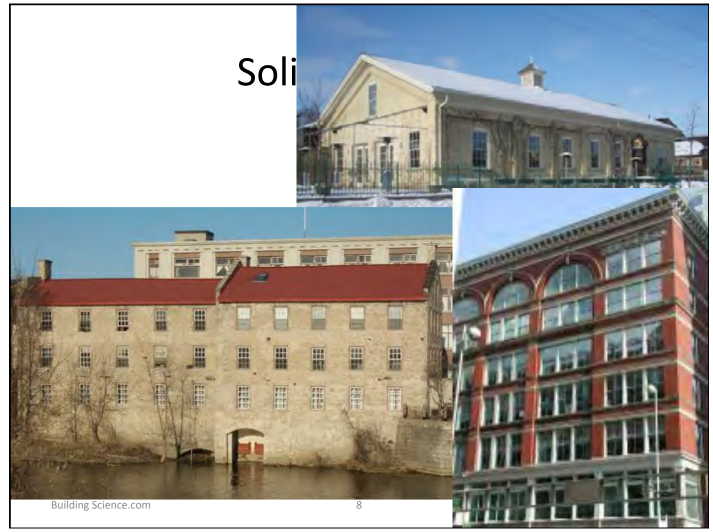

AIM HIGH
A seminar.
CREATING HIGH PERFORMANCE BUILDINGS
Presented by:
John Straube Ph.D. P.Eng.
www.BuildingScience.com


Soli
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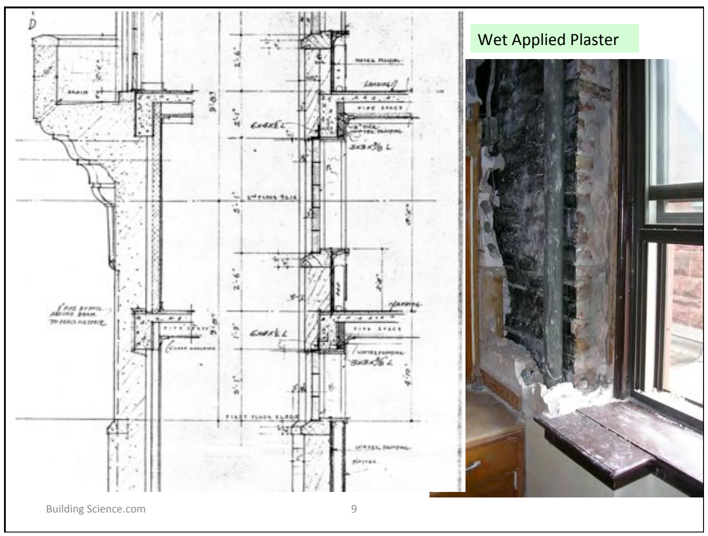
Wet Applied Plaster
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Old Growth Timber
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## Pre-WWII Buildings

- No added insulation (or very little)
- Heating systems and some natural ventilation
- No air conditioning
- No vapor barriers
- Few explicit air-tightening or “draft-stopping” details
- Masonry and old-growth solid timber structures
- Plaster is the dominant interior finish





## Five Fundamental Changes

1. Increasing Thermal Resistance
2. Changing Permeance of Enclosure Linings
3. Water/Mold Sensitivity of Materials
4. Moisture Storage Capacity
5. 3-D Airflow Networks

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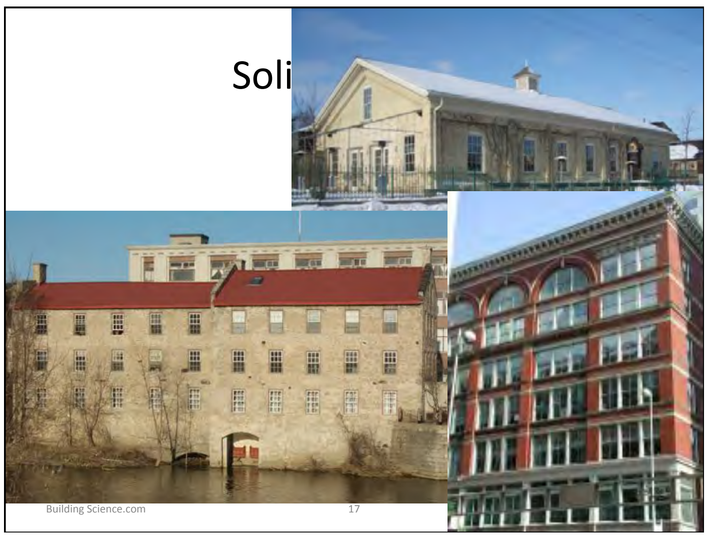
Soli



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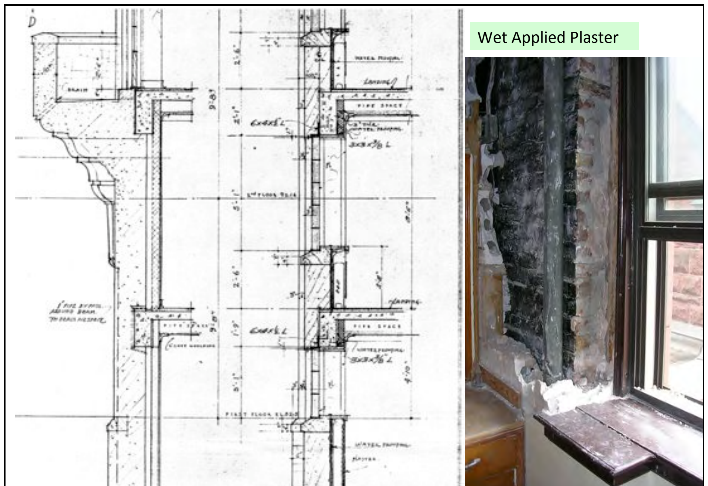


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## Pre-WWII Buildings

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## Five Fundamental Changes

1. Increasing Thermal Resistance
2. Changing Permeance of Enclosure Linings
3. Water/Mold Sensitivity of Materials
4. Moisture Storage Capacity
5. 3-D Airflow Networks



## Changes …

- Expectations are rising
  – Faster design and construction
  – Lower risk of delays / cost over runs
  – Lower operating costs
  – less energy consumption (same cost?)
  – more comfort and IAQ
- In short …

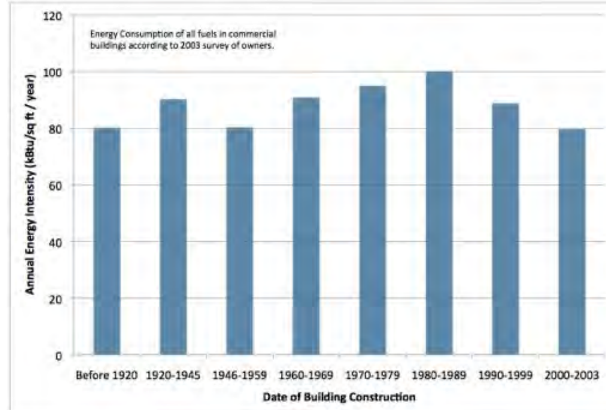
  **better buildings at less total cost**

## Measuring Performance

- Performance metrics
  - Beauty
  - Awards
  - On-time
  - Utility
  - On budget
  - Green, LEED
  - Healthy
  - Productive
  - Operating costs
  - Operational energy use

How do we measure these?

## How have we been doing?




R2

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R2

R4

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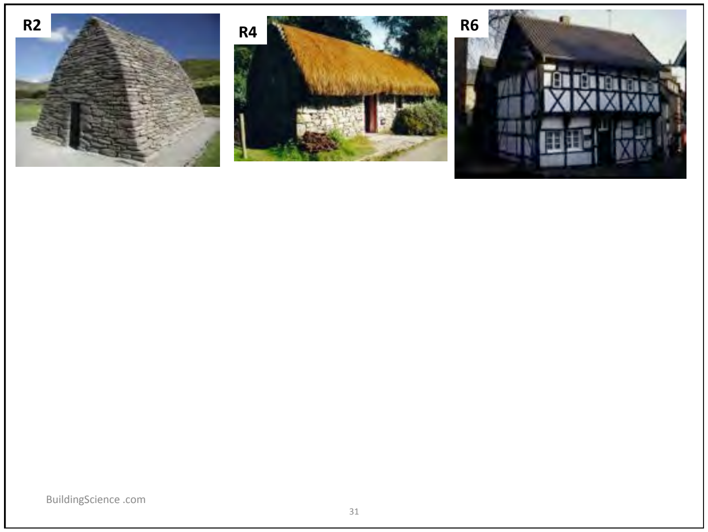
R2
R4
R6
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31


R2
R4
R6
R8
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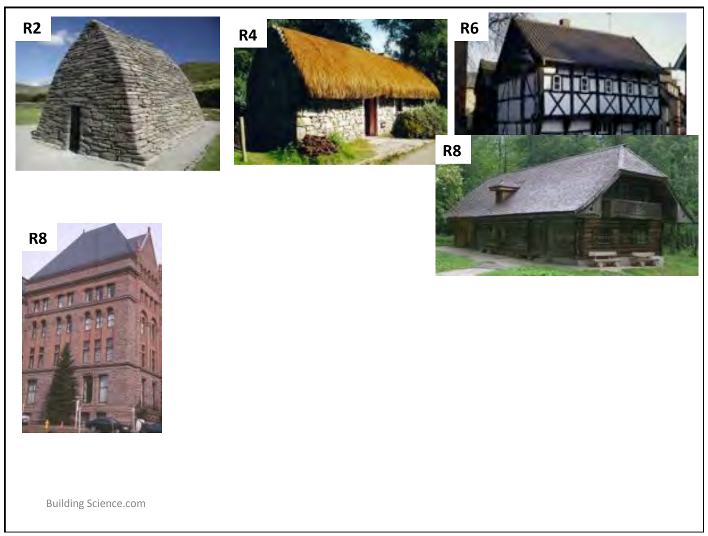
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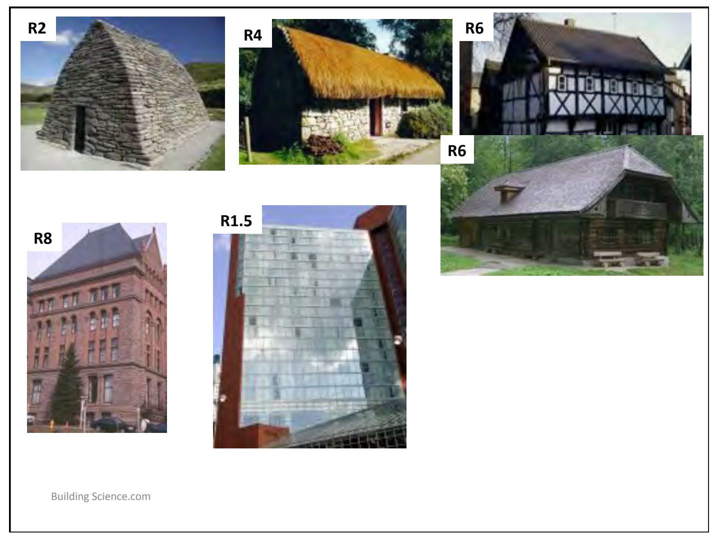
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R8
R1.5
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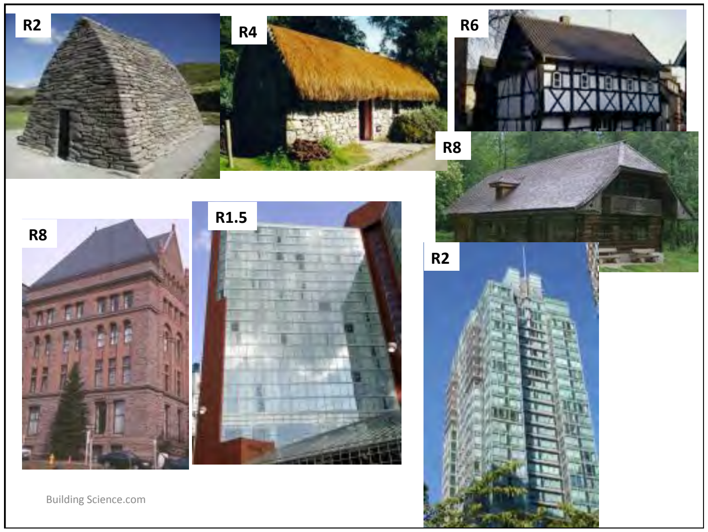


## Why such poor performance?

- Not enough insulation
  - Thermal bridges
- Not enough solar control
  - Windows!
- Too much ventilation
  - And/or poor control of
- Too many complex systems
  - HVAC no one understands

## Beware Unintended consequences

- Improving enclosure changes things
- Less heat gain
  = change in AC performance
- Less heat flow
  = more condensation
- More airtightness
  = better ventilation control required

