Kohta Ueno

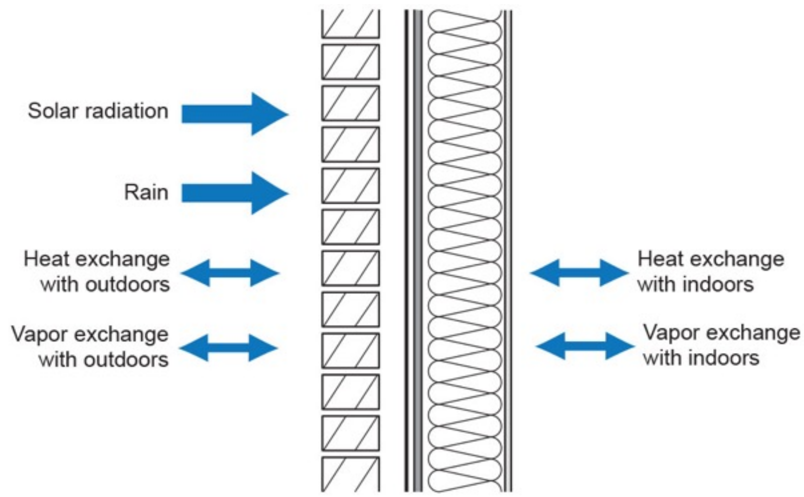
# Building Science of Walls

March 24, 2017

Building Science Corporation

# Background

# Environmental Separator





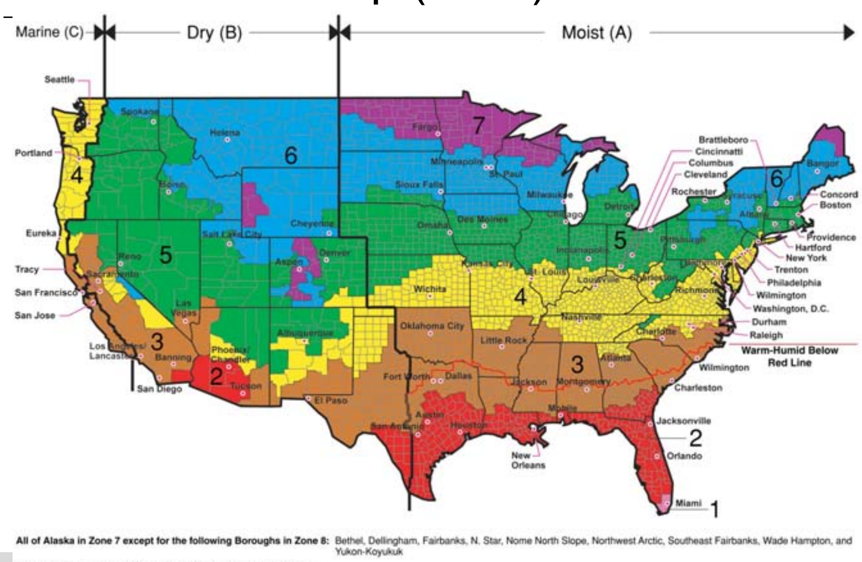

# What Separation Roles?

- 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

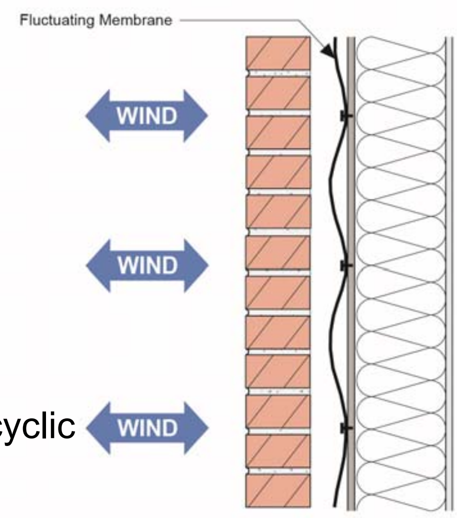


## Housewrap (Residential)

# 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

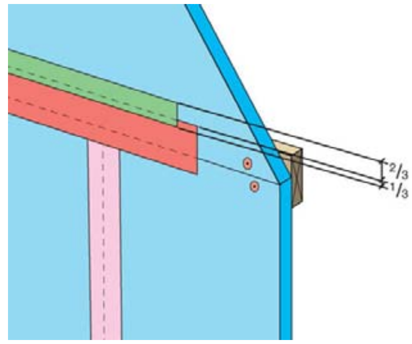
- Self-sealing
- Air leakage improvement; no blow-off/billowing
- No 'hidden path' water leakage/bypass
- Reverse laps not as critical



## 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

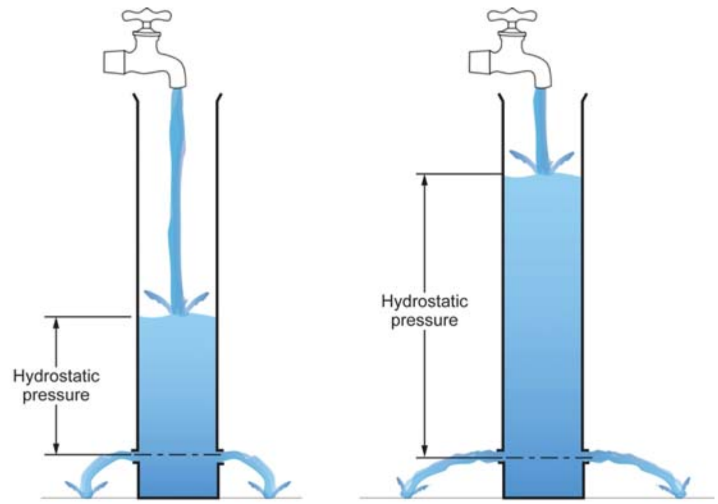


## Water Control and Drainage Gaps

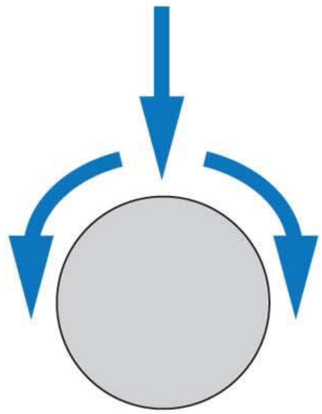
- Water control layer
- Key is control of hydrostatic pressure
- All about "the gap"

- See "Mind the Gap" and "Hockey Pucks and Hydrostatic Pressure"

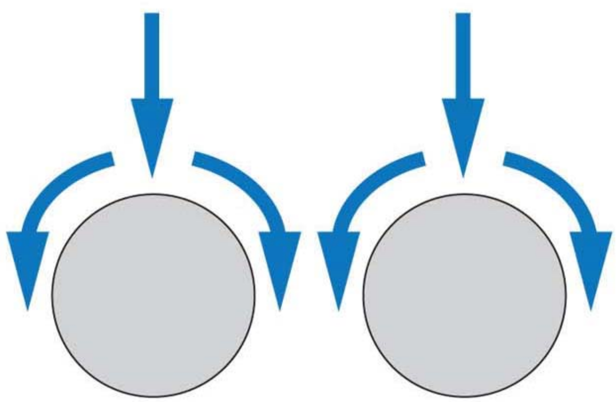
## Hydrostatic Pressure

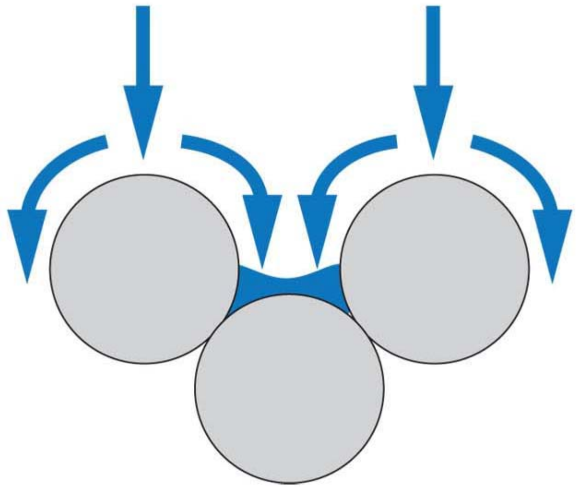




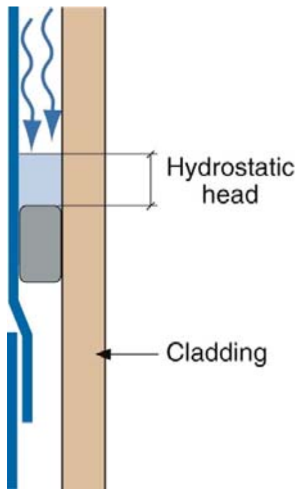







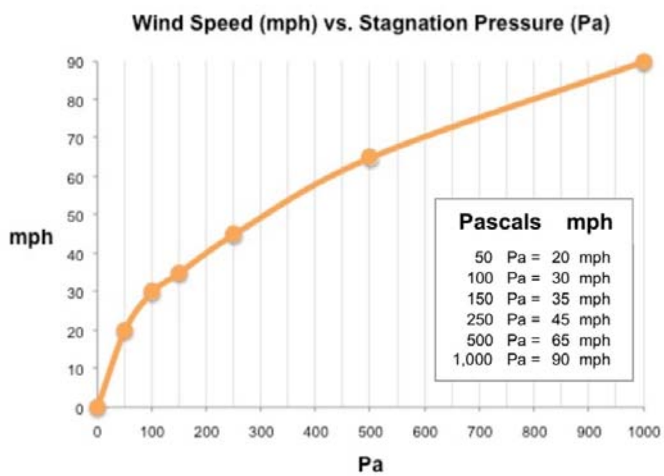









## Wind Speed vs. Pressures



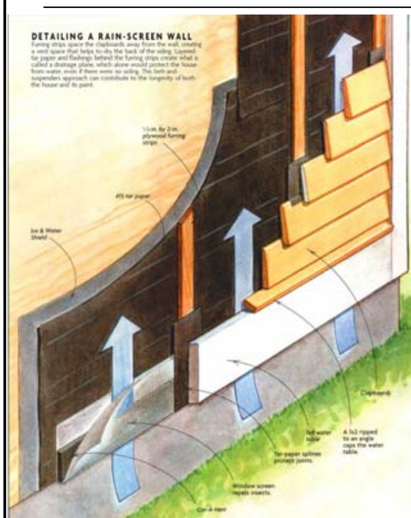

| Pascals | | mph | |
|---|---|---|---|
| 50 | Pa = | 20 | mph |
| 100 | Pa = | 30 | mph |
| 150 | Pa = | 35 | mph |
| 250 | Pa = | 45 | mph |
| 500 | Pa = | 65 | mph |
| 1,000 | Pa = | 90 | mph |

