



# High Performance Enclosures

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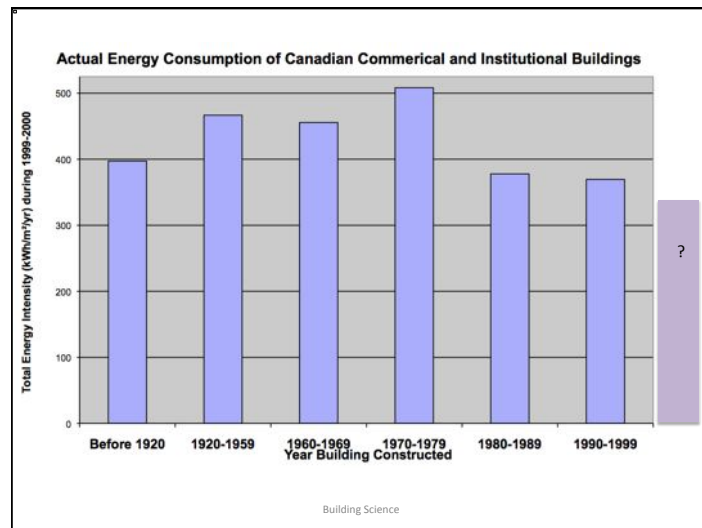
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## Goal

- “provide Canadian Architects with the knowledge and new design solutions required to design energy-efficient building enclosures (roofs, walls, foundations, windows and doors) appropriate for net-zero energy buildings.”
- This means 70-90% reductions in energy use
- Perhaps half of this can be achieved by enclosure, half by mechanicals

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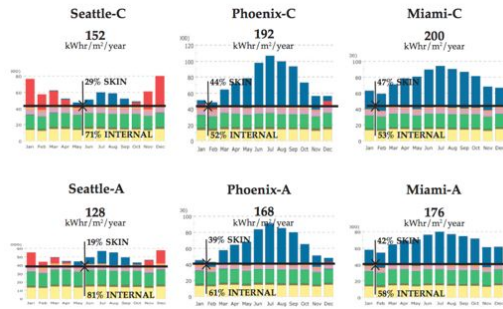
## Enclosures in Context

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

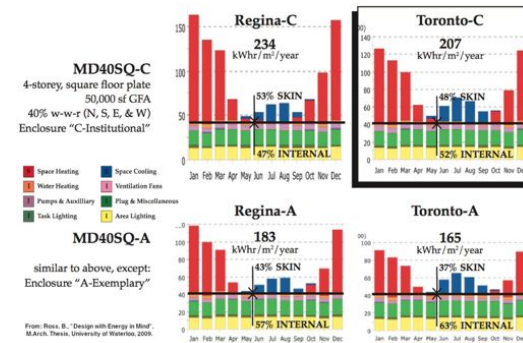
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## Climate matters

- Beware architecture magazines



## Other things use energy



## 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**
  - 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

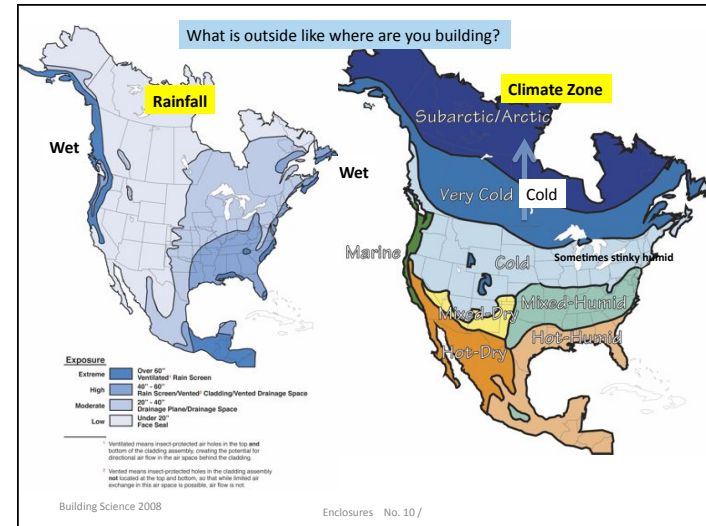


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## Buildings: Why do we Build?

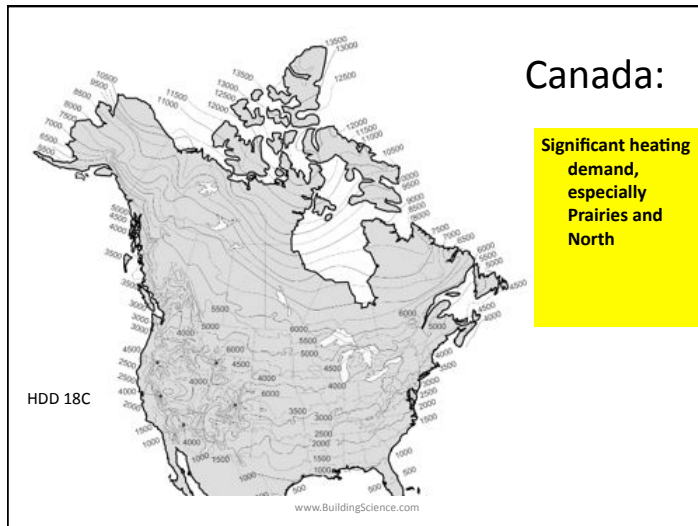
- To keep the wind, sun, rain, snow, heat, cold, dust, bugs, animals, and nasty people outside.
- But we let in some things
  - Nice people, pets, sunshine, daylight, clean air, clean water, supplies
- And let some things out
  - Views, polluted water and air

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## Canada:

Significant heating demand, especially Prairies and North

## 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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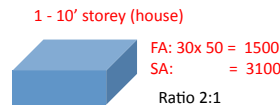
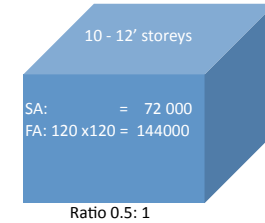
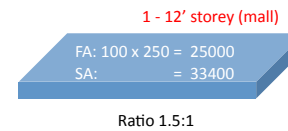
Enclosures No. 12 /

## 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

## Size: Surface Area to Floor Area

- Size matters



The higher the ratio, the more enclosure design & climate impact performance

## Small, Compact Form

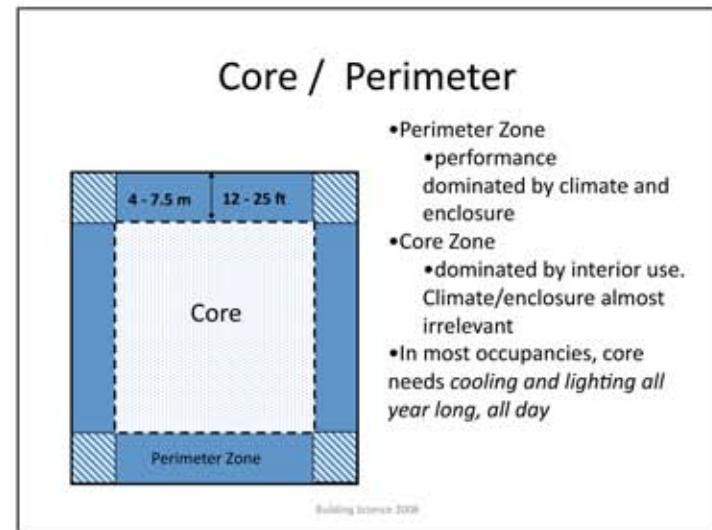
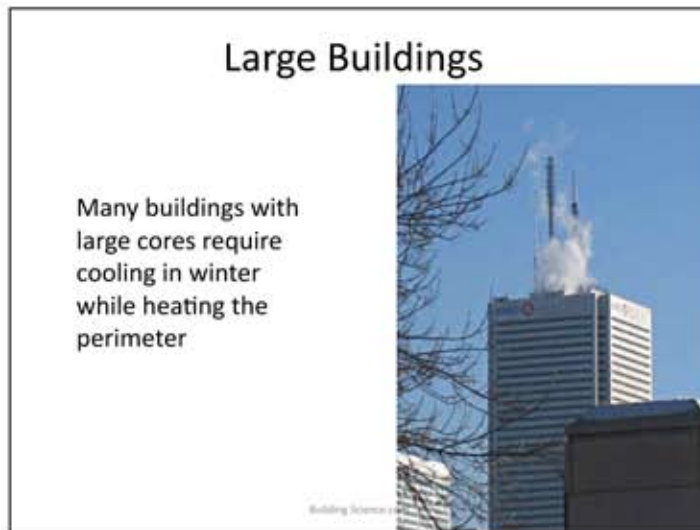
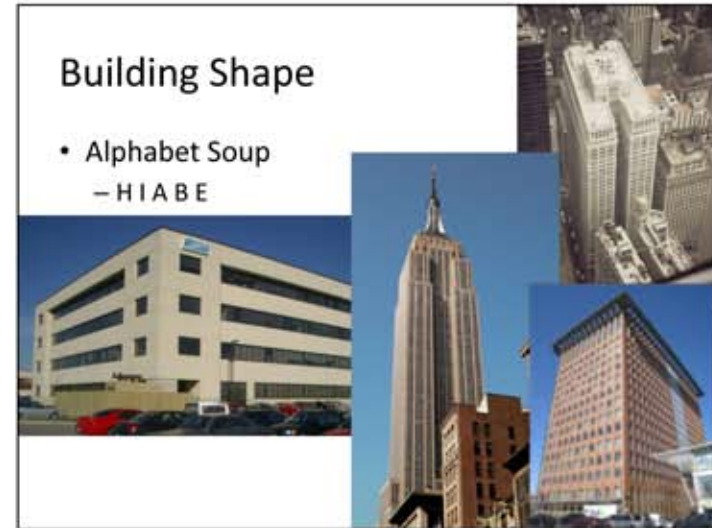
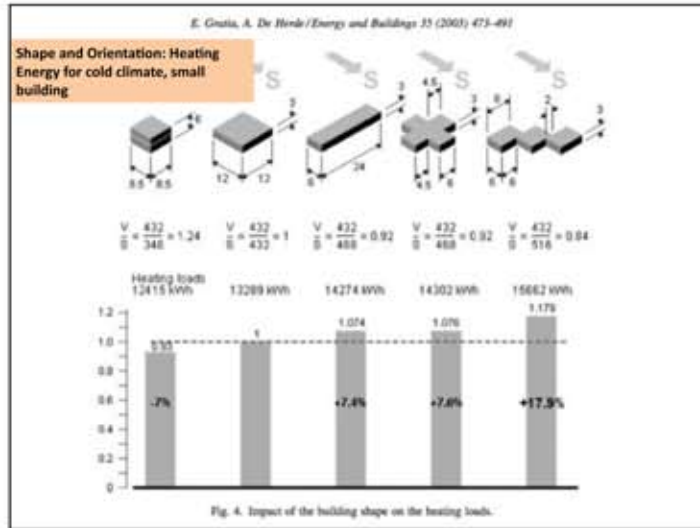
- Fewer resources
- Less heat loss and gain



## Form & Massing

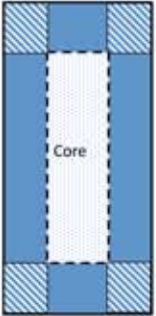
- Keep it simple
- Cheaper, easier, faster
- Fewer
  - thermal bridges, air leaks
  - Material volumes
  - construction challenges







### Skin Dominated Building



Core


- Perimeter Zone over most of building area
- Excellent daylighting and cross ventilation opportunities
- Termed "Skin Dominated"
- Demands good building enclosure

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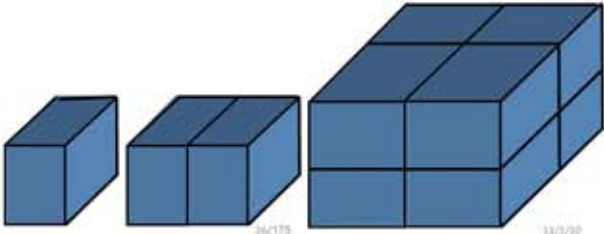
### Expanded Plans

- Better daylight, easier ventilation but more enclosure heat loss and gain and air leaks



### Grouping buildings

- Grouping units reduces heat loss/gain through shared walls
- Reduces resource use per unit



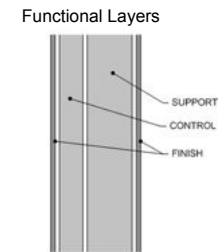
## Enclosure Intro Summary

- 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

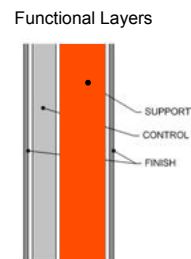
- 1. Support
  - Resist and transfer physical forces from inside and out
- 2. Control
  - Control mass and energy flows
- 3. Finish
  - Interior and exterior surfaces for people
- Distribution – a building function



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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

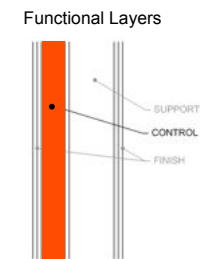


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## Basic Enclosure Functions

- **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

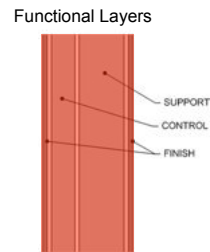


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## Other Control . . .

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

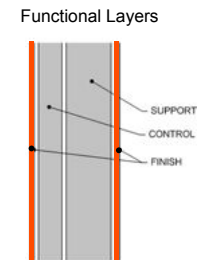


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## Basic Enclosure Functions

- 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

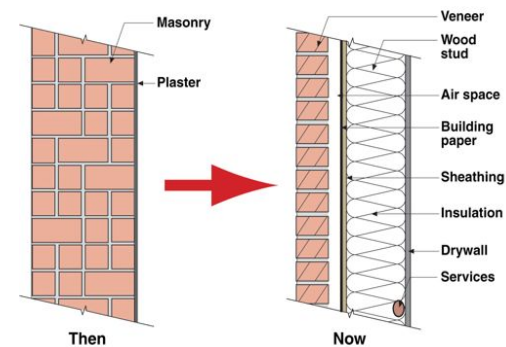
- Older Buildings
  - One layer does everything
- Newer Building
  - Separate layers, . . . separate functions



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Enclosures No. 33/

## Changes



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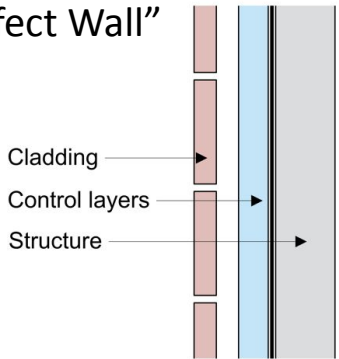
Enclosures No. 34/



### 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

Fire Control may be needed  
Sound Control optional



The diagram shows a vertical cross-section of a wall. On the left, there are several vertical rectangular blocks representing cladding. To the right of the cladding is a thin vertical line representing control layers. Further right is a thicker vertical block representing the structure. Arrows point from the labels 'Cladding', 'Control layers', and 'Structure' to their respective parts in the diagram.

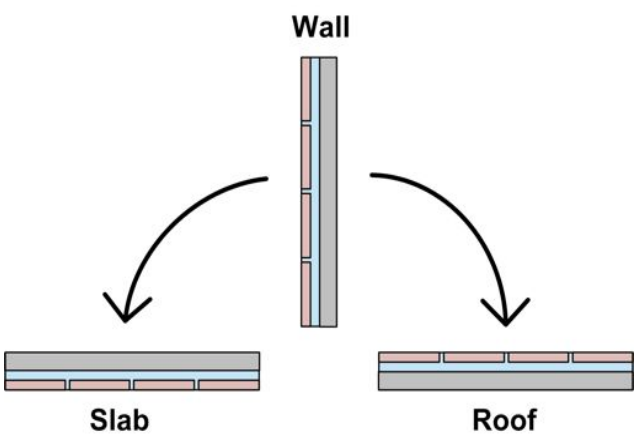
Cladding →  
Control layers →  
Structure →

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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

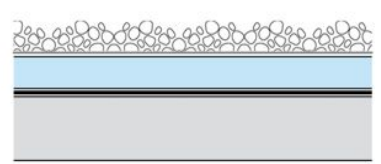
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The diagram shows a vertical wall section labeled 'Wall' at the top. Below the wall, two curved arrows point to a 'Slab' on the left and a 'Roof' on the right. The slab and roof are shown as horizontal cross-sections with multiple layers, including control layers and structure. The wall, slab, and roof are shown as continuous parts of a single enclosure system.

