University of Waterloo

The BS of *more* Sustainable Building

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bsc Building Science Corporation

Sustainable buildings

- "Can keep doing what we are doing indefinitely"
  - A sustainable society, process, or product is one that can be sustained or continue to be produced over the long term, without adversely affecting the natural conditions (e.g, soil, ecosystem, water quality, climate, etc) necessary to support those same activities in the future.
  - **Even the greenest buildings today are not sustainable**
- Low-Energy, Net-Zero, Zero-Carbon are all just on the path in the right direction

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Intro

- What about Green Buildings?
- How about Good Buildings?
- The changing paradigm
  - Reliably-delivered (quality) High-Performance

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Performance?

- More than on-time, on-budget, to code
  - Safe
  - Healthy
  - Comfortable
- A growing clamor for….
  - Durable
  - Low-energy
  - Maintainable
  - Modifiable
  - Repairable
- All delivered reliably, predictably

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How do buildings damage environment?

- Resource Extraction
  - Cutting trees, mining, drilling oil, etc.
- Processing materials
  - Refining, melting, etc. Pollutants and energy
- Transportation of products
  - Mass and Mode (ship/truck) and Mileage
- Construction of the building
  - Energy, worker transport
- Operational Energy

The Majority of Impact

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Low- Energy Buildings

- Energy during operation swamps embodied energy in most buildings
- So first step is reduce operational energy
- THEN
  - Reduce embodied energy/pollution
  - Generate renewable clean energy
  - Make reusable and recyclable

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Good news and bad news

- LEED is not a good predictor of energy use
- ASHRAE 90.1 is not either
- Real measures
  - kBtu/sf/yr or kWh/m2/yr or MJ/m2/yr
  - kBtu/student or /desk or /employee

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E.g. Architecture 2030

- Focus on energy consumption
  - Real targets, not "% below something"
- Goal is Net Zero Energy
  - 60% until 2015
  - 100% by 2030
- Baseline is approximately the energy use of all buildings of same type and location in 2003 or so

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2030 CHALLENGE Targets: Canadian Commercial Regional Averages

Averages for Site Energy Use and 2030 Challenge Energy Reduction Targets by Commercial Space/Building Type[1]

Commercial Space/Building Type	Average Site EUI (GJ/m²/yr)	2030 Challenge Site EUI Targets (GJ/m²/Yr)				
		50% Target	60% Target	70% Target	80% Target	90% Target
Canada						
Wholesale Trade	1.470	**0.735**	0.588	0.441	0.294	0.147
Retail Trade	1.707	**0.854**	0.683	0.512	0.341	0.171
Transportation and Warehousing	1.323	**0.661**	0.529	0.397	0.265	0.132
Information and Cultural Industries	1.892	**0.946**	0.757	0.568	0.378	0.189
Offices	1.382	**0.691**	0.553	0.415	0.276	0.138
Educational Services	1.696	**0.848**	0.678	0.509	0.339	0.170
Healthcare and Social Assistance	2.212	**1.106**	0.885	0.664	0.442	0.221
Arts, Entertainment and Recreation	2.156	**1.078**	0.863	0.647	0.431	0.216
Accommodation and Food Services	4.670	**2.335**	1.868	1.401	0.934	0.467
Other Services	1.439	**0.719**	0.576	0.432	0.288	0.144
Ontario						
Wholesale Trade	1.853	**0.926**	0.741	0.556	0.371	0.185
Retail Trade	1.622	**0.811**	0.649	0.487	0.324	0.162
Transportation and Warehousing	1.398	**0.699**	0.559	0.419	0.280	0.140
Information and Cultural Industries	1.734	**0.867**	0.693	0.520	0.347	0.173
Offices	1.421	**0.710**	0.568	0.426	0.284	0.142
Educational Services	1.768	**0.884**	0.707	0.530	0.354	0.177
Healthcare and Social Assistance	2.036	**1.019**	0.815	0.611	0.408	0.204
Arts, Entertainment and Recreation	2.677	**1.338**	1.071	0.803	0.535	0.268
Accommodation and Food Services	2.597	**1.299**	1.039	0.779	0.519	0.260
Other Services	1.568	**0.784**	0.627	0.470	0.314	0.157
Ontario						
Single Detached	0.830	**0.415**	0.332	0.249	0.166	0.083
Single Attached	0.830	**0.415**	0.332	0.249	0.166	0.083
Apartments	0.677	**0.339**	0.271	0.203	0.135	0.068
Mobile Homes	1.203	**0.602**	0.481	0.361	0.241	0.120

395 kWh/m²/yr

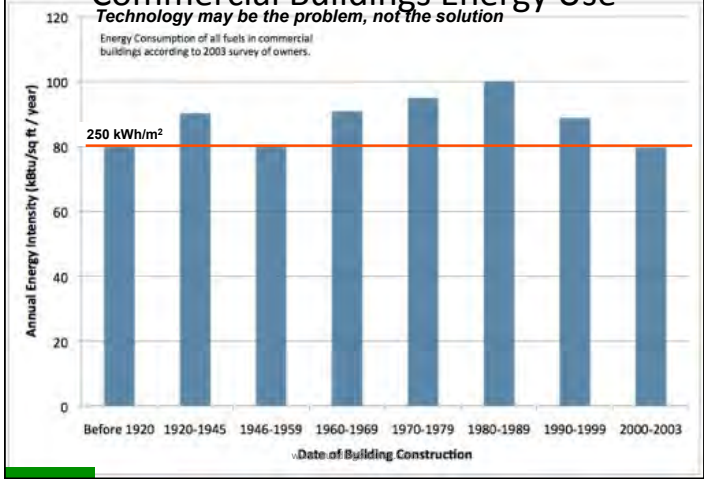
490 kWh/m²/yr

190 kWh/m²/yr

Commercial Buildings Energy Use

Technology may be the problem, not the solution

Energy Consumption of all fuels in commercial buildings according to 2003 survey of owners.



Sustainable Strategies

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Process and Philosophy

- Decide to value low energy consumption
- Set ***measurable targets***, predict usage, measure performance
- Stamp out waste everywhere
- Use energy efficiently when you need to use it
- *Do **not*** sacrifice safety, comfort, health and durability

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Available Strategies

- Siting (small impact)
  - Orient with sun, wind, rain, earth shelter?
- Shape and Form (small to moderate impact)
  - Small, Compact, simple
- Exceptional building enclosure (mod to large impact)
  - Insulated, airtight, durable, solar control
- Efficient Equipment (mod impact)
  - Not there or off is best, controls help
- Renewable Energy Generation (impact varies)
  - Only after very significant reductions

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Basic Goals (cold/mixed)

- Keep heat in
  - When it is cold
- Keep heat / sun out
  - When it is warm/hot

Insulation
Airtightness
Solar Control

- Last a long time
  - Reduce construction/repair resources over time

Rain Control

- Use efficient equipment
  - Efficient lighting
  - Efficient computers, elevators

Off is very efficient

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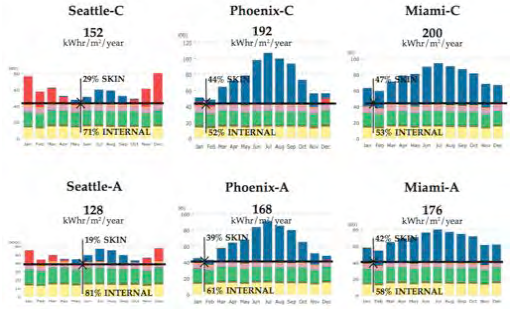
Climate matters



- Beware architecture magazines

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Typical market Building in Toronto 55% heat+cool

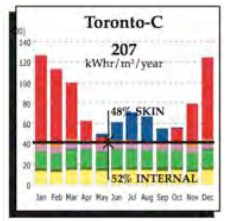
Other things use energy

MD40SQ-C
4-storey, square floor plate
50,000 sf GFA
40% w-w-r (N, S, E, & W)
Enclosure "C-Institutional"

Space Heating
Space Cooling
Water Heating
Ventilation Fans
Pumps & Auxiliary
Plug & Miscellaneous
Task Lighting
Area Lighting

MD40SQ-A
similar to above, except:
Enclosure "A-Exemplary"

From: Ross, B., "Design with Energy in Mind", M.Arch. Thesis, University of Waterloo, 2009.



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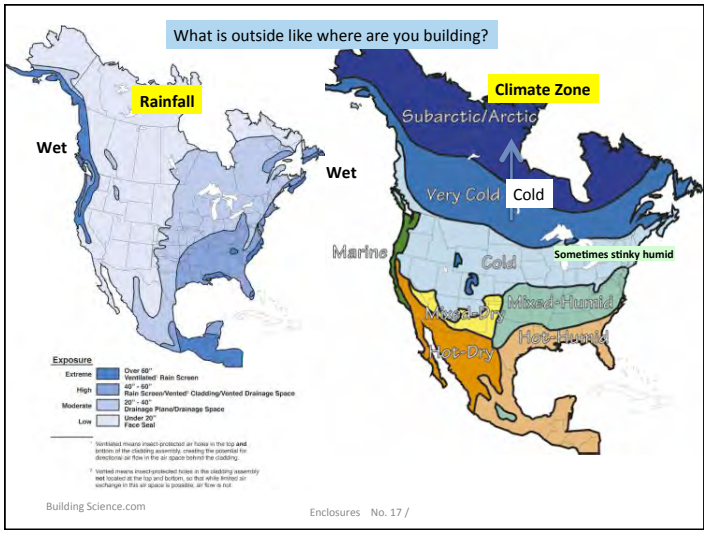

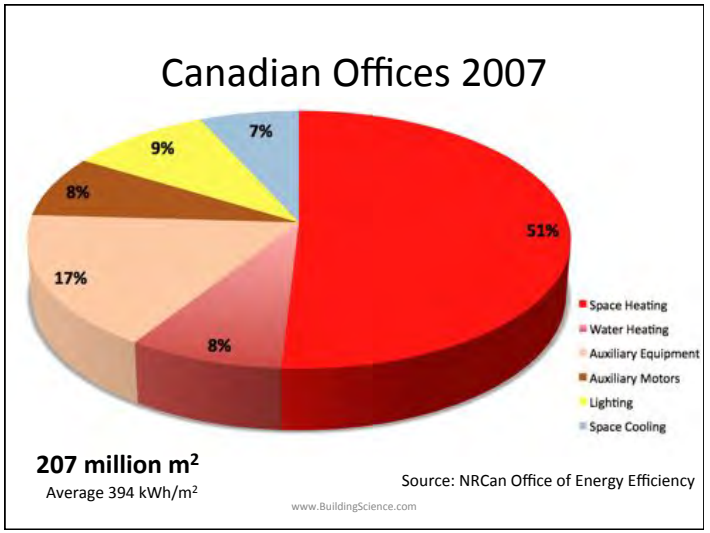

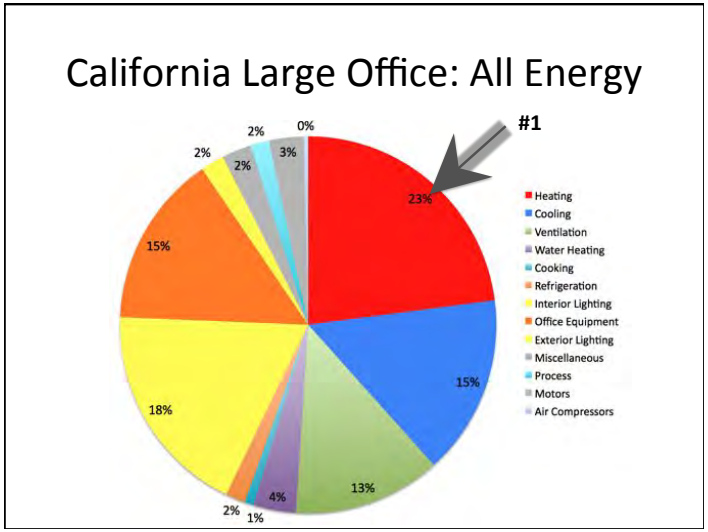

Can we do it?

- Is it possible or practical to drop energy use by 60% in cold-climates (Zones 5, 6, 7+)?
- Average US office uses 80 kBtu/sf/yr
  - 250 kWh/m²/yr
- Can we get an office to 60? 30? kBtu/sf/yr
  - 200, 100 kWh/m²/yr?

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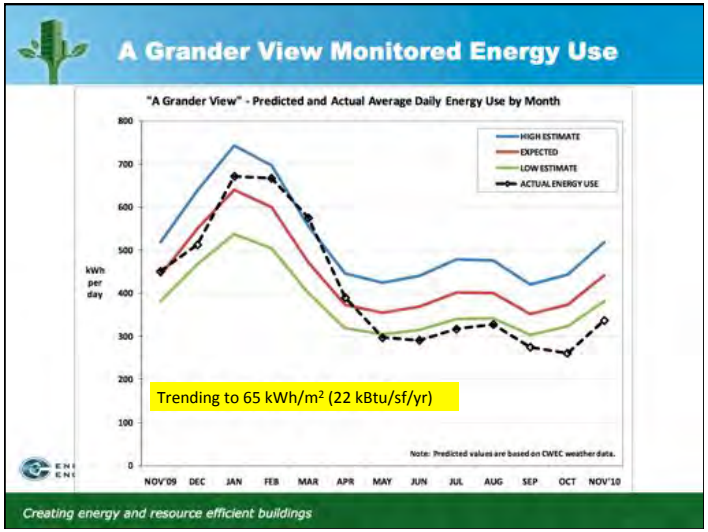
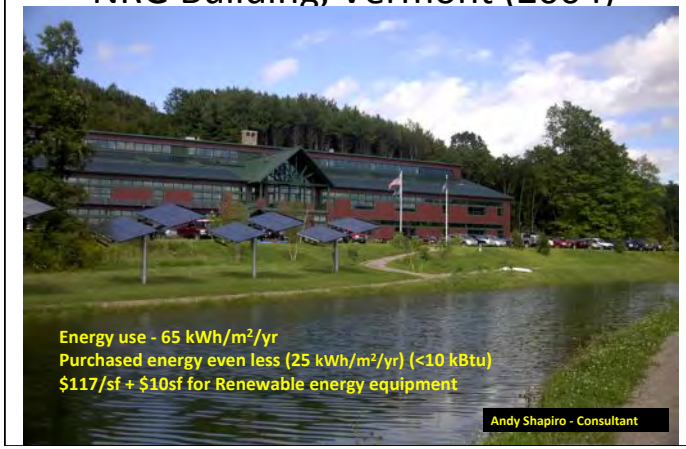
Grander View, 2010

- Mostly simple, standard technology
- Modest cost premium

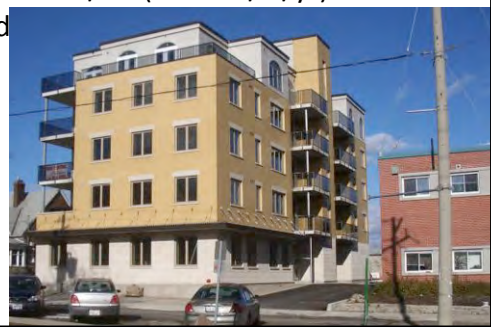


NRG Building, Vermont (2004)



Waterloo Apartment / Office

- Built for median cost in 2005
- Around 100 ekWh/m^2 (30 kBtu/sf/yr)
- All standard products



John Straube

Waterloo Region Health & Welfare

- Built 1990. 160 ekWh/m^2/yr (50 kBtu/sf/yr).

London City Hall

"Greenest city hall in the world" 2002
"Virtually non-polluting" 2011

London UK City Hall

- **Measured: 125 kBtu/sf/yr (376 kWh/m^2/yr)**

Low-energy buildings

- Three primary components
  1. Enclosure
  2. HVAC
  3. Occupancy, people

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1. Enclosures

Architects control this!

- 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**!
- Can't "insulate to zero"

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2. HVAC

Mech Eng design this

- Architect helps select
- Critical role, as HVAC offers about half the possible savings
- Fancy, complex, expensive not often the lowest energy choice
  – Beware "advanced controls"
  – Great enclosure often means simple HVAC

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3. Occupancy

Client & Occupant Driven

- 24 hr occupancy
- 9-5 M-F?
- Schools

- Do people care? Do they have information to act?

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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**
- 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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Enclosure Design Principles

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The Enclosure

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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.)

Building Science Enclosures No. 36 /

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

Form & Massing

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

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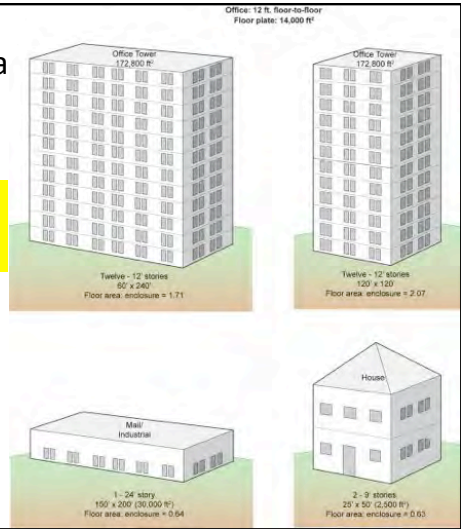
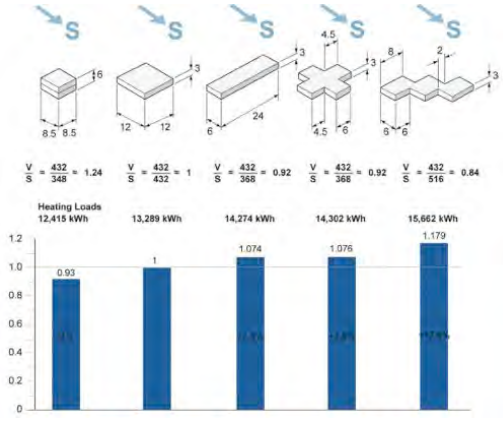
Size: Floor Area to Enclosure Area

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



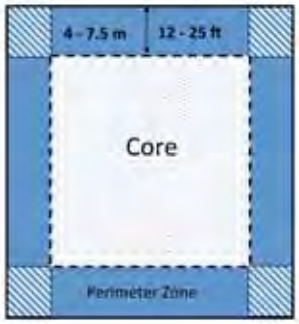
Impact of Shape and Orientation: Heating Energy for cold climate, small building



Large Buildings

Many buildings with large cores require cooling in winter while heating the perimeter
What do with that heat?

Core / Perimeter



- Perimeter Zone
  - performance dominated by climate and enclosure
- Core Zone
  - dominated by interior use. Climate/enclosure almost irrelevant
- In most occupancies, core needs ***cooling and lighting all year long, all day***

Skin Dominated Building

- "Skin-dominated": Perimeter Zone over most of floor area
- Excellent daylighting and cross ventilation opportunities
- Best massing for many commercial buildings
- ***Demands good building enclosure because of increased enclosure area***

Building Shape

- Alphabet Soup
  - H I A B E

Usually skin dominated

Daylight access, view
Cross Ventilation

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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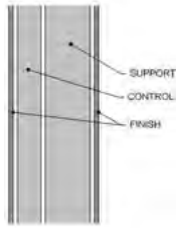
Basic Functions of the Enclosure

- 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

Functional Layers



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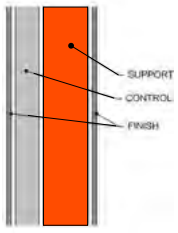
Basic Enclosure Functions

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

Functional Layers

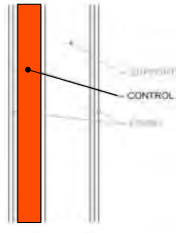


Building Science Enclosures No. 47 /

Basic Enclosure Functions

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

Functional Layers



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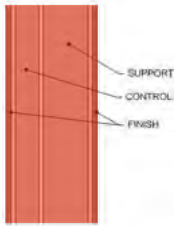
Other Control . . .

