



University of
Waterloo



High Performance Enclosures

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Enclosures in Context

- Enclosures **reduce** space heating/cooling
– and help with lighting, ventilation
- We still need **energy** for other things
– Lights, appliances, computers, elevators, etc
- Still need to provide some **HVAC!**
- Hence, good mechanicals and renewables will *also* be needed for net zero
- Great enclosures reduce demand & hrs of operation

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Top Ten List

Commercial and institutional mid-size buildings, Canadian 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** (shade is more important in hot climates)
- 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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Design Principles

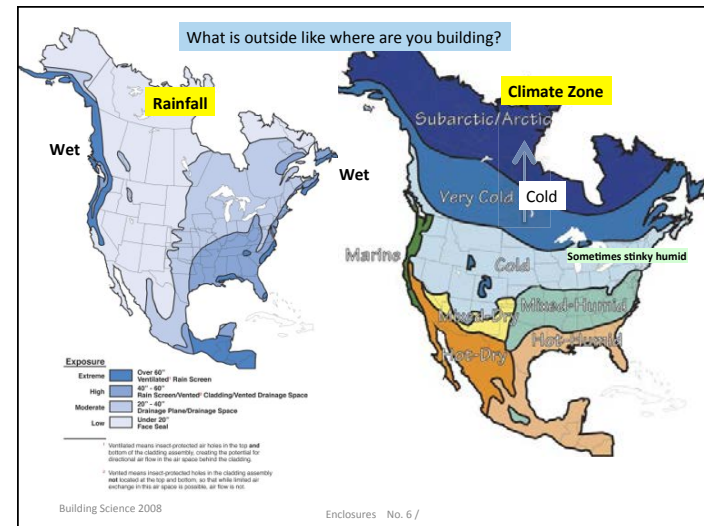


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Buildings: Why do we Build?

- To keep the wind, sun, rain, snow, heat, cold, dust, bugs, animals, and nasty people outside.
- But we let in some things
 - Nice people, pets, sunshine, daylight, clean air, clean water, supplies
- And let some things out
 - Views, polluted water and air

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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.)

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Enclosures No. 7 /

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

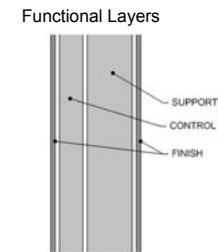
Enclosure Intro Summary

- Enclosure often defines the H/C load
 - Architecture defines massing, orientation, enclosure
- Enclosure **more critical** for skin-dominated
 - Heat flow, Solar control, air tightness
- Lighting, ventilation critical for deep plan

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Basic Functions of the Enclosure

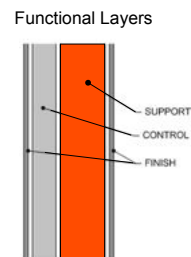
- 1. Support
 - Resist and transfer physical forces from inside and out
- 2. Control
 - Control mass and energy flows
- 3. Finish
 - Interior and exterior surfaces for people
- Distribution – a building function



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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

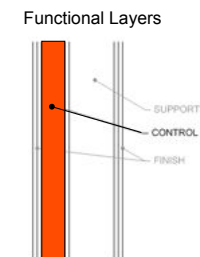


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Enclosures No. 11 /

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

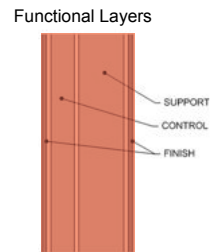


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Enclosures No. 12 /

Other Control . . .

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

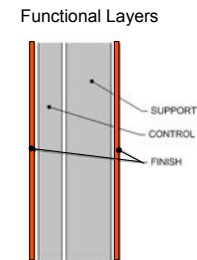


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Enclosures No. 13 /

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



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History of Control Functions

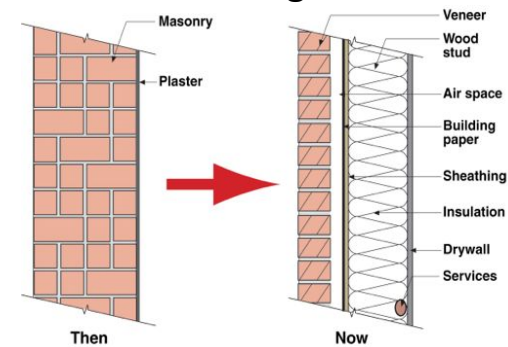
- Older Buildings
 - One layer does everything
- Newer Building
 - Separate layers, . . . separate functions



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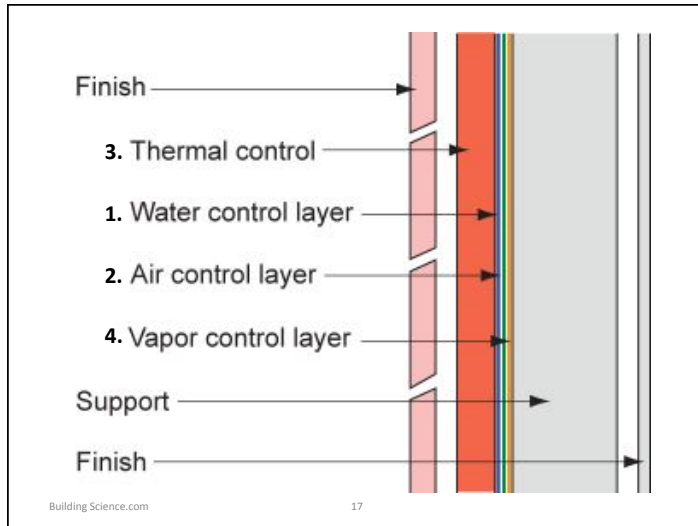
No. 15

Changes



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16



The "Perfect Wall"

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

Fire Control may be needed
Sound Control optional

Cladding

Control layers

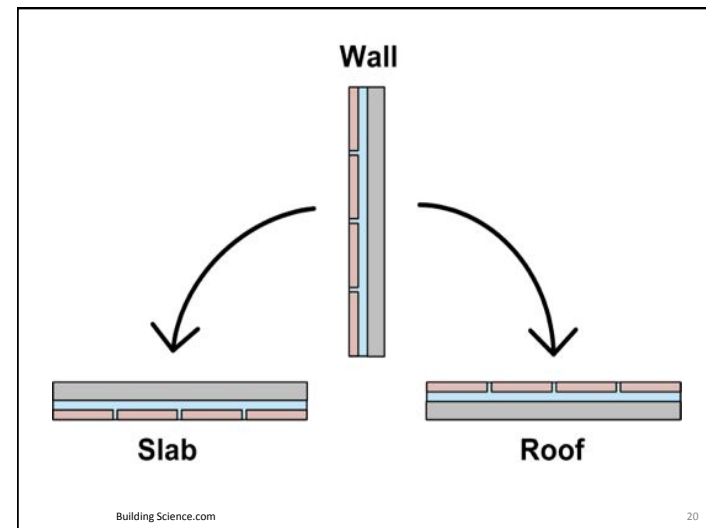
Structure

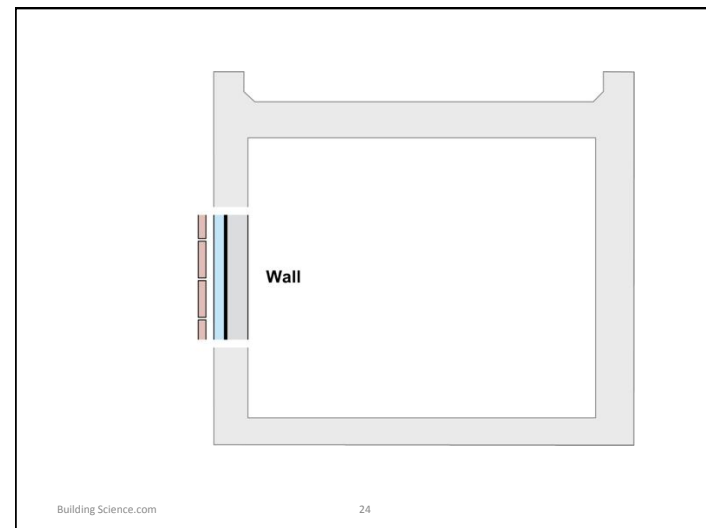
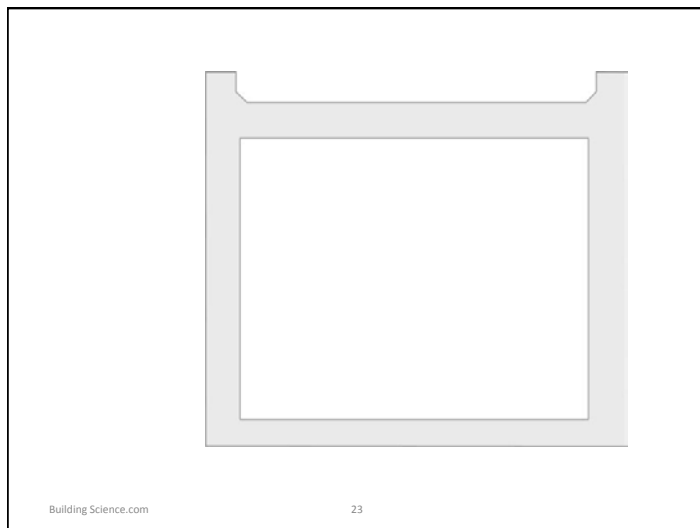
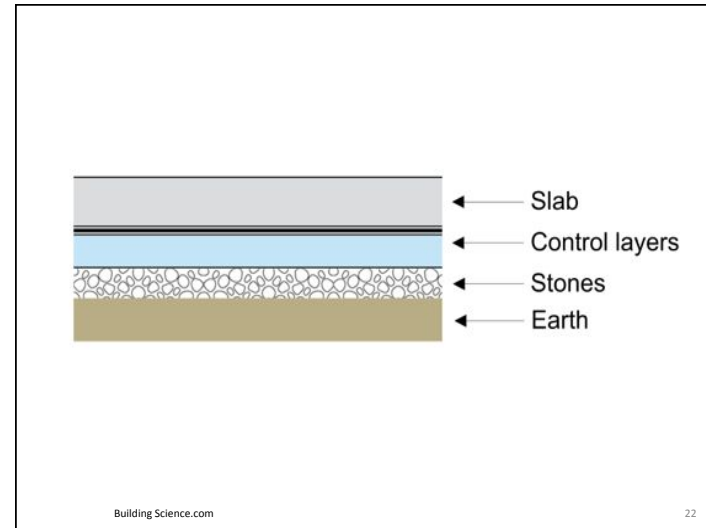
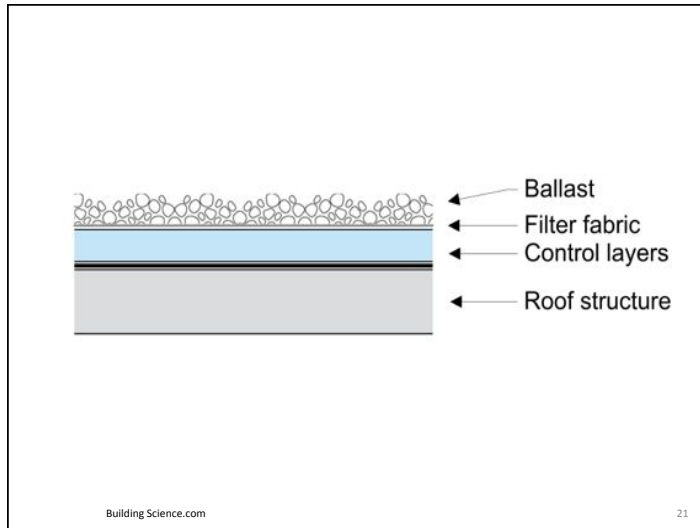
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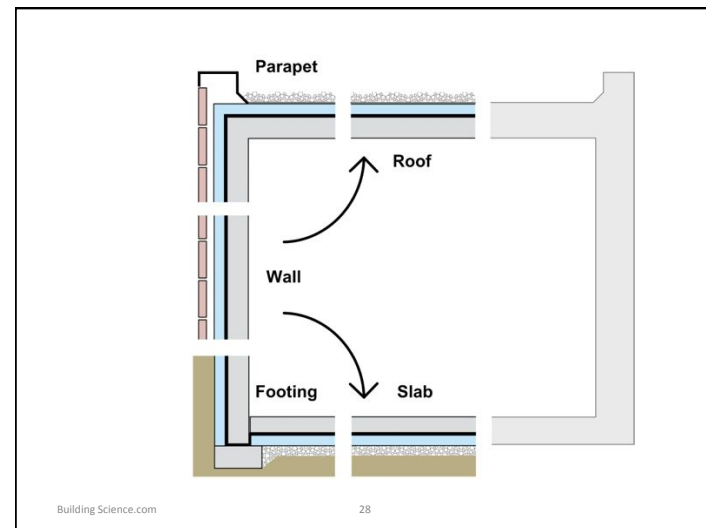
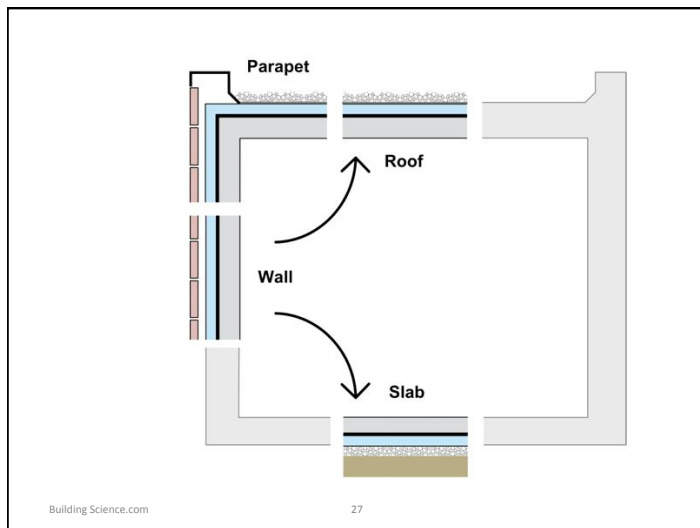
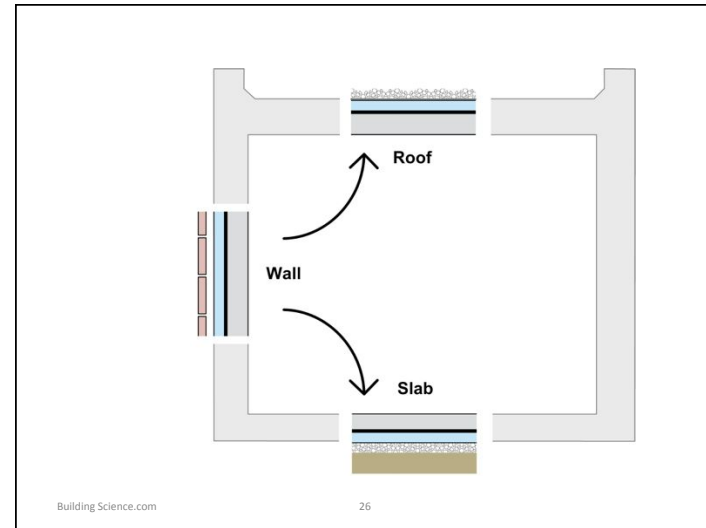
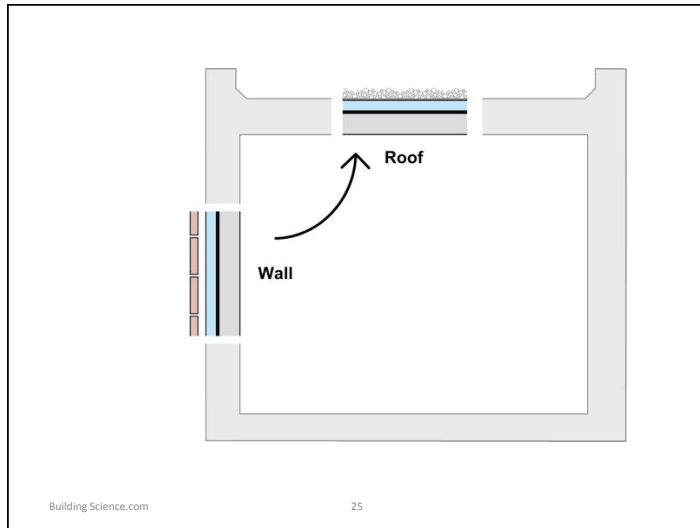
What is a high performance enclosure?

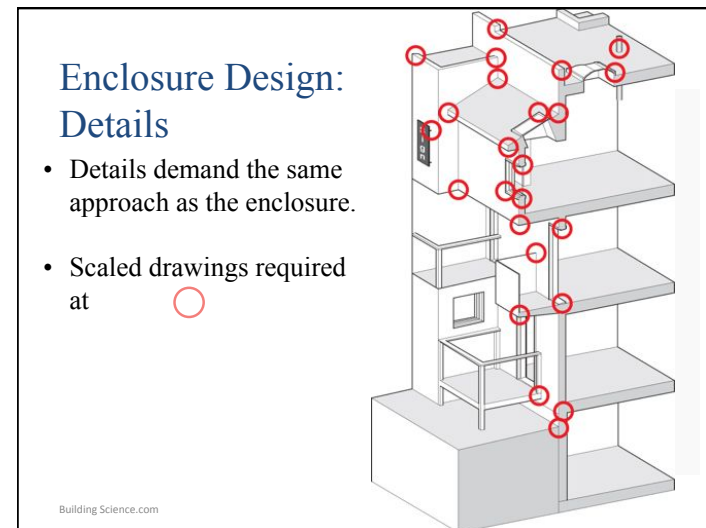
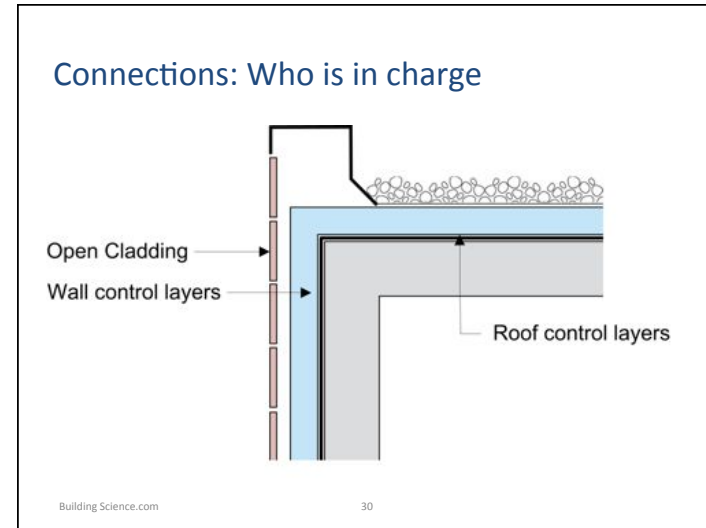
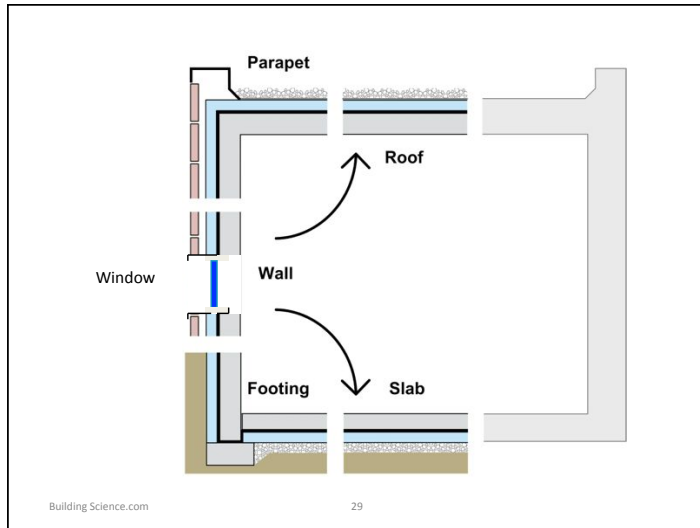
- One which provides high levels of control
- Poor continuity limits performance
- Poor continuity causes most problems too:
 - E.g. air leakage condensation
 - Rain leakage
 - Surface condensation
 - Cold windows
- This course: continuity + high levels