**Wall**  
**Slab**      **Roof**

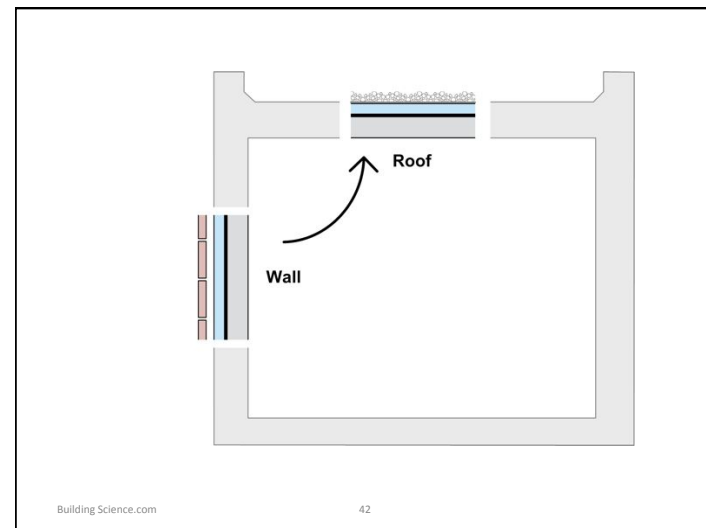
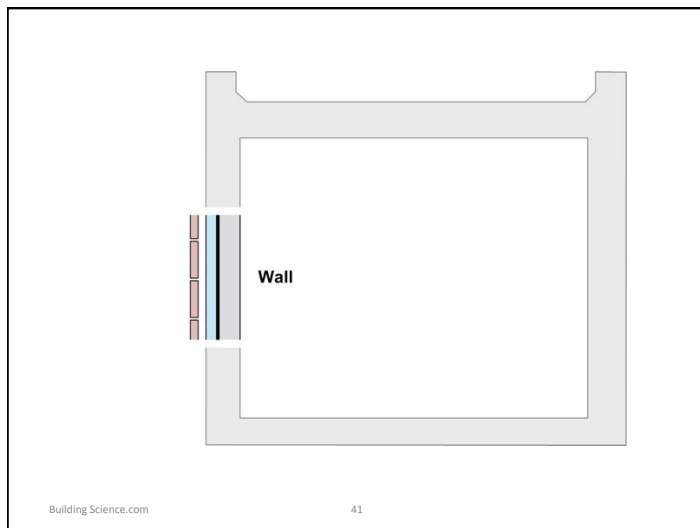
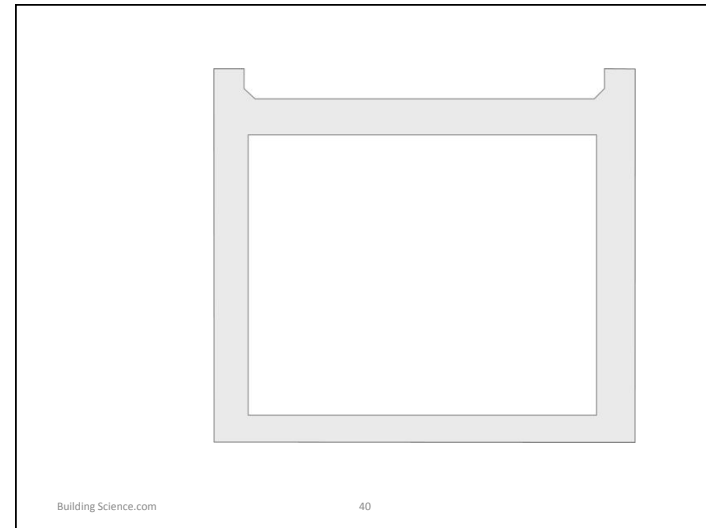
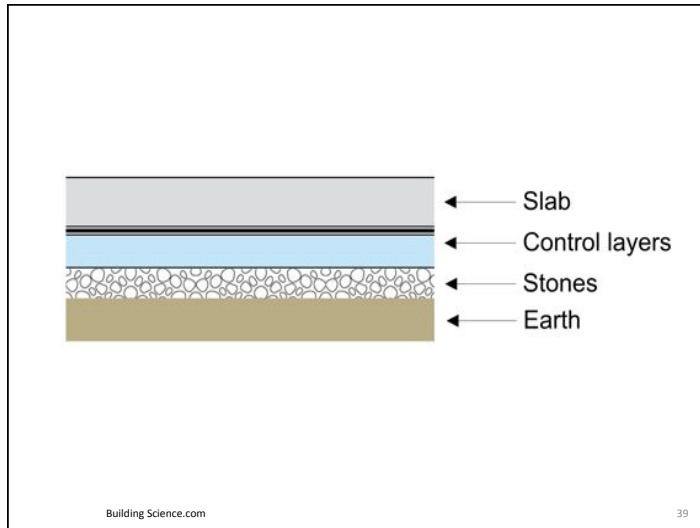
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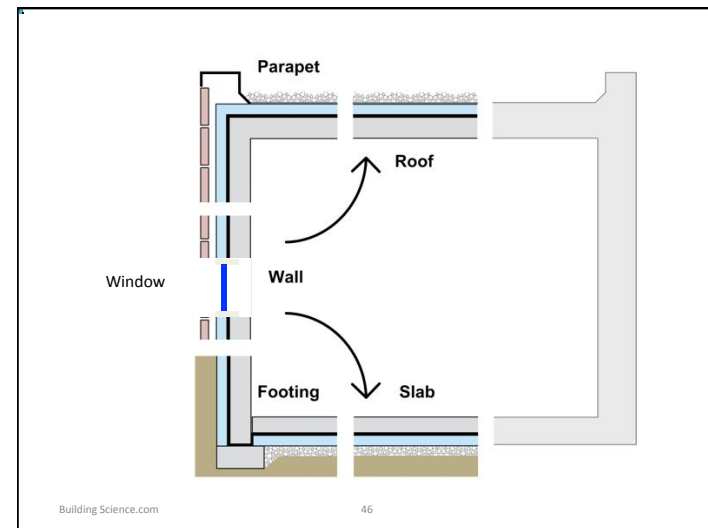
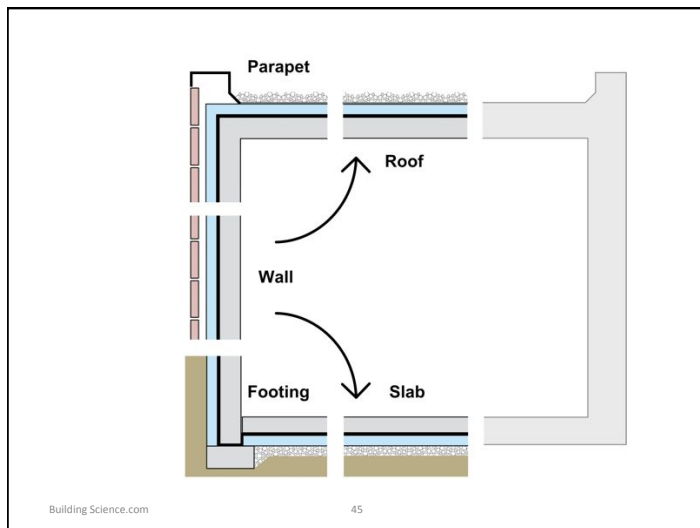
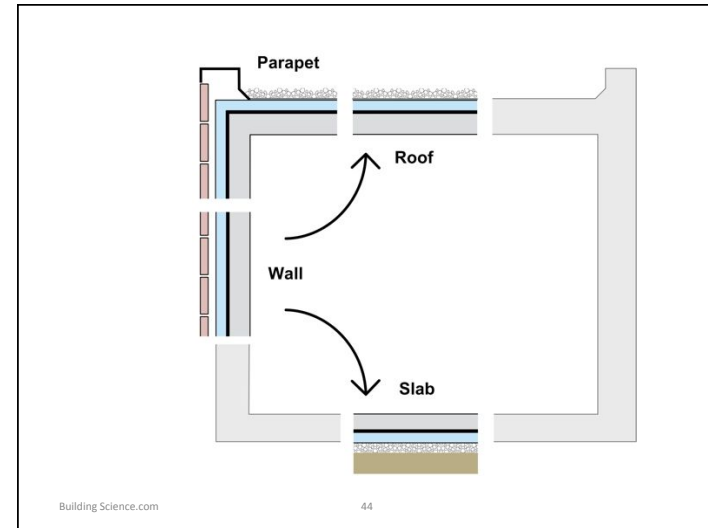
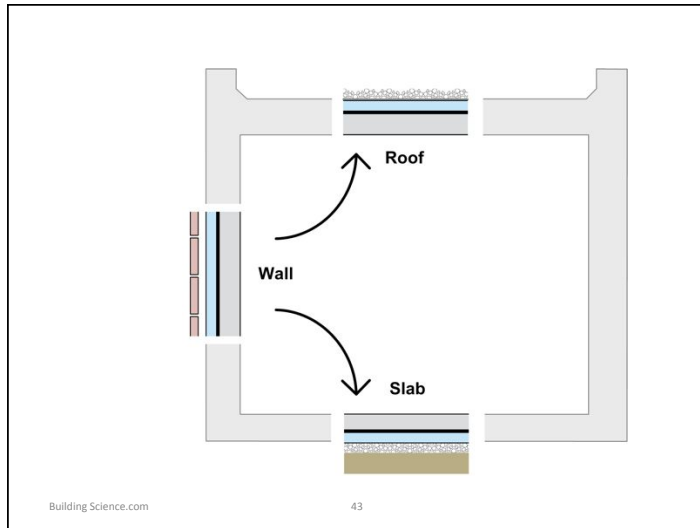


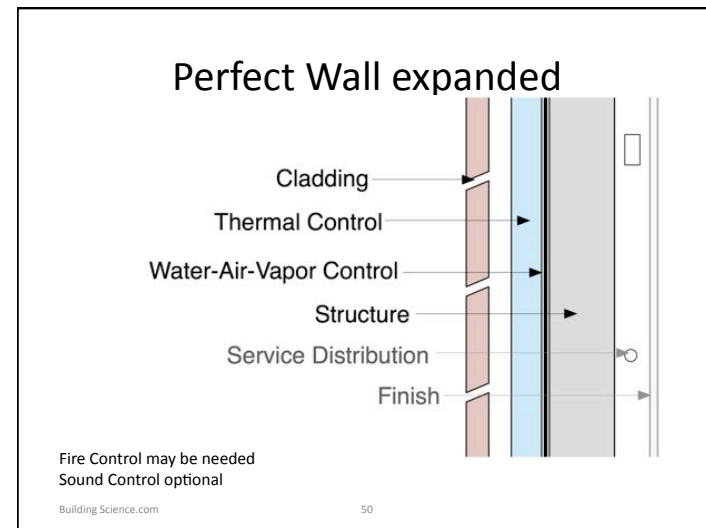
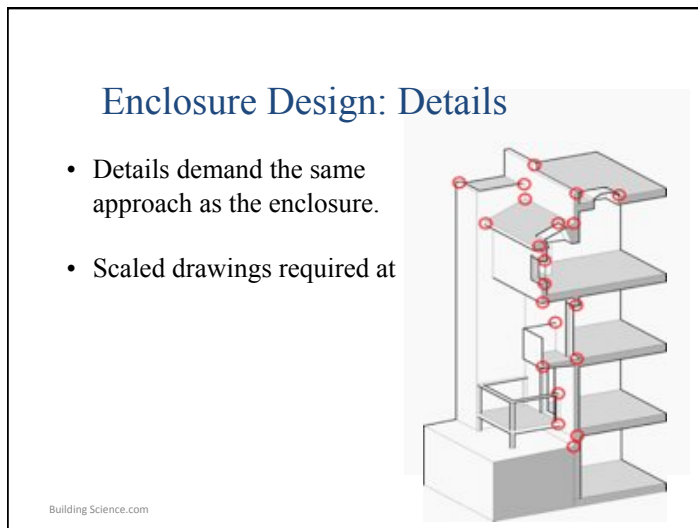
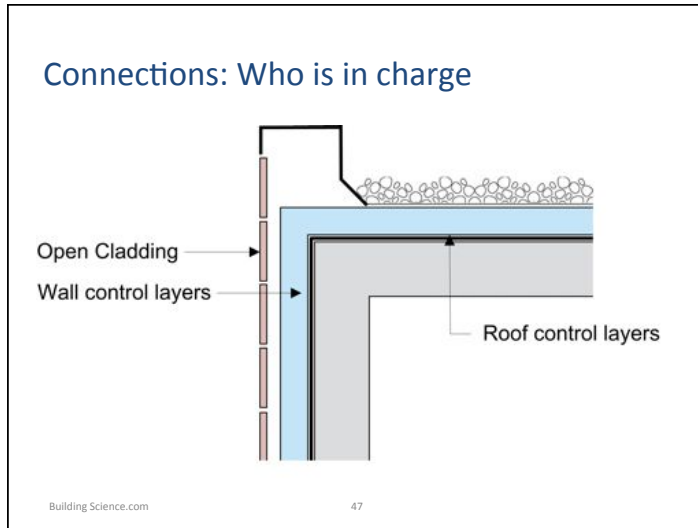
The diagram shows a horizontal cross-section of a roof assembly. From top to bottom, the layers are: a layer of small circles representing ballast, a thin layer representing filter fabric, a thicker blue layer representing control layers, and a thick grey layer representing the roof structure. Arrows point from the labels on the right to each of these layers.

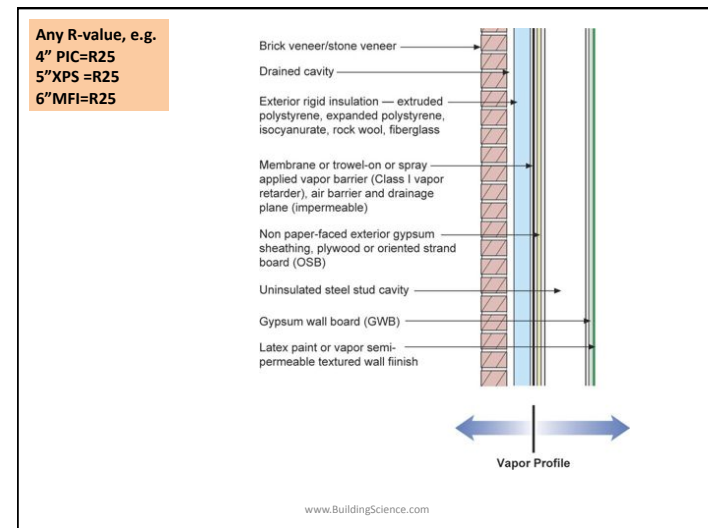
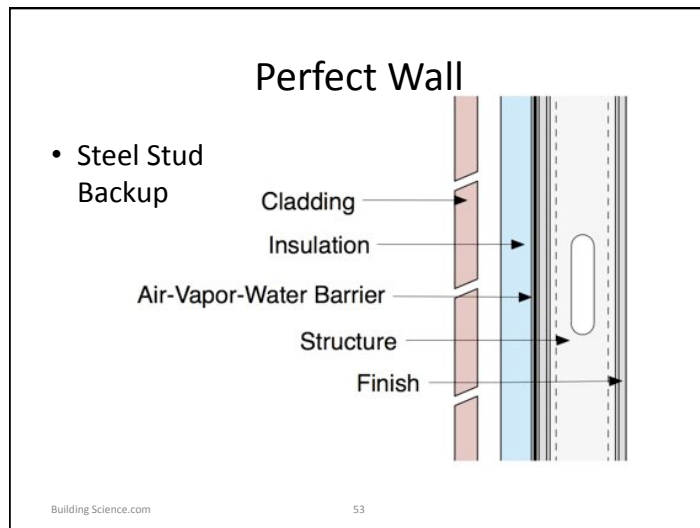
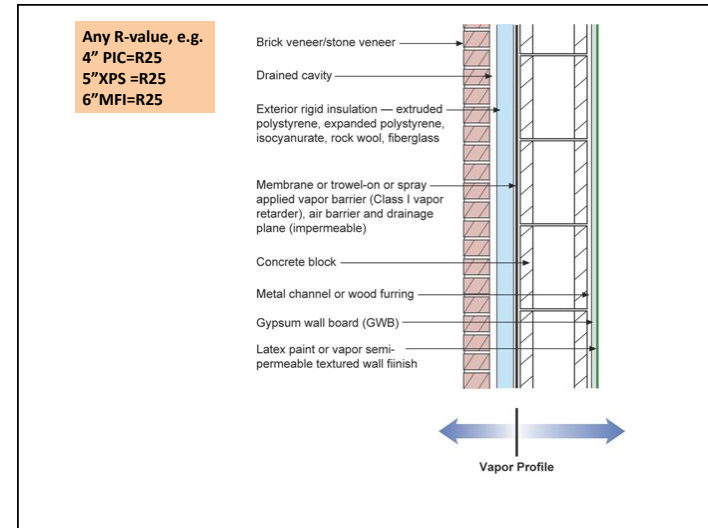
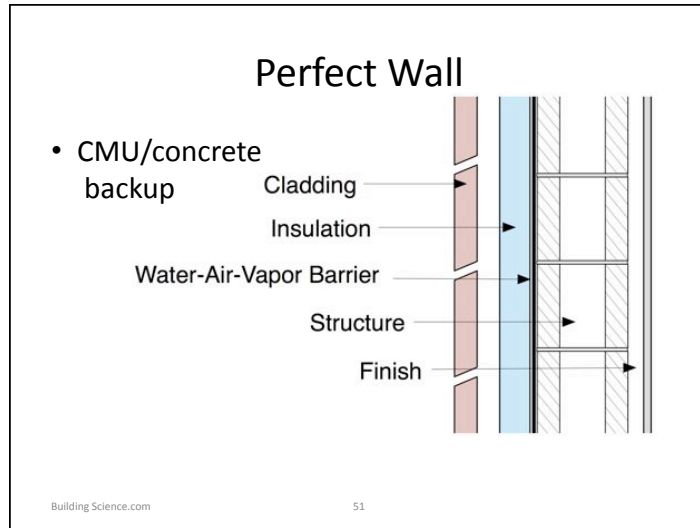
Ballast  
Filter fabric  
Control layers  
Roof structure

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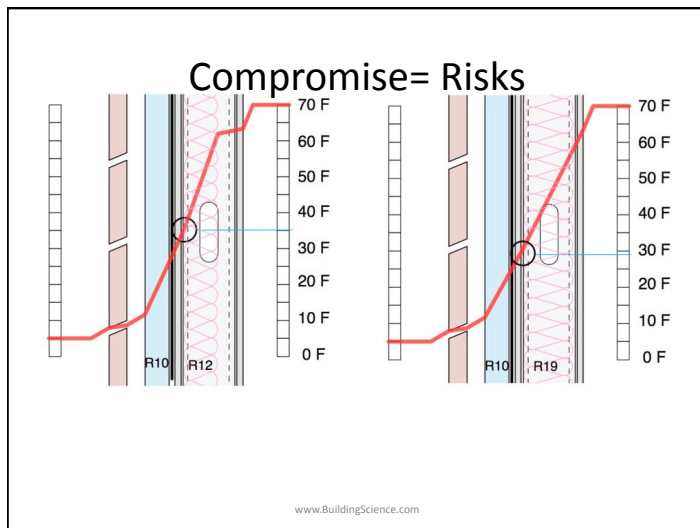
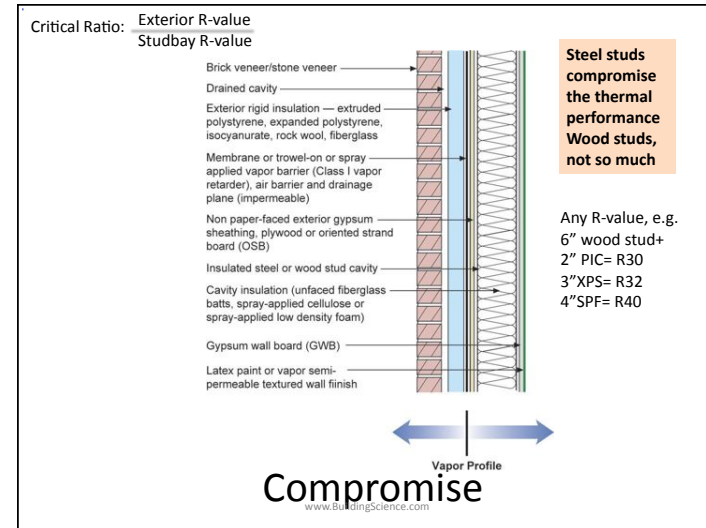
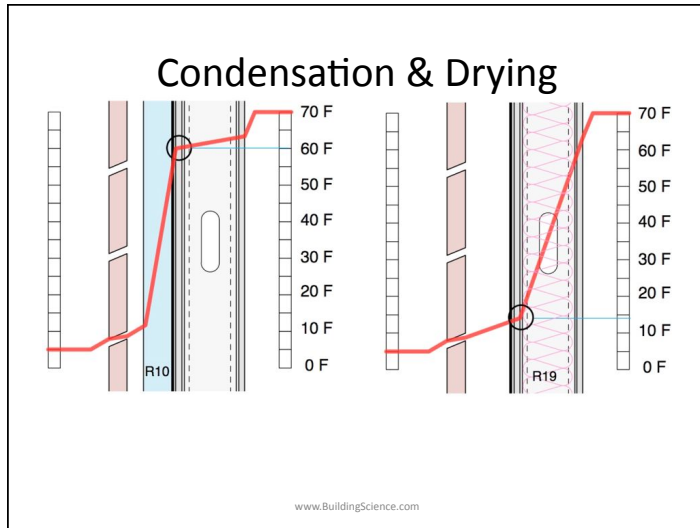












