Kohta Ueno

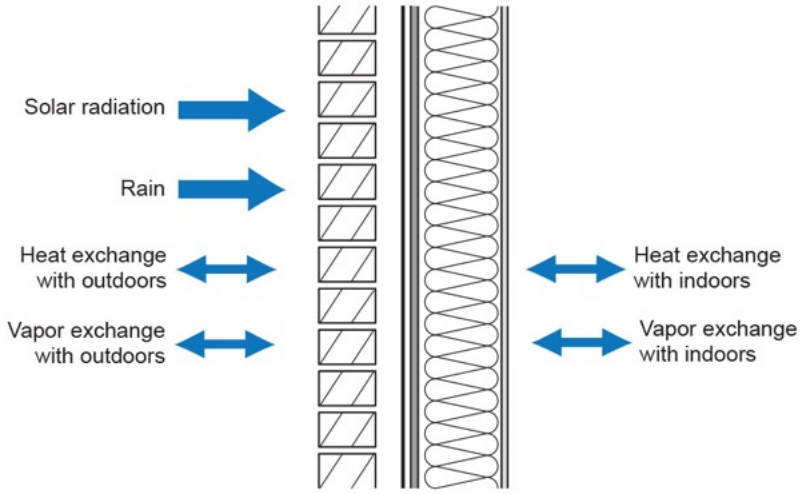
Building Science of Walls

June 6, 2017

Building Science Corporation

Background

Environmental Separator

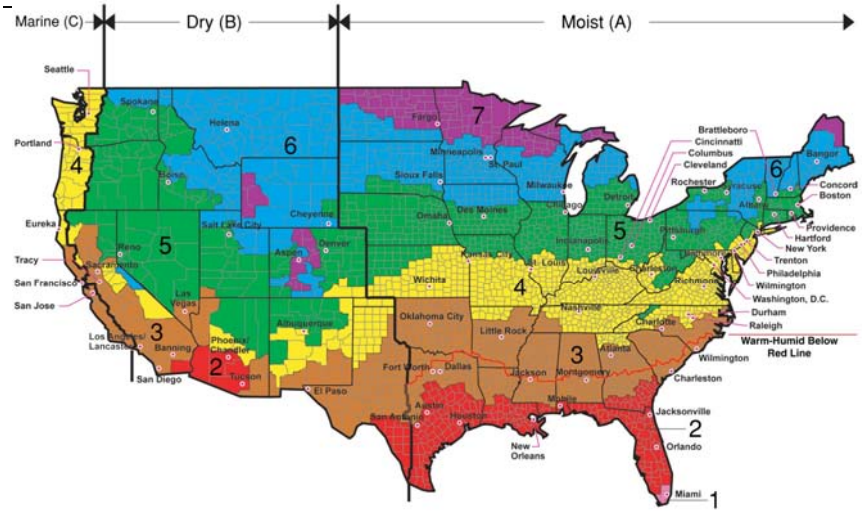


What Separation Roles?

- 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)

Climate Zone Map (BSC)

Climate Zone Map (DOE)

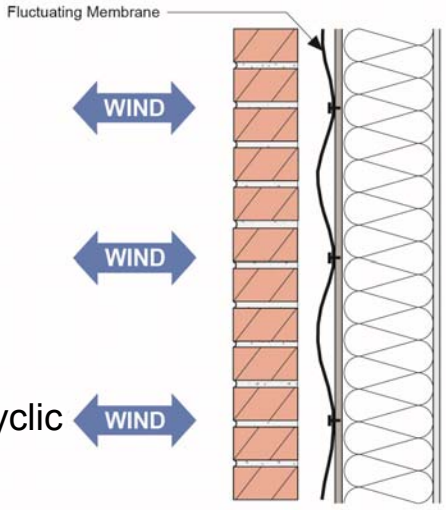


Water Control Layer

Housewrap (Residential)

Housewrap (Commercial)

Billowing Housewrap



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

Vapor-Impermeable Adhered Membrane

- Cold climate + no exterior insulation = danger

Vapor-Permeable Adhered Membrane

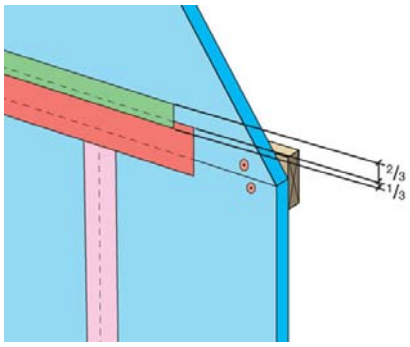
Self-Adhered Membranes

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

Taped Sheathings (WRB Surface)

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

Taped Joints (Foam Sheathing)



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

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.

Reverse Lap Termination

- "Termination mastic" at reverse lap condition

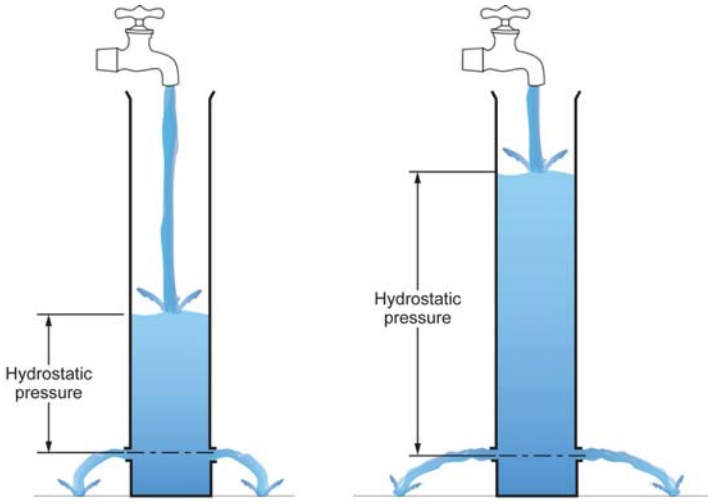
Water Control-Hydrostatic Pressure

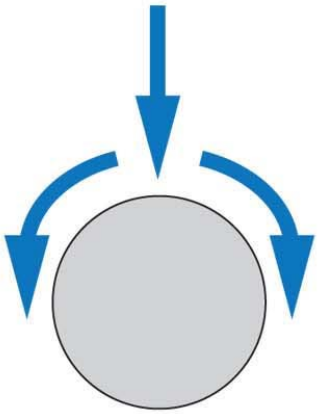
Water Control and Drainage Gaps

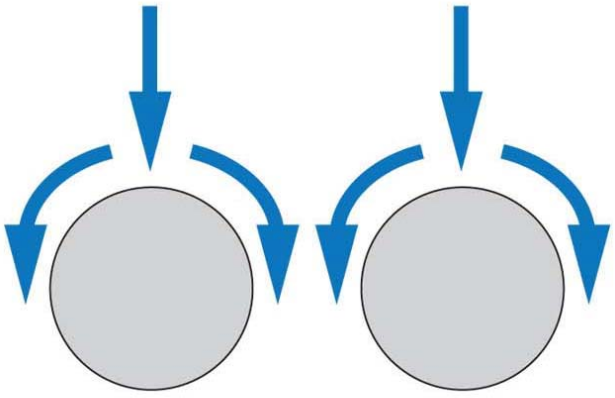
- Water control layer
- Key is control of hydrostatic pressure
- All about “the gap”

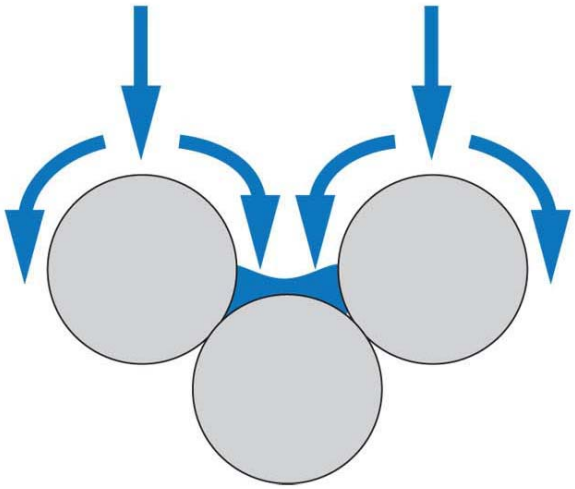
- See “Mind the Gap” and “Hockey Pucks and Hydrostatic Pressure”