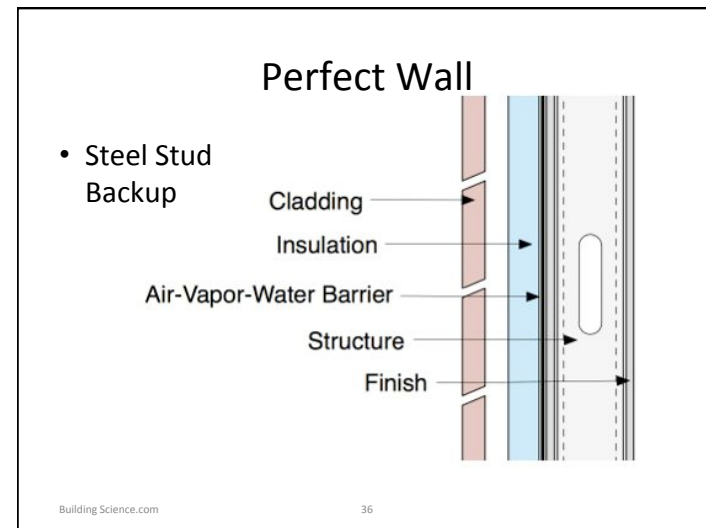
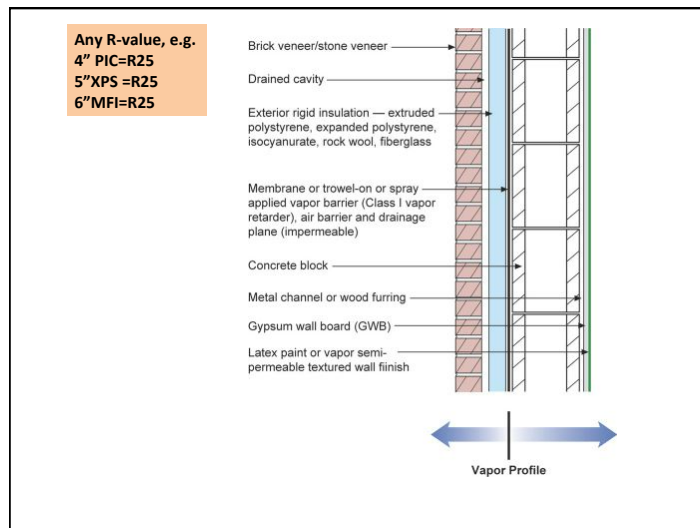
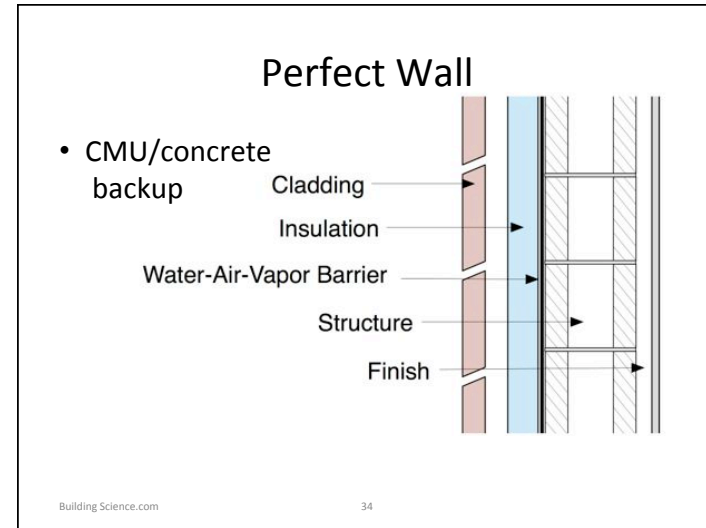
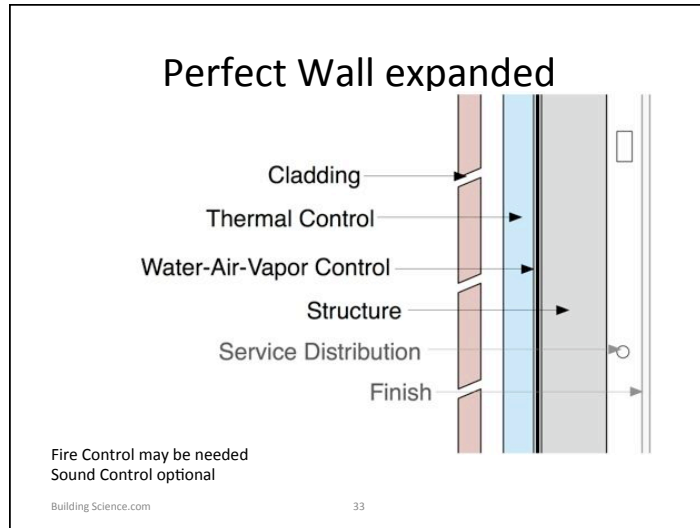
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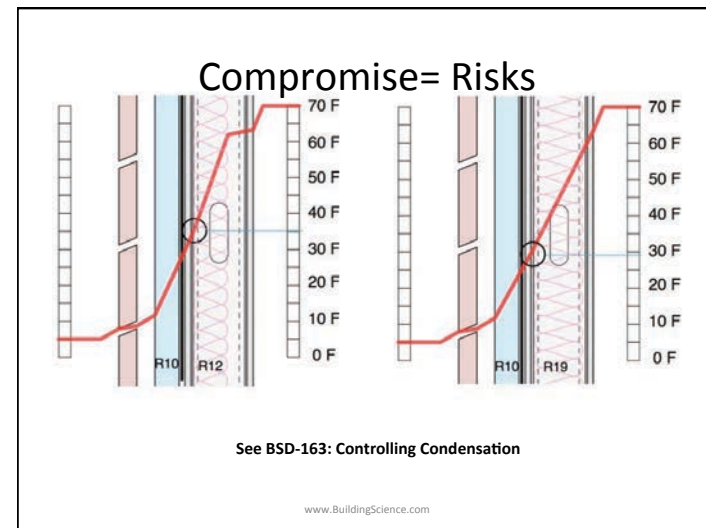
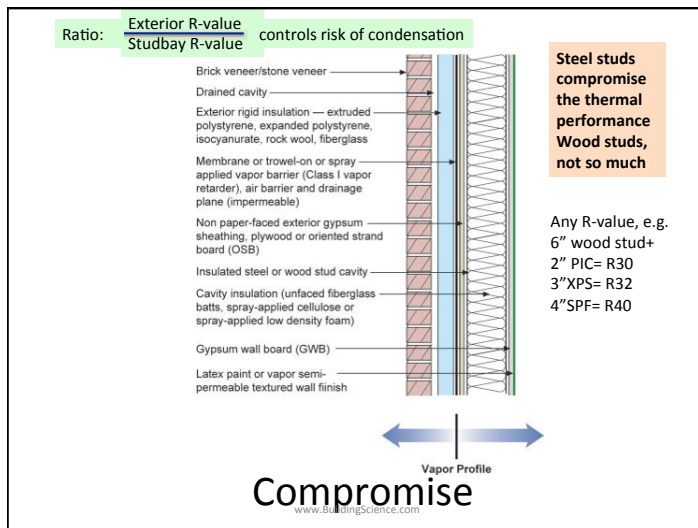
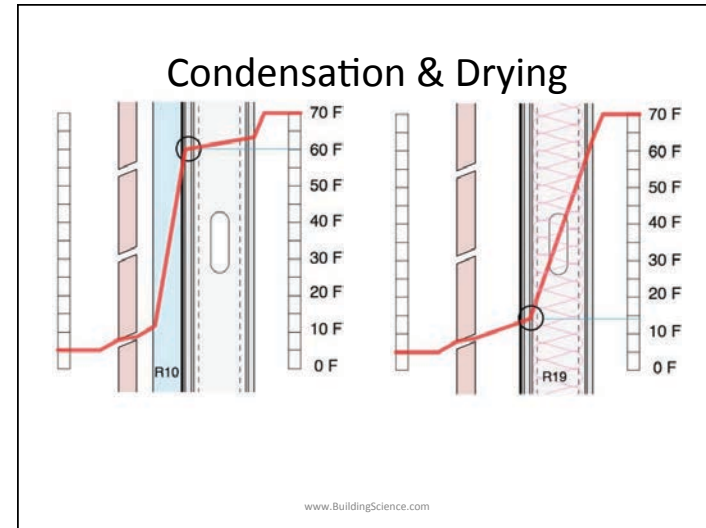
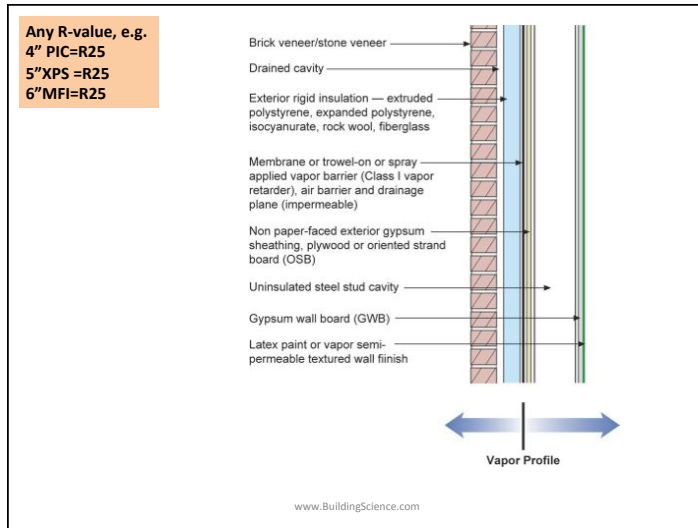


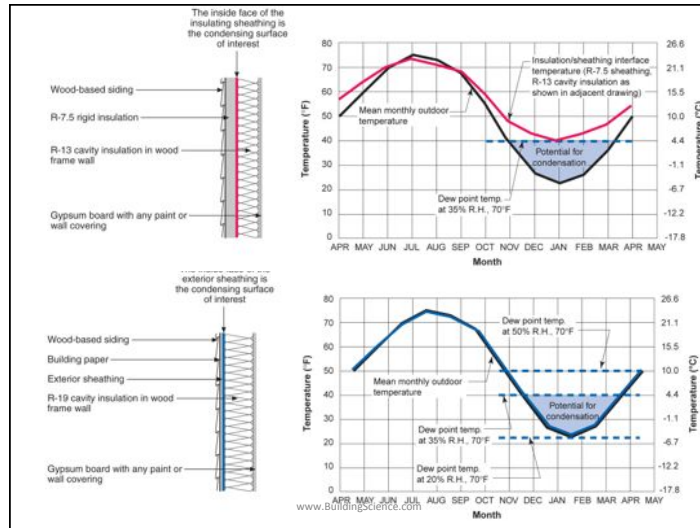












Specifics

- Now we will look at
 - Rain Control
 - Air Flow Control
 - Thermal Control
 - In some detail
- } Energy & Comfort } Durability, Health

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Rain Control

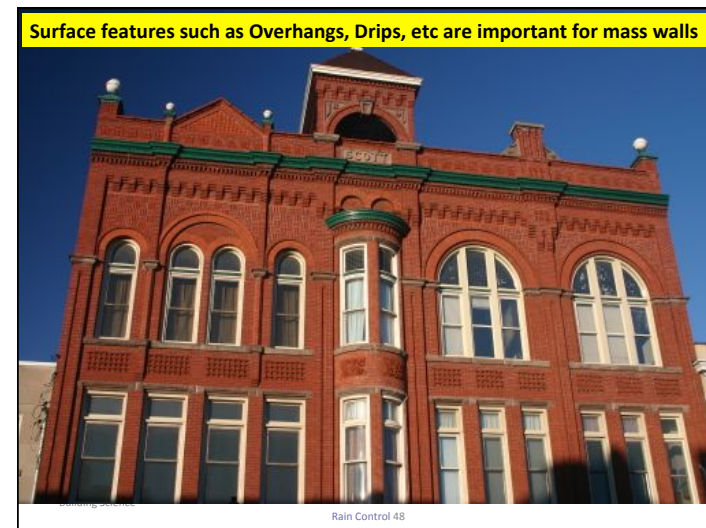
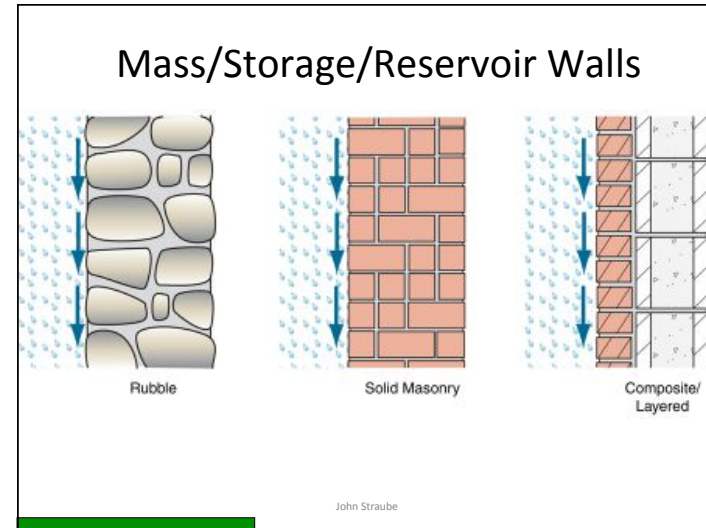
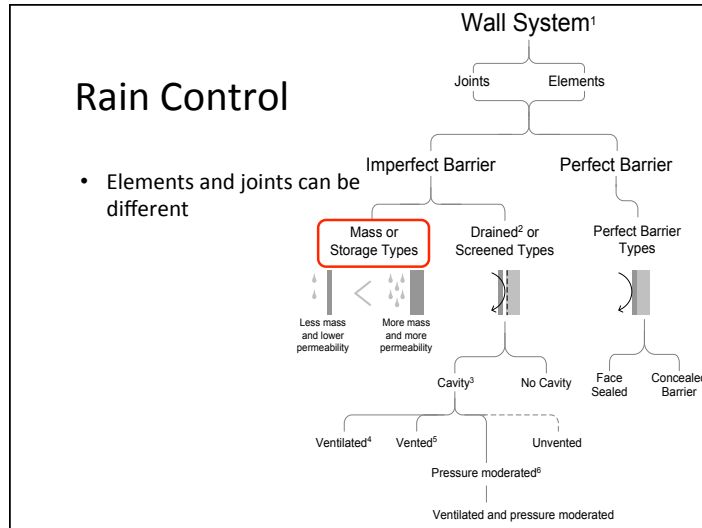


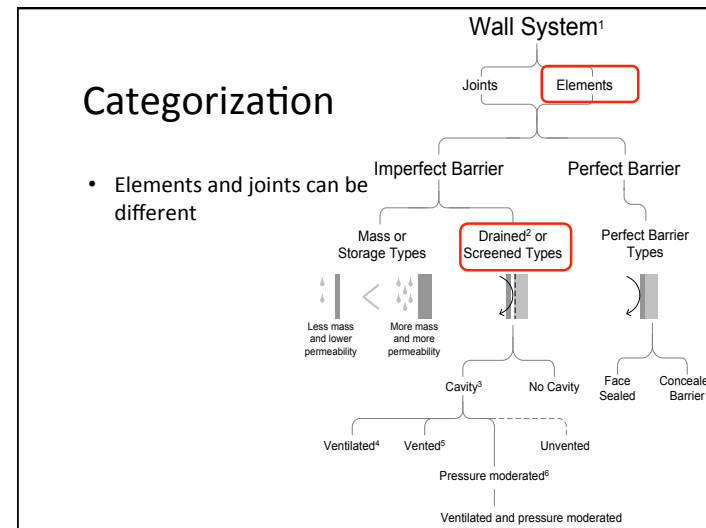
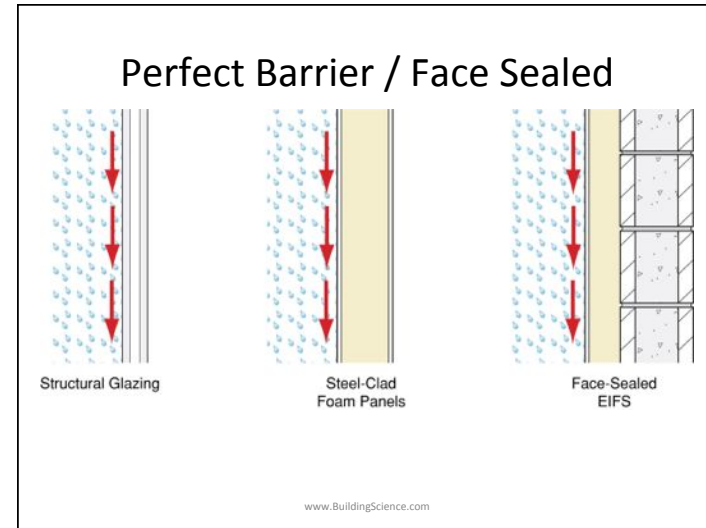
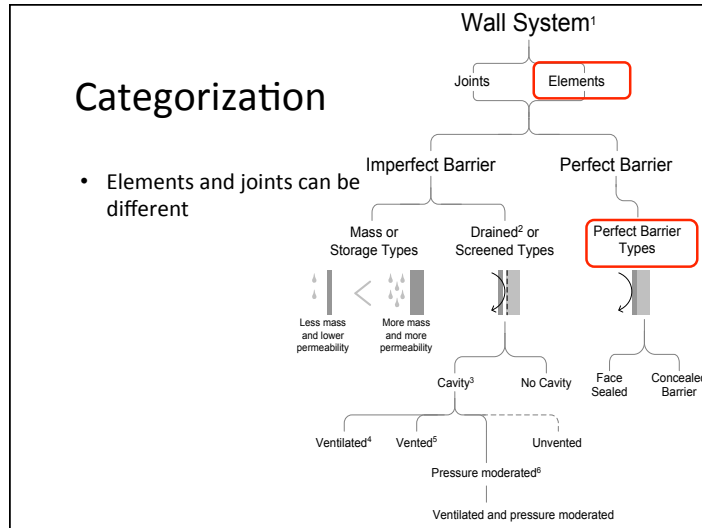
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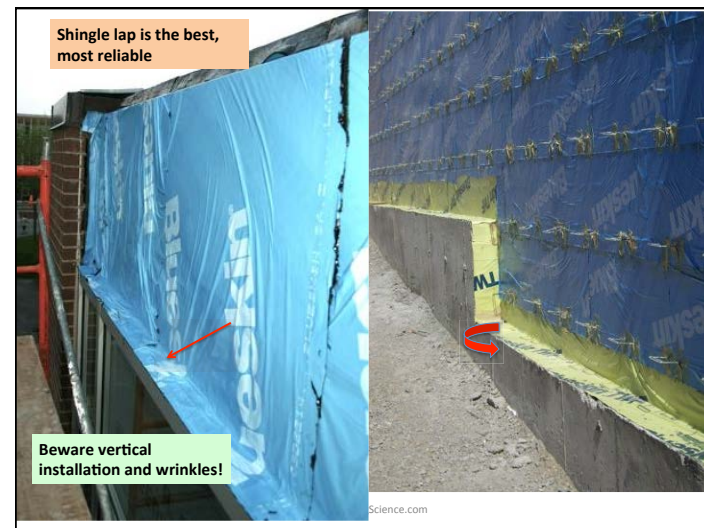
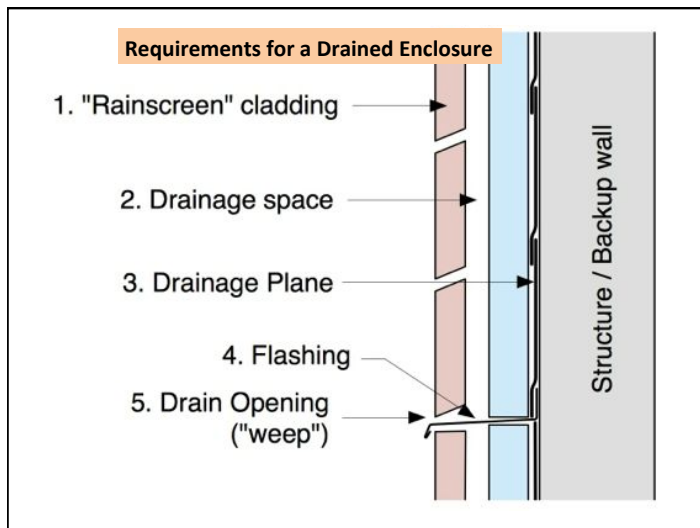
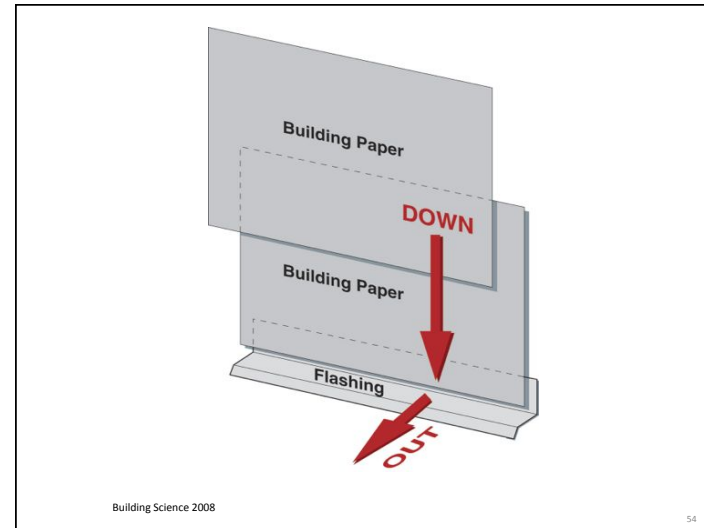
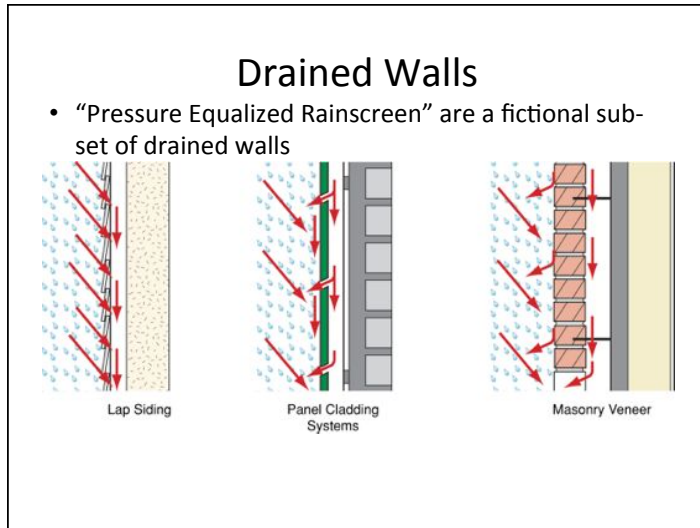
Rain Control

