




Kohta Ueno

Building Science of Walls

January 25, 2018

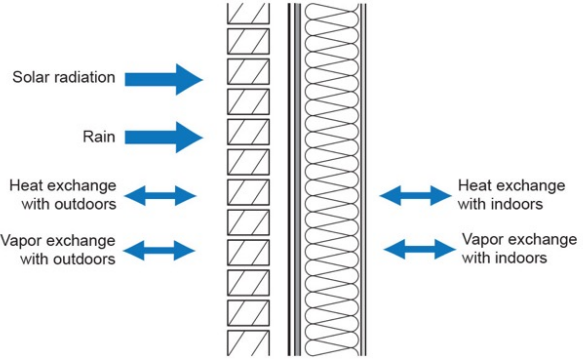

Background



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Environmental Separator





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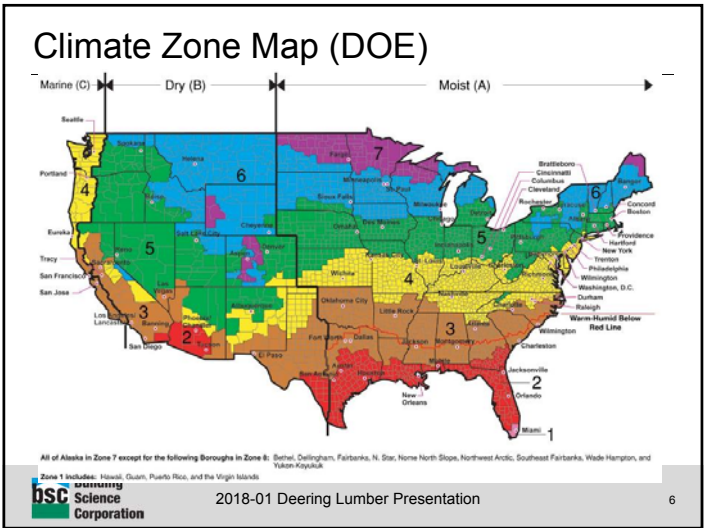
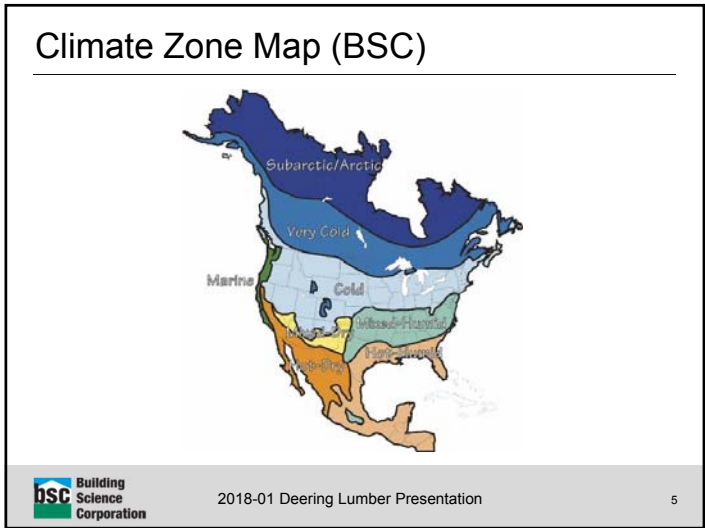
What Separation Roles?

- Water control layer
 - A.k.a. “drainage plane,” “water resistive barrier,” “weather resistive barrier,” WRB
 - Housewraps, tar paper... more modern options
- Air control layer
 - A.k.a. “air barrier”
 - Drywall, sheathing, spray foam... and continuity
- Vapor control layer
 - A.k.a. “vapor barrier”—poly, Kraft paper, latex paint
- Thermal control layer
 - Insulation (fluffy in stud bays, continuous on outside)



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Water Control Layer



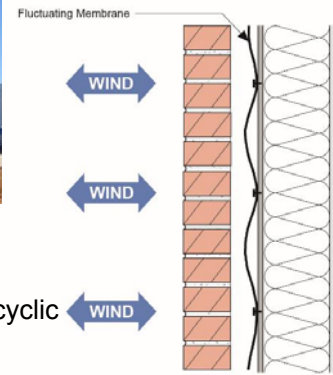
Housewrap (Commercial)



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Billowing Housewrap



- Is it really an air barrier (network airflow)?
- Potential damage from cyclic loading



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Vapor-Impermeable Adhered Membrane



- Cold climate + no exterior insulation = danger



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Vapor-Permeable Adhered Membrane



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Self-Adhered Membranes



- Self-sealing
- Air leakage improvement; no blow-off/billowing
- No 'hidden path' water leakage/bypass
- Reverse laps not as critical



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Taped Sheathings (WRB Surface)



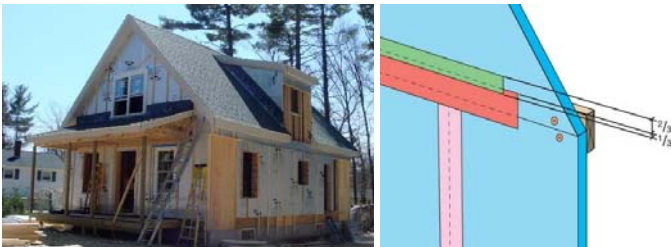
- Fast dry-in
- Airtightness
- Reliance on adhesive vs. laps? Surface prep
- Rigid foam insulation too



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Taped Joints (Foam Sheathing)



- Membrane-type flashing tape at joints
- Horizontals more important than verticals



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Fluid-Applied WRBs



- "Housewrap in a can" (GBA Column)
- Continuous water control
- Airtightness
- Can be applied with air gun (paint sub)
- Issues: surface prep, application temperature, substrate condition, etc.



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Reverse Lap Termination



- "Termination mastic" at reverse lap condition



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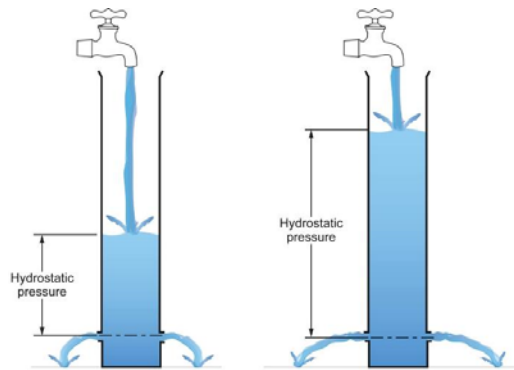
Water Control- Hydrostatic Pressure