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

Functional Layers



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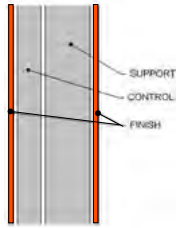
Basic Enclosure Functions

- 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

Functional Layers



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History of Control Functions

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

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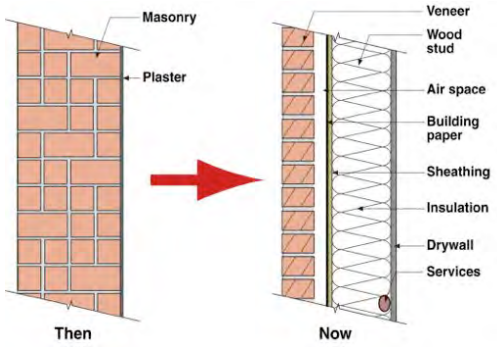
Changes



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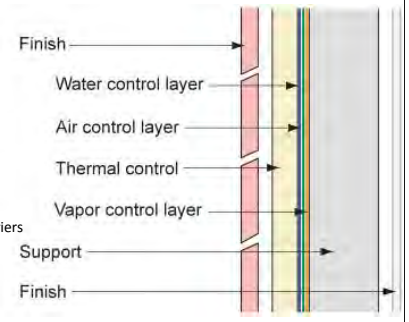
The "Perfect Wall"

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



Fire Control may be needed
Sound Control optional

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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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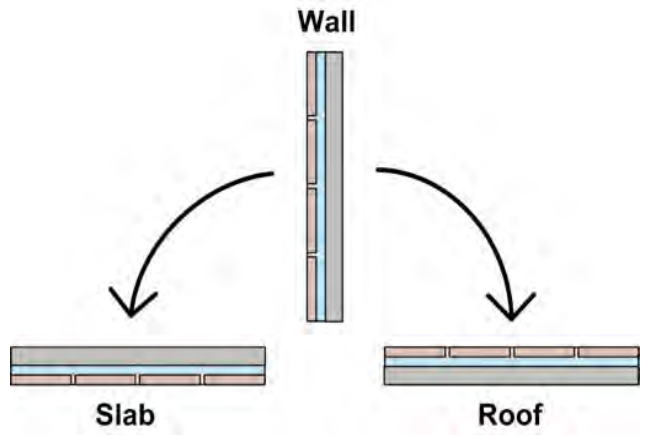

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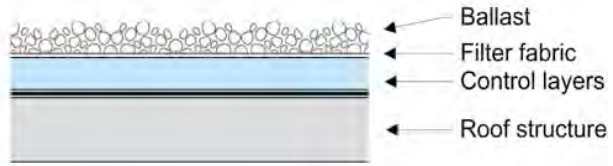

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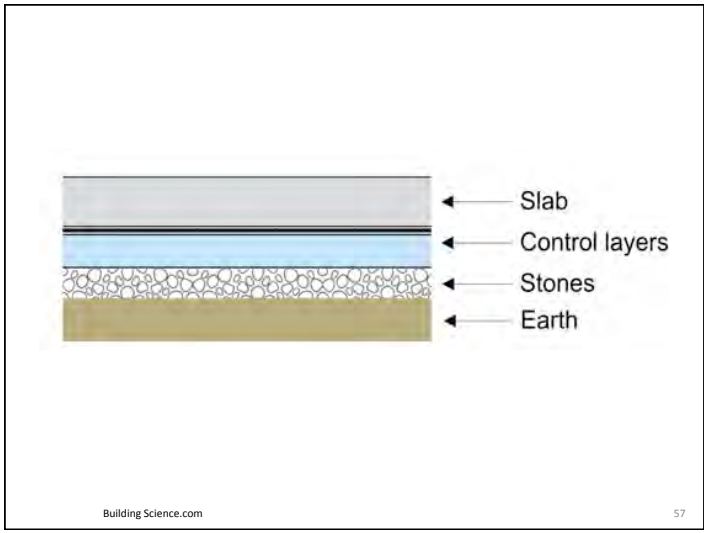
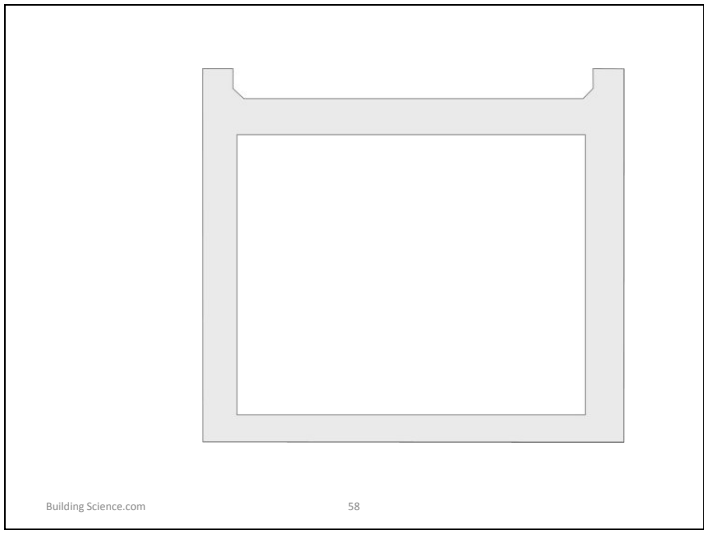

Slab
Control layers
Stones
Earth
Building Science.com
57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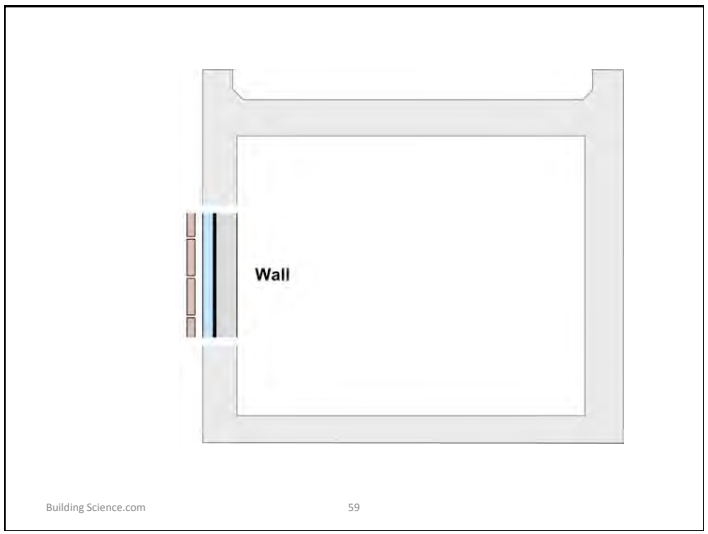
Wall
Building Science.com
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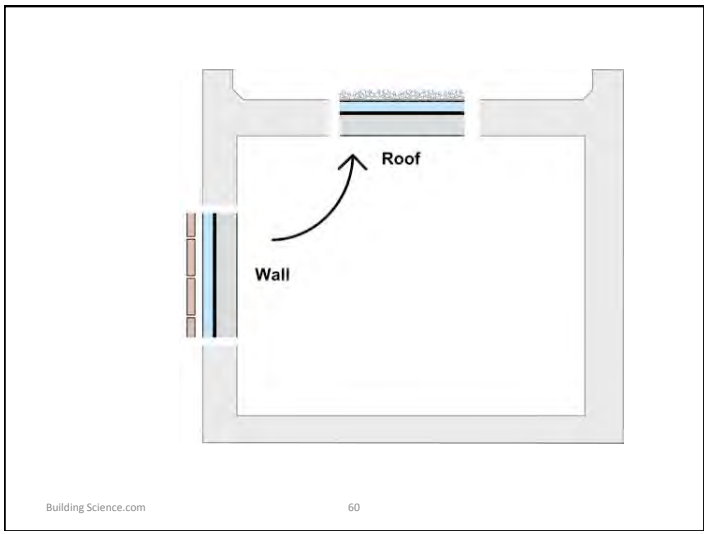
Roof
Wall
Building Science.com
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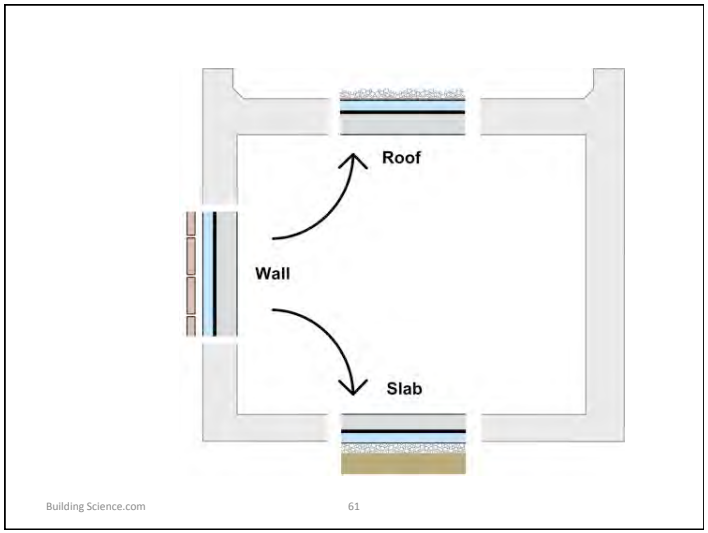
Roof
Wall
Slab
Building Science.com
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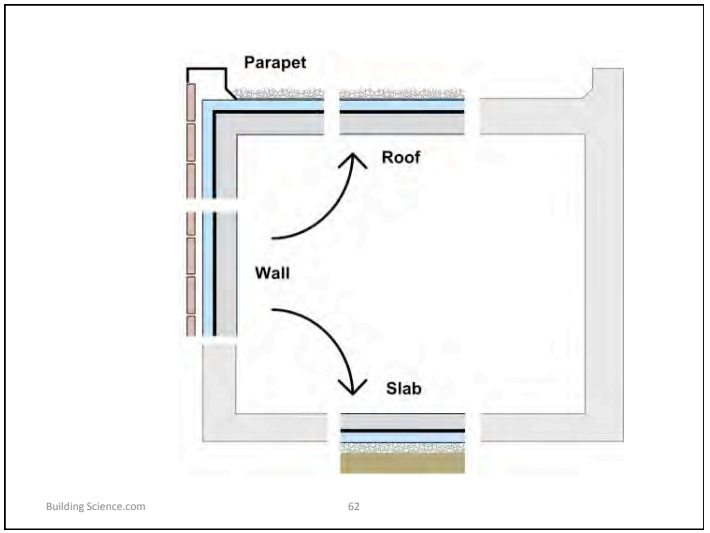
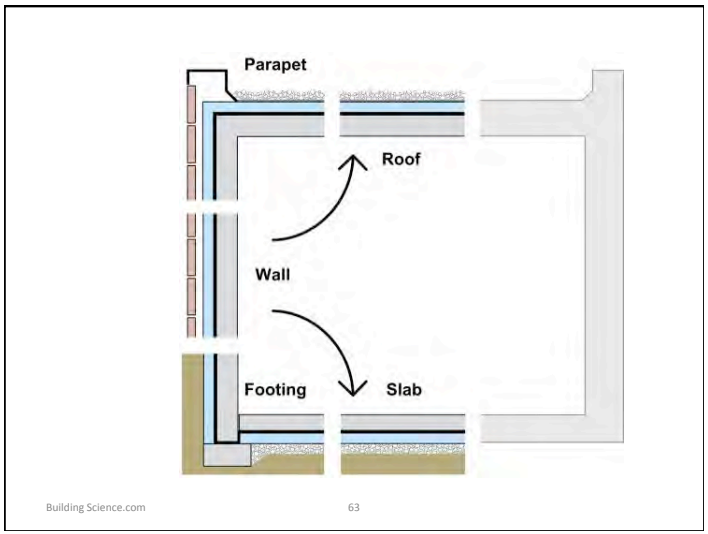
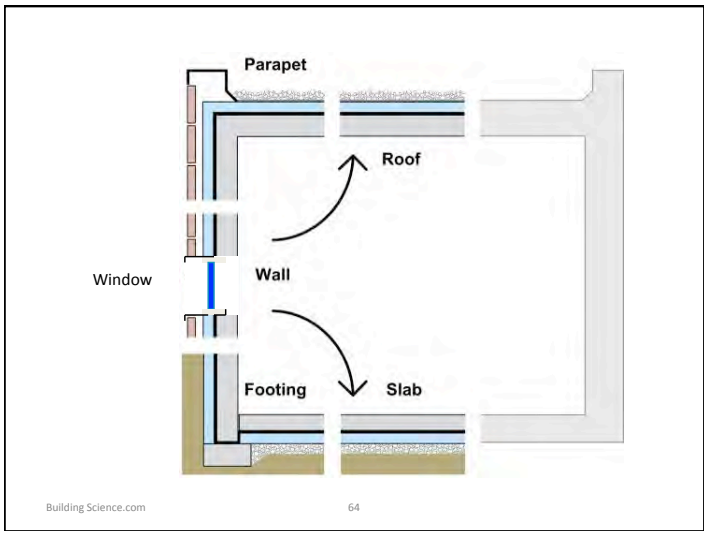
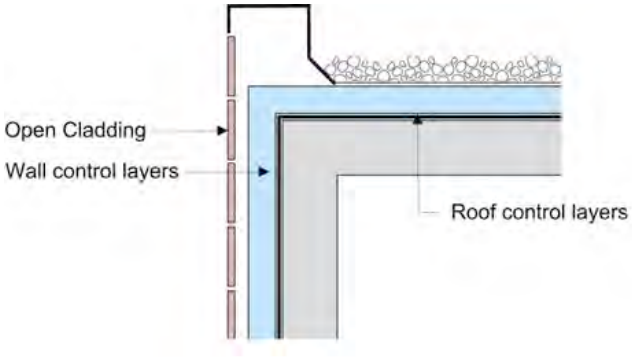

Parapet
Roof
Wall
Slab
Building Science.com
62


Parapet
Roof
Wall
Footing
Slab
Building Science.com
63


Parapet
Roof
Window
Wall
Footing
Slab
Building Science.com
64

Connections: Who is in charge



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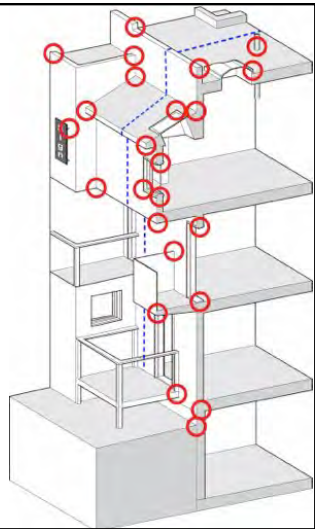
Complexity increases detailing effort / risk of failure / cost reduces performance

Building Science.com Enclosures No. 66 /

Enclosure Design: Details

- Details demand the same approach as the enclosure.
- Scaled drawings required at ◯



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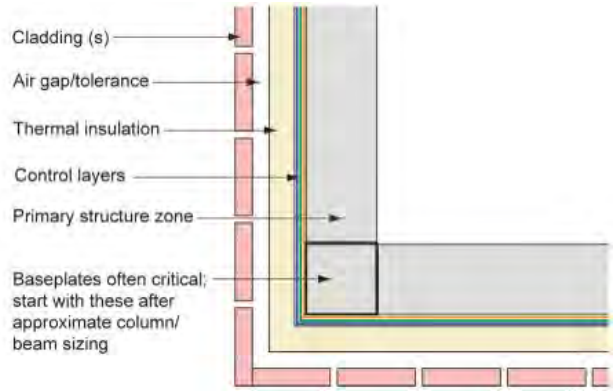
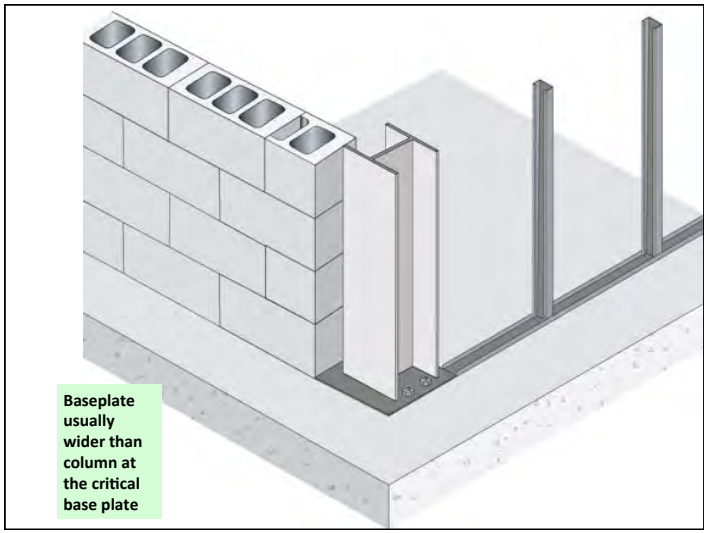
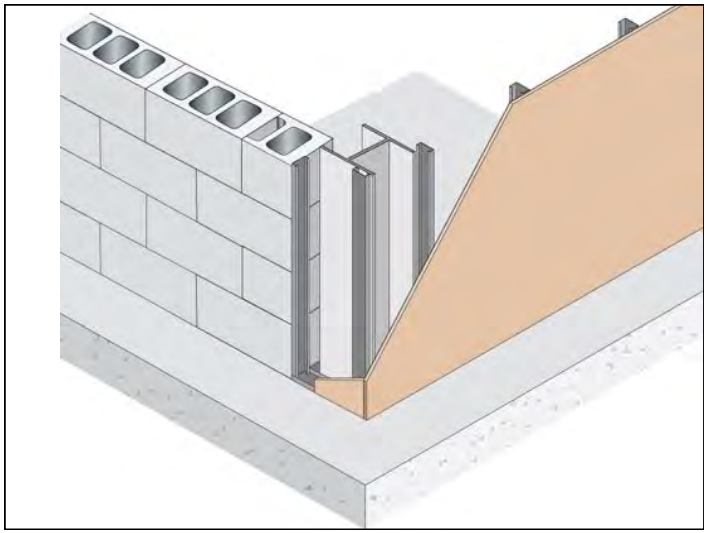
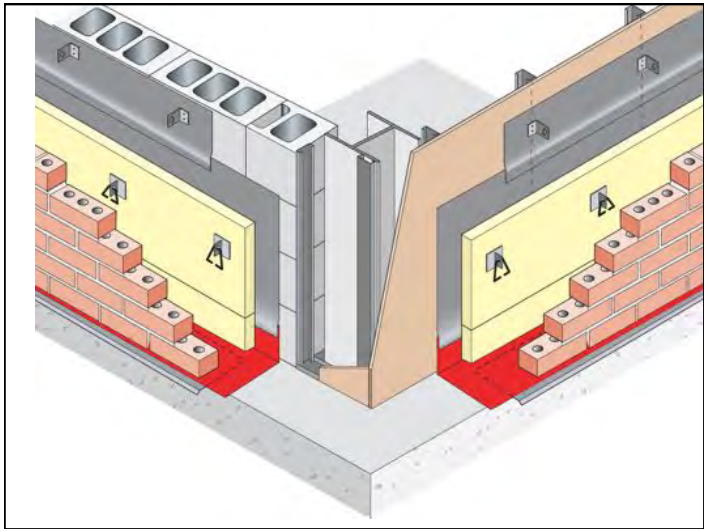
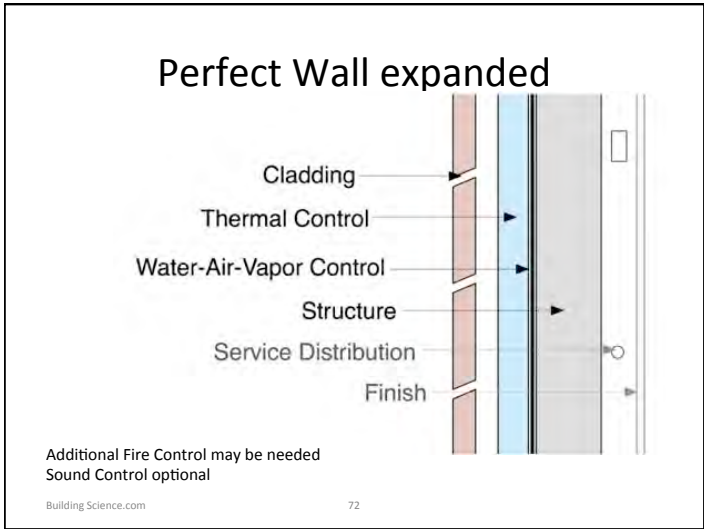
Early stage planning




