University of Waterloo

Architectural Design for the 2030 Challenge

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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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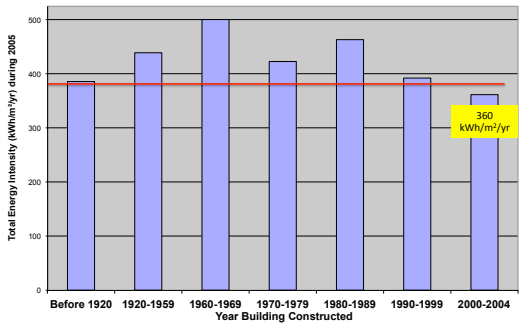
Actual Energy Consumption of Canadian Commerical and Institutional Buildings



Data from NRCan, OEE

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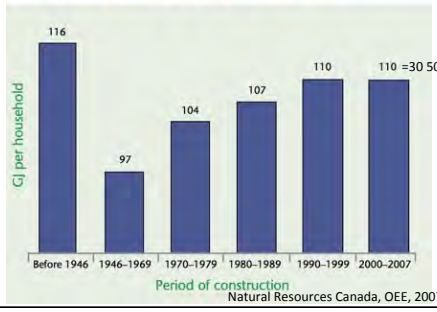
Single Family Housing

Chart 9. Energy consumption by year of construction, 2007 (GJ per household)



Natural Resources Canada, OEE, 2007 Survey

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

Design Principles

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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

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

Basic Goals (cold/mixed)

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

Insulation
Airtightness
Solar Control

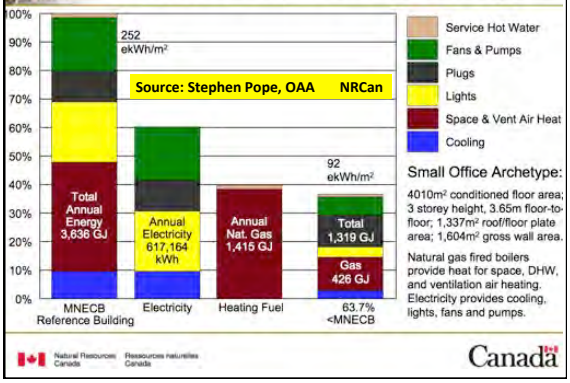
- Last a long time
  - Reduce construction/repair resources over time

Rain Control

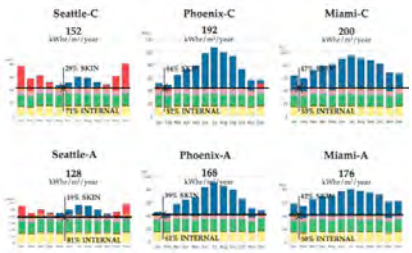
- Use efficient equipment
  - Efficient lighting
  - Efficient computers, elevators

Off is very efficient

Toronto Small Office Archetype



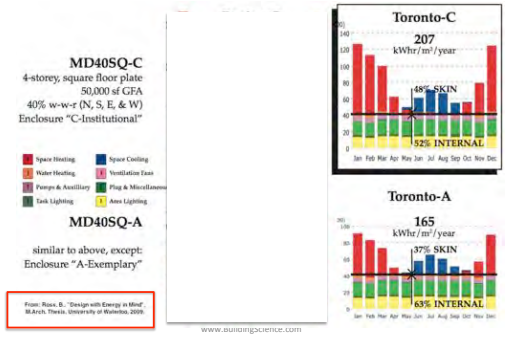
Climate matters



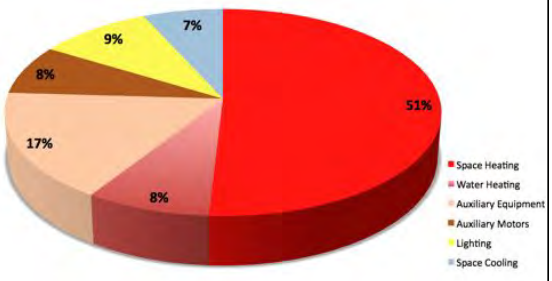
- Beware architecture magazines

Typical market Building in Toronto 55% heat+cool

Other things use energy



Canadian Offices 2007



207 million m²
Average 394 kWh/m²

Source: NRCan Office of Energy Efficiency

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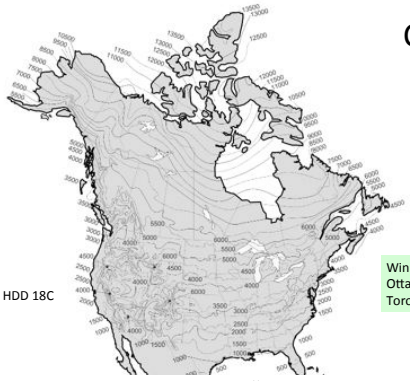
Canada:



Significant heating demand, especially Prairies and North

HDD 18C

Winnipeg 5750
Ottawa 4600
Toronto 4000

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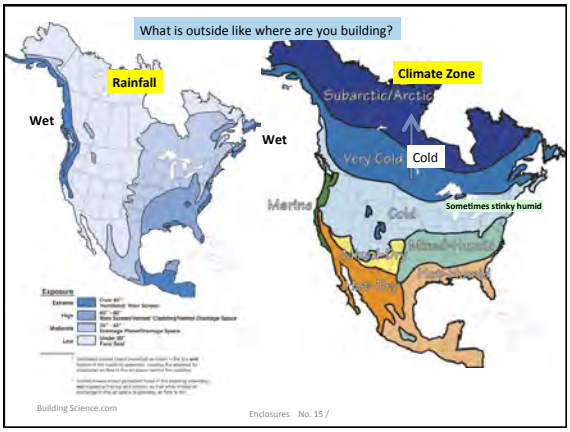

Can we do it?

- Is it possible or practical to drop energy use by 60% in cold-climate Canada?
- Standard Ontario office uses almost 400 kWh/m²/yr
- Can we get an office to 200? 100? kWh/m²/yr?

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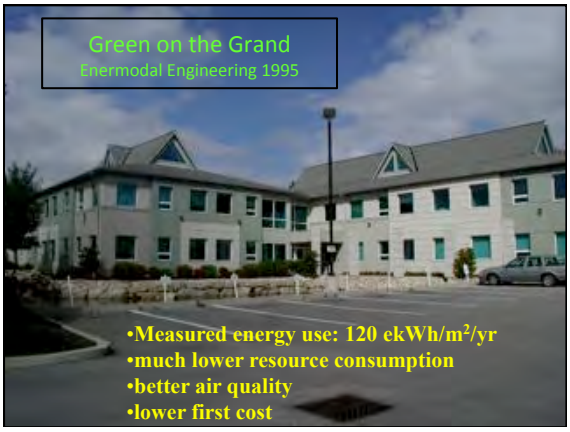
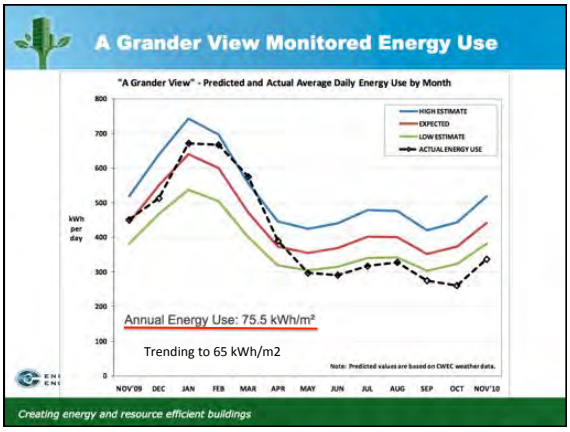
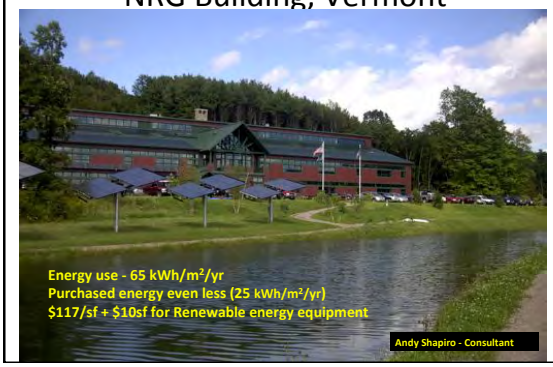


Grander View, 2010

- Mostly simple, standard technology
- Modest cost premium



NRG Building, Vermont



Waterloo Apartment / Office

- Built for median cost in 2005
- Around 100 ekWh/m² (Ont avg around 250)
- All standard products

John Straube

Waterloo Region Health & Welfare

- Built 1990. 160 ekWh/m²/yr.

London City Hall

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

London UK City Hall

- **Measured: 376 kWh/m²/yr**

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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HVAC

- Architect helps select
- Critical role, as HVAC offers about half the possible savings
- Fancy, complex, expensive not often the lowest energy choice

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Enclosures

- 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**!
- Great enclosures reduce demand & hrs of operation
- Can't "insulate to zero"

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The Enclosure: An Environmental Separator

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

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Enclosures No. 29 /

Climate Load Modification

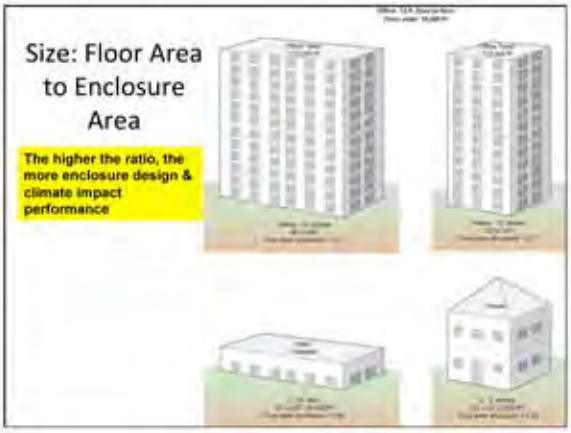
- Building & Site (overhangs, trees…)
  - – Creates microclimate
- Building Enclosure (walls, windows, roof…)
  - – Separates climates
  - – Passive modification
- Building Environmental Systems (HVAC…)
  - – Use energy to change climate
  - – Active modification

Form & Massing

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

Size: Floor Area to Enclosure Area

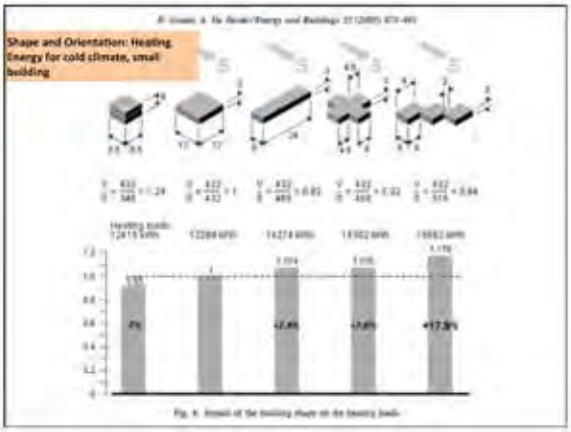
The higher the ratio, the more enclosure design & climate impact performance



Small, Compact Form

- Fewer resources
- Less heat loss and gain

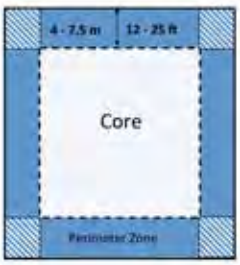
Shape and Orientation: Heating Energy for cold climate, small building



Large Buildings

Many buildings with large cores require cooling in winter while heating the perimeter

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***

Define "perimeter"

- Maximum distance about 25 ft/ 7.5 m
  - Classrooms often 25-30 ft, open plan office
- Minimum often set by walls/partitions of exterior offices
  - Cellular offices often 15 ft/ 4.5m deep

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

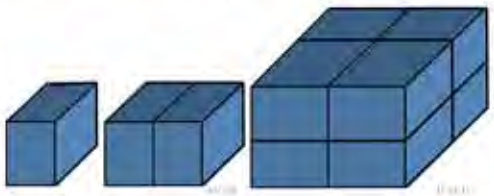
- Alphabet Soup
  - H I A B E

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



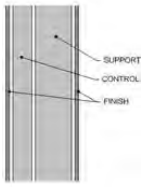
Enclosure Intro Summary

- 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

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

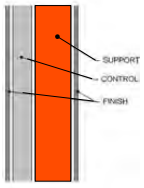
Functional Layers



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

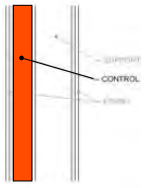
Functional Layers



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

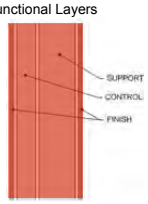
Functional Layers



Other Control . . .