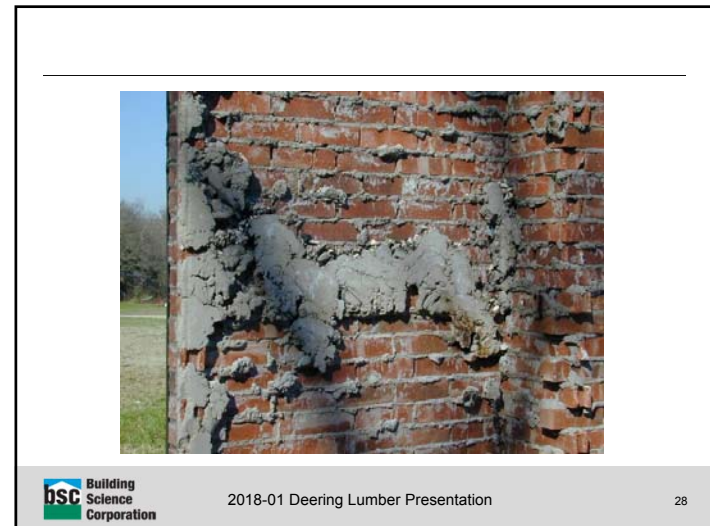
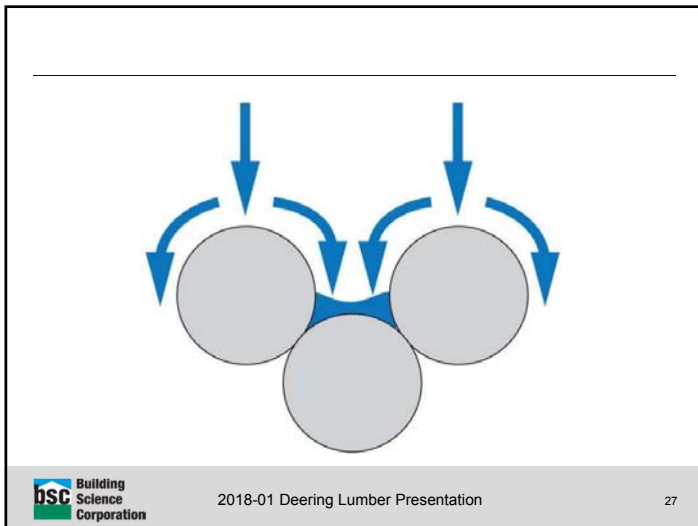
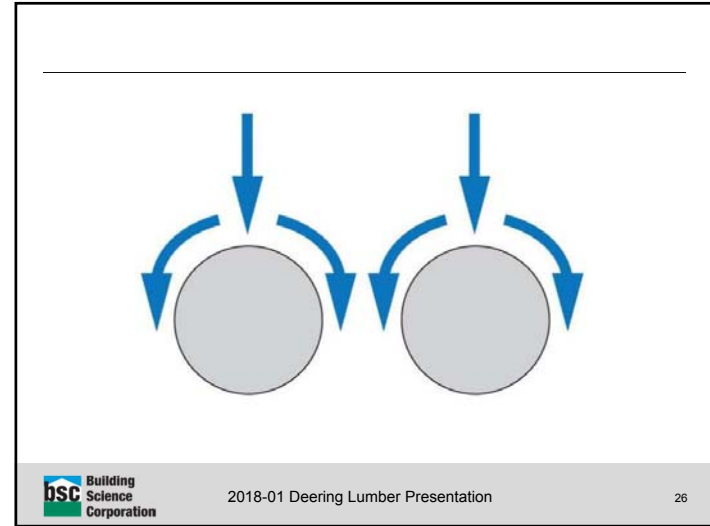
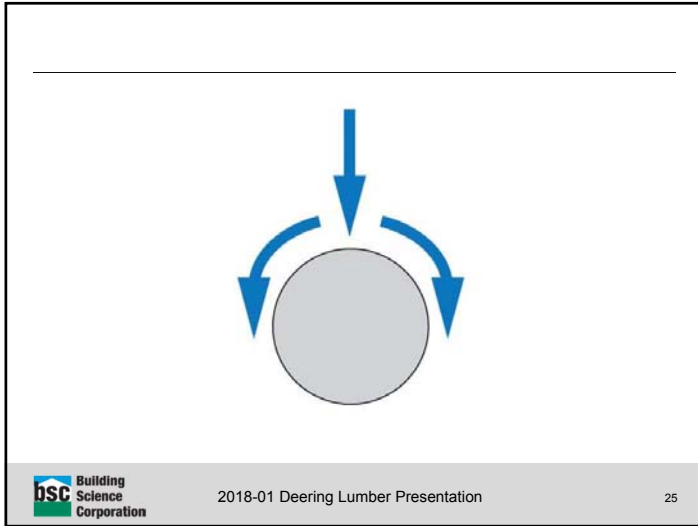
Water Control and Drainage Gaps

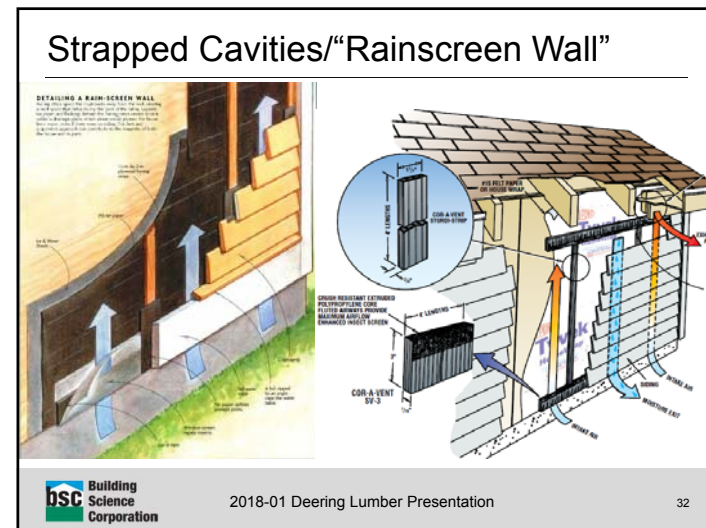
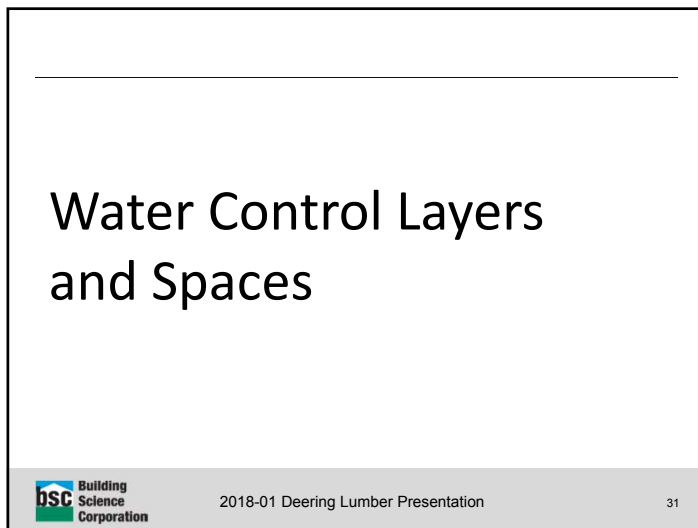
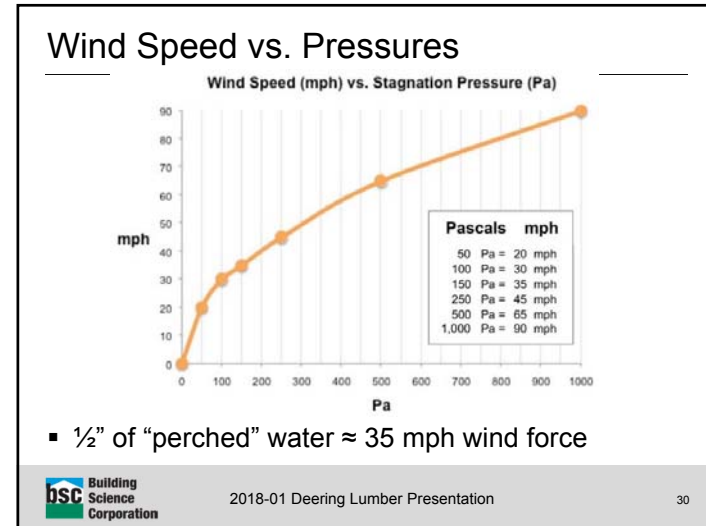
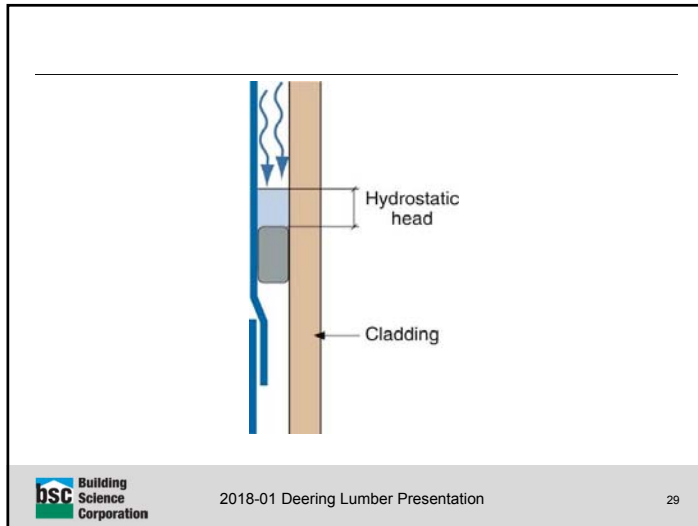
- Water control layer
- Key is control of hydrostatic pressure
- All about “the gap”

- See “Mind the Gap” and “Hockey Pucks and Hydrostatic Pressure”

Hydrostatic Pressure







Why Rainscreen/Air Gap



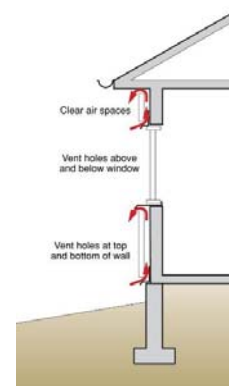
- “Sandwiched” water (surface tension) hangs up
- Staying wet or wet/dry cycling
 - Paint blow off
 - Damage over time



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Cladding Ventilation



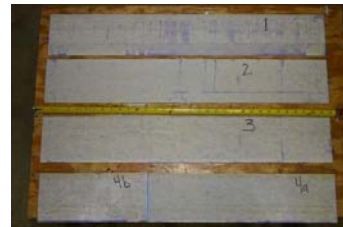
- Airflow behind cladding dries out both cladding & backup wall
- Brick veneer example
- Why vinyl siding and metal panel cladding work in cold climates



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Drainage from Lap Siding



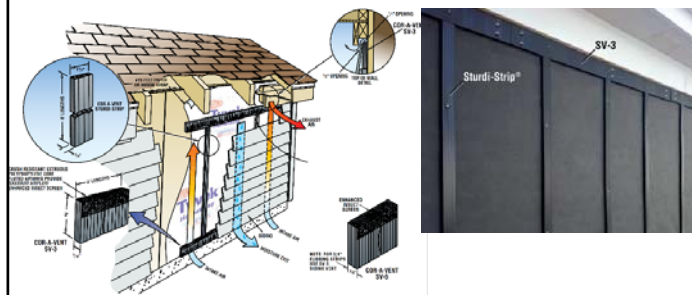
- Added water between siding & housewrap
- Lap sidings “self draining”
- Window head flashings!