## Complexity

- Modern buildings and systems are complex
  - Good design must manage complexity
  - Allows for focus on the big things
    - e.g., program, massing, quality
- Enclosure and HVAC **can** be made simpler *and* more robust by early design-stage decisions

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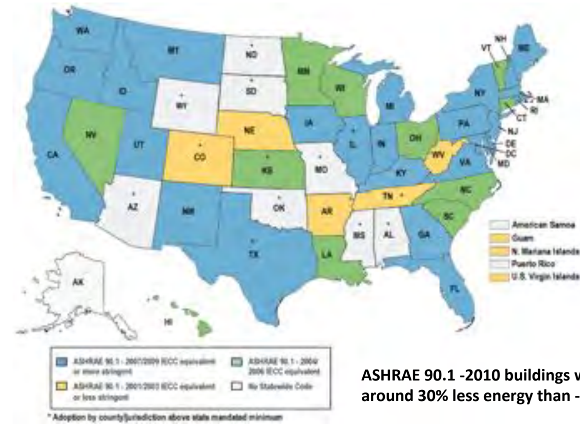
## New Solutions

- Step change in performance required
- Different approach to design& construction
  - Target, predict, measure performance
  - Quality assurance/control in drawings, on site
- Different assemblies and systems
  - More robust of operational/construction errors
  - Less complex, easier to manage

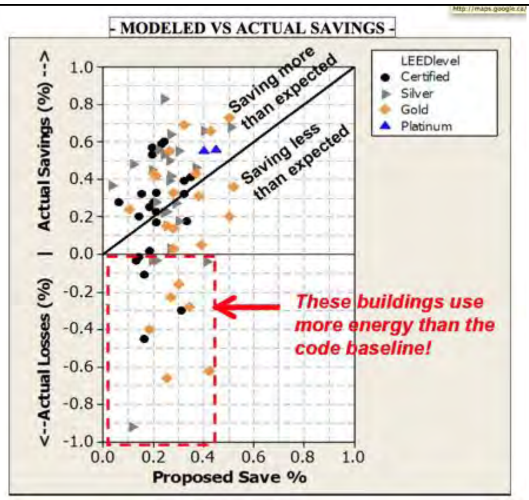
## Status of Code Adoption: Commercial

Overview of the currently adopted commercial energy code in each state

as of March 31, 2011



ASHRAE 90.1 -2010 buildings will use around 30% less energy than -2004




From: New Buildings Institute Study

## Prescription of High Performance

- Good skin
  - Rain, air, heat, vapor control
  - Simple to understand/analyze assemblies
- Good HVAC
  - Control temperature, RH, Fresh air seperately
  - Simple to understand/analyze systems
- Good design
  - Daylight, view, program, enjoyment
  - Assume future changes will occur

## Top Ten List

Commercial and institutional mid-size buildings, Zone 5-7 climates

- **Limit window-to-wall ratio** (WWR) to the range of 20-40%, 50% with ultra-performance windows
- **Increase window performance** (lowest U-value affordable in cold climates, including frame effects)
- Increase wall/roof **insulation** (esp. by controlling thermal bridging) and **airtighten**
- Separate **ventilation** air supply from heating and cooling.
- Use **occupancy** and **daylighting controls** for lights and equipment
- **Reduce** equipment/plug & lighting **power densities**
- Don't over ventilate, use **heat recovery** & **demand controlled ventilation**
- Improve boiler and **chiller efficiency** & recover waste heat (eg IT rooms!)
- Use **variable speed controls** for all large pumps and fans and implement **low temperature hydronic** heating and cooling where appropriate.
- Use a simple and compact building form, oriented to the sun, with a depth that allows daylight harvesting.

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## Enclosures in Context

- Enclosures are key to comfort and durability
- Enclosures **reduce** space heating/cooling
  - and help with lighting, ventilation
- We still need **energy** for other things
  - Lights, appliances, computers, elevators, etc
- But
  - **Bad enclosures ruin good HVAC**
  - **Bad HVAC can ruin good enclosures**

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## This seminar

- Enclosure
- HVAC (afternoon)

## The Enclosure: An Environmental Separator

- The part of the building that physically ***separates*** the ***interior*** and ***exterior*** environments.
- Includes all of the parts that make up the wall, window, roof, floor, caulked joint etc.
- Sometimes, interior partitions also are environmental separators (pools, rinks, etc.)

Building Science Enclosures No. 46 /

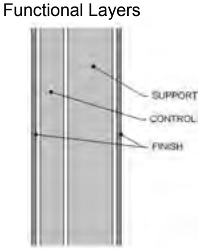
## Climate Load Modification

- Building & Site (overhangs, trees…)
  - Creates microclimate
- Building Enclosure (walls, windows, roof…)
  - Separates climates
  - Passive modification
- Building Environmental Systems (HVAC…)
  - Use energy to change climate
  - Active modification

## Basic Functions of the Enclosure

- 1. Support
  - Resist and transfer physical forces from inside and out
- 2. Control
  - Control mass and energy flows
- 3. Finish
  - Interior and exterior surfaces for people
- Distribution – a building function

Functional Layers

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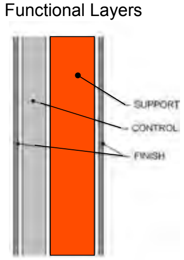
## Basic Enclosure Functions

- **Support**
  - **Resist & transfer physical forces from inside and out**
    - Lateral (wind, earthquake)
    - Gravity (snow, dead, use)
    - Rheological (shrink, swell)
    - Impact, wear, abrasion
- Control
  - Control mass and energy flows
- Finish
  - Interior and exterior surfaces for people

Functional Layers

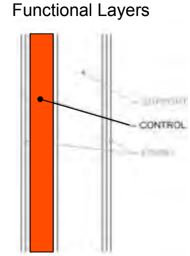



Building Science  Enclosures No. 49 /

## Basic Enclosure Functions

- Support
  - Resist & transfer physical forces from inside and out
- **Control**
  - **Control mass and energy flows**
    - **Rain** (and soil moisture)
      - Drainage plane, capillary break, etc.
    - **Air**
      - Continuous air barrier
    - **Heat**
      - Continuous layer of insulation
    - **Vapor**
      - Balance of wetting/drying
- Finish
  - Interior and exterior surfaces for people

Functional Layers

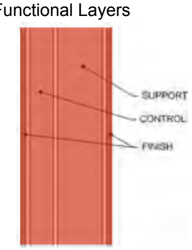



Building Science.com  Enclosures No. 50 /

## Other Control . . .

- Support
- **Control**
  - **Fire**
    - **Penetration**
    - **Propagation**
  - **Sound**
    - **Penetration**
    - **Reflection**
  - **Light**
    - **Diffuse/glare**
    - **View**
- Finish

Functional Layers

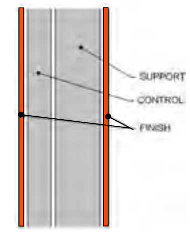



Building Science.com     Enclosures No. 51 /

## Basic Enclosure Functions

- Support
  - Resist & transfer physical forces from inside and out
- Control
  - Control mass and energy flows
- **Finish**
  - **Interior & exterior surfaces for people**
    - Color, speculance
    - Pattern, texture

Functional Layers

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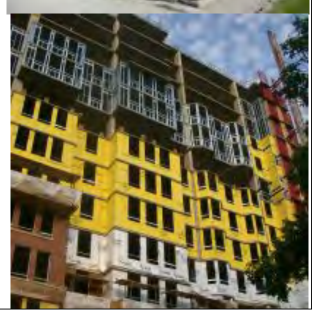
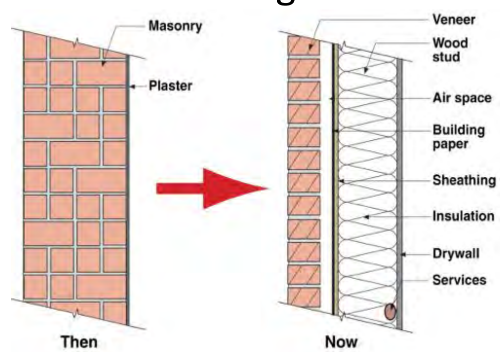
## History of Control Functions

- Older Buildings
  - One layer does everything
- Newer Building
  - Separate layers,
    
    . . . separate functions



Building Science.com     No. 53

## Changes

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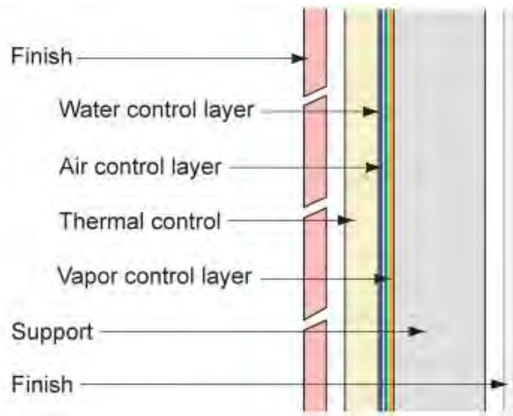
## The Perfect Wall

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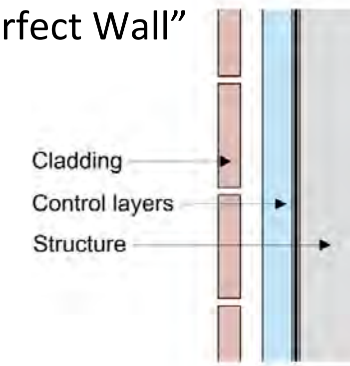
## The "Perfect Wall"

- Finish of whatever
- Control continuity
  - Rain control layer
    - Perfect barrier
    - Drained with gap
    - Storage
  - Air control layer
    - Air barrier
  - Thermal control layer
    - Aka insulation, radiant barriers
  - Vapor control layer
    - Retarders, barriers, etc
- Structure can be anything




Additional Fire Control may be needed
Additional Sound Control optional

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## What is a high performance enclosure?

- High levels of control
- **But**, poor continuity limits performance
- **&** Poor continuity causes most problems too:
  - E.g. air leakage condensation
  - Rain leakage
  - Surface condensation
  - Cold windows
- Thus: *continuity + high levels of control*

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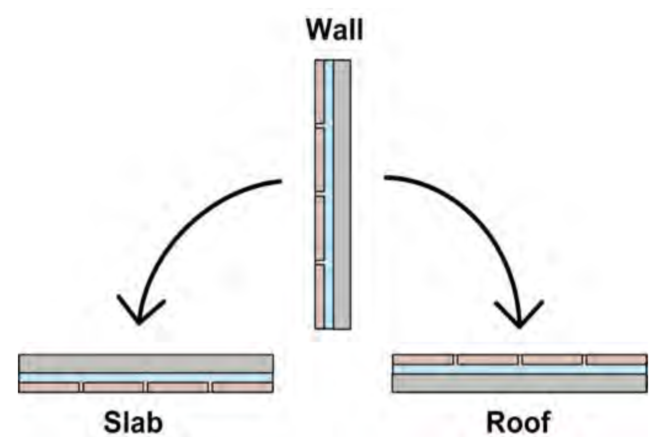


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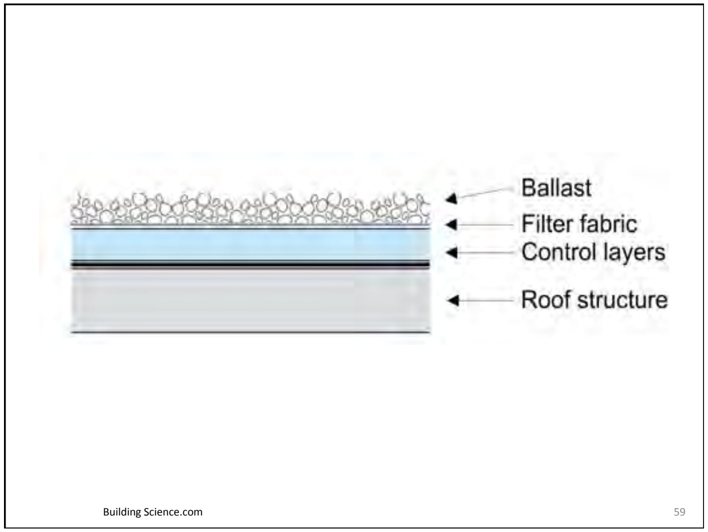
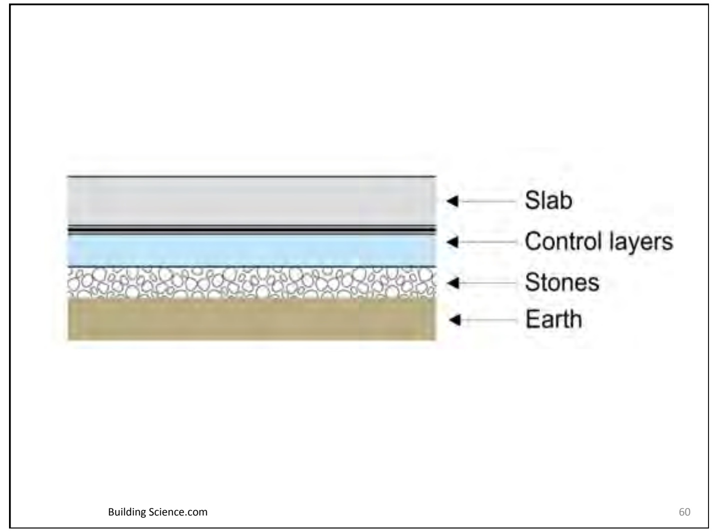
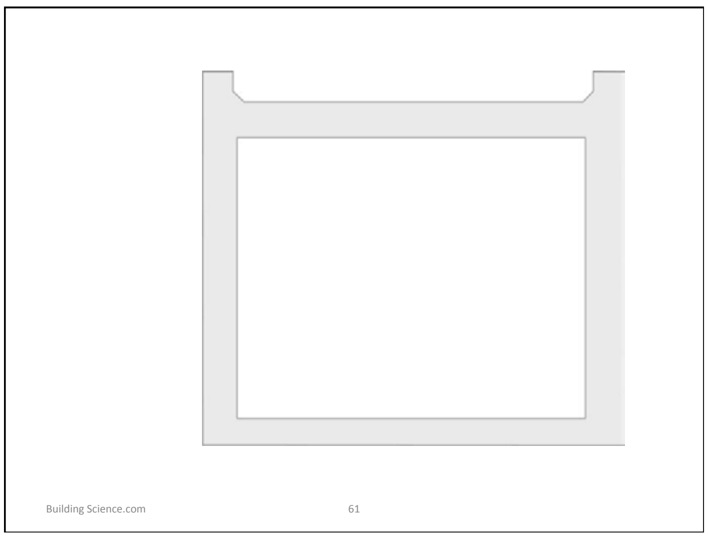