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

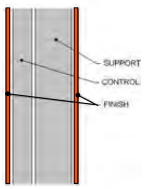
Functional Layers



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



History of Control Functions

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

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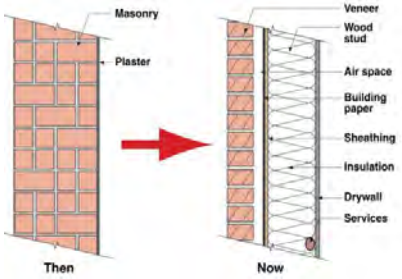
Changes



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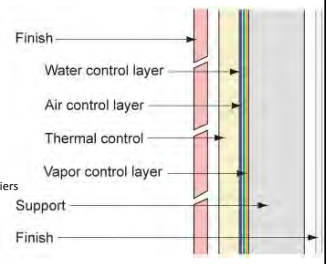
The "Perfect Wall"

- 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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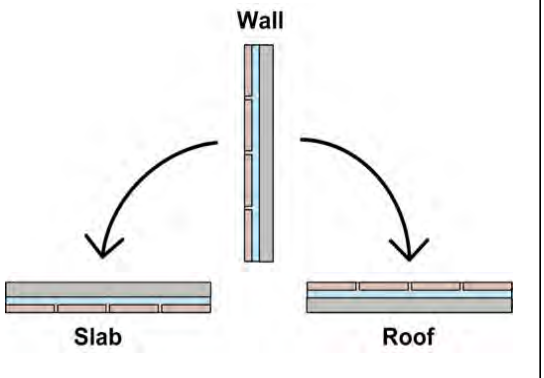

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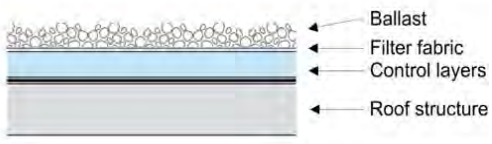

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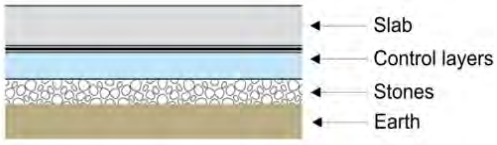

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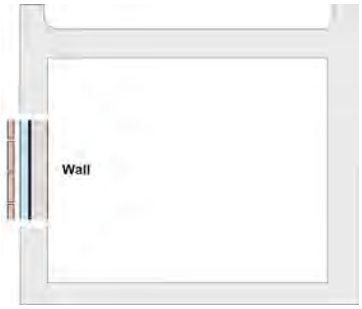

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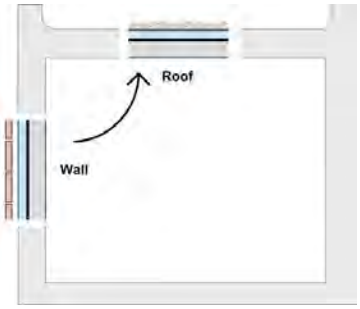

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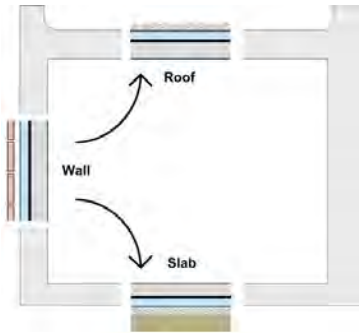

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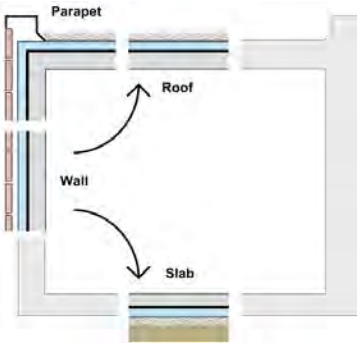

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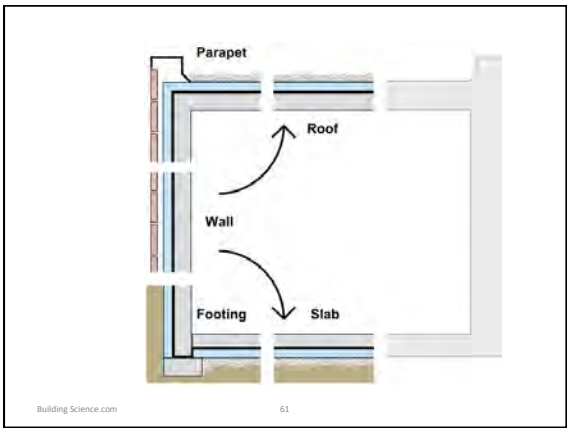
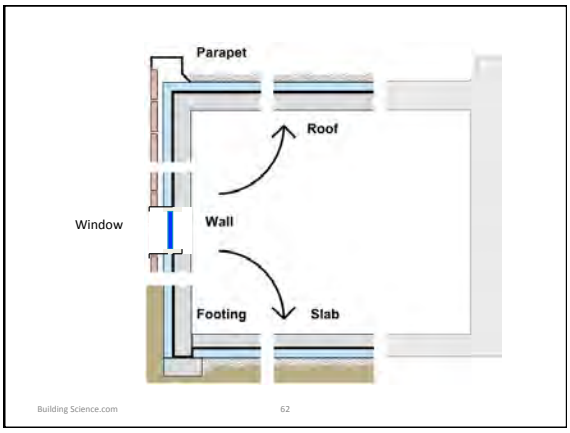

Parapet
Roof
Wall
Footing
Slab
Building Science.com
61


Parapet
Roof
Window
Wall
Footing
Slab
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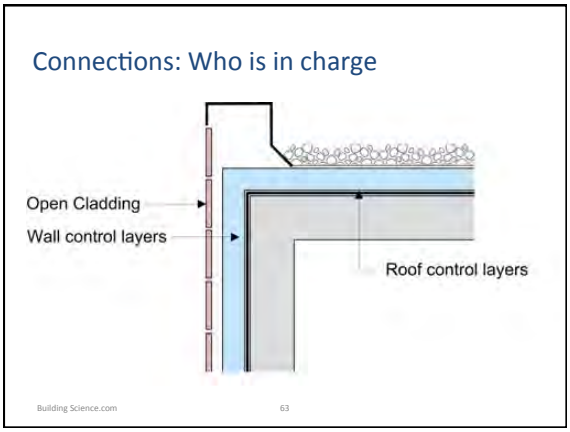
Connections: Who is in charge
Open Cladding
Wall control layers
Roof control layers
Building Science.com
63


Complexity increases detailing effort / risk of failure / cost reduces performance
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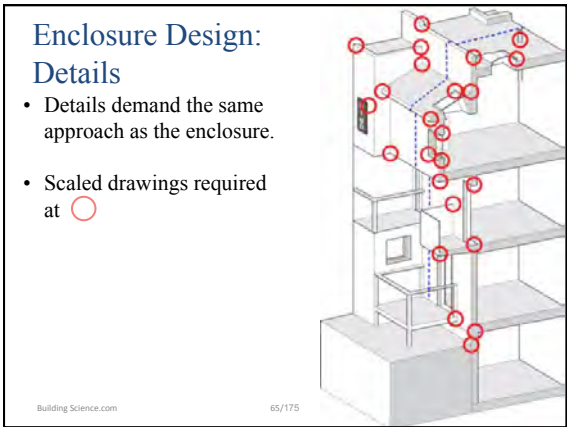
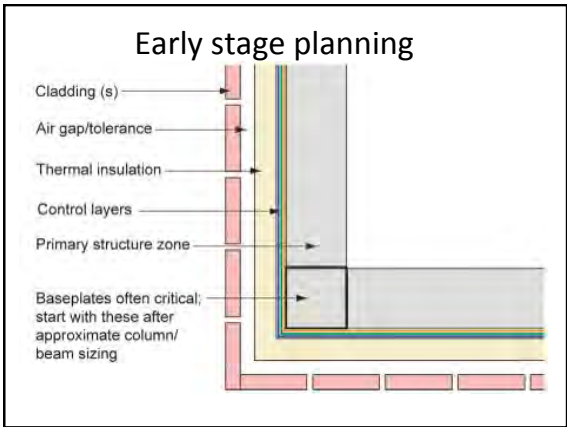
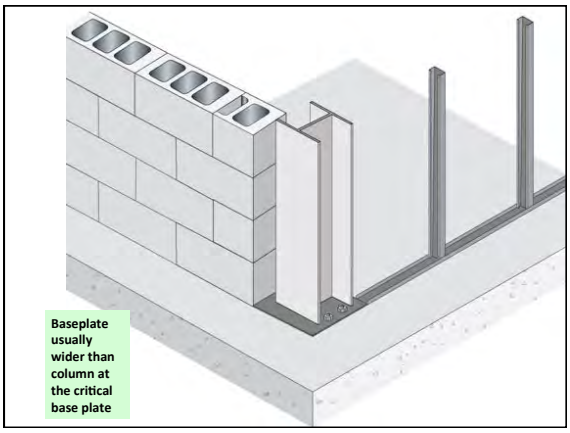
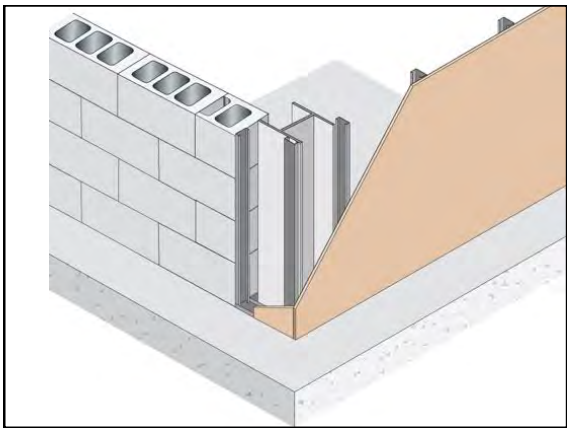
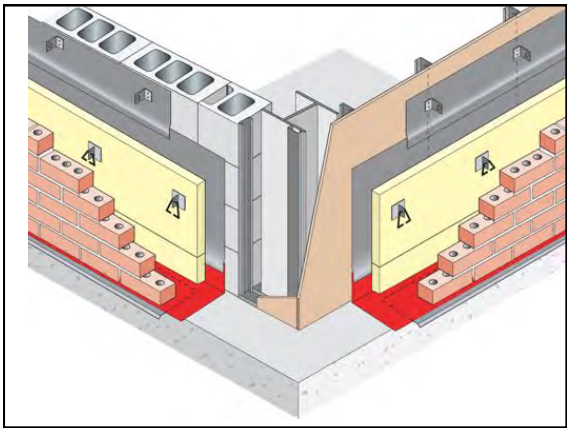
Enclosures No. 64 /

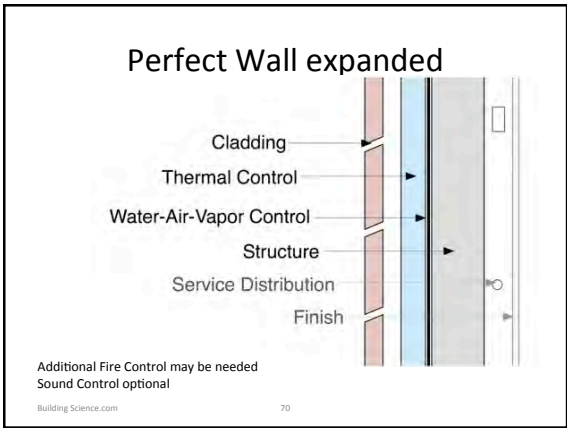

Enclosure Design: Details
• Details demand the same approach as the enclosure.
• Scaled drawings required at
Building Science.com
65/175

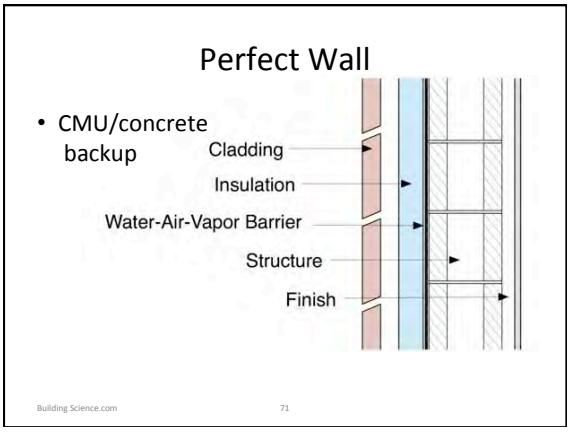

Early stage planning
Cladding (s)
Air gap/tolerance
Thermal insulation
Control layers
Primary structure zone
Baseplates often critical; start with these after approximate column/ beam sizing