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Commercial Rainscreen Options



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Shingle Wall Rainscreen/Air Gap



- Mesh style
(Home Slicker, Keene Building Products)



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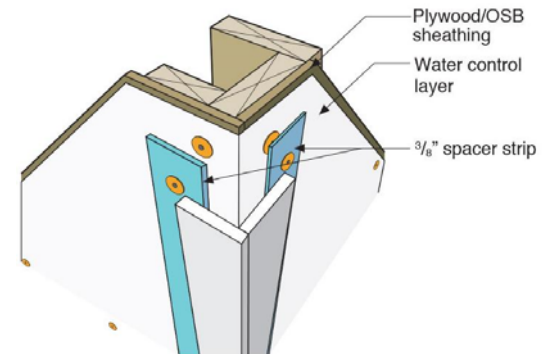
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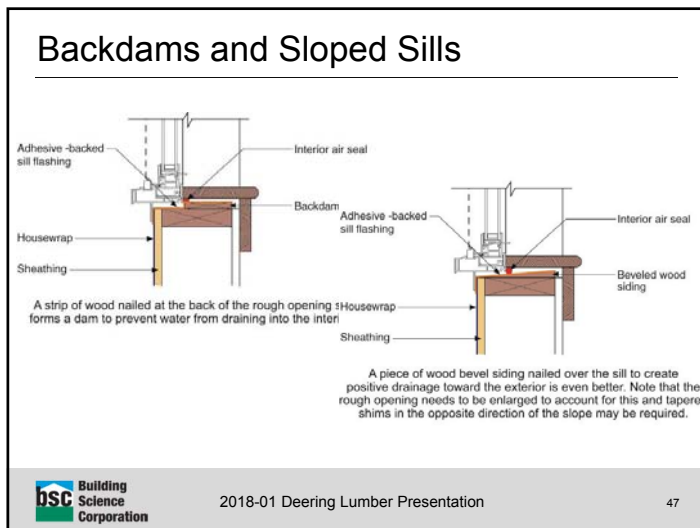
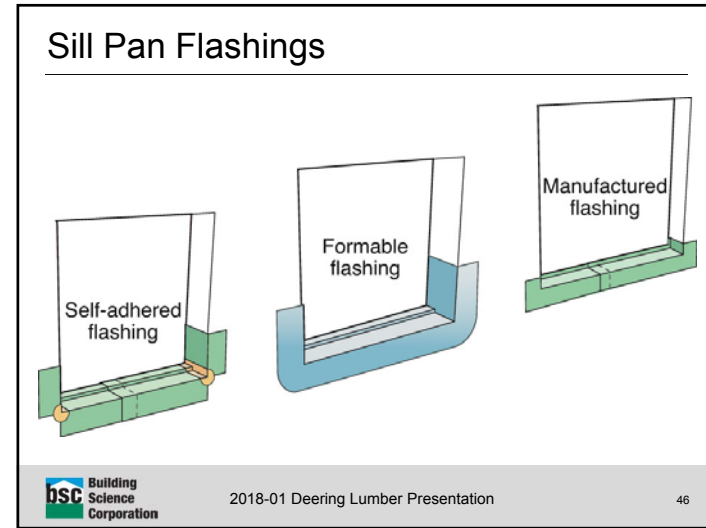
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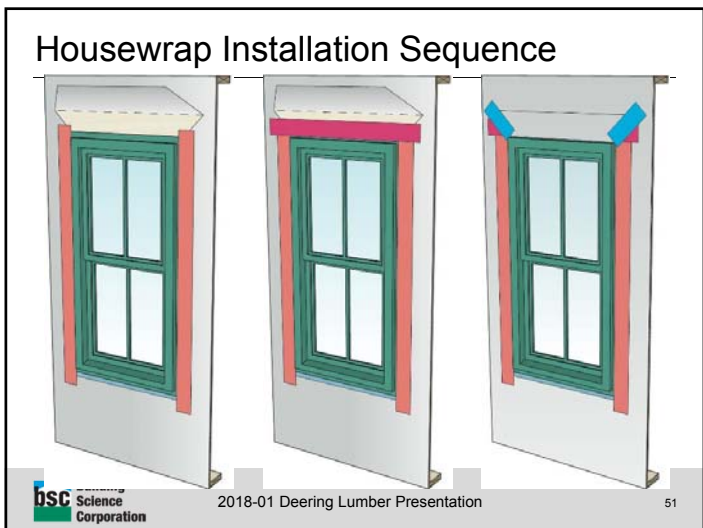
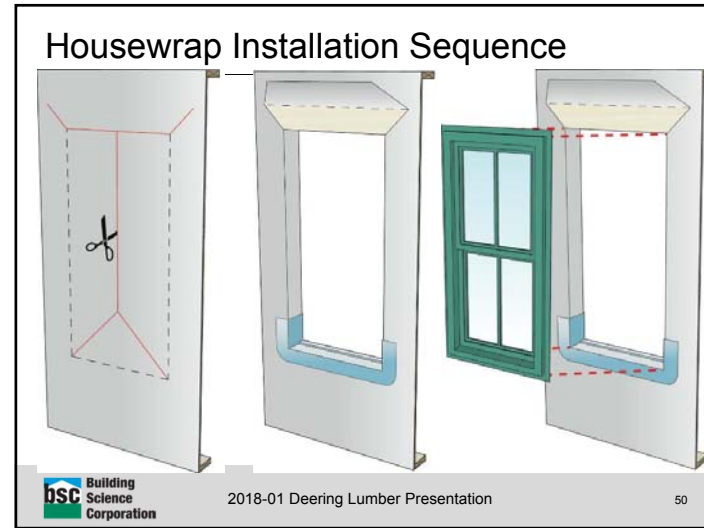


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Windows Flashings

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Window Failure Examples




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Window Failure Examples



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Window Failure Repair



- Stripped shingles and housewrap
- Windows pulled, re-flashed (fluid-applied window 'wrap'), and reinstalled
- Fluid-applied WRB
- Added rainscreen mat under shingles

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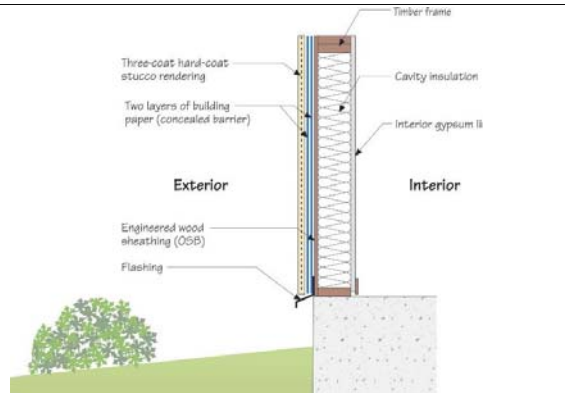
Stucco & Adhered Stone

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Stucco on Wood Frame Walls



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Stucco Failures (MN, PA)



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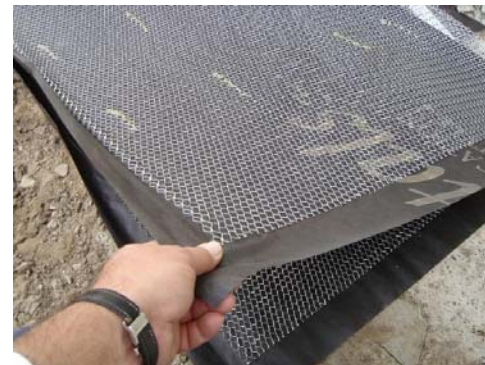
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Stucco-to-Paper Bond