Ballast
Filter fabric
Control layers
Roof structure
Building Science.com
59


Slab
Control layers
Stones
Earth
Building Science.com
60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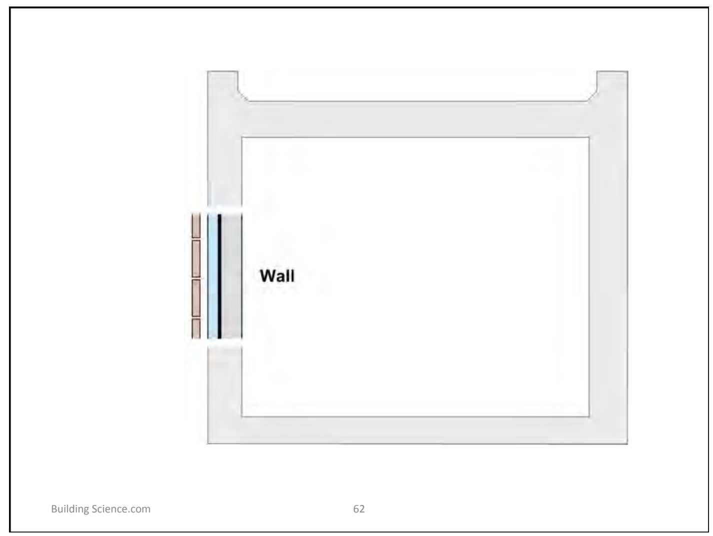
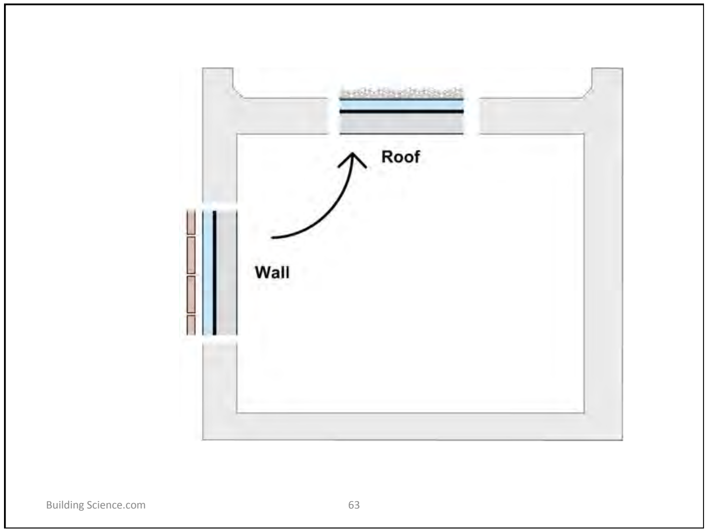
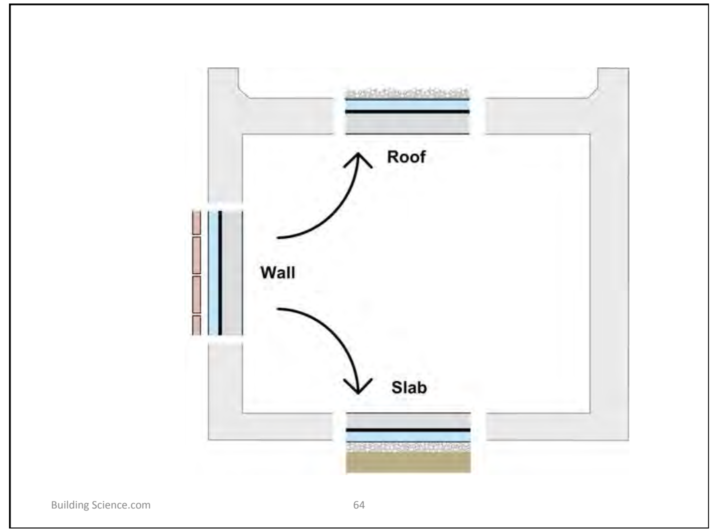
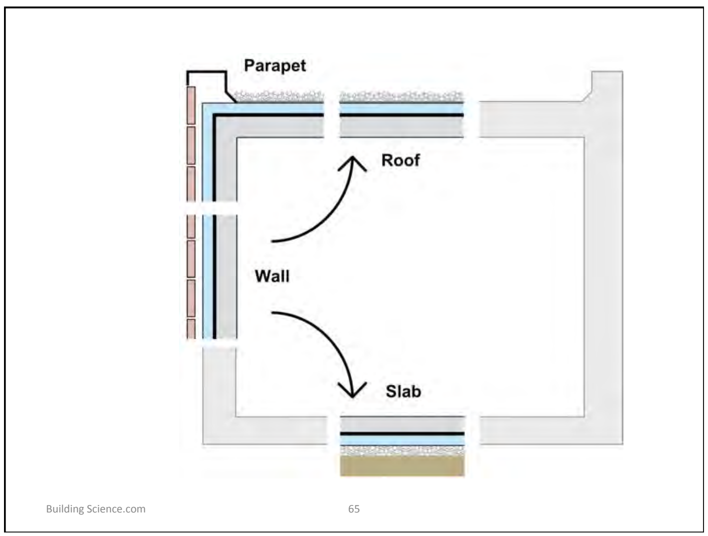
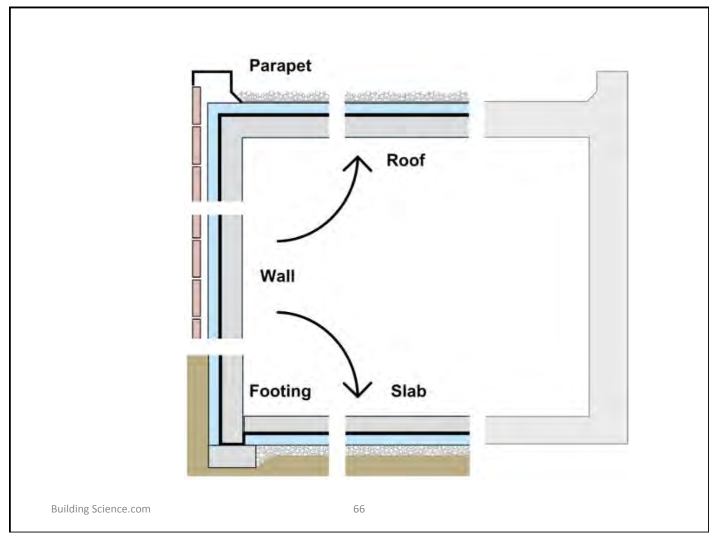
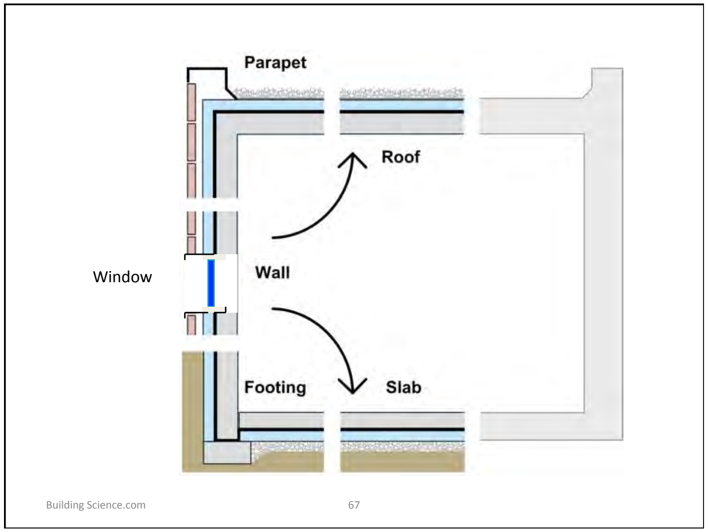

Wall
Building Science.com
62

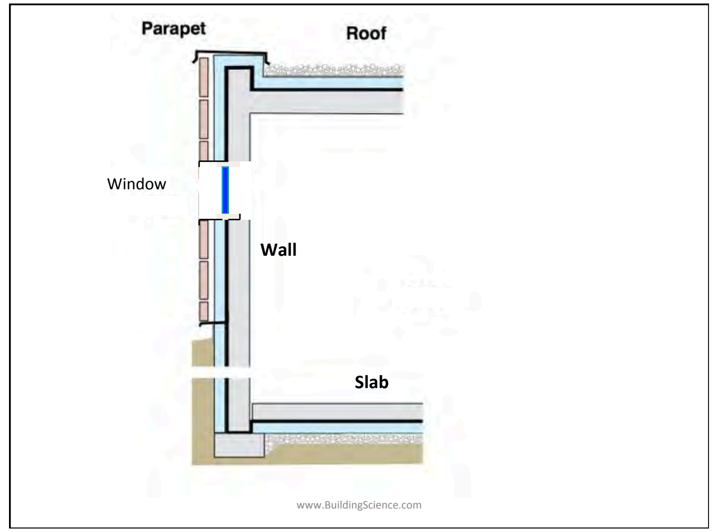

Roof
Wall
Building Science.com
63


Roof
Wall
Slab
Building Science.com
64

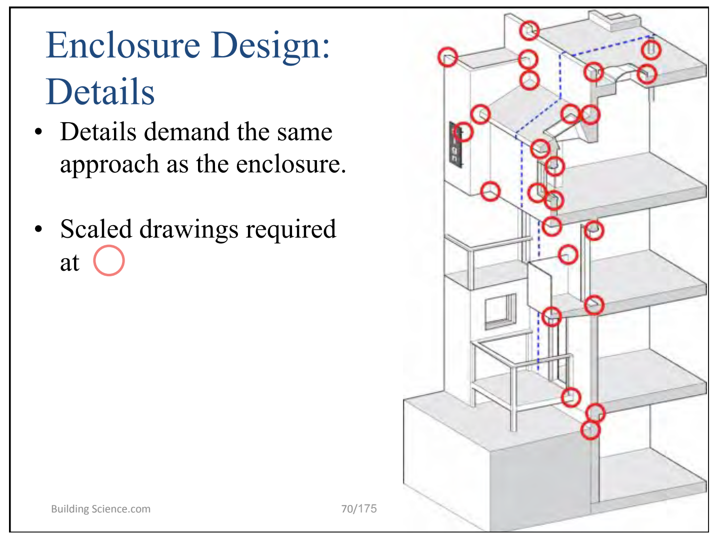

Parapet
Roof
Wall
Slab
Building Science.com
65


Parapet
Roof
Wall
Footing
Slab
Building Science.com
66


Parapet
Roof
Window
Wall
Footing
Slab
Building Science.com
67


Parapet
Roof
Window
Wall
Slab
www.BuildingScience.com


Complexity increases detailing effort / risk of failure / cost
reduces performance