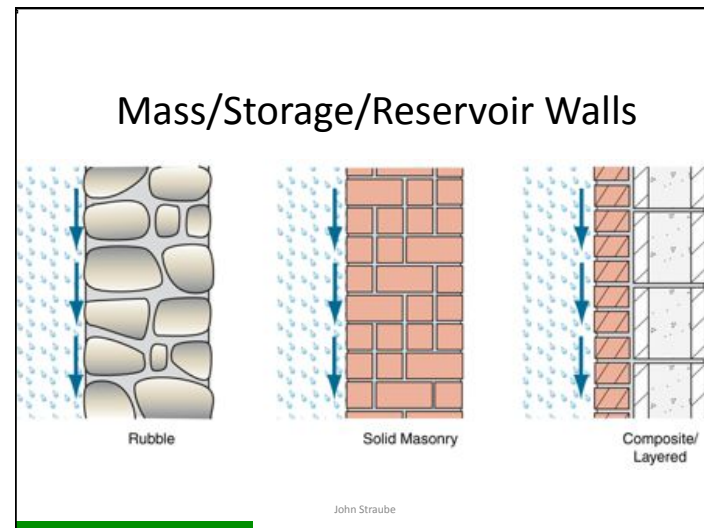
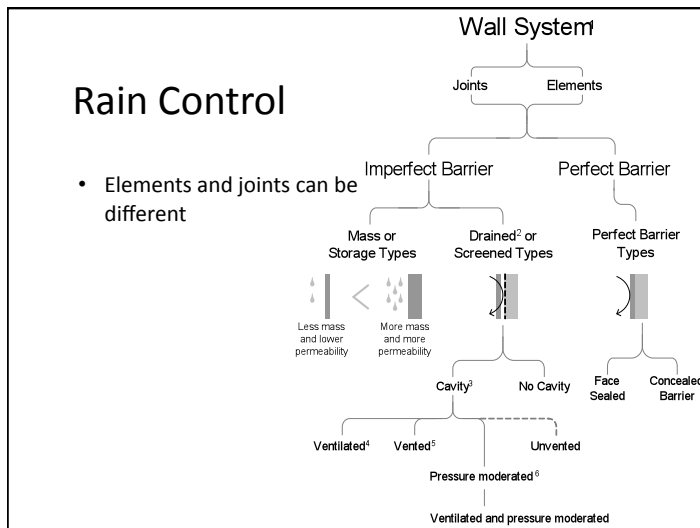
- ### Specifics
- Now we will look at
    - Rain Control
    - Air Flow Control
    - Thermal Control
- } Energy & Comfort } Durability, Health
- In some detail
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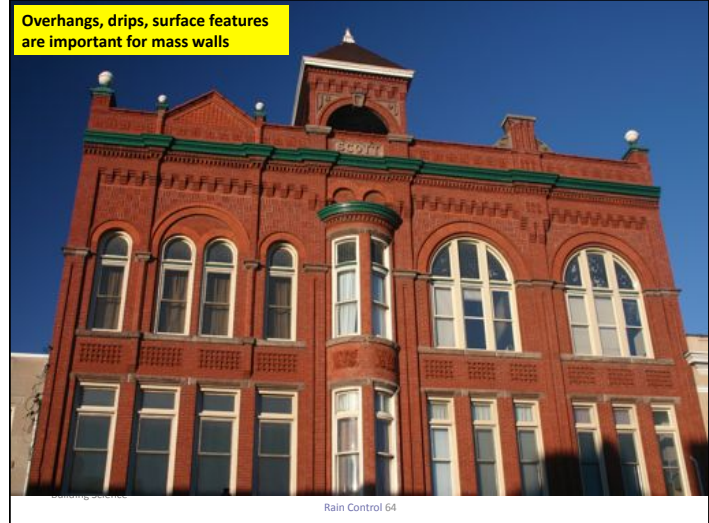
## Rain Control

- 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

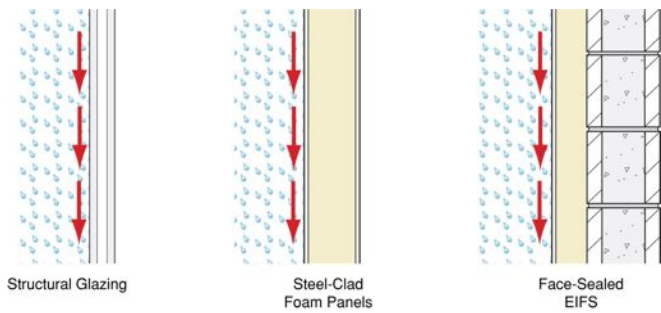
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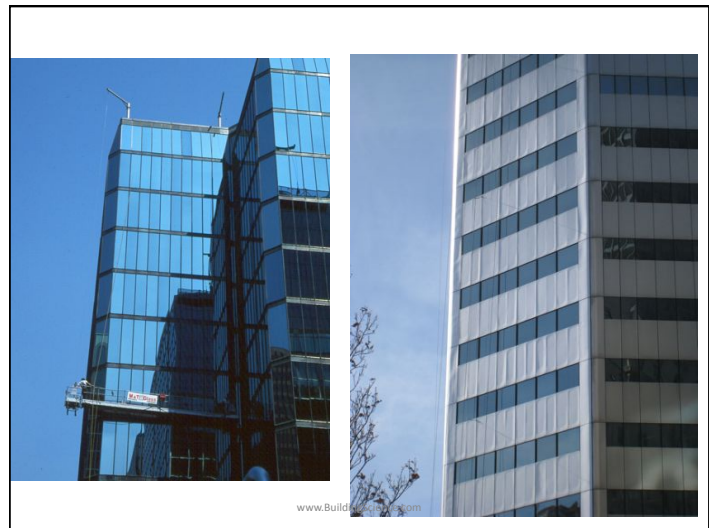
No building paper, flashing, weepholes

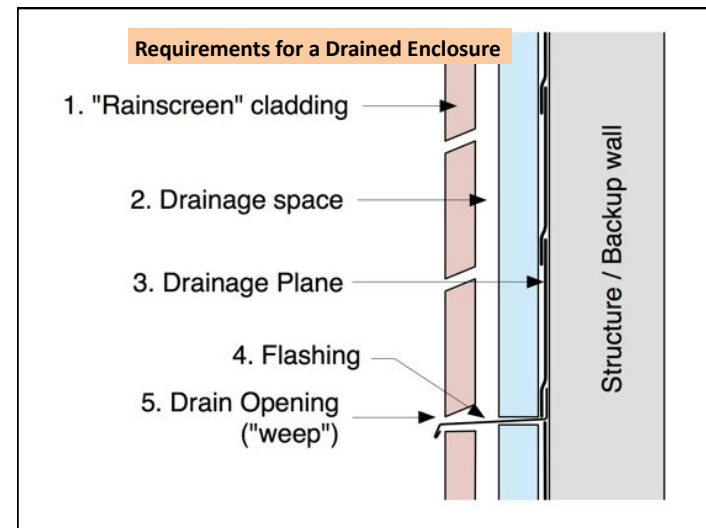
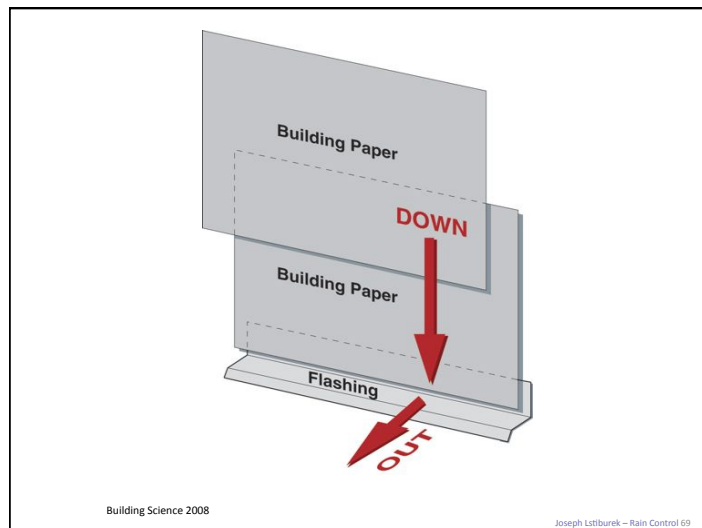
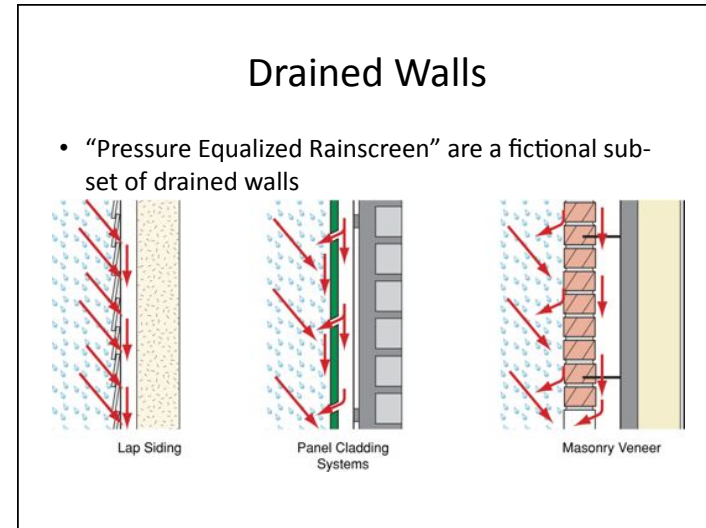
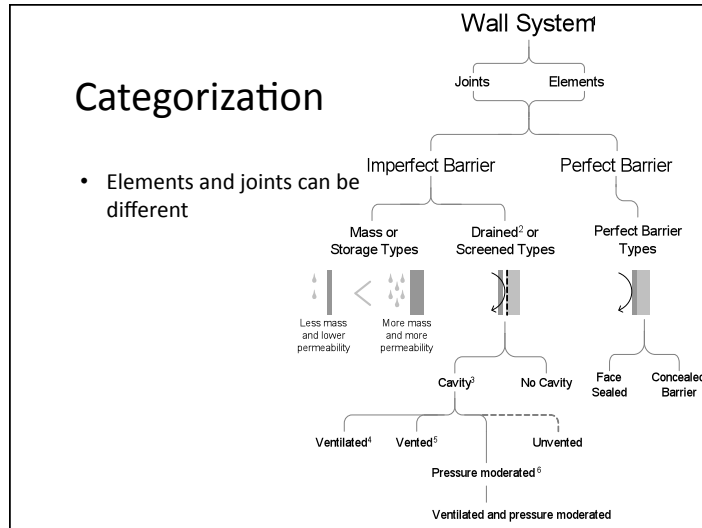


Perfect Barrier / Face Sealed

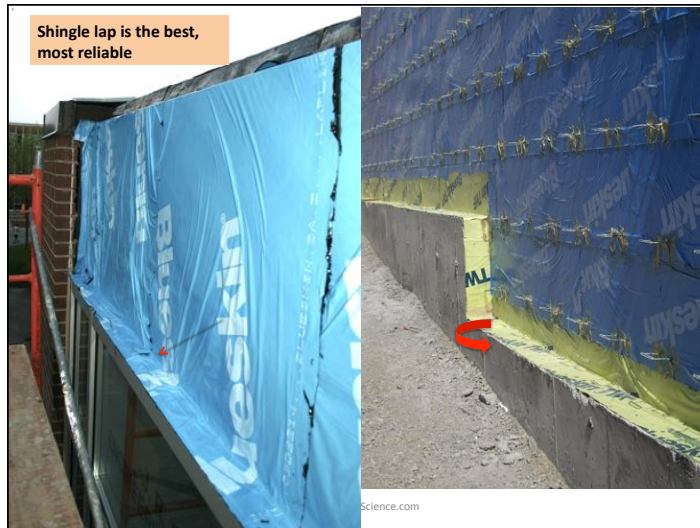


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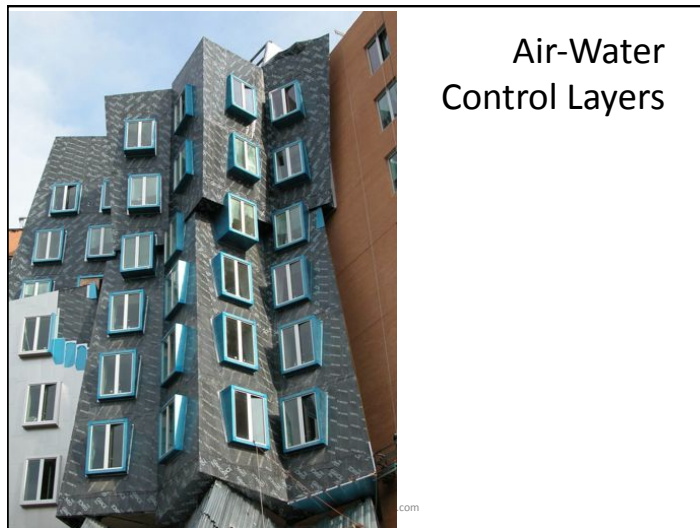




## Air-Water-Vapor

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

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### Details

- Air & water & vapor transition membranes



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Air/Water/Vapor Control No. 75/79

### Non-adhered, vapor permeable

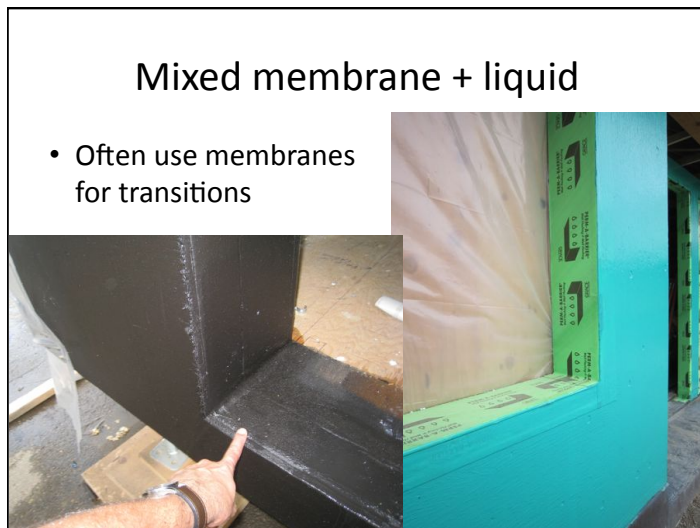
- Supported flexible membrane



Tyvek  
COMMERCIAL WRAP

### Mixed membrane + liquid

- Often use membranes for transitions



### Spray/Trowel Applied Air/water

- Semi-permeable



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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 than diffusion!

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

Wall 1	Wall 2	Wall 3
• Vapor diffusion only • Class II vapor control	• Vapor diffusion only • Class III vapor control	• Air leakage only • Class I vapor control
48 grams / month = 3 tablespoons	538 grams / month = 2.4 cups	22,200 grams / month = 98 cups

Exterior  
T = 0°F / -18°C  
RH = 80%

Interior  
T = 70°F / 21°C  
RH = 35%

1 in<sup>2</sup> opening  
10 Pa pressure

## 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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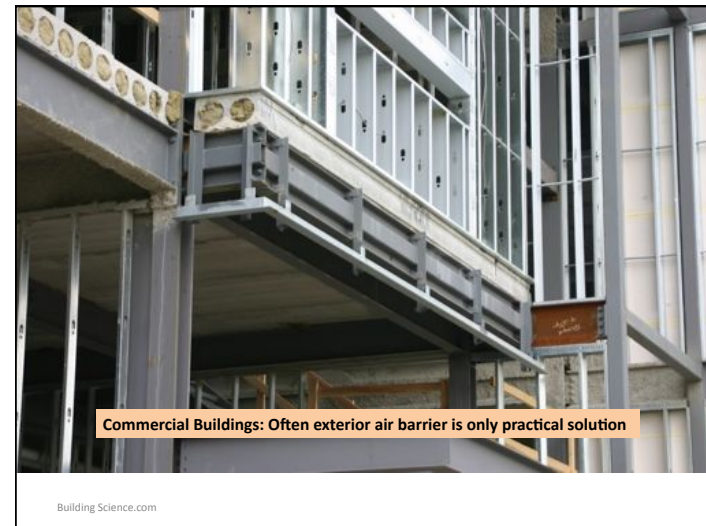
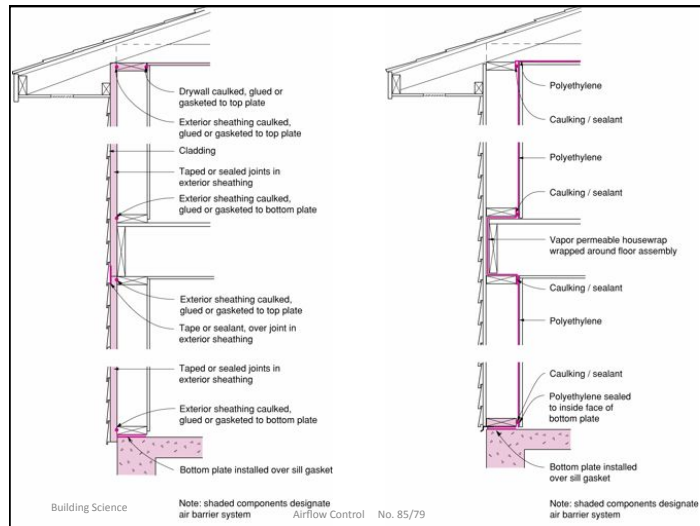
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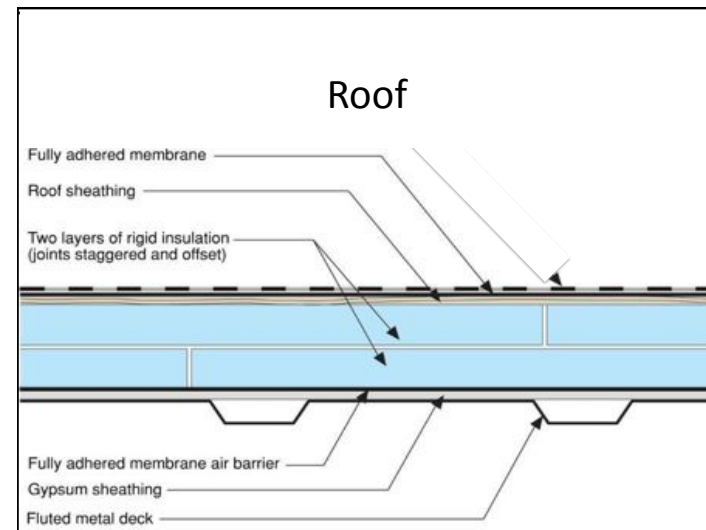
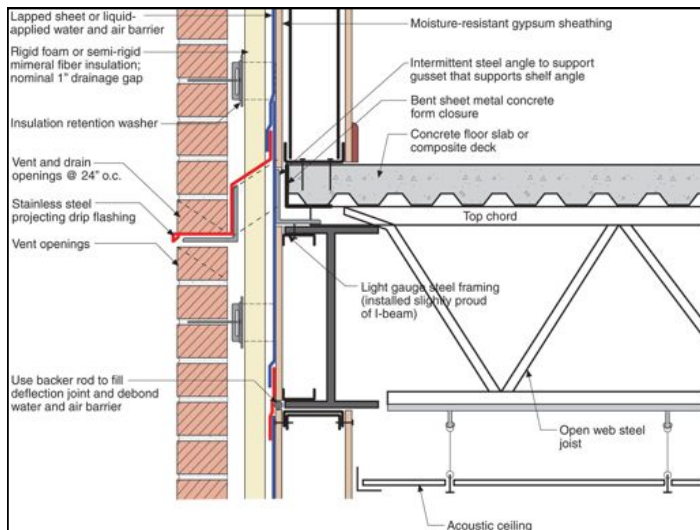
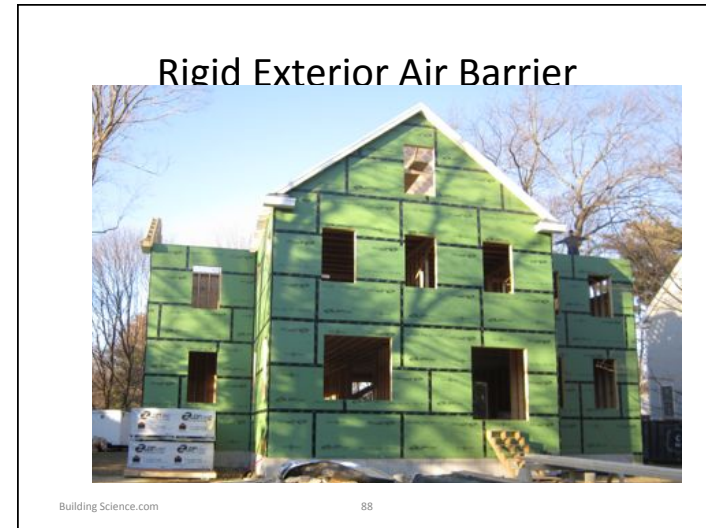
## Air Barriers and Energy