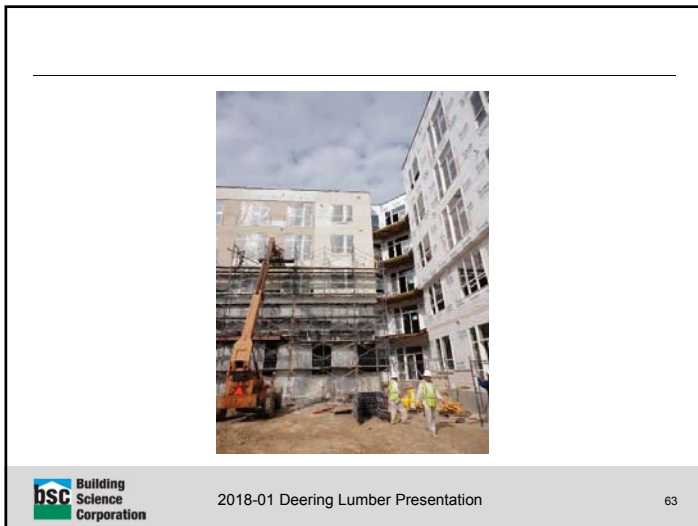
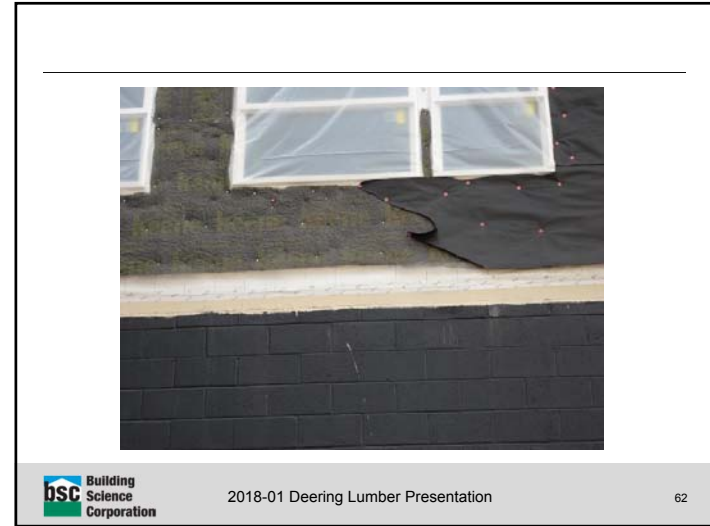
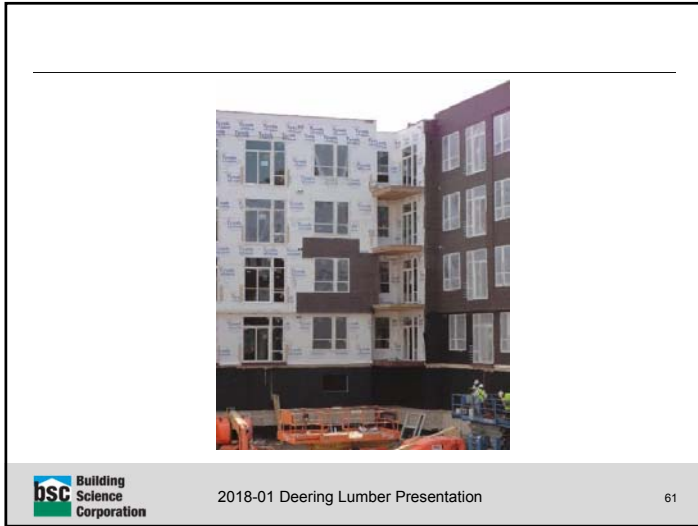
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Stone Veneer Rainscreen Options

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Wood.. and Other Things Move...

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Wood Moisture Movement

Studs get much wider and thicker, but not much longer, when they pick up moisture

Fibers get much thicker than longer when they pick up moisture

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Room for Expansion

- Wood will move—let it expand
 - For every 4" width of dry Certi-label Western Cedar shingle material, the product will expand 1/8"
- Wood floors indoors similar

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Wood Framing Shrinkage

resentation 69

Expanded PVC Trim

- PVC trim, painted black, and facing due south
- Fasten like crazy, or add movement joints

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Air Flow

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Airflow Control: Why

- Moisture control
 - air leakage condensation
- Comfort and Health
 - Drafts
 - Odors, particles, gases
- Energy
 - Heat transferred with air
- Sound
- Required by some codes

If you can't enclose air, you can't condition it

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Driving Forces

- 1. Wind Pressures
- 2. Buoyancy (or stack effect)
- 3. HVAC

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Driving Forces

The diagram shows three cross-sections of a house. The first, 'Wind Effect', shows wind hitting the side of the house with arrows indicating air flow. The second, 'Stack Effect', shows air rising from the ground level through the house and exiting through the roof. The third, 'Combustion and Ventilation', shows a fire in a fireplace with a chimney, with arrows indicating air being drawn in from the ground and exhausted through the chimney.

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Wind Flow Patterns

The diagram shows a blue cube representing a building. To the left, a blue arrow points towards the building, with horizontal lines representing wind flow. The lines are more densely packed near the ground and become more spread out as they rise, indicating that wind speed increases with height. Orange arrows on the cube show air being drawn in from the windward side and exiting from the roof and leeward side.

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2. Stack Effect: Cold Weather

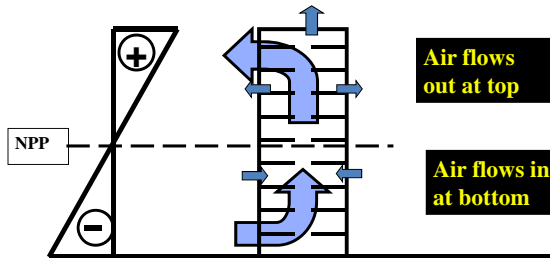
- Hot air rises
- Tall Building in Winter = Heavy Balloon

The diagram shows a cross-section of a building with a fire in a fireplace. A blue arrow points from the ground level into the building, indicating cold air being drawn in. A yellow arrow points upwards from the fireplace, indicating hot air rising. To the right, a tall building is shown with a '+' sign at the top and a '-' sign at the bottom, representing the pressure differential that causes the stack effect.

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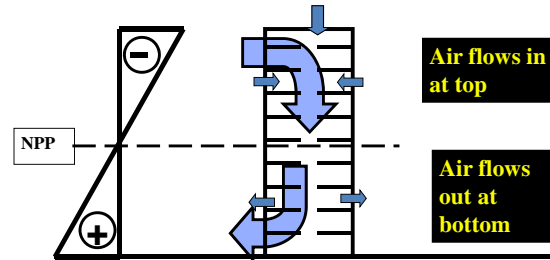
Stack Effect: Cold Weather

- “Perfect” Building equally leaky everywhere
- **Neutral Pressure Plane** at mid-height



Stack Effect: Warm Weather

- “Perfect” Building equally leaky everywhere
- **Neutral Pressure Plane** at mid-height



Air Barriers

Air Barrier Systems

- Function: to stop airflow through enclosure
- ABS can be placed anywhere in the enclosure
- Must be strong enough to take wind gusts (code requirement)
- Many materials are air impermeable, but most systems are not airtight

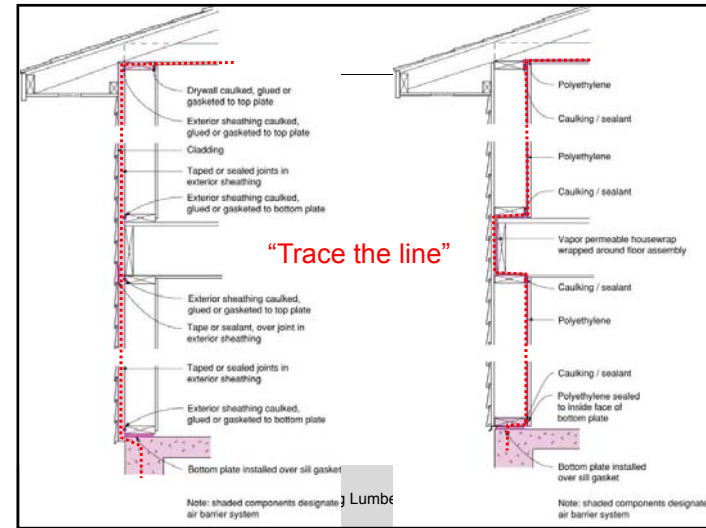
Air Barrier Systems: Requirements

- Continuous
 - primary need, common failure
- Strong
 - designed for full wind load
- Durable
 - critical component - repair, replacement
- Stiff
 - control billowing, pumping
- Air Impermeable
 - (may be vapour permeable)