Enclosure Design: Details
• Details demand the same approach as the enclosure.
• Scaled drawings required at
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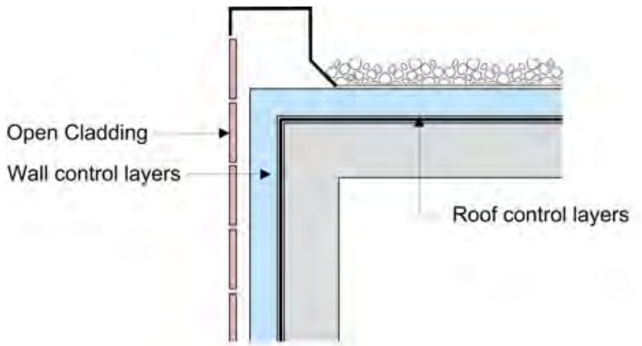
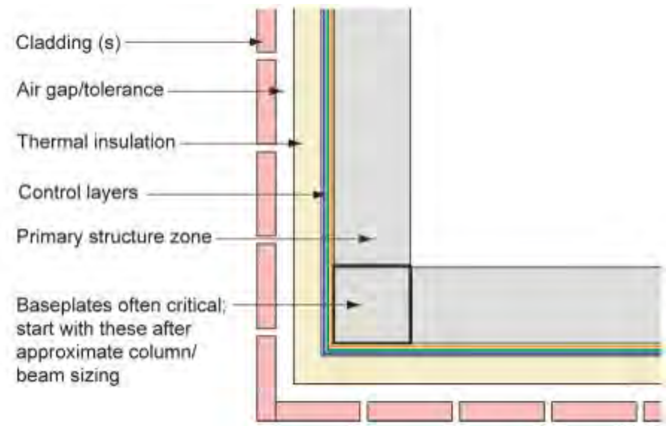
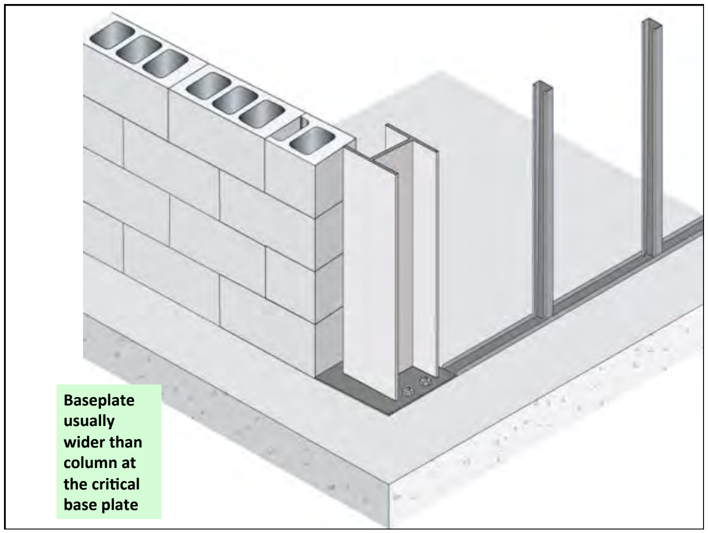
70/175

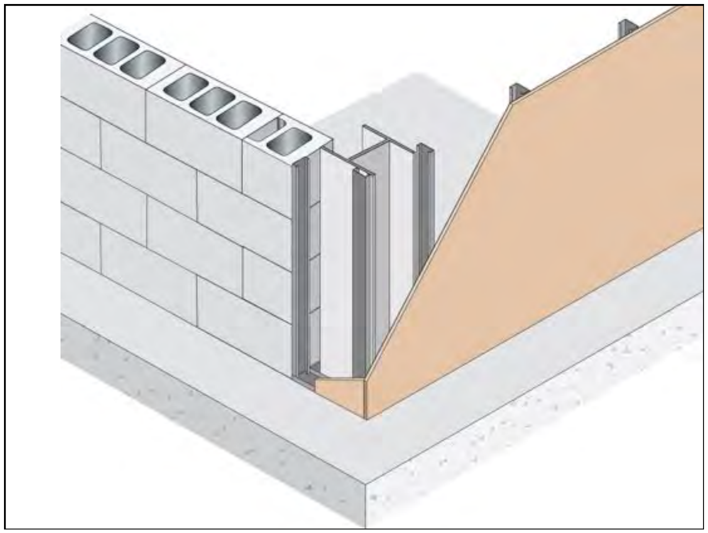
## Connections: Who is in charge

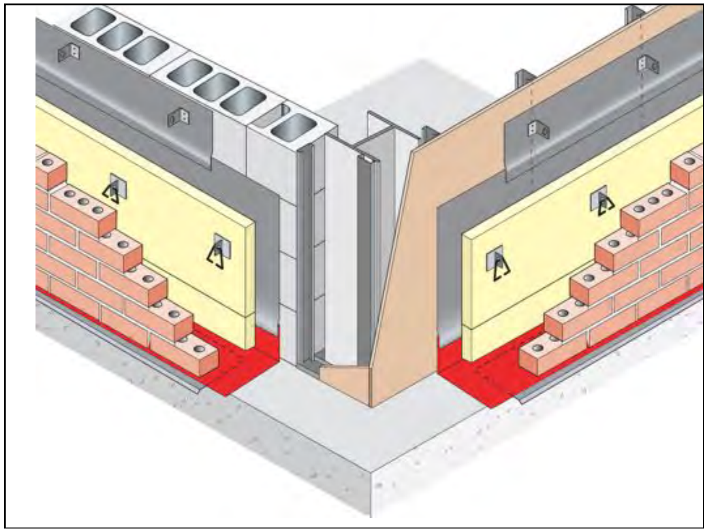


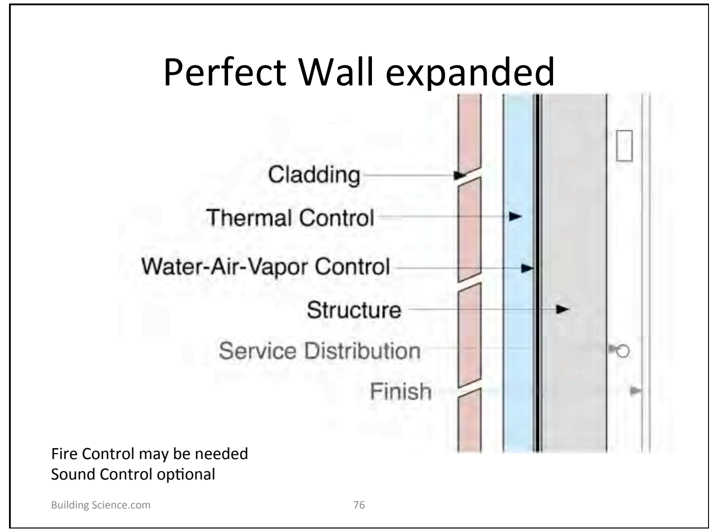

## Plan Dimensions

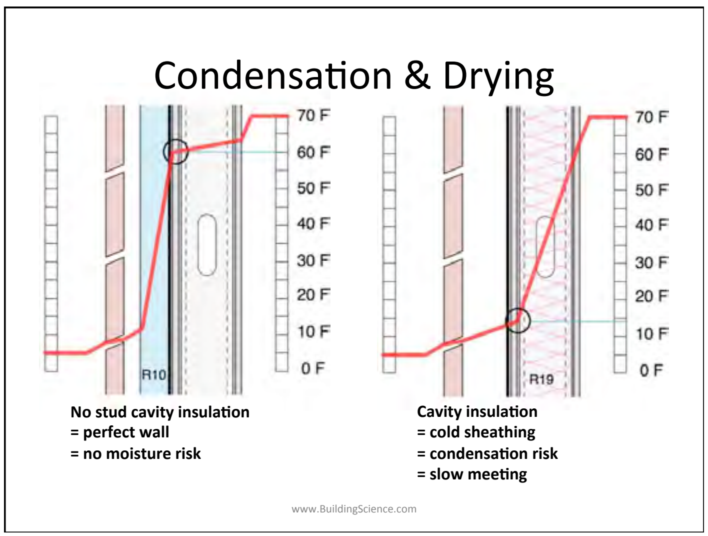


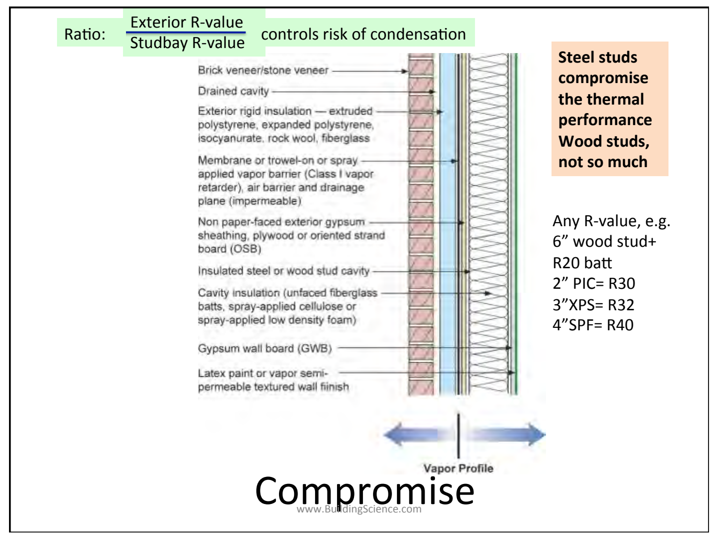



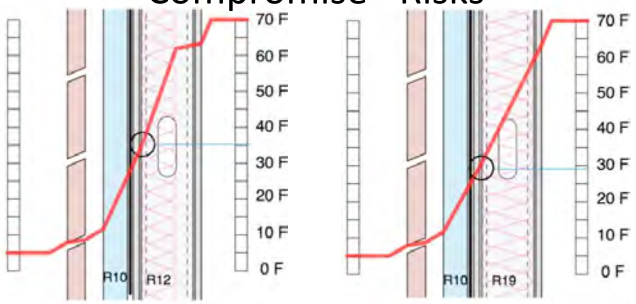



Perfect Wall expanded
Cladding
Thermal Control
Water-Air-Vapor Control
Structure
Service Distribution
Finish
Fire Control may be needed
Sound Control optional
Building Science.com
76


Condensation & Drying
70 F
60 F
50 F
40 F
30 F
20 F
10 F
0 F
R10
R19
No stud cavity insulation
= perfect wall
= no moisture risk
Cavity insulation
= cold sheathing
= condensation risk
= slow meeting
www.BuildingScience.com


Ratio: Exterior R-value / Studbay R-value controls risk of condensation
Brick veneer/stone veneer
Drained cavity
Exterior rigid insulation — extruded polystyrene, expanded polystyrene, isocyanurate, rock wool, fiberglass
Membrane or trowel-on or spray applied vapor barrier (Class I vapor retarder), air barrier and drainage plane (impermeable)
Non paper-faced exterior gypsum sheathing, plywood or oriented strand board (OSB)
Insulated steel or wood stud cavity
Cavity insulation (unfaced fiberglass batts, spray-applied cellulose or spray-applied low density foam)
Gypsum wall board (GWB)
Latex paint or vapor semi-permeable textured wall finish
Steel studs compromise the thermal performance
Wood studs, not so much
Any R-value, e.g.
6" wood stud+
R20 batt
2" PIC= R30
3"XPS= R32
4"SPF= R40
Vapor Profile
Compromise
www.BuildingScience.com

## Compromise= Risks

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## Continuity is key!