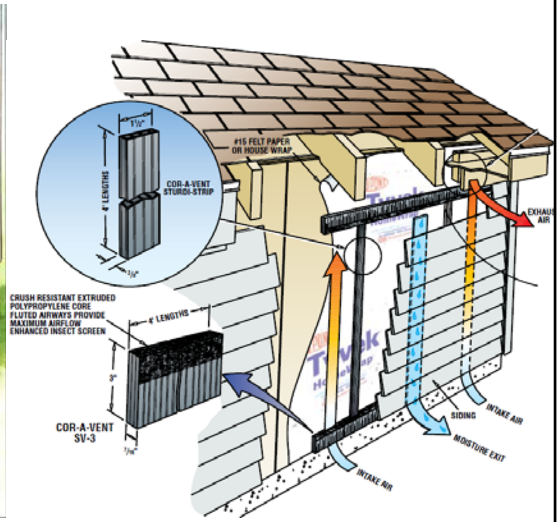
- ½" of "perched" water ≈ 35 mph wind force

# Water Control Layers and Spaces



## Strapped Cavities/“Rainscreen Wall”



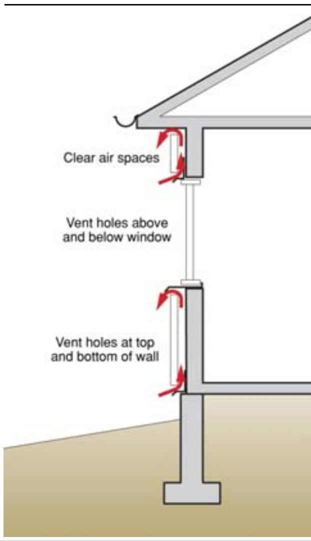



## Why Rainscreen/Air Gap

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

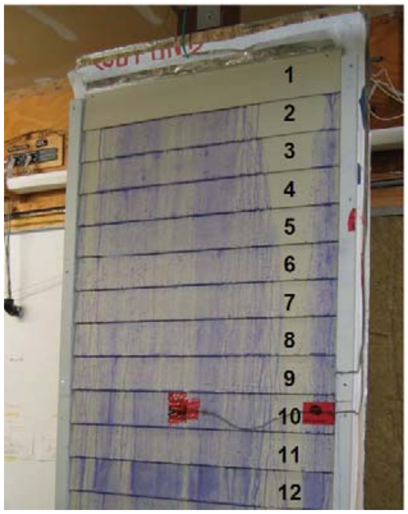


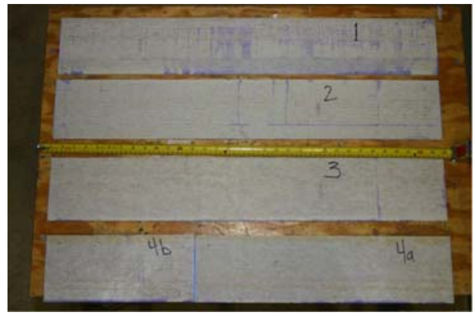
## Cladding Ventilation




- 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

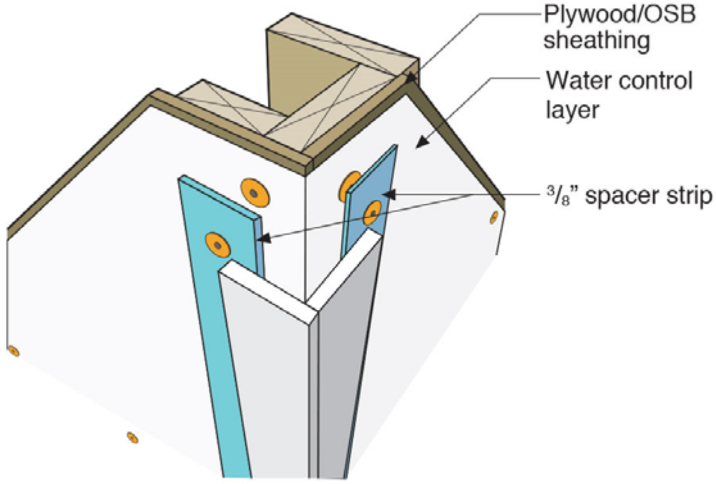


- Mesh style
  (Home Slicker, Keene Building Products)

Tyvek
DrainWrap




N-6

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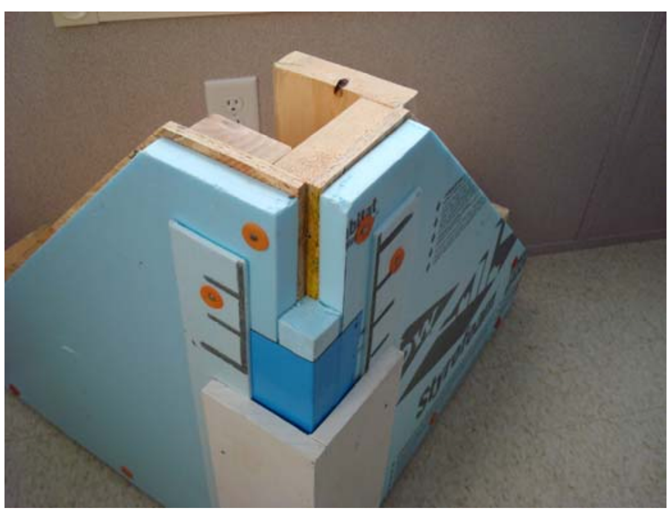

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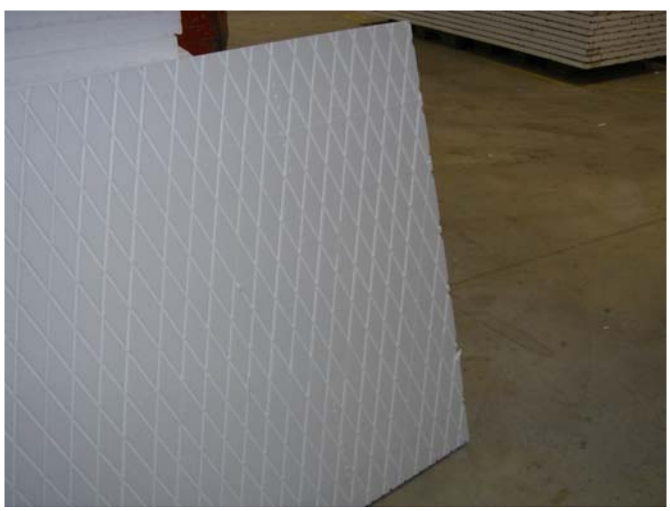
Tyvek
Tyvek