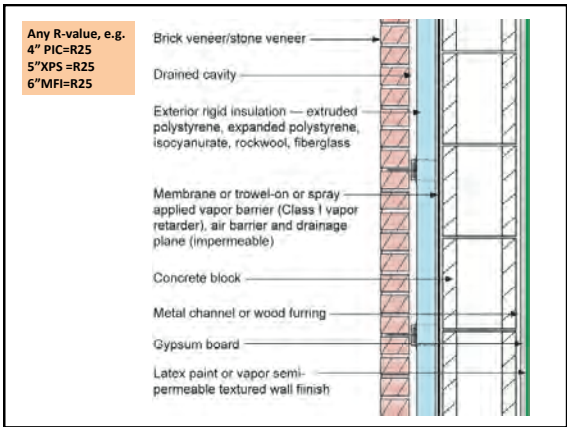

Baseplate usually wider than column at the critical base plate

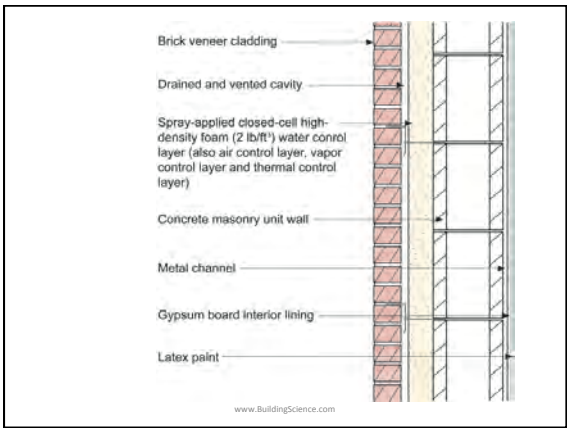





Perfect Wall expanded
Cladding
Thermal Control
Water-Air-Vapor Control
Structure
Service Distribution
Finish
Additional Fire Control may be needed
Sound Control optional
Building Science.com
70

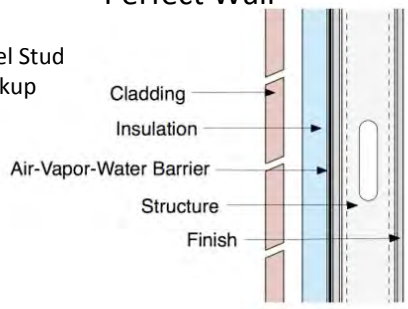

Perfect Wall
• CMU/concrete backup
Cladding
Insulation
Water-Air-Vapor Barrier
Structure
Finish
Building Science.com
71


Any R-value, e.g.
4" PIC=R25
5"XPS =R25
6"MFI=R25
Brick veneer/stone veneer
Drained cavity
Exterior rigid insulation — extruded polystyrene, expanded polystyrene, isocyanurate, rockwool, fiberglass
Membrane or trowel-on or spray applied vapor barrier (Class I vapor retarder), air barrier and drainage plane (impermeable)
Concrete block
Metal channel or wood furring
Gypsum board
Latex paint or vapor semi-permeable textured wall finish



Perfect Wall

- Steel Stud Backup



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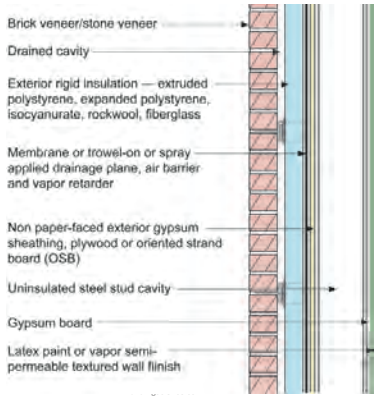
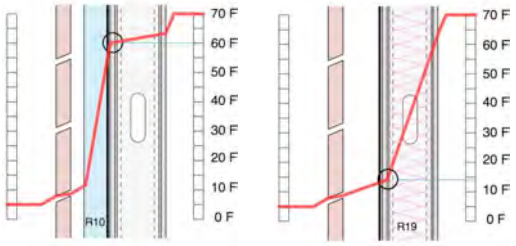
Any R-value, e.g.
4" PIC=R25
5"XPS =R25
6"MFI=R25



Condensation & Drying



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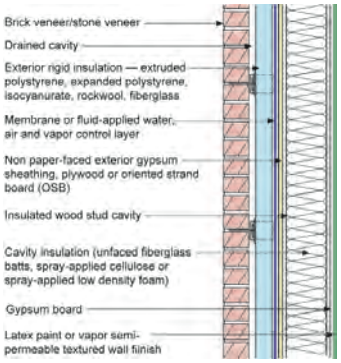
Ratio: Exterior R-value / Studbay R-value controls risk of condensation

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

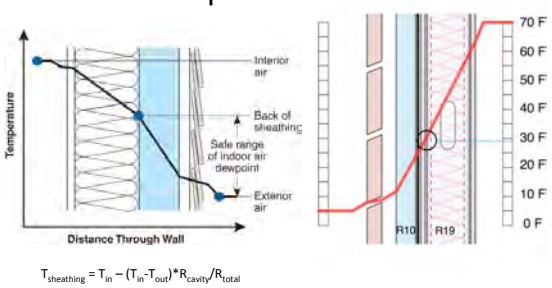
Compromise



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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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

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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= need for better control!

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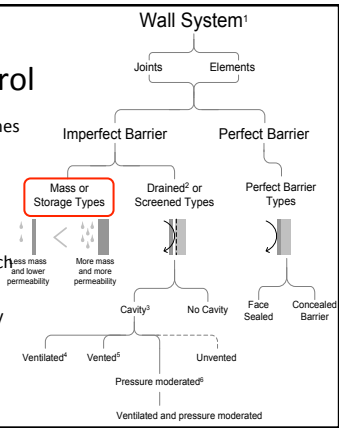
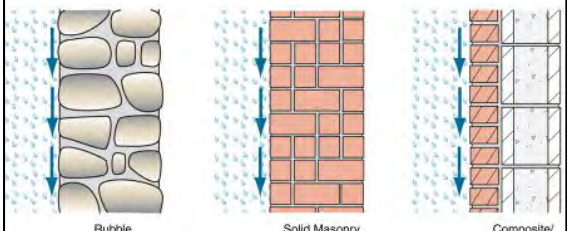
1. Rain Control

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



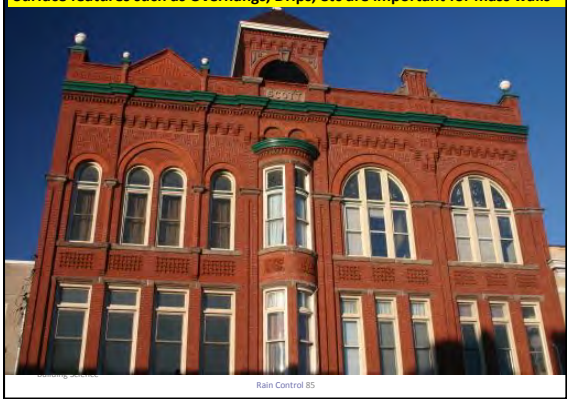
Mass/Storage/Reservoir Walls



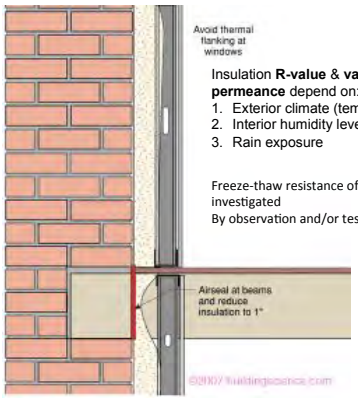
John Straube

No building paper, flashing, weepholes

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



Rain Control 85

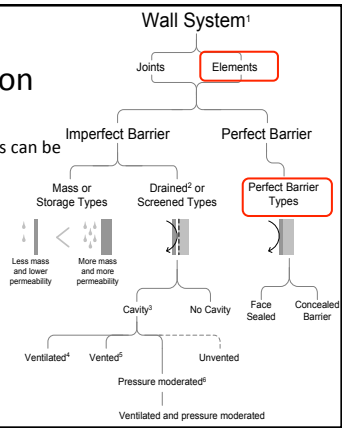


Insulation **R-value** & **vapor permeance** depend on:
1. Exterior climate (temp / drying)
2. Interior humidity levels
3. Rain exposure

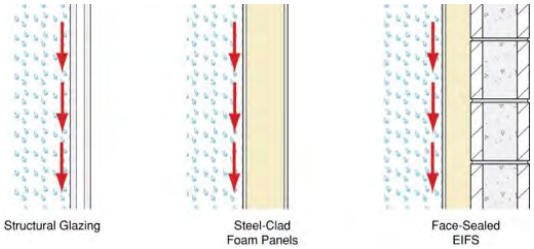
Freeze-thaw resistance of brick should be investigated
By observation and/or testing

Categorization

- Elements and joints can be different



Perfect Barrier / Face Sealed



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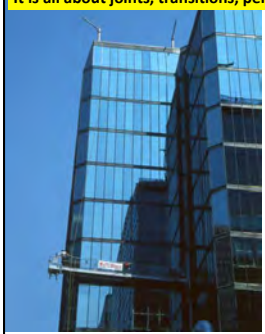
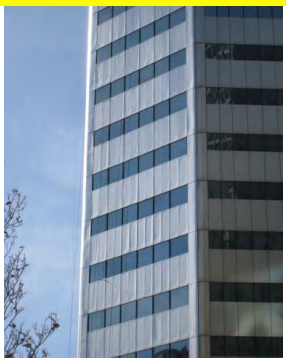
It is all about joints, transitions, penetrations





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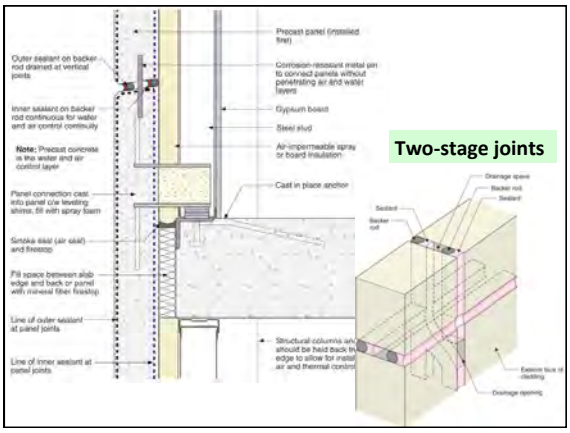
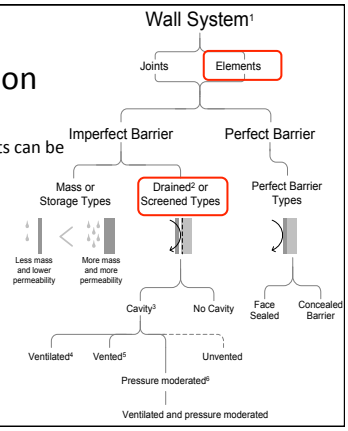
Precast is often a functional perfect barrier wall
.. but the joints leak



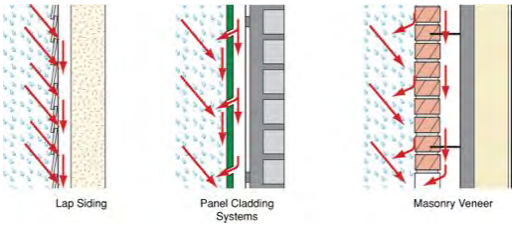
Categorization

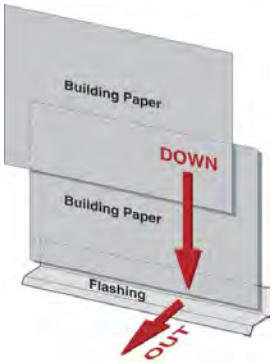
- Elements and joints can be different



Drained Walls

- "Pressure Equalized Rainscreen" are a fictional sub-set of drained walls





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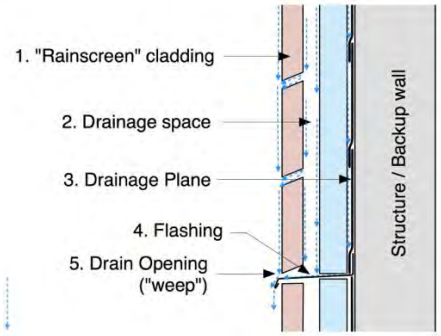
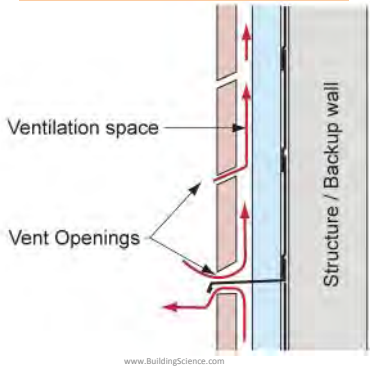
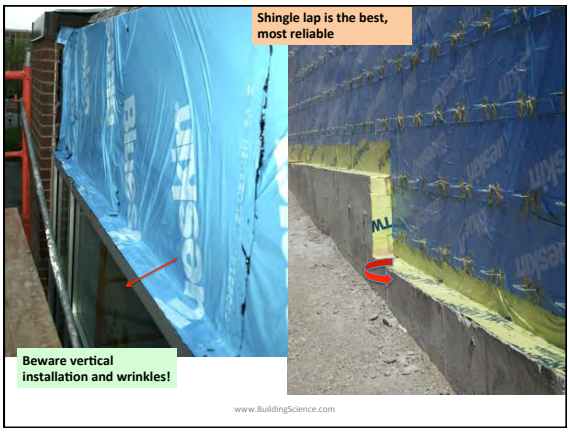
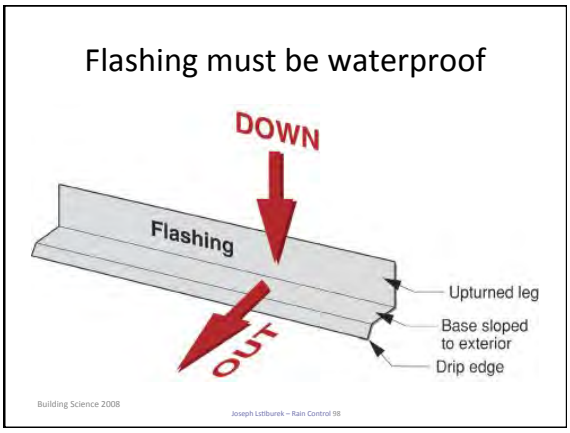
Requirements for a Drained Enclosure