- 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

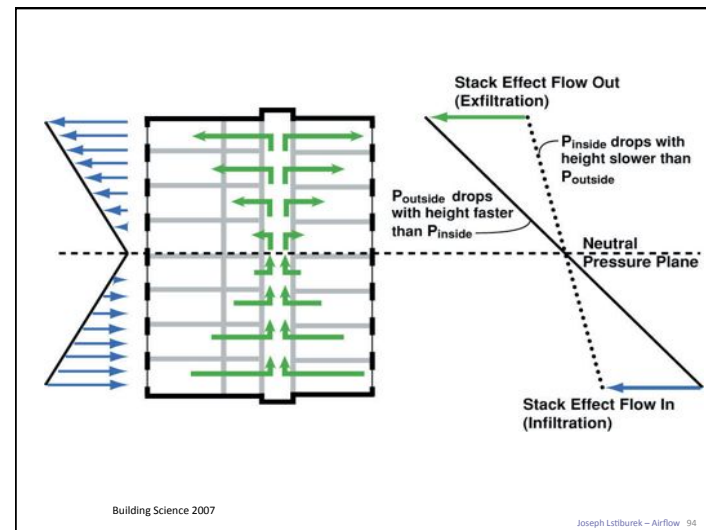
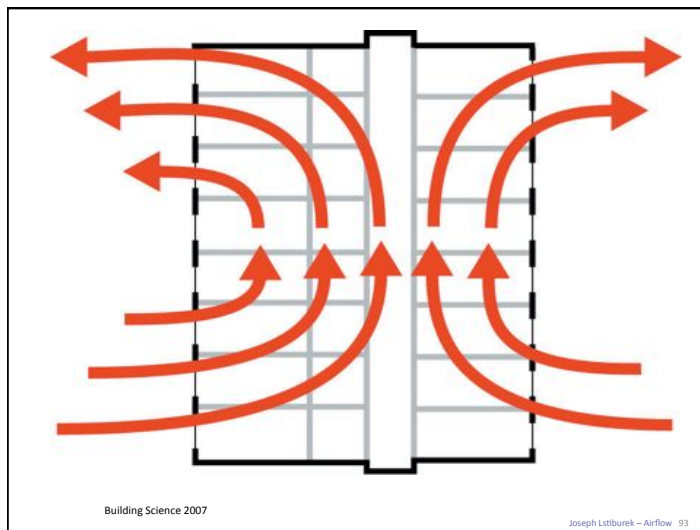
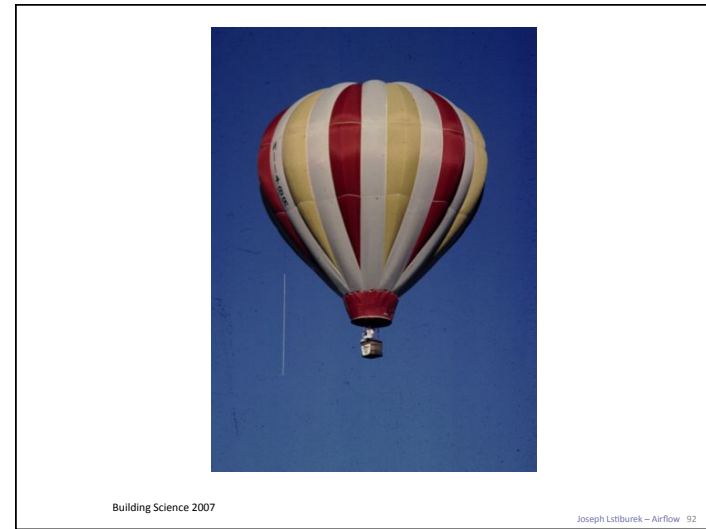
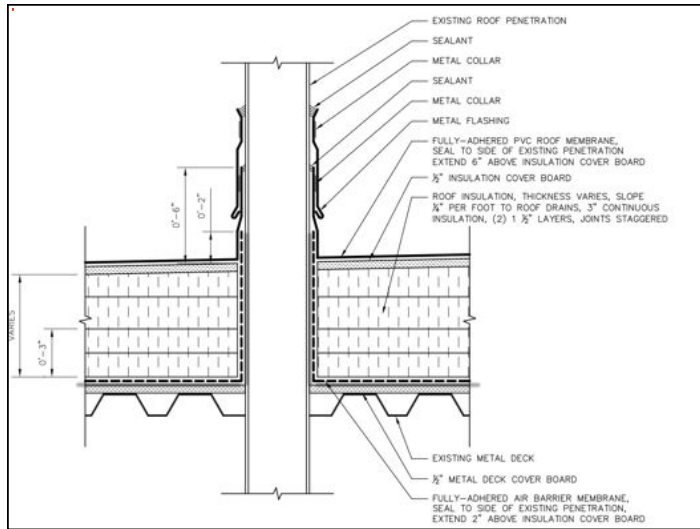
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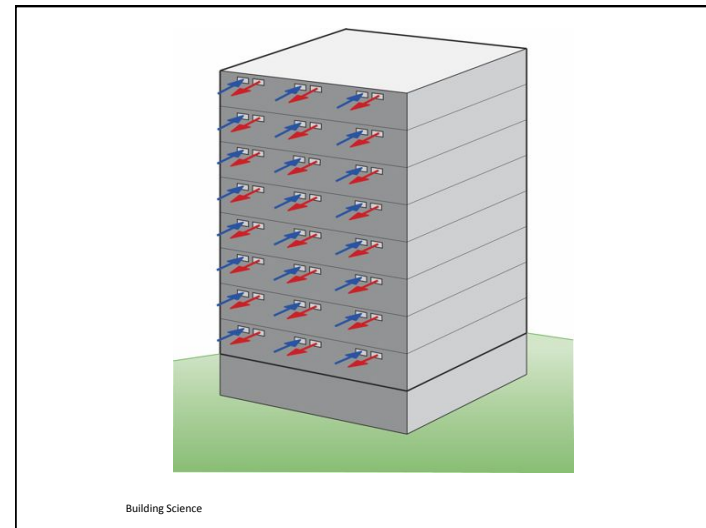
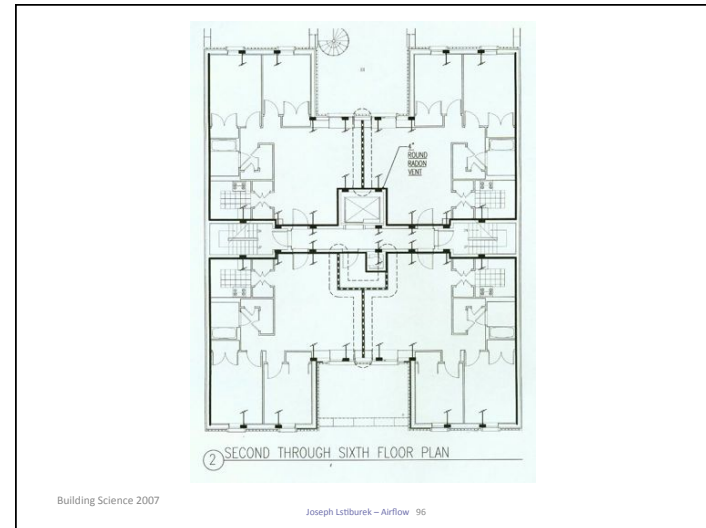
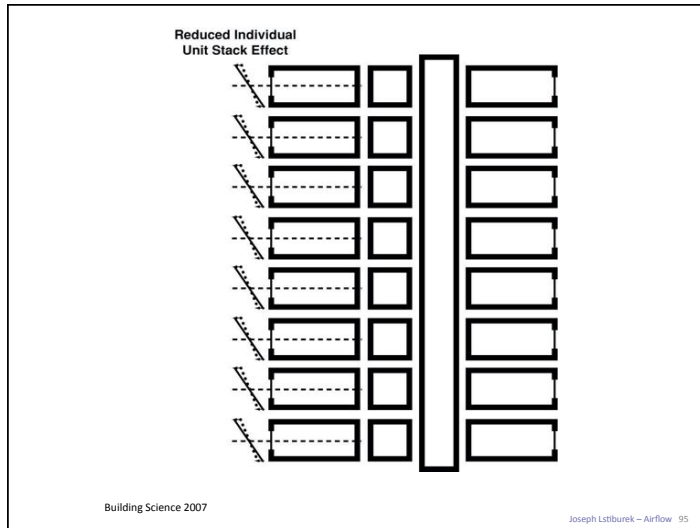


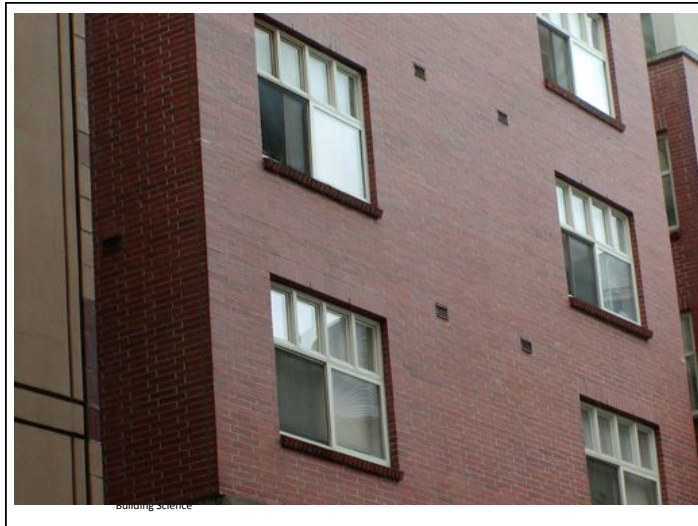












### Thermal Control

- 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/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)	20-35	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

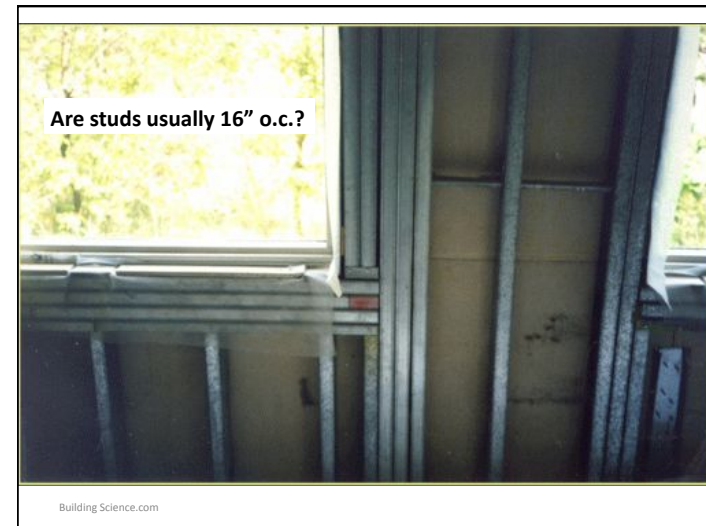
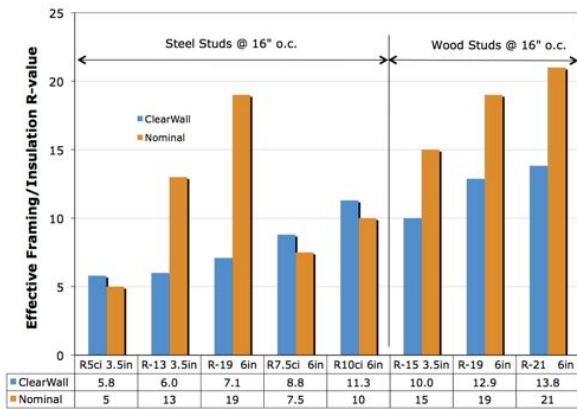
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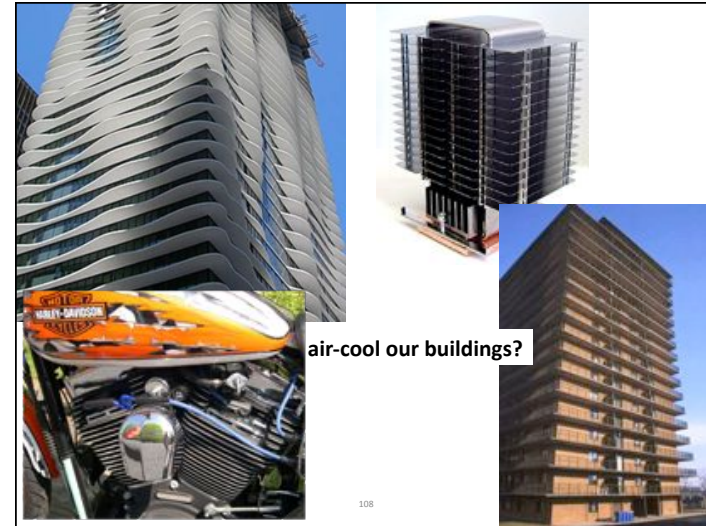
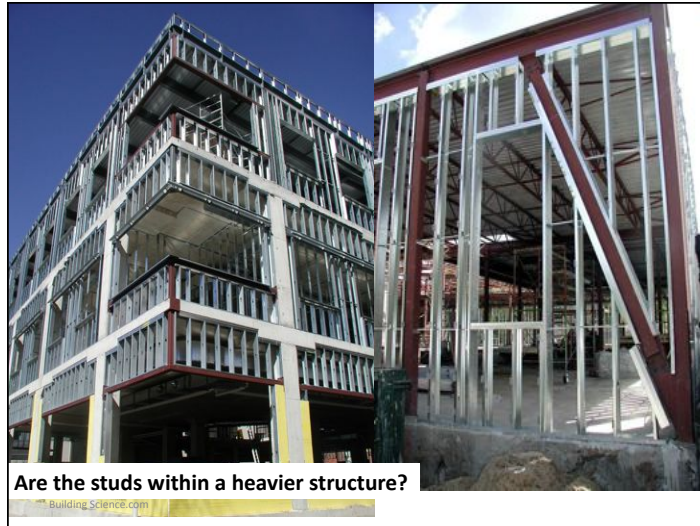
## Thermal Continuity

- 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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## Best-case R-values for stud walls





### Thermal Bridge Examples

- Balconies, etc
- Exposed slab edges

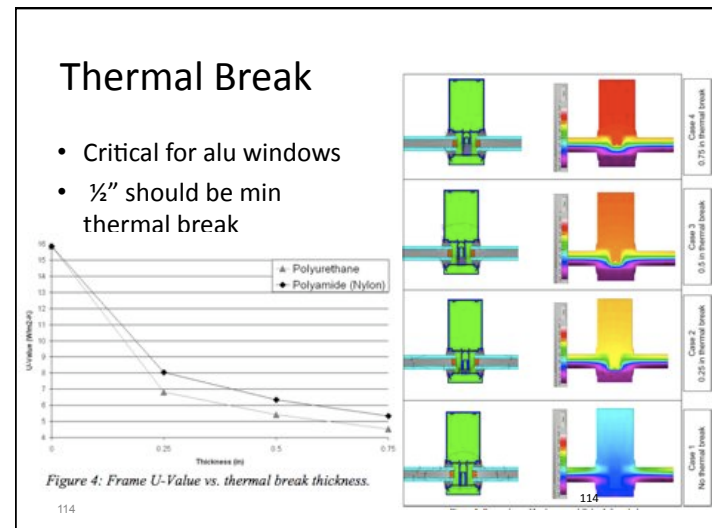
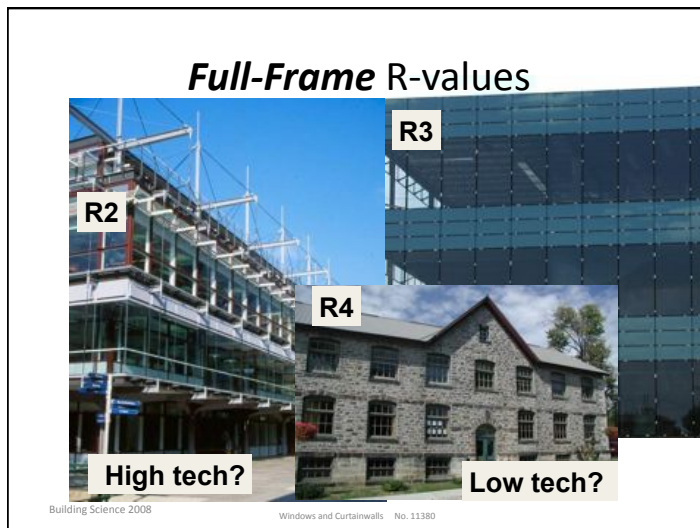
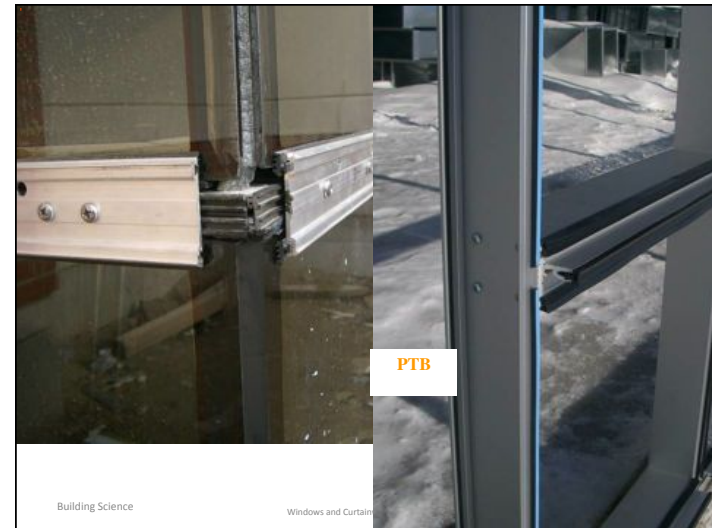
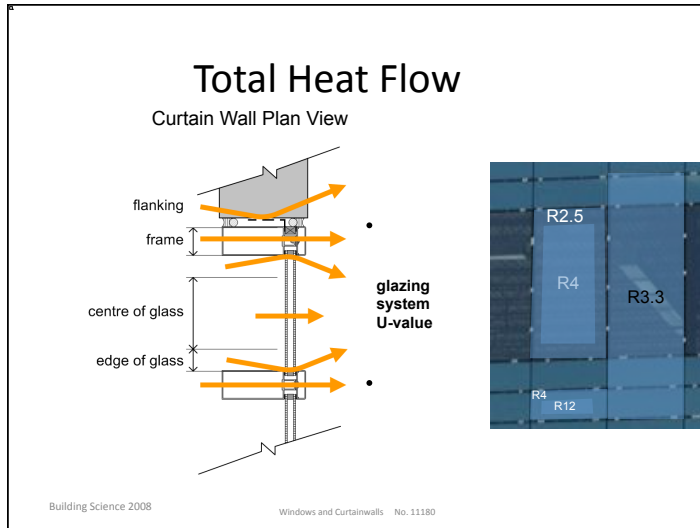
Insulation