Baseplate usually wider than column at the critical base plate

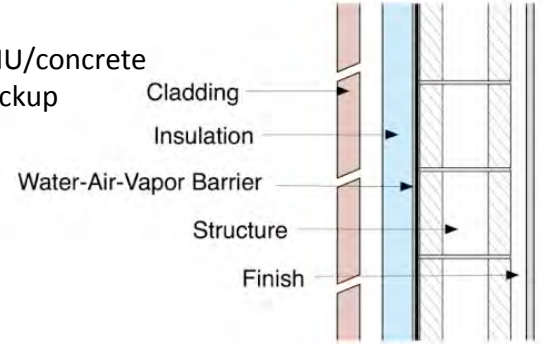





Perfect Wall expanded
Cladding
Thermal Control
Water-Air-Vapor Control
Structure
Service Distribution
Finish
Additional Fire Control may be needed
Sound Control optional
Building Science.com
72

Perfect Wall

- CMU/concrete backup



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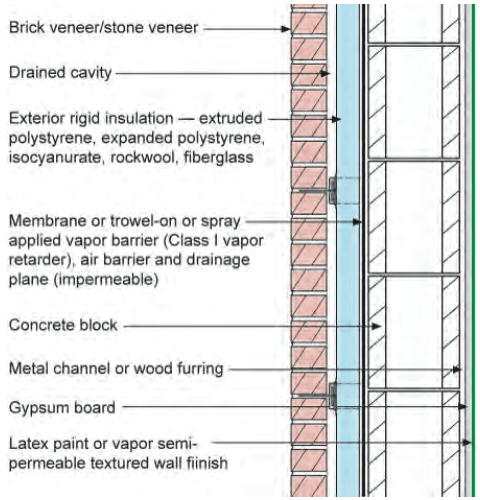
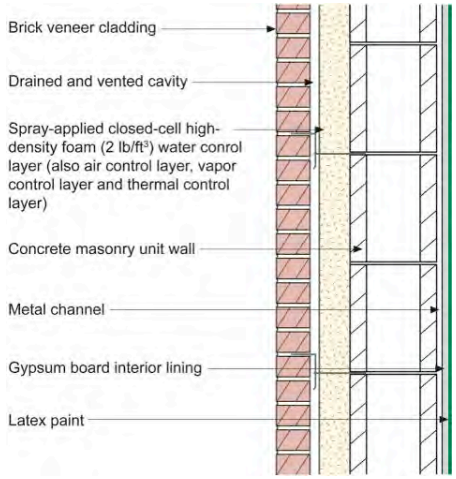
Any R-value, e.g.
4" PIC=R25
5"XPS =R25
6"MFI=R25



Combined water-air-thermal control layer



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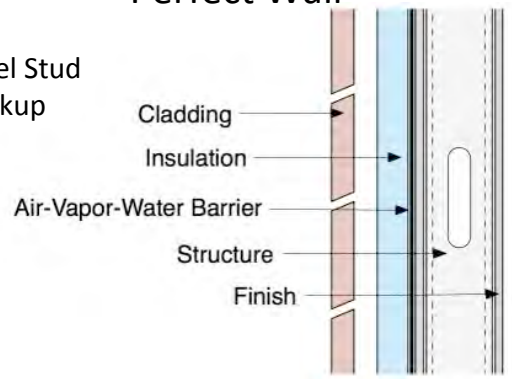
Perfect Wall

- Steel Stud Backup



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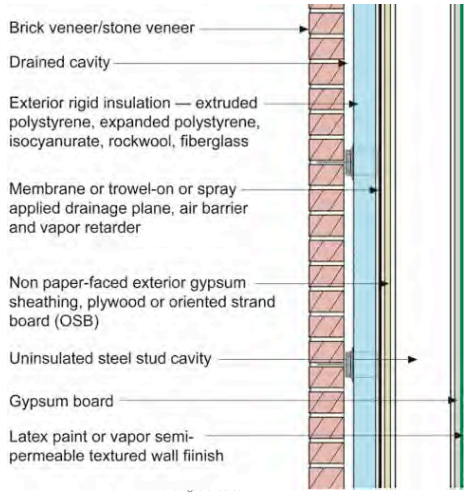
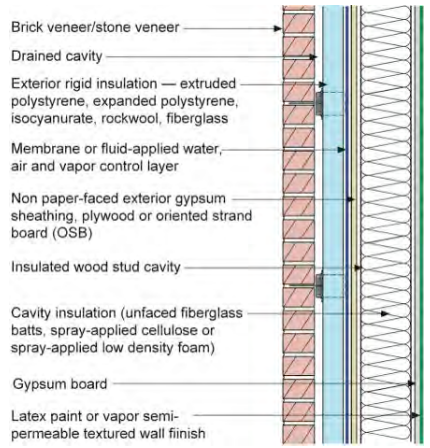
Any R-value, e.g.
4" PIC=R25
5"XPS =R25
6"MFI=R25



Ratio: $\frac{\text{Exterior R-value}}{\text{Studbay R-value}}$ controls risk of condensation

Compromise

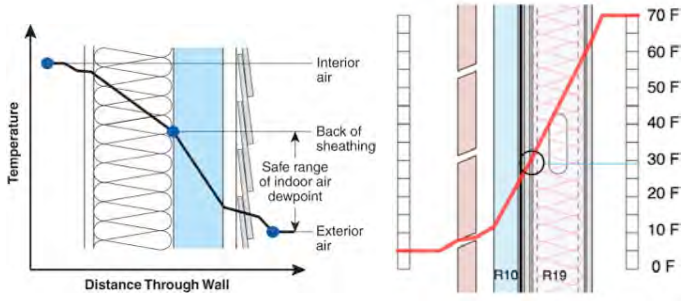


Steel studs compromise the thermal performance Wood studs, not so much

Any R-value, e.g.
6" wood stud+
2" PIC= R30
3"XPS= R32
4"SPF= R40

BSD-163

Compromise= Risks



$T_{sheathing} = T_{in} - (T_{in}-T_{out})*R_{cavity}/R_{total}$

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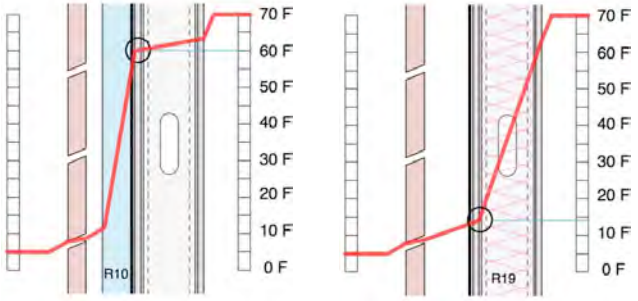
Condensation & Drying



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Specifics

- Now we will look at
  - Rain Control
  - Air Flow Control
  - Thermal Control

  (Air Flow Control, Thermal Control: Energy & Comfort; Rain Control, Air Flow Control: Durability, Health)
- In some detail

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Rain Control

www.buildingscience.com

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= need for better control!

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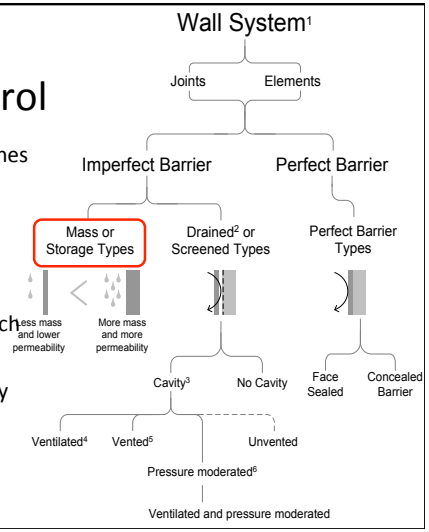
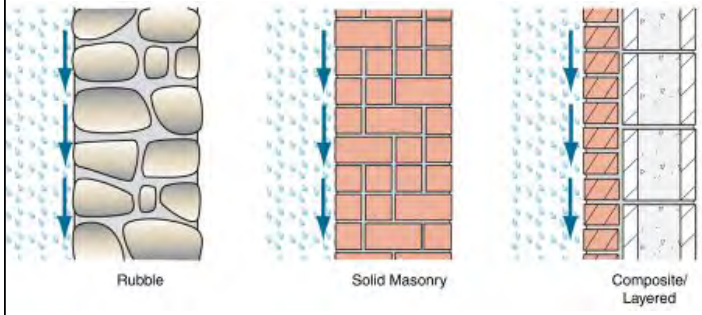
1. Rain Control

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



Mass/Storage/Reservoir Walls



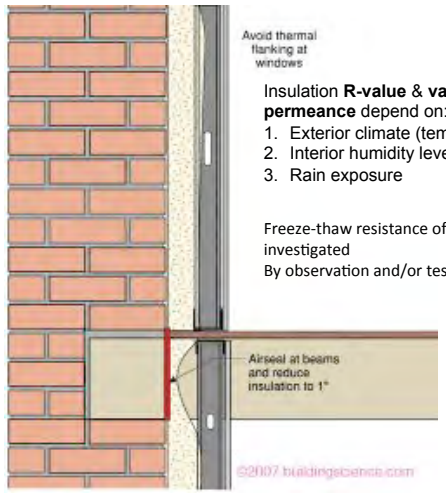
John Straube

No building paper, flashing, weepholes

Rain Control 86

Surface features such as Overhangs, Drips, etc are important for mass walls

Rain Control 87



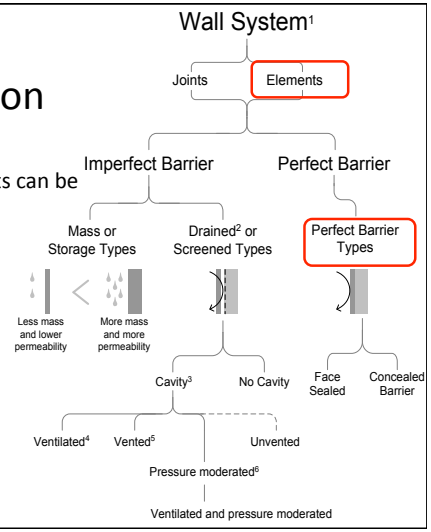
Insulation **R-value** & **vapor permeance** depend on:

1. Exterior climate (temp / drying)
2. Interior humidity levels
3. Rain exposure

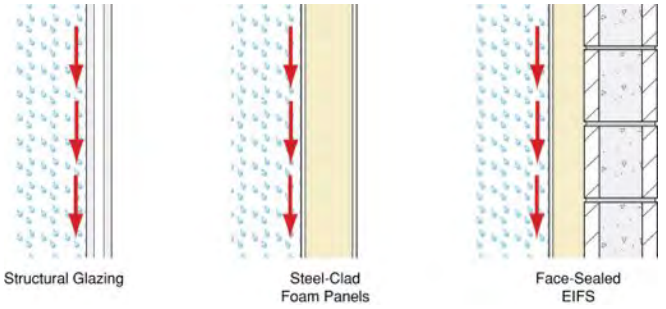
Freeze-thaw resistance of brick should be investigated
By observation and/or testing

Categorization

- Elements and joints can be different



Perfect Barrier / Face Sealed



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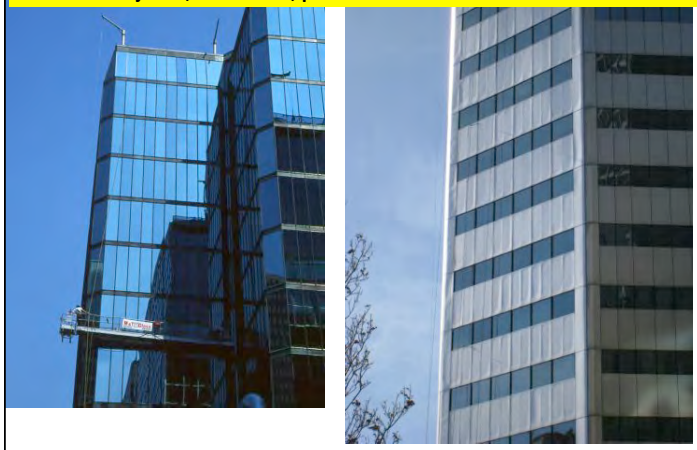
It is all about joints, transitions, penetrations



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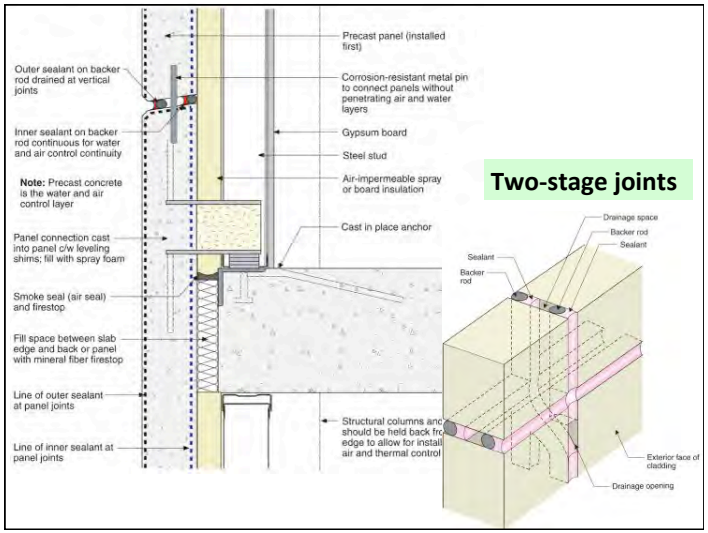
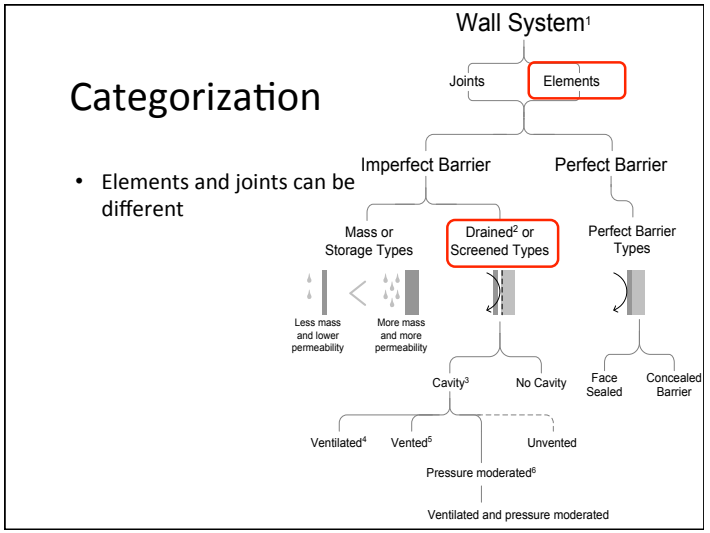
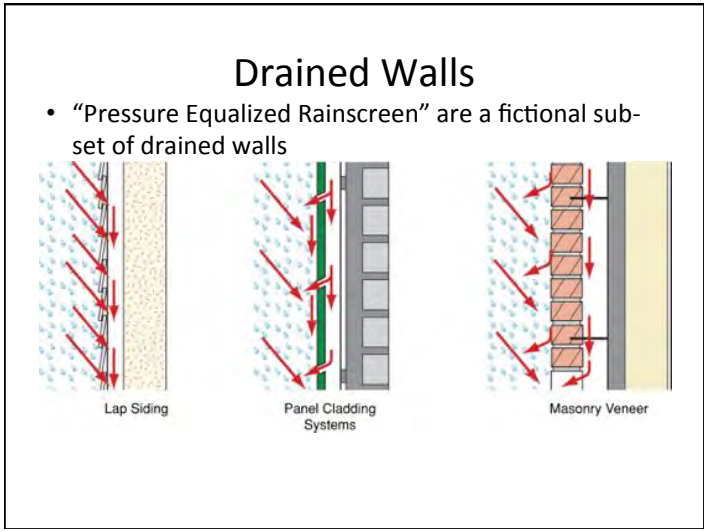
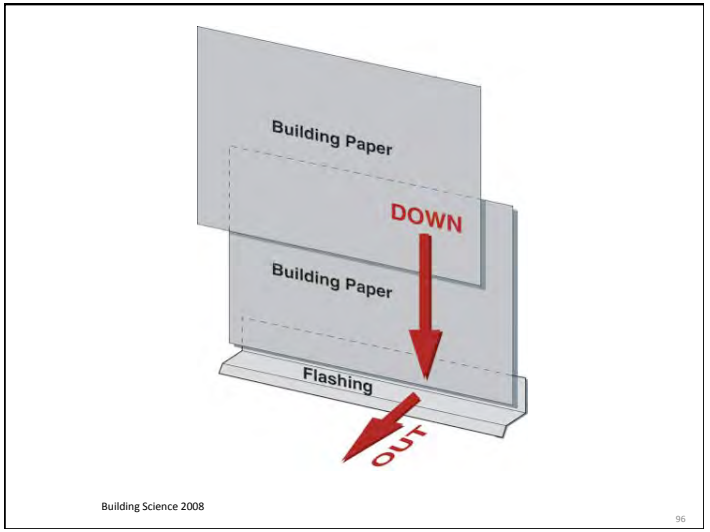
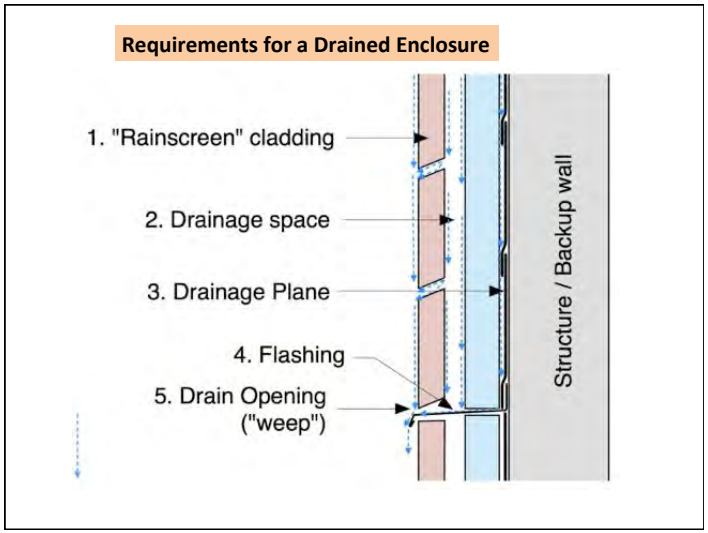
Precast is often a functional perfect barrier wall .. but the joints leak