- Next to structure, the most important, fundamental requirement
- Source of many serious building problems
- Major impact on durability
- Low-energy buildings & rain
 - Different enclosure assemblies
 - Reduced drying ability

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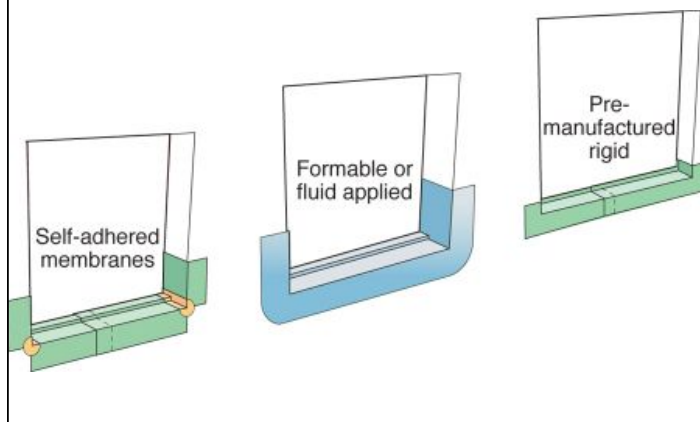


Leaky windows

- Studs and sheathing are sensitive to leaks



Window flashing is key



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

Beware vapor barriers outside insulation

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Fluid-applied products avoids laps

Details

- Air & water & vapor transition membranes



building-science.com Airflow control No. 63/79



Non-adhered, vapor permeable =modest performance

Supported flexible membrane is better



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Mixed membrane + liquid

Often use membranes for transitions

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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



Continuity is key!

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

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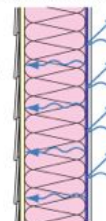
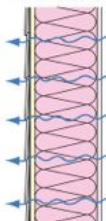
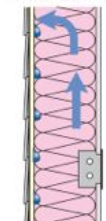


Air Barrier Systems

- Need an excellent air barrier in all buildings
 - Comfort & health
 - Moisture / condensation
 - Energy
 - Sound, fire, etc.
- Cant make it too tight.
- Multiple air barriers improve redundancy

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Air moves more vapor than diffusion!

<p>Wall 1</p> <ul style="list-style-type: none"> • Vapor diffusion only • Class II vapor control  <p style="font-size: small;">48 grams / month = 3 tablespoons</p>	<p>Wall 2</p> <ul style="list-style-type: none"> • Vapor diffusion only • Class III vapor control  <p style="font-size: small;">538 grams / month = 2.4 cups</p>	<p>Wall 3</p> <ul style="list-style-type: none"> • Air leakage only • Class I vapor control  <p style="font-size: small;">22,200 grams / month = 98 cups</p>
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Exterior
T = 0°F / -18°C
RH = 80%

Interior
T = 70°F / 21°C
RH = 35%

1 in² opening
10 Pa pressure

Diffusion is rarely a big deal
Air leakage almost always is!

Calculations for a single stud bay, 8 ft tall, 16" wide
www.BuildingScience.com

Air leakage

- Hard to save energy with the door open
- Buildings getting tighter, but . . .
 - Many still leak way too much
 - We can't identify the leakers
 - Need to test! Commission!
- Ventilation: Many try to improve air quality by increasing quantity
 - Target good air when and where needed

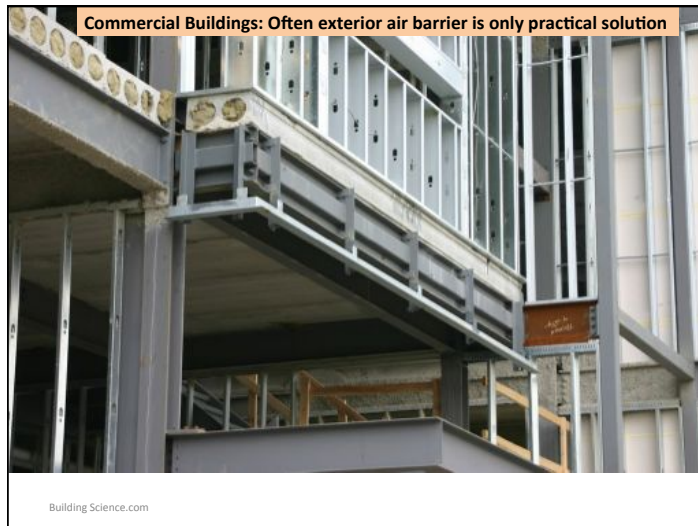
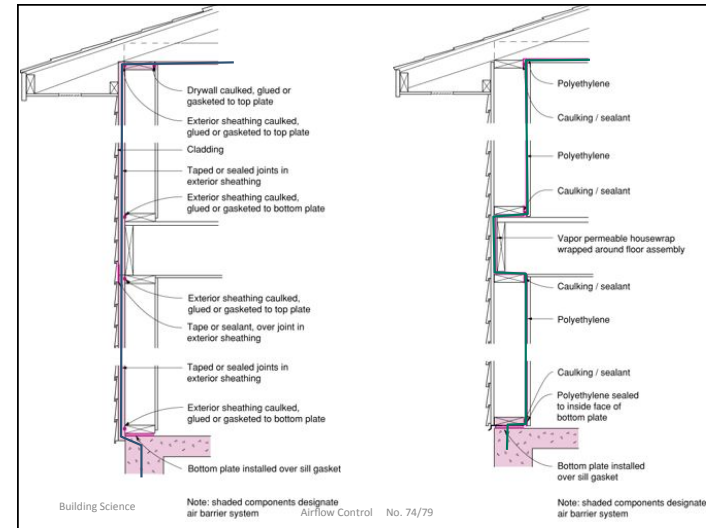
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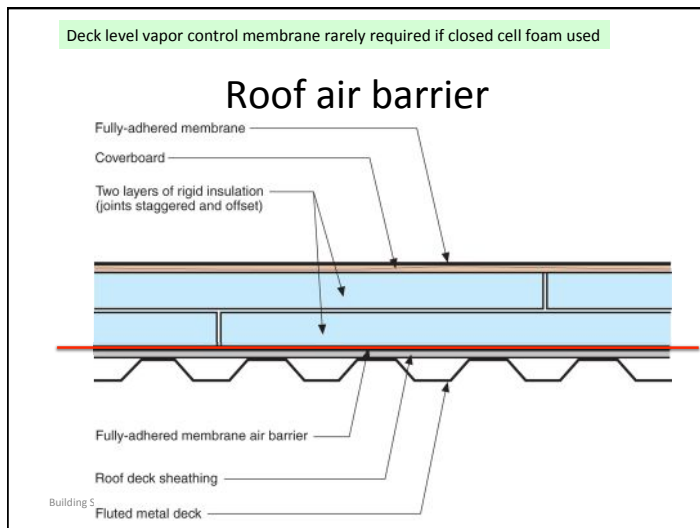
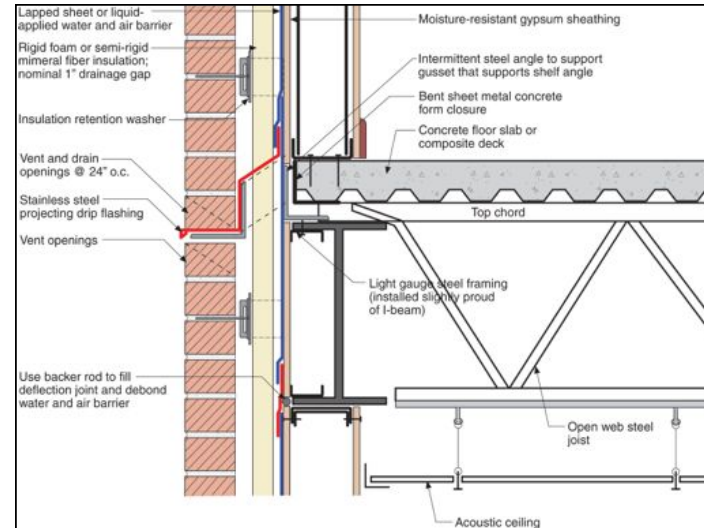
Air Barriers and Energy

- Requirements
 - **Continuous (most important)**
 - **Strong**
 - **Stiff,**
 - **Durable,**
 - **Air Impermeable (least important)**
- Easily 1/3 of total heat loss is due to air leakage in well-insulated building

73/175

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Thermal Control

- Insulation
 - Slows heat flow in and out
- Windows
 - Slow heat flow in and out
 - Control solar gain : allow or reject?
- “cool” roofs
 - Reduce solar gain
- Radiant barriers



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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/m ² K
Empty airspace 3.5"-5.5" (90-140 mm)	R2.75	0.50 W/m ² K
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)	20-35	0.004-0.008

How much Insulation

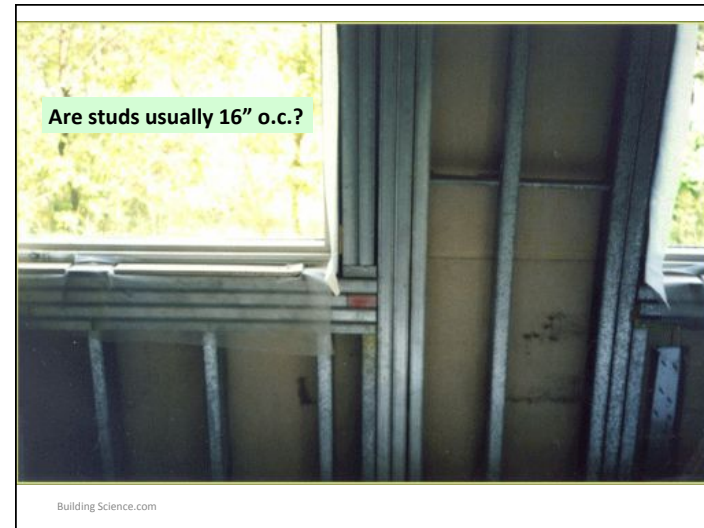
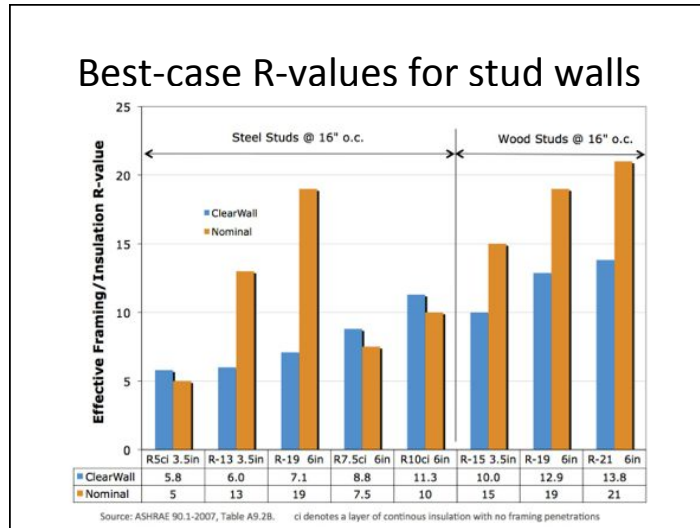
- Heat Flow = $\frac{\text{Area} * (T_{\text{inside}} - T_{\text{outside}})}{\text{R-value}}$
- Double R-value, halve heat flow. Always.
- Optimum depends on
 - Cost of energy over life of building
 - Cost of adding more insulation
 - Savings in mechanical equipment, controls

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Thermal Continuity

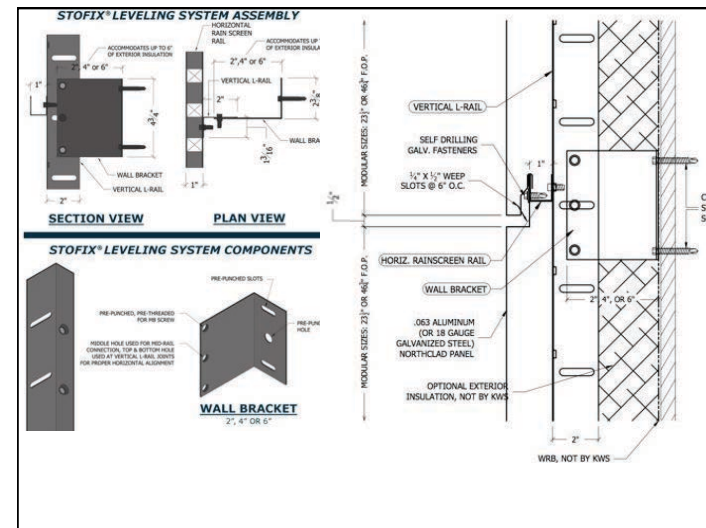
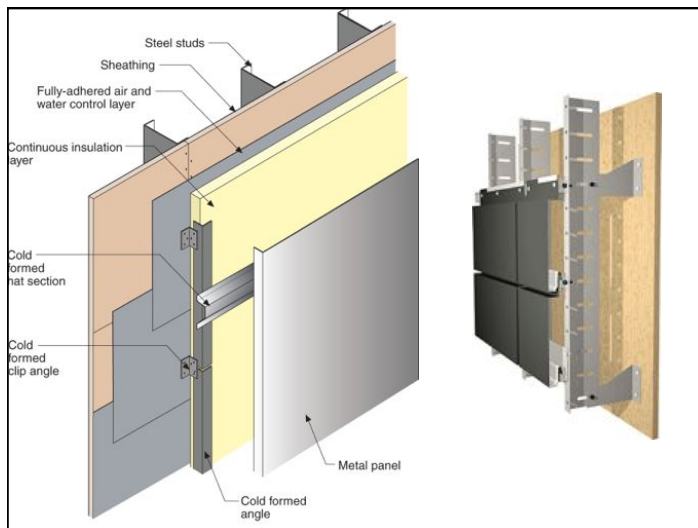
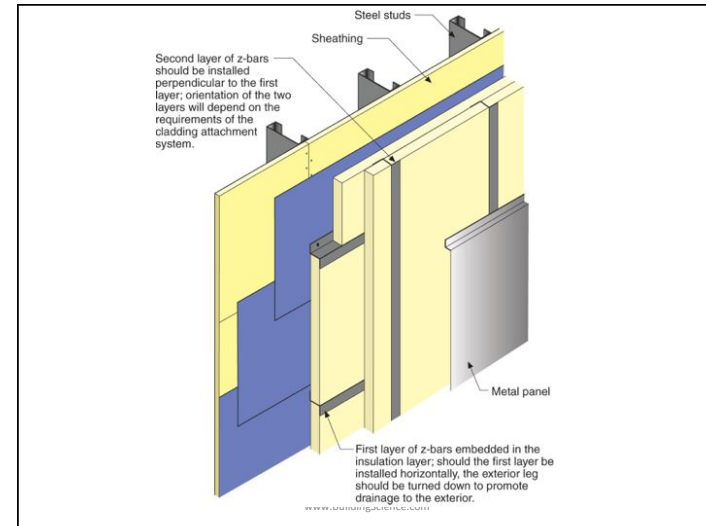
- Some short circuiting is normally tolerated.
- High-performance walls tolerate few
- Major offenders / weak spots
 - Penetrating slabs (<R1)
 - Steel studs (<R1)
 - Windows (R2-R3)
- Area and low R matter to overall significance

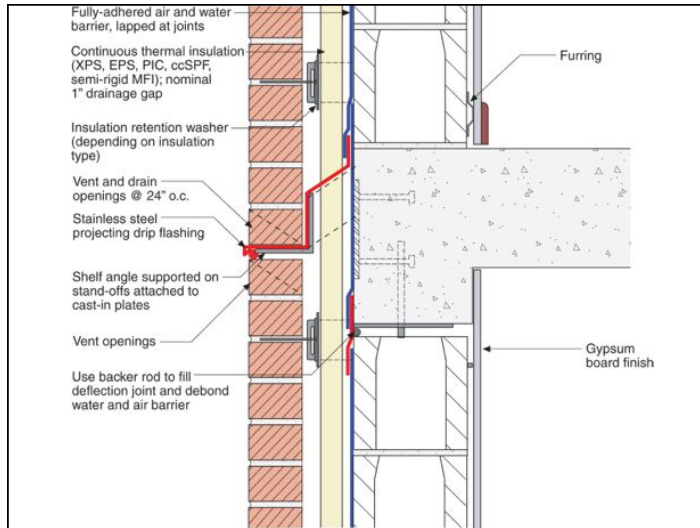
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Thermal Bridge Examples