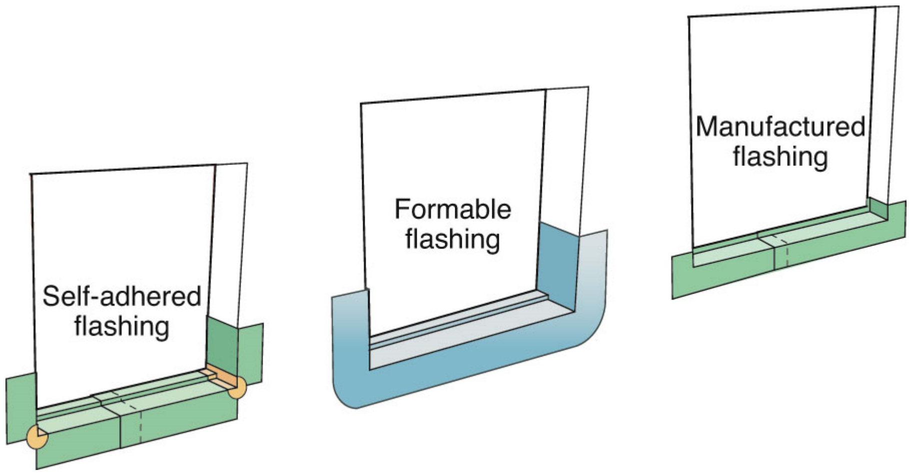


# Windows Flashings



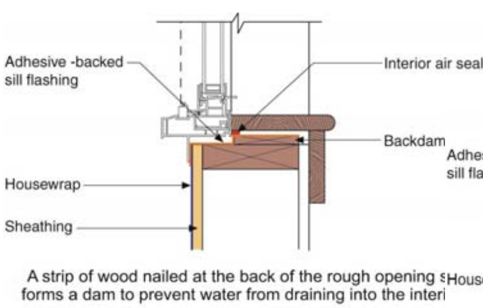
# EIFS & Windows - Oops

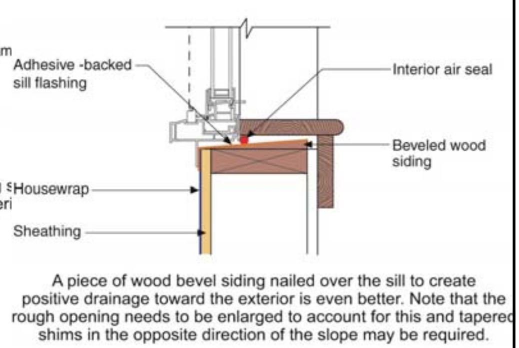
## Sill Pan Flashings






## Backdams and Sloped Sills

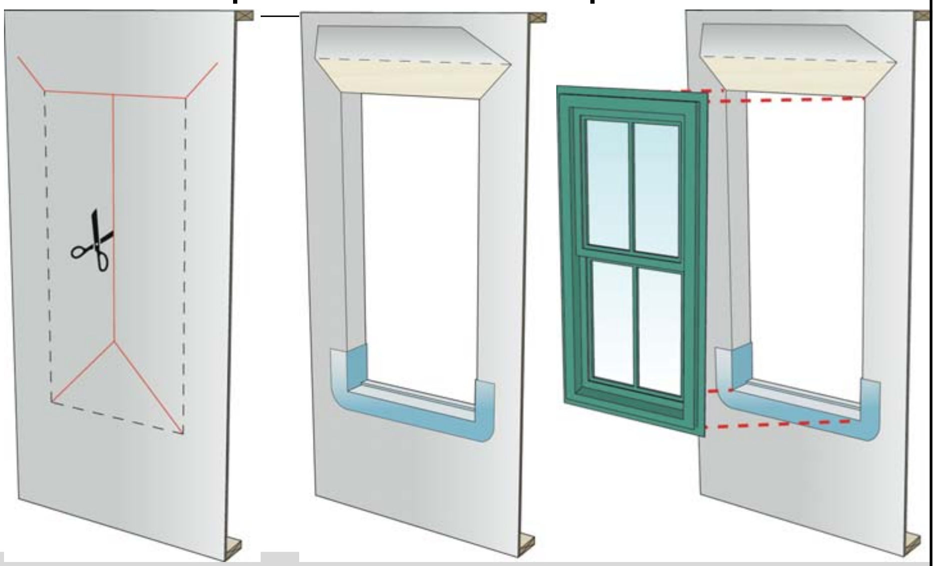


## Formable Sub-sill Flashing

## Subsill

## Housewrap Installation Sequence





## Housewrap Installation Sequence

# Foam Sheathing Window Flashing



# Window Failure Examples

# Window Failure Examples





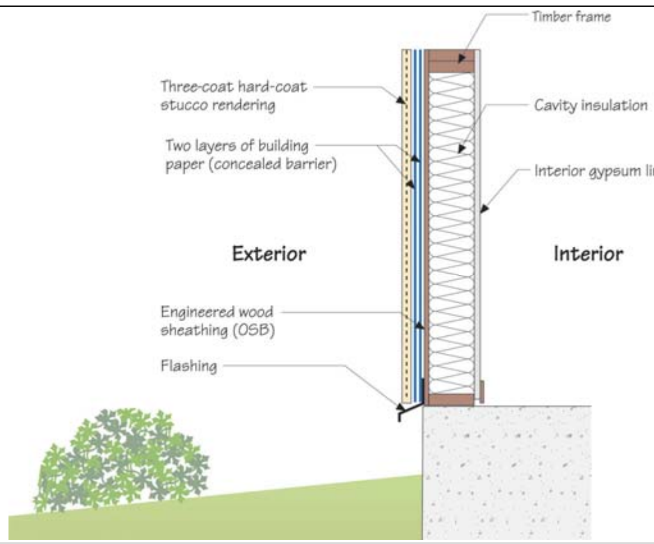
# Window Failure Repair

- 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

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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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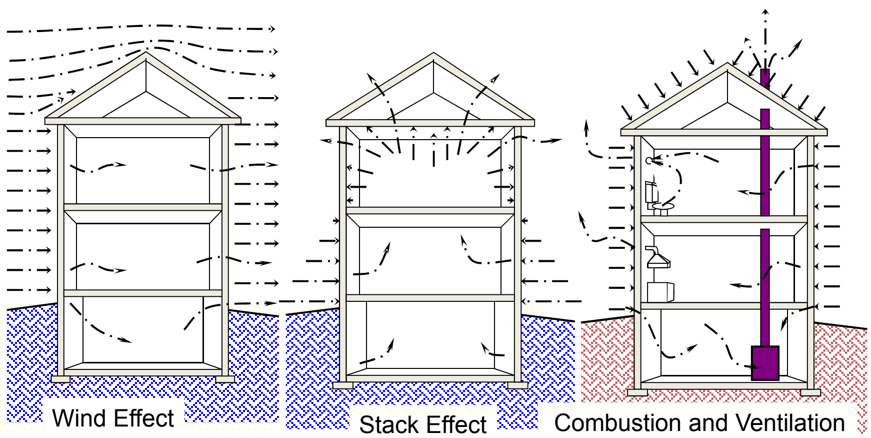
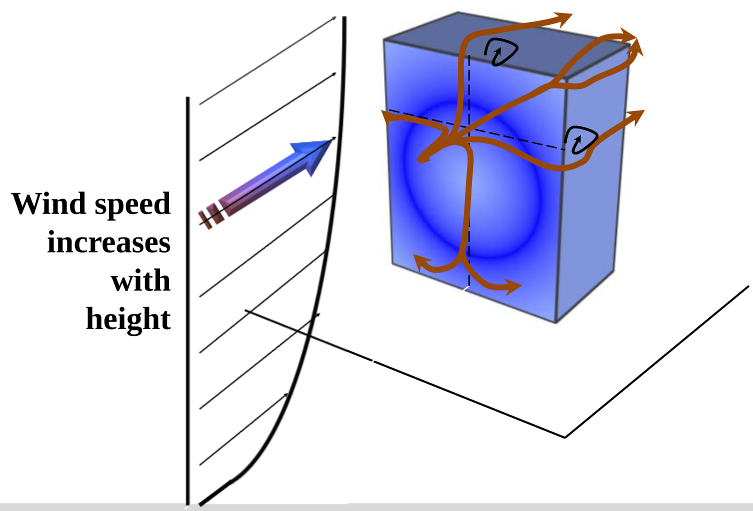
# Driving Forces



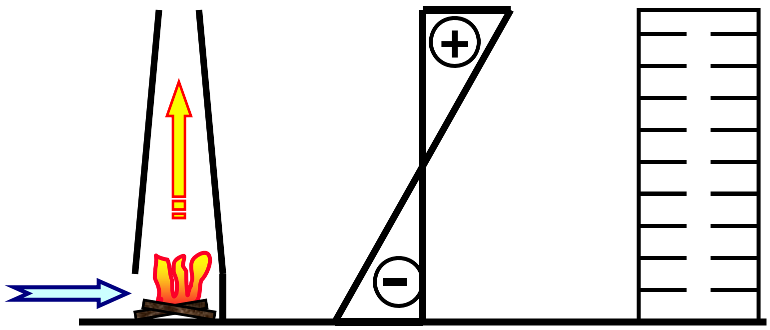



# Wind Flow Patterns



# 2. Stack Effect: Cold Weather

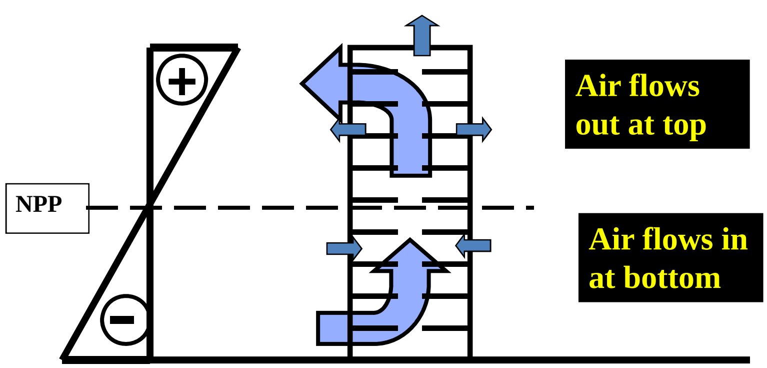
- Hot air rises
- Tall Building in Winter = Heavy Balloon