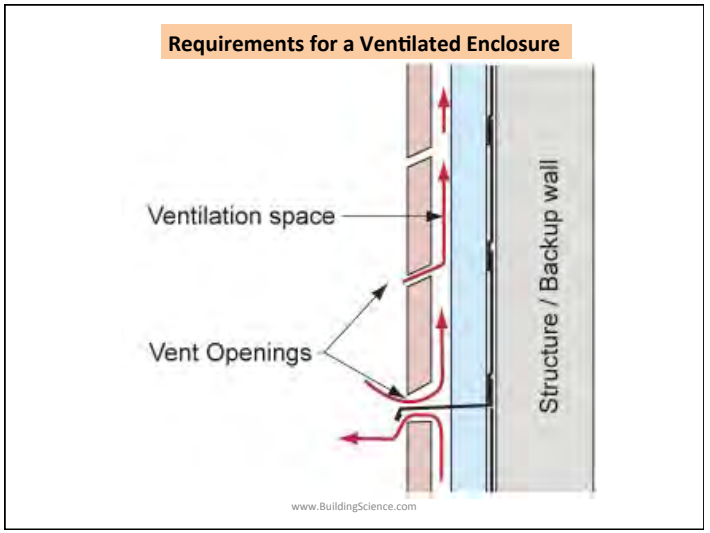

Precast panel (installed first)
Outer sealant on backer rod drained at vertical joints
Corrosion-resistant metal pin to connect panels without penetrating air and water layers
Inner sealant on backer rod continuous for water and air control continuity
Gypsum board
Steel stud
Note: Precast concrete is the water and air control layer
Air-impermeable spray or board insulation
Cast in place anchor
Panel connection cast into panel c/w leveling shims; fill with spray foam
Smoke seal (air seal) and firestop
Fill space between slab edge and back or panel with mineral fiber firestop
Line of outer sealant at panel joints
Line of inner sealant at panel joints
Two-stage joints
Drainage space
Backer rod
Sealant
Exterior face of cladding
Drainage opening

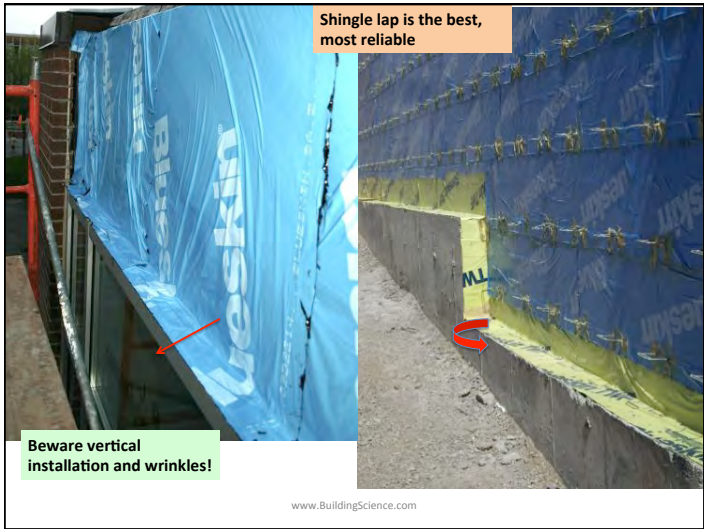

Categorization
Wall System[1]
Joints
Elements
Imperfect Barrier
Perfect Barrier
Mass or Storage Types
Drained[2] or Screened Types
Perfect Barrier Types
Less mass and lower permeability
More mass and more permeability
Cavity[3]
No Cavity
Face Sealed
Concealed Barrier
Ventilated[4]
Vented[5]
Unvented
Pressure moderated[6]
Ventilated and pressure moderated
• Elements and joints can be different

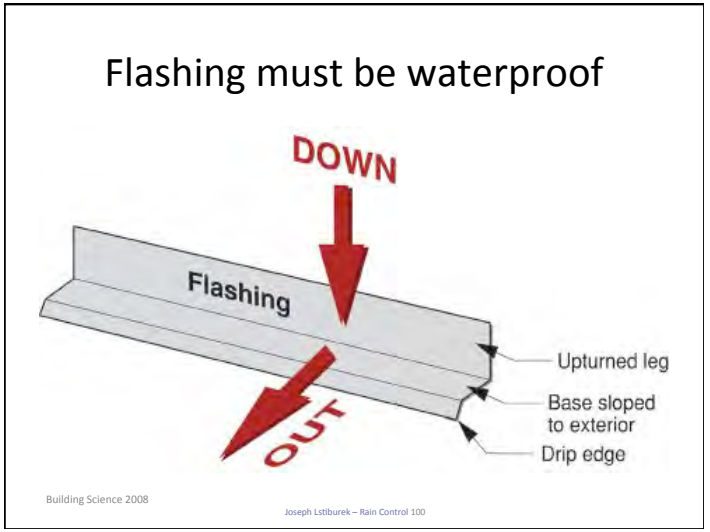

Drained Walls
• "Pressure Equalized Rainscreen" are a fictional sub-set of drained walls
Lap Siding
Panel Cladding Systems
Masonry Veneer

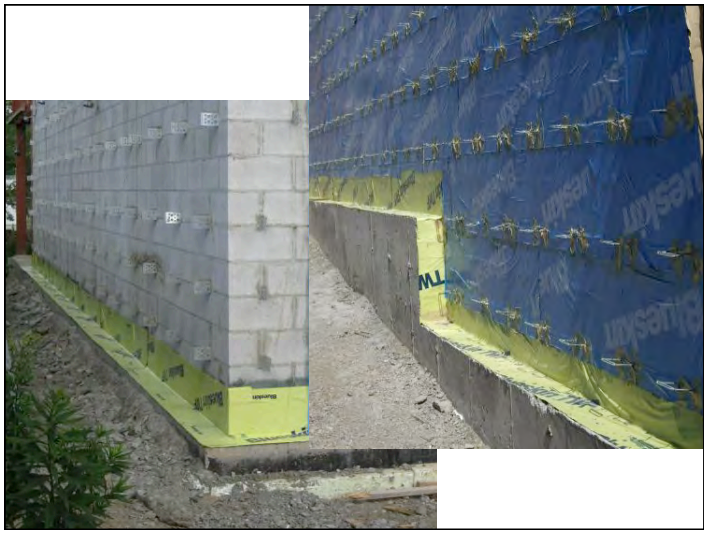

Building Paper
DOWN
Building Paper
Flashing
OUT
Building Science 2008
96

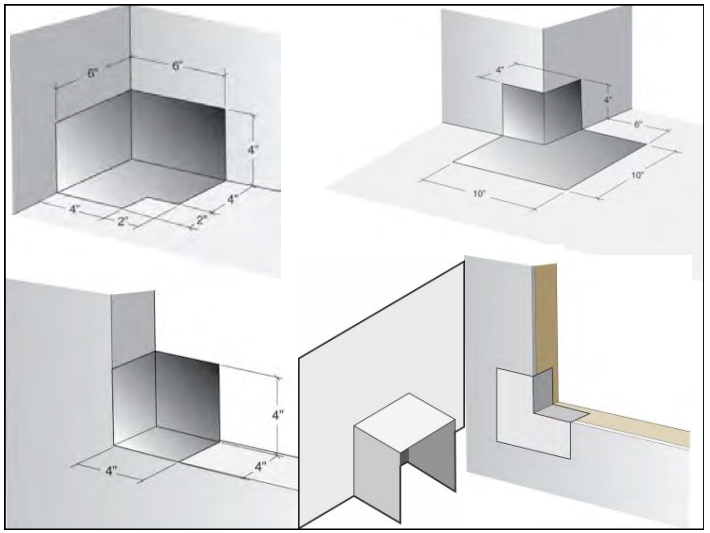

Requirements for a Drained Enclosure
1. "Rainscreen" cladding
2. Drainage space
3. Drainage Plane
4. Flashing
5. Drain Opening ("weep")
Structure / Backup wall


Requirements for a Ventilated Enclosure
Ventilation space
Vent Openings
Structure / Backup wall
www.BuildingScience.com

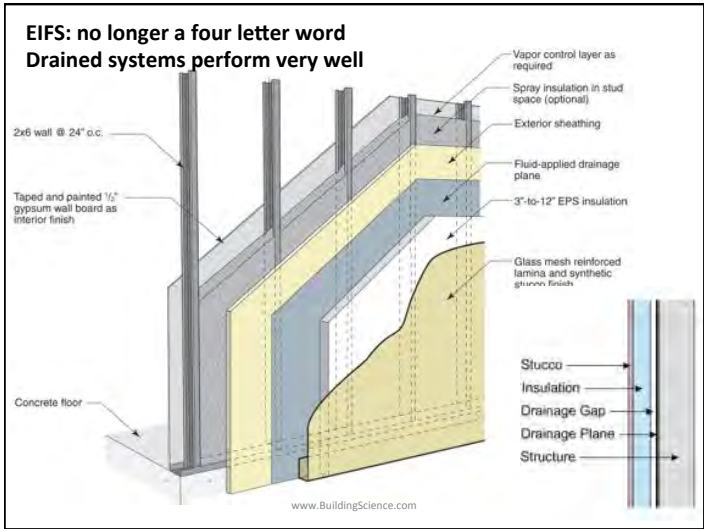

Shingle lap is the best, most reliable
Beware vertical installation and wrinkles!
www.BuildingScience.com


Flashing must be waterproof
DOWN
Flashing
OUT
Upturned leg
Base sloped to exterior
Drip edge
Building Science 2008
Joseph Lstiburek – Rain Control 100



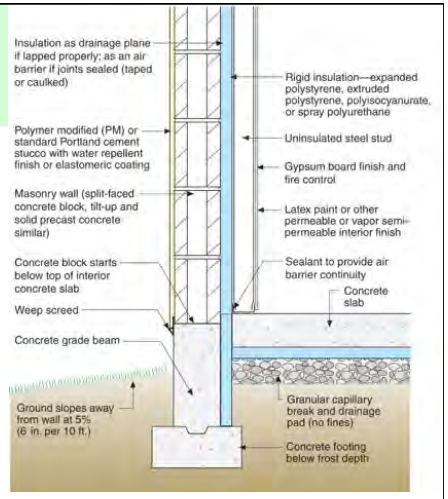


EIFS: no longer a four letter word
Drained systems perform very well

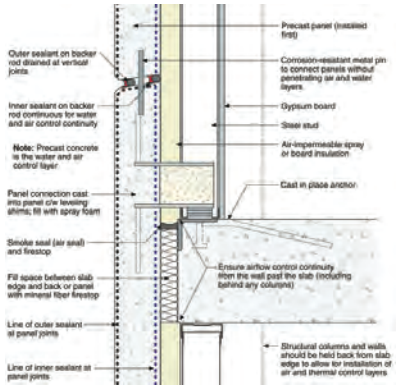


Drained EIFS is High Performance

Mass walls changed to drained walls and insulated!



Architectural Precast

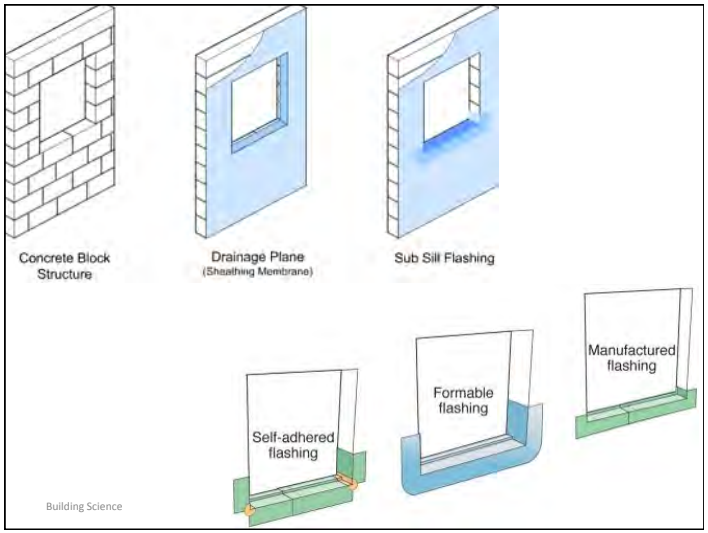


Windows and Doors

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

Leaky windows

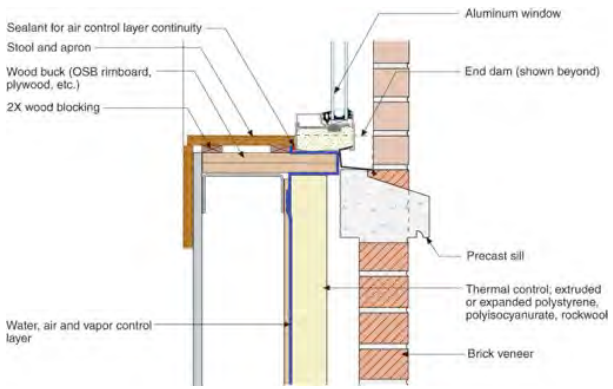
- Studs and sheathing are sensitive to leaks

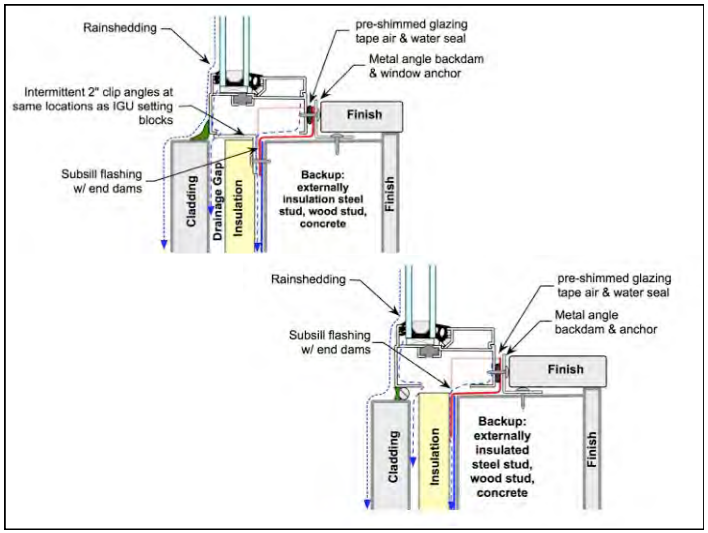


Mixed membrane + liquid

Often use membranes for transitions

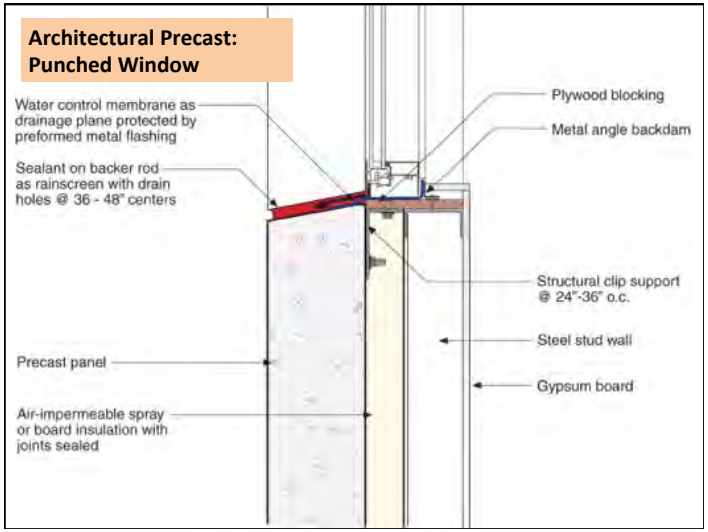
Backdams / Slopes are Important



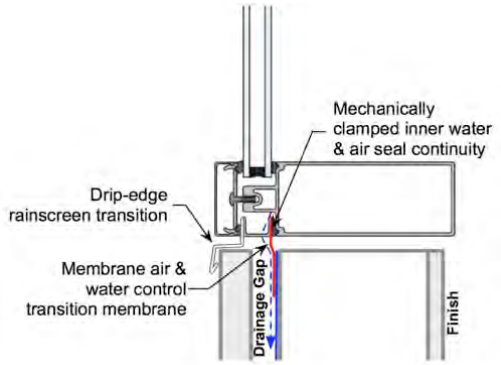


Continuous interior angle provides backdam and airseal continuity

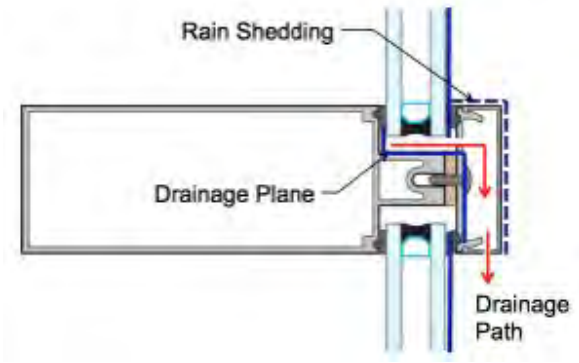
Architectural Precast: Punched Window

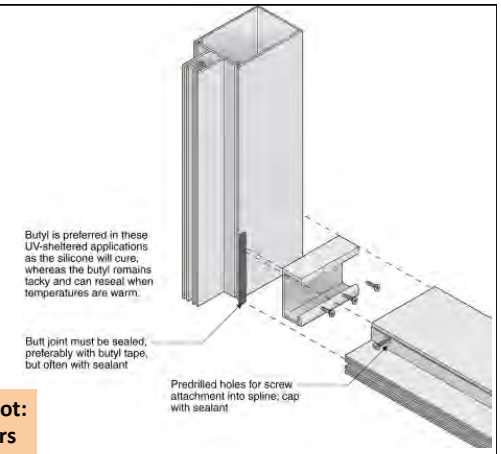


Curtainwall Integration



Rain Control





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

Building Science.com

Air-Water-Vapor

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

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Air-Water Control Layers

Sloped and complex surfaces demand very high performance. LAPPING very Important

.com

Details

- Air & water & vapor transition membranes

Fully-adhered air-water barrier

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Spray/Trowel Applied Air/water

- Semi-permeable

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Non-adhered, vapor permeable
=modest performance

Supported **flexible membrane is better**

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

Air Flow Control

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Air Barrier Systems

- Rain Control is priority Number 1, but…..
- Need an excellent air barrier in all buildings
  - Comfort & health
  - Moisture / condensation
  - Energy
  - Sound, fire, etc.
- Can't make it too tight.
- Multiple air barriers improve redundancy

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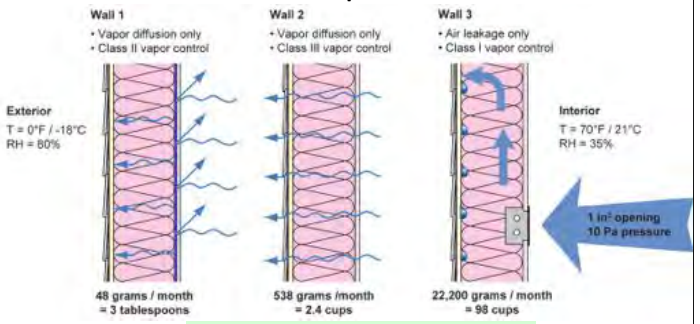
Why Control Air leakage

- Air leakage feeds condensation in cold weather and hot-humid weather
- Indoor Air Quality at risk
- 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!

129/175 12-03-15

Air moves more vapor than diffusion!