### Windows

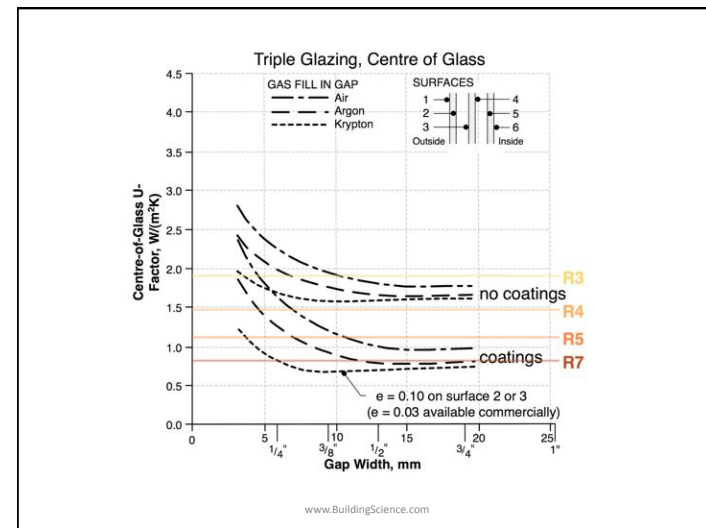
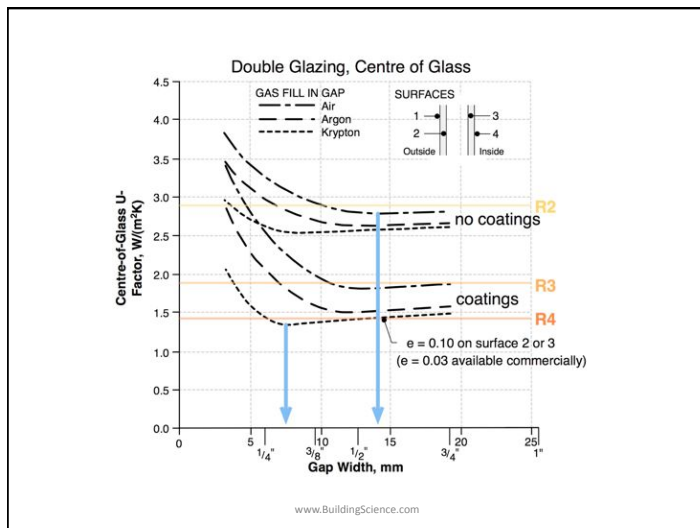
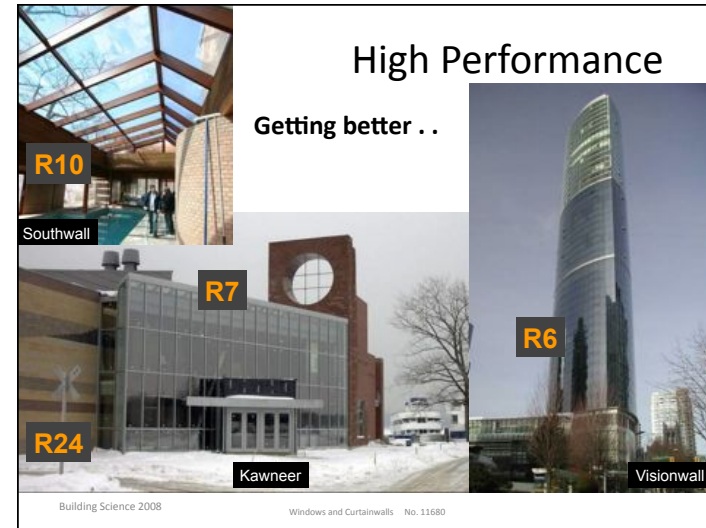
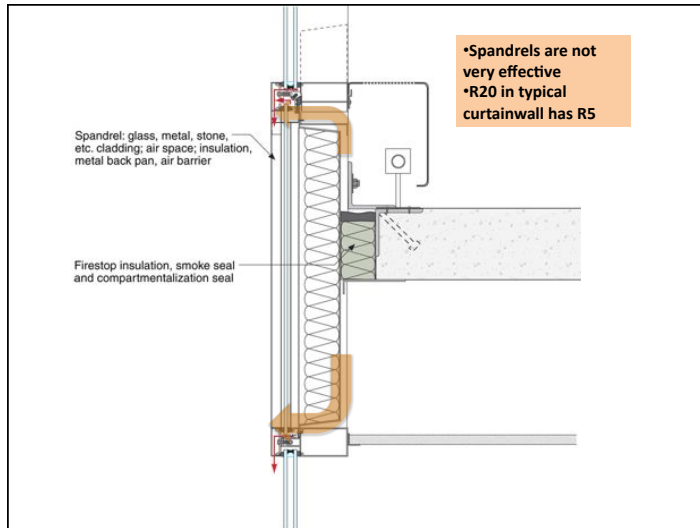
- Our most expensive thermal bridges
- Aluminum is 4-5 times as conductive as aluminum
- Difficult to buy commercial aluminum windows / curtainwall over R3.
- Allow solar heat in
  - Useful in cold weather
  - Requires cooling in summer

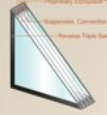
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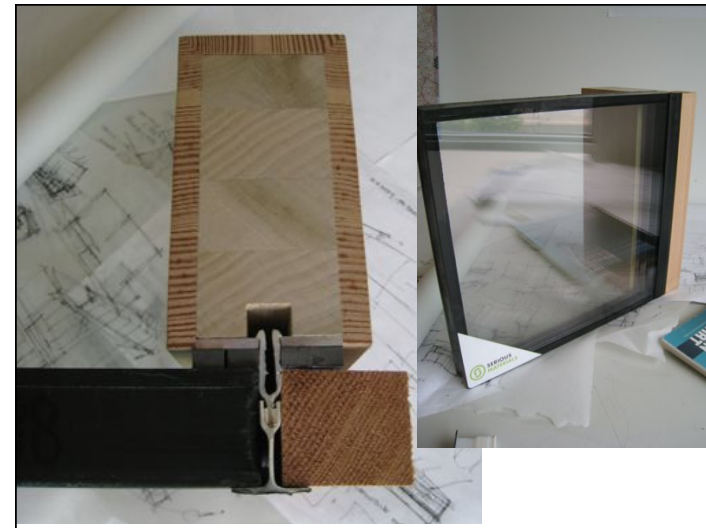




Industry Leading Performance	Center of Glass (COG) Performance*				AlpenGlass™	
	U-Value	R-Value	SHGC	VT	Glazing	Fill
	0.05	20.00	0.29	0.44	Dual Pane, Triple Low Solar Heat Coefficient Film	Xenon
Premium Performance	0.07	14.29	0.24	0.43	Dual Pane, Dual Low Solar Heat Coefficient Film	Krypton
	0.11	9.09	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

\*Performance numbers are centered values based on IBC Window 4.2 software

Courtesy of ThermoProof Windows and AlpenGlass+



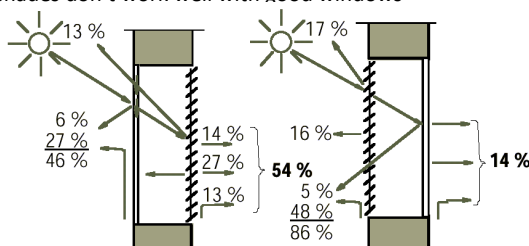
### Solar Gain

- 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

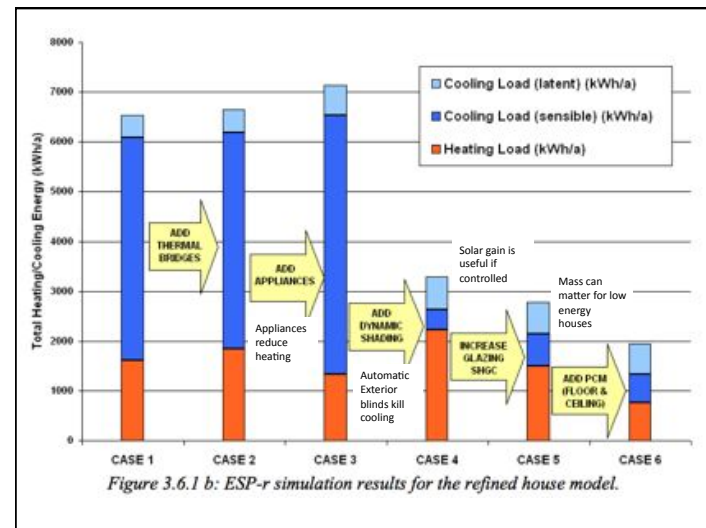
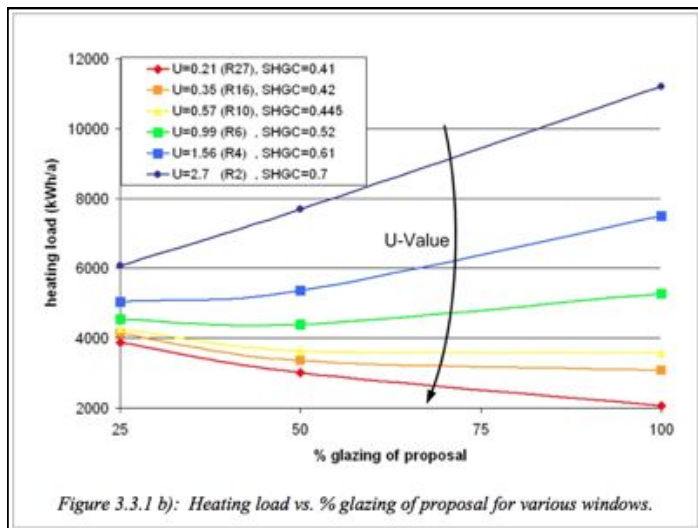
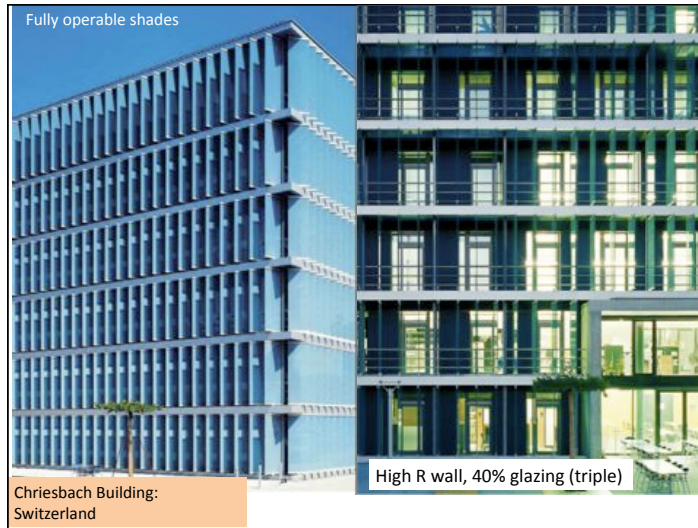
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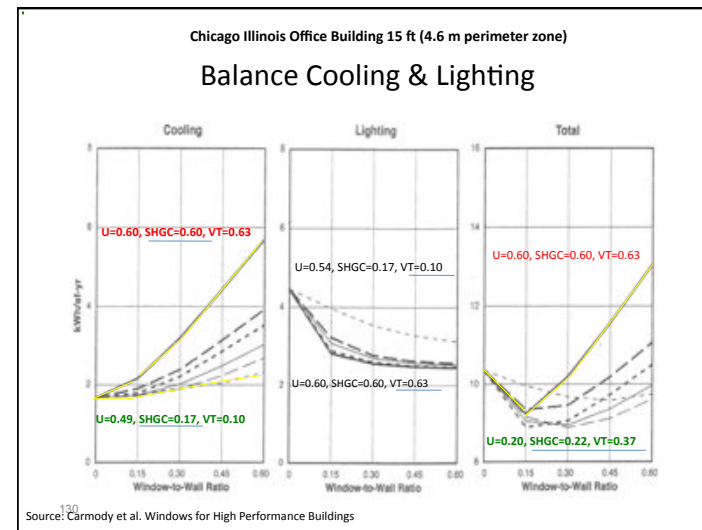
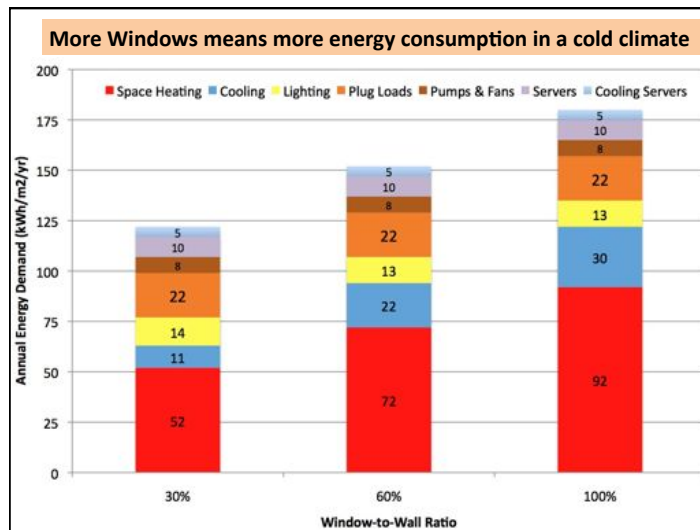
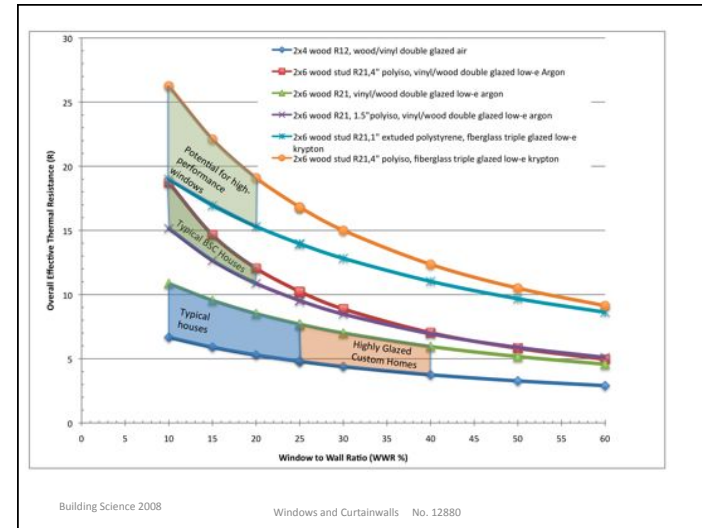
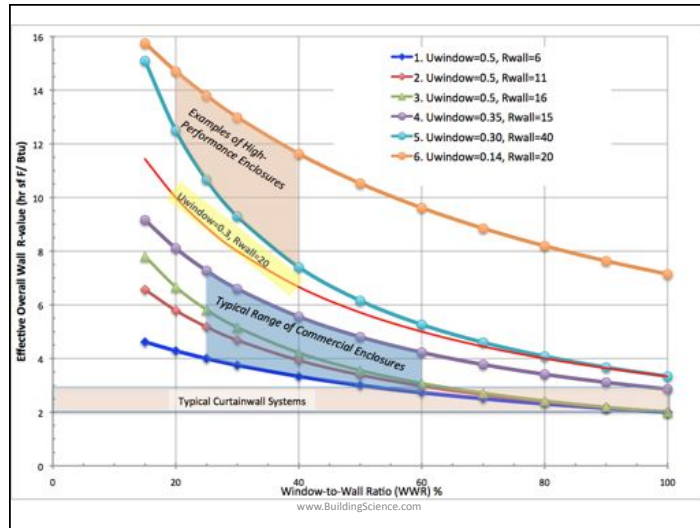
### Interior or Exterior Shade

- 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



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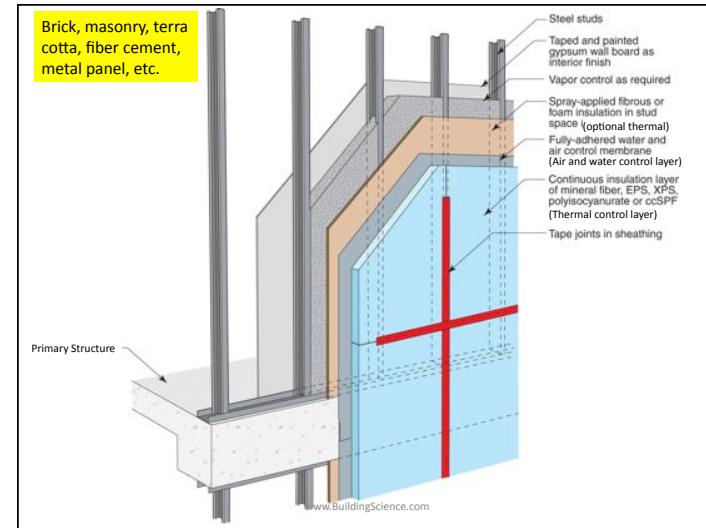
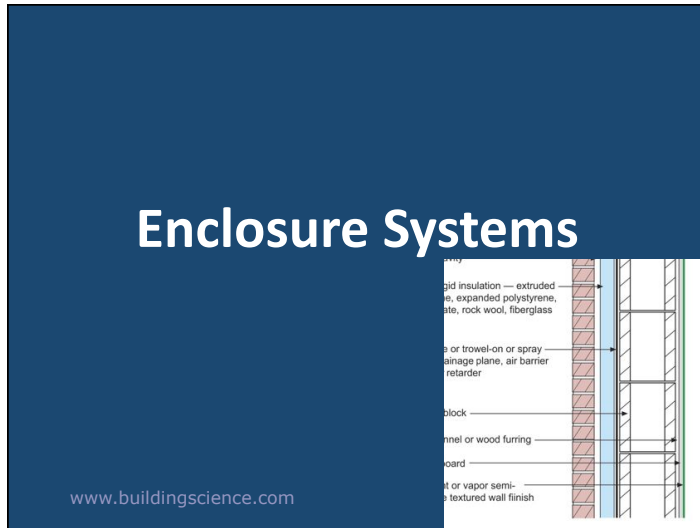


## Summary

- Identify functional control layers
  - Rain, air, heat, vapor
- Provide continuity of control layers
  - details
- Select high levels of performance