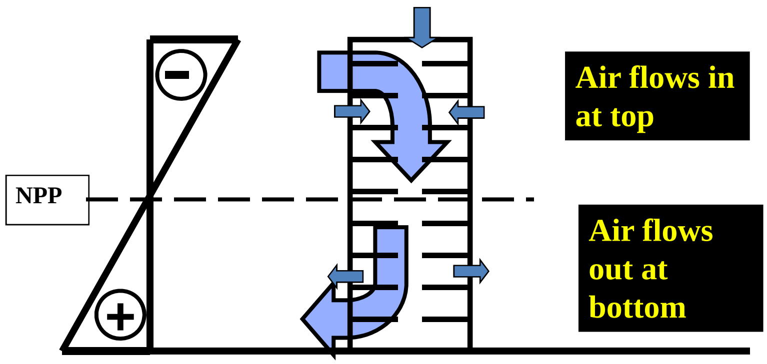
# Stack Effect: Cold Weather

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



## Stack Effect: Warm Weather

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






# Air Barriers

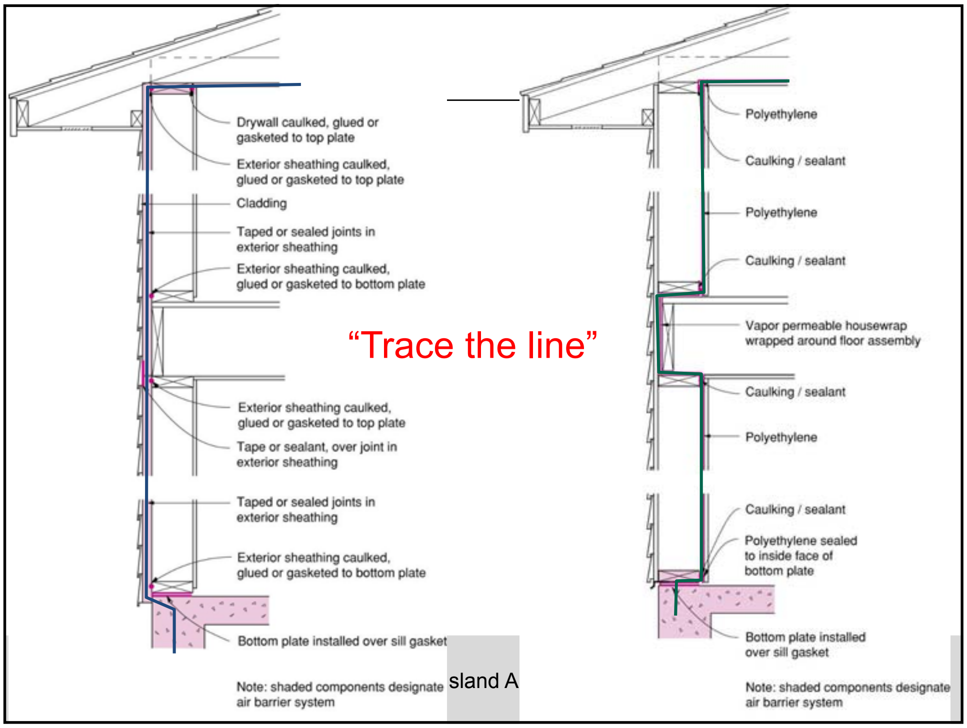
## Air Barrier Systems

- 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

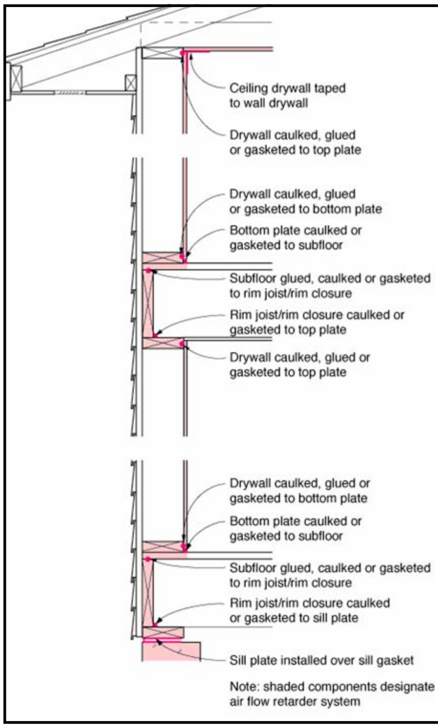


## Air Barrier Systems: Requirements

- 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)


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
"Trace the line"
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
sland A
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

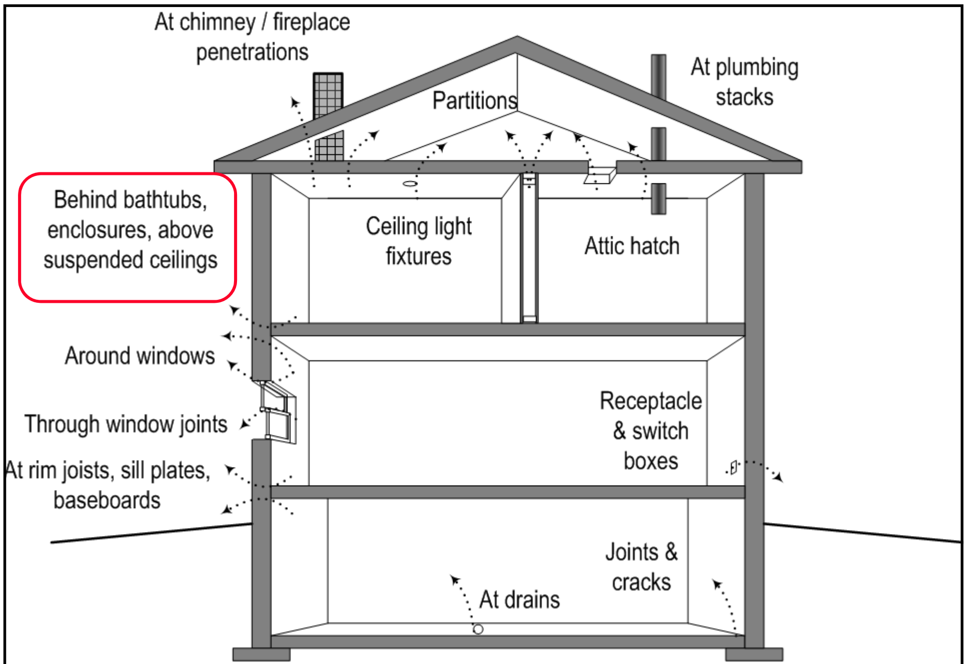
**Use drywall, framing members**

- **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**

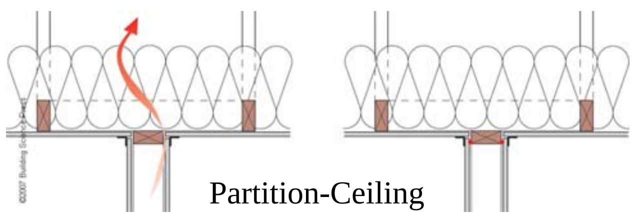
## Air sealing around components:

**e.g., windows and walls**

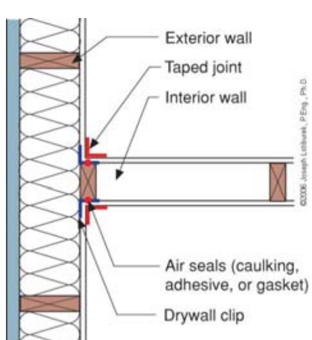
**other Openings and penetrations**



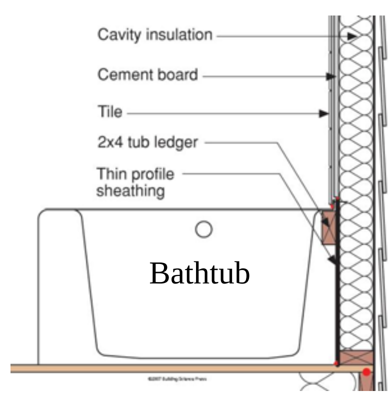

**Typical Air Leakage Points**



Partition-Ceiling



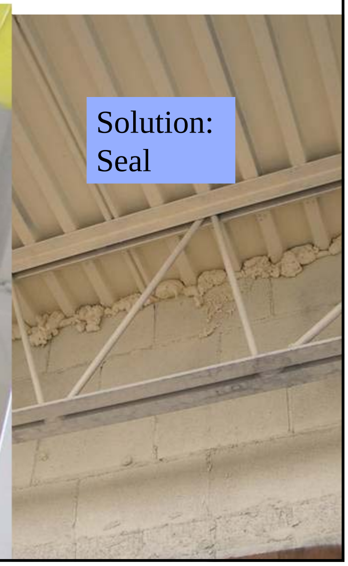

Partition-Wall

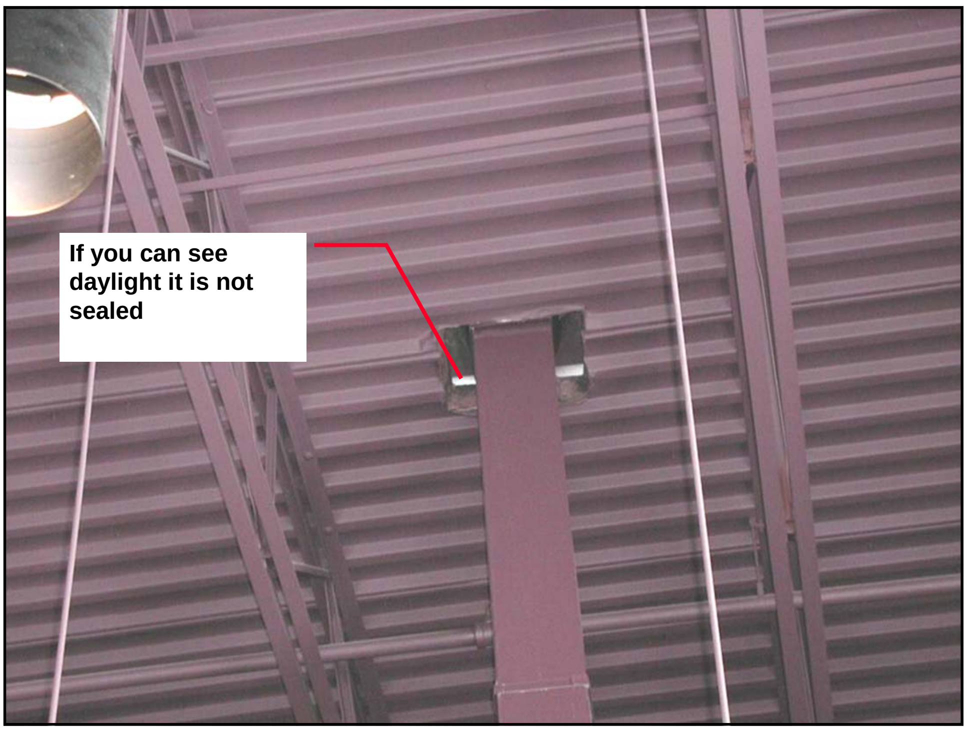



Bathtub

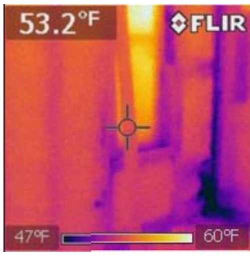
# Big holes

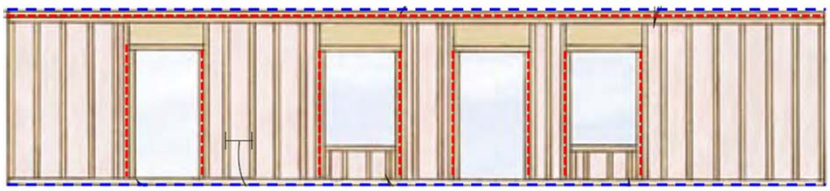

Problem:
Filter


Solution:
Seal


If you can see daylight it is not sealed

# Spray Foam as an Air Barrier

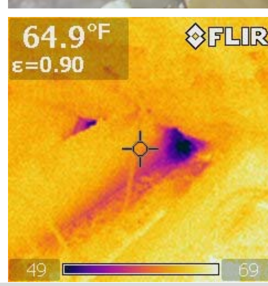


- Spray foam doesn't air seal where it isn't there!
- Wood-to-wood connections



# Spray Foam as an Air Barrier



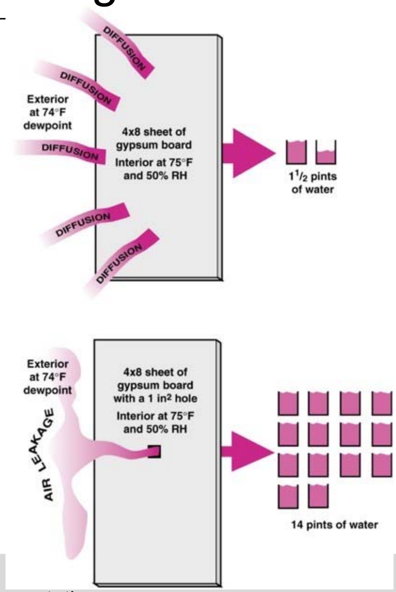
## Spray Foam as an Air Barrier



# Cold Weather Condensation in Walls

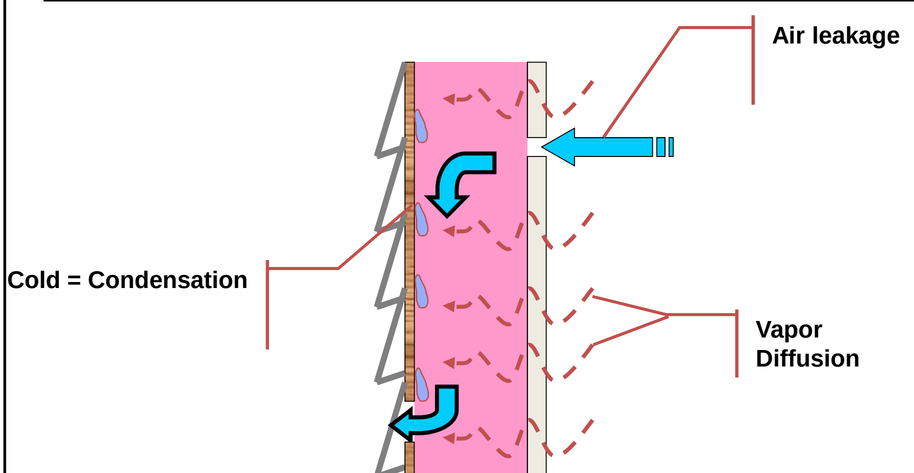
# Vapor Diffusion vs. Air Leakage

- 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





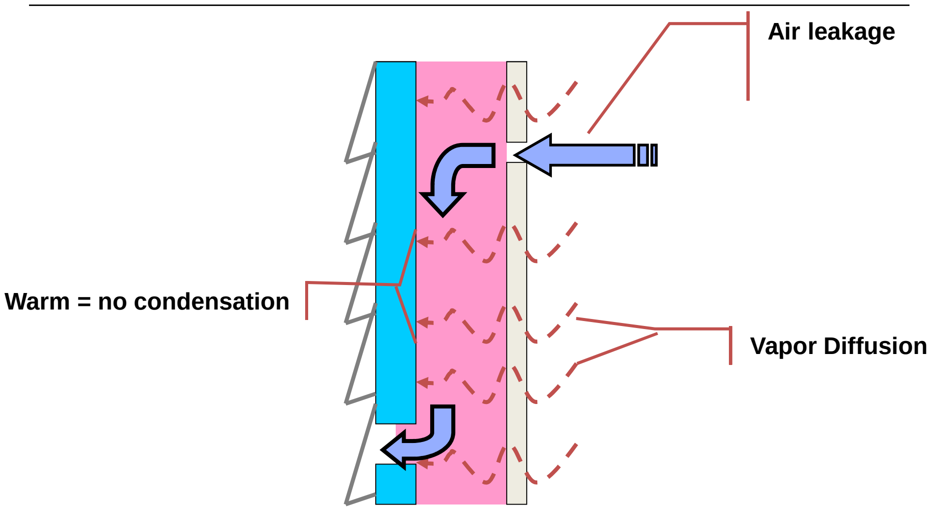

# Wall w/o Insulated Sheathing



# 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<br>Vented cladding over plywood<br>Vented cladding over fiberboard<br>Vented cladding over gypsum<br>Insulated sheathing with *R*-value ≥ 2.5 over 2x4 wall<br>Insulated sheathing with *R*-value ≥ 3.75 over 2x6 wall |
| 5 | Vented cladding over OSB<br>Vented cladding over plywood<br>Vented cladding over fiberboard<br>Vented cladding over gypsum<br>Insulated sheathing with *R*-value ≥ 5 over 2x4 wall<br>Insulated sheathing with *R*-value ≥ 7.5 over 2x6 wall |
| 6 | Vented cladding over fiberboard<br>Vented cladding over gypsum<br>Insulated sheathing with *R*-value ≥ 7.5 over 2x4 wall<br>Insulated sheathing with *R*-value ≥ 11.25 over 2x6 wall |
| 7 and 8 | Insulated sheathing with *R*-value ≥ 10 over 2x4 wall<br>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 5A = 30%/70% R-value ratio

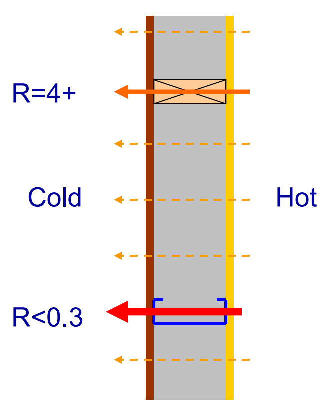
# Thermal Bridging at Framing



## Thermal Bridging at Steel Framing

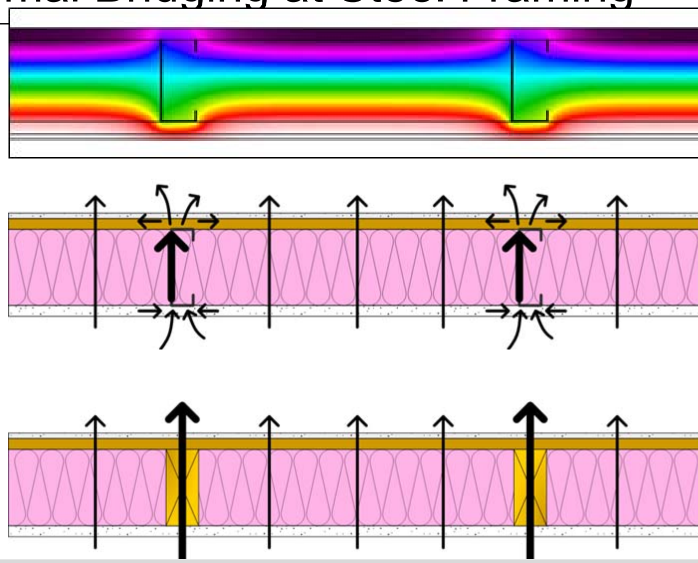
*Steel is 400 times more conductive than wood*

*Steel studs are about 40 times thinner*



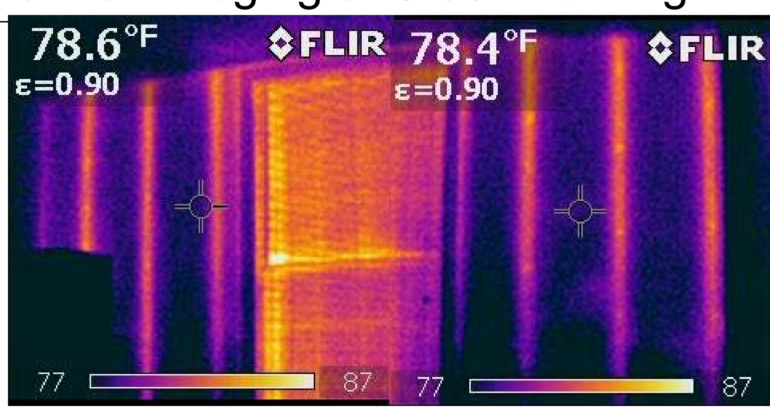

*A 2x6 steel stud wall 16" OC with R-19 Fiberglass Batt = effective R-9 wall assembly.*