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

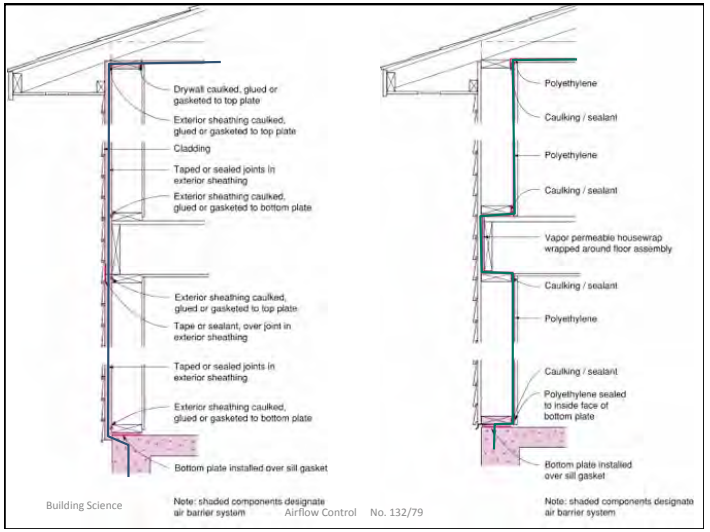
Calculations for a single stud bay, 8 ft tall, 16" wide

www.BuildingScience.com

Air Barriers

- Five 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

131/175 12-03-15



Building Science Airflow Control No. 132/79

Poly combines air *and* vapour control
-Must be sealed and supported to be air barrier
-Cover most area and you have vapor control

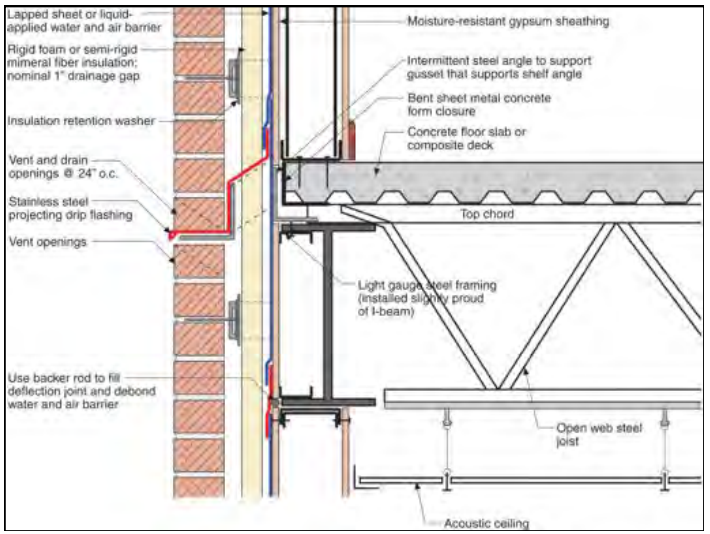
Building Science.com Airflow Control 133

Rigid Exterior Air Barrier

Building Science.com 134

Commercial Buildings: Often exterior air barrier is only practical solution

Building Science.com

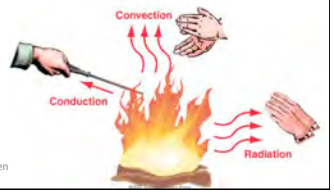


Thermal Control

www.buildingscience.com

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



www.BuildingScien

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 = $\frac{\text{Area} * (T_{inside} - T_{outside})}{\text{R-value}}$
- 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

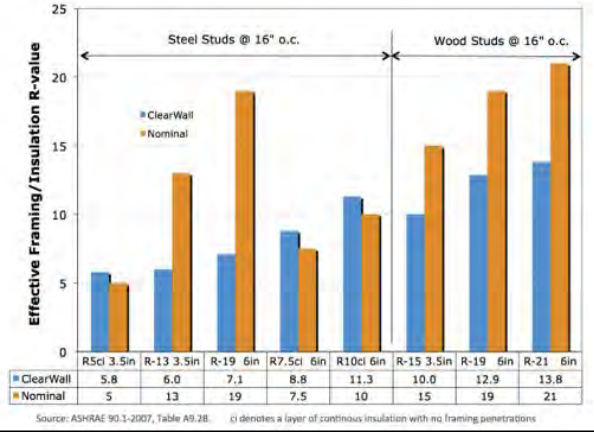
www.BuildingScience.com

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

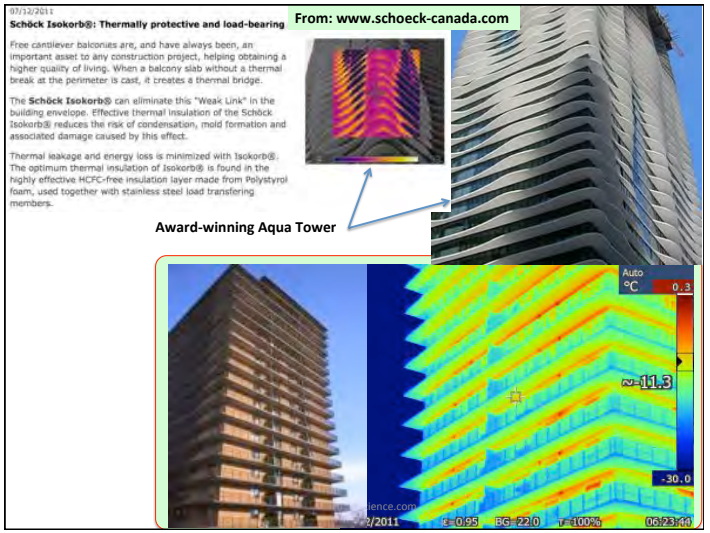
www.BuildingScience.com

Best-case R-values for stud walls



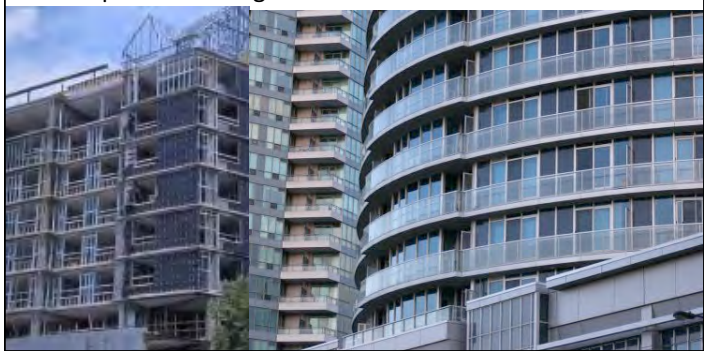
	R5ci 3.5in	R-13 3.5in	R-19 6in	R7.5ci 6in	R10ci 6in	R-15 3.5in	R-19 6in	R-21 6in
ClearWall	5.8	6.0	7.1	8.8	11.3	10.0	12.9	13.8
Nominal	5	13	19	7.5	10	15	19	21

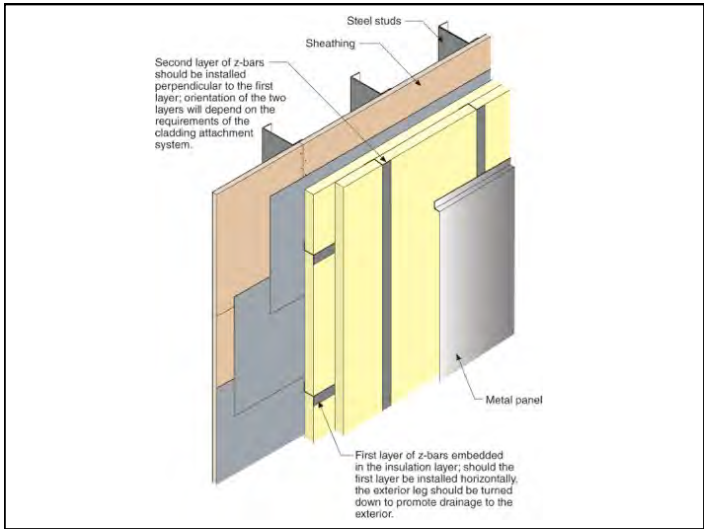
Source: ASHRAE 90.1-2007, Table A9.2B. ci denotes a layer of continous insulation with no framing penetrations

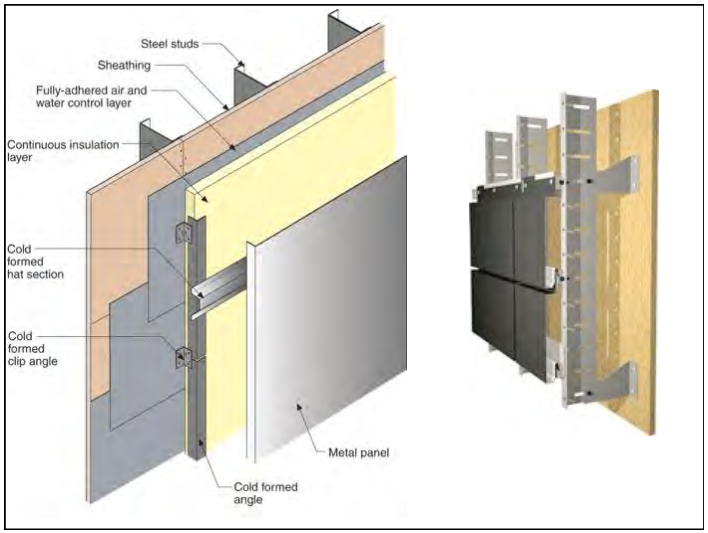


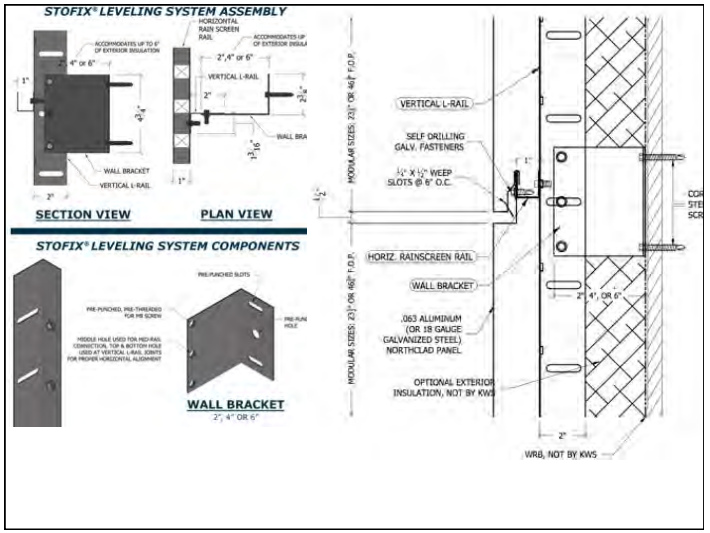
Thermal Bridge Examples

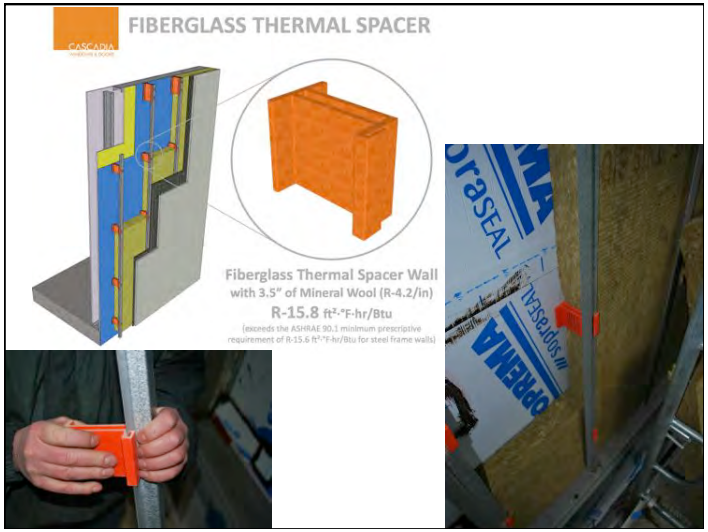
- Balconies, etc
- Exposed slab edges






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


STOFIX® LEVELING SYSTEM ASSEMBLY
SECTION VIEW
PLAN VIEW
STOFIX® LEVELING SYSTEM COMPONENTS
WALL BRACKET
VERTICAL L-RAIL
SELF DRILLING GALV. FASTENERS
HORIZ. RAINSCREEN RAIL
WALL BRACKET
.063 ALUMINUM (OR 18 GAUGE GALVANIZED STEEL) NORTHCLAD PANEL
OPTIONAL EXTERIOR INSULATION, NOT BY KWS
WRB, NOT BY KWS


FIBERGLASS THERMAL SPACER
Fiberglass Thermal Spacer Wall
with 3.5" of Mineral Wool (R-4.2/in)
R-15.8 ft²·°F·hr/Btu

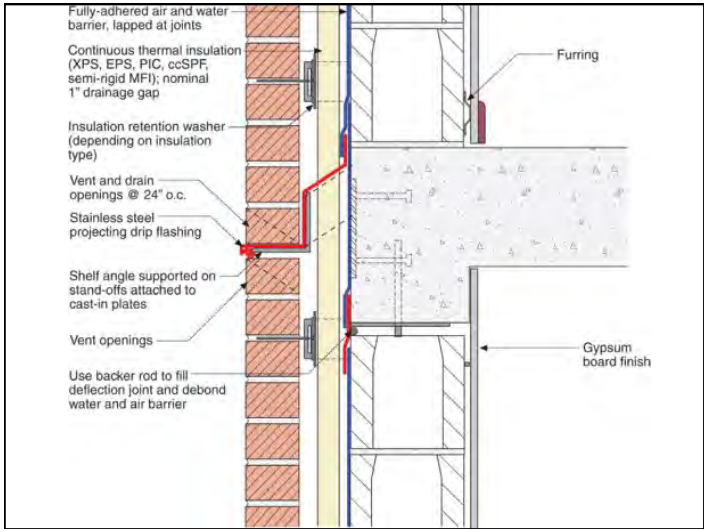
Furring Strips: least thermal performance impact

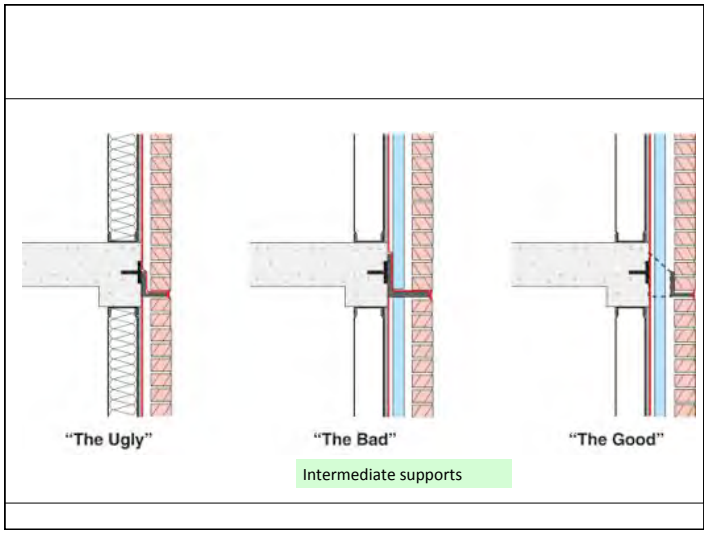
Just screws meets "ci" requirement of ASHRAE 90.1

Structural penetrations

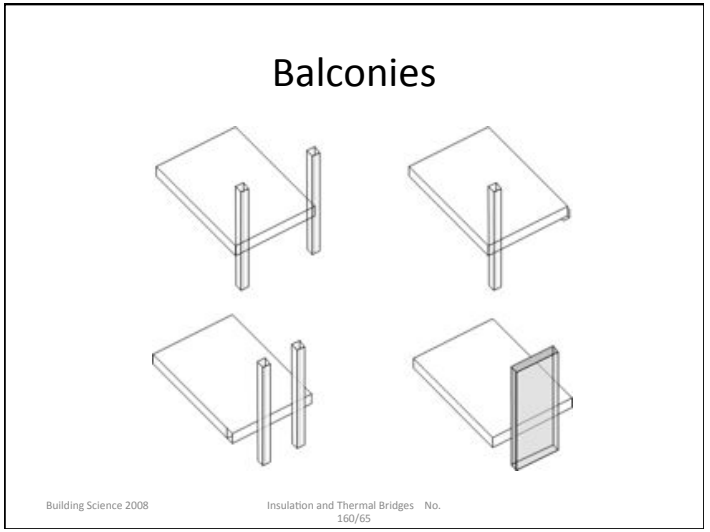
- Relieving/Shelf angles
- Balconies
- Canopies
- Signs