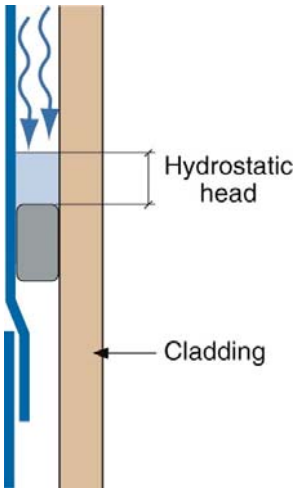
Hydrostatic Pressure



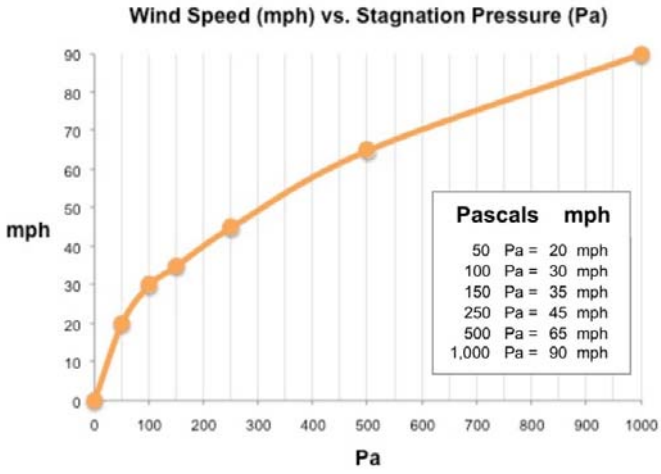








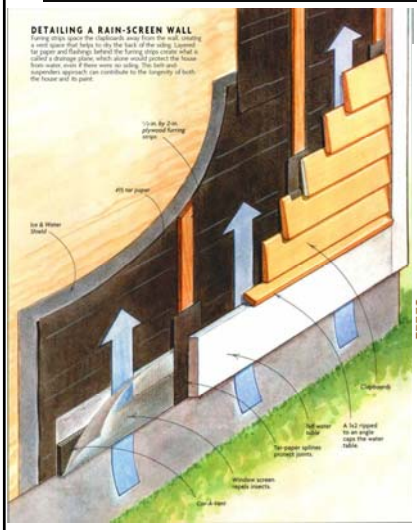
Wind Speed vs. Pressures

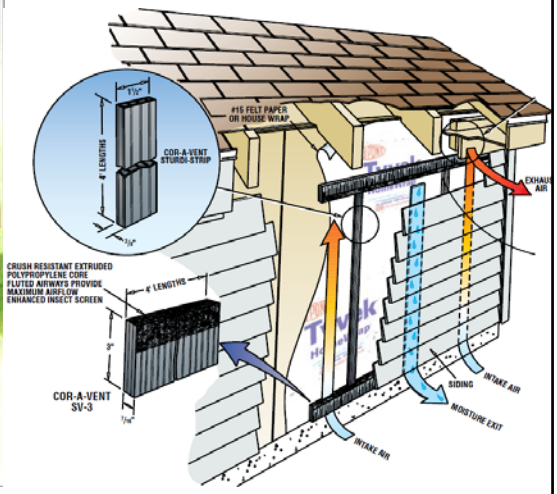


- ½" of "perched" water ≈ 35 mph wind force

Water Control Layers and Spaces

Strapped Cavities/“Rainscreen Wall”

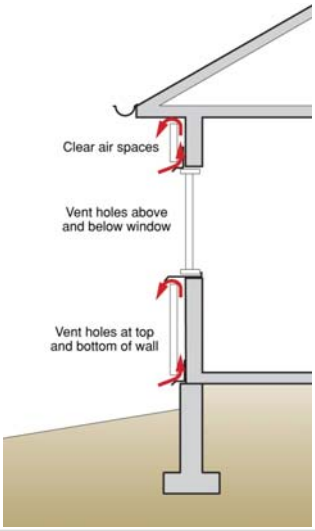




Why Rainscreen/Air Gap

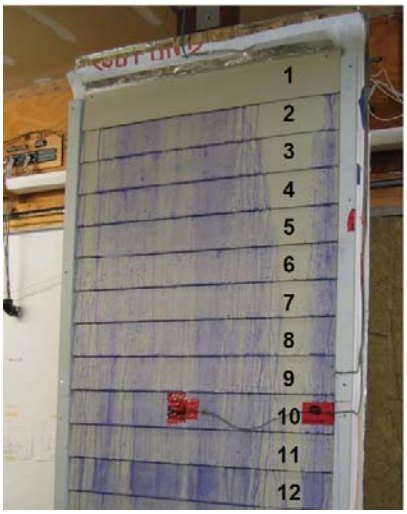
- "Sandwiched" water (surface tension) hangs up
- Staying wet or wet/dry cycling
  - Paint blow off
  - Damage over time

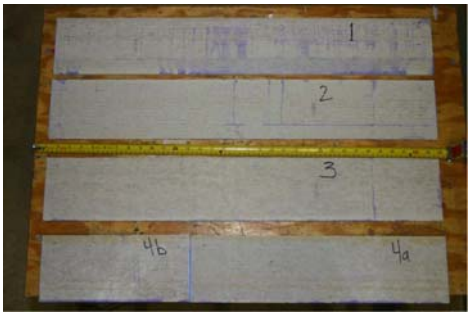
Cladding Ventilation



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

Drainage from Lap Sidings



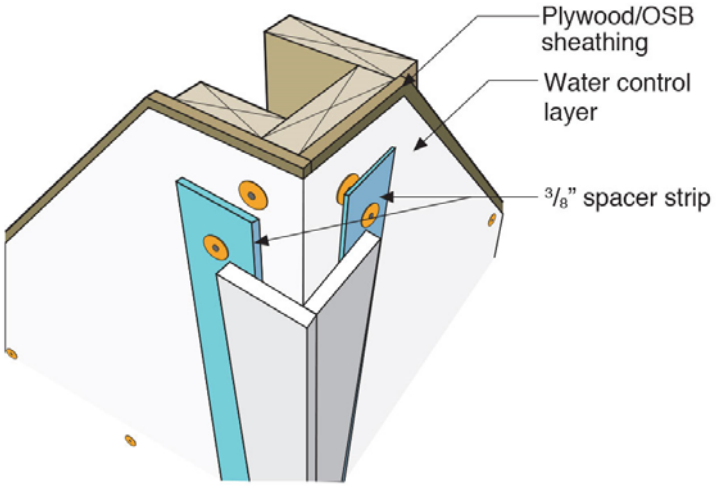


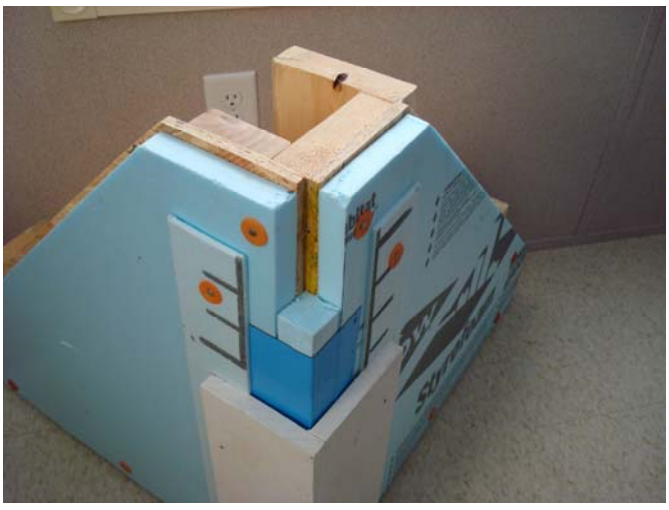
- Added water between siding & housewrap
- Lap sidings “self draining”
- Window head flashings!

Shingle Wall Rainscreen/Air Gap

- Mesh style
  (Home Slicker, Keene Building Products)