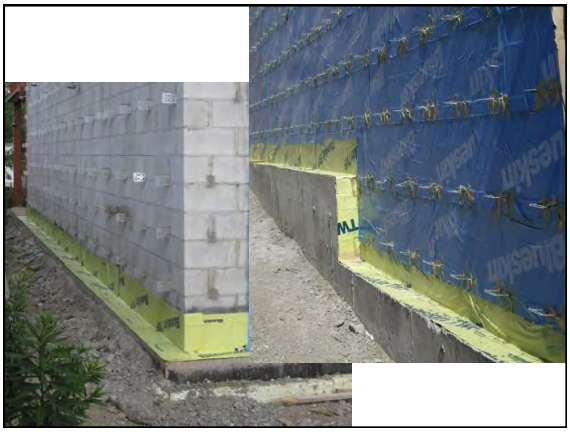


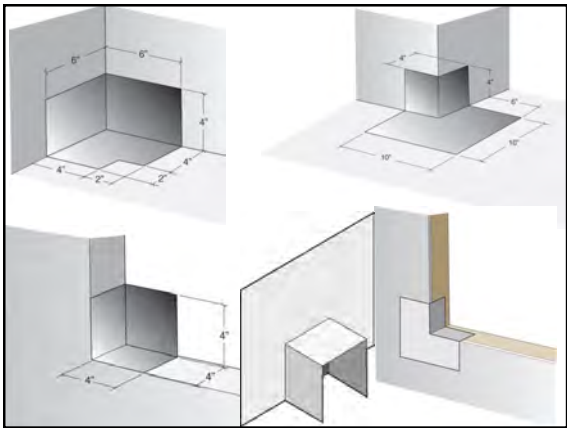
Requirements for a Ventilated Enclosure

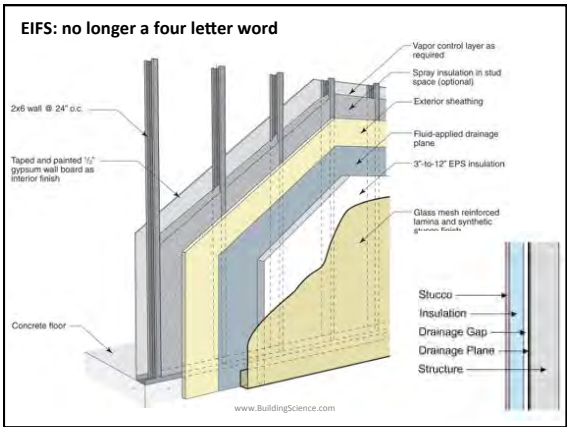


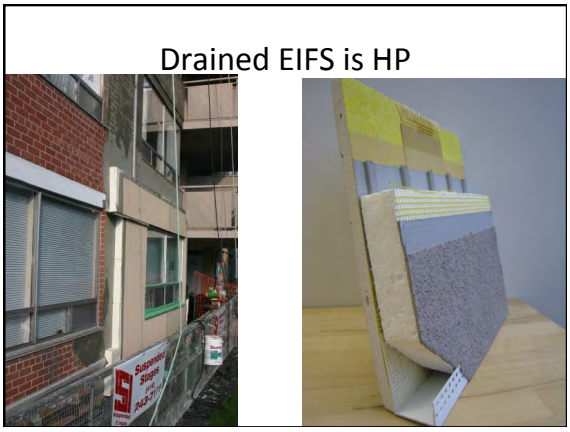

Shingle lap is the best, most reliable
Beware vertical installation and wrinkles!
www.BuildingScience.com


Flashing must be waterproof
DOWN
Flashing
OUT
Upturned leg
Base sloped to exterior
Drip edge
Building Science 2008
Joseph Lstburek – Rain Control 98

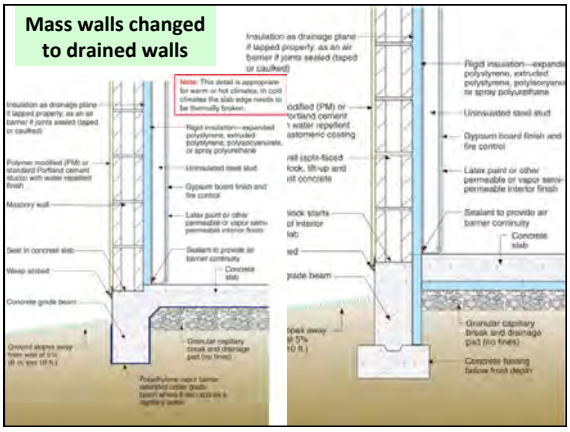


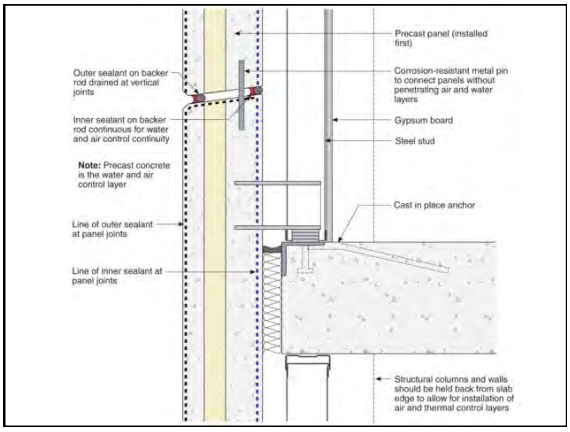



EIFS: no longer a four letter word
Vapor control layer as required
Spray insulation in stud space (optional)
Exterior sheathing
Fluid-applied drainage plane
3"-to-12" EPS insulation
Glass mesh reinforced lamina and synthetic
2x6 wall @ 24" o.c.
Taped and painted ½" gypsum wall board as interior finish
Concrete floor
Stucco
Insulation
Drainage Gap
Drainage Plane
Structure
www.BuildingScience.com


Drained EIFS is HP

Mass walls changed to drained walls



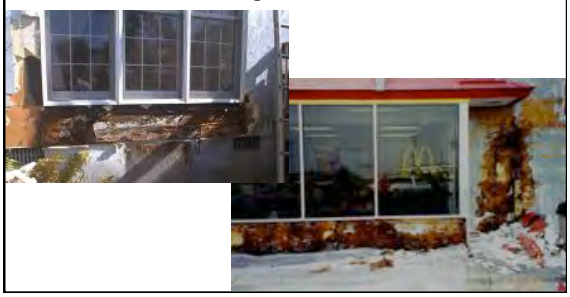


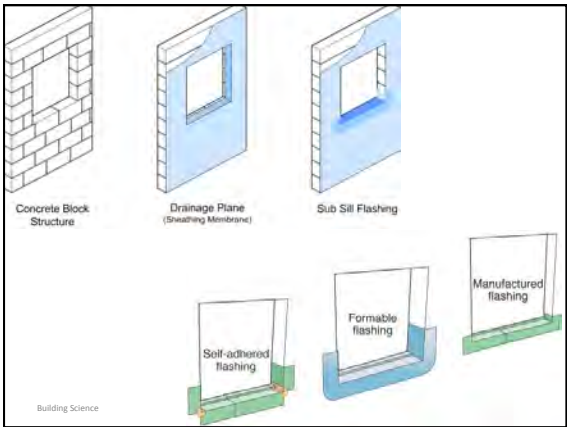
Windows and Doors

- 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

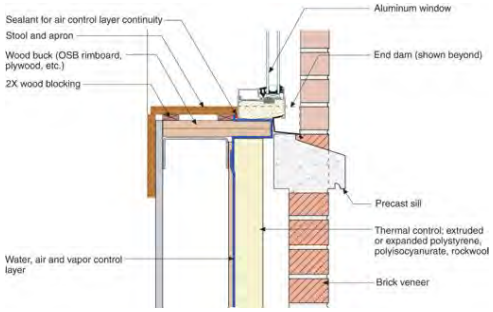


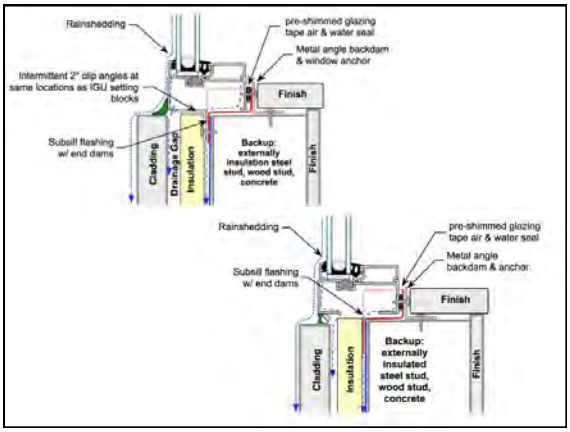


Mixed membrane + liquid

Often use membranes for transitions

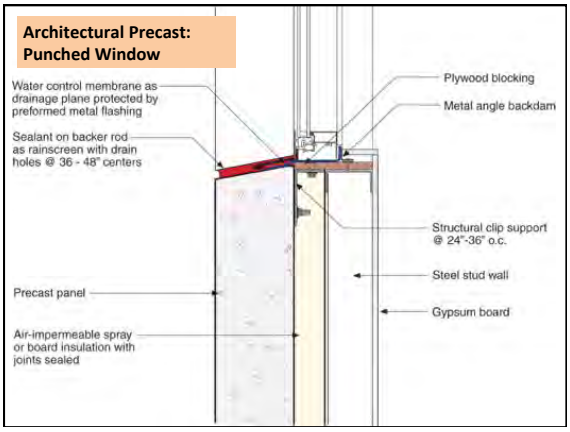
Backdams / Slopes are Important



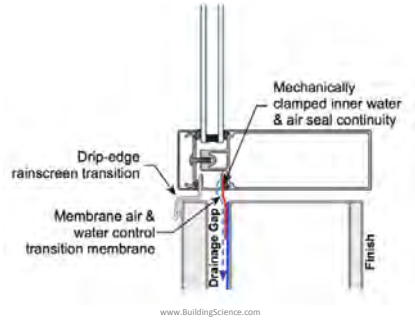


Continuous interior angle provides backdam and airseal continuity

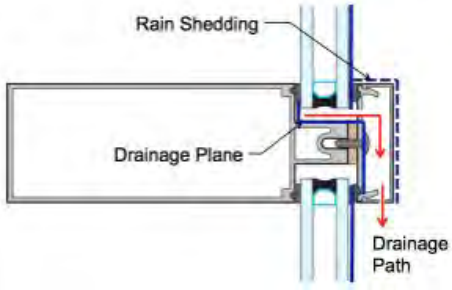
Architectural Precast: Punched Window

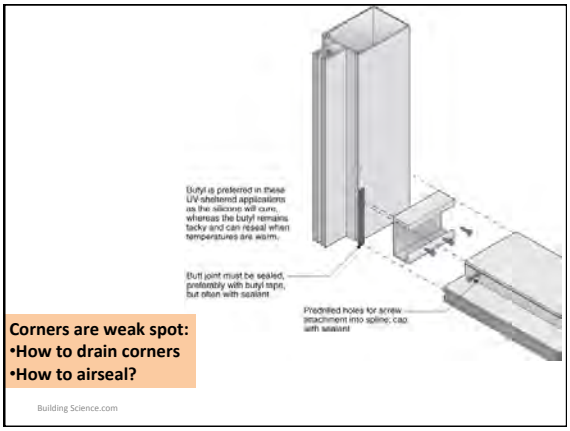


Curtainwall Integration



Rain Control





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

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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

Details

- Air & water & vapor transition membranes

Building Science.com Airflow Control No. 120/79

Fully-adhered air-water barrier

Vapor Permeable!

www.BuildingScience.com

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

Rain Control Summary

- Rain control should be top priority

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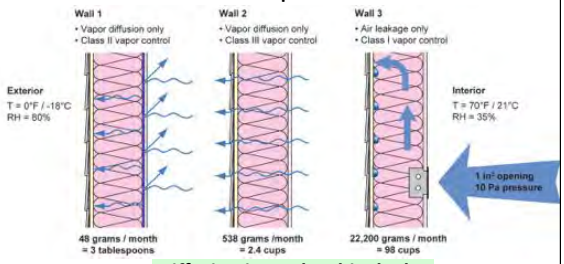
Air Flow Control

www.buildingscience.com

Air Barrier Systems

- 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

Air moves more vapor than diffusion!



Diffusion is rarely a big deal

Air leakage almost always is!