- Balconies, etc
- Exposed slab edges

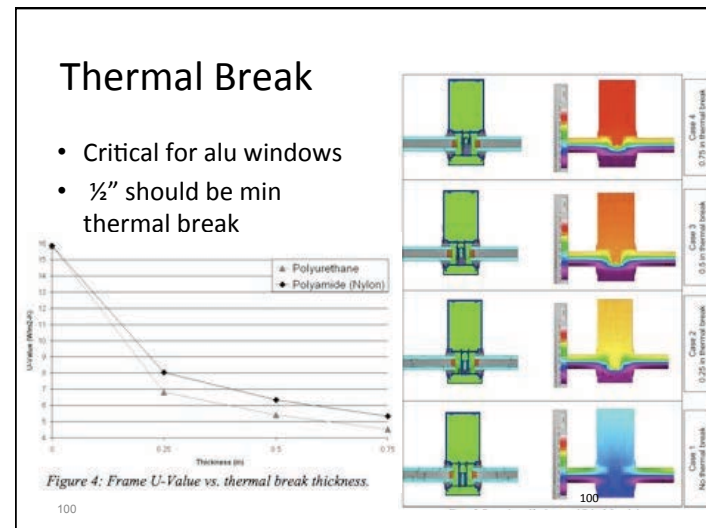
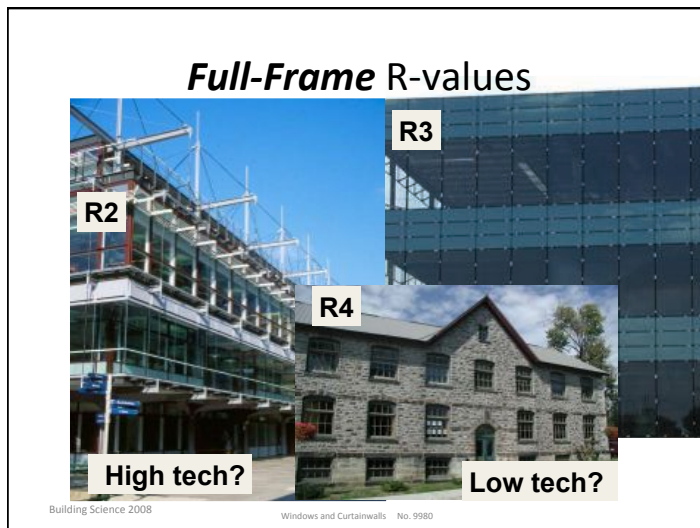
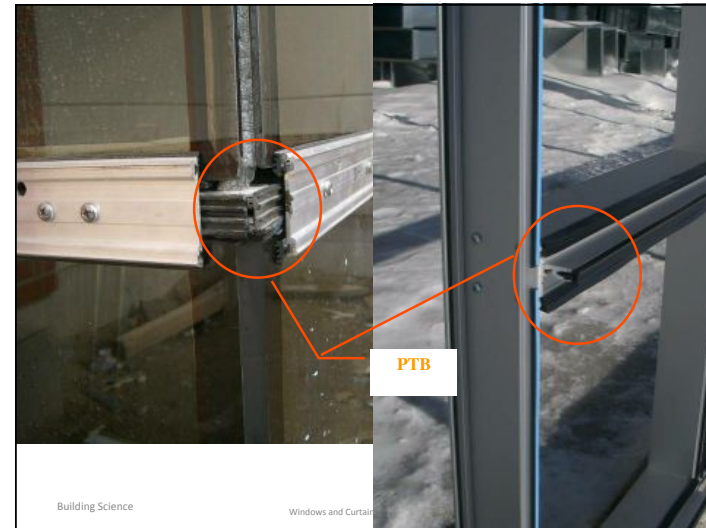
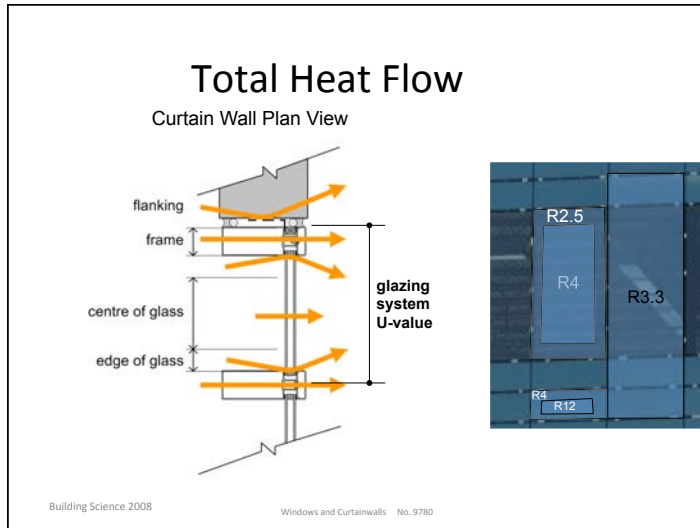


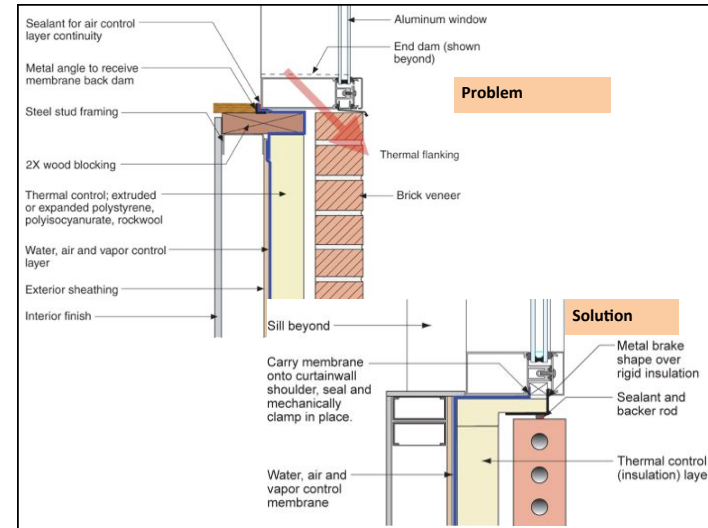
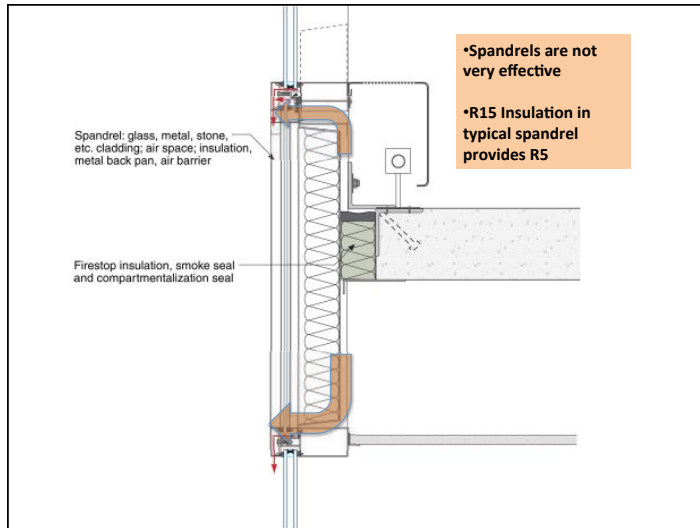


Windows

- Our most expensive thermal bridges
- Aluminum is 4-5 times as conductive as insulation
- Difficult to buy commercial aluminum windows / curtainwall over R3.
- Allow solar heat in
 - Useful in cold weather
 - Requires cooling in summer

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High Performance

Getting better . .

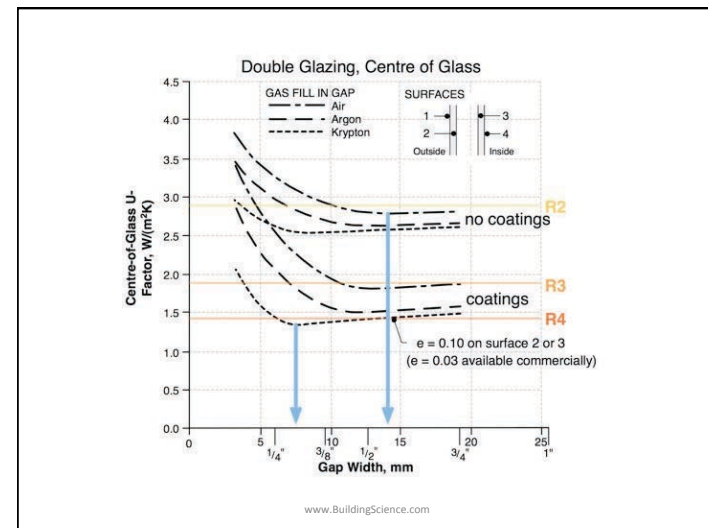
R10
Southwall

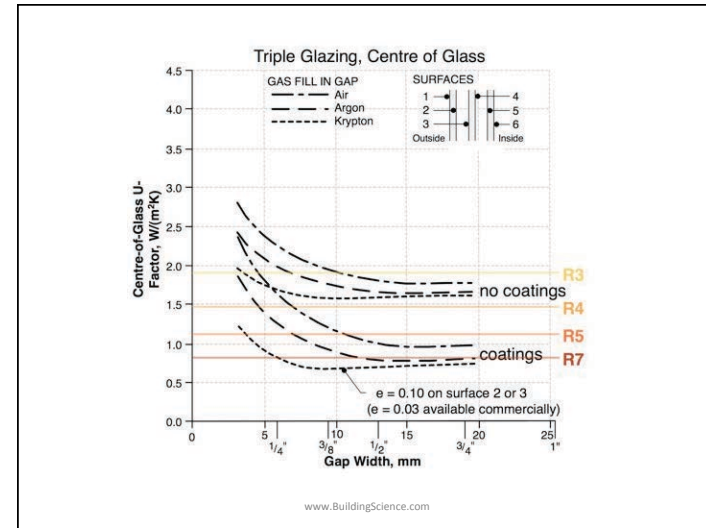
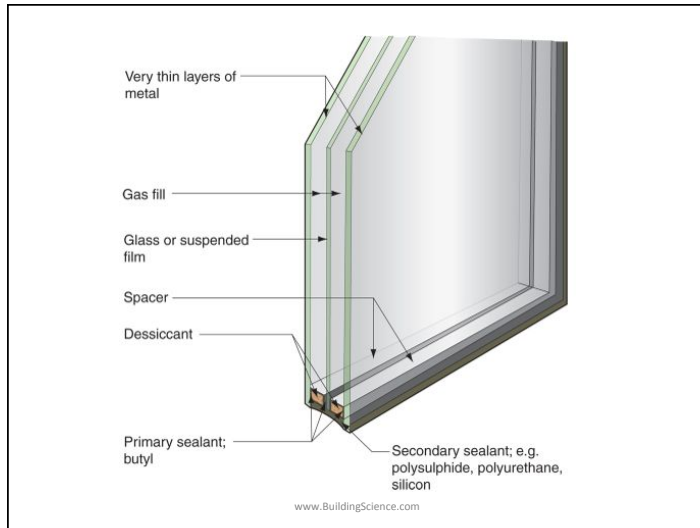
R7
Kawneer

R6
Visionwall

R24

Building Science 2008 Windows and Curtainwalls No. 10380





Industry Leading Performance	Center of Glass (COG) Performance*				AlpenGlass+™	
	U-Value	R-Value	SHGC	VT	Glazing	Fill
	0.05	20.00	0.29	0.44	Dual Pane, Triple Low Solar Heat Coefficient Film	Xenon
Premium Performance	0.07	14.29	0.24	0.43	Dual Pane, Dual Low Solar Heat Coefficient Film	Krypton
	0.11	9.09	0.51	0.65	Dual Pane, Dual High Solar Heat Coefficient Film	Krypton
High Performance	0.11	9.09	0.30	0.55	Dual Pane, Single Low Solar Heat Coefficient Film	Krypton
	0.19	5.26	0.60	0.73	Dual Pane, Single High Solar Heat Coefficient Film	Krypton

*The average numbers are center-of-glass values based on 100% Windows & 0% shutters

Courtesy of ThermaProof Windows and AlpenGlass+



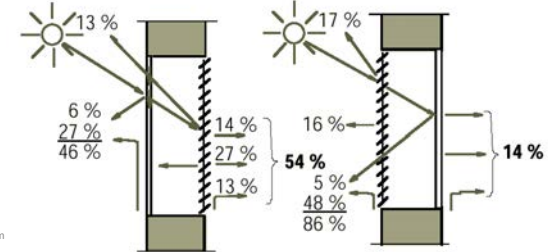
Solar Gain

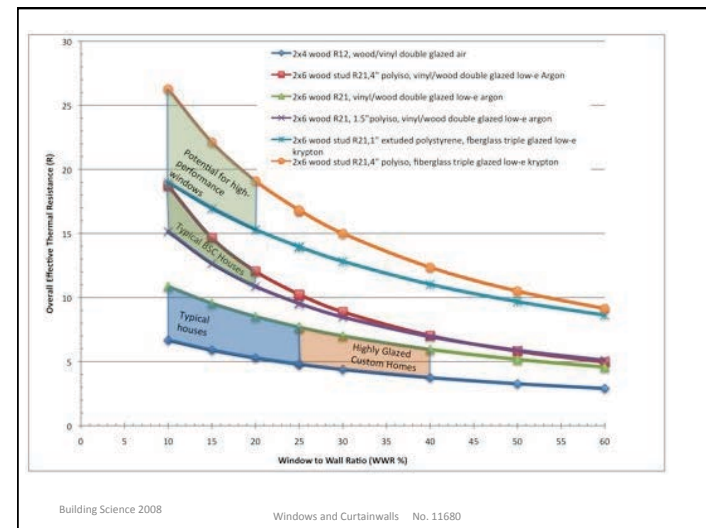
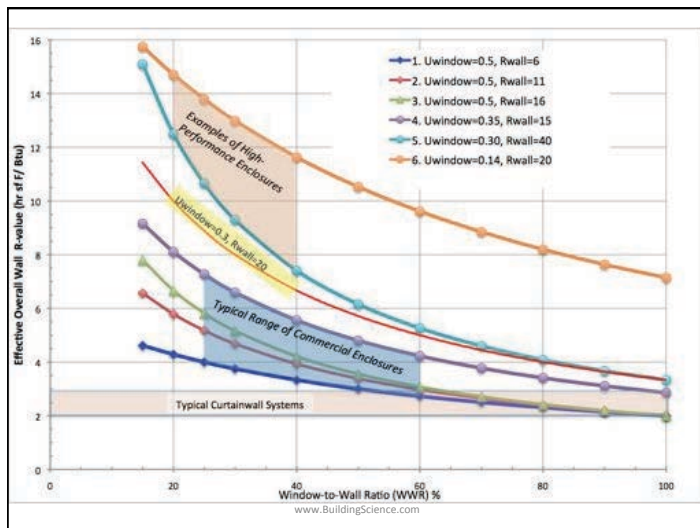
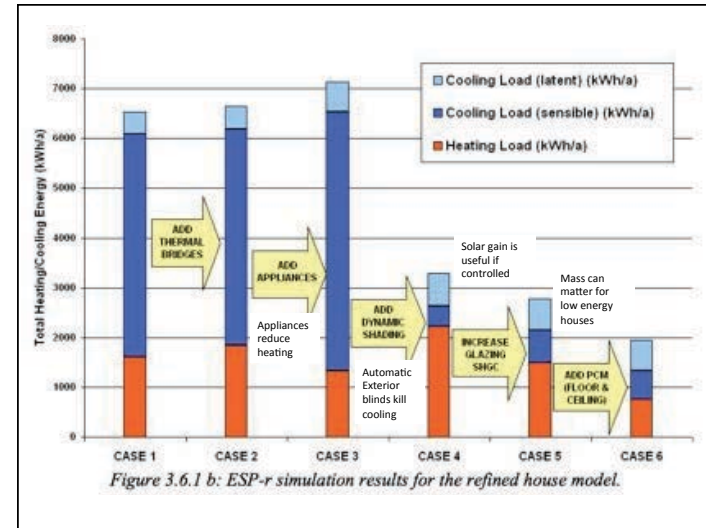
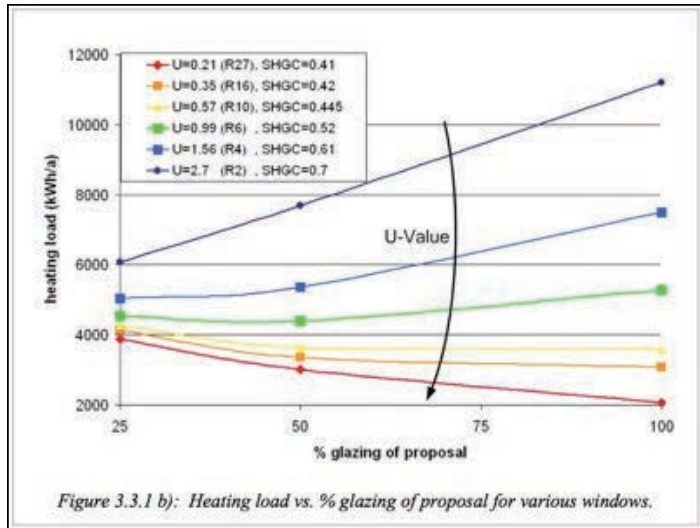
- Measured by SHGC
- Solar gain useful during cold sunny weather
- But least heating is needed during daytime for commercial buildings
- Overheating discomfort is a real risk
- Must size glass Area x SHGC carefully
 - High values = air conditioning and discomfort

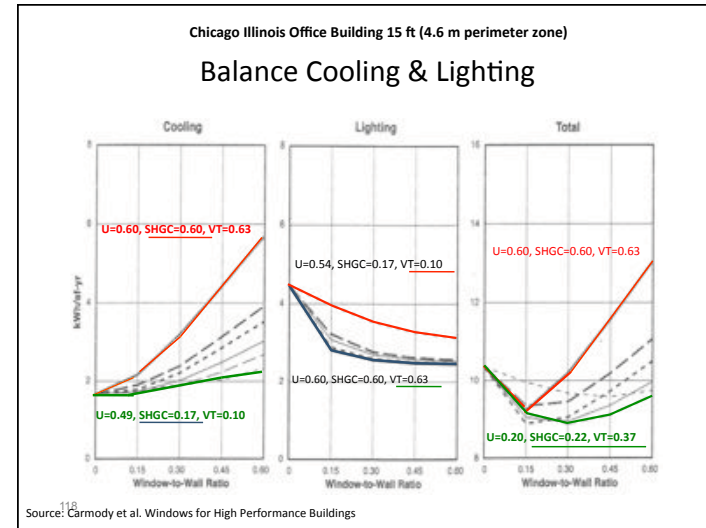
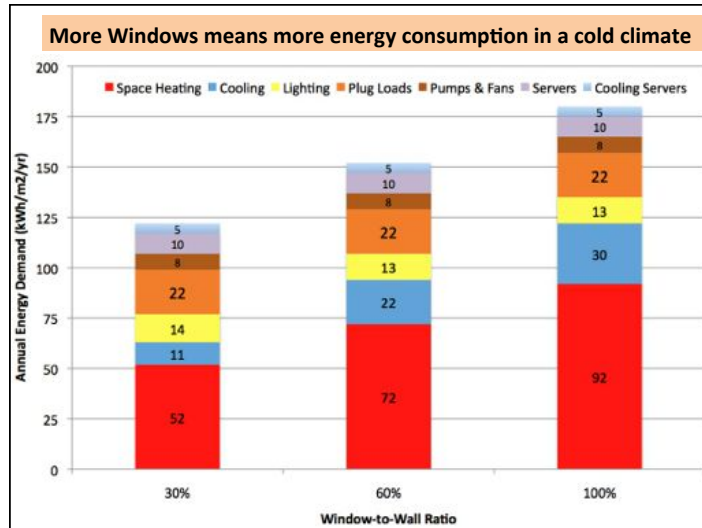
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Interior or Exterior Shade