Tyvek

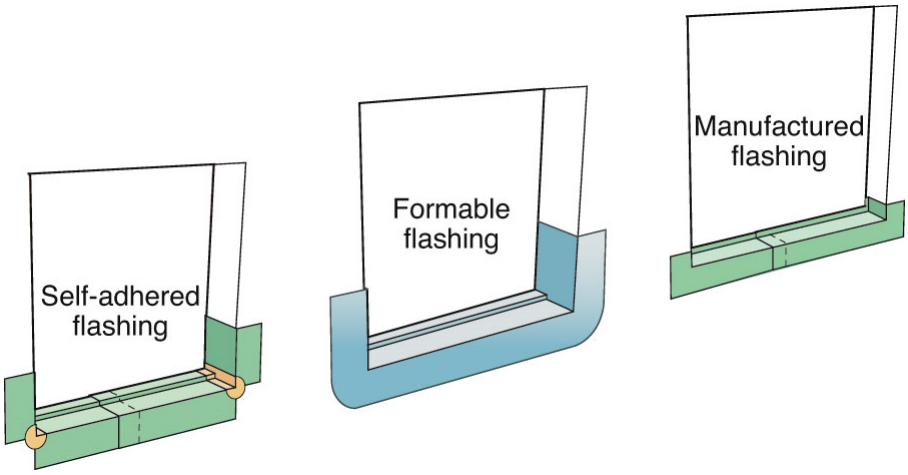

Plywood/OSB sheathing
Water control layer
3/8" spacer strip



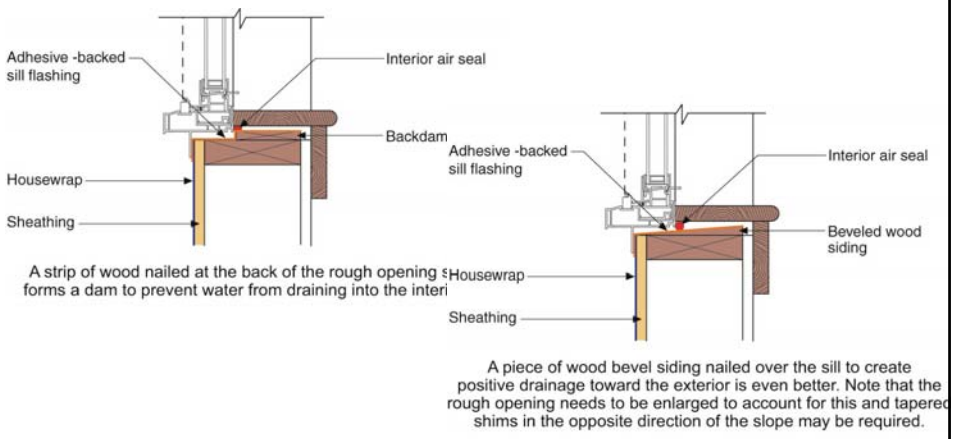
Windows Flashings

EIFS & Windows - Oops

Sill Pan Flashings



Backdams and Sloped Sills

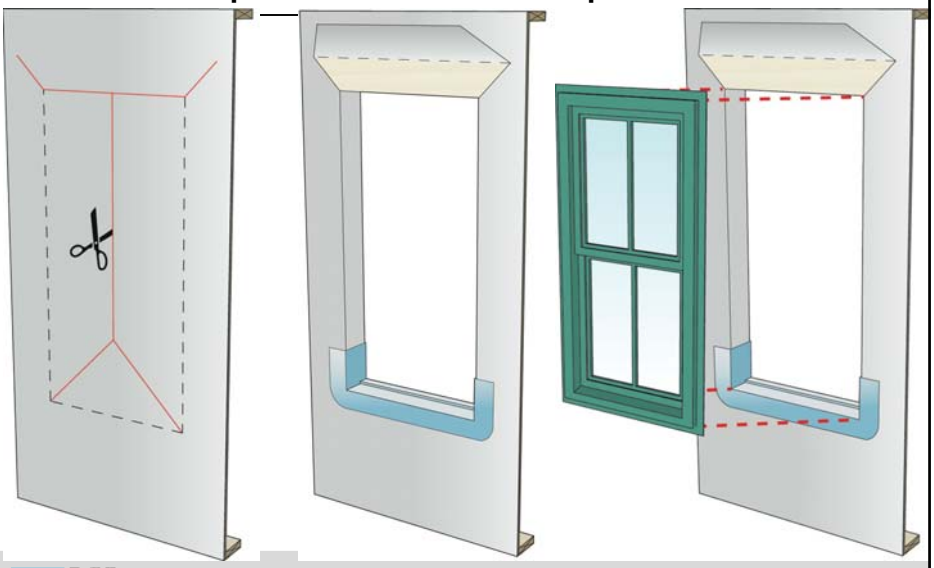



Formable Sub-sill Flashing

Subsill


PARR LUMBER
E-Z Seal
Moisture
Tyvek

Housewrap Installation Sequence



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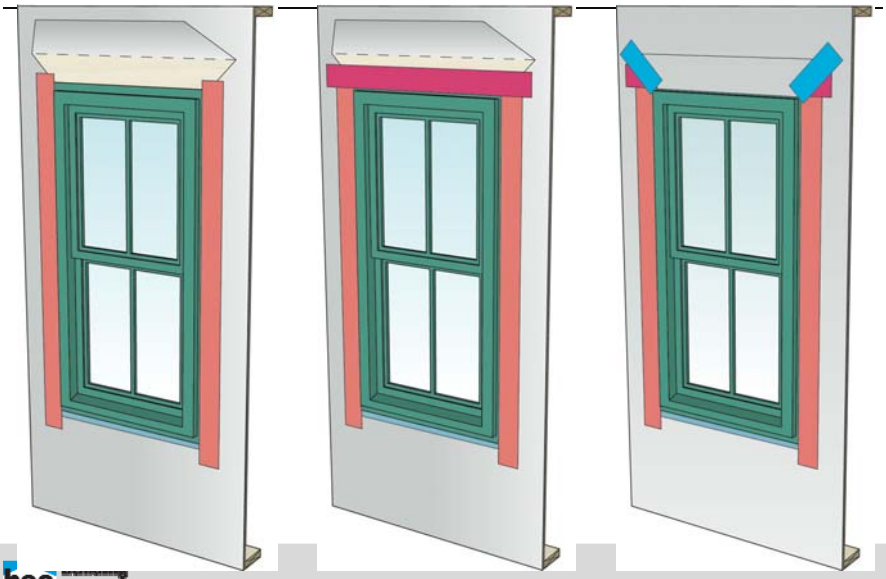


Foam Sheathing Window Flashing

Window Failure Examples

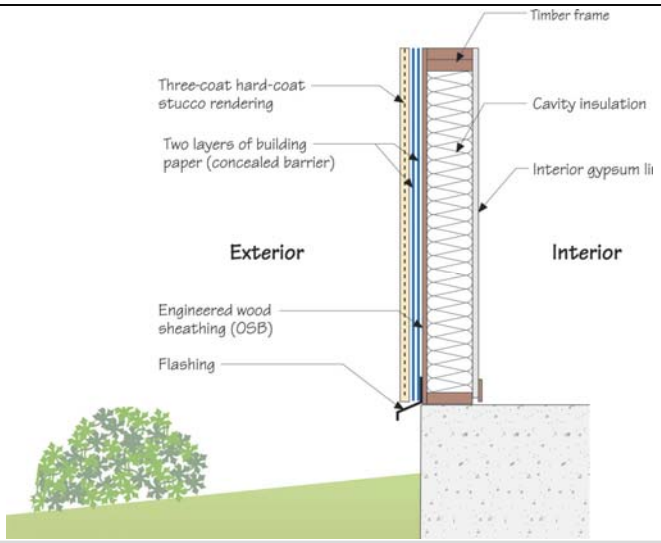
Window Failure Examples

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

Stucco & Adhered Stone

Stucco on Wood Frame Walls



Stucco Failures (MN, PA)

Stucco-to-Paper Bond

Adhered Stone Veneer

Air Flow

Airflow Control: Why

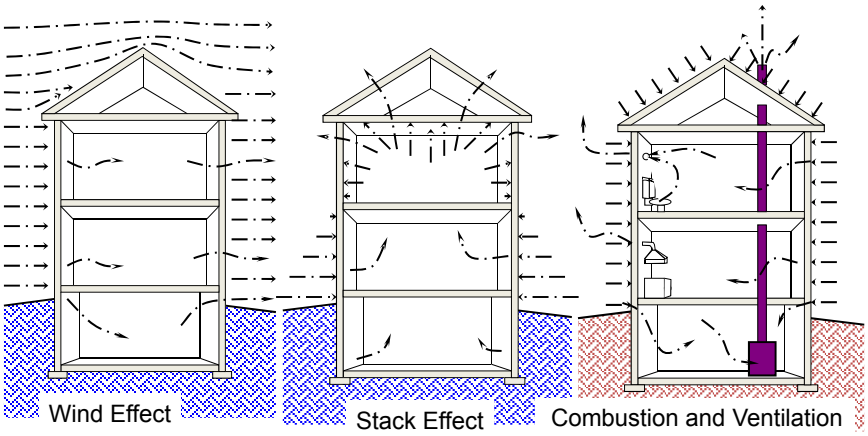
- Moisture control
  - air leakage condensation
- Comfort and Health
  - Drafts
  - Odors, particles, gases
- Energy
  - Heat transferred with air
- Sound
- Required by some codes

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

Driving Forces

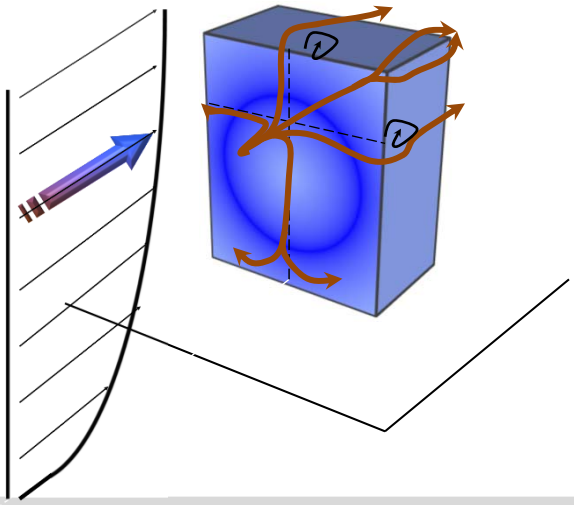
- 1. Wind Pressures
- 2. Buoyancy (or stack effect)
- 3. HVAC

Driving Forces



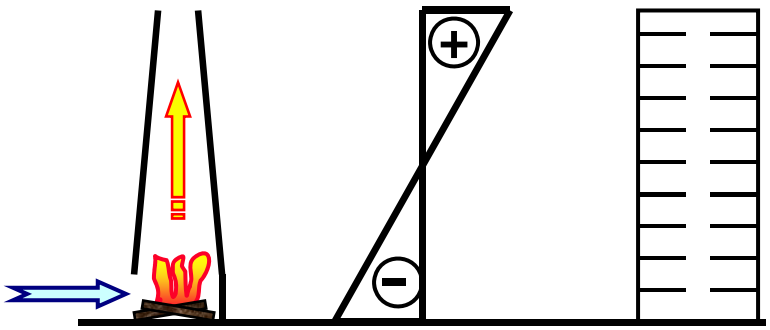
Wind Flow Patterns

Wind speed increases with height



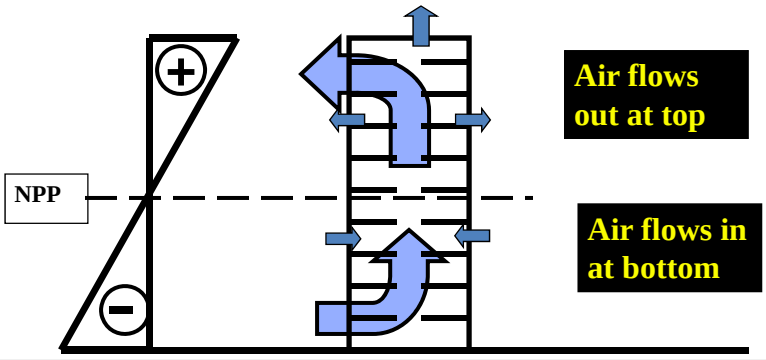
2. Stack Effect: Cold Weather

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



Stack Effect: Cold Weather

- "Perfect" Building equally leaky everywhere
- Neutral Pressure Plane at mid-height



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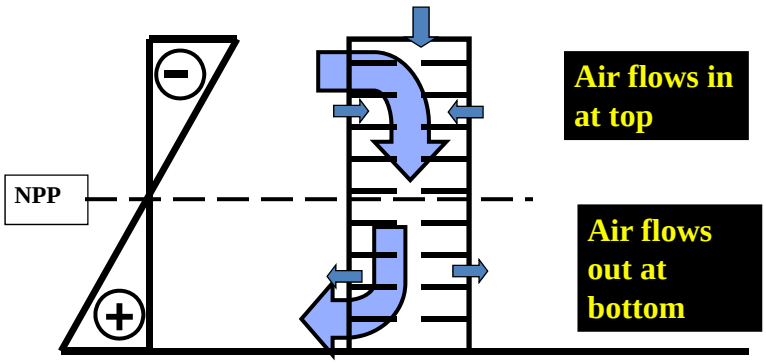