# Thermal Bridging at Steel Framing





# Thermal Bridging at Steel Framing

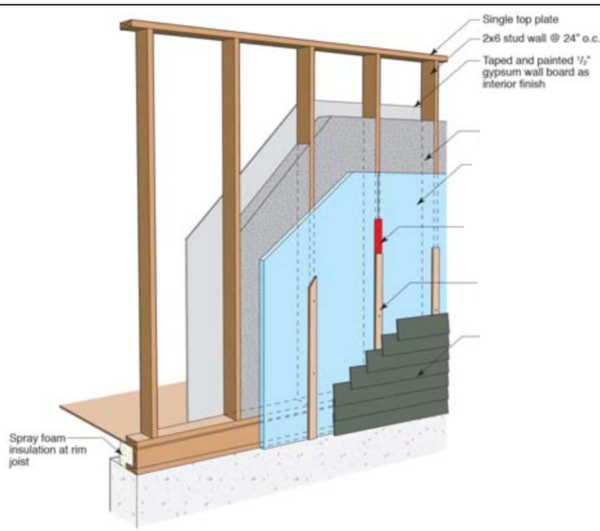



- Summertime/AC example
- Sun is hitting the wall (southeast orientation)

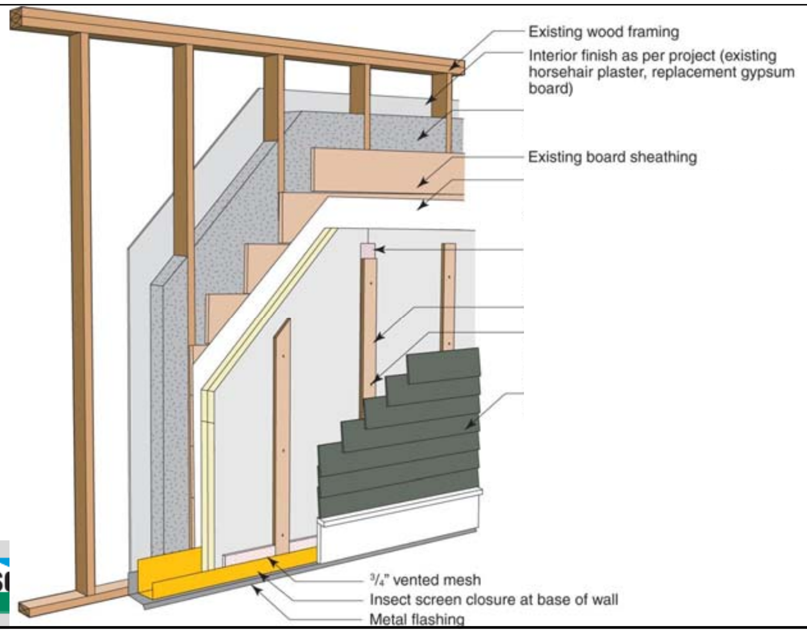
# Exterior Continuous Insulation



## Exterior Rigid Foam (Taped Seams)



# 4” Polyisocyanurate Foam Retrofit




99

# Mineral Fiber, Nailbase Panel

100

# 4” Polyisocyanurate Foam



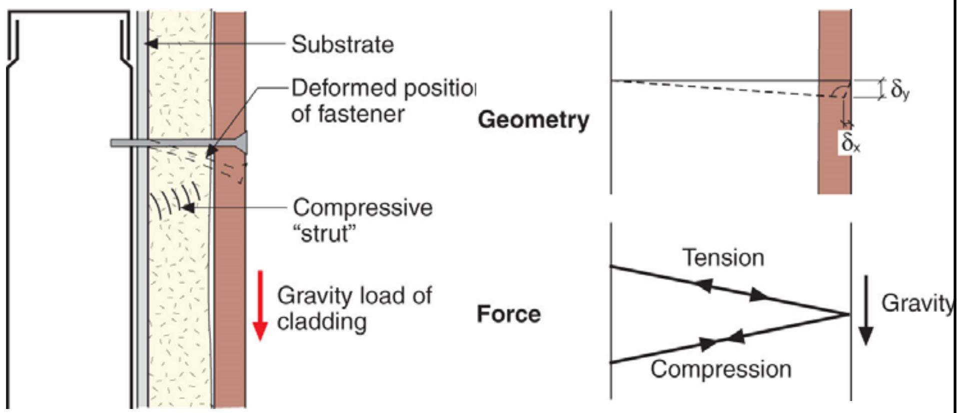
# Foam Sheathing Cladding

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

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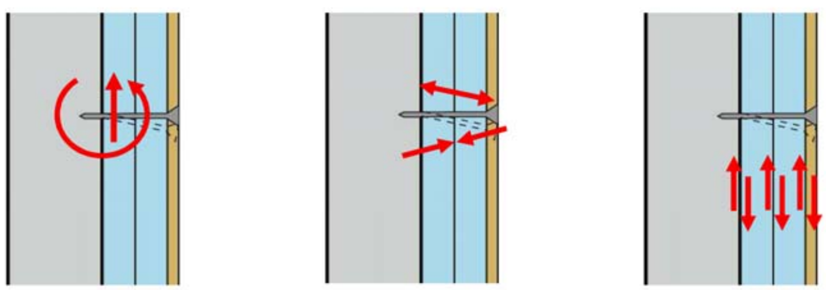
# BSC Cladding Attachment Research

- 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



## Recommendations

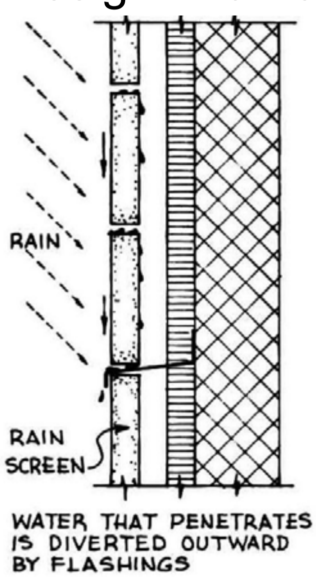
- Based on the results of the testing it is currently recommended to use a maximum load per fastener of no more than 10lbs for up to 4” of insulation

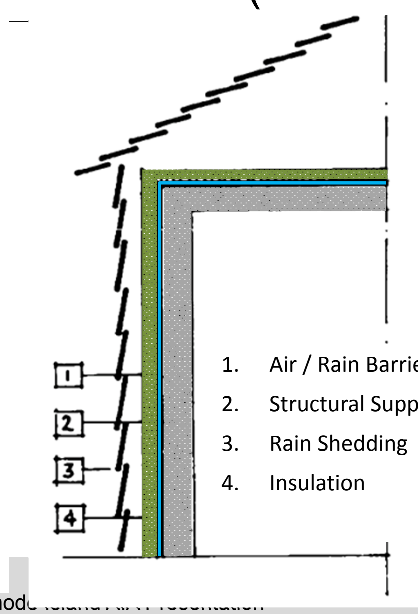
| Cladding weight (psf) | 16” oc Furring | 24” oc Furring |
|---|---|---|
| **5** | 18 | 12 |
| **10** | 9 | 6 |
| **15** | 6 | 4 |
| **20** | 4 | 3 |
| **25** | 3 | 2 |

# The "Perfect Wall"



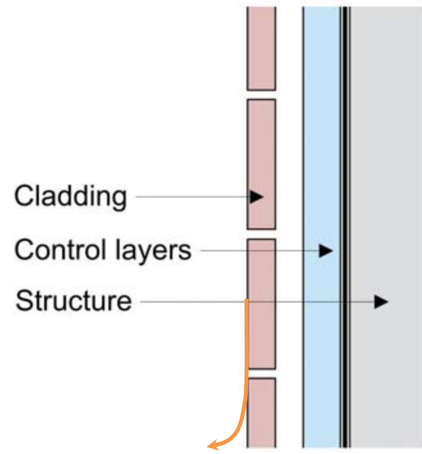
## Design Info from the 1960's (Canada)