- Must ensure no rain leaks, no holes
- Airflow control should be as continuous as practical
- Thermal control
  - We live with penetrations
  - Minimize steel &concrete to small local points
- Vapor control
  - Not that important to ensure continuity

Energy

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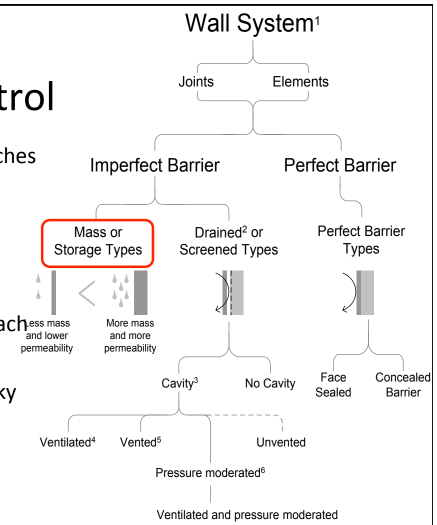
## Next Steps

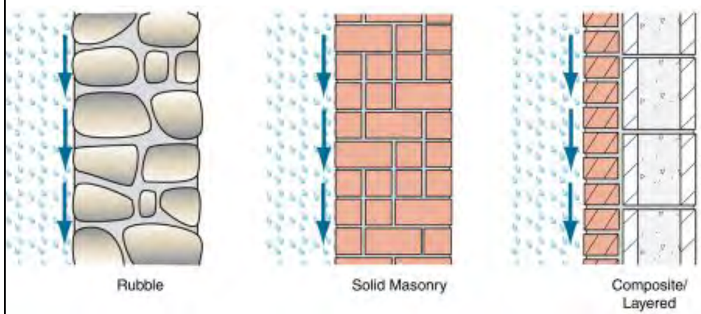
- Rain Control
- Air Control
- Thermal Control

## 1. Rain Control

- Three possible approaches
  - Mass
  - Drained
  - Perfect Barriers
- Element and joint can be different approach
- Perfect Barriers are risky



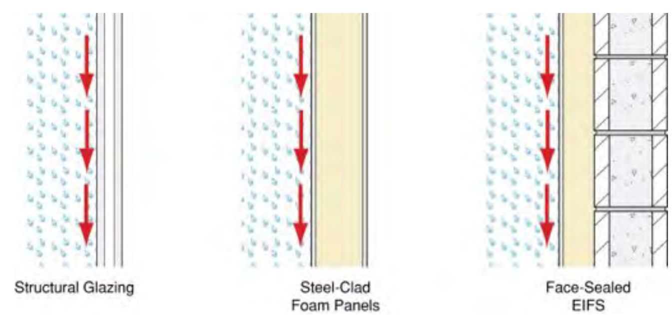
## Historic: Mass/Storage Walls




John Straube

## No building paper, flashing, weepholes

## Perfect Barrier / Face Sealed

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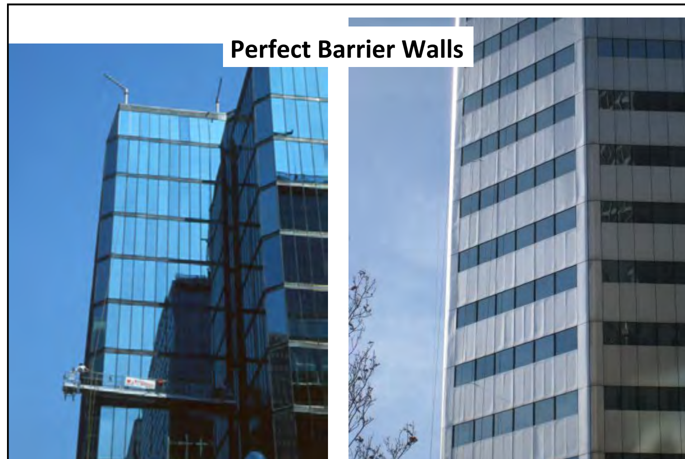
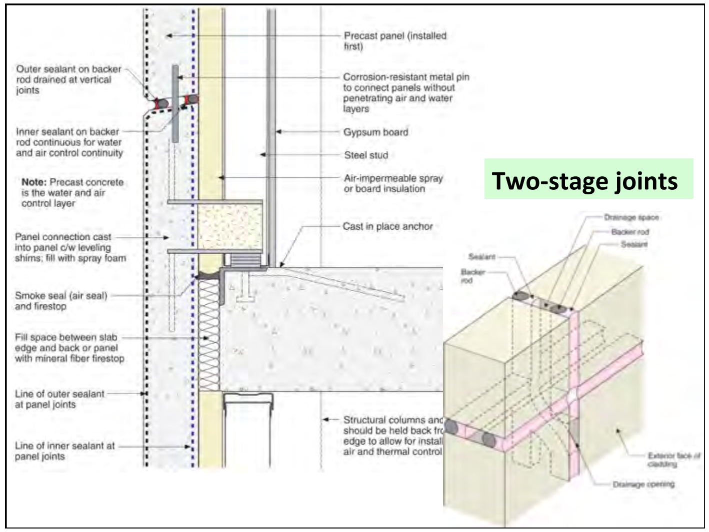
## Perfect Barrier Walls



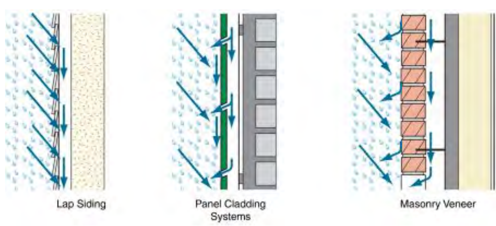
**It is all about joints, transitions, penetrations which may not be built, or remain perfect**

**Precast is often a functional perfect barrier wall**
**.. but the joints leak**



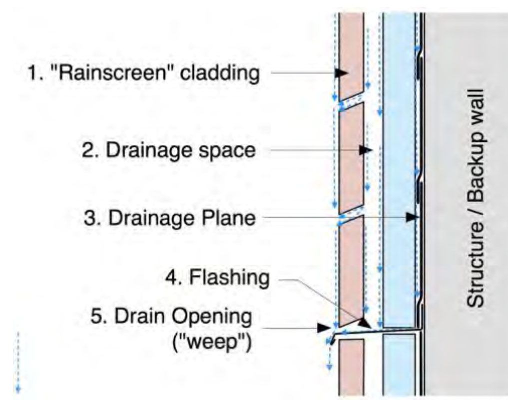

# Drained

- Drained systems preferred
- Account for joints and penetrations as well as installation defects and material failure

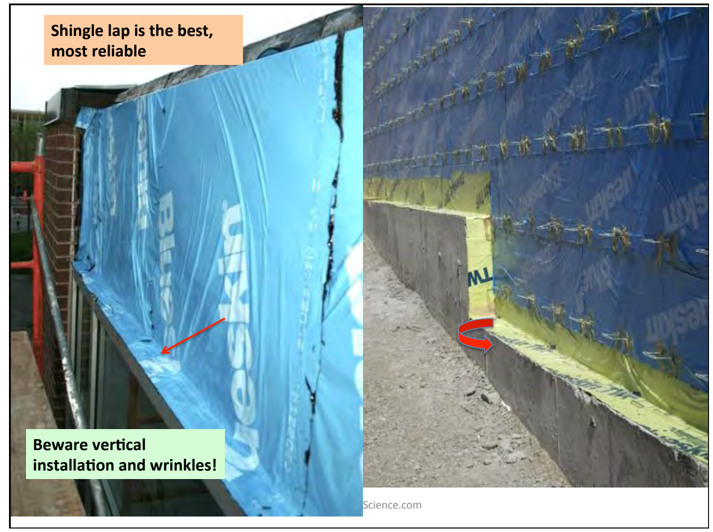


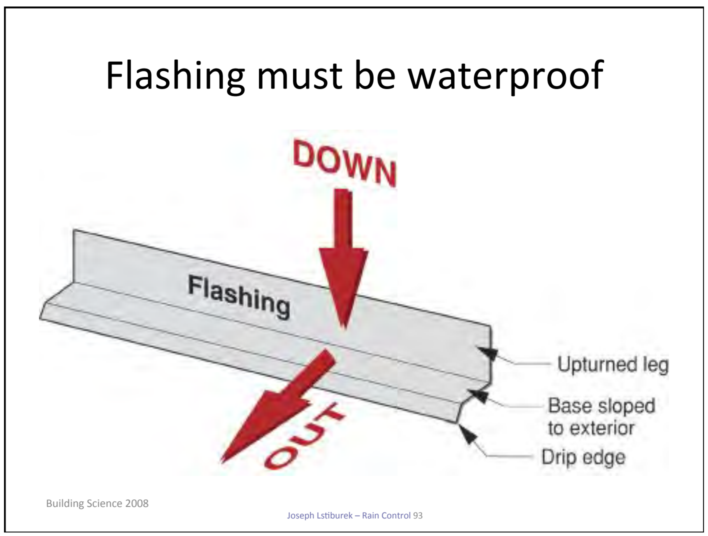


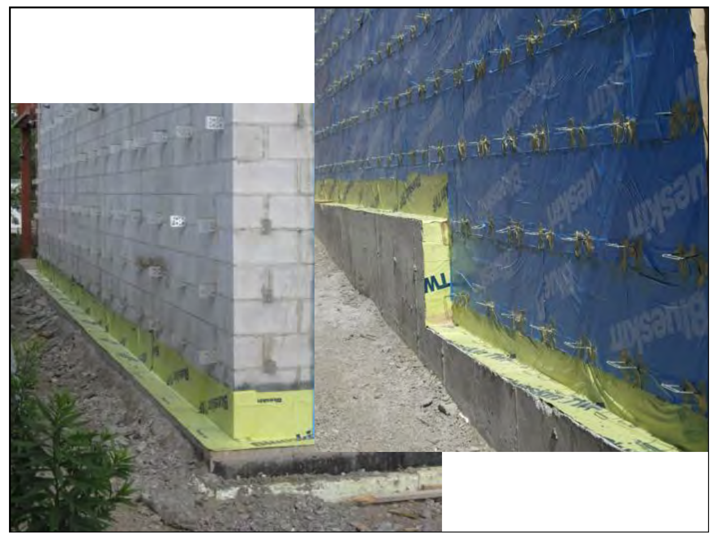

**"Rainscreen" or "Drained" System**

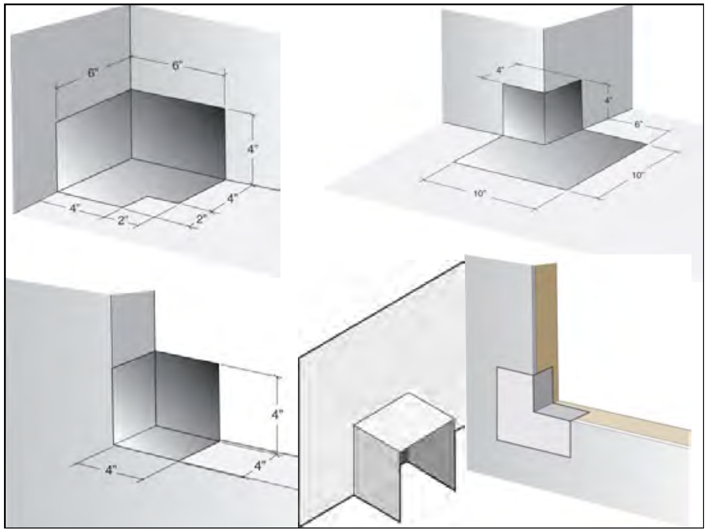



Fluid-applied products
avoids laps


Shingle lap is the best,
most reliable
Beware vertical
installation and wrinkles!


Flashing must be waterproof
DOWN
Flashing
OUT
Upturned leg
Base sloped
to exterior
Drip edge
Building Science 2008
Joseph Lstiburek – Rain Control 93





## Details

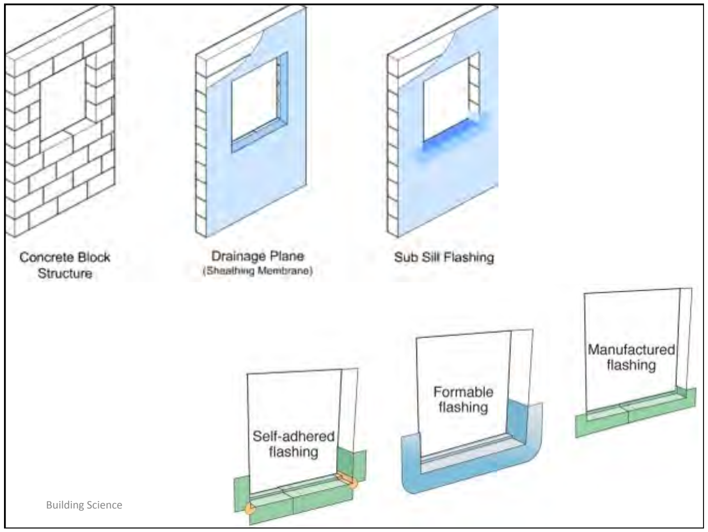
- Air & water & vapor transition membranes

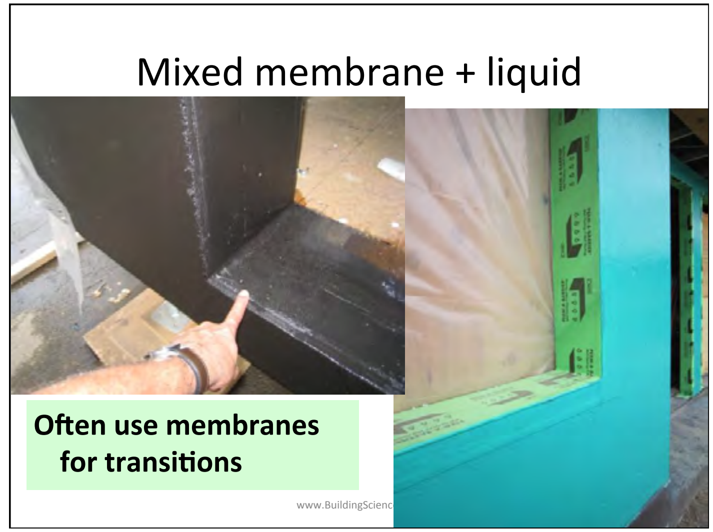
## Windows and Doors

- All penetrations should be drained, regardless of the approach taken to the element
- Windows and doors are the most critical openings to drain
- Rough opening must be drained