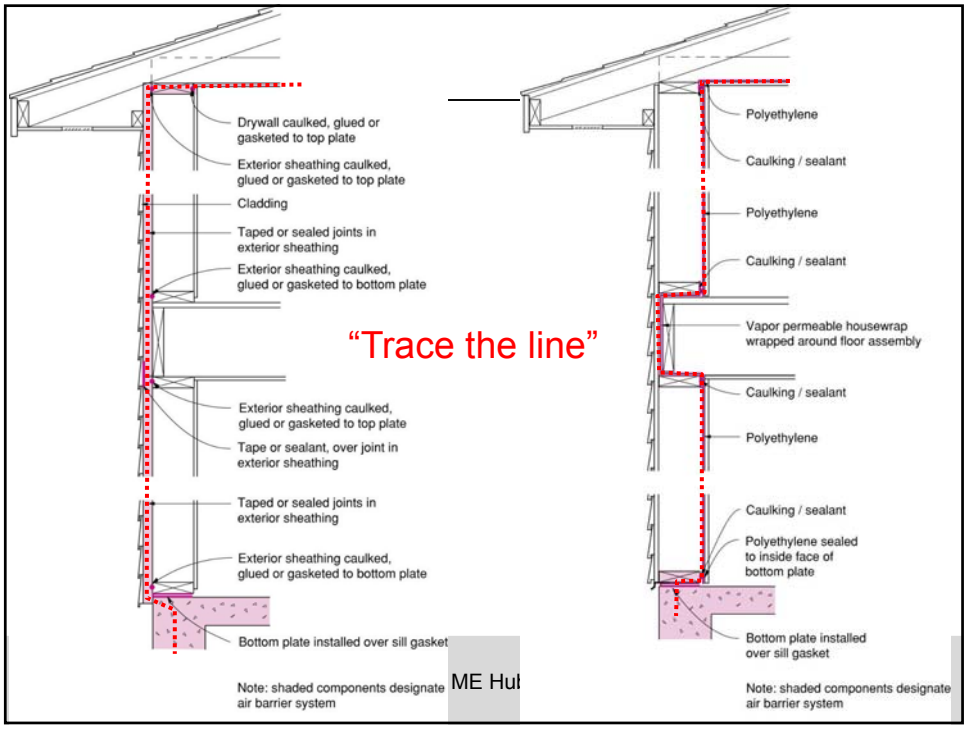
Air Barriers

Air Barrier Systems

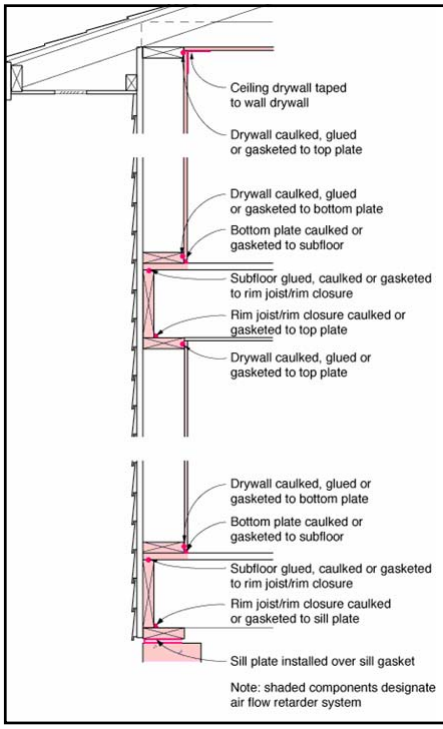
- Function: to stop airflow through enclosure
- ABS can be placed anywhere in the enclosure
- Must be strong enough to take wind gusts (code requirement)
- Many materials are air impermeable, but most systems are not airtight

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)


Drywall caulked, glued or gasketed to top plate
Exterior sheathing caulked, glued or gasketed to top plate
Cladding
Taped or sealed joints in exterior sheathing
Exterior sheathing caulked, glued or gasketed to bottom plate
Exterior sheathing caulked, glued or gasketed to top plate
Tape or sealant, over joint in exterior sheathing
Taped or sealed joints in exterior sheathing
Exterior sheathing caulked, glued or gasketed to bottom plate
Bottom plate installed over sill gasket
Note: shaded components designate air barrier system
"Trace the line"
Polyethylene
Caulking / sealant
Polyethylene
Caulking / sealant
Vapor permeable housewrap wrapped around floor assembly
Caulking / sealant
Polyethylene
Caulking / sealant
Polyethylene sealed to inside face of bottom plate
Bottom plate installed over sill gasket
Note: shaded components designate air barrier system

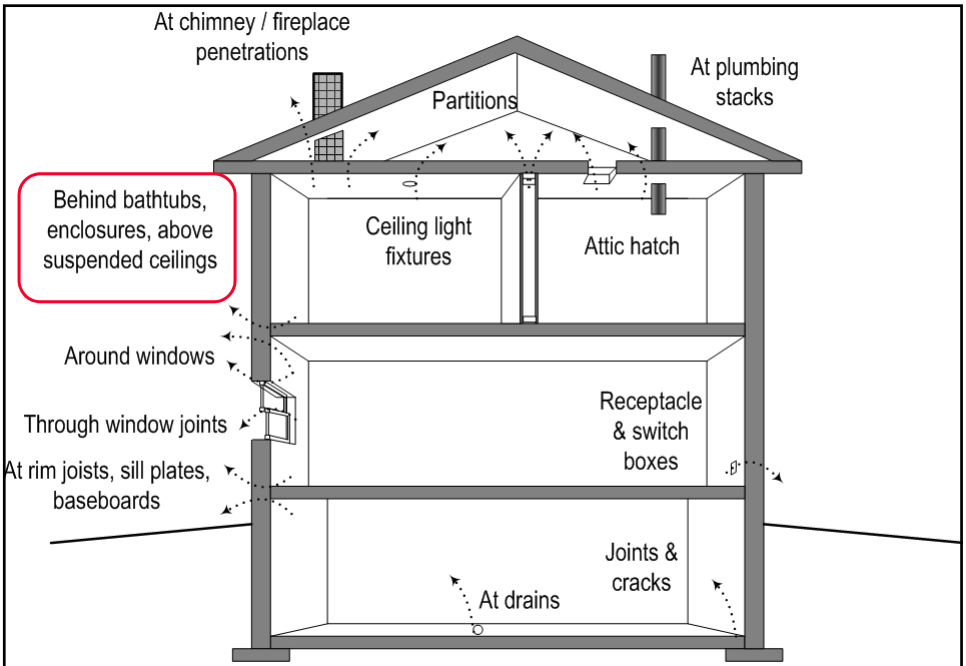

Poly can be (?) an air *and* vapour barrier
But
BEWARE when Air Conditioning
Definitely not in South



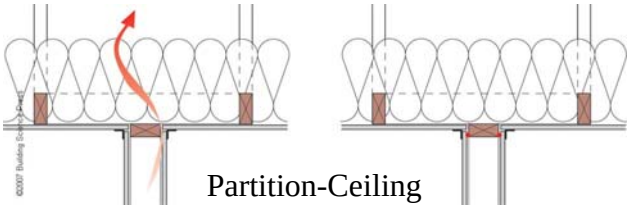
The Airtight Drywall Approach

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**

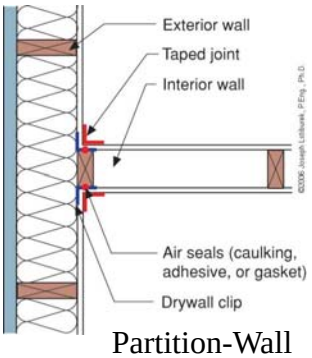
Air sealing around components:
e.g., windows and walls other Openings and penetrations