- Operable Solar Control of windows may be necessary for ultra-low energy buildings
- Exterior Shades always beat low SHGC glazing
 - But the cost capital and maintenance
- Interior shades don't work well with good windows

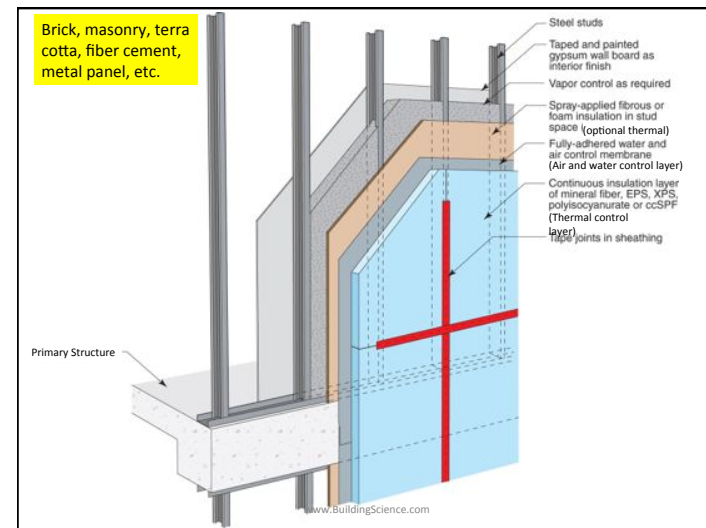


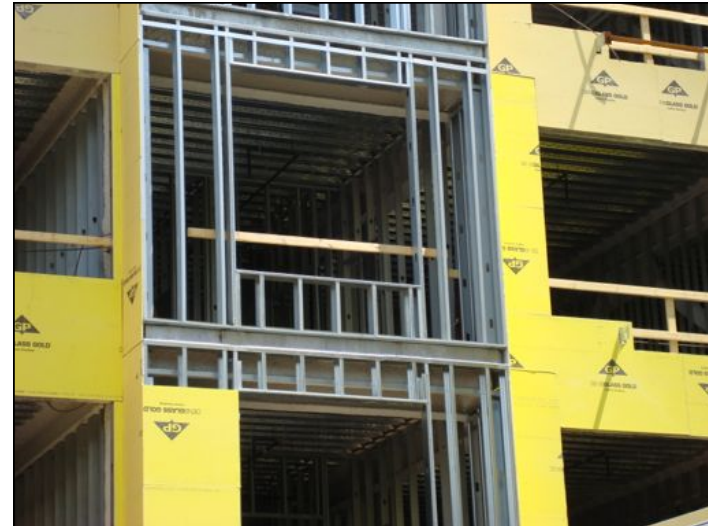


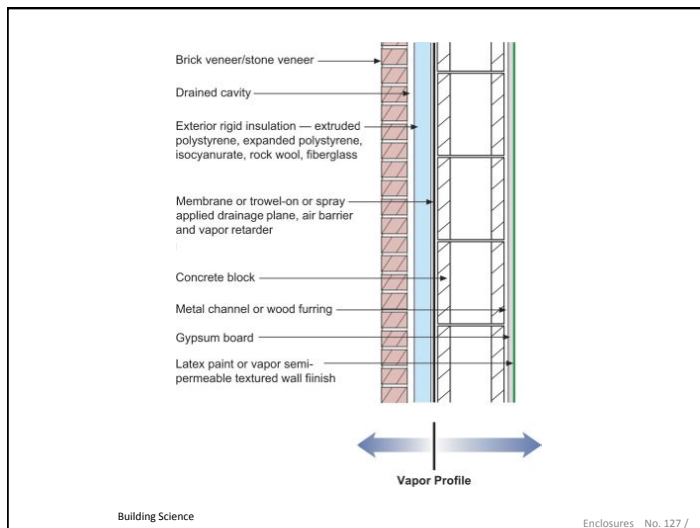
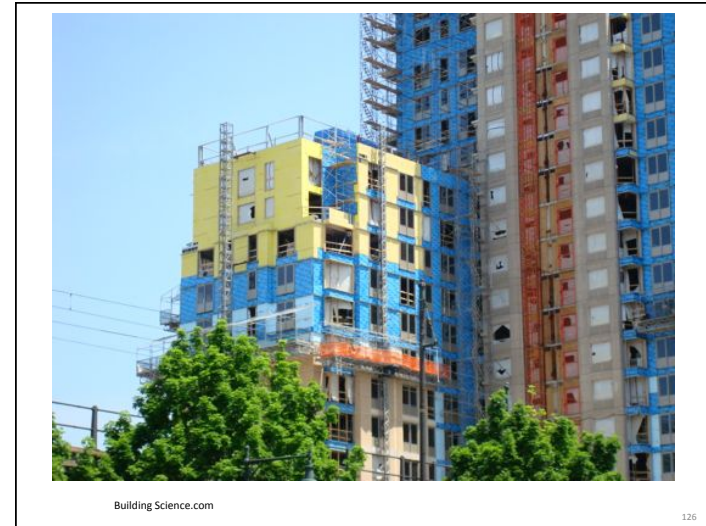


Enclosure Systems

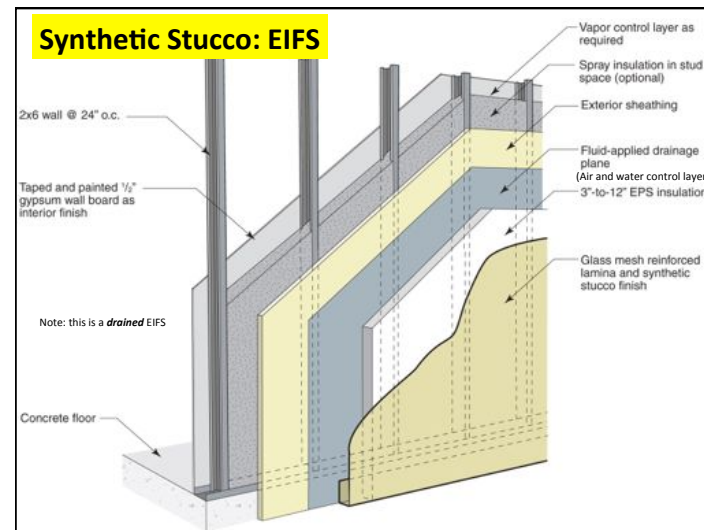
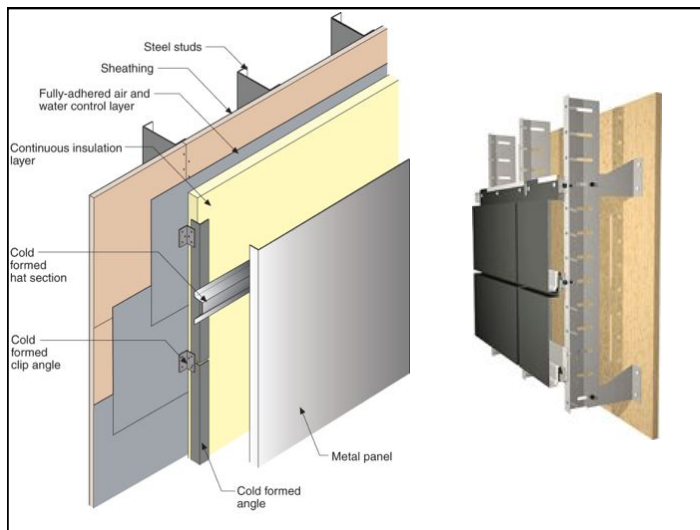
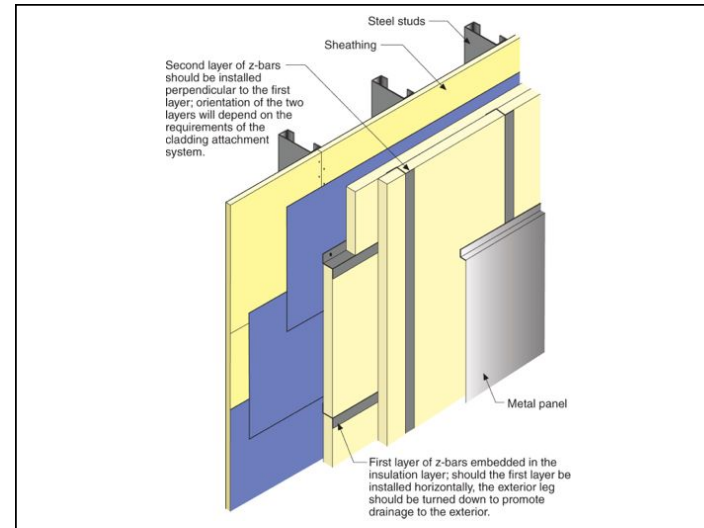
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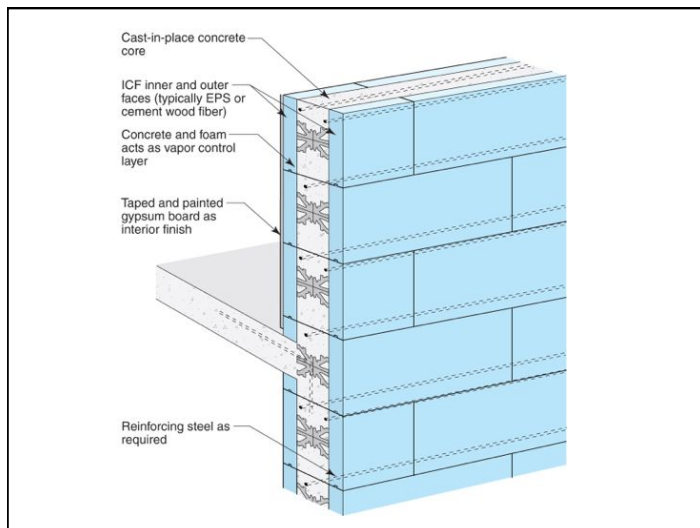
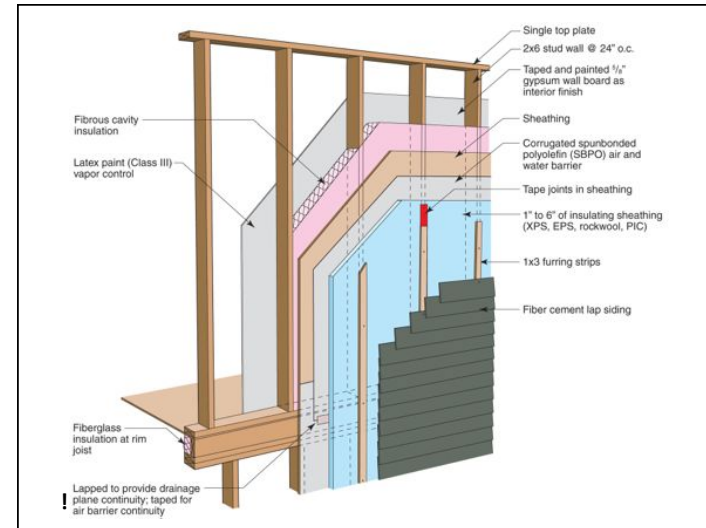
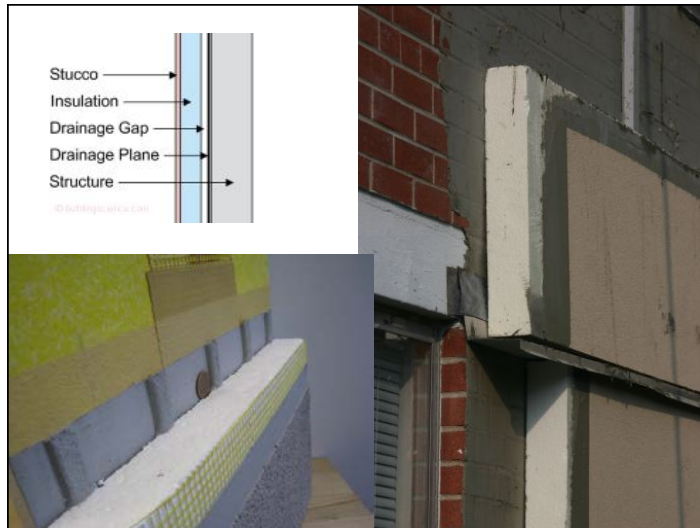












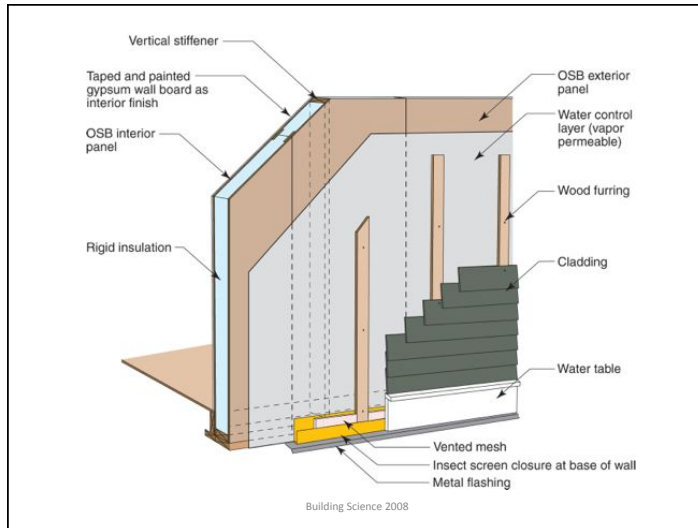
Insulated Concrete Form

- Excellent thermal control
- Concrete acts as air barrier
- Rain Control! Drain all penetrations
- No vapor barrier needed

Typical ICF Floor Wall
Typical ICF Core Wall
Typical ICF Floor and Beam Wall

Building Science Insulation

The block contains a list of benefits for Insulated Concrete Form (ICF) walls: excellent thermal control, concrete acting as an air barrier, rain control with drainage of all penetrations, and no vapor barrier needed. Below the list are three diagrams showing typical ICF applications: a floor wall, a core wall, and a floor and beam wall. To the right is a photograph of a multi-story building under construction, showing the ICF walls. At the bottom left, the text 'Building Science' and 'Insulation' is visible.

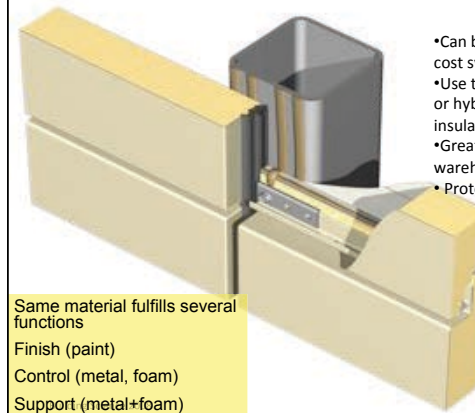


Structural Insulated Panels

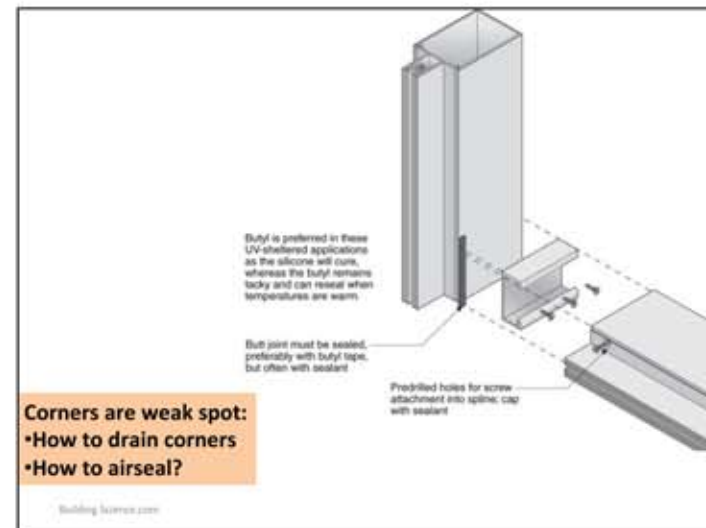
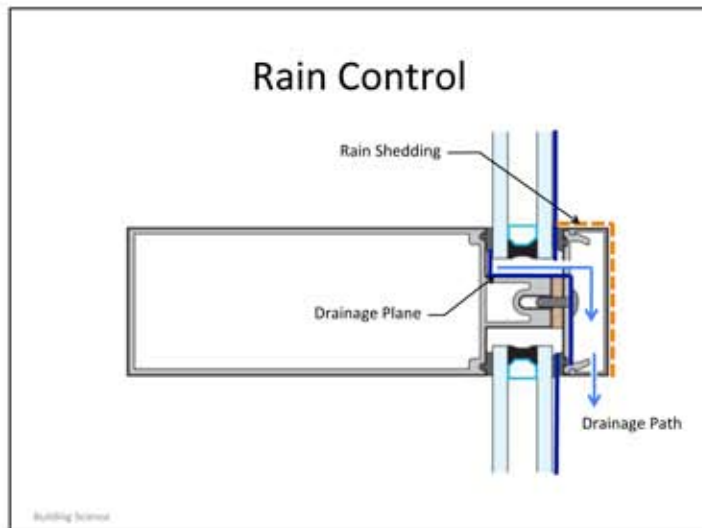
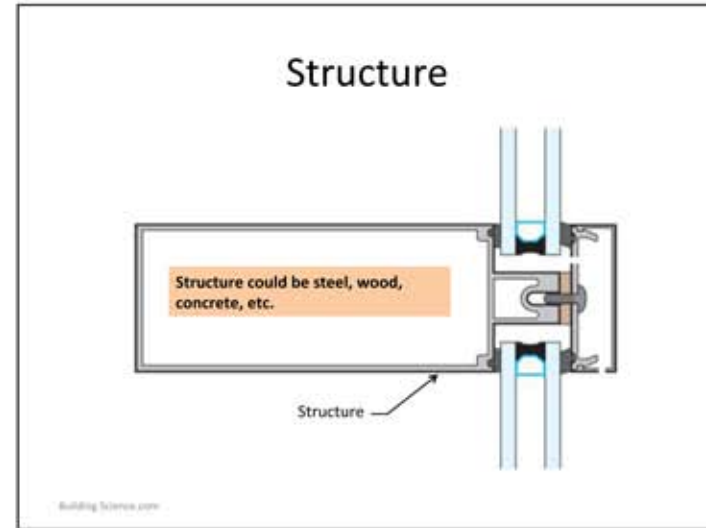
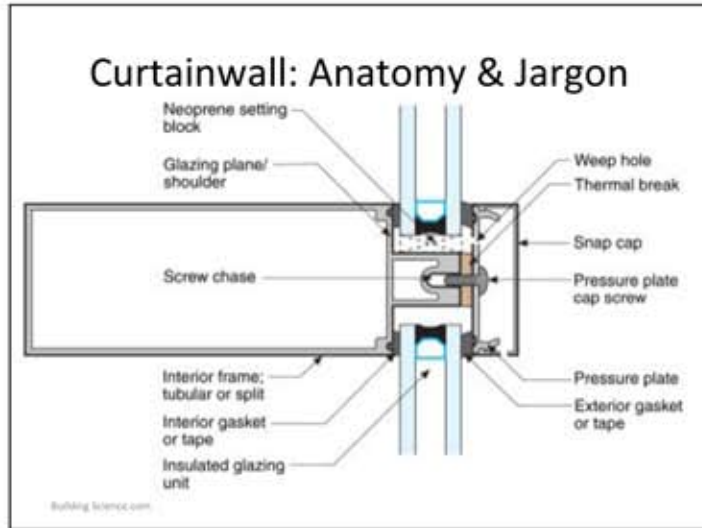
- Advantages
 - Superior blanket of insulation
 - if no voids then no convection or windwashing
 - May seal OSB joints for excellent air barrier system
- Therefore, done right = excellent
- Small air leaks at joints in roofs can cause problems
- Don't get them too wet from rain
 - Low perm layers means limited drying
 - Always use drained / ventilated cladding! Stucco!