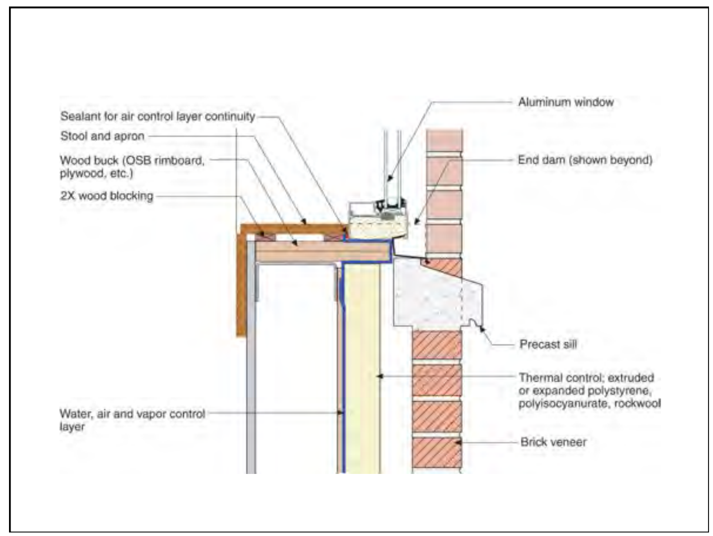
## Leaky windows

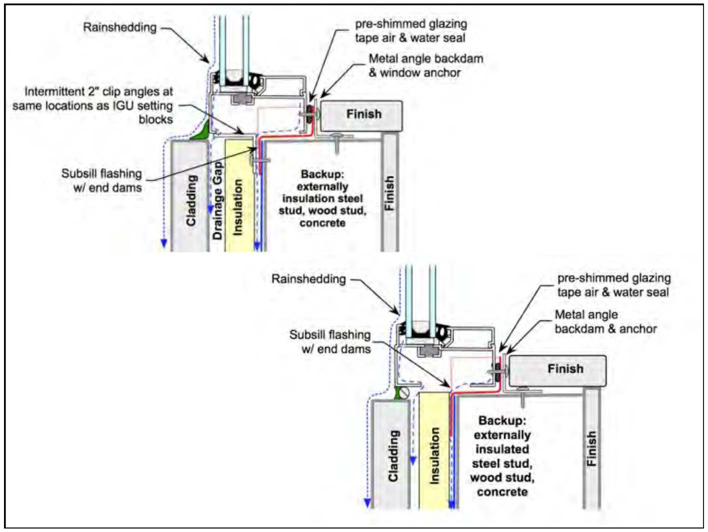
- Studs and sheathing are sensitive to leaks


Concrete Block Structure
Drainage Plane
(Sheathing Membrane)
Sub Sill Flashing
Manufactured flashing
Formable flashing
Self-adhered flashing
Building Science

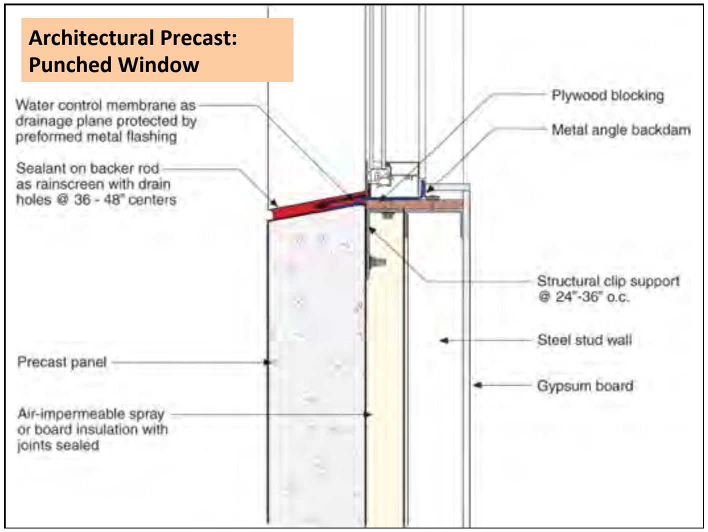

Mixed membrane + liquid
Often use membranes for transitions
www.BuildingScienc

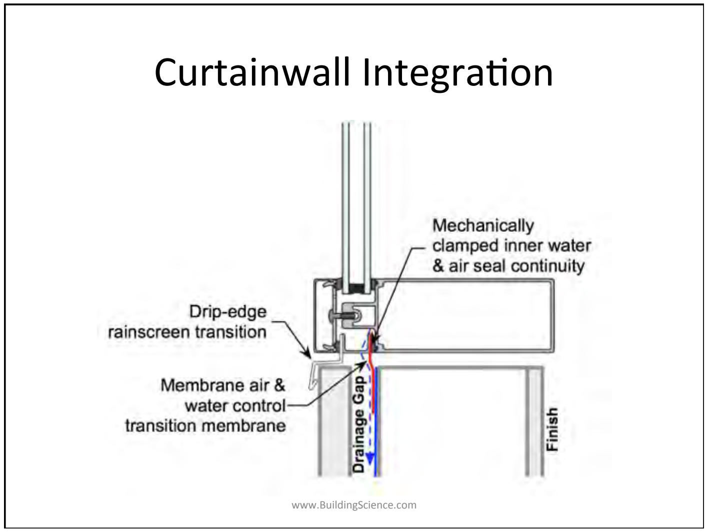

Backdams / Slopes are Important


Sealant for air control layer continuity
Stool and apron
Wood buck (OSB rimboard, plywood, etc.)
2X wood blocking
Water, air and vapor control layer
Aluminum window
End dam (shown beyond)
Precast sill
Thermal control; extruded or expanded polystyrene, polyisocyanurate, rockwool
Brick veneer


Rainshedding
pre-shimmed glazing tape air & water seal
Metal angle backdam & window anchor
Intermittent 2" clip angles at same locations as IGU setting blocks
Finish
Subsill flashing w/ end dams
Backup: externally insulation steel stud, wood stud, concrete
Cladding
Drainage Gap
Insulation
Finish
Rainshedding
pre-shimmed glazing tape air & water seal
Metal angle backdam & anchor
Subsill flashing w/ end dams
Finish
Backup: externally insulated steel stud, wood stud, concrete
Cladding
Insulation
Finish


Continuous interior angle provides backdam and airseal continuity


Architectural Precast: Punched Window
Water control membrane as drainage plane protected by preformed metal flashing
Sealant on backer rod as rainscreen with drain holes @ 36 - 48" centers
Plywood blocking
Metal angle backdam
Structural clip support @ 24"-36" o.c.
Steel stud wall
Gypsum board
Precast panel
Air-impermeable spray or board insulation with joints sealed


Curtainwall Integration
Mechanically clamped inner water & air seal continuity
Drip-edge rainscreen transition
Membrane air & water control transition membrane
Drainage Gap
Finish
www.BuildingScience.com

## Air-Water-Vapor

- Often thin layers
- *Can be*
  1. Water control (vapor permeable, not airtight), **or**
  2. Air & water control (vapor permeable), **or**
  3. Air, water & vapor (vapor impermeable).
- Examples
  – Building paper, untaped housewrap, sealed and supported housewrap, fluid applied, peel and stick

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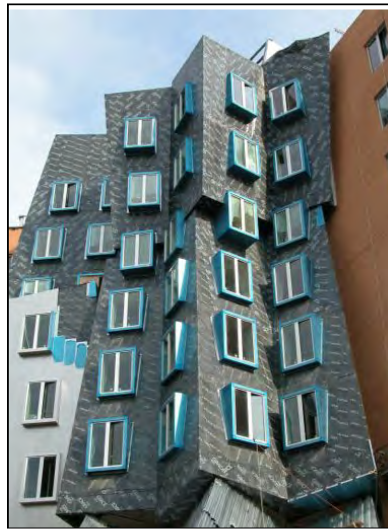


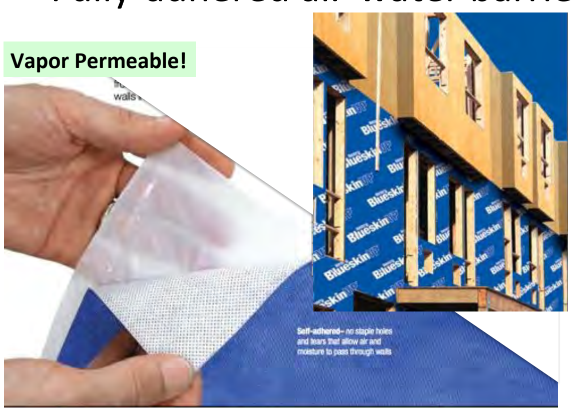
## Air-Water Control Layers

Sloped and complex surfaces demand very high performance

.com

## Fully-adhered air-water barrier

**Vapor Permeable!**

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## Spray/Trowel Applied Air/water

- Semi-permeable

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**Closed-cell spray polyurethane foam: ccSPF**
- Rain control
- Air Control
- Thermal Control
- Vapor Control

**Non-adhered, vapor permeable =modest performance**

***Supported*** **flexible membrane is better**


## 2. Airflow control

- Airtightness critical for all climates
  - Control condensation (summer and winter) and energy waste
- Airflow Control Layer
  - Practically, an air barrier system
- Cant be TOO tight
  - But must provide ventilation

113/175

## Airtightness

- Materials not important, *system* is
- GSA and Army Corp requiring testing to tightness targets now
  - 0.40 and 0.25 cfm/sf@75 Pa respectively
- IECC/IRC likely to require soon
  - Measured at 50 Pa in houses

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Commercial Buildings: Often exterior air barrier is only practical solution

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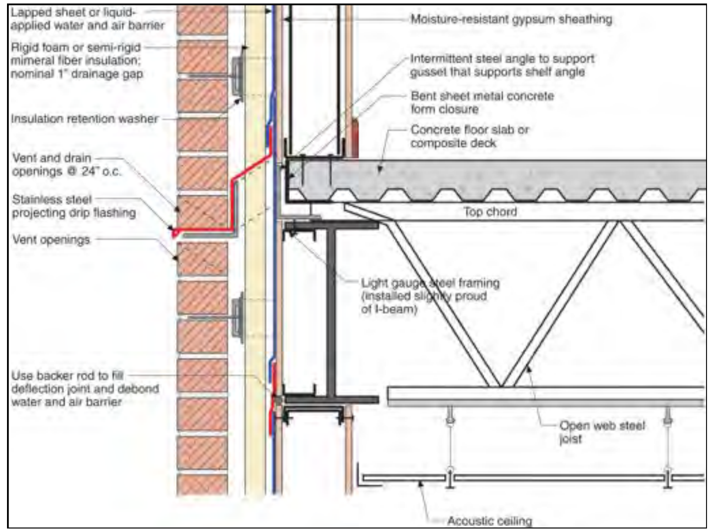


## Rigid Exterior Air Barrier

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## 3. Thermal control

- Ensure Comfort
  - Avoid hot/cold interior surfaces
- Warms surfaces = durability
  - Avoids condensation in hot and cold weather
  - hence, a durability and health strategy
  - Keep structure warm and dry and stable
- Save Energy
  - Reduce heat flow

11-11-08

## Thermal Control

- Insulation (conduction)
  - Slows heat flow in and out
- Windows (conduction, radiation)
  - Slow heat flow in and out
  - Control solar gain : allow or reject?
- "cool" roofs
  - Reduce solar gain
- Radiant barriers

## Thermal Insulation

| Insulation | R-value/inch | k (W/mK) |
|---|---|---|
| Empty airspace 0.75"-1.5" (20-40 mm) | R2.0 - 2.75 | 0.36 – 0.50 W/m²K |
| Empty airspace 3.5"-5.5" (90-140 mm) | R2.75 | 0.50 W/m²K |
| Batt (mineral fiber) | 3.5-3.8 | 0.034 - 0.042 |
| Extruded polystyrene (XPS) | 5.0 | 0.029 |
| Polyisocyanurate (PIC) | 6.0-6.5 | 0.022 - 0.024 |
| Expanded polystyrene (EPS) | 3.6-4.2 | 0.034 - 0.040 |
| Semi-rigid mineral fiber (MFI) | 3.6-4.2 | 0.034 - 0.040 |
| Spray fiberglass | 3.7-4.0 | 0.034 - 0.038 |
| Closed-cell spray foam (2 pcf) ccSPF | 5.8-6.6 | 0.022 - 0.025 |
| Open-cell spray foam (0.5 pcf) ocSPF | 3.6 | 0.040 |
| Aerogel | 8-12 | 0.012-0.018 |
| Vacuum Insulated Panels (VIP) | 20-30 | 0.004-0.008 |

## Insulation

- How much? Use much *more than normal practise*
- Comfort & condensation resistance:
  - **True** R5-10 is usually enough, but .....
- For energy / environment:
  - "As much as practical", eg R10-R20
- Practical constraints likely the limit
  - How much space available in studs?
  - Fastening, windows: exterior sheathing of 1.5"/4"
- Increased insulation should reduce HVAC capital as well as operating!