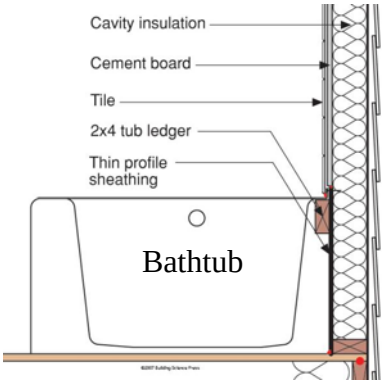
Typical Air Leakage Points



Partition-Ceiling

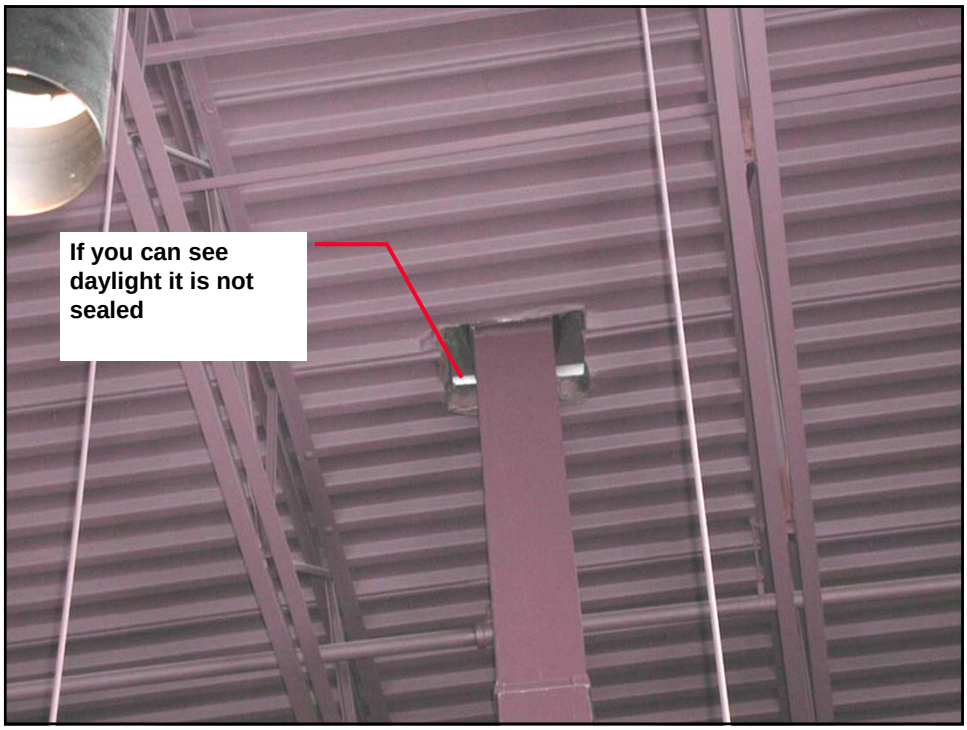


Partition-Wall

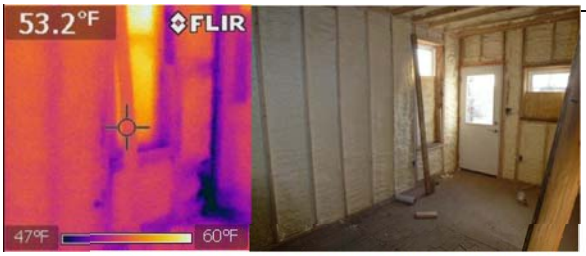


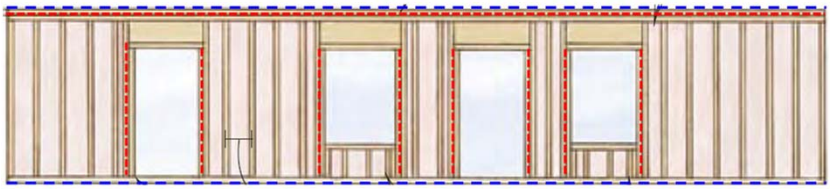
Big holes


Problem:
Filter
Solution:
Seal


If you can see daylight it is not sealed

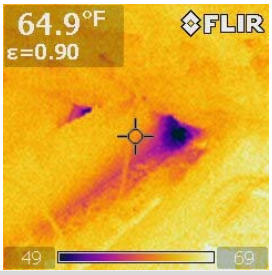
Spray Foam as an Air Barrier





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

Spray Foam as an Air Barrier



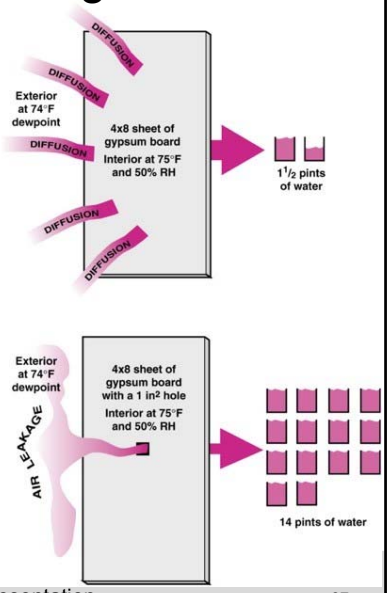
Spray Foam as an Air Barrier



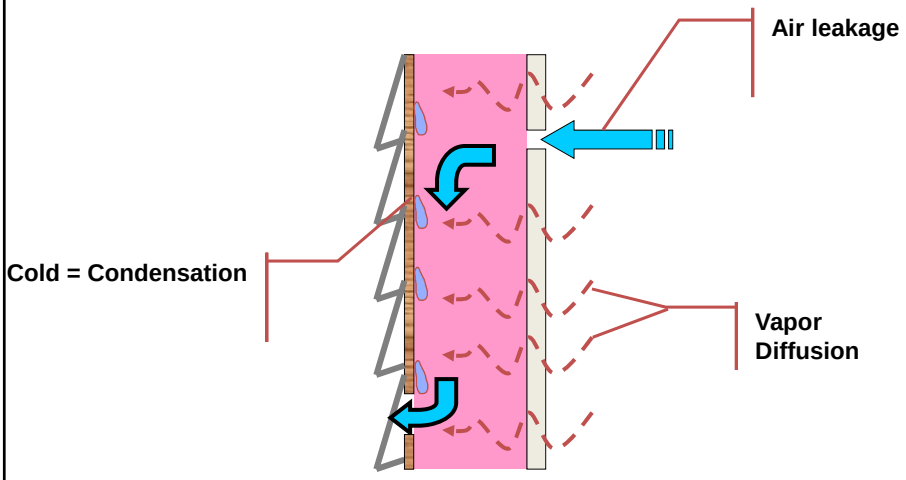

Cold Weather Condensation in Walls

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

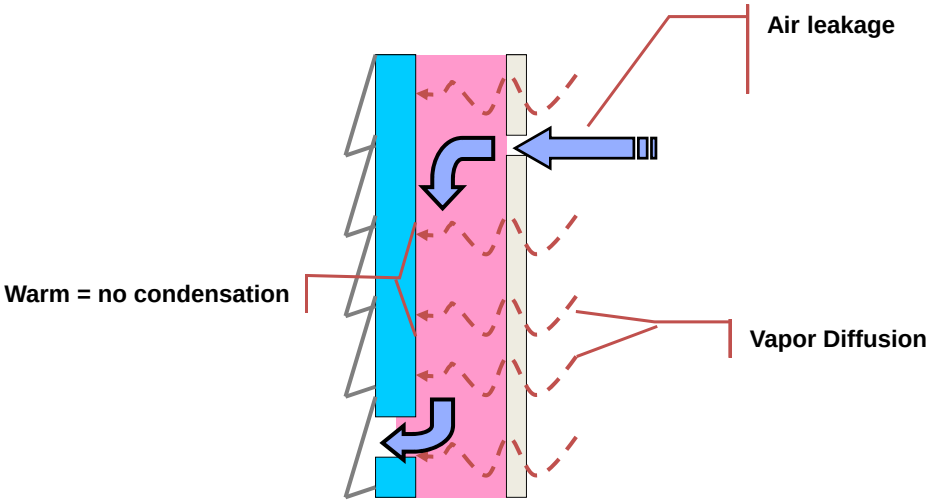


Wall w/o Insulated Sheathing



Frosting on Sheathing

Wall with Insulated Sheathing



Vapor Barriers and the Code

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

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

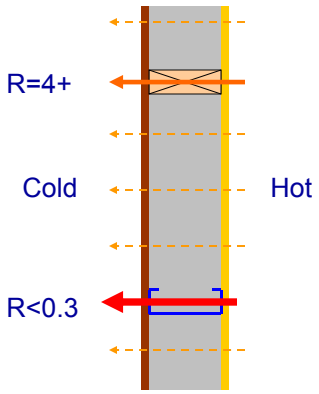
Can just use latex paint (no vapor barrier) if you add enough insulation outside of the stud bay insulation. Safer -> controls diffusion and air leakage moisture.
Zone 6A = ~40%/60% R-value ratio

Thermal Bridging at Framing

Thermal Bridging at Steel Framing

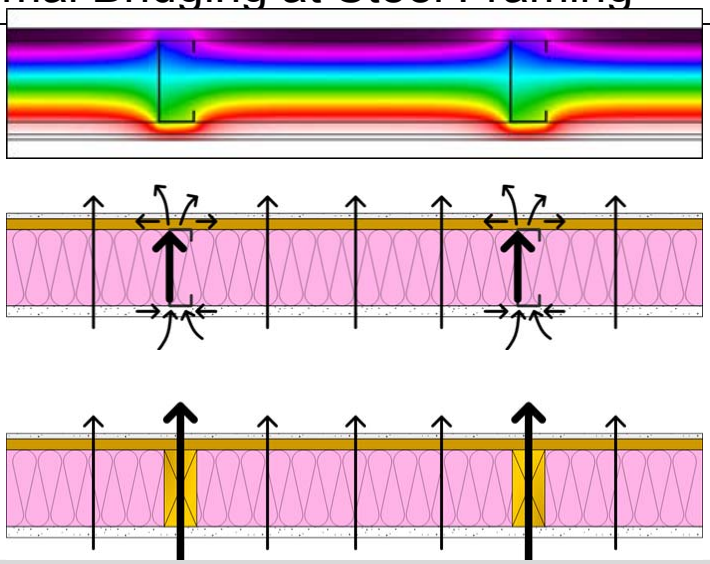
Steel is 400 times more conductive than wood

Steel studs are about 40 times thinner



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

Thermal Bridging at Steel Framing



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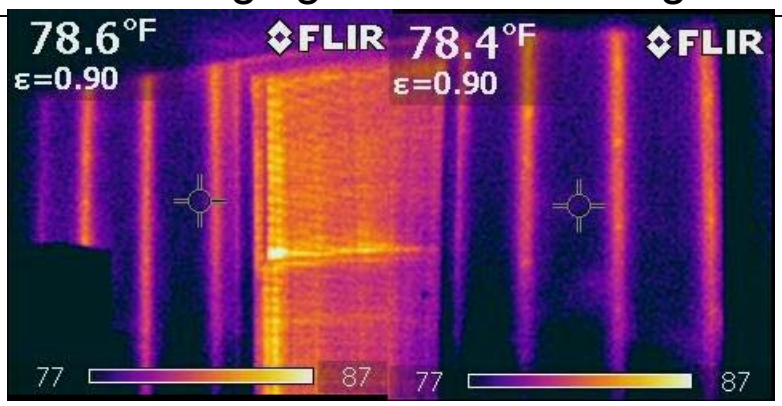
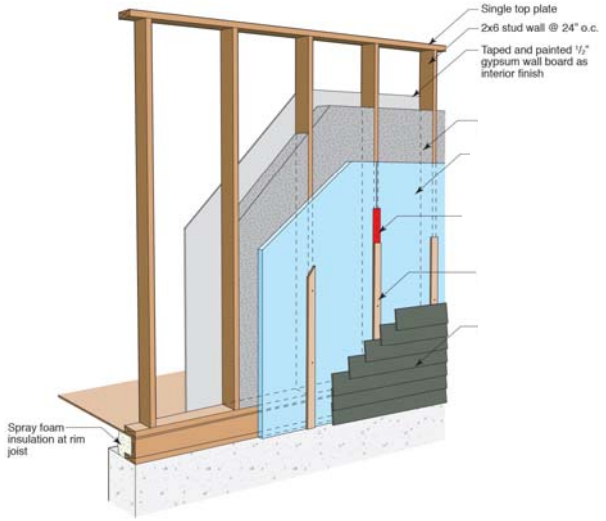