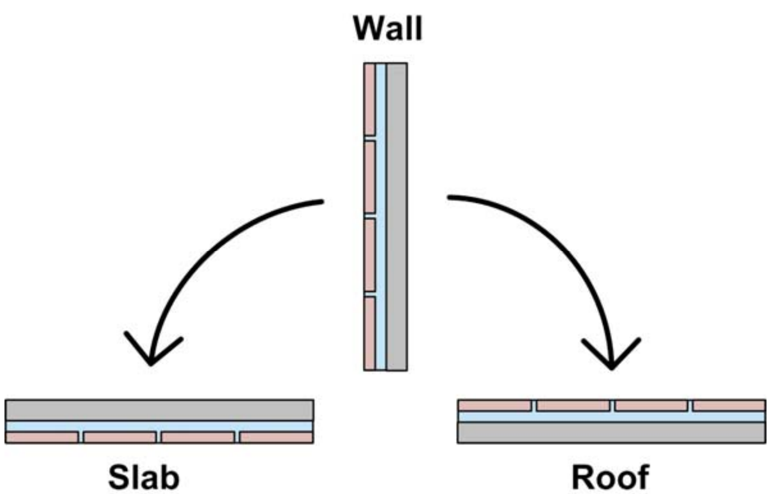



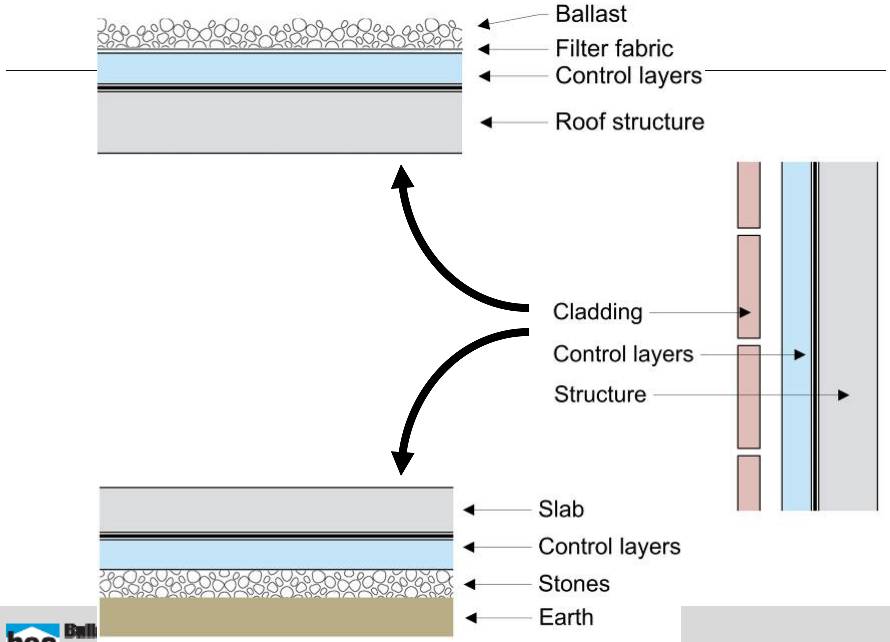

1. Air / Rain Barrier
2. Structural Support
3. Rain Shedding
4. Insulation

# The Perfect Wall

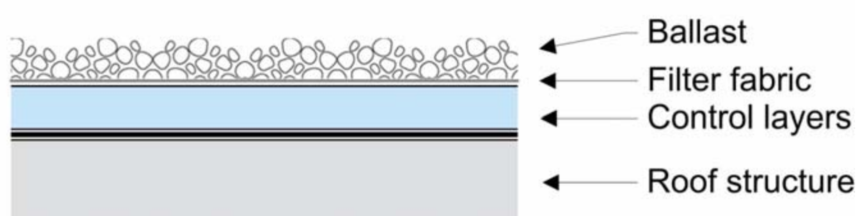


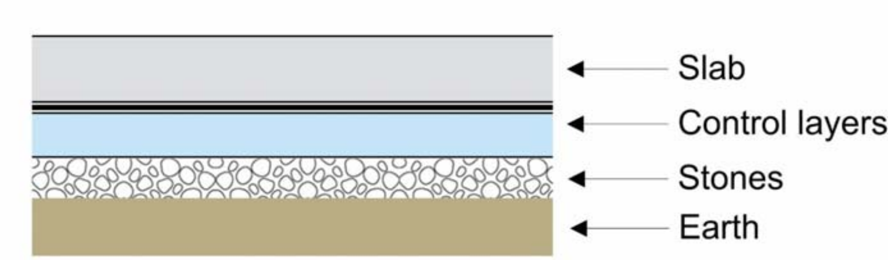


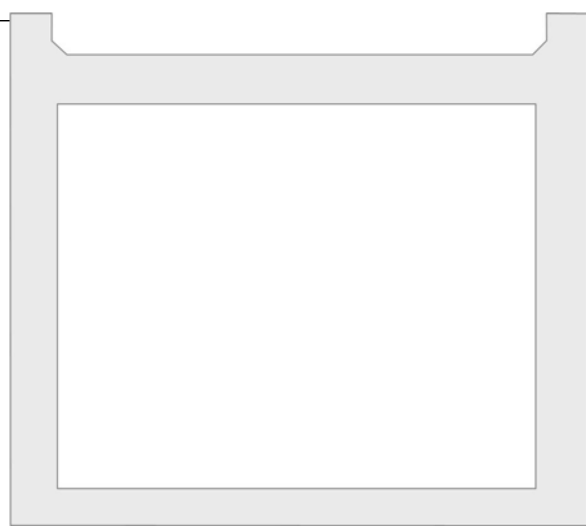

Ballast
Filter fabric
Control layers
Roof structure
Cladding
Control layers
Structure
Slab
Control layers
Stones
Earth

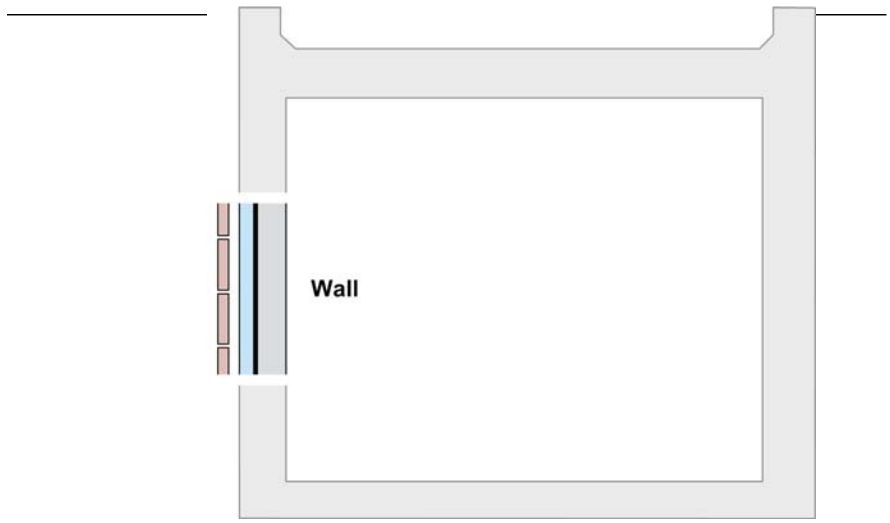



Ballast
Filter fabric
Control layers
Roof structure


Slab
Control layers
Stones
Earth





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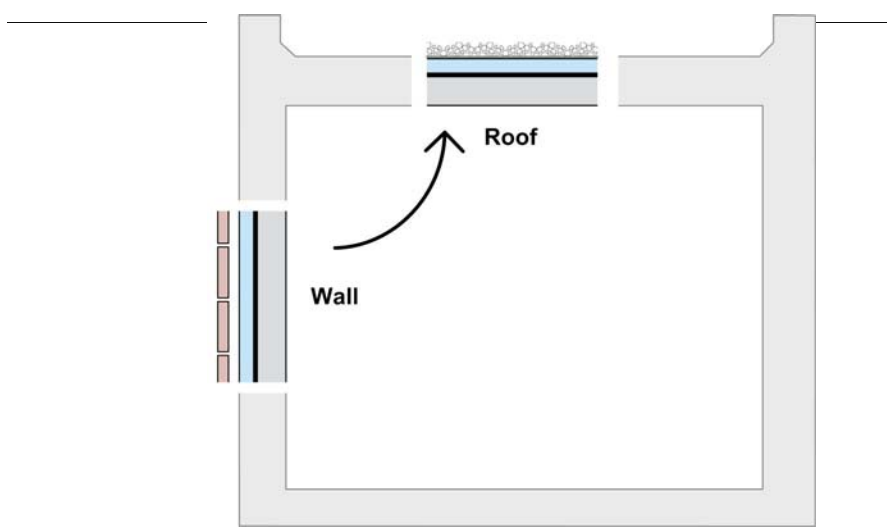


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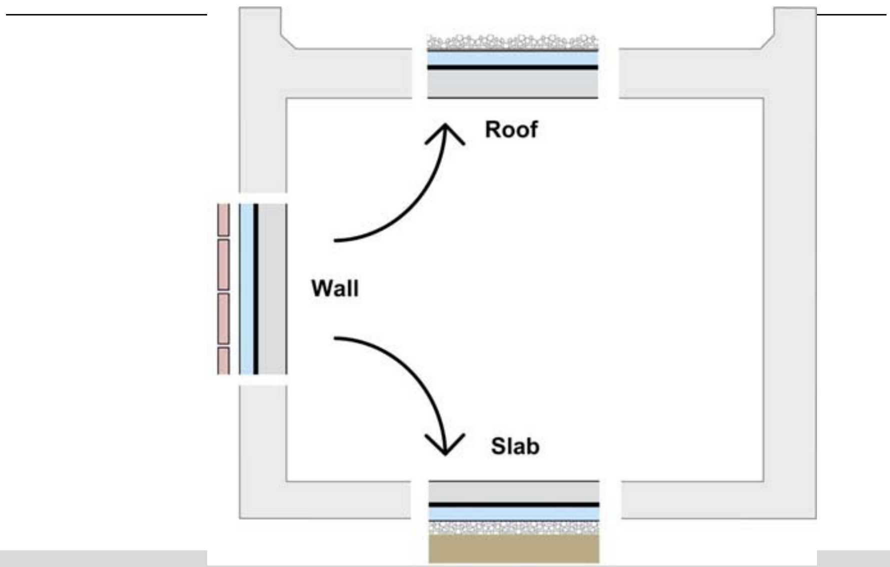


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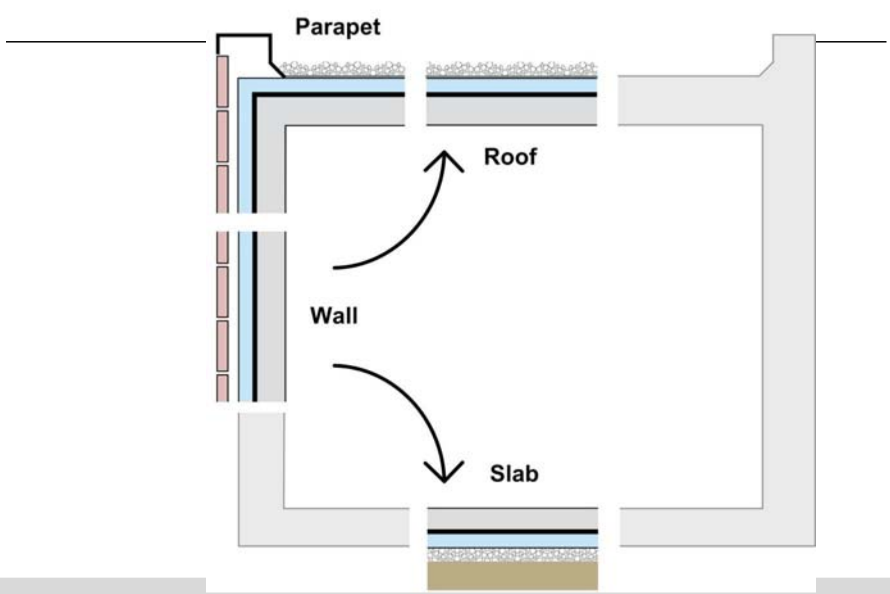