www.BuildingScience.com

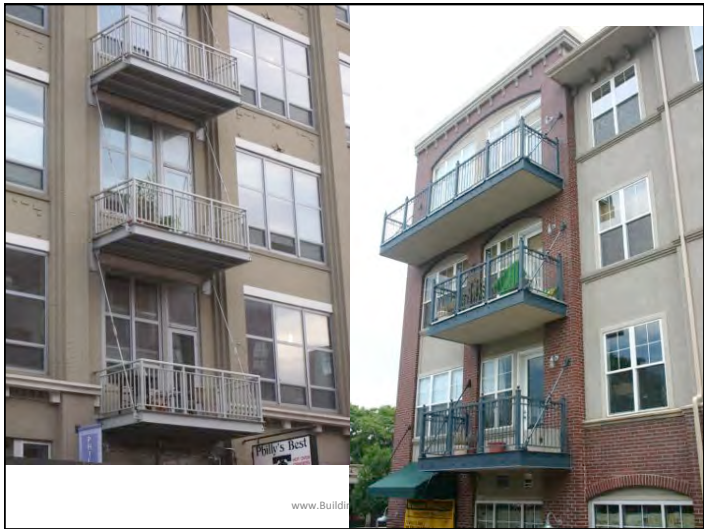



"The Ugly"
"The Bad"
"The Good"
Intermediate supports

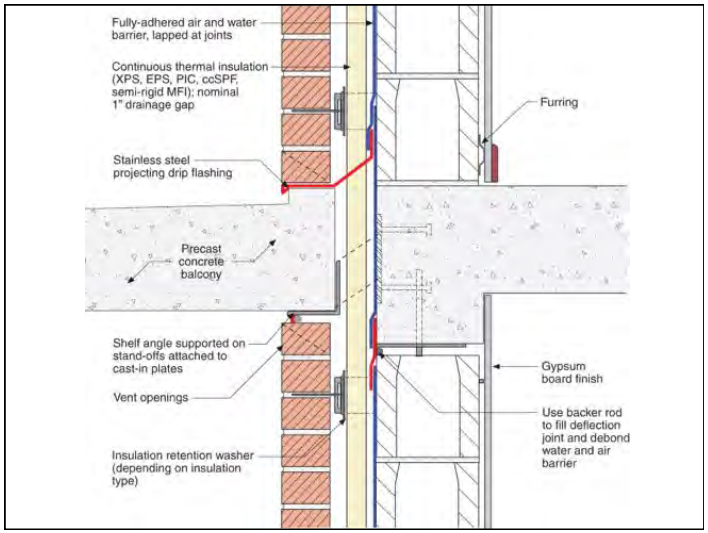

Small metal clips dramatically reduce thermal bridging

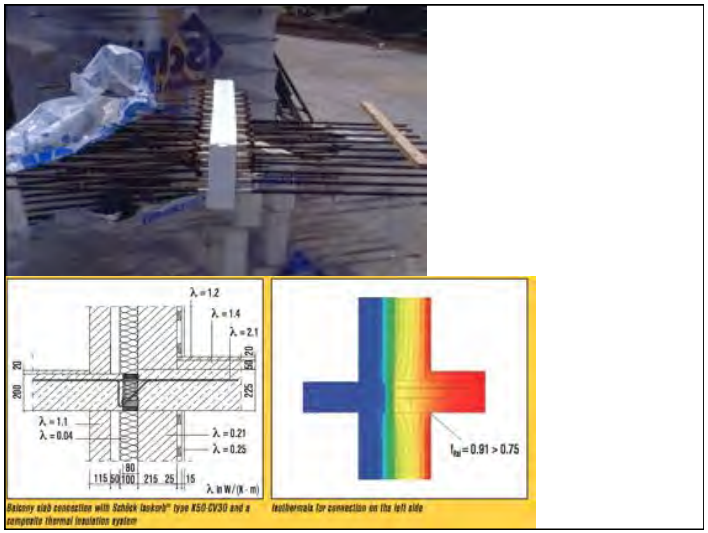

Balconies
Building Science 2008
Insulation and Thermal Bridges No. 160/65

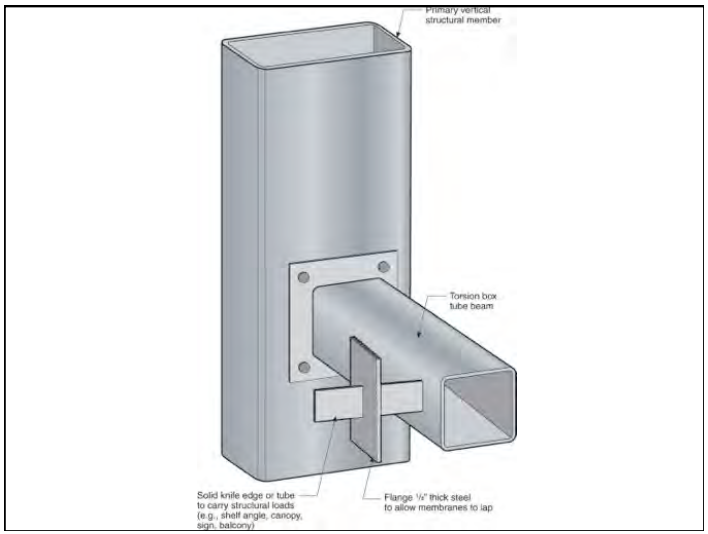

Building Science 2008
Insulation and Thermal Bridges No. 161/65

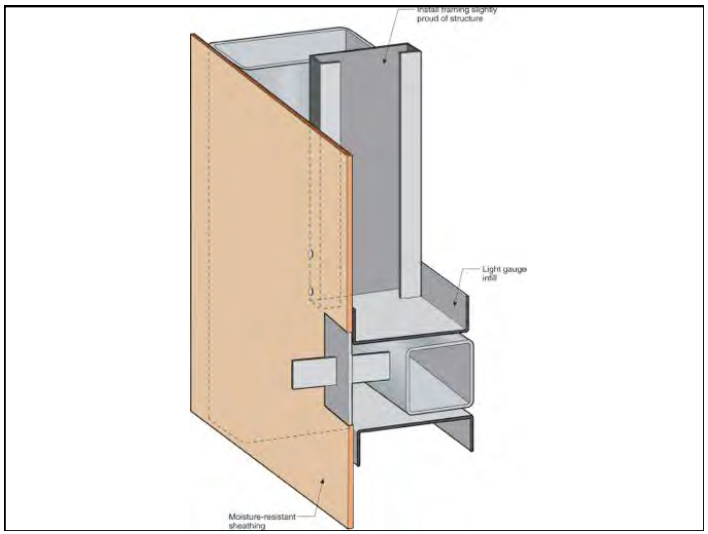

Philly's Best

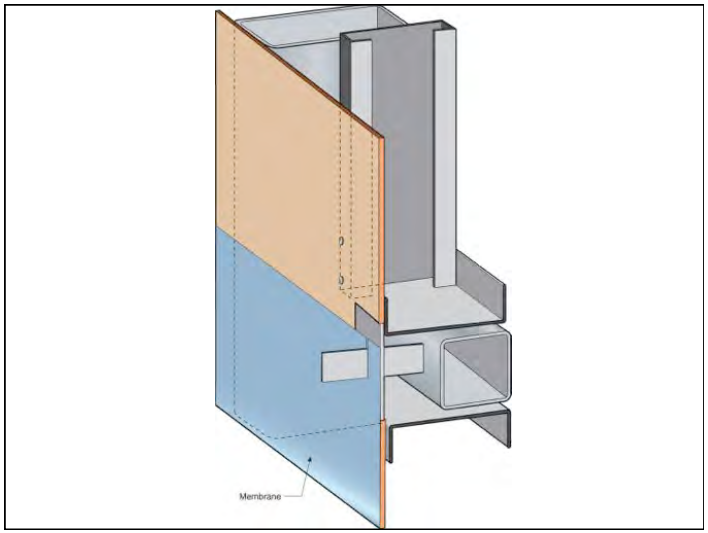

Precast balcony supported on knife edge supports to limit thermal losses

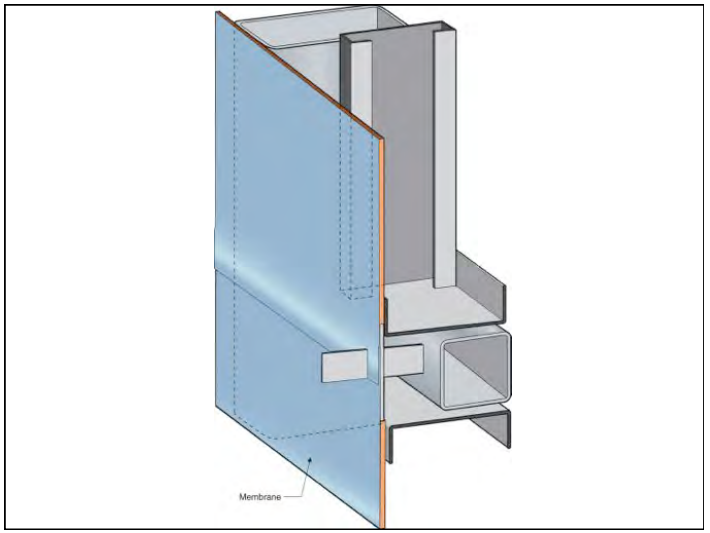

Fully-adhered air and water barrier, lapped at joints
Continuous thermal insulation (XPS, EPS, PIC, ccSPF, semi-rigid MFI); nominal 1" drainage gap
Furring
Stainless steel projecting drip flashing
Precast concrete balcony
Shelf angle supported on stand-offs attached to cast-in plates
Vent openings
Gypsum board finish
Use backer rod to fill deflection joint and debond water and air barrier
Insulation retention washer (depending on insulation type)


λ = 1.2
λ = 1.4
λ = 2.1
λ = 1.1
λ = 0.04
λ = 0.21
λ = 0.25
f_Rsi = 0.91 > 0.75


Primary vertical structural member
Torsion box tube beam
Solid knife edge or tube to carry structural loads (e.g., shelf angle, canopy, sign, balcony)
Flange ½" thick steel to allow membranes to lap


Light gauge infill
Moisture-resistant sheathing





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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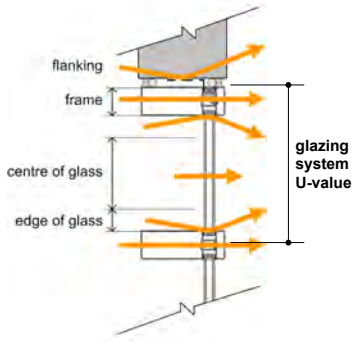
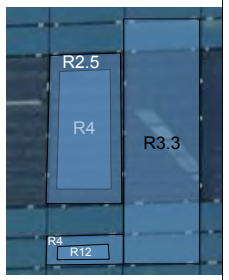
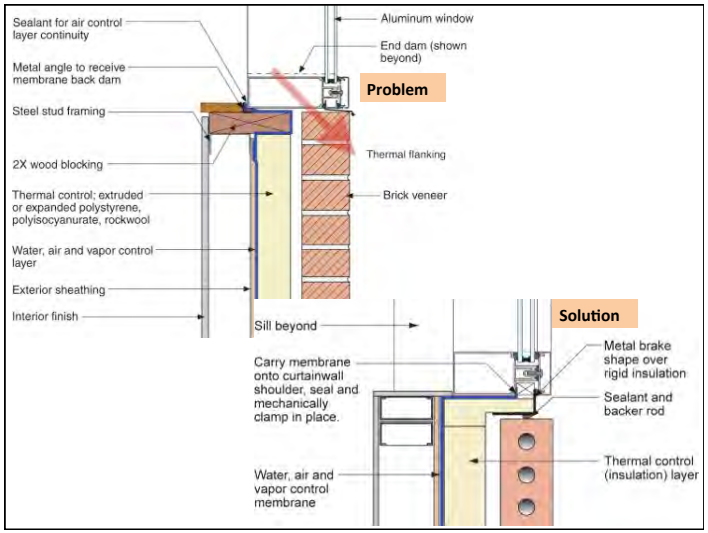
Total Heat Flow

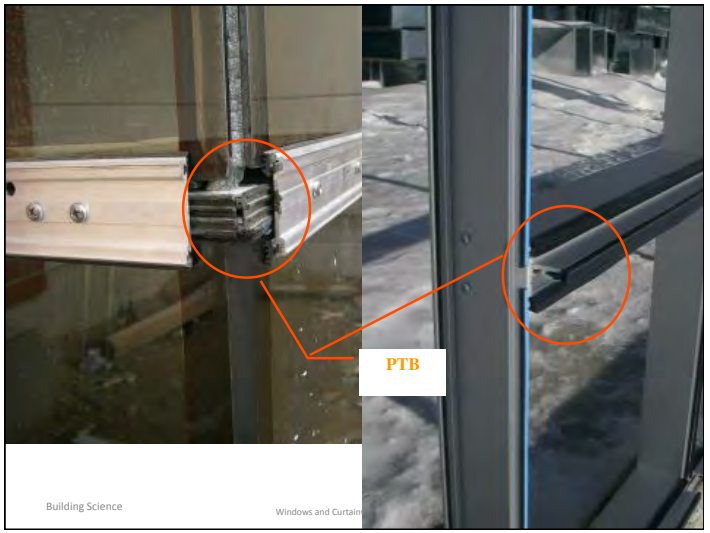
Curtain Wall Plan View



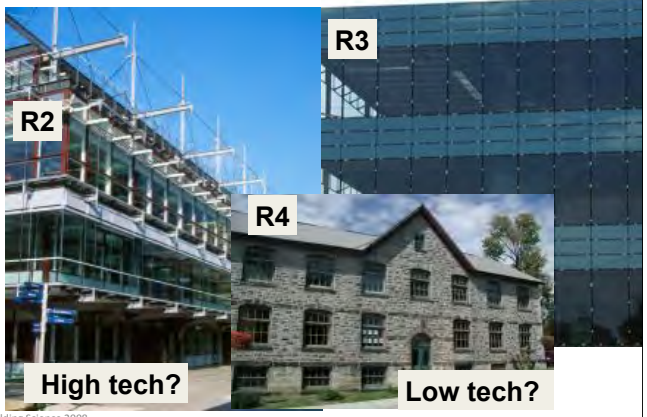


Building Science 2008 Windows and Curtainwalls No. 17280





Full-Frame R-values



Building Science 2008 Windows and Curtainwalls No. 17580

Thermal Break

- Critical for alu windows
- ½" should be min thermal break

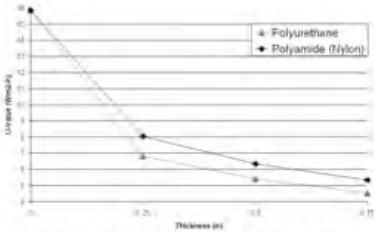
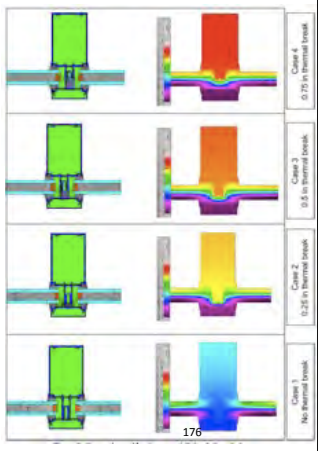
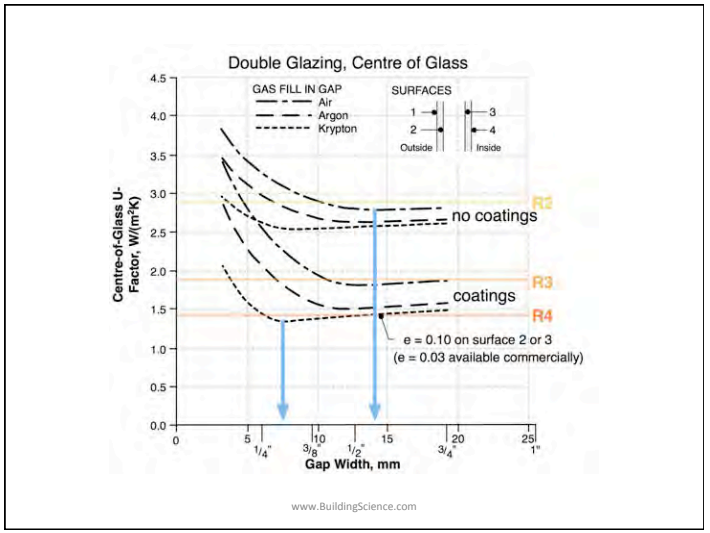


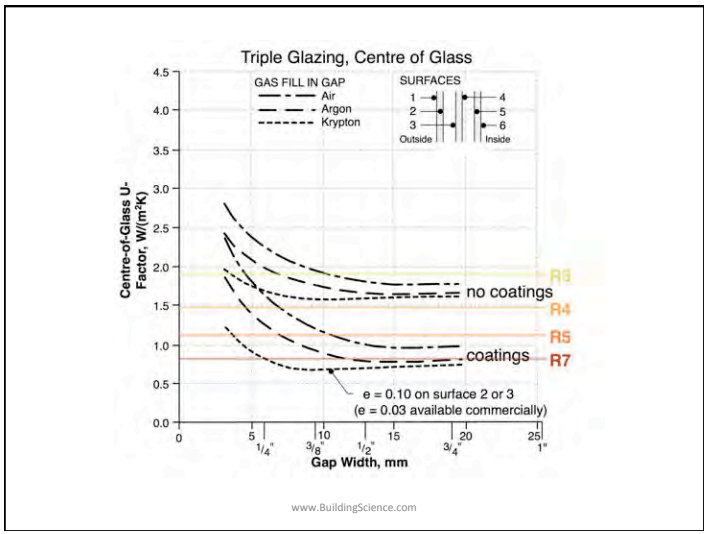
Figure 4: Frame U-Value vs. thermal break thickness.



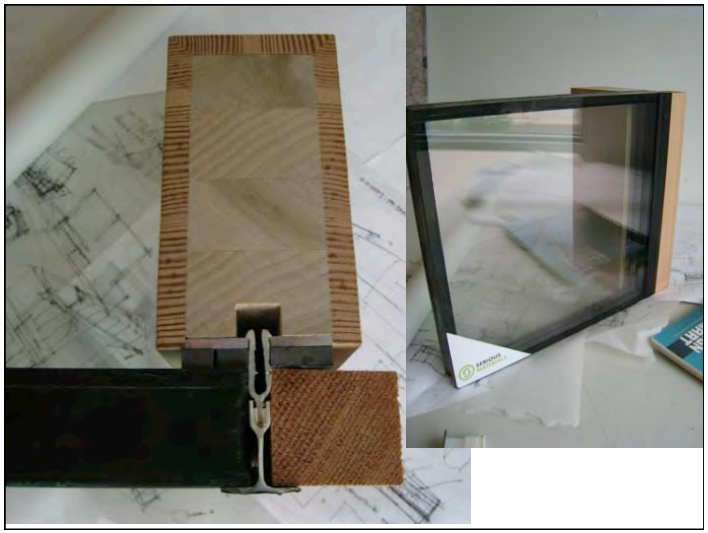
176

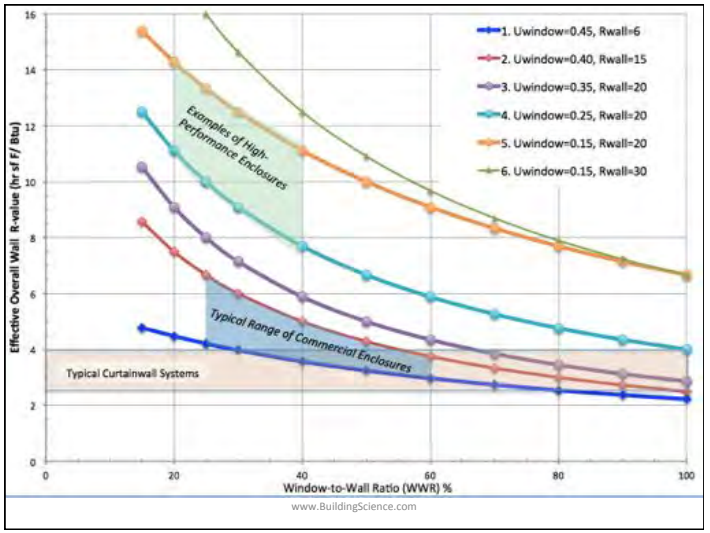

High Performance
Getting better . .
R8
Southwall
R6
R24
Kawneer
R6
Visionwall
Building Science.com

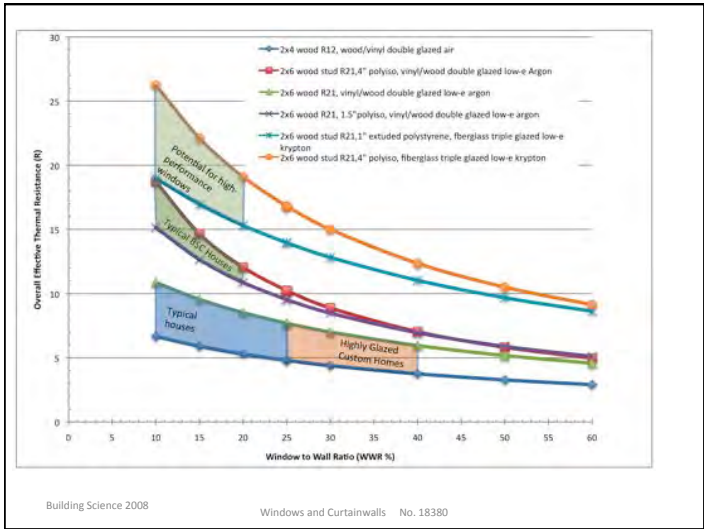

Double Glazing, Centre of Glass
GAS FILL IN GAP
Air
Argon
Krypton
SURFACES
Outside
Inside
Centre-of-Glass U-Factor, W/(m²K)
no coatings
coatings
R2
R3
R4
e = 0.10 on surface 2 or 3
(e = 0.03 available commercially)
Gap Width, mm
www.BuildingScience.com