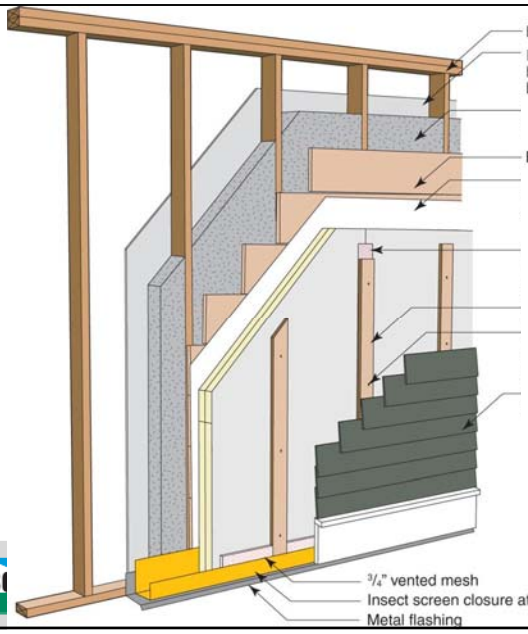
- Summertime/AC example
- Sun is hitting the wall (southeast orientation)

Exterior Continuous Insulation

Exterior Rigid Foam (Taped Seams)



4” Polyisocyanurate Foam Retrofit



99

Mineral Fiber, Nailbase Panel




100

4” Polyisocyanurate Foam

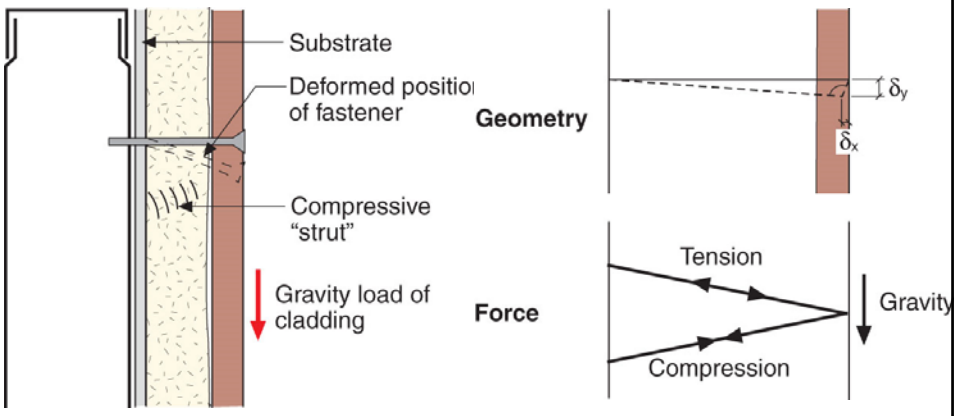
Foam Sheathing Cladding

250 lbs/113 kg load (7.8 psf): <0.003” deflection

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

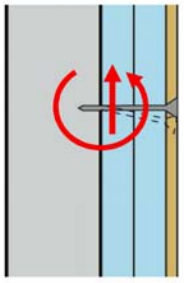
Image c/o Petersen Engineering

Foam Sheathing Cladding Attachment

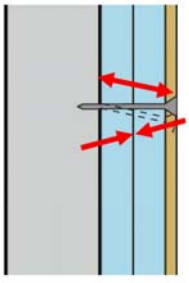


BSC Cladding Attachment Research

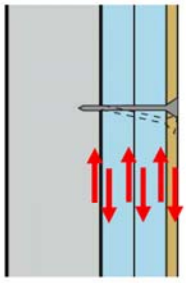
- System Mechanics



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

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

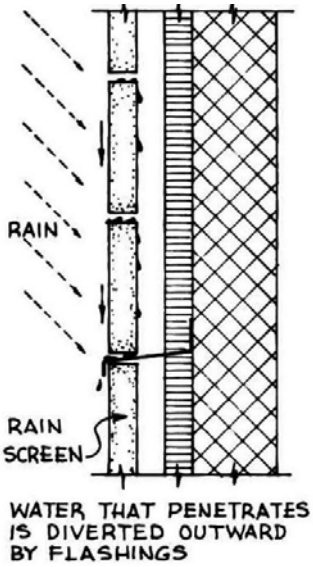
Recommendations

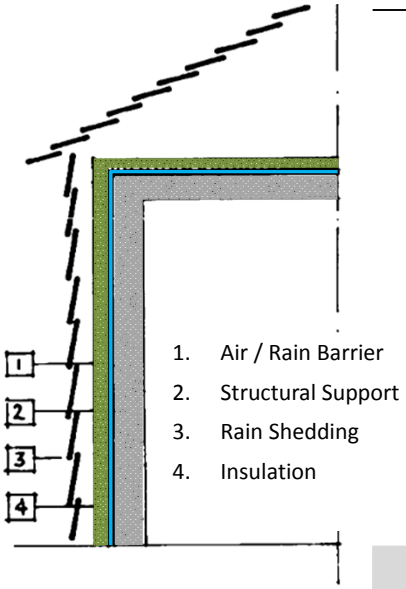
- Based on the results of the testing it is currently recommended to use a maximum load per fastener of no more than 10lbs for up to 4" of insulation

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

The "Perfect Wall"

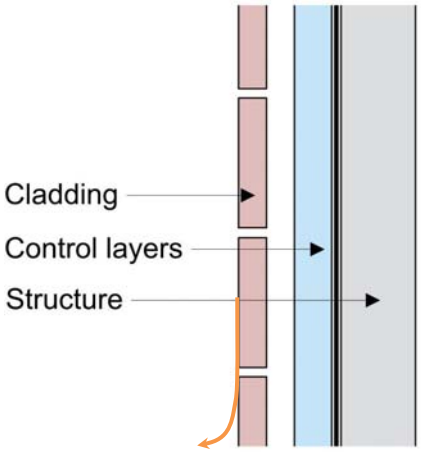
Design Info from the 1960's (Canada)

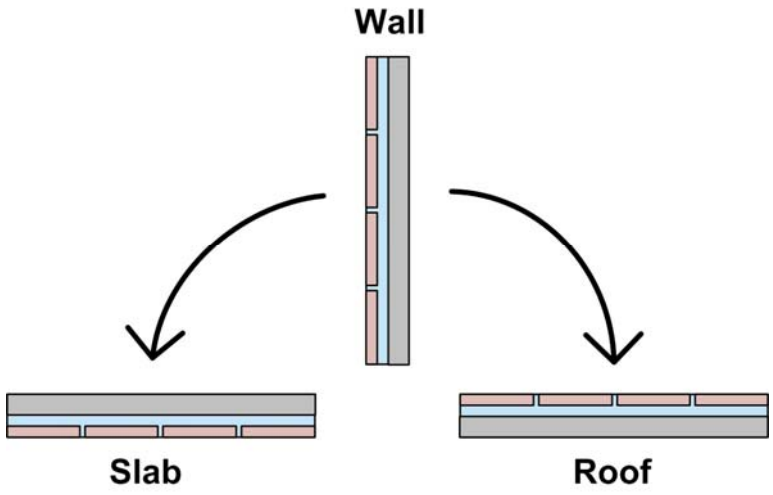


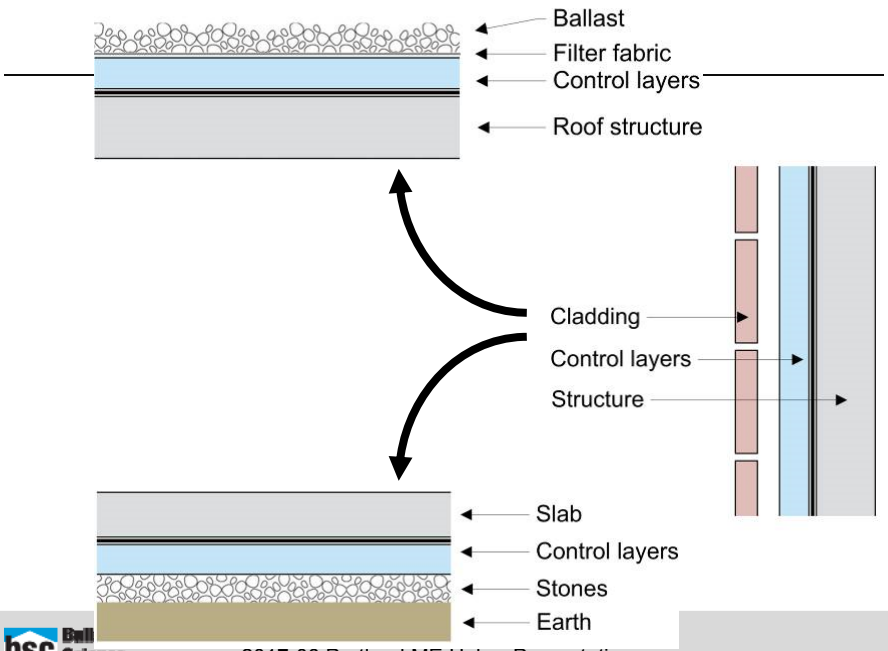


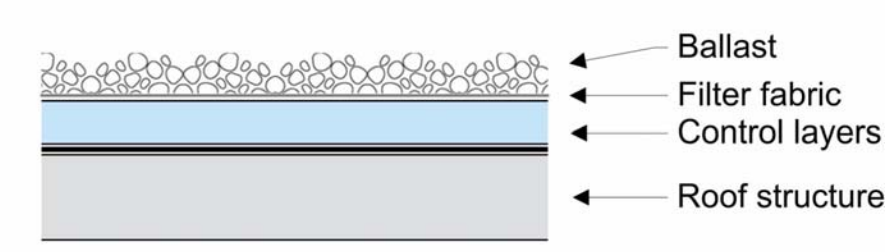
1. Air / Rain Barrier
2. Structural Support
3. Rain Shedding
4. Insulation