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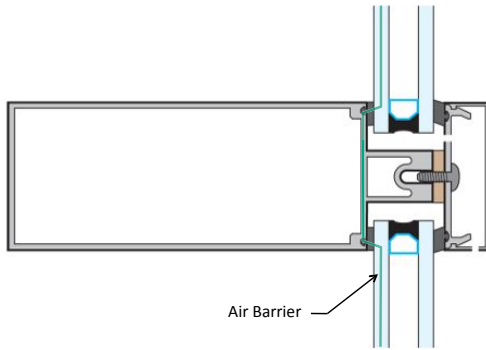
Insulated metal panels



- Can be high-performance low-cost system
- Use thicker panels (4-8") and/or hybrid with interior fibrous insulation
- Great for arenas, pools, warehouses, big box stores
- Protect from impact at grade



Air Flow Control

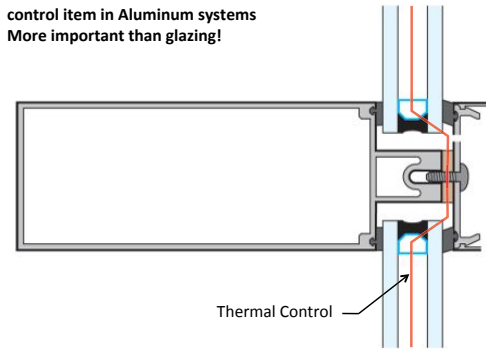


Air Barrier

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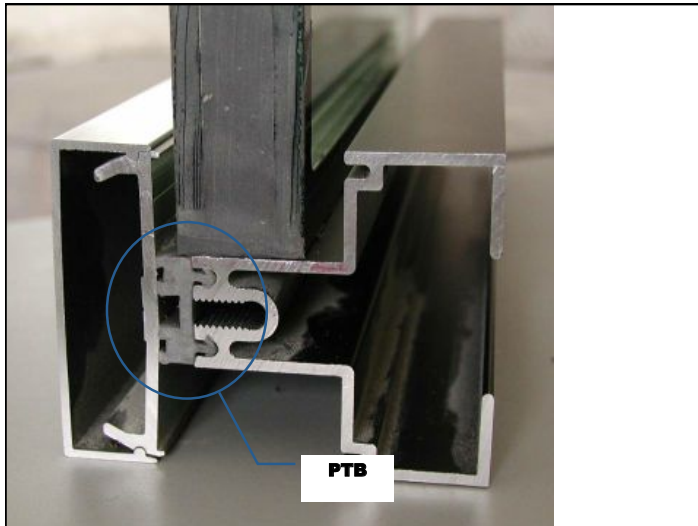
Thermal Control

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



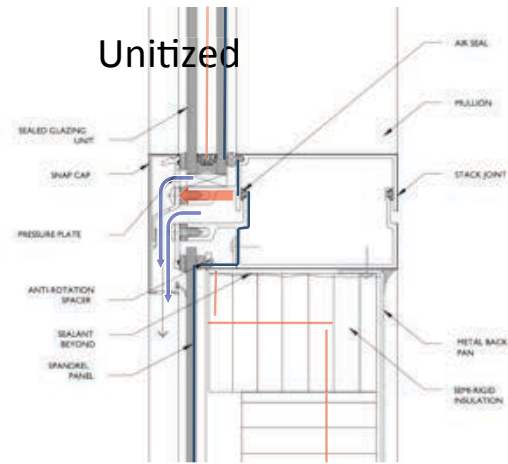
Thermal Control

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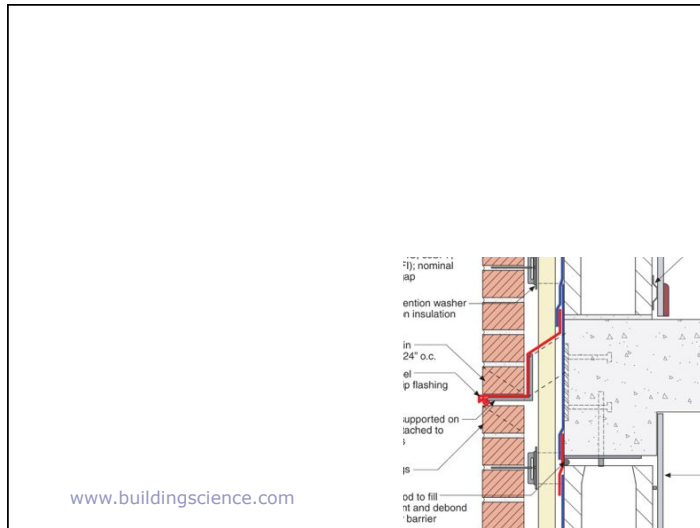
PTB

Unitized



Building Science

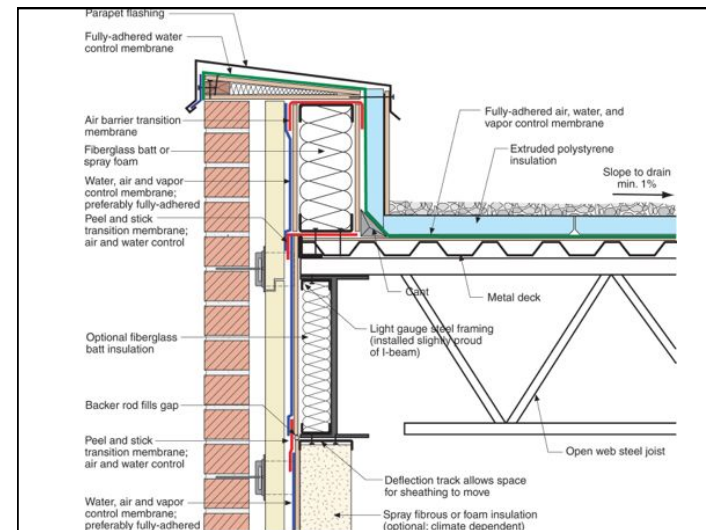
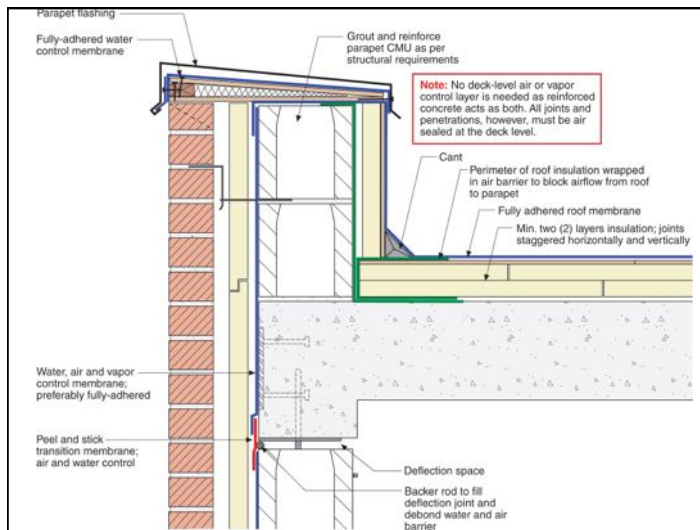
Windows and Curtainwalls No. 15280

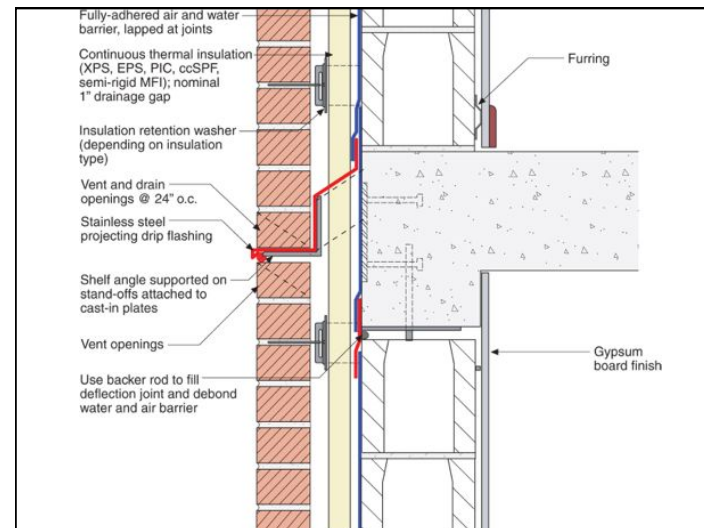
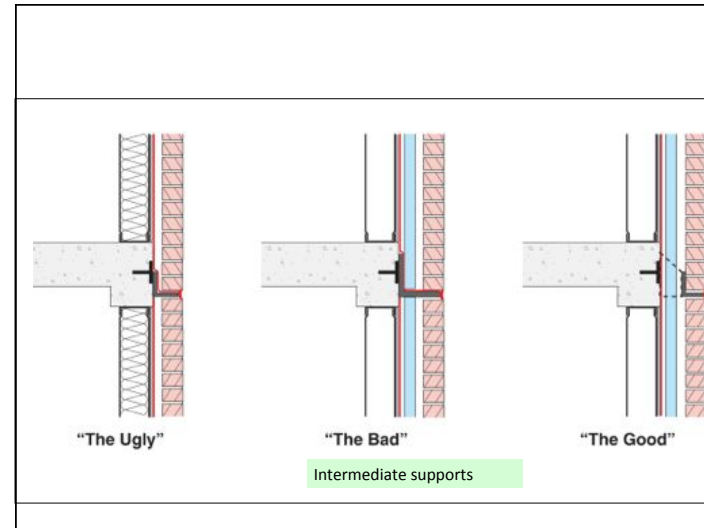
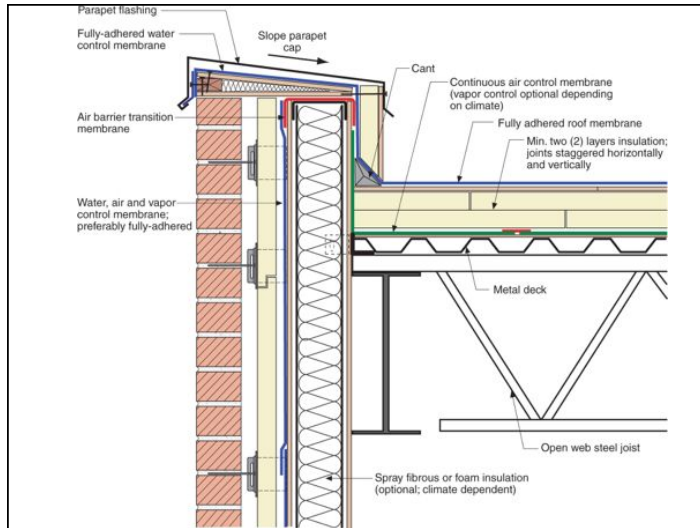


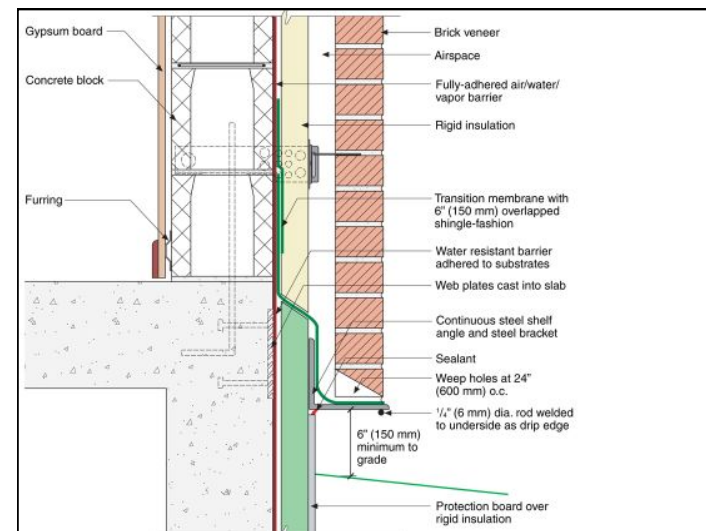
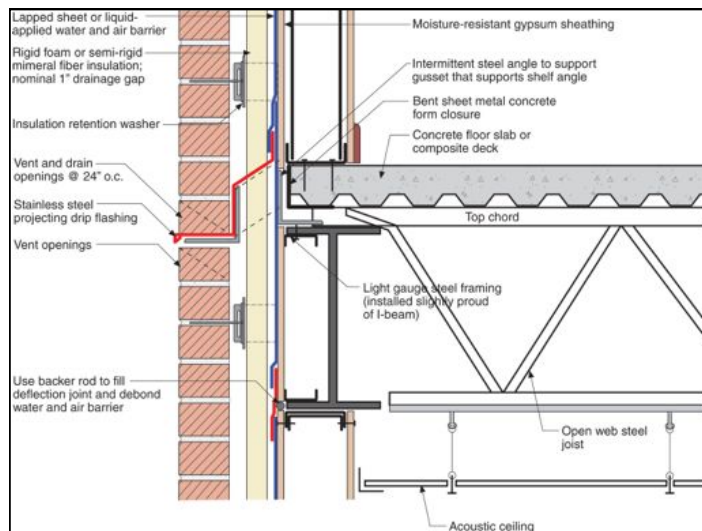
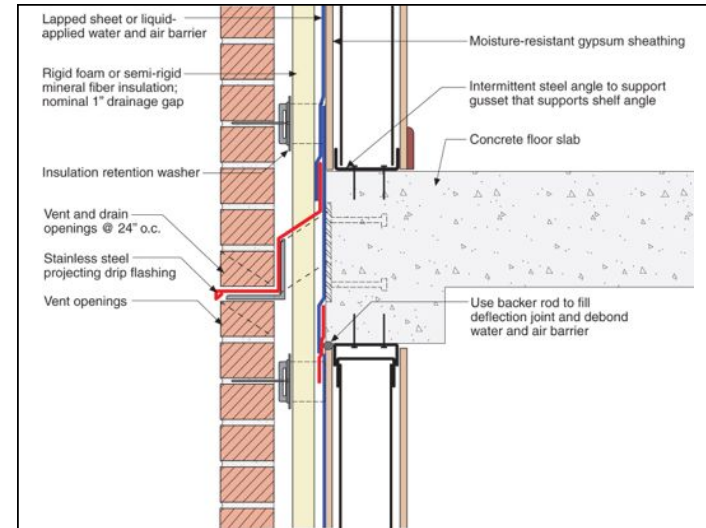
Details

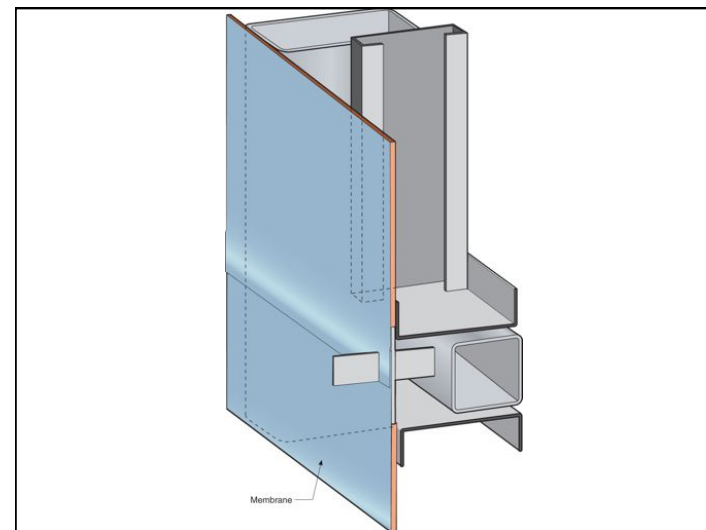
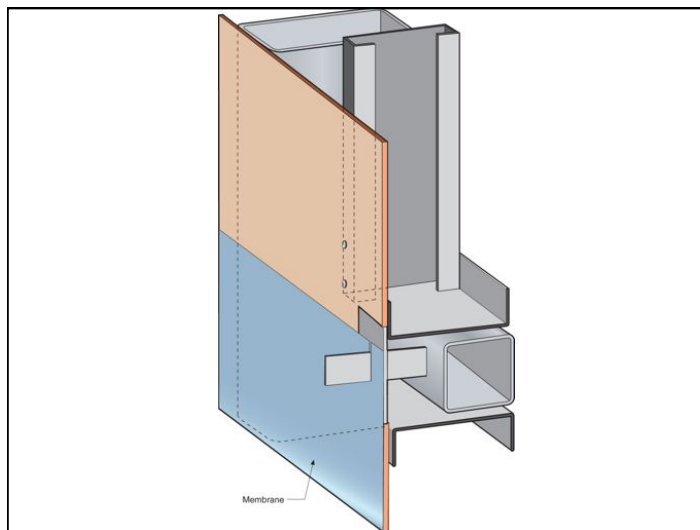
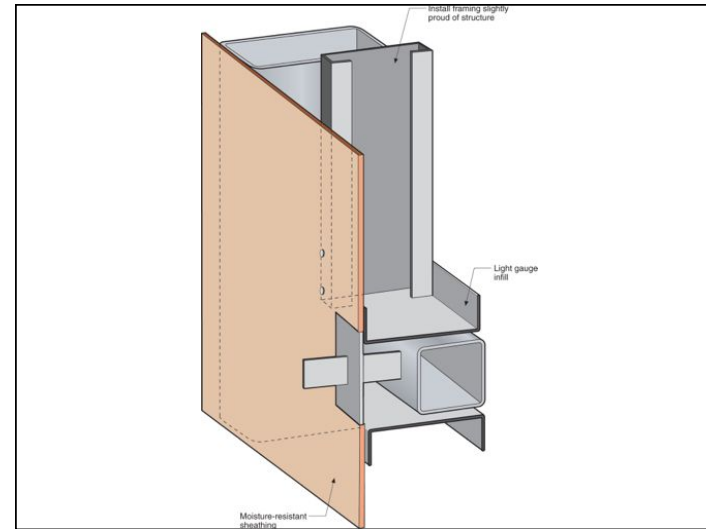
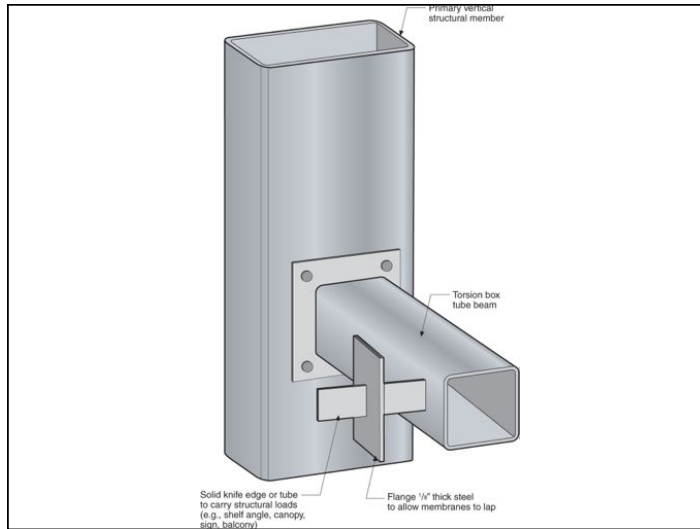
- Integration of penetrations and transitions is critical
 - Must maintain continuity of rain, air, thermal and vapor control through the transition!
 - Exposure and performance expectations guide designers level of compromise