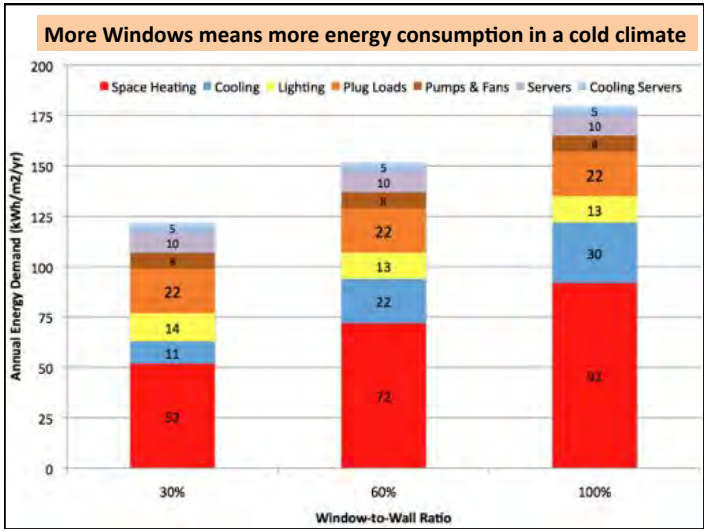

Triple Glazing, Centre of Glass
GAS FILL IN GAP
Air
Argon
Krypton
SURFACES
Outside
Inside
Centre-of-Glass U-Factor, W/(m²K)
no coatings
coatings
R3
R4
R5
R7
e = 0.10 on surface 2 or 3
(e = 0.03 available commercially)
Gap Width, mm
www.BuildingScience.com


Center of Glass (COG) Performance*
AlpenGlass+™
Industry Leading Performance
U-Value
R-Value
SHGC
VT
Glazing
Fill
Premium Performance
High Performance
Courtesy Seriious Windows

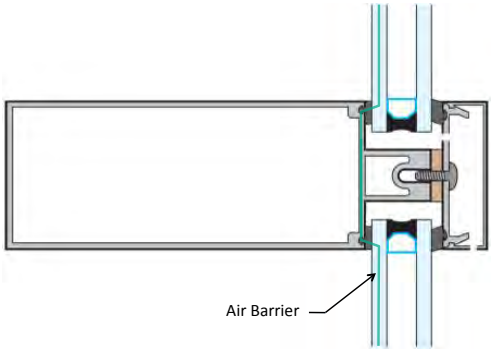



1. Uwindow=0.45, Rwall=6
2. Uwindow=0.40, Rwall=15
3. Uwindow=0.35, Rwall=20
4. Uwindow=0.25, Rwall=20
5. Uwindow=0.15, Rwall=20
6. Uwindow=0.15, Rwall=30
Examples of High-Performance Enclosures
Typical Range of Commercial Enclosures
Typical Curtainwall Systems
Effective Overall Wall R-value (hr sf F/ Btu)
Window-to-Wall Ratio (WWR) %
www.BuildingScience.com


2x4 wood R12, wood/vinyl double glazed air
2x6 wood stud R21,4" polyiso, vinyl/wood double glazed low-e Argon
2x6 wood R21, vinyl/wood double glazed low-e argon
2x6 wood R21, 1.5"polyiso, vinyl/wood double glazed low-e argon
2x6 wood stud R21,1" extuded polystyrene, fiberglass triple glazed low-e krypton
2x6 wood stud R21,4" polyiso, fiberglass triple glazed low-e krypton
Potential for high-performance windows
Typical R2C Houses
Typical houses
Highly Glazed Custom Homes
Overall Effective Thermal Resistance (R)
Window to Wall Ratio (WWR %)
Building Science 2008
Windows and Curtainwalls No. 18380


More Windows means more energy consumption in a cold climate
Space Heating
Cooling
Lighting
Plug Loads
Pumps & Fans
Servers
Cooling Servers
Annual Energy Demand (kWh/m2/yr)
30%
60%
100%
Window-to-Wall Ratio

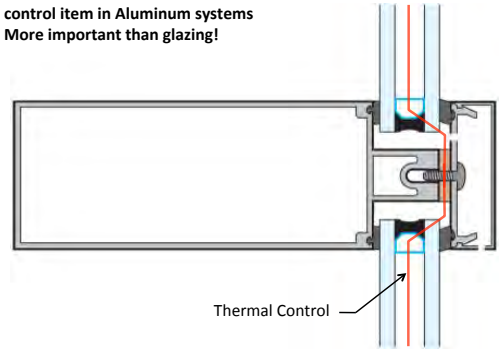
Air Flow Control



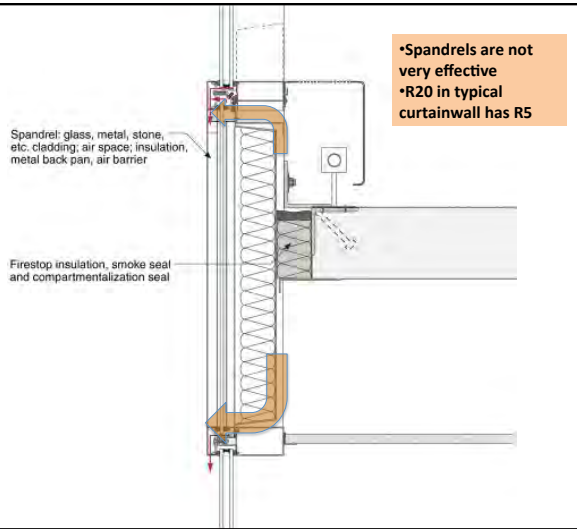
Building Science.com

Thermal Control

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



Building Science.com



•Spandrels are not very effective
•R20 in typical curtainwall has R5

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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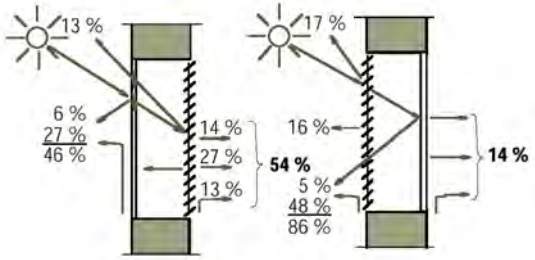
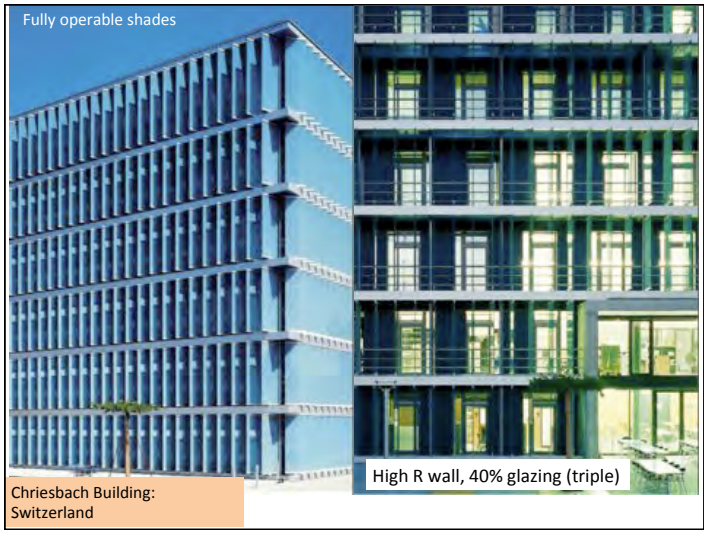
Interior or Exterior Shade

- 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



Building Science.com



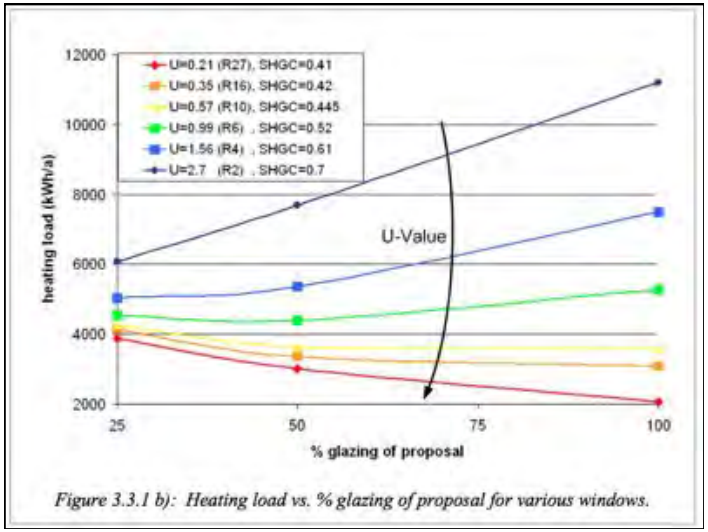


Figure 3.3.1 b): Heating load vs. % glazing of proposal for various windows.

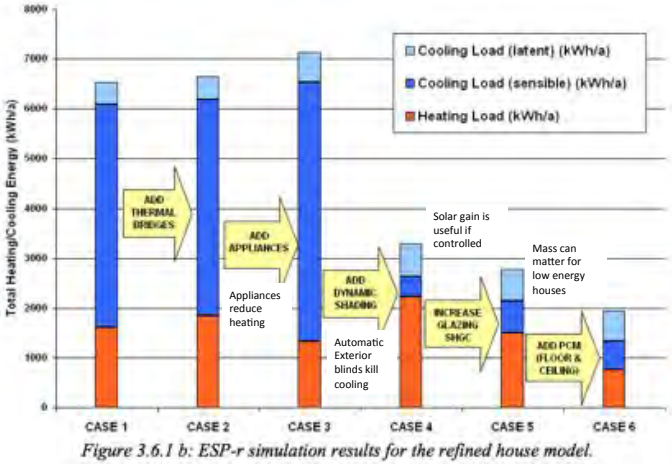


Figure 3.6.1 b: ESP-r simulation results for the refined house model.

ROOFS

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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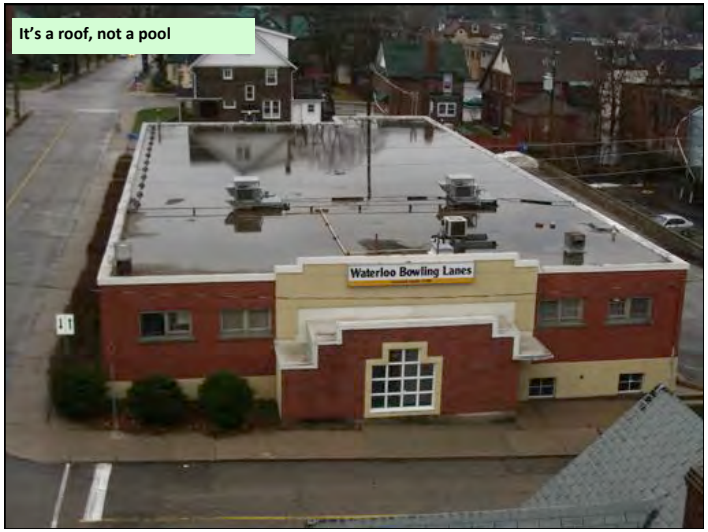
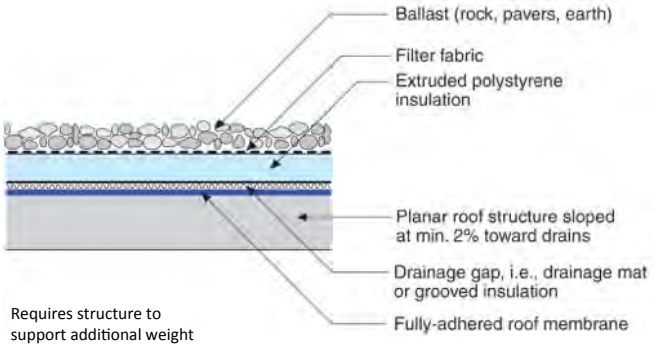


Perfect Roof (PMR / IRMA)



Requires structure to support additional weight

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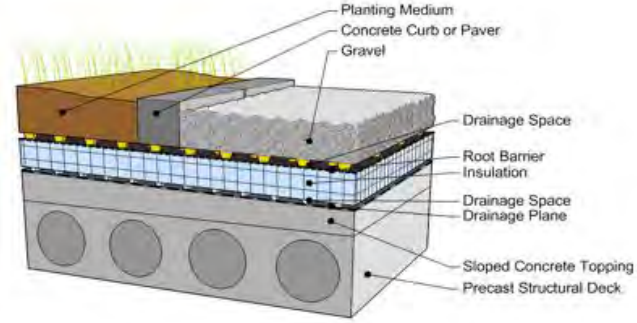

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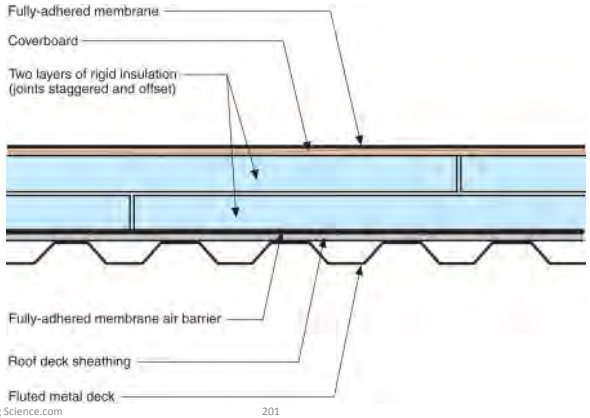
Green roofs and LEED

- LEED-NC currently gives one point for a vegetated roof on at least 50% of roof area
  - This is a design credit, only visual inspection of installation
- In density development, green roofs can count towards to other points:
  - Sustainable Sites 5.2 Open Space (if accessible)
  - Sustainable Sites 5.1 Habitat (if native plants)
  - But GR alone will rarely achieve these two

Good Compromise



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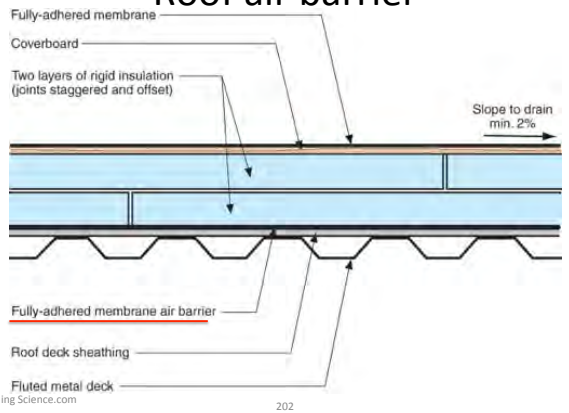
Deck level vapor control membrane rarely required if closed cell foam used

Roof air barrier



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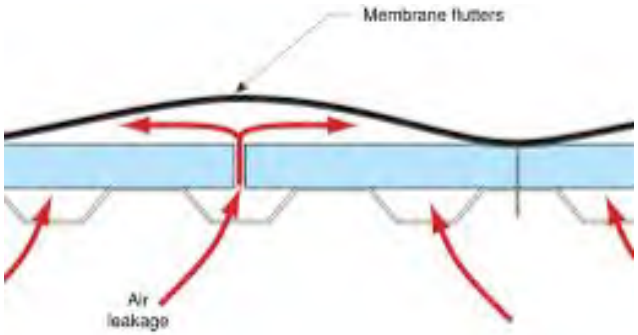
Why fully adhered?



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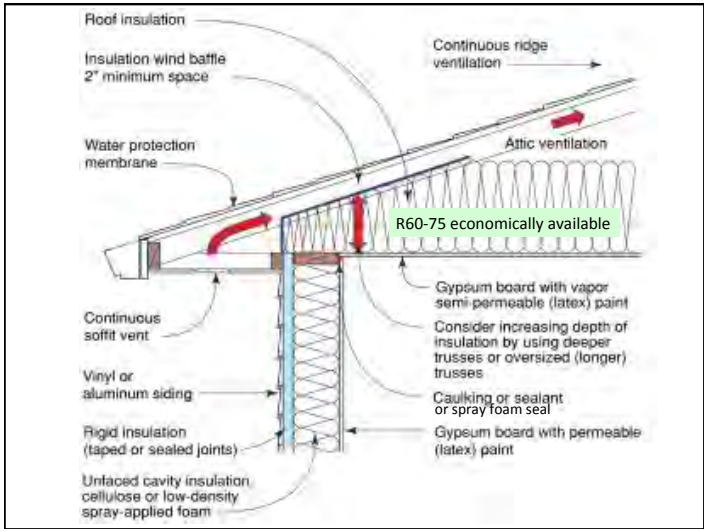
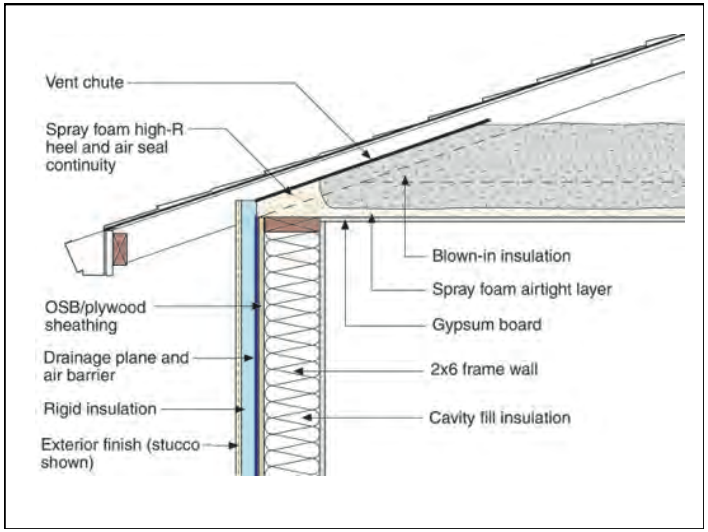
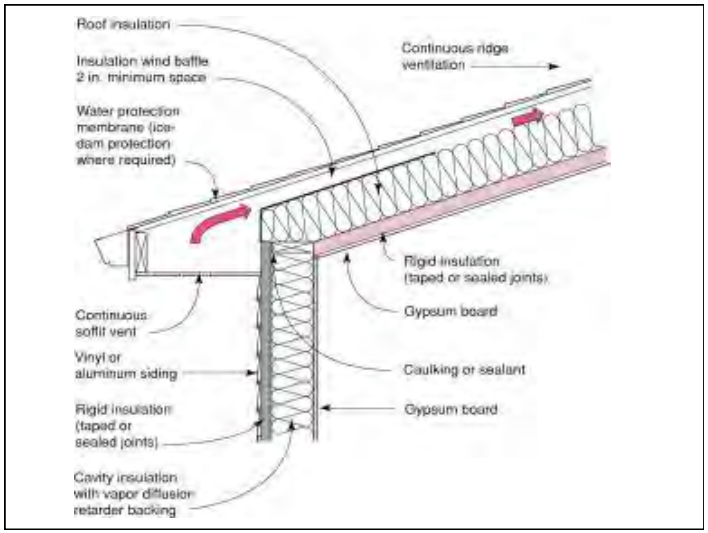
Andy Shapiro. Energy Balance, VT


Roof insulation
Insulation wind baffle
2" minimum space
Continuous ridge
ventilation
Water protection
membrane
Attic ventilation
R60-75 economically available
Gypsum board with vapor
semi-permeable (latex) paint
Continuous
soffit vent
Consider increasing depth of
insulation by using deeper
trusses or oversized (longer)
trusses
Vinyl or
aluminum siding
Caulking or sealant
or spray foam seal
Rigid insulation
(taped or sealed joints)
Gypsum board with permeable
(latex) paint
Unfaced cavity insulation
cellulose or low-density
spray-applied foam