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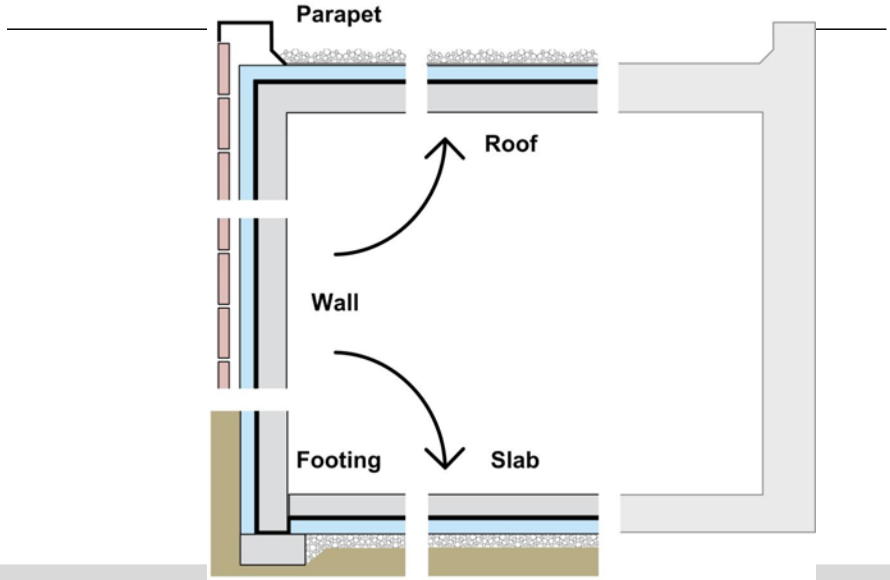


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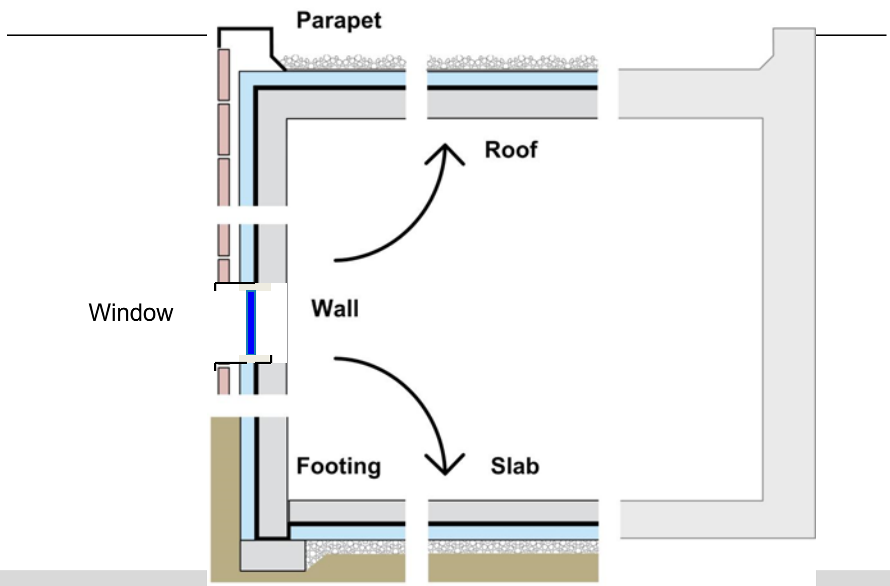


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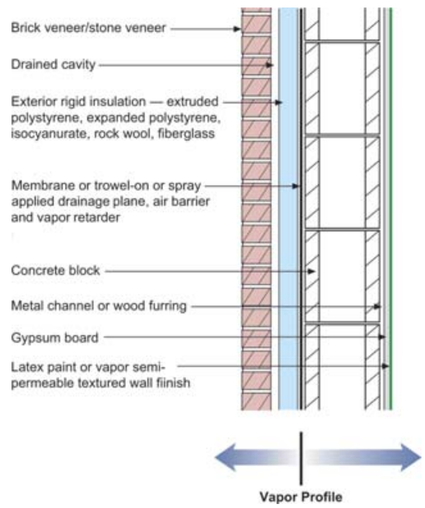
# The “Perfect” Wall: Higher Performance

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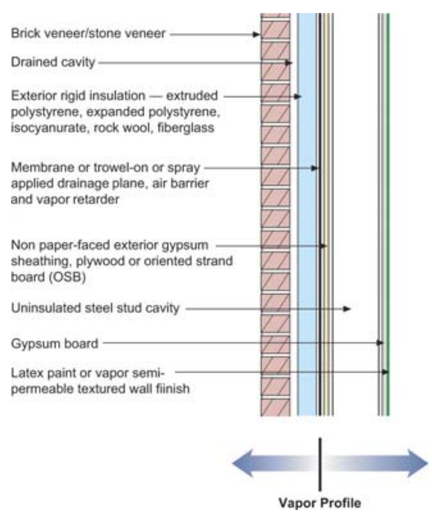
# The Commercial Steel Frame Wall

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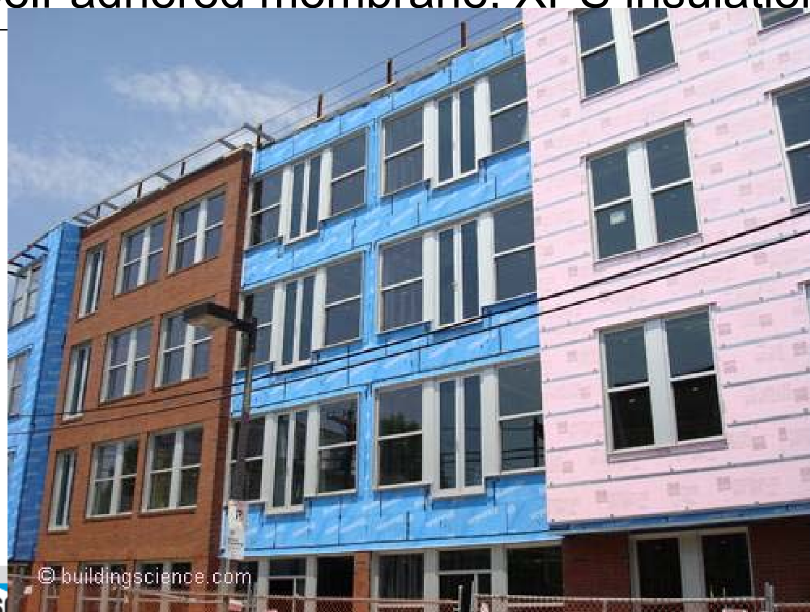
## "Perfect Wall" Advantages

- 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



## 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**

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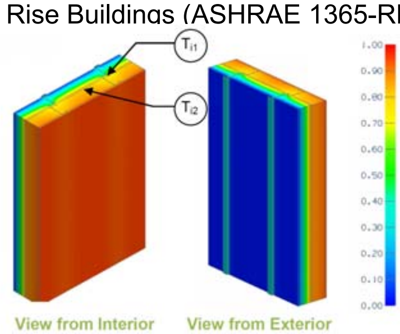
## Cladding Support (Z-Furring)

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

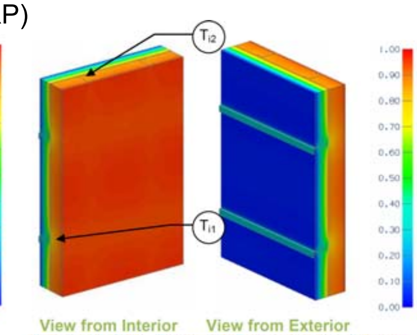
# Thermal Bridging at Cladding

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




Nominal (1D) vs. Assembly Performance Indicators

| Exterior Insulation 1D R-Value (RSI) | $R_{1D}$ ft²·hr·°F / Btu (m² K / W) | $R_o$ ft²·hr·°F / Btu (m² K / W) | $U_o$ Btu/ft²·hr·°F (W/m² 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) |

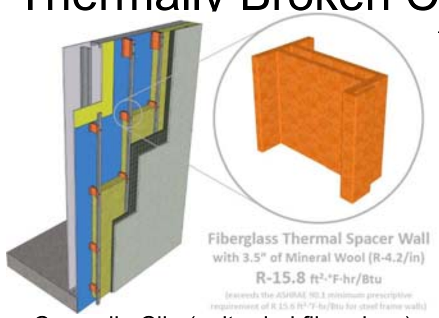



Nominal (1D) vs. Assembly Performance Indicators

| Exterior Insulation 1D R-Value (RSI) | $R_{1D}$ ft²·hr·°F / Btu (m² K / W) | $R_o$ ft²·hr·°F / Btu (m² K / W) | $U_o$ Btu/ft²·hr·°F (W/m² 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) |

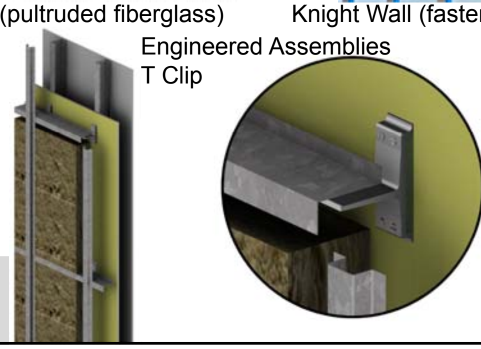


# Thermally Broken Cladding Supports




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