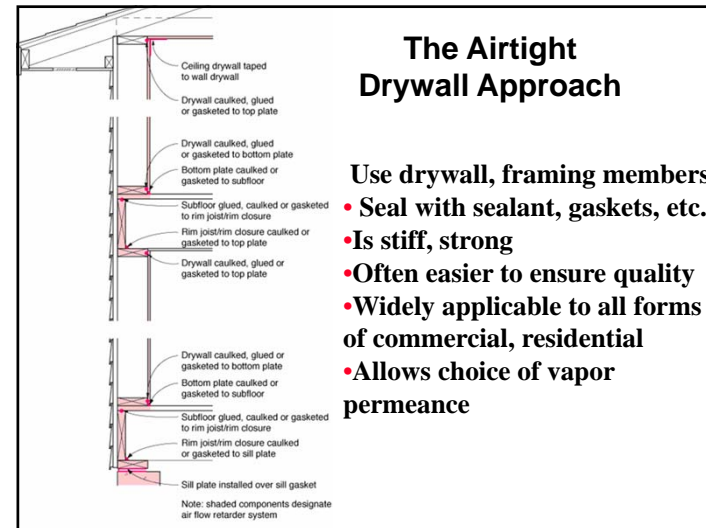


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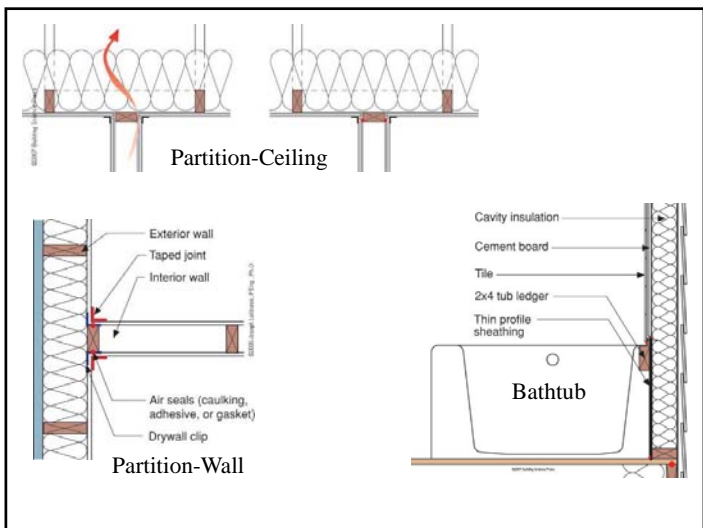
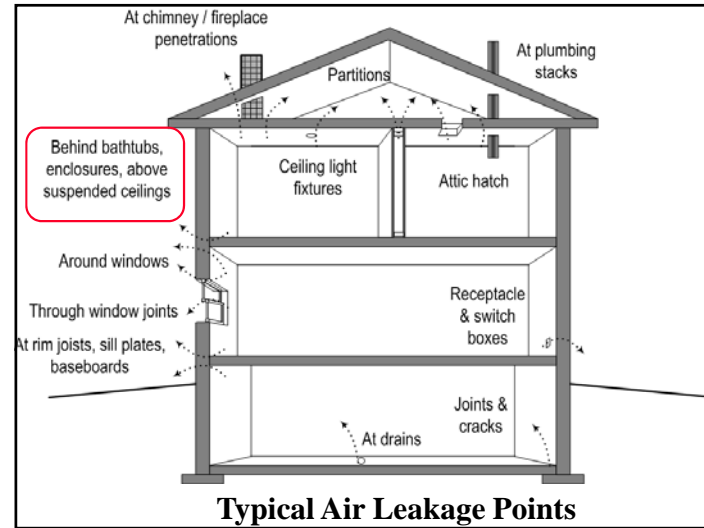


Poly can be (?) an air and vapour barrier
But
BEWARE when Air Conditioning
Definitely not in South



The Airtight Drywall Approach

- Use drywall, framing members
- Seal with sealant, gaskets, etc.
- Is stiff, strong
- Often easier to ensure quality
- Widely applicable to all forms of commercial, residential
- Allows choice of vapor permeance



Air Leakage Testing

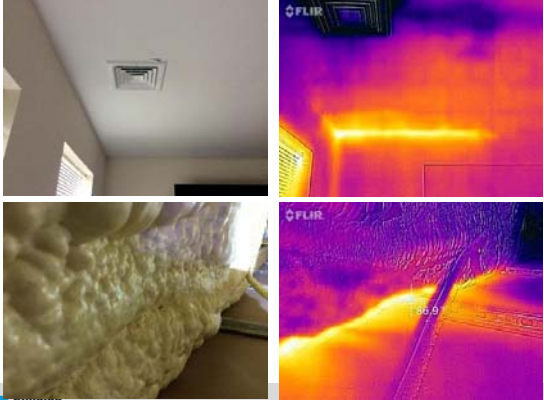
- 2009 IECC (Maine) does not have testing requirement; 2012 IECC onward requires 5 ACH 50

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Air Leakage Testing



The top-left image shows a square ceiling vent in a room. The top-right image is a thermal scan of a ceiling with a bright yellow/orange horizontal line indicating a leak. The bottom-left image is a close-up of yellow spray foam applied to a gap. The bottom-right image is a thermal scan of a wall joint with a bright yellow/orange line indicating a leak.

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Big holes




The left photo shows a large hole in a ceiling with insulation and a yellow tarp covering it. A blue box with white text says "Problem: Filter". The right photo shows the same hole with a sealant applied to the edges. A blue box with white text says "Solution: Seal".



If you can see daylight it is not sealed

Spray Foam as an Air Barrier



53.2°F FLIR
47°F 60°F

- Spray foam doesn't air seal where it isn't there!
- Wood-to-wood connections

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Spray Foam as an Air Barrier

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Spray Foam as an Air Barrier

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Cold Weather Condensation in Walls

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Vapor Diffusion vs. Air Leakage

- Vapor Diffusion
 - more to less vapor
 - no air flow
 - flow through tiny pores
- Air Convection
 - more to less air pressure
 - flow through visible cracks and holes
 - vapor is just along for the ride

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Wall w/o Insulated Sheathing

A cross-sectional diagram of a wall assembly without insulated sheathing. From left to right, it shows a wooden stud, a layer of insulation, and a sheathing board. Red dashed arrows indicate air leakage from the exterior to the interior. Blue arrows show vapor diffusion from the interior to the exterior. Blue water droplets are shown on the interior side of the sheathing, labeled "Cold = Condensation".

Air leakage

Cold = Condensation

Vapor Diffusion

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Frosting on Sheathing

A photograph showing a vertical section of a wall. The sheathing board is covered in a thick layer of white frost, indicating condensation and freezing within the wall assembly.

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Wall with Insulated Sheathing

A cross-sectional diagram of a wall assembly with insulated sheathing. From left to right, it shows a wooden stud, a layer of insulation, and a sheathing board with an additional insulation layer on its exterior side. Red dashed arrows indicate air leakage. Blue arrows show vapor diffusion. The interior side of the sheathing is labeled "Warm = no condensation".

Air leakage

Warm = no condensation

Vapor Diffusion

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Vapor Barriers and the Code

- Class I: 0.1 perm or less (polyethylene)
- Class II: $0.1 < \text{perm} \leq 1.0$ perm (Kraft facing, vapor retarder paint)
- Class III: $1.0 < \text{perm} \leq 10$ perm (Latex paint)
- Polyethylene = no inward drying
- More open vapor control allows greater drying—more "forgiveness" in wall

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Vapor Barriers and the Code

TABLE N1102.5.1
CLASS III VAPOR RETARDERS

Zone	Class III vapor retarders permitted for:
Marine 4	Vented cladding over OSB Vented cladding over plywood Vented cladding over fiberboard Vented cladding over gypsum Insulated sheathing with R-value ≥ 2.5 over 2x4 wall Insulated sheathing with R-value ≥ 3.75 over 2x6 wall
5	Vented cladding over OSB Vented cladding over plywood Vented cladding over fiberboard Vented cladding over gypsum Insulated sheathing with R-value ≥ 5 over 2x4 wall Insulated sheathing with R-value ≥ 7.5 over 2x6 wall
6	Vented cladding over fiberboard Vented cladding over gypsum Insulated sheathing with R-value ≥ 7.5 over 2x4 wall Insulated sheathing with R-value ≥ 11.25 over 2x6 wall
7 and 8	Insulated sheathing with R-value ≥ 10 over 2x4 wall Insulated sheathing with R-value ≥ 15 over 2x6 wall

Can just use latex paint (no vapor barrier) if you add enough insulation outside of the stud bay insulation. Safer -> controls diffusion and air leakage moisture.
Zone 6A = ~40%/60% R-value ratio

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Thermal Bridging at Framing

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Thermal Bridging at Steel Framing

Steel is 400 times more conductive than wood

Steel studs are about 40 times thinner

R=4+ ← Cold Hot

R<0.3 ←

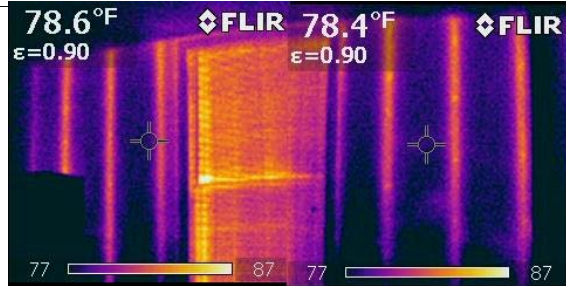
A 2x6 steel stud wall 16" OC with R-19 Fiberglass Batt = effective R-9 wall assembly.