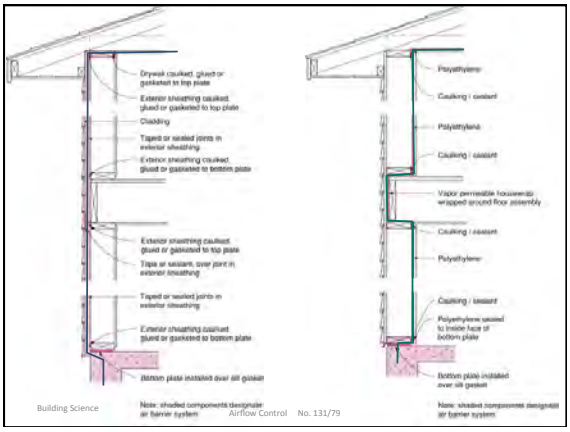
Calculations for a single stud bay, 8 ft tall, 16" wide

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

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



Poly combines air *and* vapour control

-Must be sealed and supported to be air barrier

-Cover most area and you have vapor control

Rigid Exterior Air Barrier

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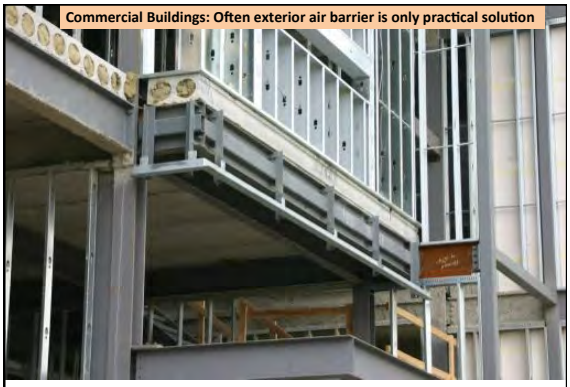

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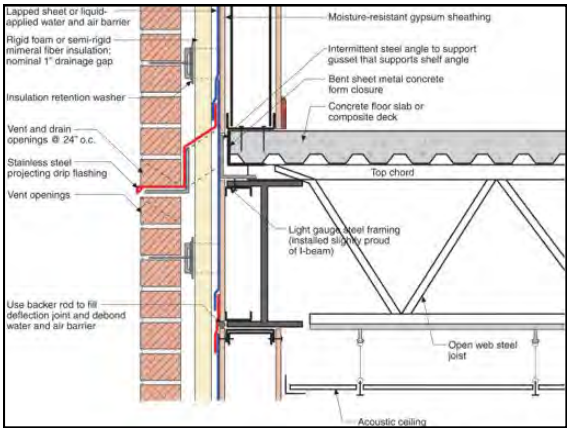
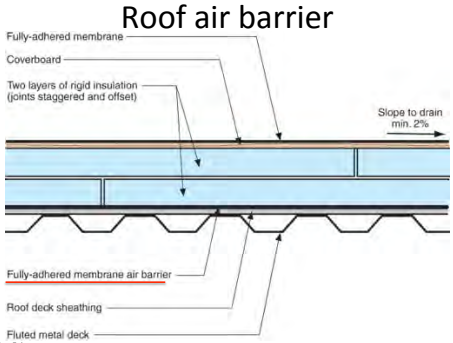


Deck level vapor control membrane rarely required if closed cell foam used

Roof air barrier



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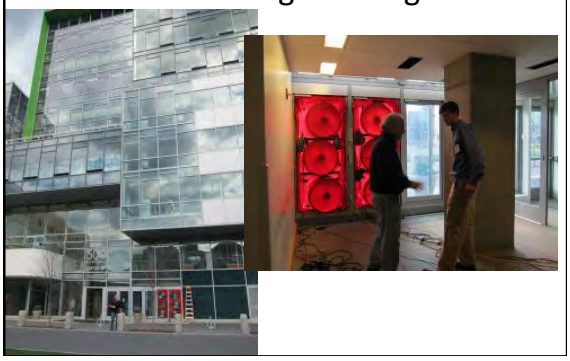
Air Leakage Testing

Air Leakage Testing



Air Leakage Testing

Air Leakage Testing

Thermal Control

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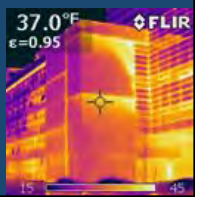

Thermal Control

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

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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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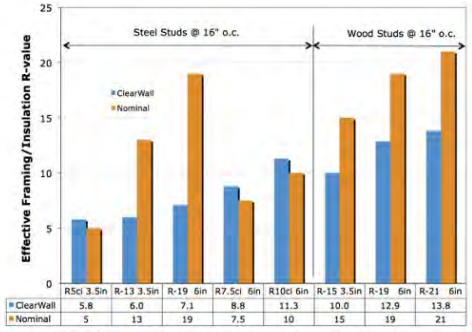
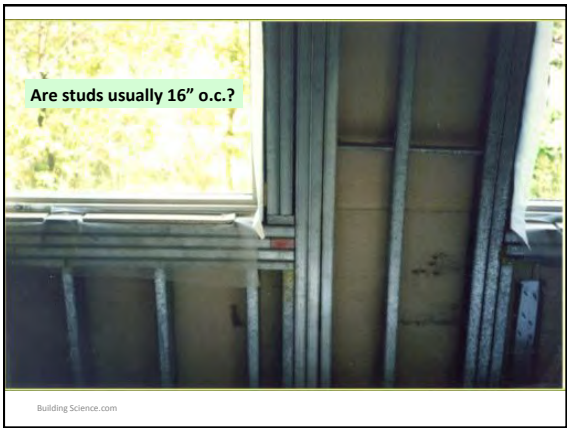
Best-case R-values for stud walls



	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 continuous insulation with no framing penetrations



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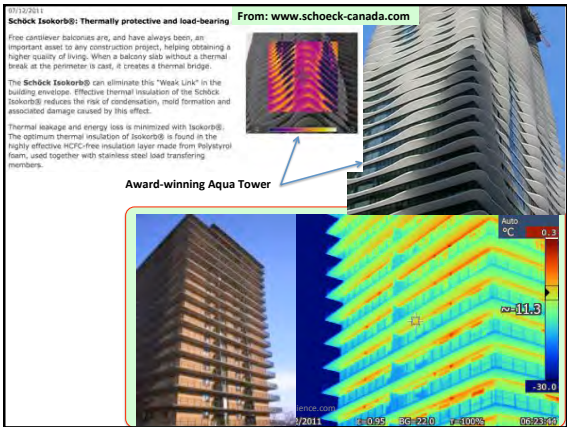
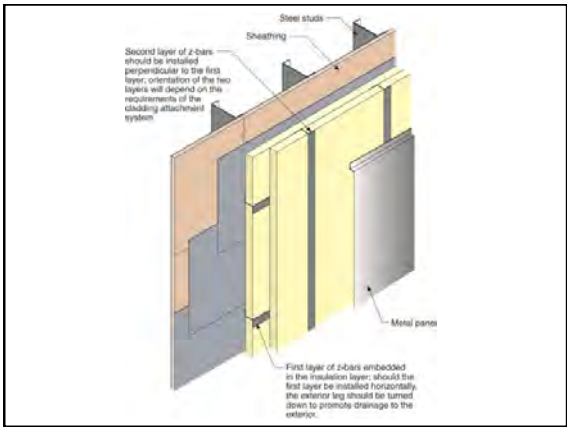
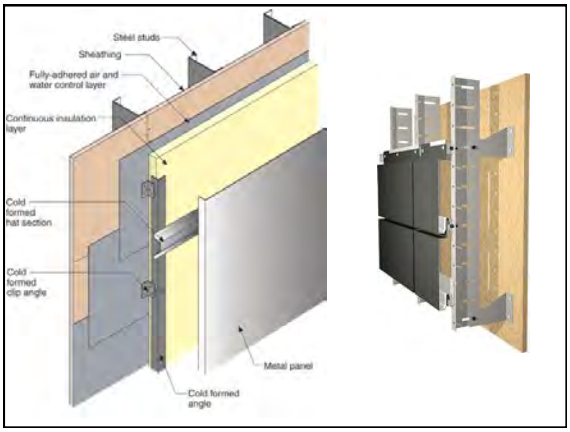
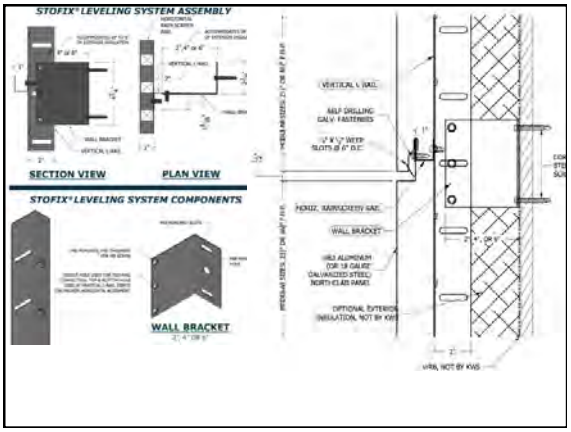


Thermal Bridge Examples

- Balconies, etc
- Exposed slab edges







Furring Strips: least thermal performance impact

Just screws meets "ci" requirement of ASHRAE 90.1

Structural penetrations

- Relieving/Shelf angles
- Balconies
- Canopies
- Signs

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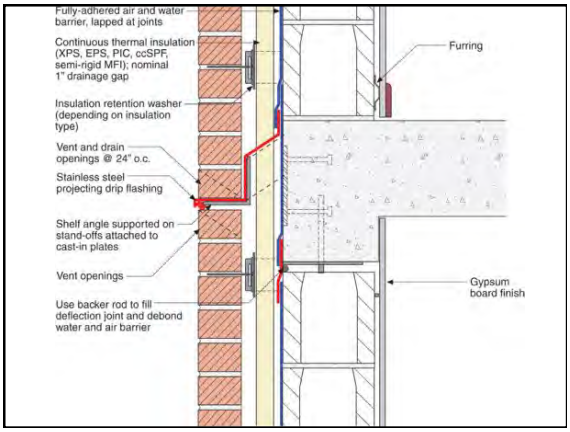
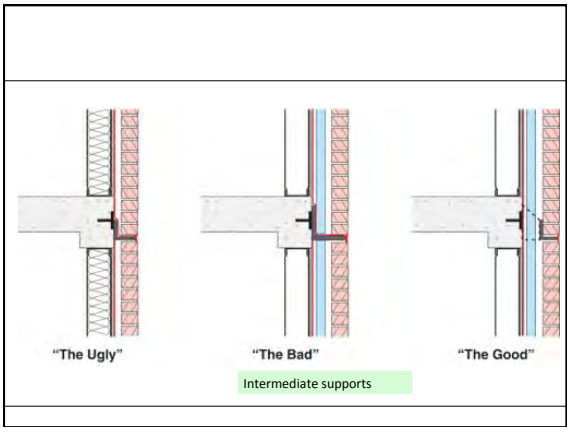
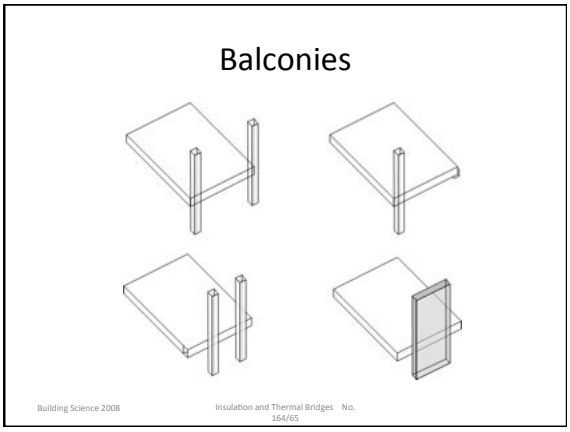
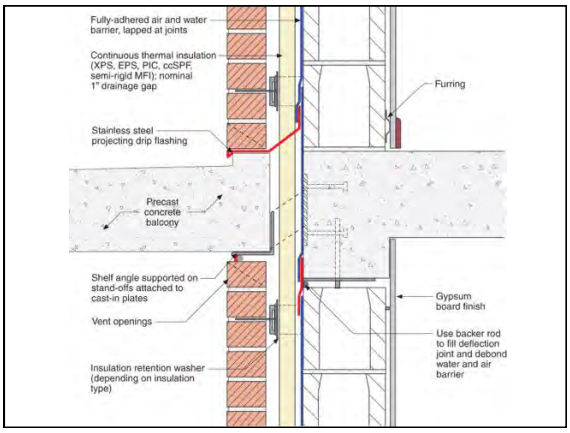