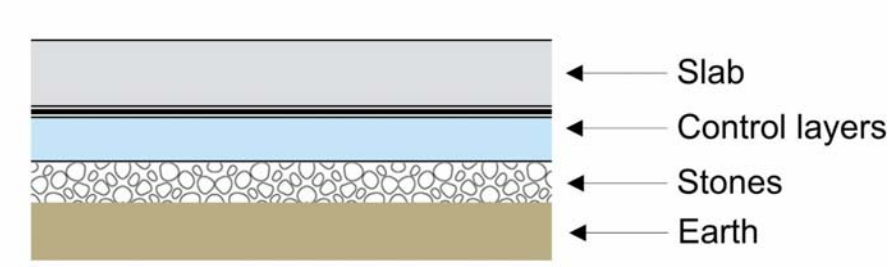
The Perfect Wall

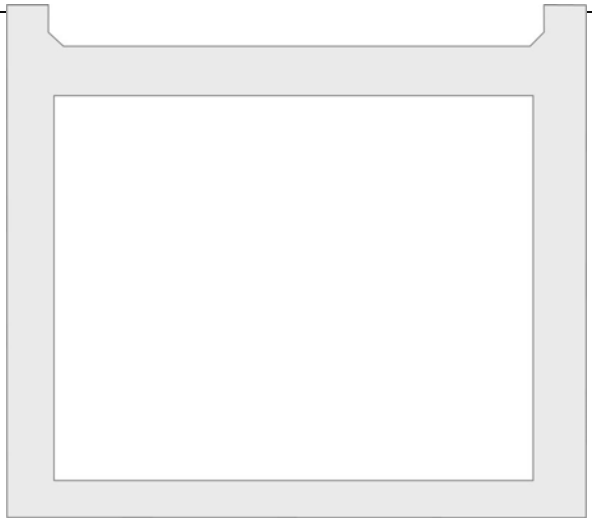


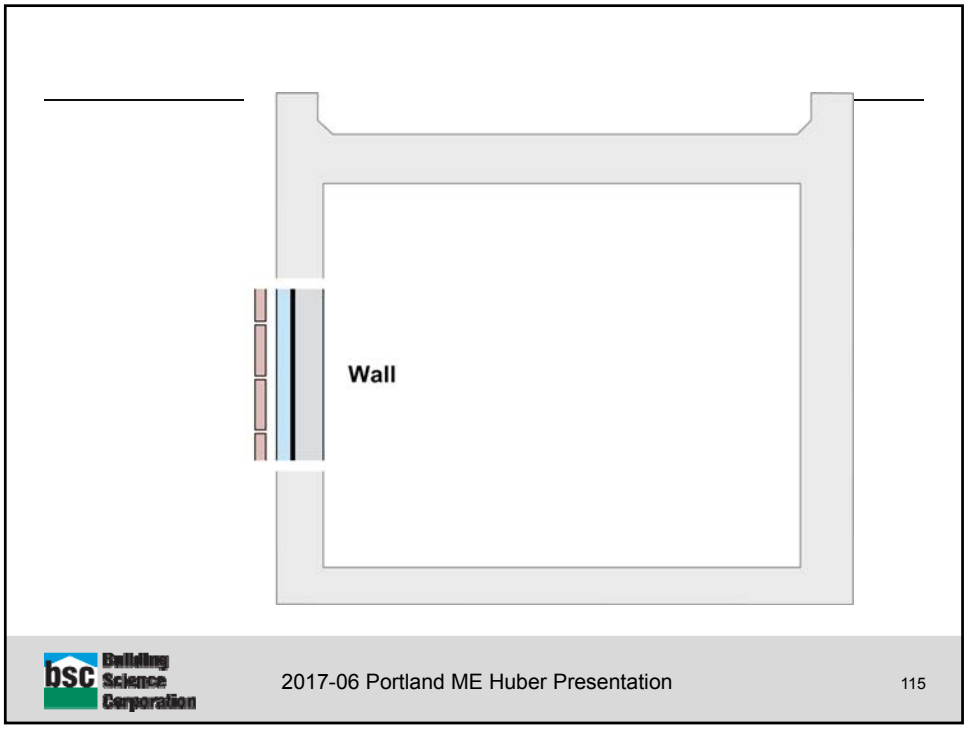


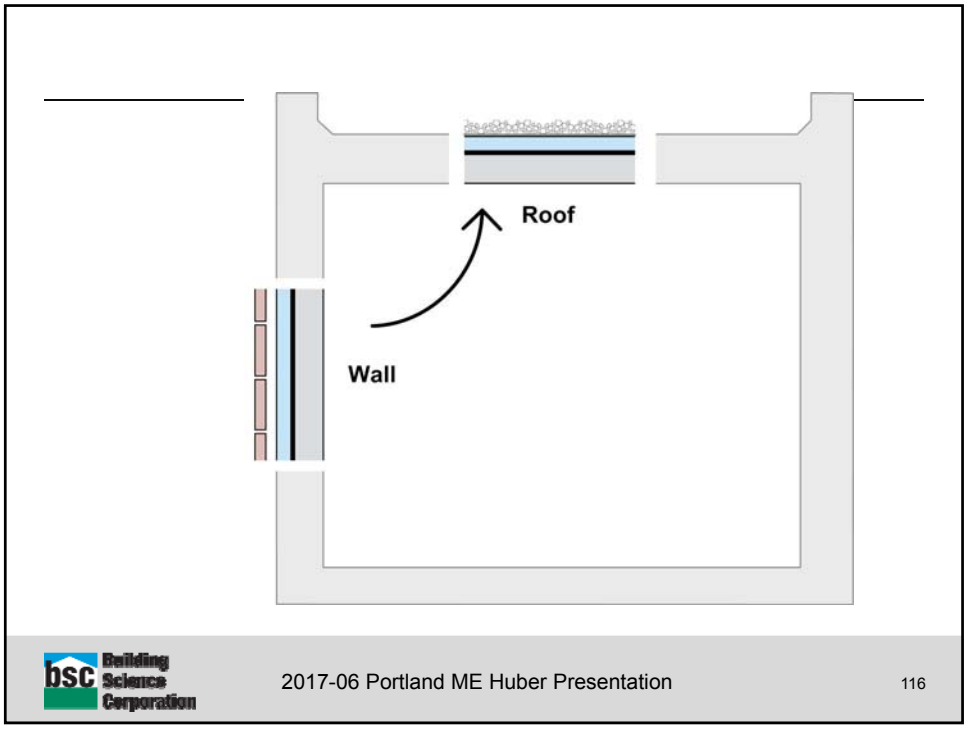

Ballast
Filter fabric
Control layers
Roof structure
Cladding
Control layers
Structure
Slab
Control layers
Stones
Earth