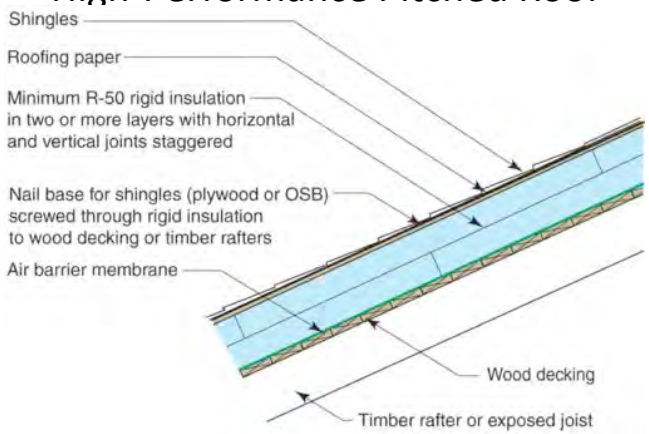

Vent chute
Spray foam high-R
heel and air seal
continuity
Blown-in insulation
Spray foam airtight layer
OSB/plywood
sheathing
Gypsum board
Drainage plane and
air barrier
2x6 frame wall
Rigid insulation
Cavity fill insulation
Exterior finish (stucco
shown)

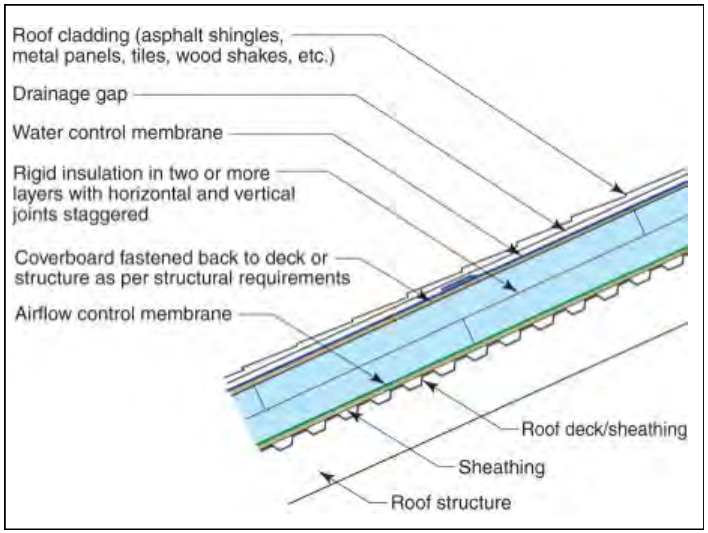


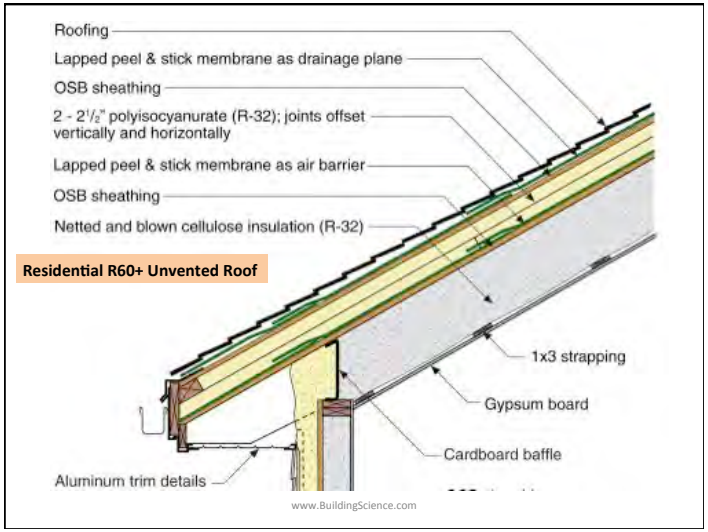
Unvented Cathedralized Attics

- 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

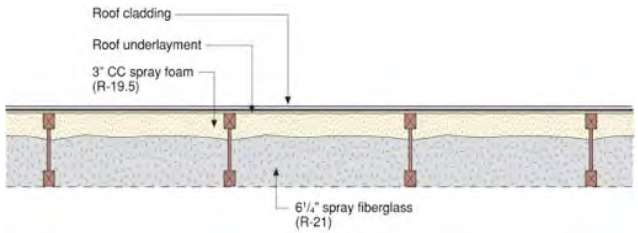
High-Performance Pitched Roof







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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Par

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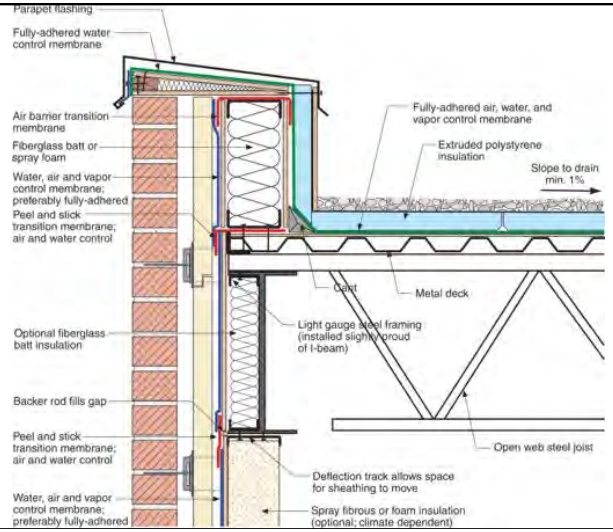

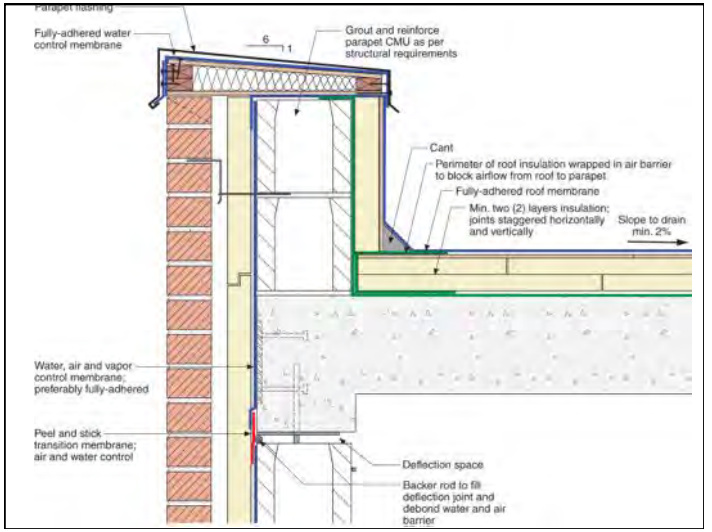

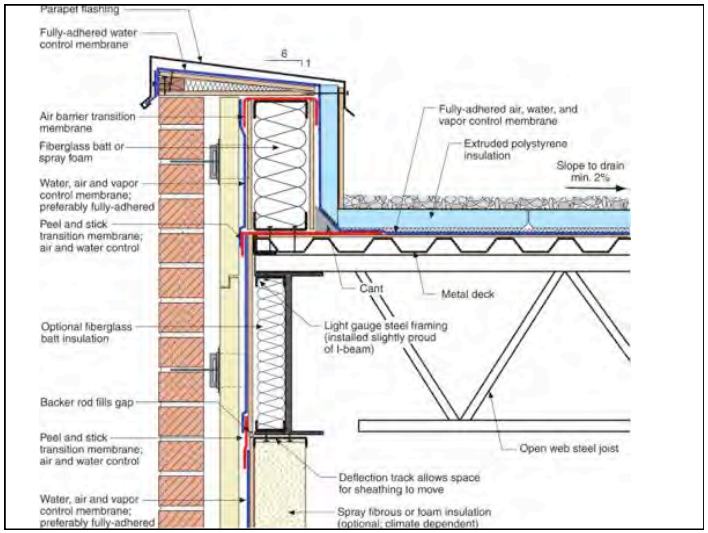

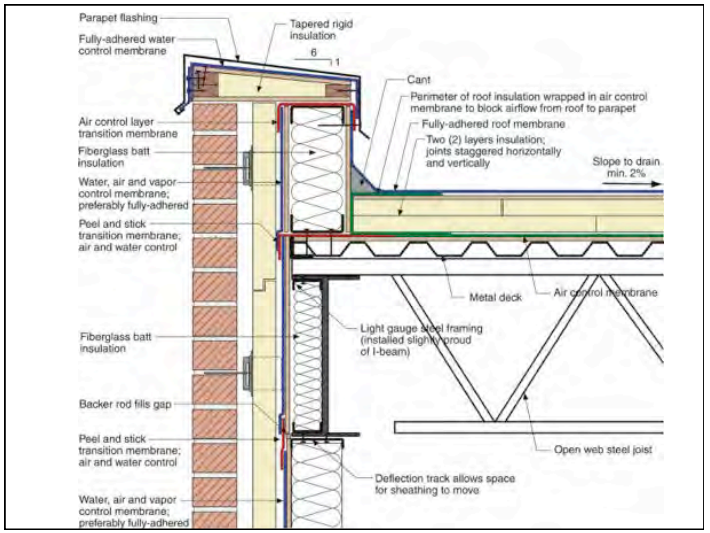

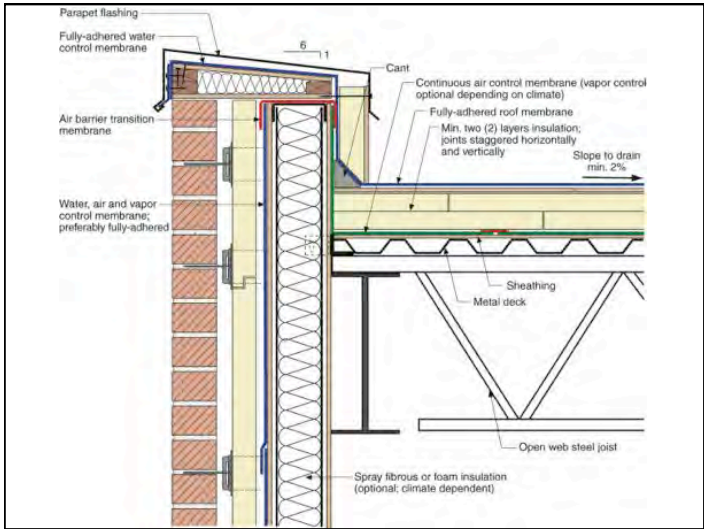

Enclosure Summary

- Simple compact form, oriented to the sun
- Identify functional control layers
  - Rain, air, heat, vapor
- Provide continuity of control layers
  - Details, thermal bridging
- Select high levels of performance

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Conclusions

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Mechanical Basics

HVAC Objectives

- Health
- Safety
- Comfort
  - Temperature, humidity, air speed, noise, light
- Reliability
  - Long term performance, maintainable
- Efficiency
  - Meet the needs imposed by occupants and enclosure with a minimum of additional energy

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Common Problems

- Poor comfort
  - Poor control of temperature and humidity,
  - Noise, drafts from high velocity air
- Health
  - Air based systems act as distribution for outdoor pollutants, mold grown in coils/ducts
  - Chilled water pipes collect condensation leading to mold
  - Insufficient ventilation/mixing common issue
- Energy
  - Systems are often very inefficient
- Maintainability / Controllability
  - Systems are complex, difficult to trouble shoot, maintain etc

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Functions

Five Critical functions are needed

- Ventilation
  - "fresh air"
  - Dilute / flush pollutants
- Heating
- Cooling
- Humidity Control
- Air filtration / pollutant Removal
  - Remove particles from inside and outside air
  - Remove pollutants in special systems

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What do you need to deliver?

Type	Temperature	Humidity	Pressure	Examples
I a	●			Heated house, warehouse
I b	●	○		Heating and normal A/C
I c	●		○	Heating + exhaust fans
I d	●	○	○	Heating+ A/C + exhaust fans
II a	●	●		Museum, fruit storage
II b	●	●	○	Pressurized + controlled
III	●	●	●	Special labs, chip fabrication
IV	●		●	Dust controlled manufacturing
V		●	●	
VI			●	

Note: ● Directly controlled ○ - Incidental Implicit

All require metered deliver of fresh air, and some exhaust of polluted air

Physical Systems & Components

- Components
  - Heat production (including cooling)
  - Heat rejection / collection
  - Heat/Cold Distribution
  - Ventilation air supply/exhaust
  - Ventilation Air Distribution Air Filtration
  - Humidification/ Dehumidification
- Confusion arises when functions are combined across different components in different systems

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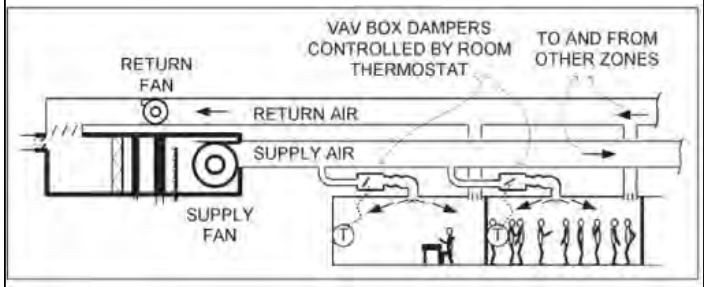
Variable Air Volume



Poor IAQ: ventilation controlled by thermostat
Poor/no RH control: depends on cooling coil operation
Either good energy performance /poor RH, or good RH / poor energy
Often no designed exhaust air: "pressurize" building

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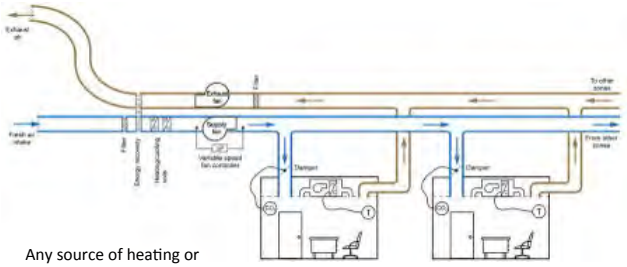
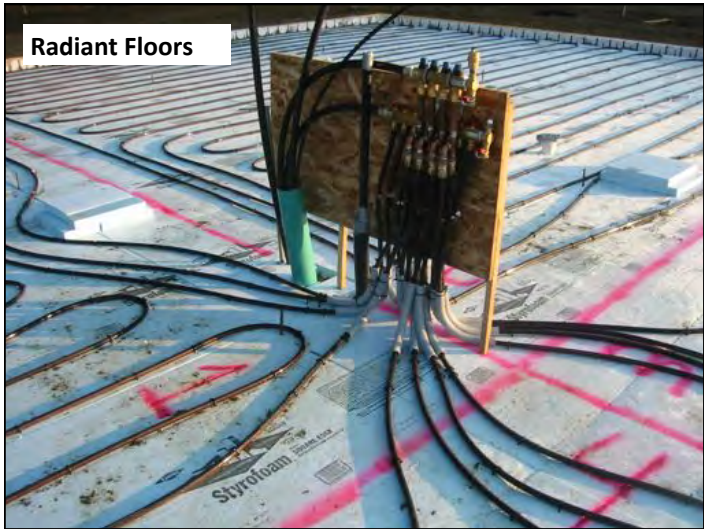
BSI-022 Perfect HVAC



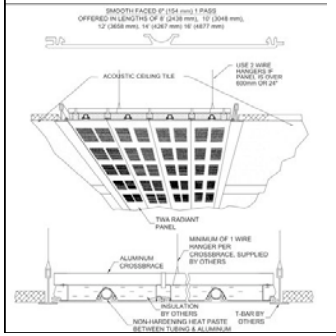
Any source of heating or cooling
Combined ventilation/ humidity control

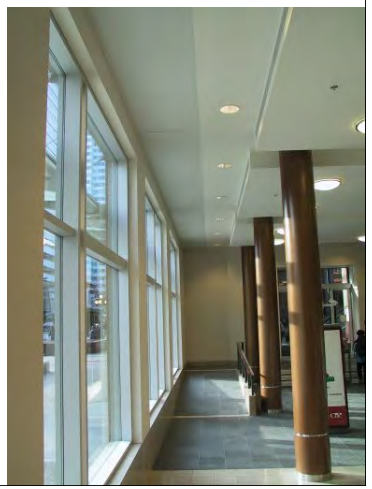
Radiant Floors



Radiant Panels

- Smaller area → higher deltaT
- About 50/50 radiant/convective
- Peak heating 150 W/m² (50 Btu/ft²)
- Peak cooling 100 W/m² (33 Btu/ft²)





Terminal Unit: Fan coils

- Use fans to below room air over coils
  - Fan-driven air movement = distribution / mixing within a space
  - Noise, maintenance issues
- Fans require electricity
  - Many existing FC are inefficient and noisy
  - **Very efficient fan motors** now available

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UnderFloor Air Distribution

- Energy savings are questionable in humid climates
- Uncontrolled air leakage limits performance
- Significant risks of indoor air quality problems
- Moving offices is often *more* difficult

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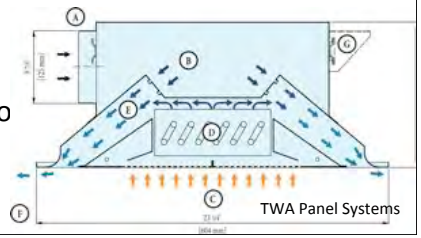
Chilled Beams

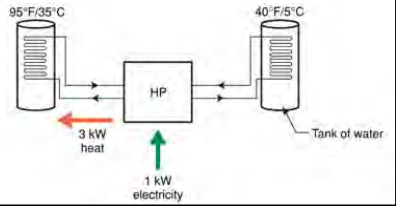
- Increase the convective component of radiant panels, usually for cooling
- Active CB use mechanically-induced airflow
- Air must flow at all times
- Good for labs
- Not great for variable ventilatio occupancies



TWA Panel Systems

Heat Pumps

- Use compressors, and refrigerant ("Freon")
- All use *internal heat exchangers* to transfer hot or cold refrigerant to water or air
- Terminology
  - "Air to air heat pump" = "air-source"
  - "Water-to-water heat pump"
  - "air conditioning"
  - Water to air
  - Ground source
  - "Geothermal"



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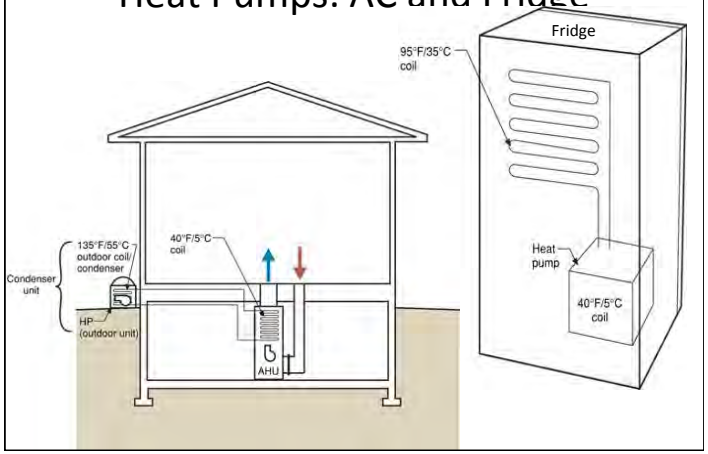
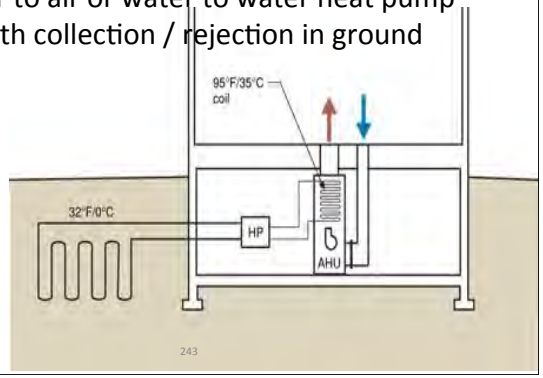
Heat Pumps: AC and Fridge



Ground Source Heat Pump

- A water to air or water to water heat pump with with collection / rejection in ground



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Heat Pump Efficiency vs Lift