## Capital Investment vs Operating Cost


Underlying Source: Dr Ren Anderson, NREL

## Thermal Continuity / Thermal Bridges

- Some short circuiting is normally tolerated.
- High-performance walls tolerate few bridges
- Major offenders / weak spots
  - Penetrating slabs (<R1)
  - Steel studs (<<R1)
  - Windows (R2-R3)
- *Product* of **Area** and **U-value** defines significance to energy and condensation

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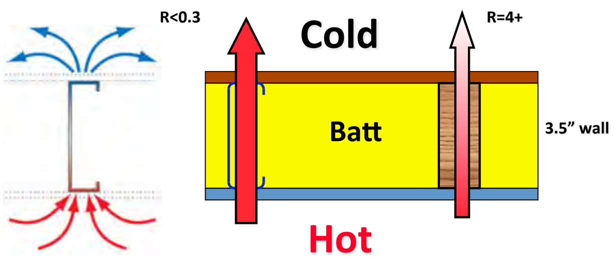
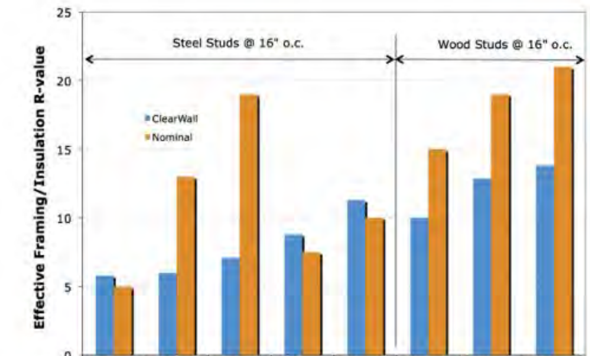
## Thermal Bridging

- Steel is 400 times more conductive than wood
- Steel studs are about 40 times thinner



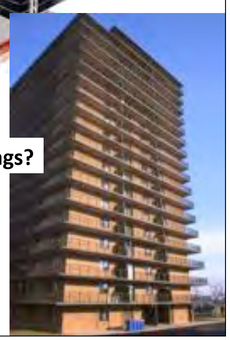

## Best-case R-values for stud walls




| | R5ci 3.5in | R-13 3.5in | R-19 6in | R7.5ci 6in | R10ci 6in | R-15 3.5in | R-19 6in | R-21 6in |
|---|---|---|---|---|---|---|---|---|
| ClearWall | 5.8 | 6.0 | 7.1 | 8.8 | 11.3 | 10.0 | 12.9 | 13.8 |
| Nominal | 5 | 13 | 19 | 7.5 | 10 | 15 | 19 | 21 |

Source: ASHRAE 90.1-2007, Table A9.28. ci denotes a layer of continous insulation with no framing penetrations





air-cool our buildings?

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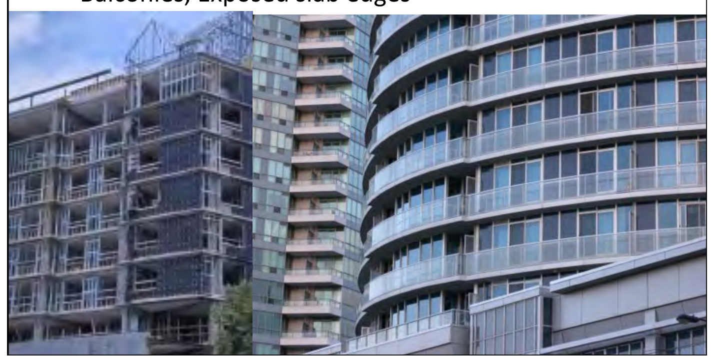
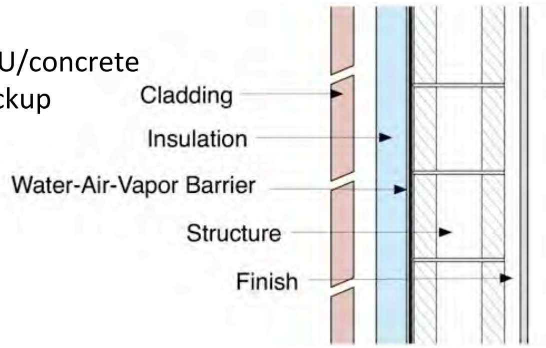
## Thermal Bridge Examples

- Aluminum framed
- Balconies, Exposed slab edges



## Perfect Wall

- CMU/concrete backup

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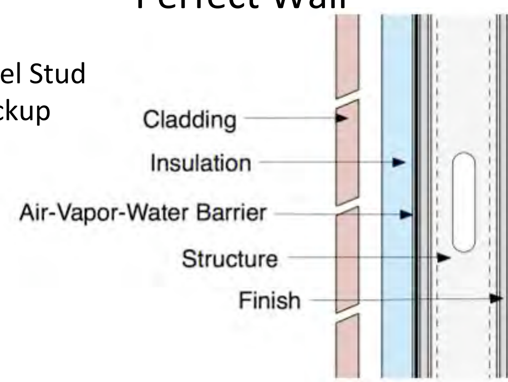
## Perfect Wall

- Steel Stud Backup

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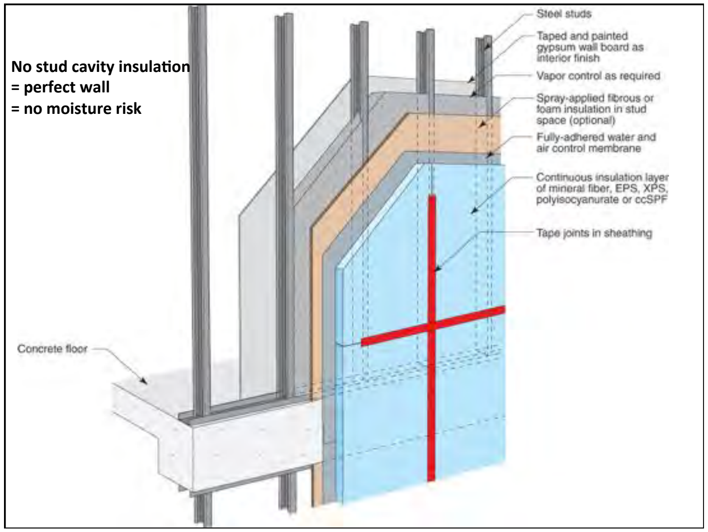
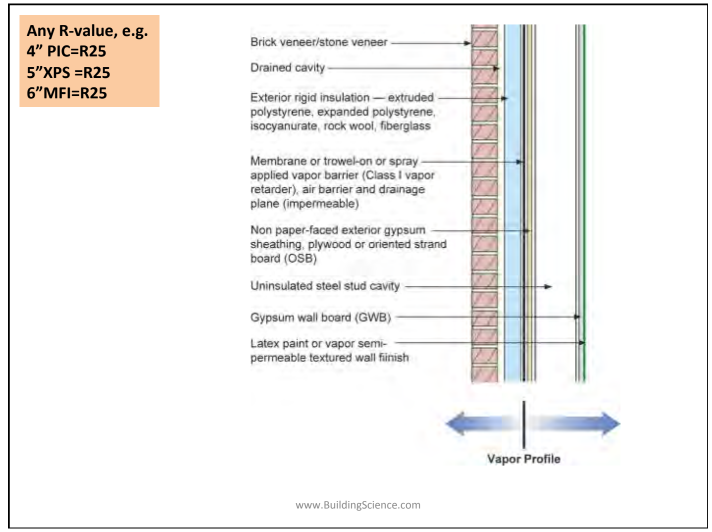

No stud cavity insulation
= perfect wall
= no moisture risk
Steel studs
Taped and painted gypsum wall board as interior finish
Vapor control as required
Spray-applied fibrous or foam insulation in stud space (optional)
Fully-adhered water and air control membrane
Continuous insulation layer of mineral fiber, EPS, XPS, polyisocyanurate or ccSPF
Tape joints in sheathing
Concrete floor


Any R-value, e.g.
4" PIC=R25
5"XPS =R25
6"MFI=R25
Brick veneer/stone veneer
Drained cavity
Exterior rigid insulation — extruded polystyrene, expanded polystyrene, isocyanurate, rock wool, fiberglass
Membrane or trowel-on or spray applied vapor barrier (Class I vapor retarder), air barrier and drainage plane (impermeable)
Non paper-faced exterior gypsum sheathing, plywood or oriented strand board (OSB)
Uninsulated steel stud cavity
Gypsum wall board (GWB)
Latex paint or vapor semi-permeable textured wall finish
Vapor Profile
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2010
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DENSGLASS GOLD
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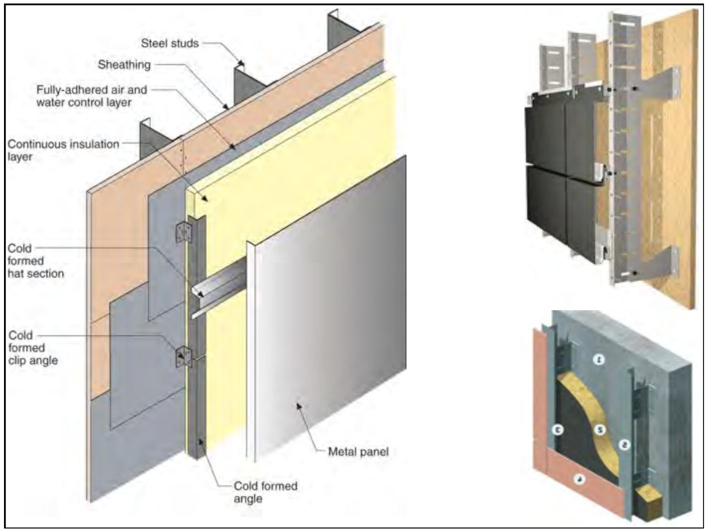
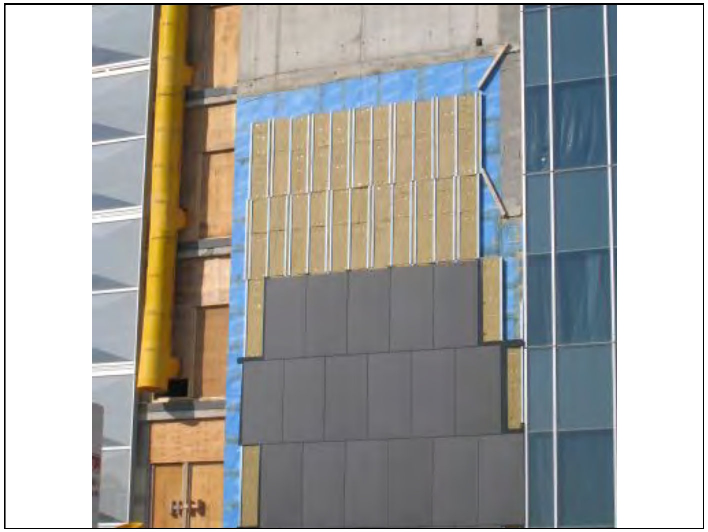
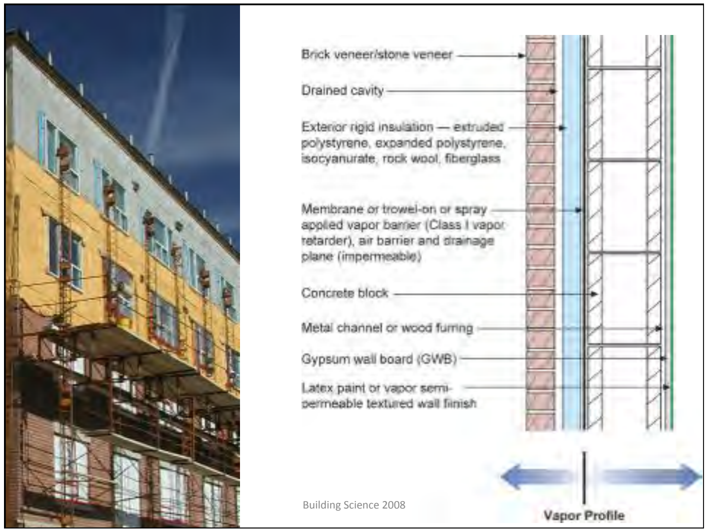
Blueskin


Steel studs
Sheathing
Fully-adhered air and water control layer
Continuous insulation layer
Cold formed hat section
Cold formed clip angle
Metal panel
Cold formed angle




University of Hartford


Brick veneer/stone veneer
Drained cavity
Exterior rigid insulation — extruded polystyrene, expanded polystyrene, isocyanurate, rock wool, fiberglass
Membrane or trowel-on or spray applied vapor barrier (Class I vapor retarder), air barrier and drainage plane (impermeable)
Concrete block
Metal channel or wood furring
Gypsum wall board (GWB)
Latex paint or vapor semi-permeable textured wall finish
Building Science 2008
Vapor Profile