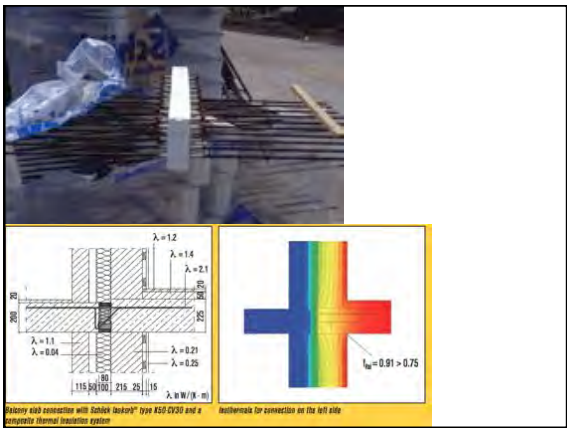


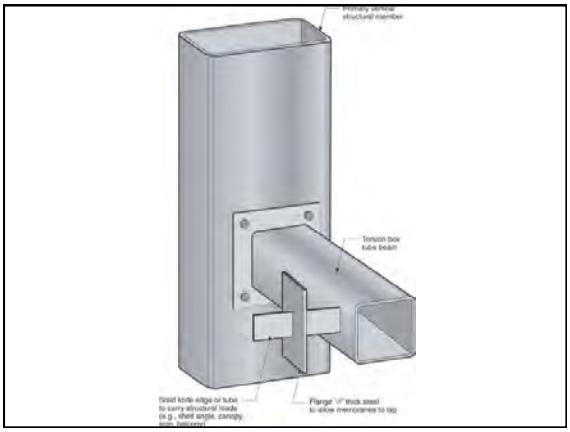

Balconies
Building Science 2008
Insulation and Thermal Bridges No. 164/65

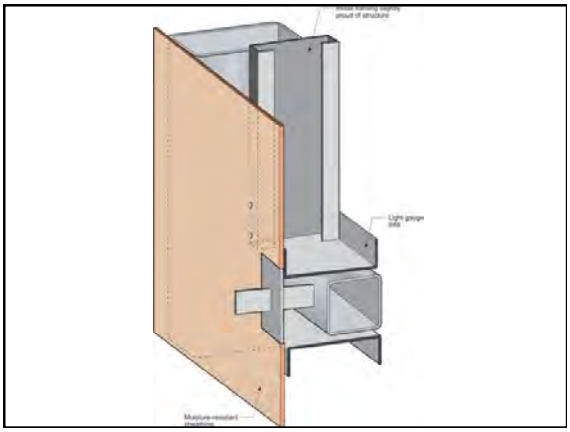

Building Science 2008
Insulation and Thermal Bridges No. 165/65

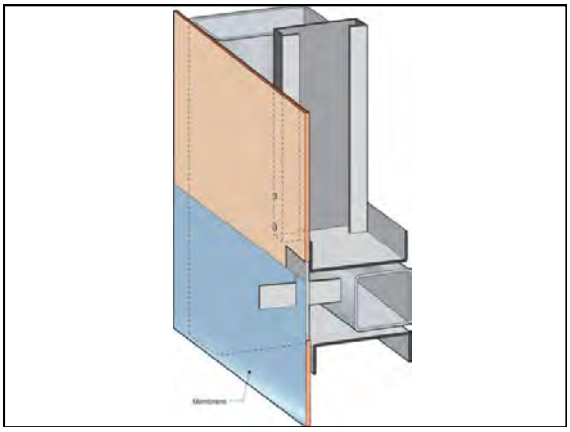

Precast balcony supported on knife edge supports to limit thermal losses

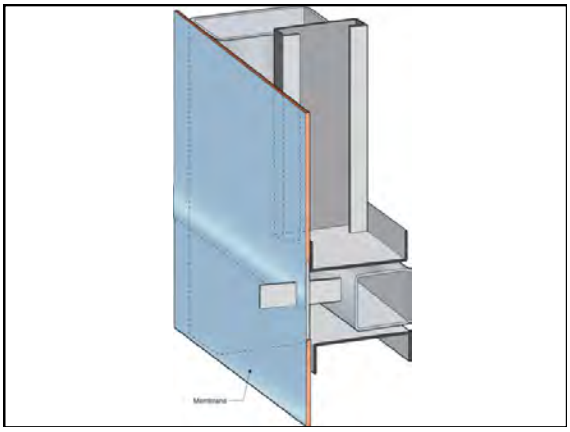

Fully-adhered air and water barrier, lapped at joints
Continuous thermal insulation (XPS, EPS, PIC, ccSPF, semi-rigid MFI); nominal 1" drainage gap
Stainless steel projecting drip flashing
Precast concrete balcony
Shelf angle supported on stand-offs attached to cast-in plates
Vent openings
Insulation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


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









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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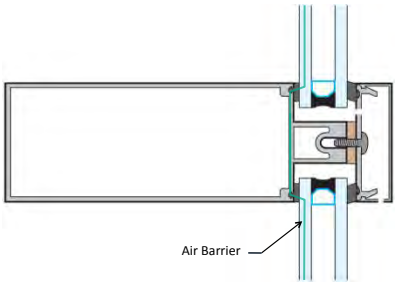
Air Flow Control



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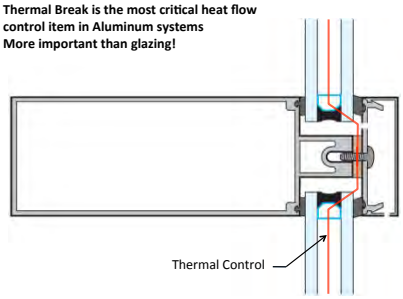
Thermal Control

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



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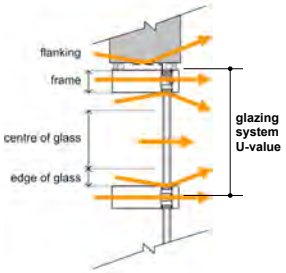
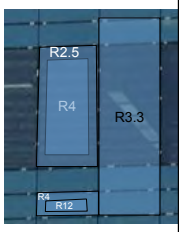
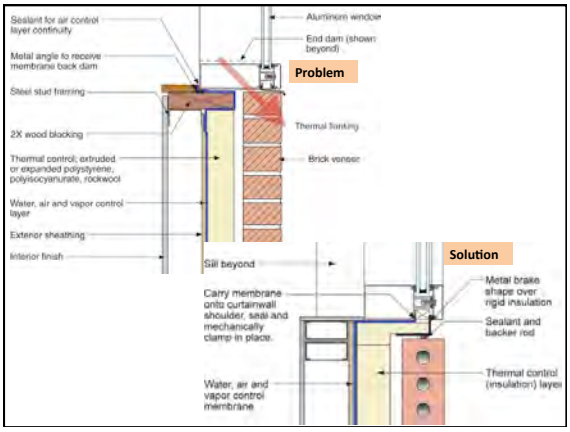
Total Heat Flow

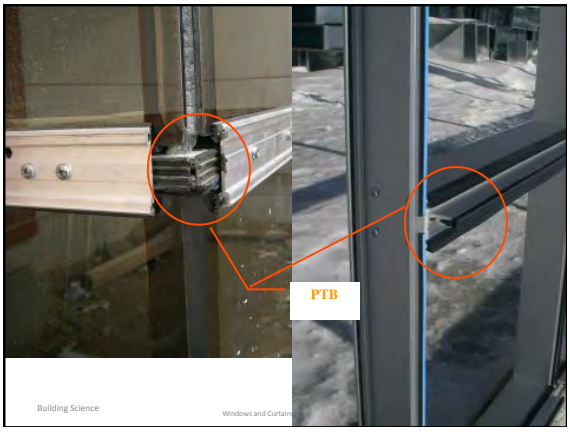
Curtain Wall Plan View





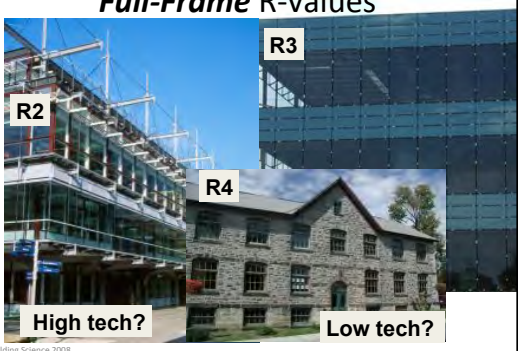
Building Science 2008 Windows and Curtainwalls No. 17880





Building Science Windows and Curtainwalls

Full-Frame R-values



Building Science 2008 Windows and Curtainwalls No. 18180

Thermal Break

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

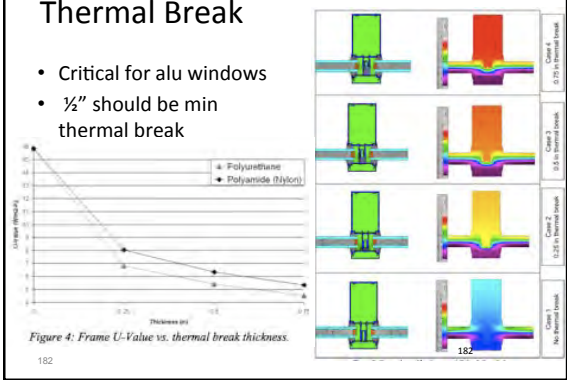
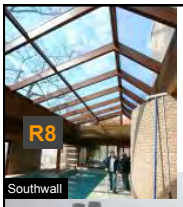


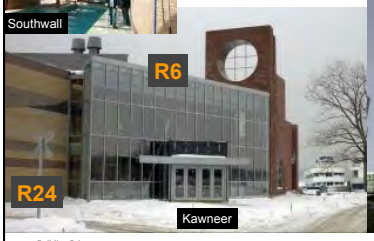
Figure 4: Frame U-Value vs. thermal break thickness.

182



High Performance

Getting better . .



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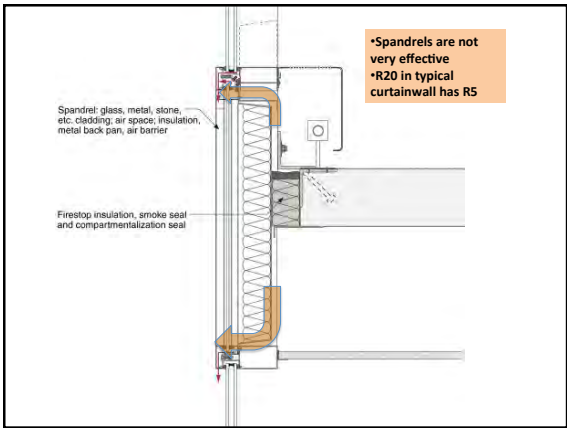