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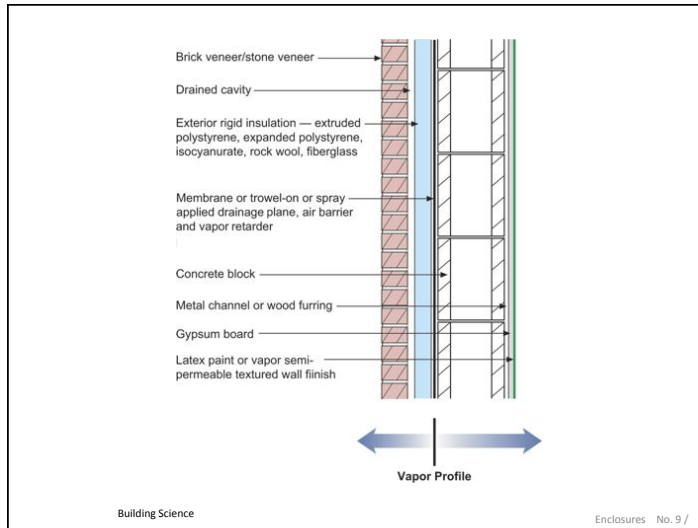
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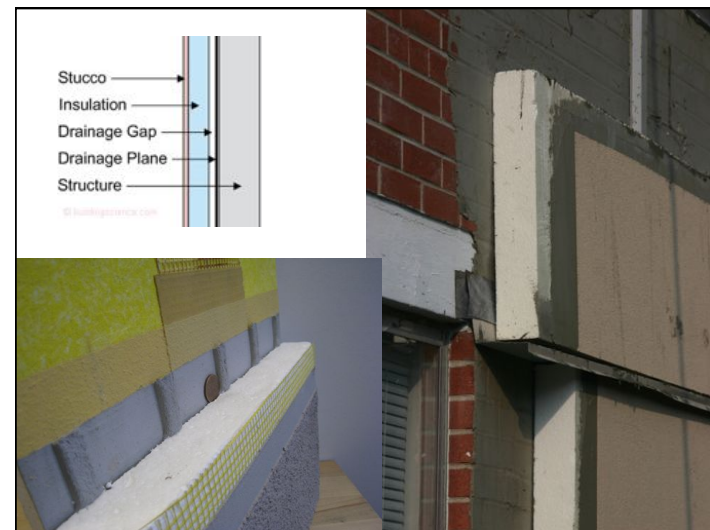
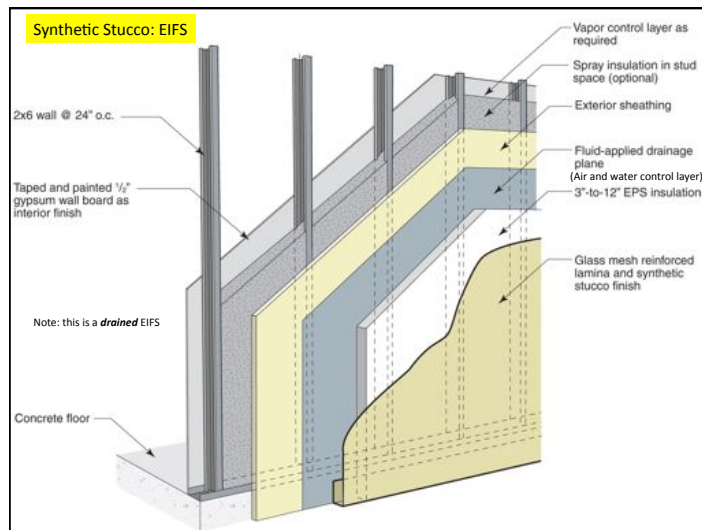


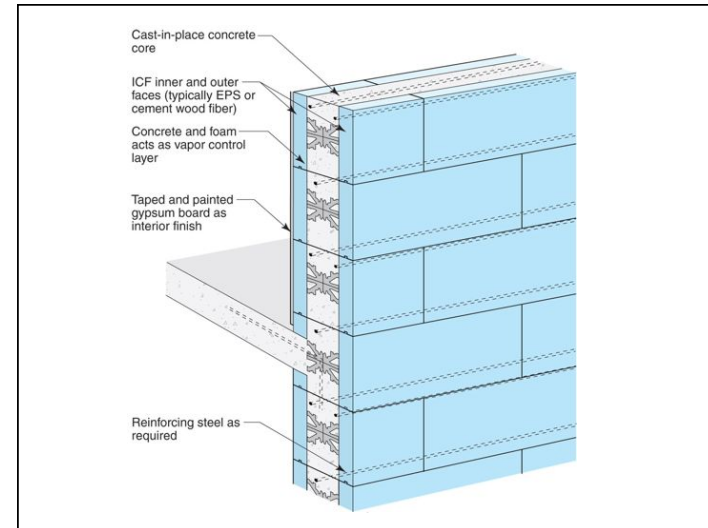
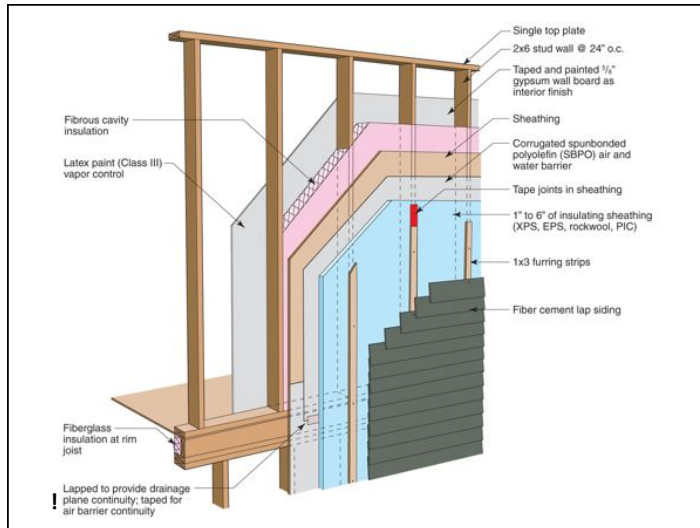
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8









### Insulated Concrete Form

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

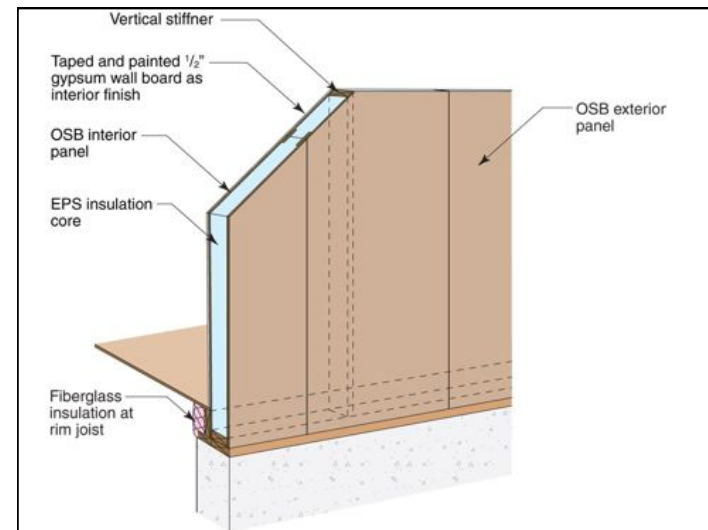
Typical ICF Floor Wall

Typical ICF Grid Wall

Typical ICF Post-and-Beam Wall

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Insulation at



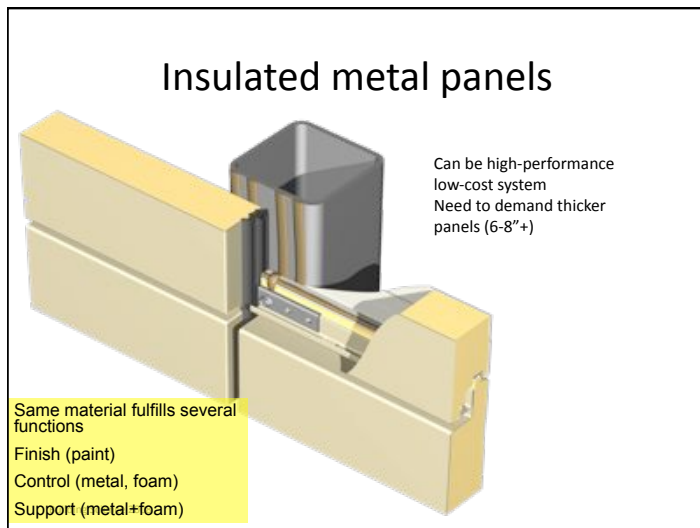




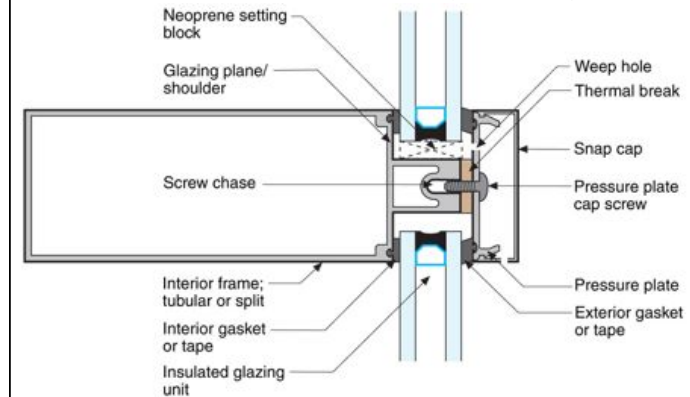
## Structural Insulated Panels

- 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!

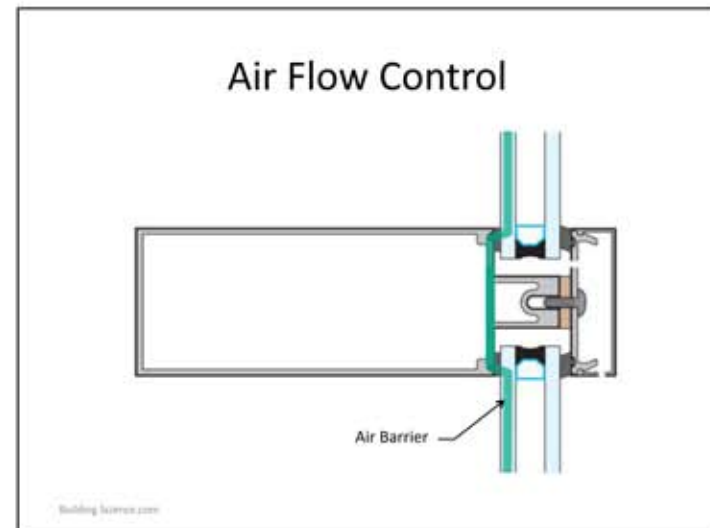
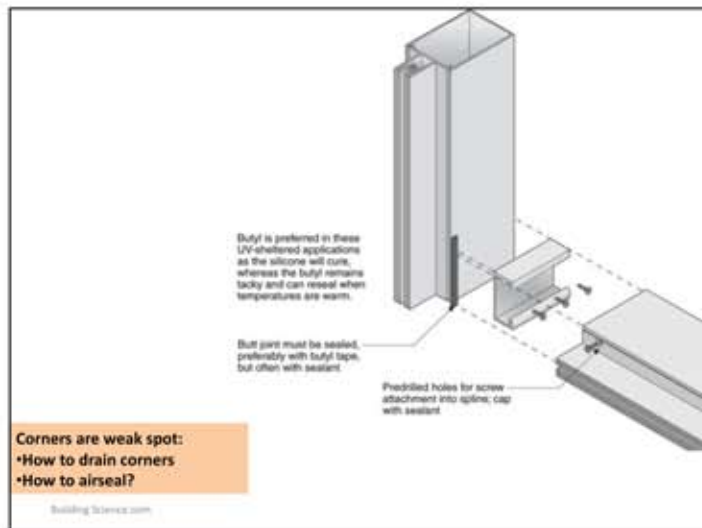
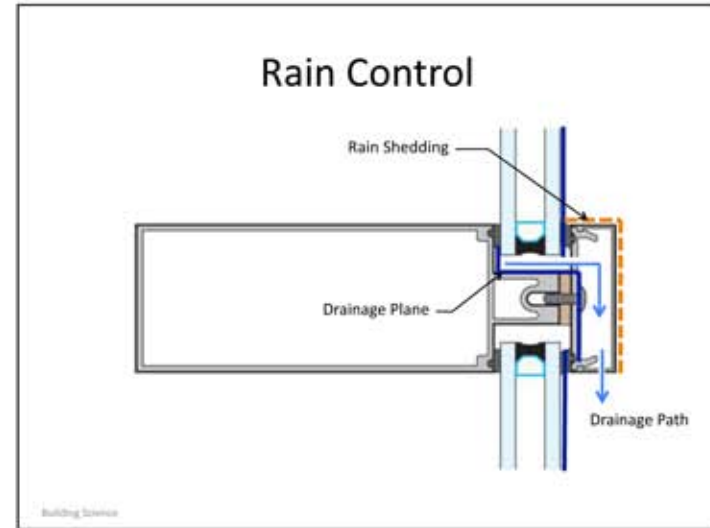
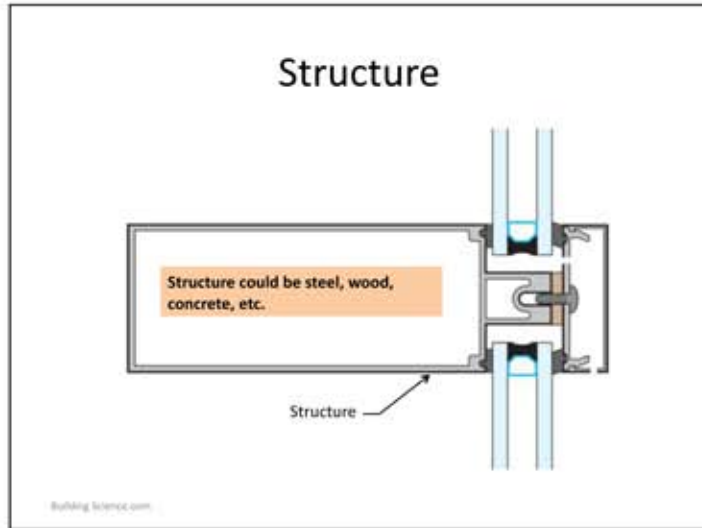
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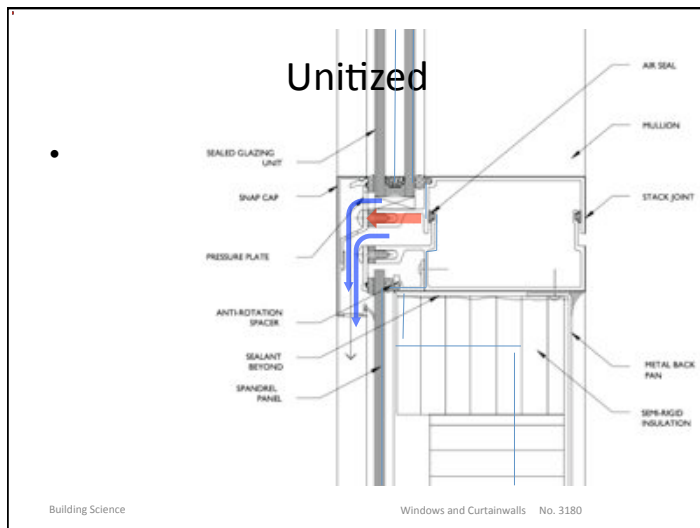
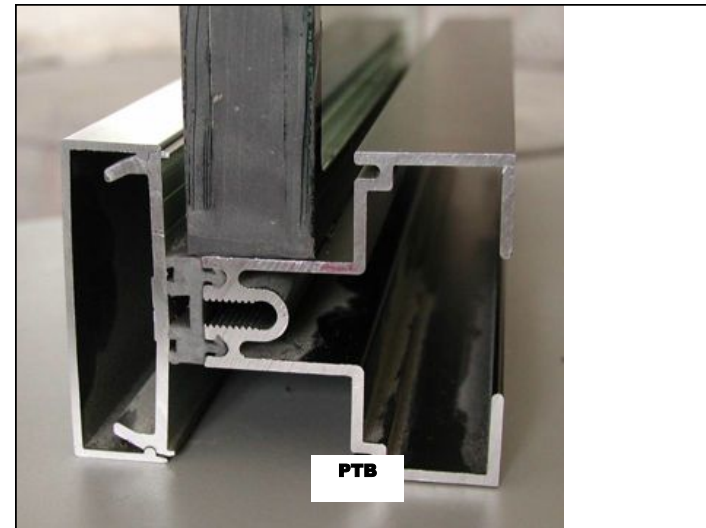
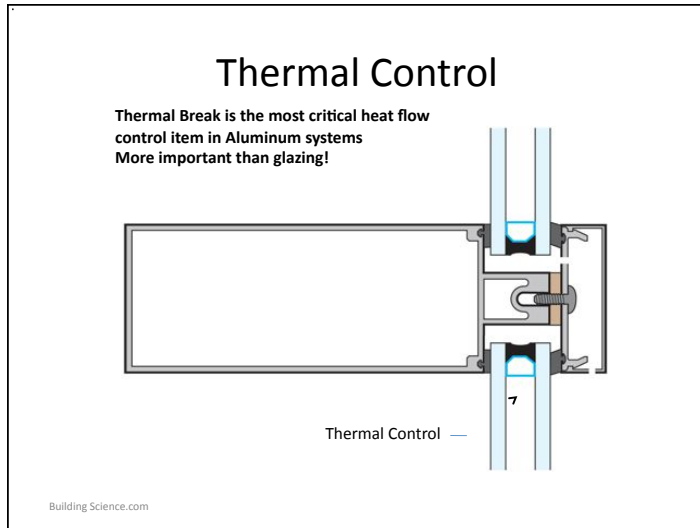
## Curtainwall: Anatomy & Jargon



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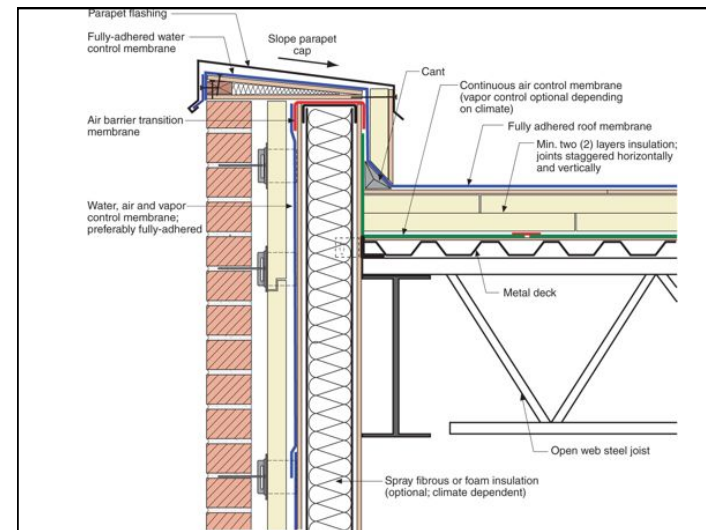
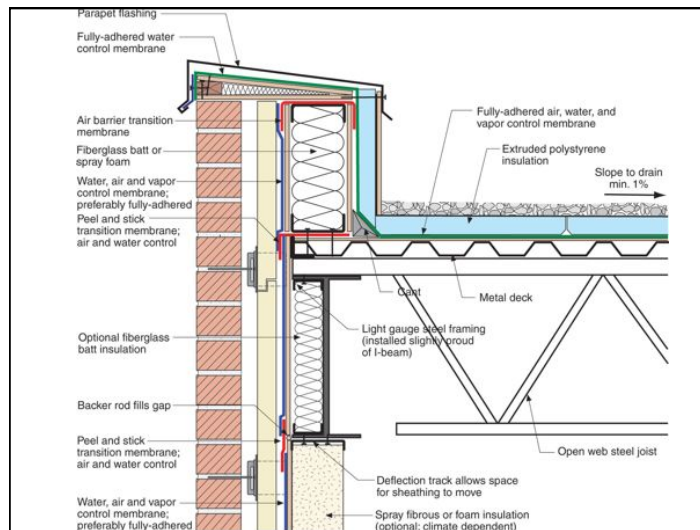
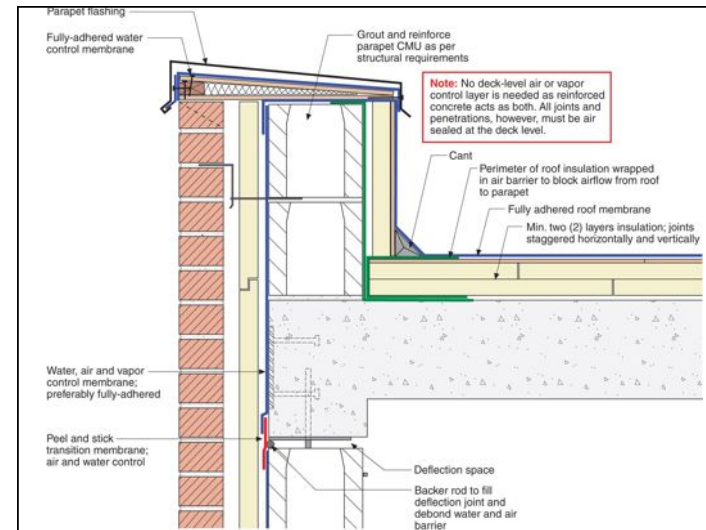


