-exterior-rigid-insulation/view
- GM-1302: Mass Save Deep Energy Retrofit Builder Guide
  https://buildingscience.com/documents/guides-and-manuals/gm-mass-save-der-builder-guide/view
- Windows and Water Leakage Testing – BSC Expert Session 2014
  https://buildingscience.com/sites/default/files/2014-11-20%20Windows%20and%20Water%20Leakage%20Baker.pdf

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Document Resources

- Payette - Glazing and Winter Comfort Tool
  https://www.payette.com/glazing-and-winter-comfort-tool/
- Efficient Windows Collaborative (NFRC)
  https://efficientwindows.org/
- GBA - Rating Windows for Condensation Resistance
  https://www.greenbuildingadvisor.com/article/rating-windows-for-condensation-resistance
- Structural Performance of Windows in Walls with Continuous Insulation (Building America/Home Innovation)
  https://www.energy.gov/eere/buildings/structural-performance-windows-walls-continuous-insulation