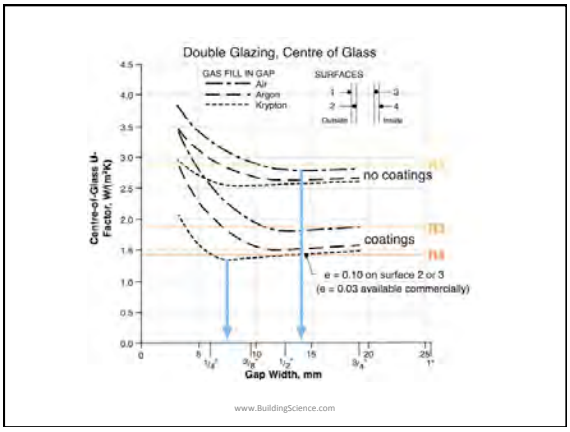

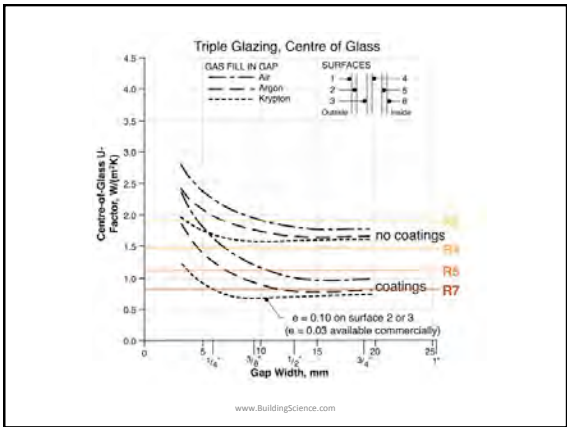

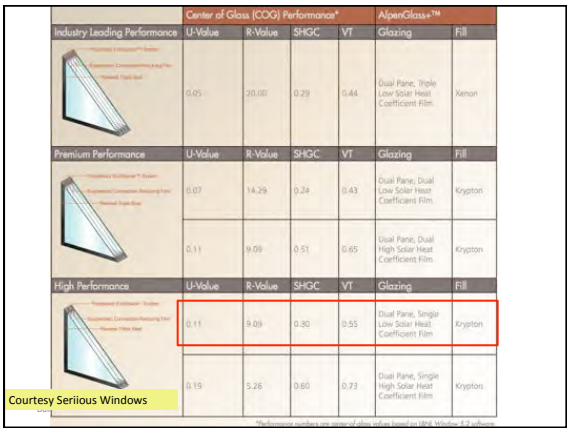

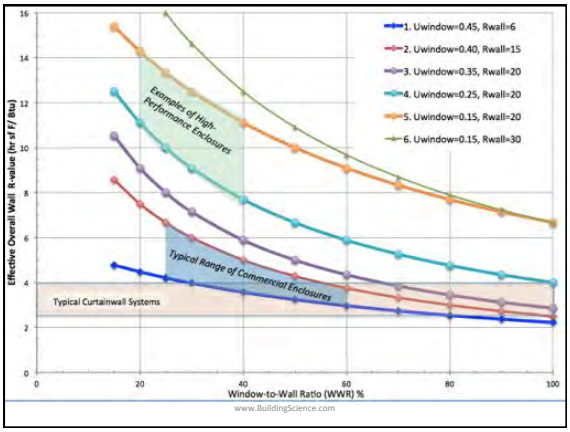

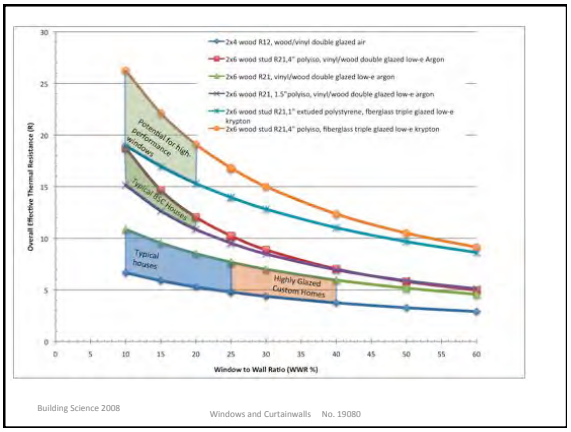

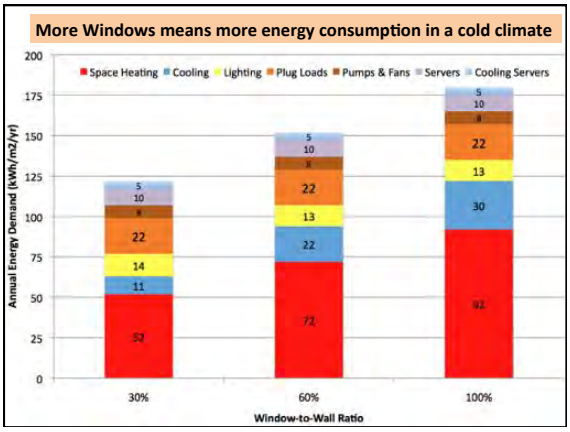

Solar Gain

- 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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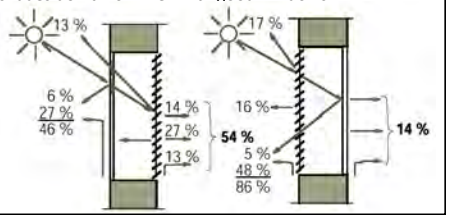
Interior or Exterior Shade

- 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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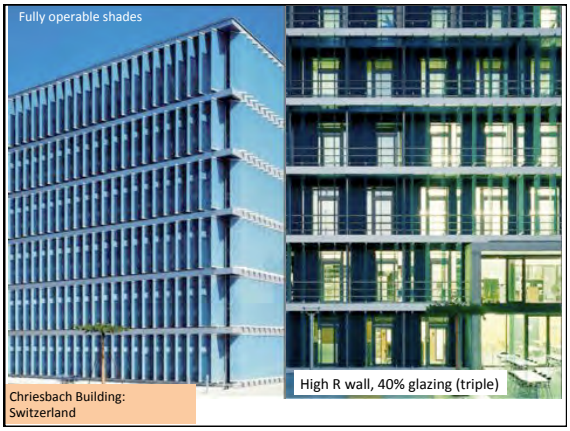

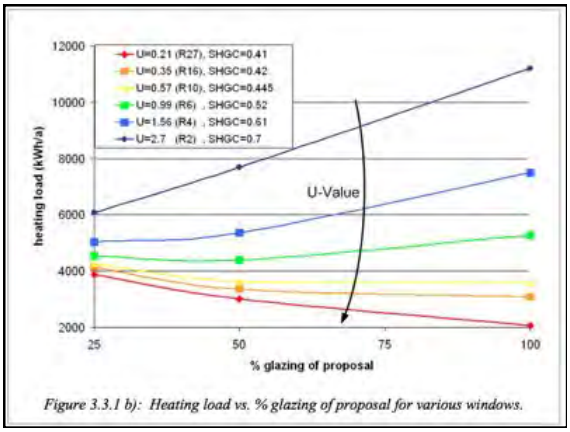

Figure 3.3.1 b): Heating load vs. % glazing of proposal for various windows.

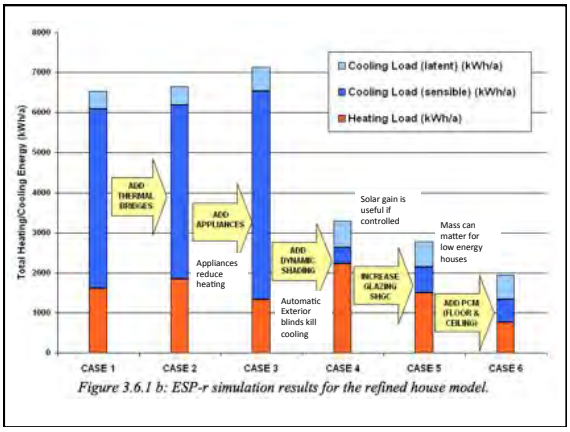

Figure 3.6.1 b: ESP-r simulation results for the refined house model.

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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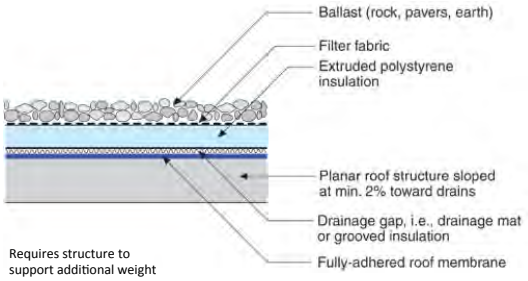
Perfect Roof (PMR / IRMA)



Requires structure to support additional weight

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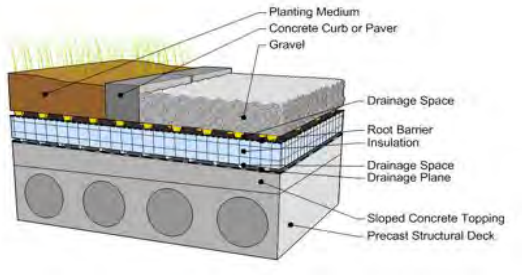

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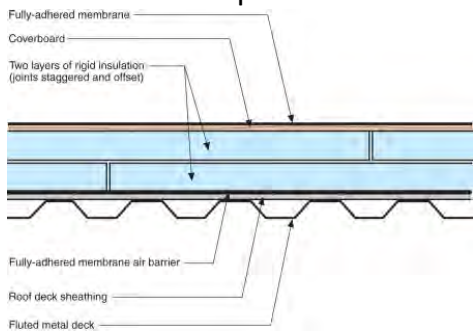
Green roofs and LEED

- 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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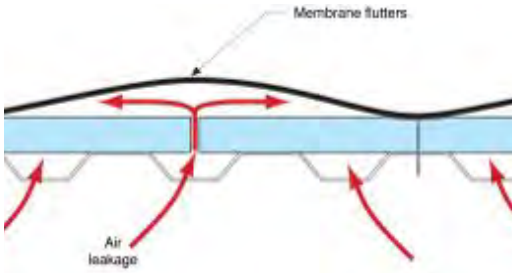
Why fully adhered?



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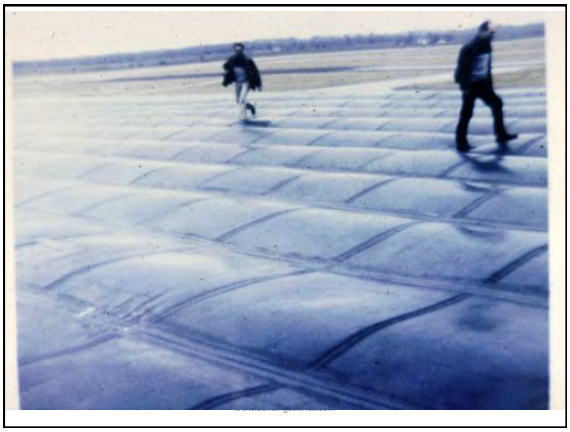

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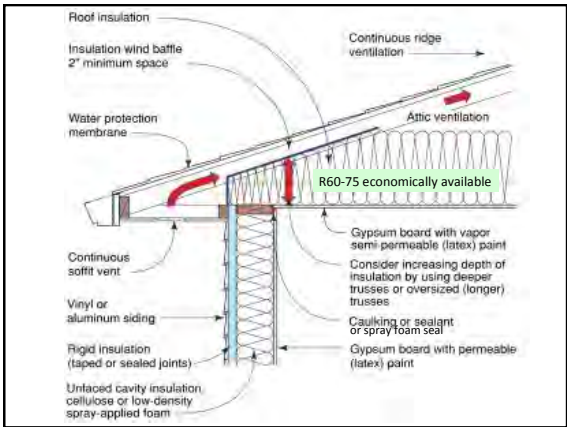
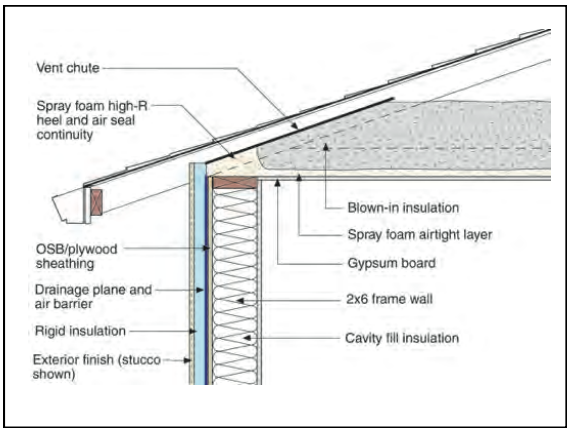
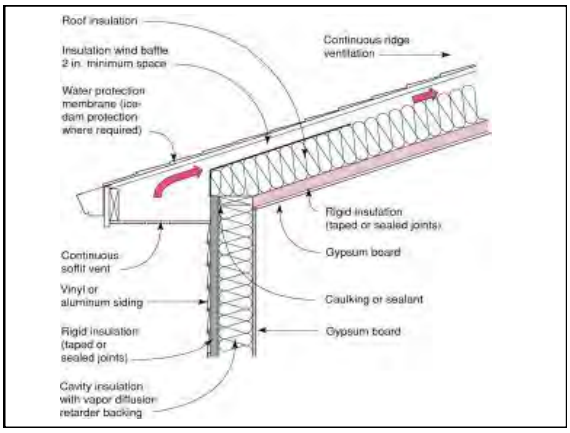