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Thermal Bridging at Steel Framing

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Thermal Bridging at Steel Framing



- Summertime/AC example
- Sun is hitting the wall (southeast orientation)



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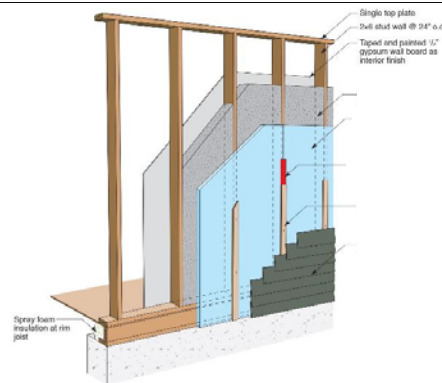
Exterior Continuous Insulation



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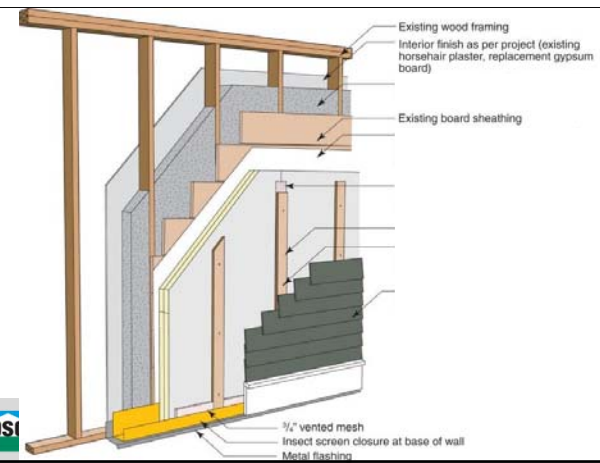
Exterior Rigid Foam (Taped Seams)



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4" Polyisocyanurate Foam Retrofit



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Mineral Fiber, Nailbase Panel



09

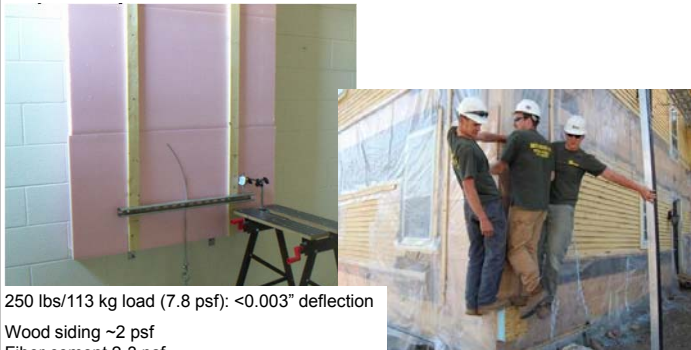
4" Polyisocyanurate Foam



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Foam Sheathing Cladding



250 lbs/113 kg load (7.8 psf): <math><0.003''</math> deflection

Wood siding ~2 psf
Fiber cement 2-3 psf
Stucco 8-10 psf

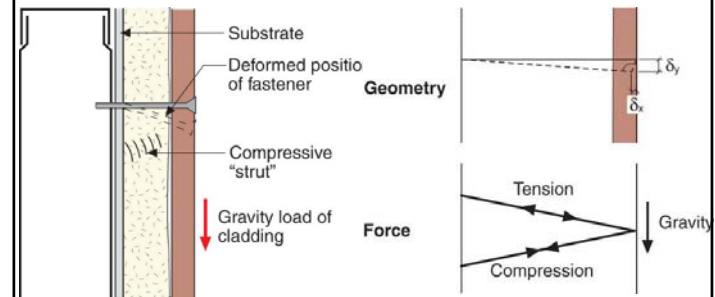
Image c/o Petersen Engineering



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Foam Sheathing Cladding Attachment

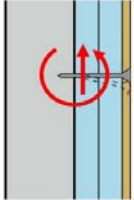


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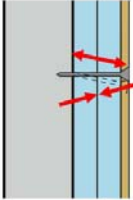
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BSC Cladding Attachment Research

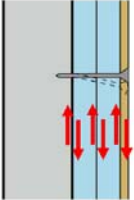
- System Mechanics




Shear and rotational resistance provided by fastener to wood connections



Rotational resistance provided by tension in fastener and compression of the insulation



Vertical movement resistance provided by friction between layers





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Full System Laboratory Tests

- Looked at initial response full system capacity as well as long term sustained loading
- Used full scale samples to limit variations in fastener installation






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Recommendations

- Based on the results of the testing it is currently recommended to use a maximum load per fastener of no more than 10lbs for up to 4" of insulation


Cladding weight (psf)	16" oc Furring	24" oc Furring
5	18	12
10	9	6
15	6	4
20	4	3
25	3	2



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The "Perfect Wall"



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Design Info from the 1960's (Canada)