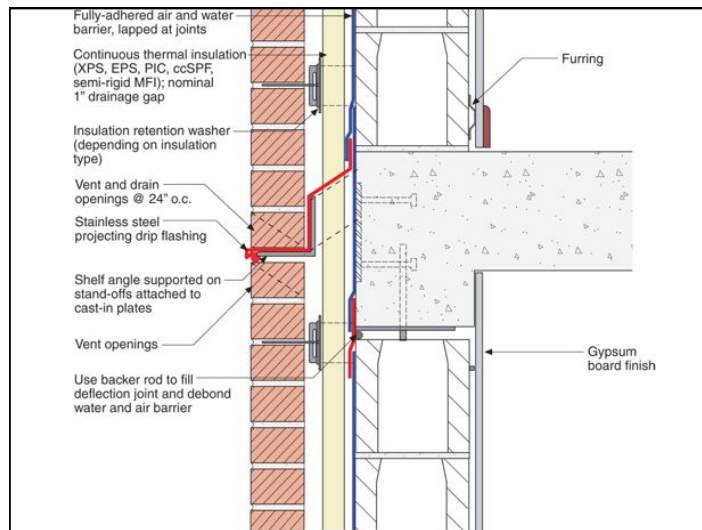
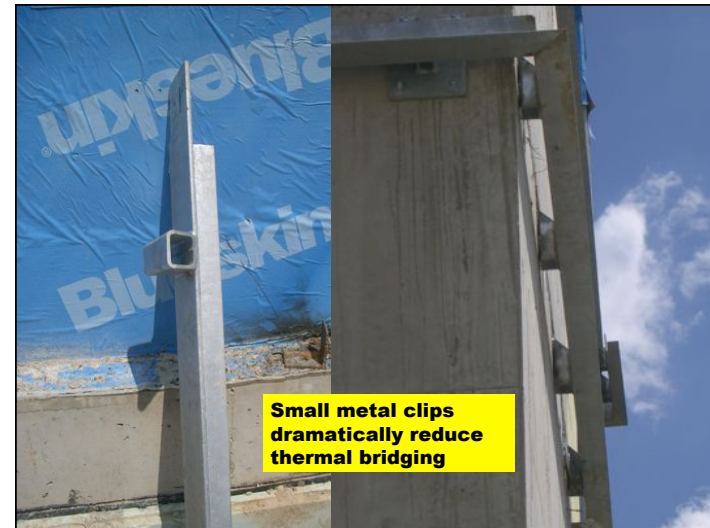
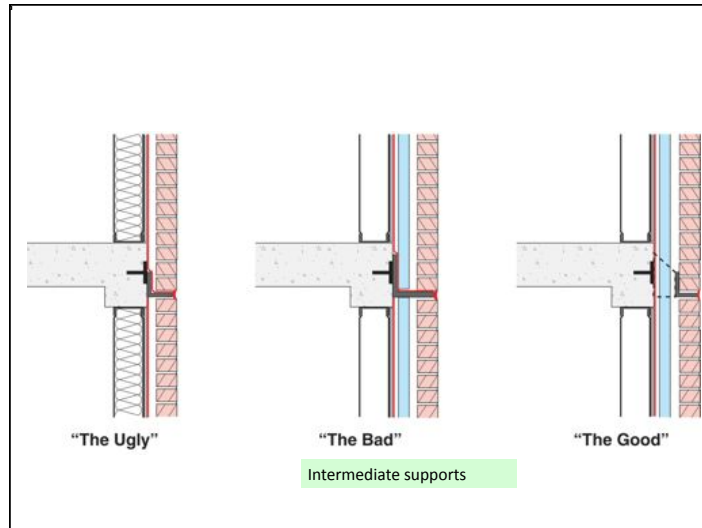


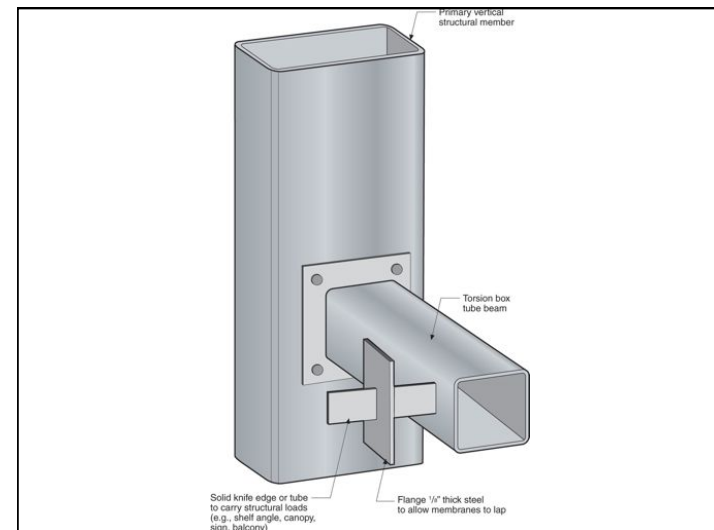
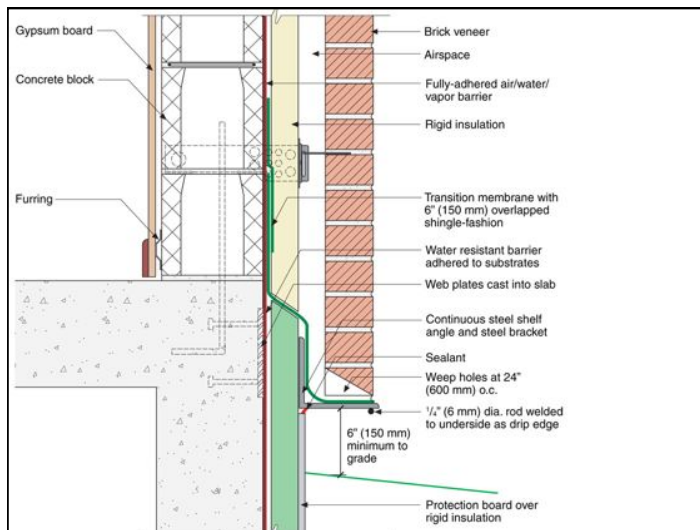
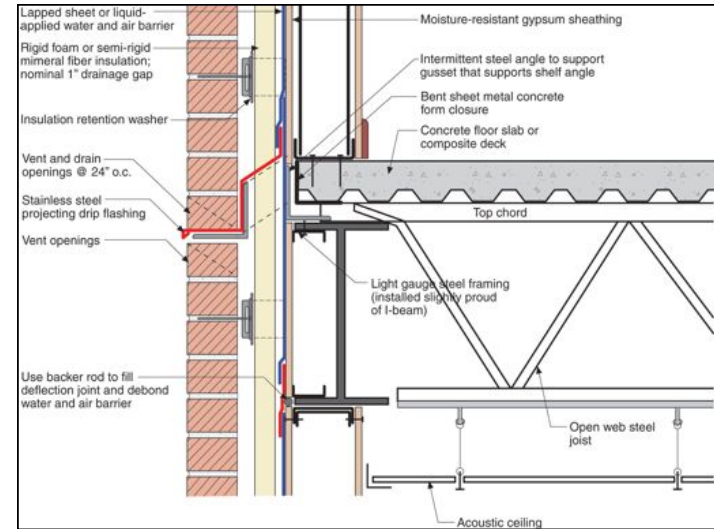
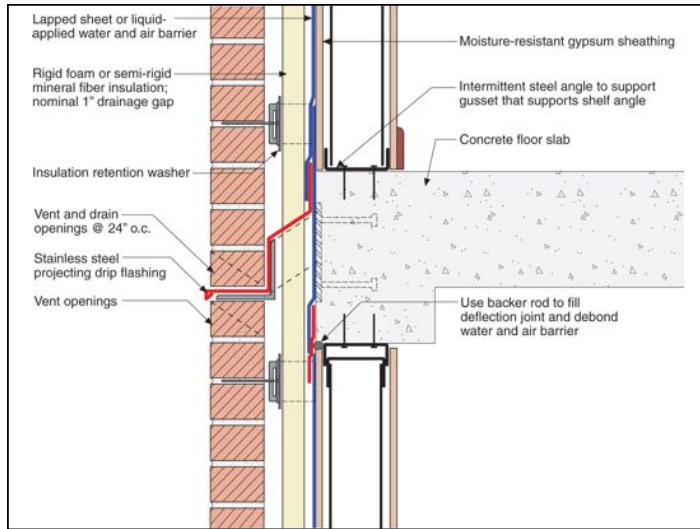
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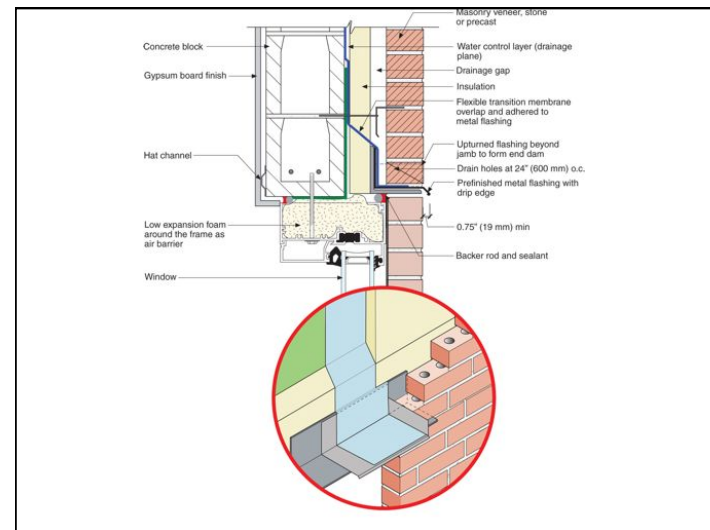
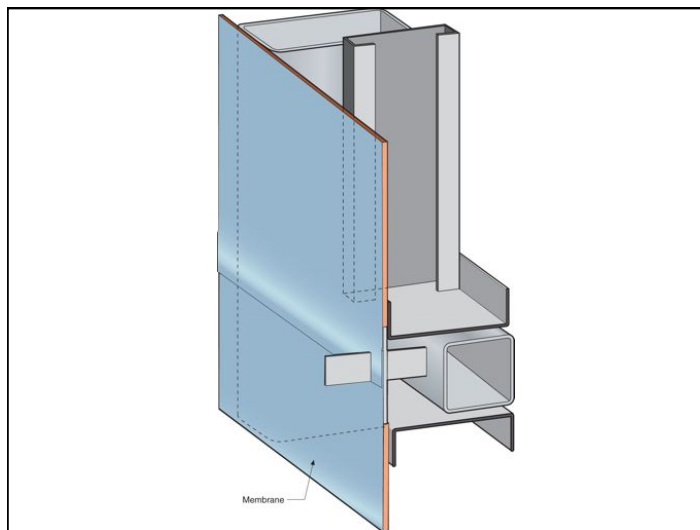
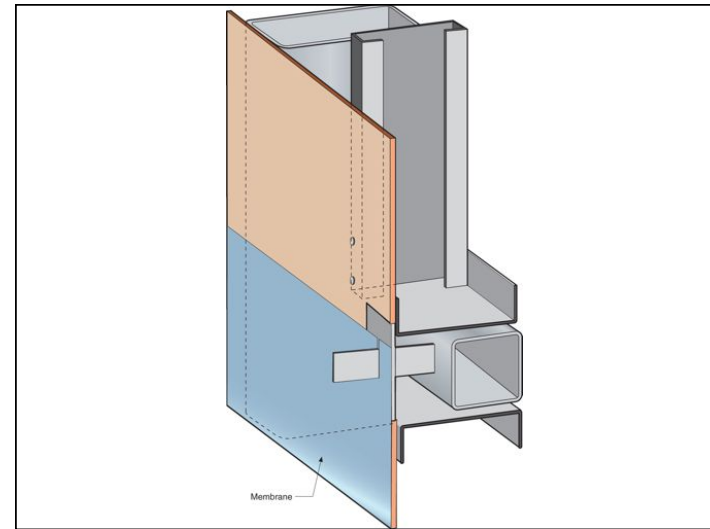
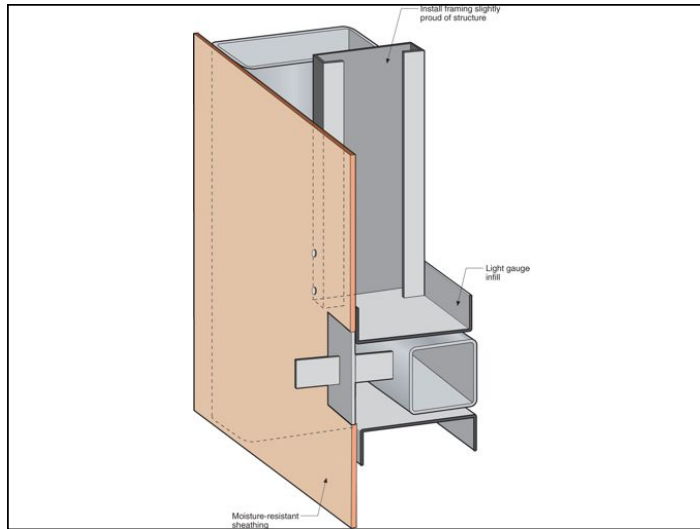
- Integration of penetrations and transitions is critical
  - Must maintain continuity of rain, air, thermal and vapor control through the transition!
  - Exposure and performance expectations guide designers level of compromise

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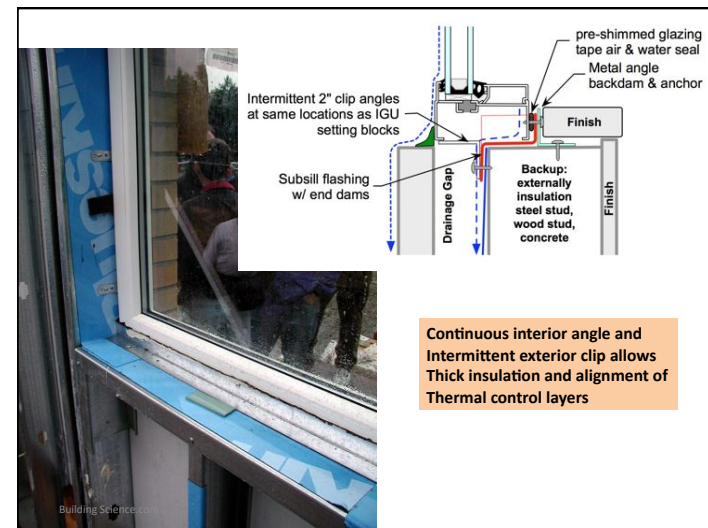
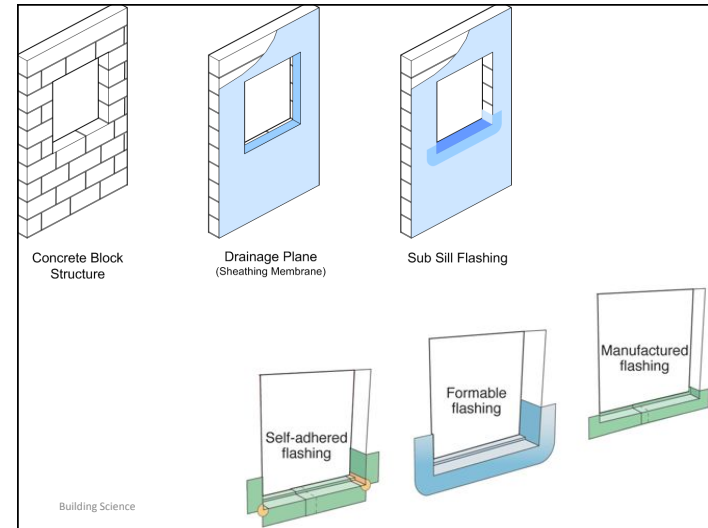
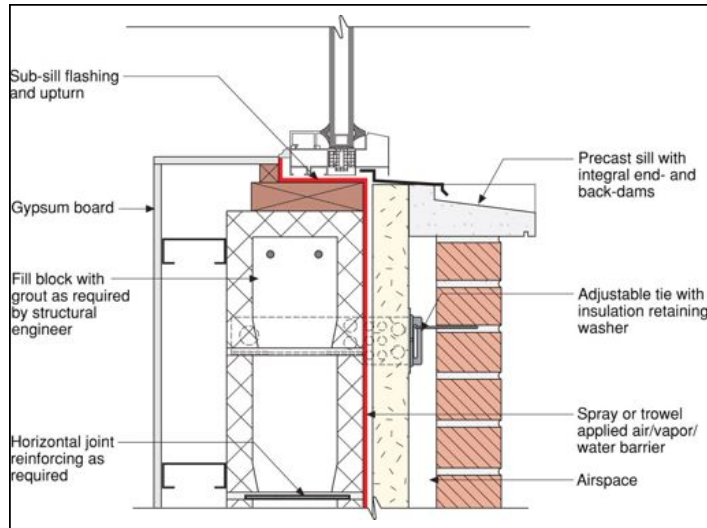