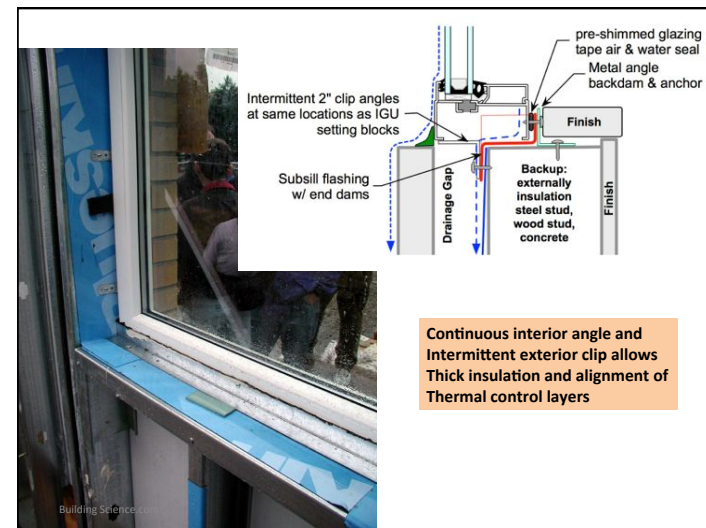
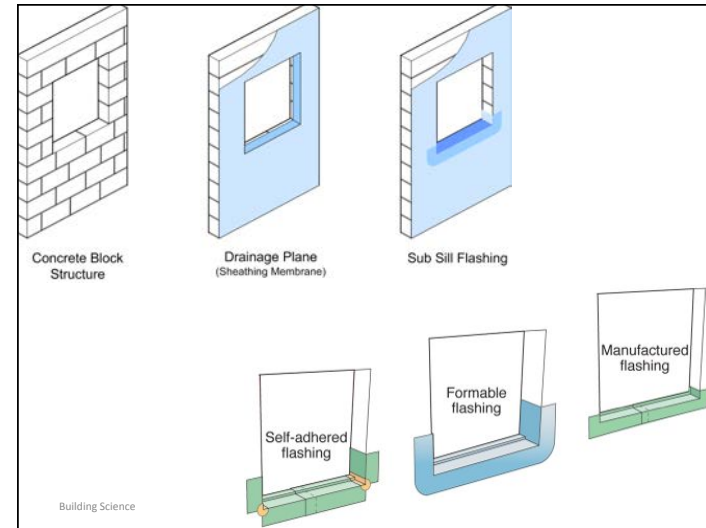
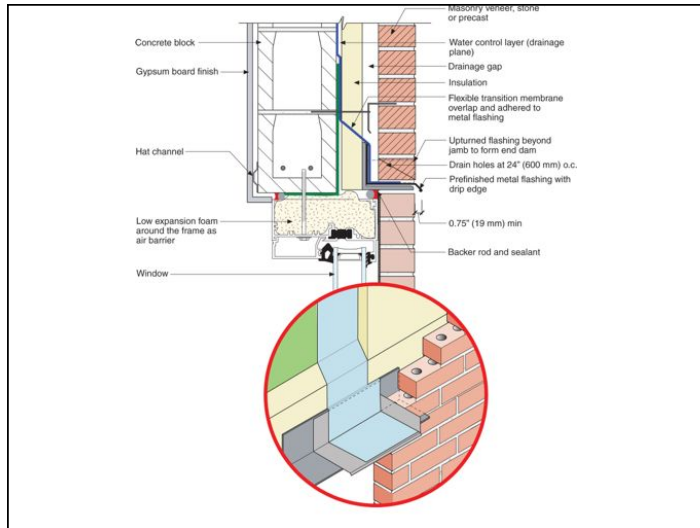
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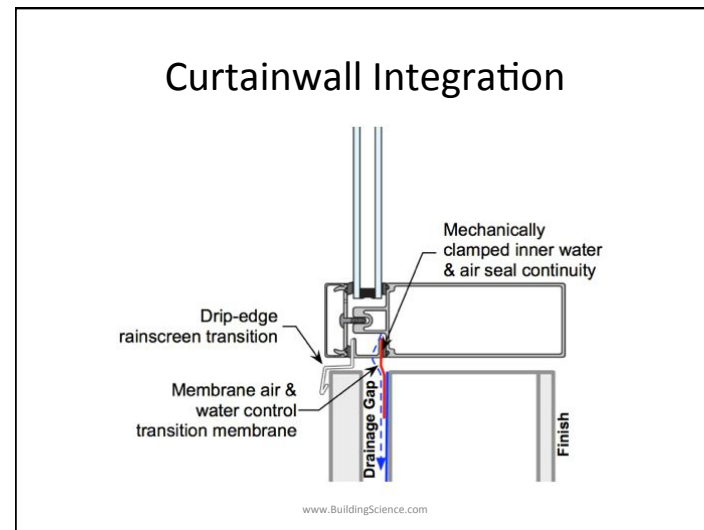
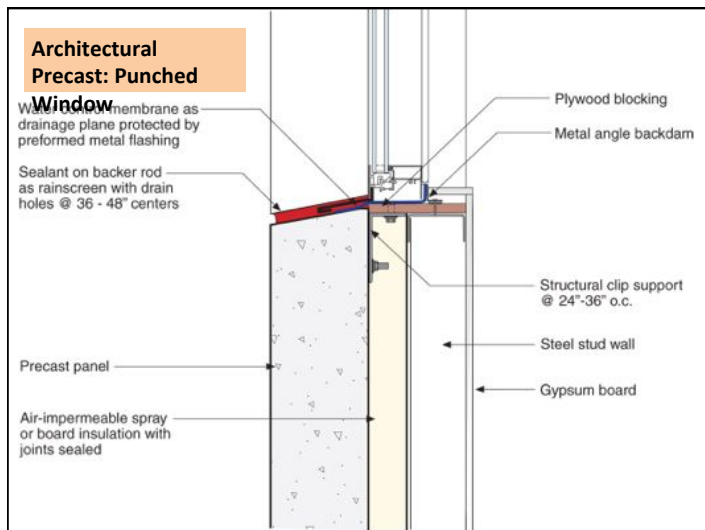
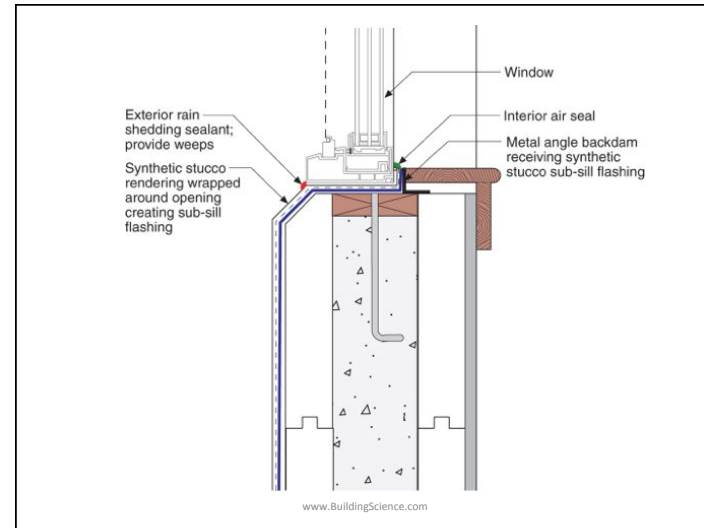
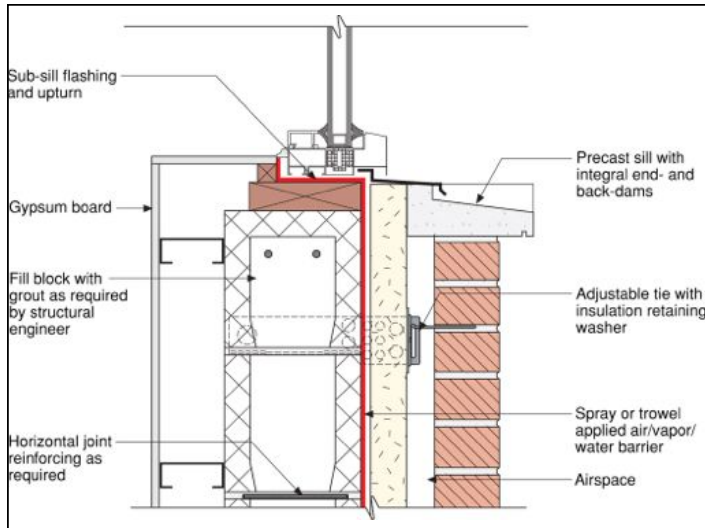


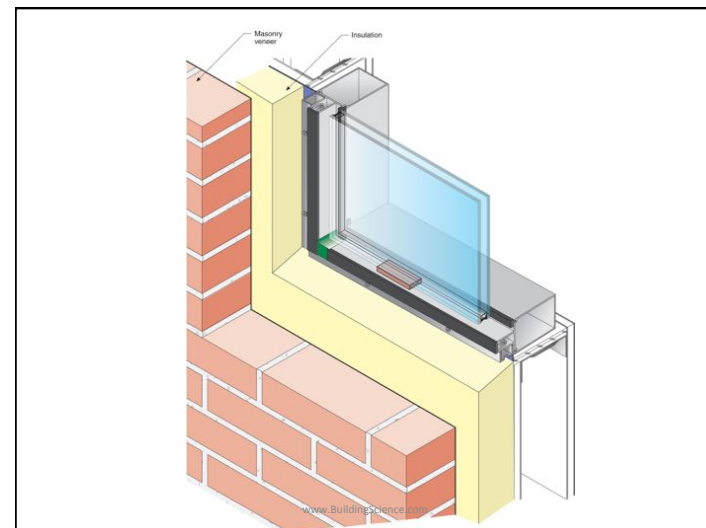
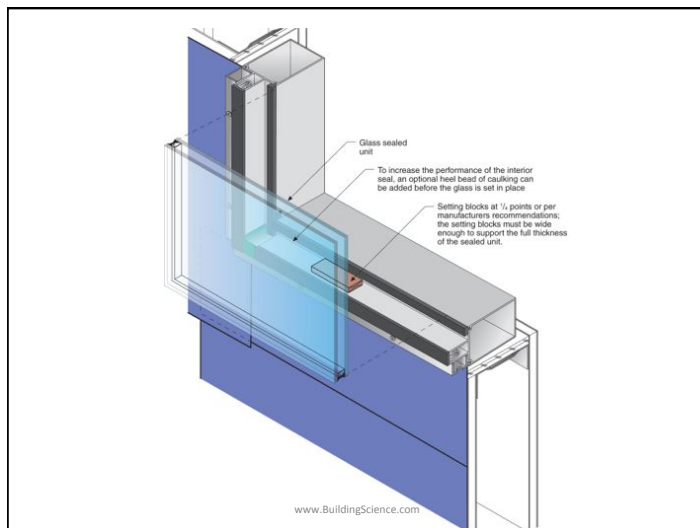
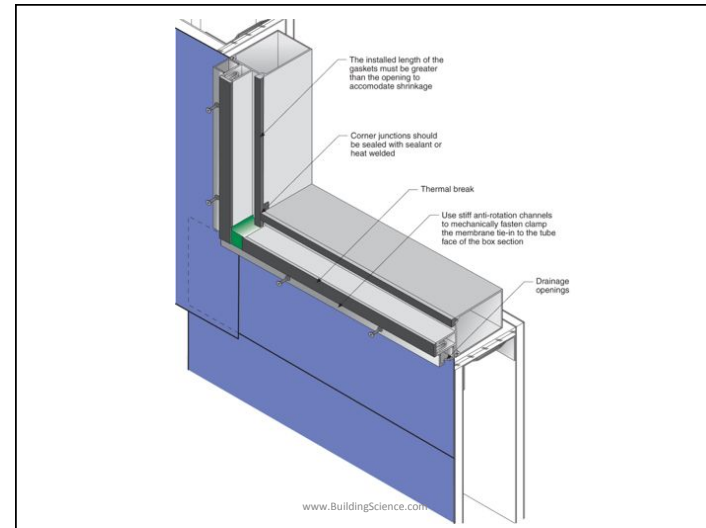
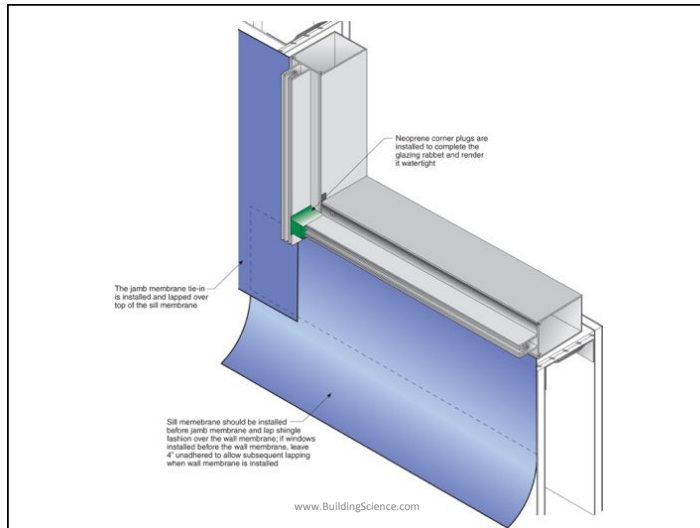


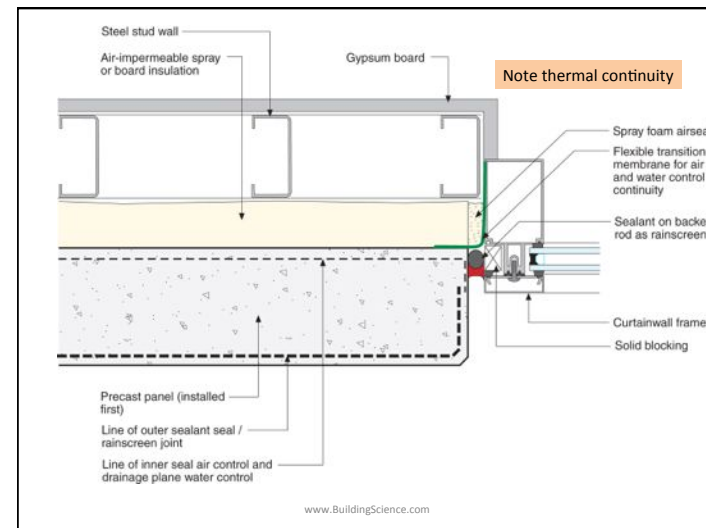
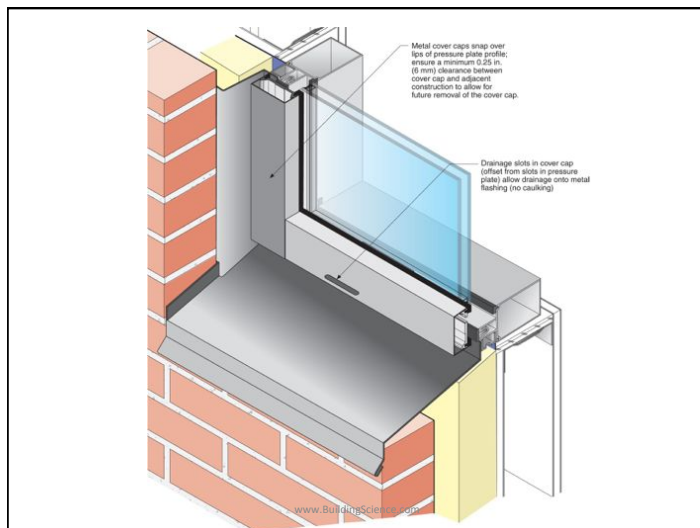
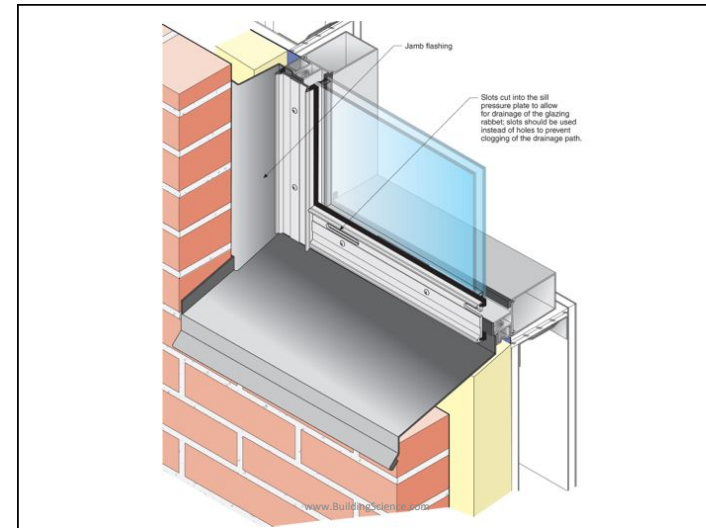
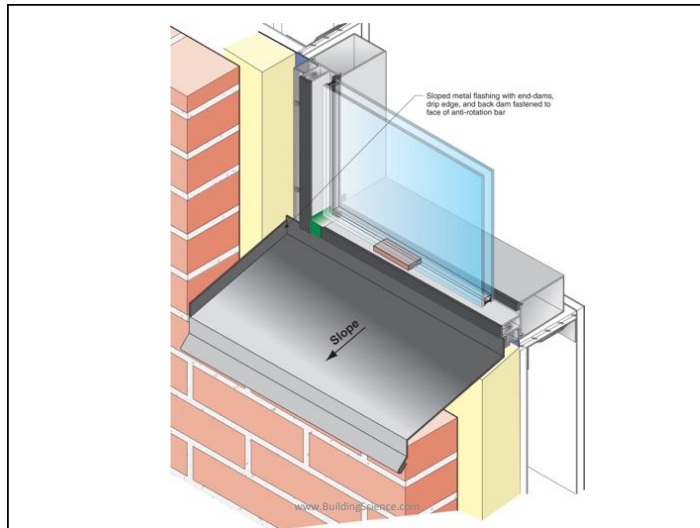