Closed-cell spray polyurethane foam: ccSPF
-Rain control
-Air Control
-Thermal Control
- Vapor Control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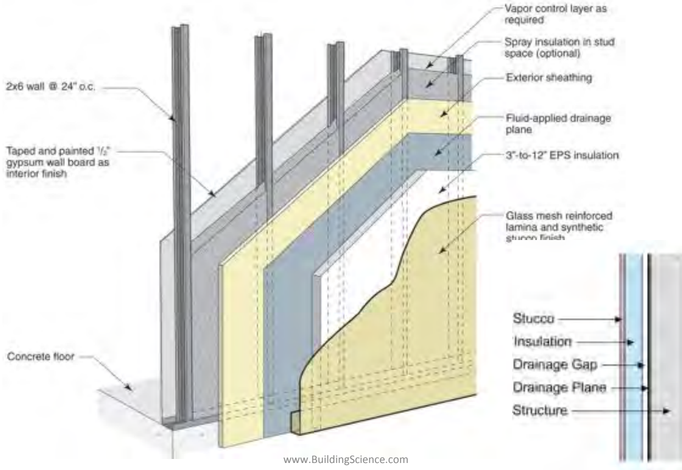
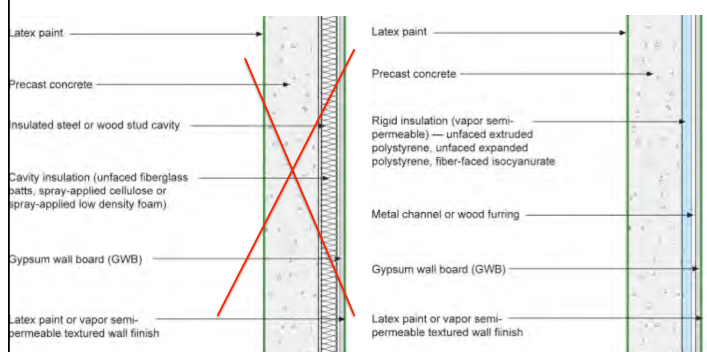
## EIFS: no longer a four letter word

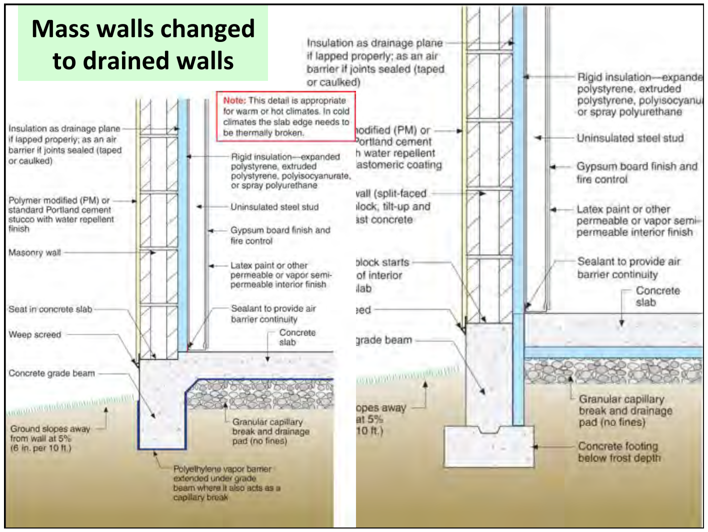


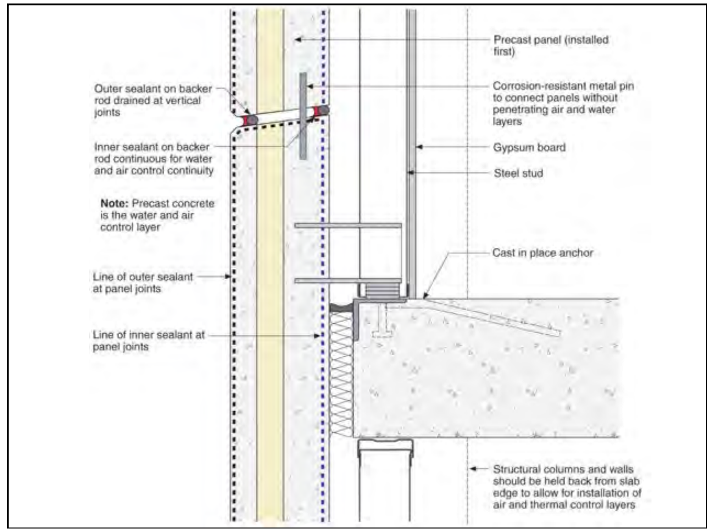

## Drained EIFS is HP

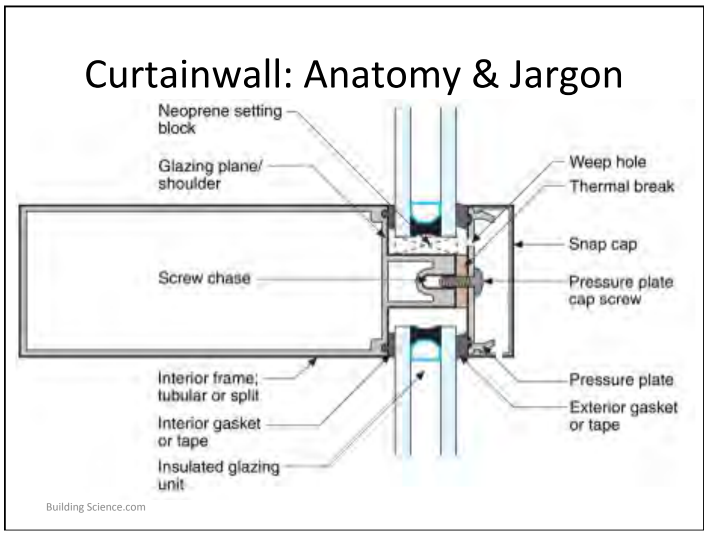
## Not "Perfect", But pretty darn good!

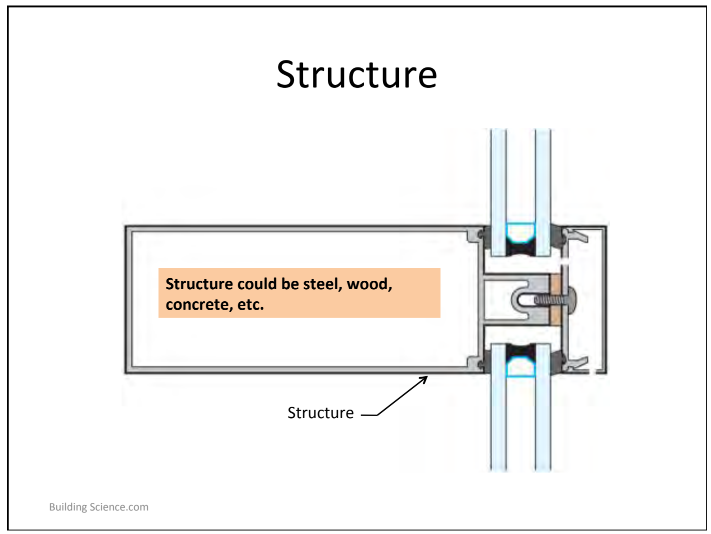


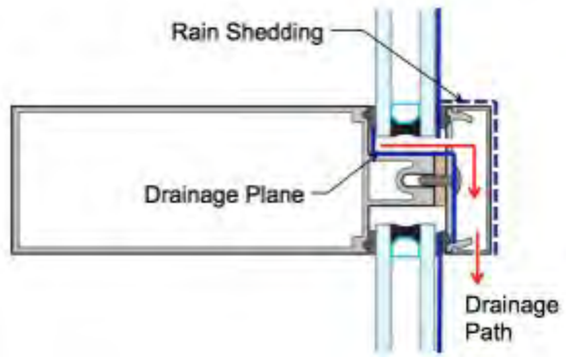

Mass walls changed to drained walls
Insulation as drainage plane if lapped properly; as an air barrier if joints sealed (taped or caulked)
Note: This detail is appropriate for warm or hot climates. In cold climates the slab edge needs to be thermally broken.
Polymer modified (PM) or standard Portland cement stucco with water repellent finish
Masonry wall
Seat in concrete slab
Weep screed
Concrete grade beam
Ground slopes away from wall at 5% (6 in. per 10 ft.)
Rigid insulation—expanded polystyrene, extruded polystyrene, polyisocyanurate, or spray polyurethane
Uninsulated steel stud
Gypsum board finish and fire control
Latex paint or other permeable or vapor semi-permeable interior finish
Sealant to provide air barrier continuity
Concrete slab
Granular capillary break and drainage pad (no fines)
Polyethylene vapor barrier extended under grade beam where it also acts as a capillary break
Concrete footing below frost depth

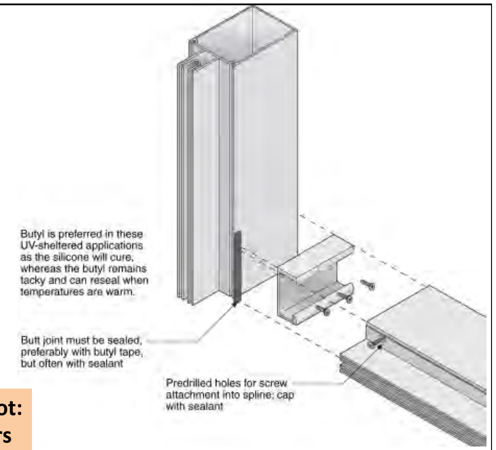

Precast panel (installed first)
Outer sealant on backer rod drained at vertical joints
Corrosion-resistant metal pin to connect panels without penetrating air and water layers
Inner sealant on backer rod continuous for water and air control continuity
Gypsum board
Steel stud
Note: Precast concrete is the water and air control layer
Cast in place anchor
Line of outer sealant at panel joints
Line of inner sealant at panel joints
Structural columns and walls should be held back from slab edge to allow for installation of air and thermal control layers


Curtainwall: Anatomy & Jargon
Neoprene setting block
Glazing plane/ shoulder
Weep hole
Thermal break
Snap cap
Screw chase
Pressure plate cap screw
Interior frame; tubular or split
Pressure plate
Exterior gasket or tape
Interior gasket or tape
Insulated glazing unit
Building Science.com


Structure
Structure could be steel, wood, concrete, etc.
Structure
Building Science.com

## Rain Control




**Corners are weak spot:**
**•How to drain corners**
**•How to airseal?**

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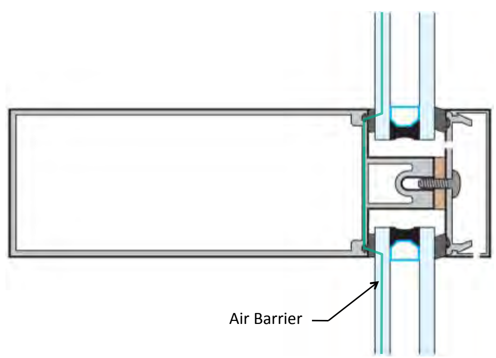
## Air Flow Control

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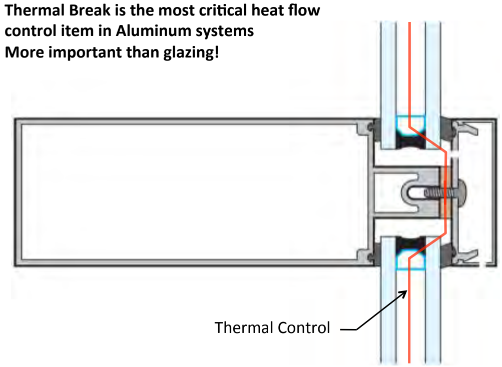
## Thermal Control

**Thermal Break is the most critical heat flow control item in Aluminum systems**
**More important than glazing!**

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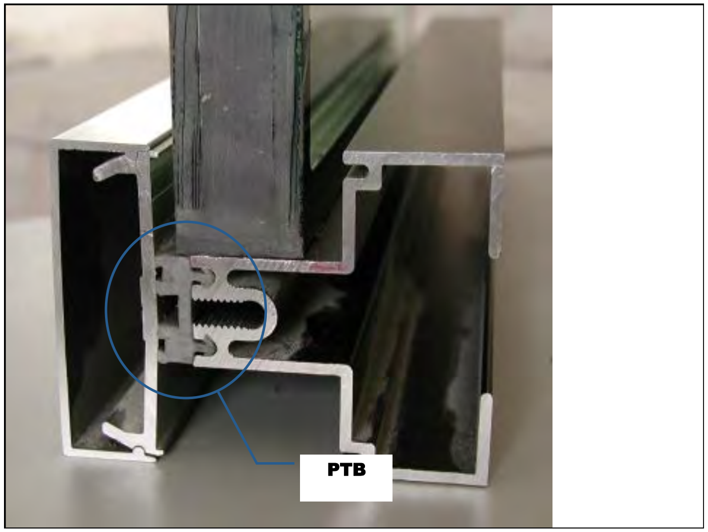


## Conclusions

- Continuous drainage and rain control layer
- Continuous air control layer (air barrier)
- Continous thermal control layer
  - Limit the thermal bridges