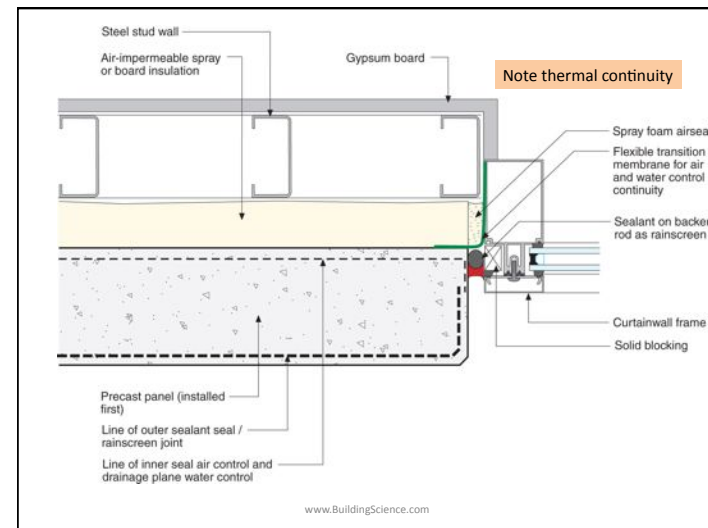
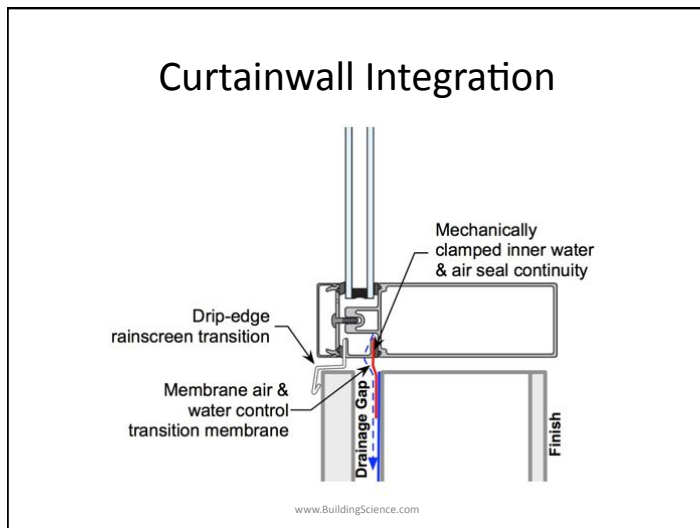
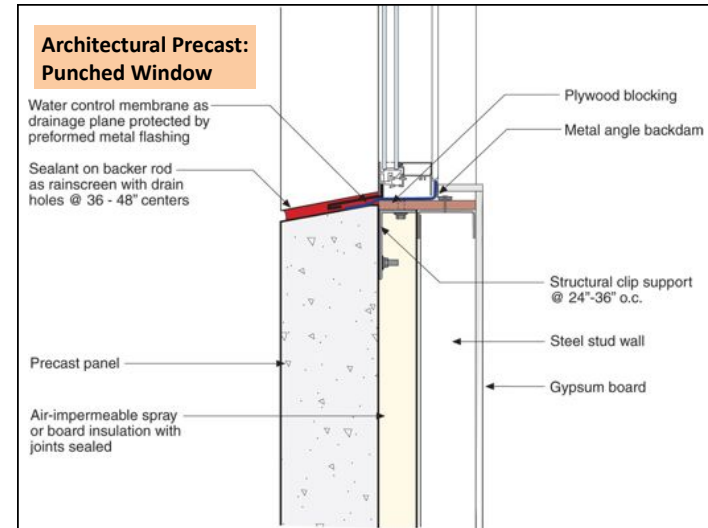
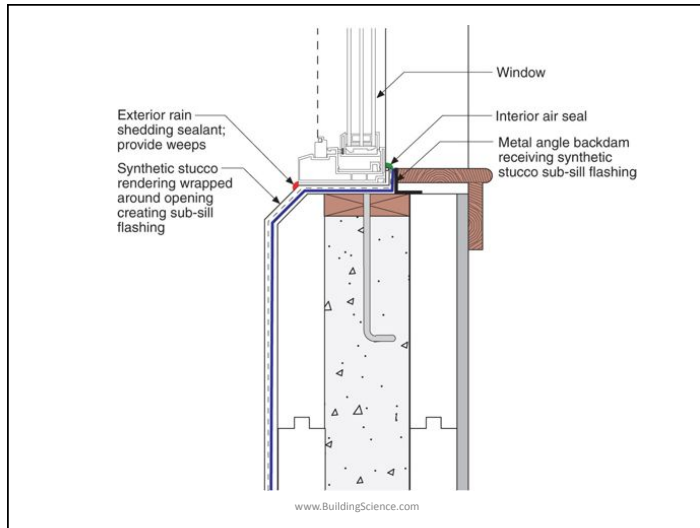


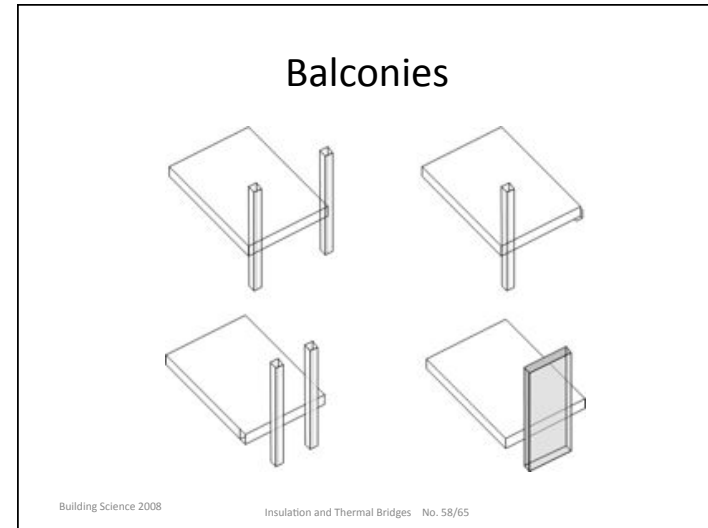
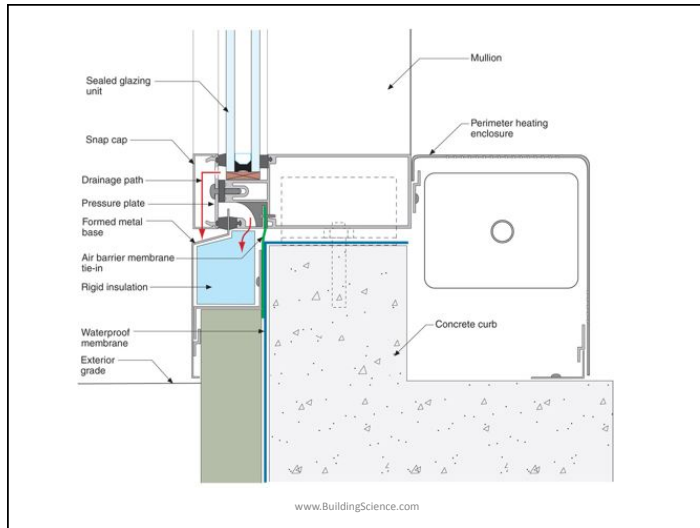


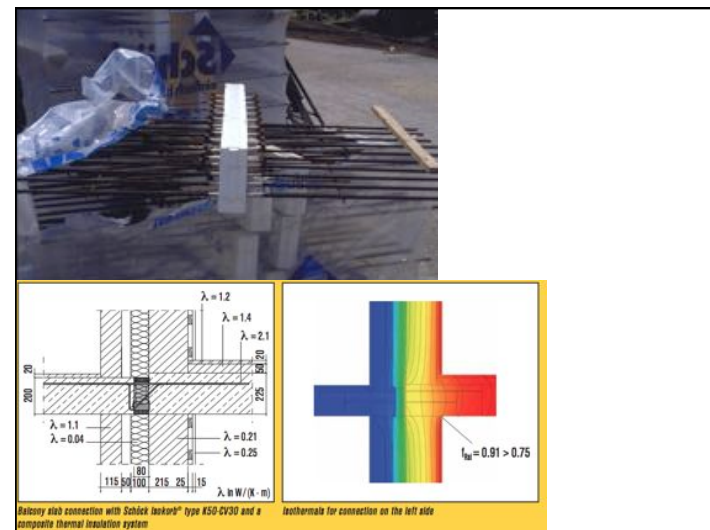
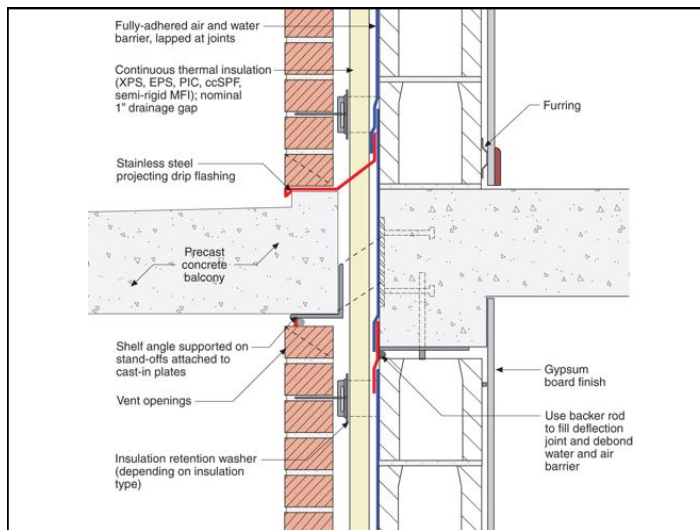




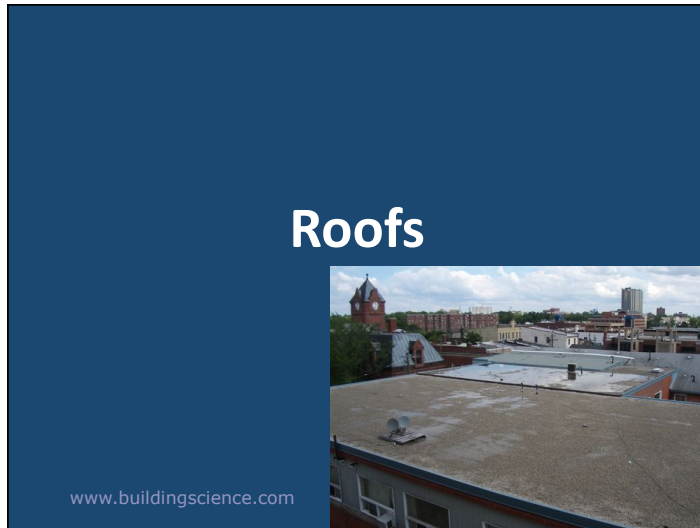








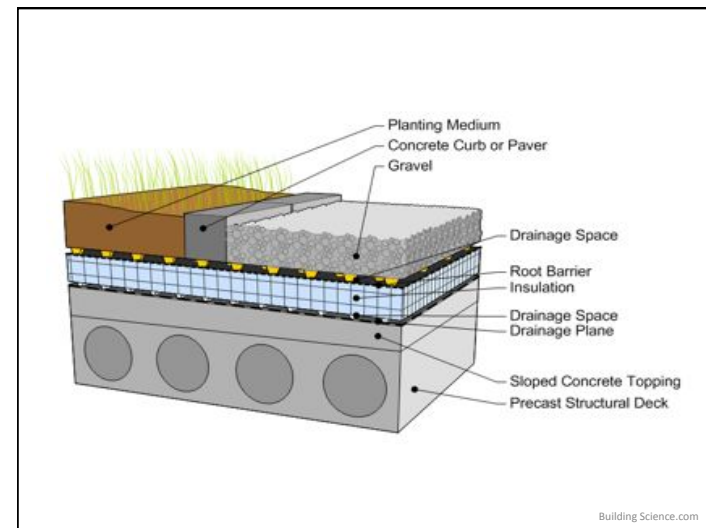
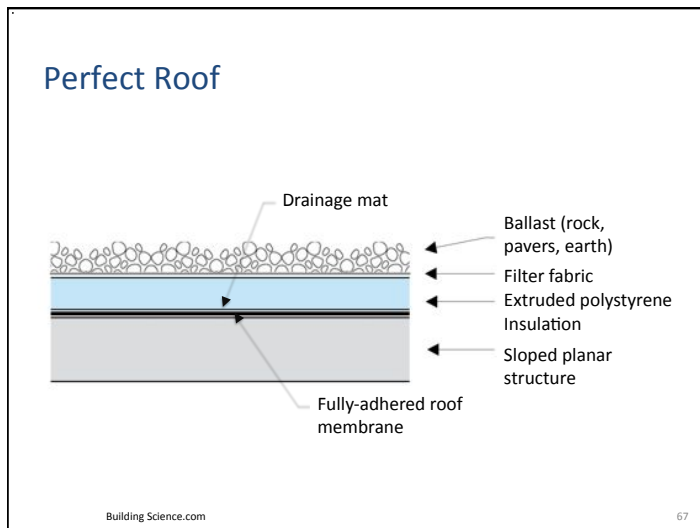




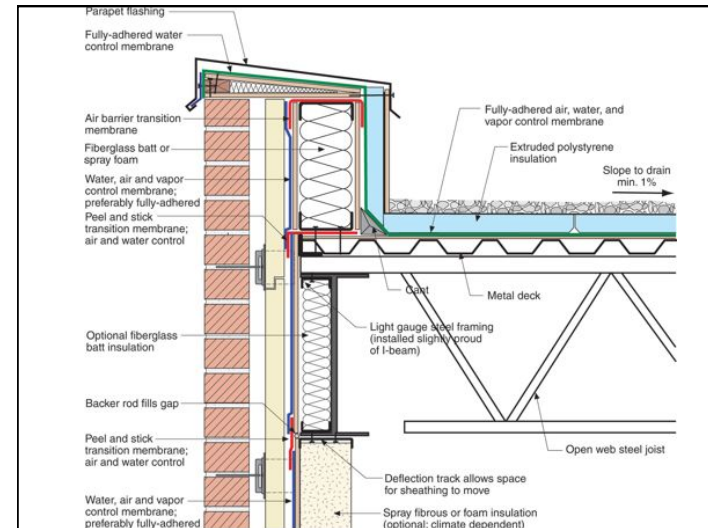
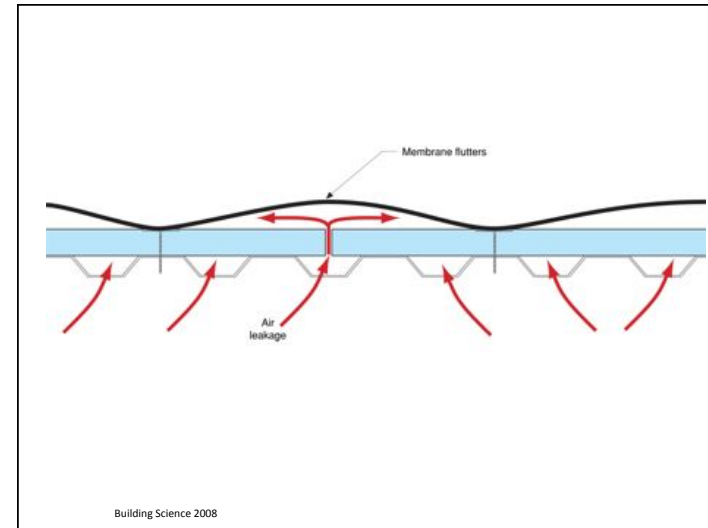
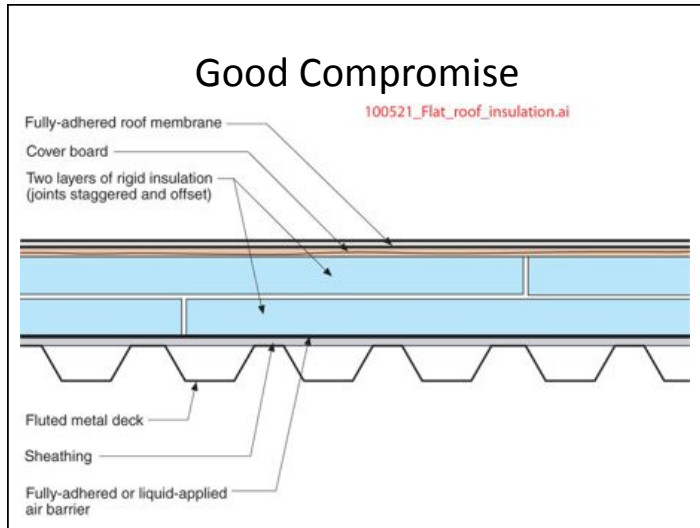
### Low-Slope Roofs

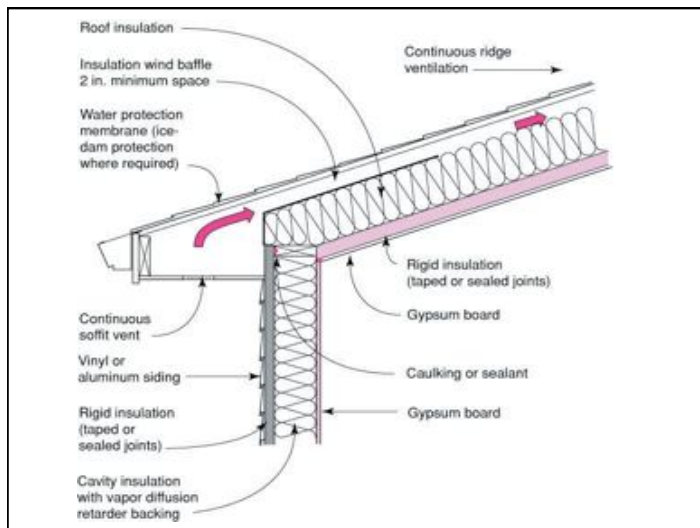
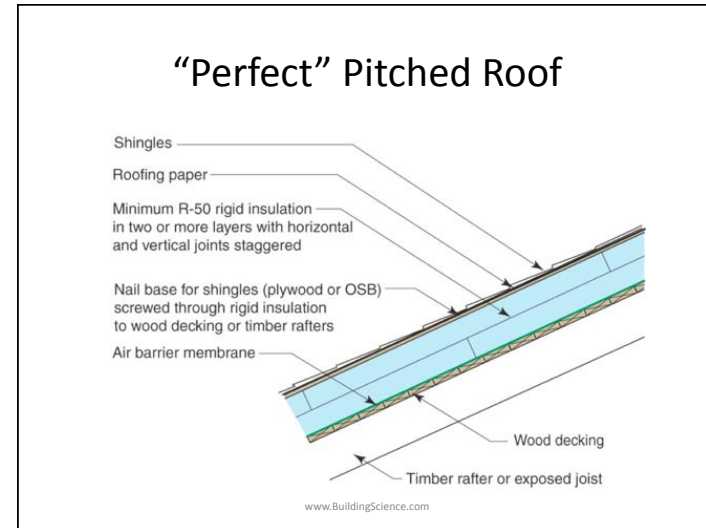
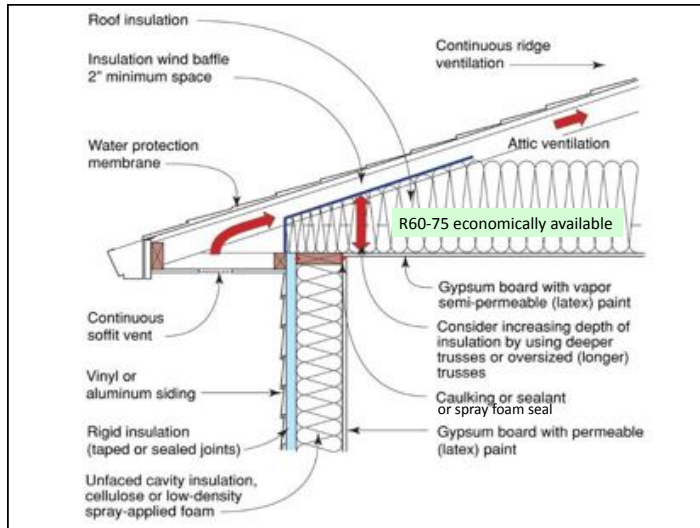
- Not flat. Ponding is not acceptable.
- Get water right, then worry about energy!
- Components
  - Rain barrier is roof membrane
    - Drainage gap is the outdoors
  - Air barrier can be roof membrane
    - Better to install interior
  - Insulation is rigid, polyiso, XPS, EPS, rockwool

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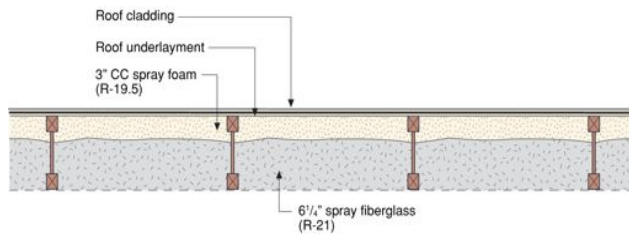


## Unvented Cathedralized Attics

- 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

## R40+ roof, fire protection



R40 10" TJI Cold climate Solution shown  
 R50 12" TJI with 4" ccSPF (R24)+ 8" FG (R30)

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