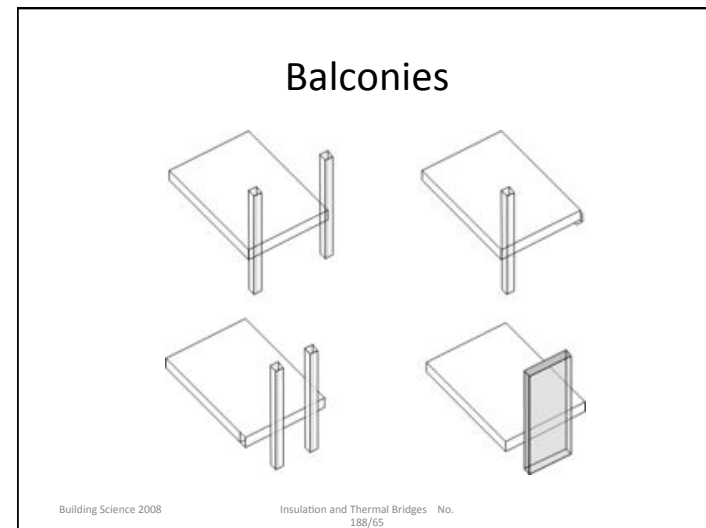
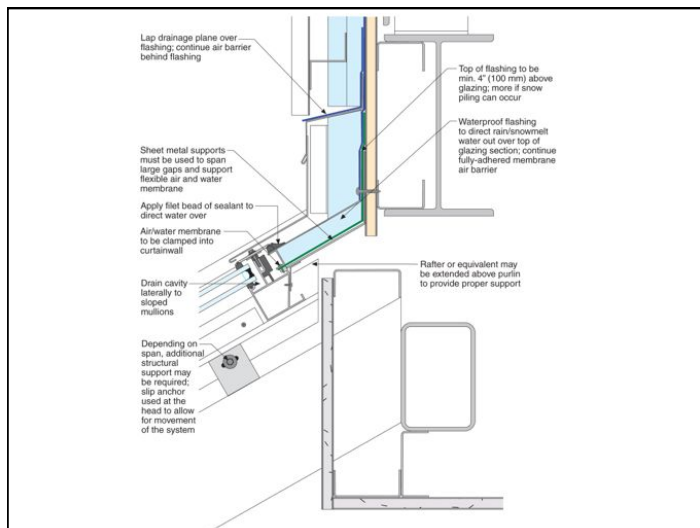
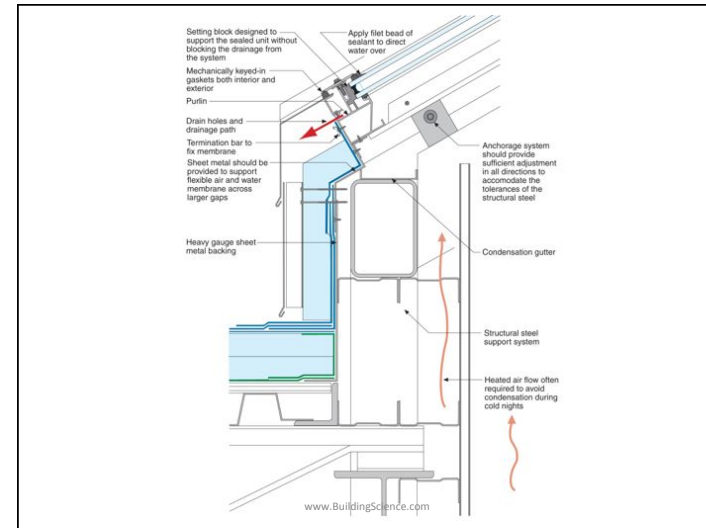
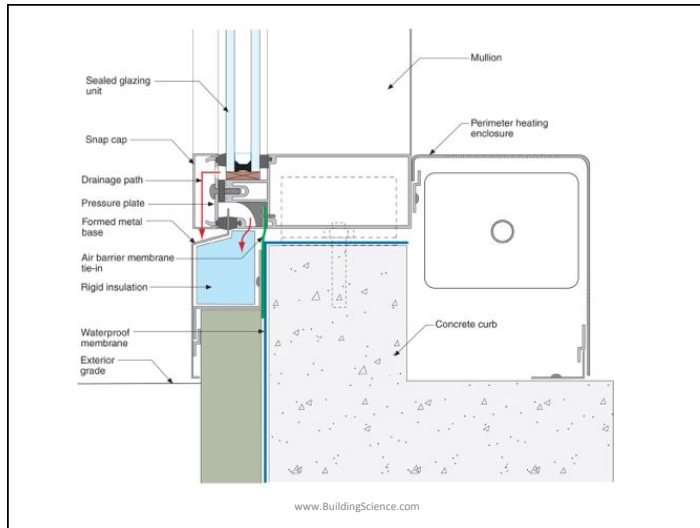


Continuous interior angle and Intermittent exterior clip allows Thick insulation and alignment of Thermal control layers

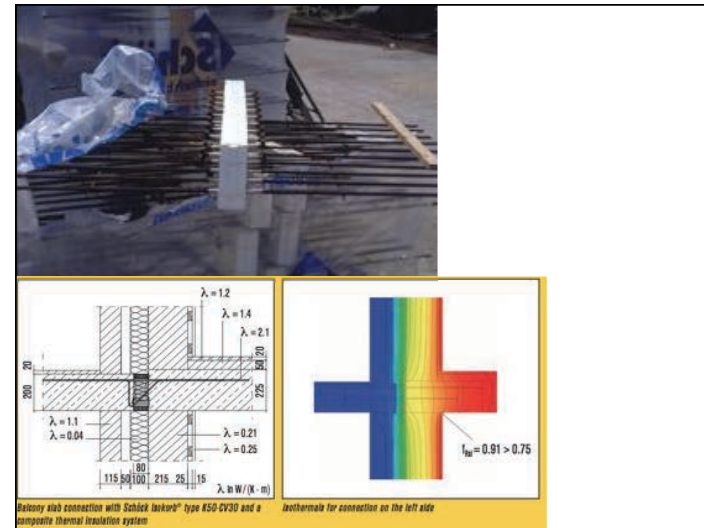
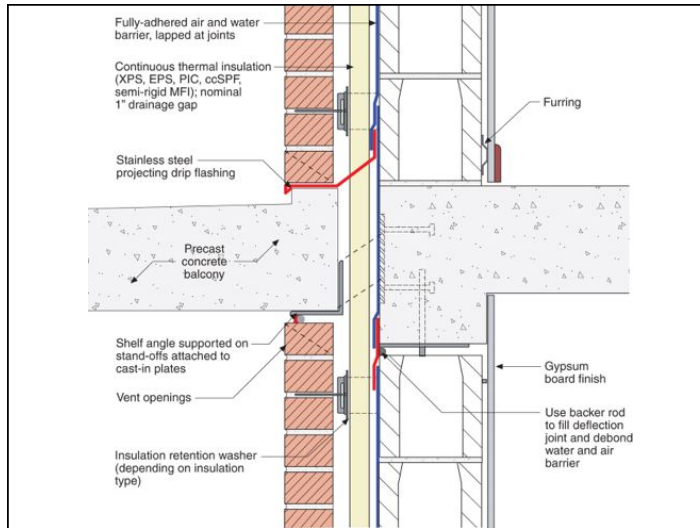








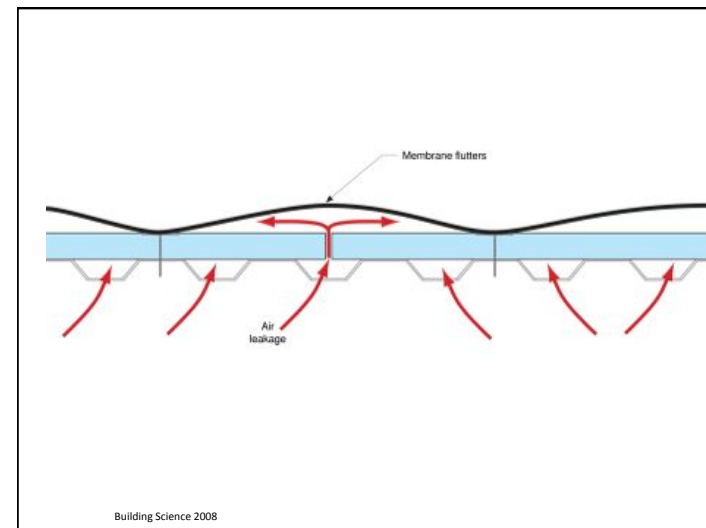
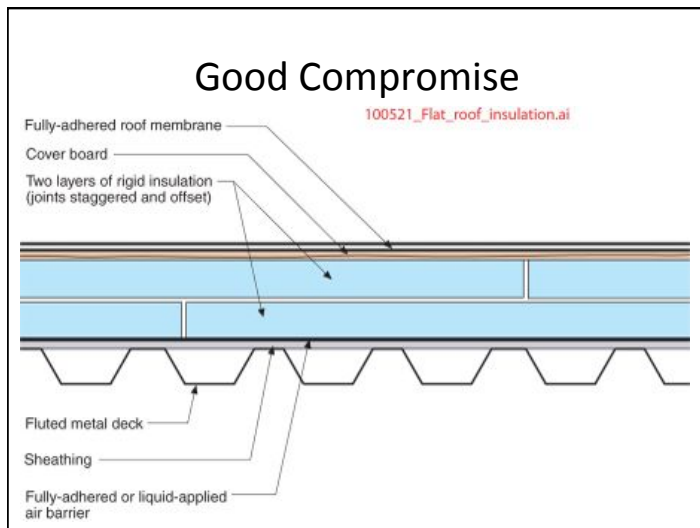
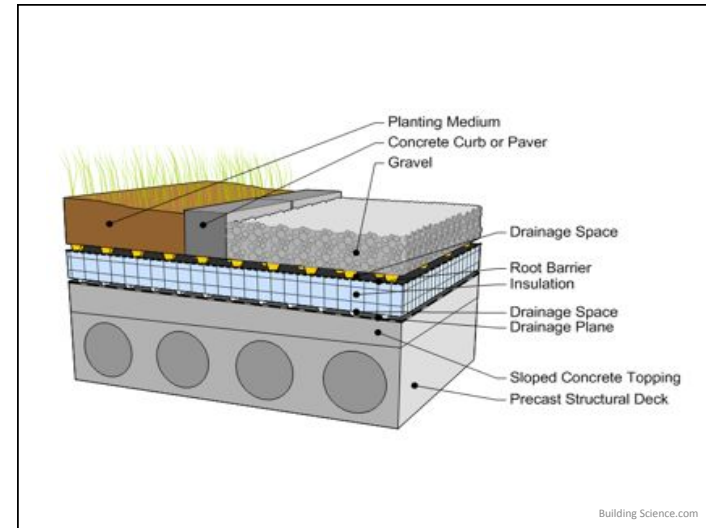
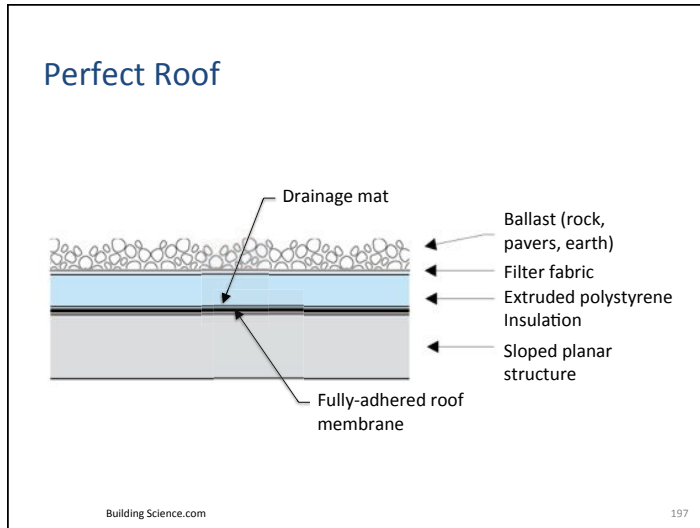


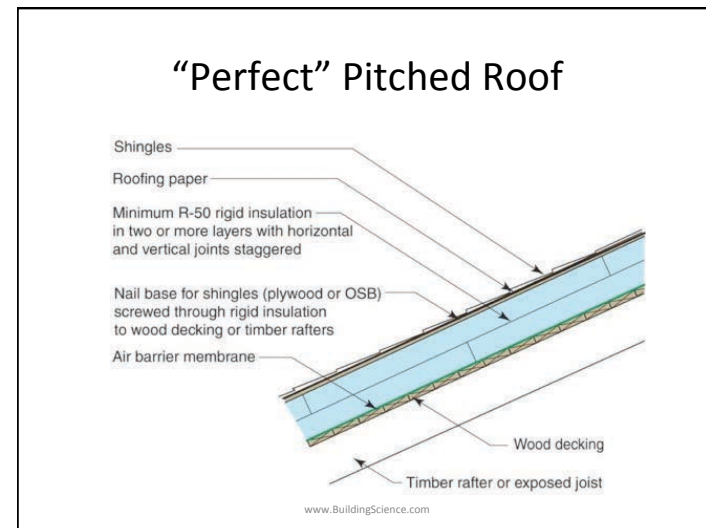
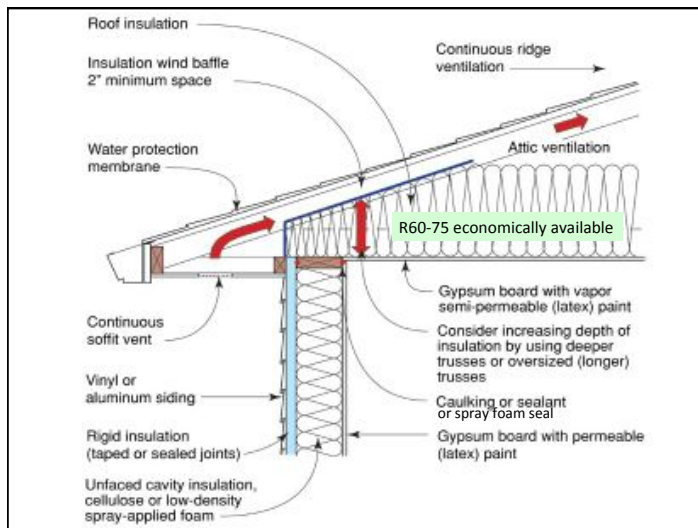
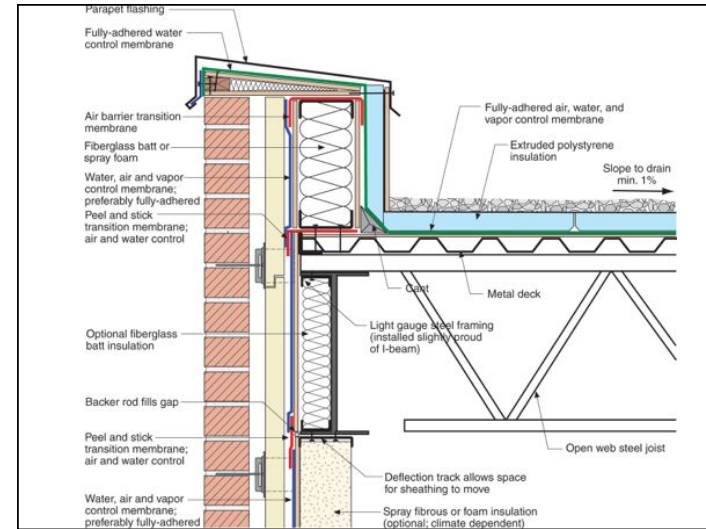
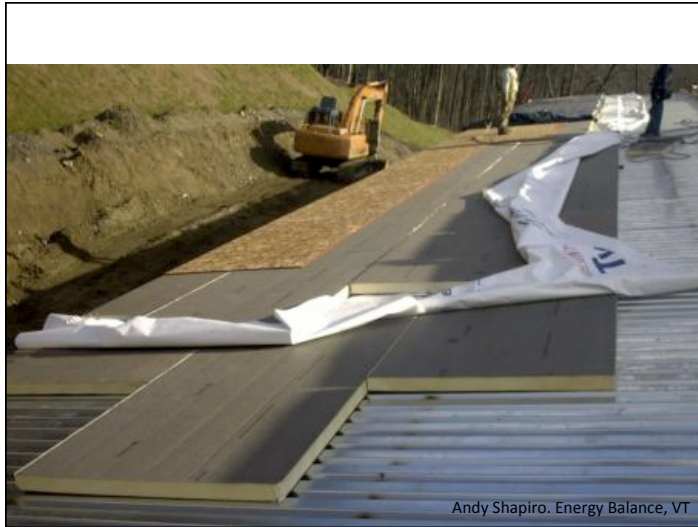


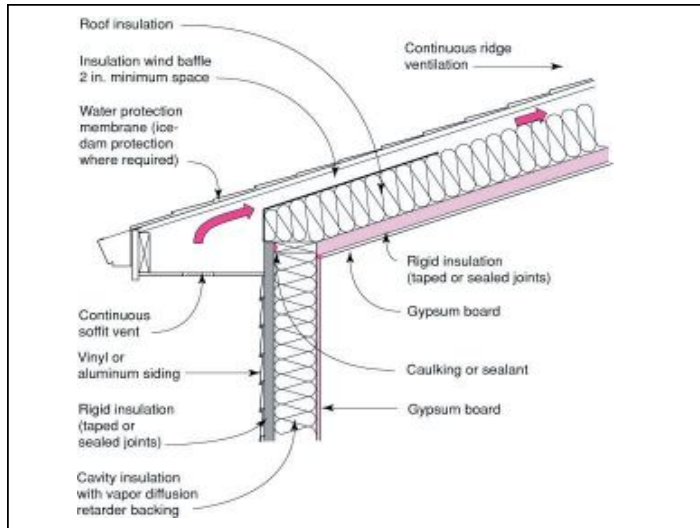
Low-Slope Roofs

- Not flat. Ponding is not acceptable.
- Get water right, then worry about energy!
- Components
 - Rain barrier is roof membrane
 - Drainage gap is the outdoors
 - Air barrier can be roof membrane
 - Better to install interior
 - Insulation is rigid, polyiso, XPS, EPS, rockwool

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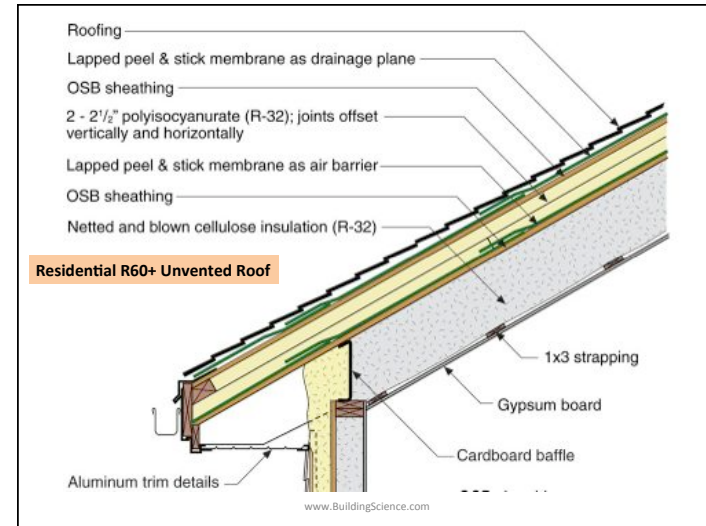
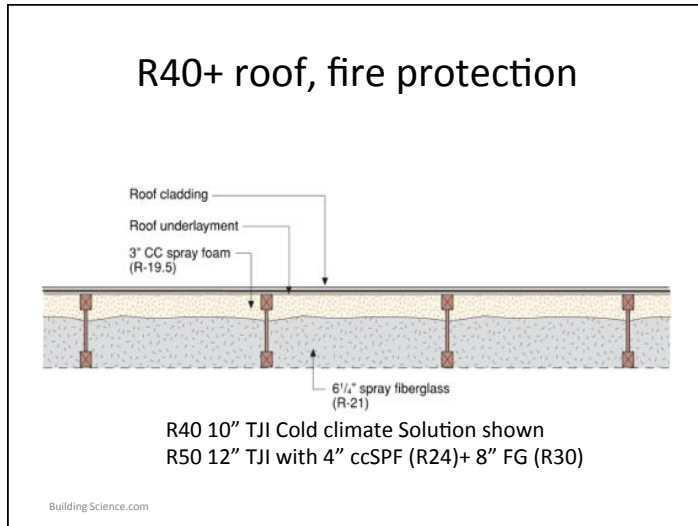




Unvented Cathedralized Attics

- Move air and insulation control from ceiling plane to roof plane
- Moves HVAC into conditioned space
 - Saves lots of energy, reduce problems with comfort, extends life of equipment
- Avoids wind blown rain, snow, and burning wildfire embers

Building Science 2008



- ### Summary
- Identify functional control layers
 - Rain, air, heat, vapor
 - Provide continuity of control layers
 - details
 - Select high levels of performance
- www.BuildingScience.com