RAIN

RAIN SCREEN

WATER THAT PENETRATES IS DIVERTED OUTWARD BY FLASHINGS

1. Air / Rain Barrier
2. Structural Support
3. Rain Shedding
4. Insulation

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The Perfect Wall

Cladding

Control layers

Structure

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Wall

Slab

Roof

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Ballast

Filter fabric

Control layers

Roof structure

Cladding

Control layers

Structure

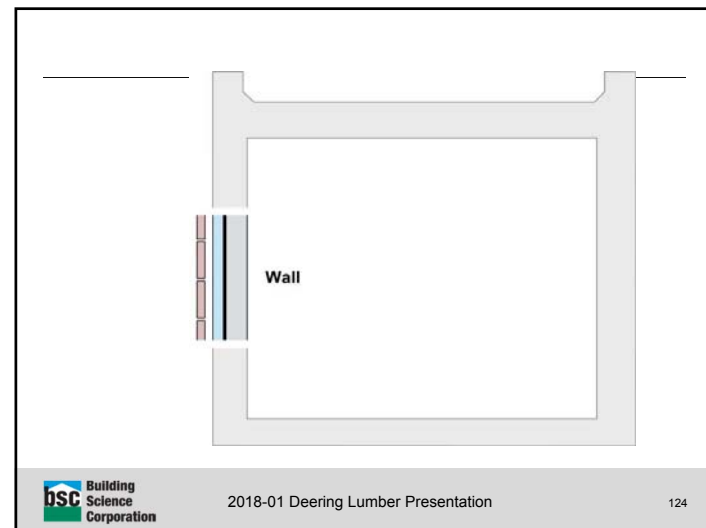
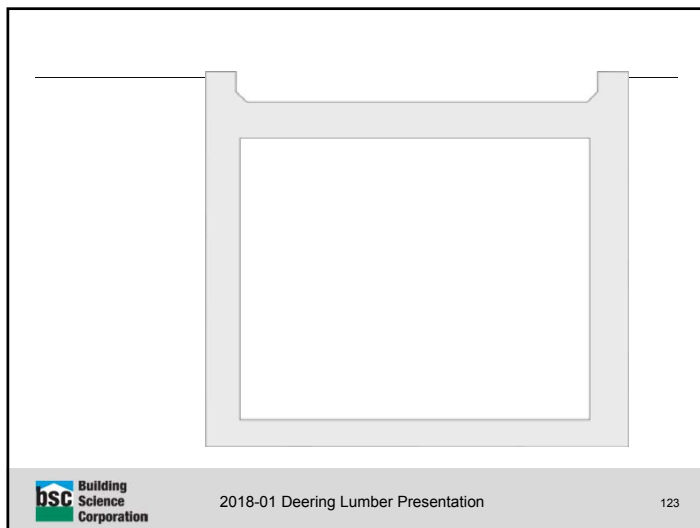
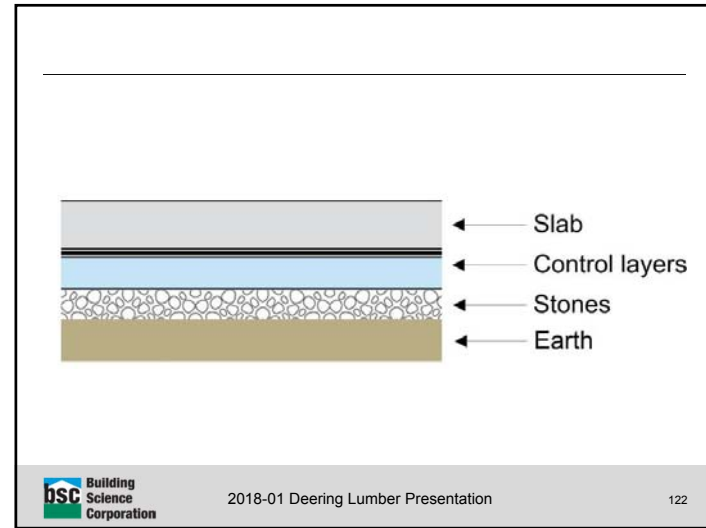
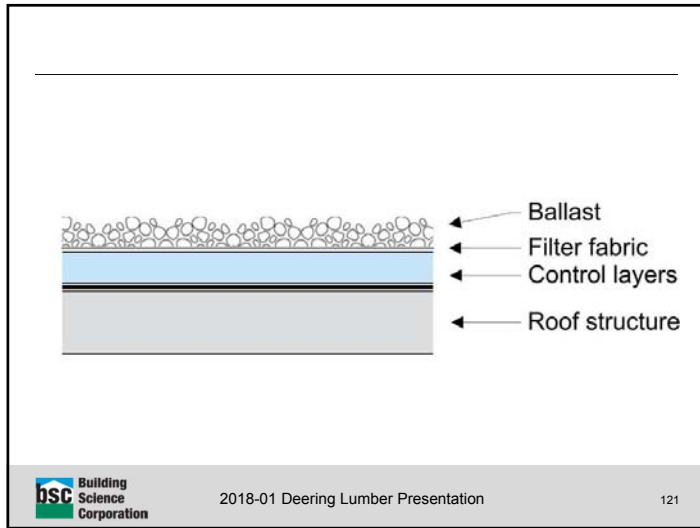
Slab

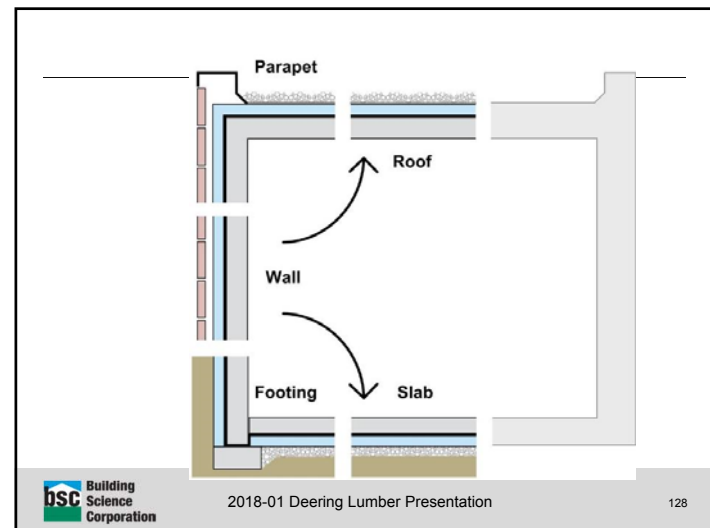
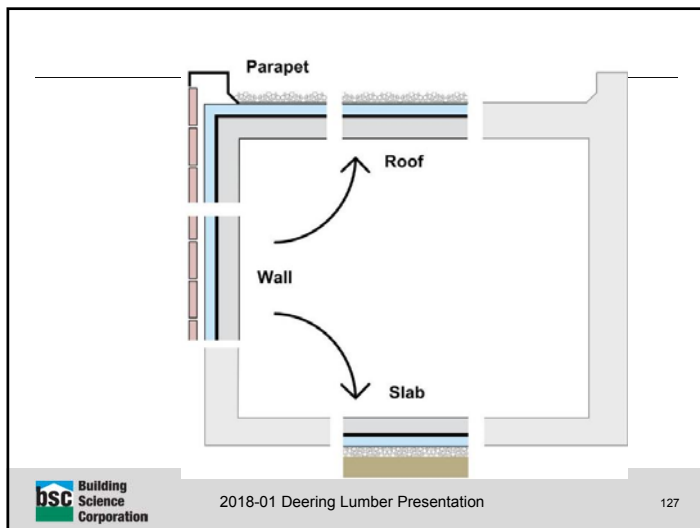
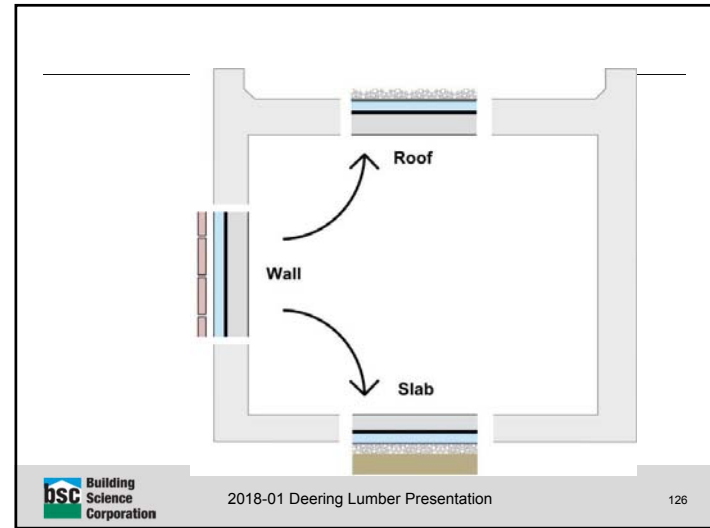
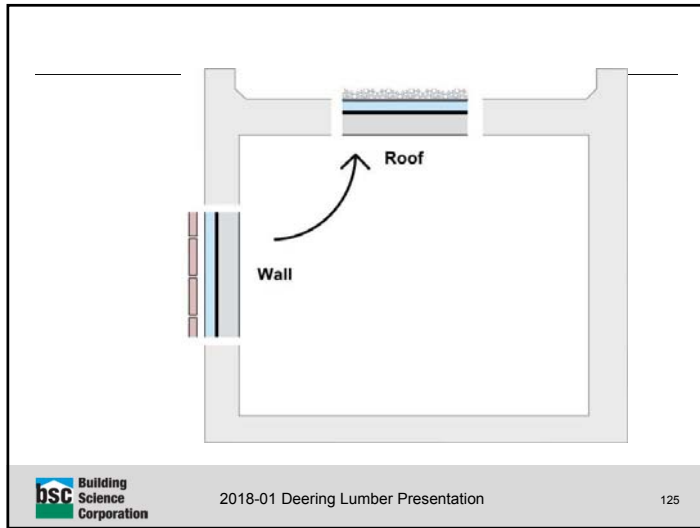
Control layers