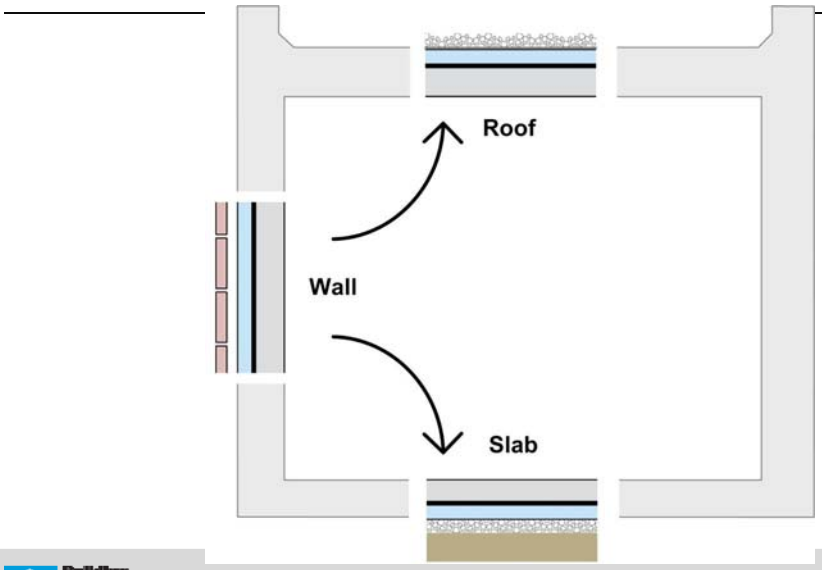

Ballast
Filter fabric
Control layers
Roof structure

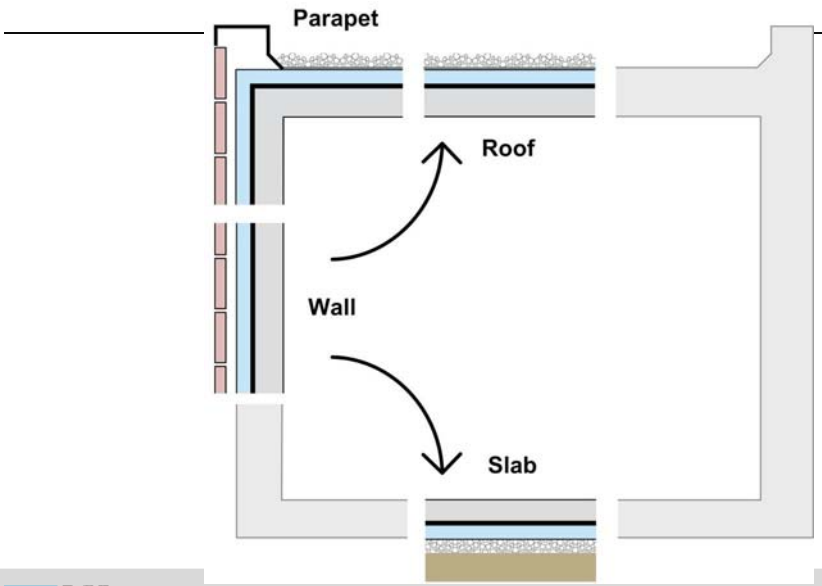

Slab
Control layers
Stones
Earth

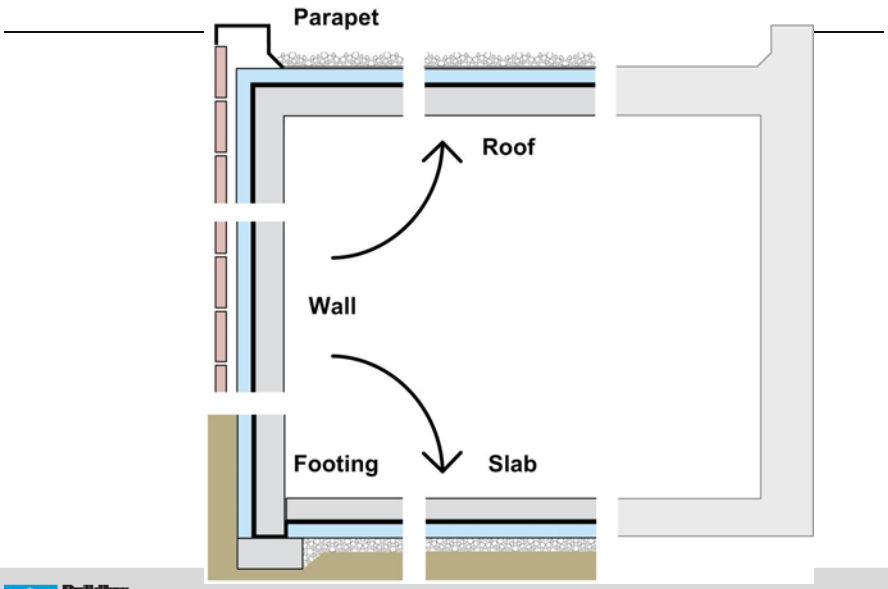


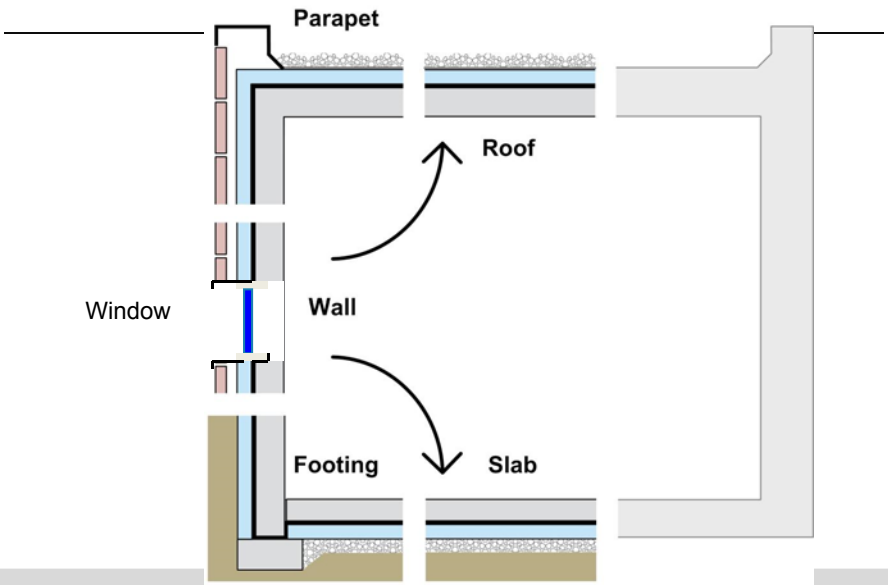

Wall


Roof
Wall

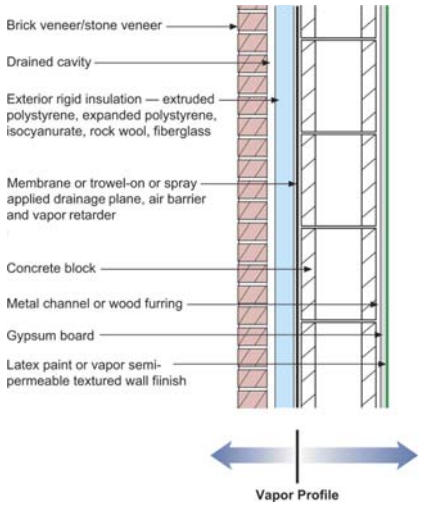

Roof
Wall
Slab


Parapet
Roof
Wall
Slab

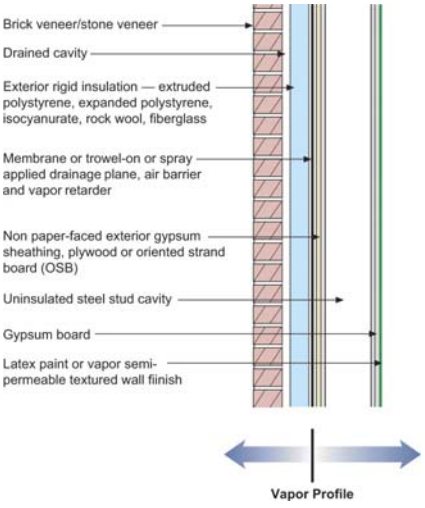

Parapet
Roof
Wall
Footing
Slab


Parapet
Roof
Window
Wall
Footing
Slab

The “Perfect” Wall: Higher Performance



The Commercial Steel Frame Wall



"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

Building the "Perfect Wall"

Self-adhered membrane. XPS insulation

Fluid-Applied Asphalt & Rock Wool

- Asphalt Drainage Plane Air Barrier
- Rock wool Insulation

Exterior Closed Cell Spray Foam

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

Transitions, Continuity, Penetrations

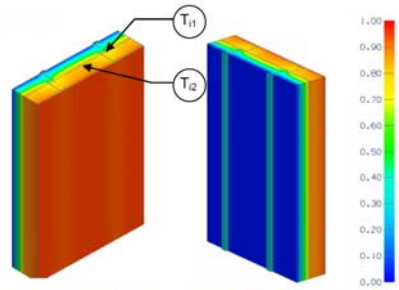
Building Science Corporation

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…

Thermal Bridging at Cladding

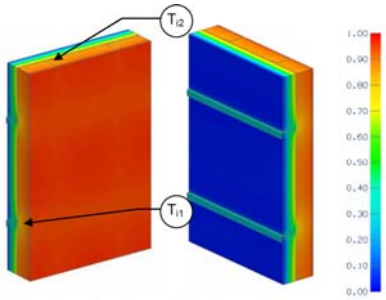
- Thermal Performance of Building Envelope Details for Mid- and High-Rise Buildings (ASHRAE 1365-RP)



View from Interior View from Exterior

Nominal (1D) vs. Assembly Performance Indicators

Exterior Insulation 1D R-Value (RSI)	R_{1D} ft²·hr·°F / Btu (m^2 K / W)	R_o ft²·hr·°F / Btu (m^2 K / W)	U_o Btu/ft²·hr·°F (W/m^2 K)
R-5 (0.88)	R-8.2 (1.44)	R-6.4 (1.12)	0.157 (0.89)
R-10 (1.76)	R-13.2 (2.32)	R-8.3 (1.47)	0.120 (0.68)
R-15 (2.64)	R-18.2 (3.20)	R-9.7 (1.71)	0.103 (0.59)
R-20 (3.52)	R-23.2 (4.08)	R-11.0 (1.93)	0.091 (0.52)
R-25 (4.40)	R-28.2 (4.96)	R-12.0 (2.11)	0.084 (0.48)

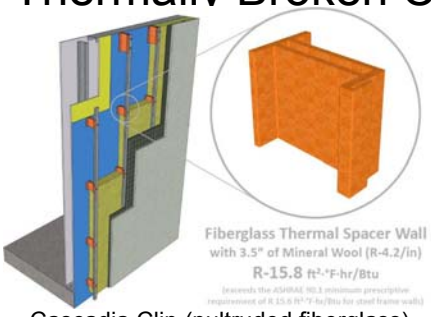


View from Interior View from Exterior

Nominal (1D) vs. Assembly Performance Indicators

Exterior Insulation 1D R-Value (RSI)	R_{1D} ft²·hr·°F / Btu (m^2 K / W)	R_o ft²·hr·°F / Btu (m^2 K / W)	U_o Btu/ft²·hr·°F (W/m^2 K)
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-9.4 (1.66)	0.106 (0.60)
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-13.1 (2.31)	0.076 (0.43)
R-25 (4.40)	R-28.2 (4.96)	R-14.5 (2.56)	0.069 (0.39)

Thermally Broken Cladding Supports



Cascadia Clip (pultruded fiberglass)

Knight Wall (fasteners through foam)

Engineered Assemblies

T Clip

Questions?

Kohta Ueno
kohta (at sign) buildingscience dot com

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

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