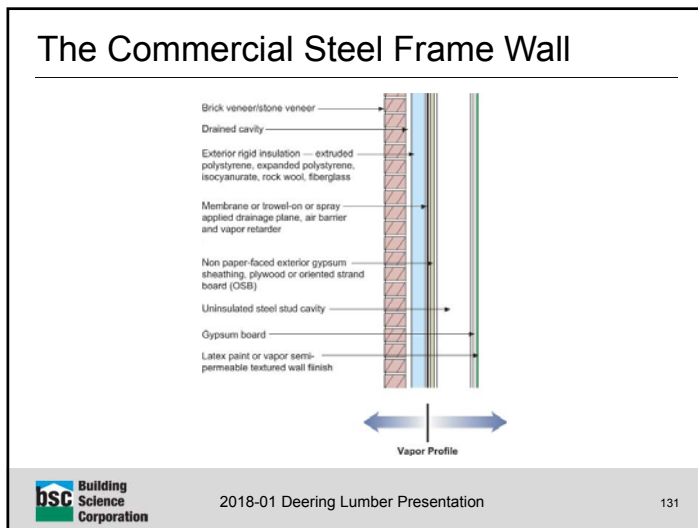
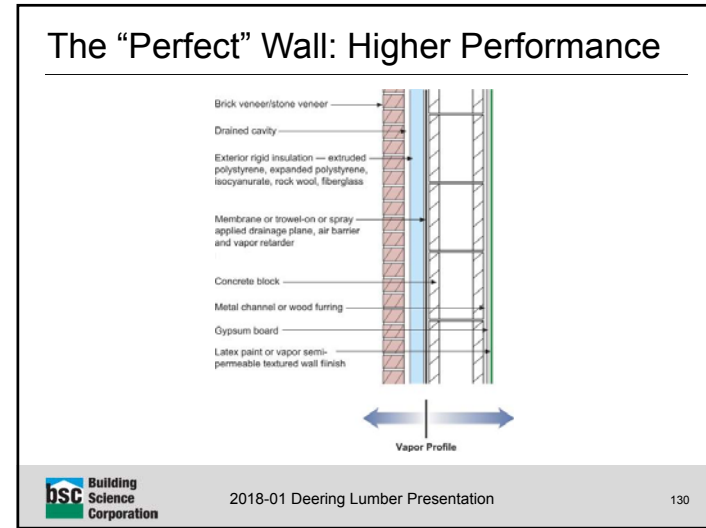
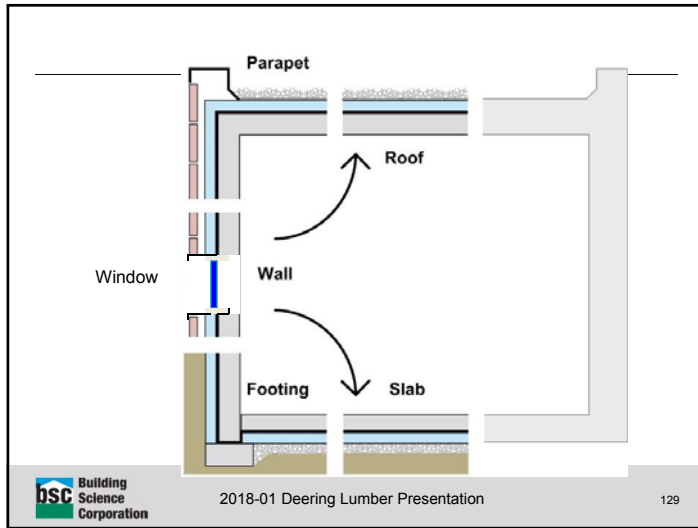
Stones

Earth

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- "Perfect Wall" Advantages**
- Very robust enclosure—"500 year building"
 - Structural portion in "interior" conditions
 - Institutional/long term buildings
 - No risk of interstitial condensation
 - Continuity of control layers
 - Continuous thermal insulation outside
 - Inspectable and simple air barrier "wrap"
 - Water control layer/WRB inspectable before insulation
 - Any interior condition
 - Any exterior condition
- BSC Building Science Corporation** 2018-01 Deering Lumber Presentation 132

Building the “Perfect Wall”



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Self-adhered membrane. XPS insulation



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Fluid-Applied Asphalt & Rock Wool

- Asphalt Drainage Plane Air Barrier
- Rock wool Insulation



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Exterior Closed Cell Spray Foam

All Four Control Layers
Spray foam= air barrier & drainage plane & insulation & vapor control

Transitions,
Continuity,
Penetrations



Cladding Support (Z-Furring)

- Z-furring 16" o.c.,
- All this effort to cover up our thermal bridges with insulation... and then we punch steel through it...

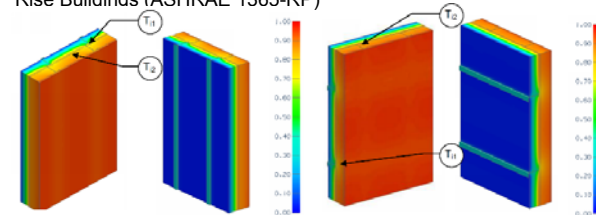


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Thermal Bridging at Cladding

- Thermal Performance of Building Envelope Details for Mid- and High-Rise Buildings (ASHRAE 1365-RP)



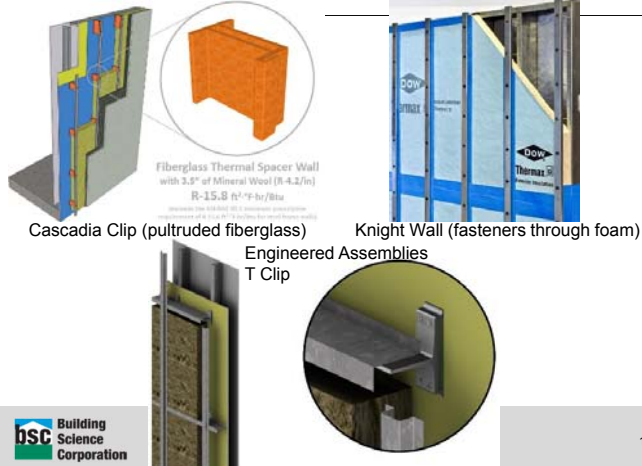
View from Interior				View from Exterior			
Nominal (1D) vs. Assembly Performance Indicators				Nominal (1D) vs. Assembly Performance Indicators			
Exterior Insulation ID (R-Value)	R _{1D} (ft ² ·h ²⁴ ·°F / Btu) (m ² ·K / W)	R _a (ft ² ·h ²⁴ ·°F / Btu) (m ² ·K / W)	U _a (Btu/h ²⁴ ·ft ² ·°F) (W/m ² ·K)	Exterior Insulation ID (R-Value)	R _{1D} (ft ² ·h ²⁴ ·°F / Btu) (m ² ·K / W)	R _a (ft ² ·h ²⁴ ·°F / Btu) (m ² ·K / W)	U _a (Btu/h ²⁴ ·ft ² ·°F) (W/m ² ·K)
R-5 (0.88)	R-8.2 (1.44)	R-6.4 (1.12)	0.157 (0.89)	R-5 (0.88)	R-8.2 (1.44)	R-6.8 (1.21)	0.146 (0.83)
R-10 (1.76)	R-13.2 (2.32)	R-8.3 (1.47)	0.120 (0.68)	R-10 (1.76)	R-13.2 (2.32)	R-9.4 (1.66)	0.106 (0.60)
R-15 (2.64)	R-18.2 (3.20)	R-9.7 (1.71)	0.103 (0.59)	R-15 (2.64)	R-18.2 (3.20)	R-11.3 (1.99)	0.088 (0.50)
R-20 (3.52)	R-23.2 (4.08)	R-11.0 (1.93)	0.091 (0.52)	R-20 (3.52)	R-23.2 (4.08)	R-13.1 (2.31)	0.076 (0.43)
R-25 (4.40)	R-28.2 (4.96)	R-12.0 (2.11)	0.084 (0.48)	R-25 (4.40)	R-28.2 (4.96)	R-14.5 (2.56)	0.069 (0.39)



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Thermally Broken Cladding Supports



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Questions?

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kohta (at sign) buildingscience dot com

This presentation will be available at <http://buildingscience.com/past-events>



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Document Resources

- Building Science Digest 014: Air Flow Control in Buildings
<http://www.buildingscience.com/documents/digests/bsd-014-air-flow-control-in-buildings>
- Building Science Digest 163: Controlling Cold-Weather Condensation Using Insulation
<https://buildingscience.com/documents/digests/bsd-controlling-cold-weather-condensation-using-insulation>
- Building Science Insight 001: The Perfect Wall
<http://www.buildingscience.com/documents/insights/bsi-001-the-perfect-wall/>
- Building Science Insight 005: A Bridge Too Far
<http://www.buildingscience.com/documents/insights/bsi-005-a-bridge-too-far/>
- Building Science Insight 029: Stucco Woes—The Perfect Storm
<http://buildingscience.com/documents/insights/bsi-029-stucco-woes-the-perfect-storm>
- Building Science Insight 038: Mind the Gap, Eh!
<http://www.buildingscience.com/documents/insights/bsi-038-mind-the-gap-eh/>
- Building Science Insight 048: Exterior Spray Foam
<http://www.buildingscience.com/documents/insights/bsi-048-exterior-spray-foam/>
- Building Science Insight 057: Hockey Pucks and Hydrostatic Pressure
<http://buildingscience.com/documents/insights/bsi-057-hockey-pucks-and-hydrostatic-pressure>
- Building Science Insight 062: Thermal Bridges Redux
<http://www.buildingscience.com/documents/insights/bsi062-thermal-bridges-redux>