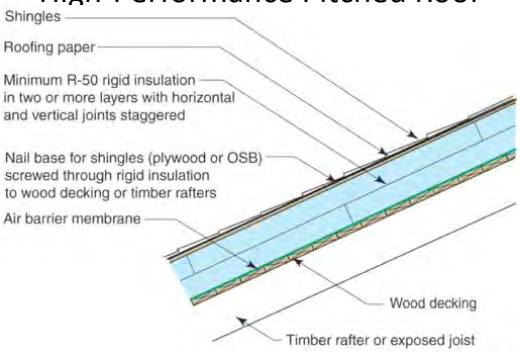


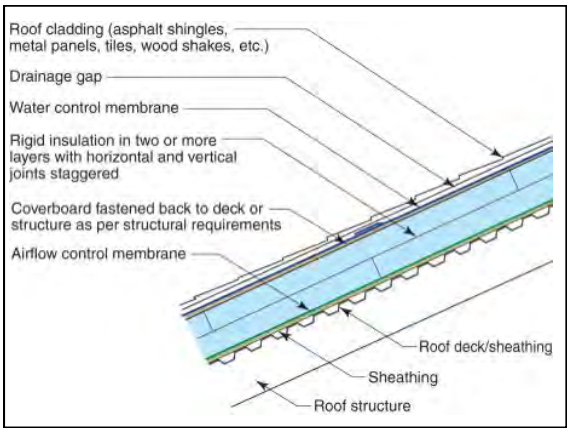


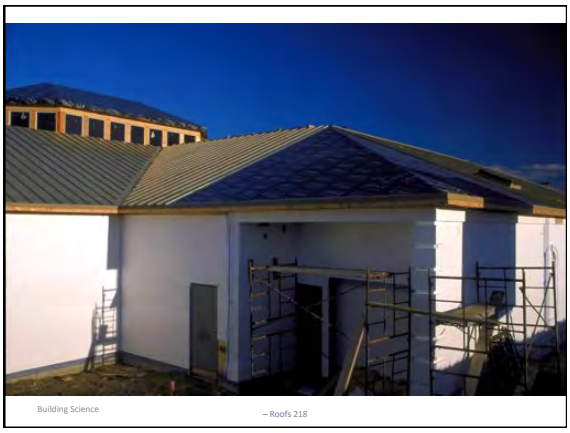
Unvented Cathedralized Attics

- 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

High-Performance Pitched Roof




Roof cladding (asphalt shingles, metal panels, tiles, wood shakes, etc.)
Drainage gap
Water control membrane
Rigid insulation in two or more layers with horizontal and vertical joints staggered
Coverboard fastened back to deck or structure as per structural requirements
Airflow control membrane
Roof deck/sheathing
Sheathing
Roof structure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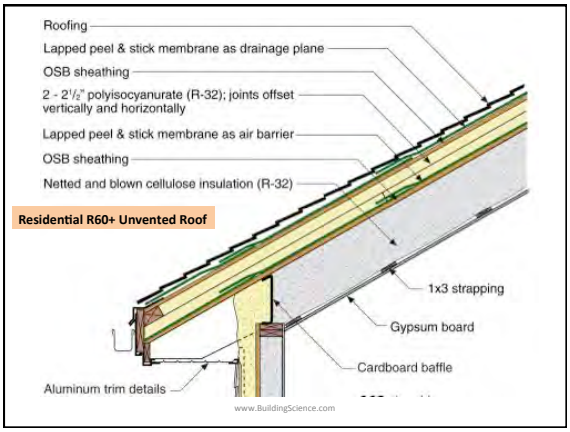
Roofing
Lapped peel & stick membrane as drainage plane
OSB sheathing
2 - 2 1/8" polyisocyanurate (R-32); joints offset vertically and horizontally
Lapped peel & stick membrane as air barrier
OSB sheathing
Netted and blown cellulose insulation (R-32)
Residential R60+ Unvented Roof
1x3 strapping
Gypsum board
Cardboard baffle
Aluminum trim details
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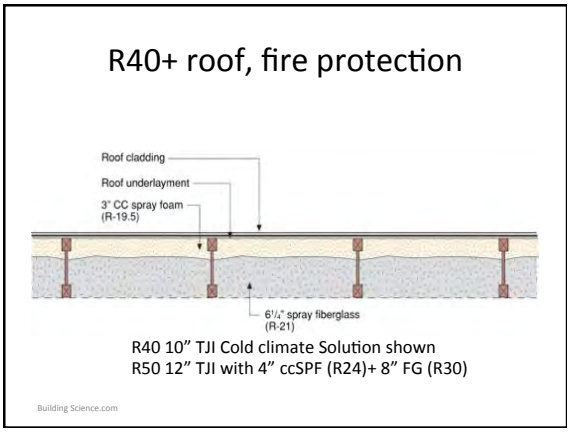
R40+ roof, fire protection
Roof cladding
Roof underlayment
3" CC spray foam (R-19.5)
6 1/4" spray fiberglass (R-21)
R40 10" TJI Cold climate Solution shown
R50 12" TJI with 4" ccSPF (R24)+ 8" FG (R30)
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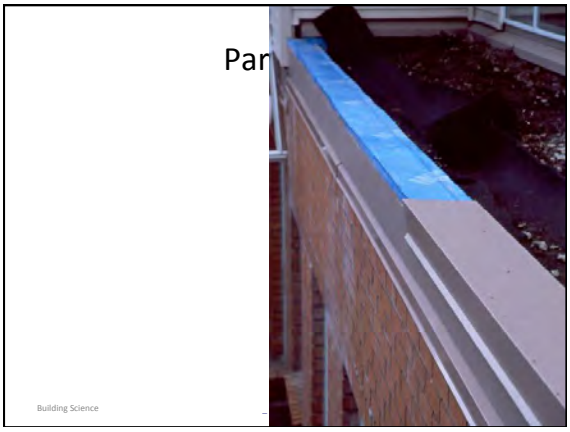
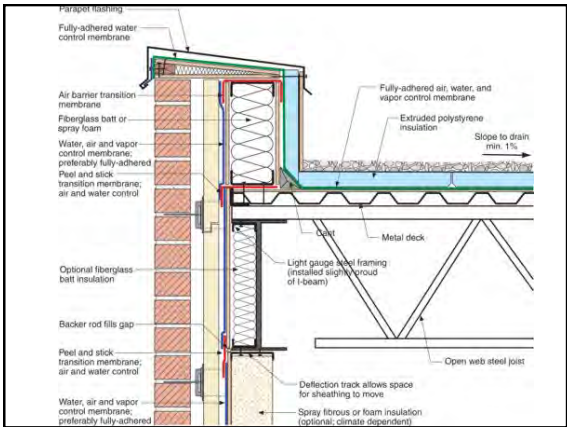
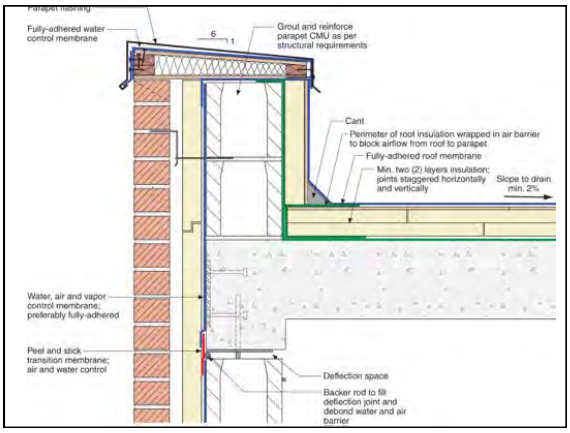
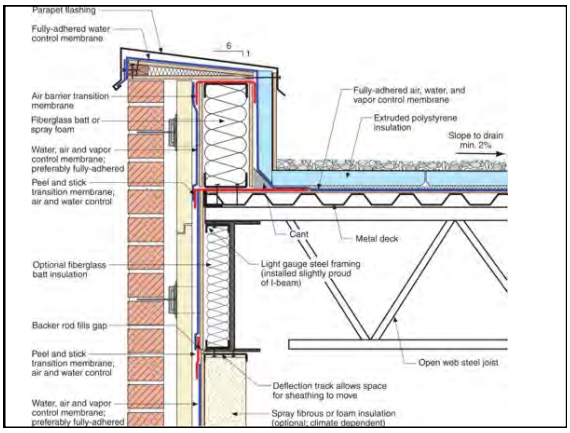
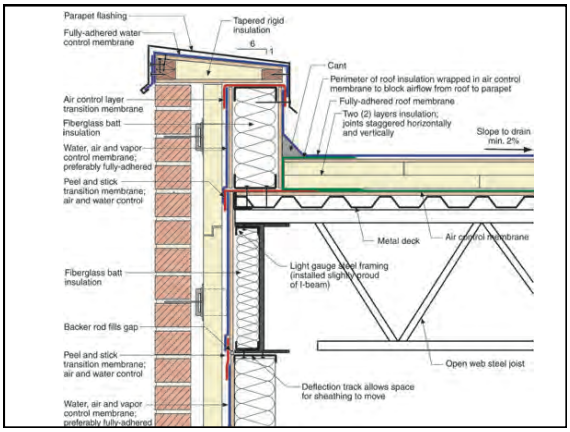
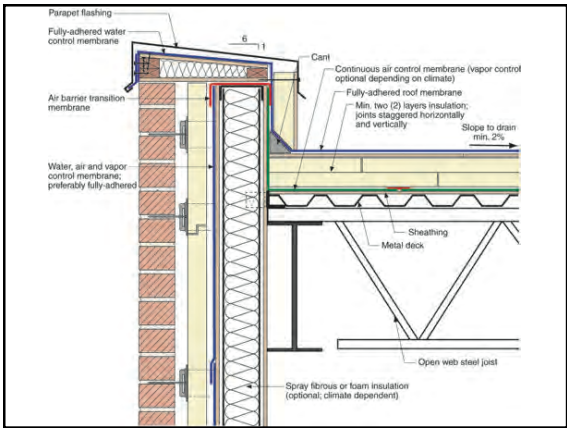

Par
Building Science


Parapet flashing
Fully-adhered water control membrane
Air barrier transition membrane
Fiberglass batt or spray foam
Water, air and vapor control membrane; preferably fully-adhered
Peel and stick transition membrane; air and water control
Optional fiberglass batt insulation
Backer rod fills gap
Peel and stick transition membrane; air and water control
Water, air and vapor control membrane; preferably fully-adhered
Fully-adhered air, water, and vapor control membrane
Extruded polystyrene insulation
Slope to drain min. 1%
Metal deck
Light gauge steel framing (installed slightly proud of I-beam)
Open web steel joist
Deflection track allows space for sheathing to move
Spray fibrous or foam insulation (optional; climate dependent)









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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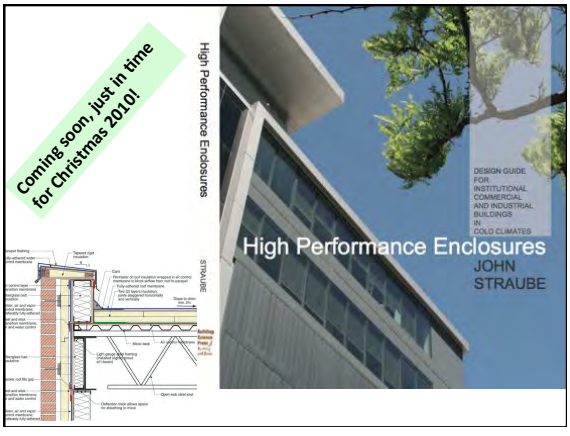

Mechanical Basics

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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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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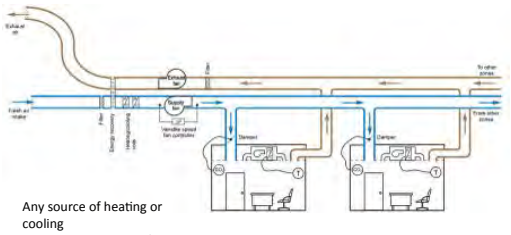
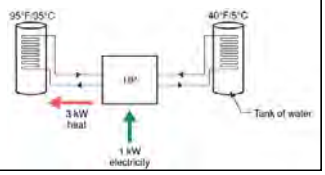
BSI-022 Perfect HVAC



Any source of heating or cooling
Combined ventilation/ humdity control

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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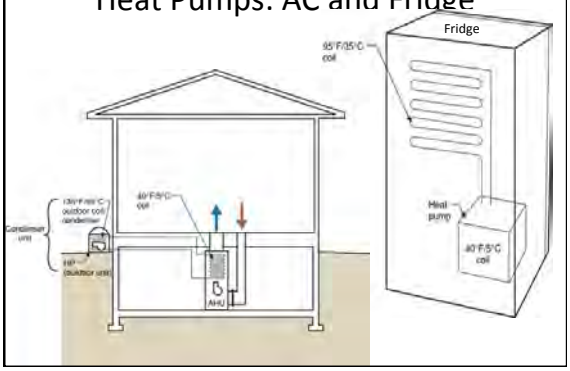
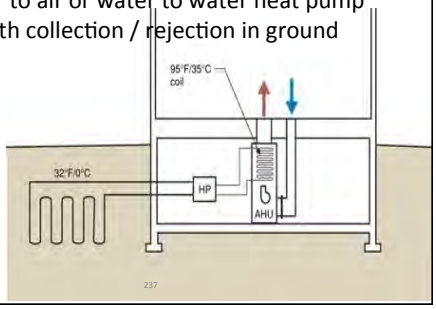
Heat Pumps: AC and Fridge



Ground Source Heat Pump

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



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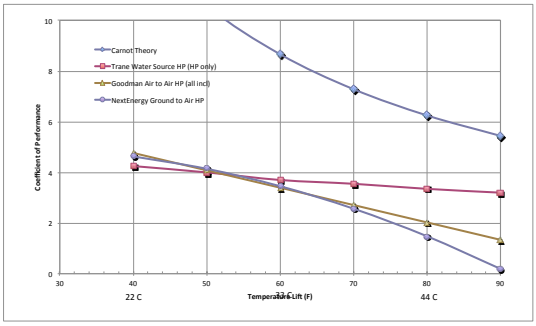
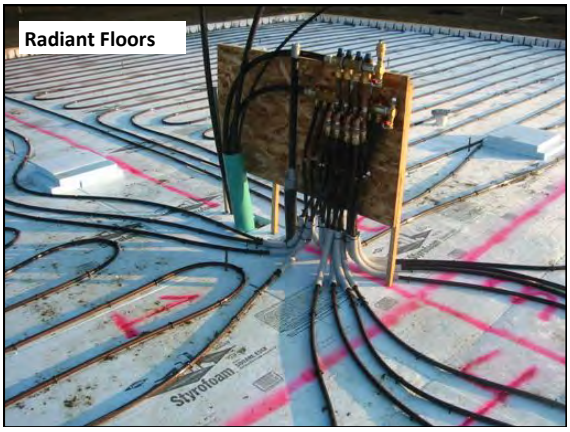
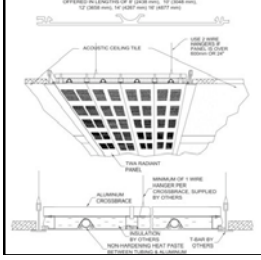
Heat Pump Efficiency vs Lift

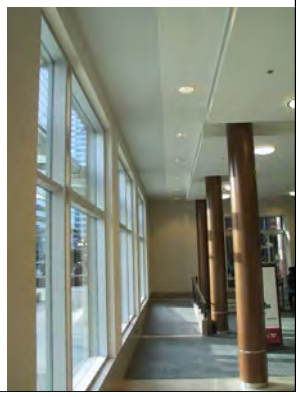




Radiant Panels

- 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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Chilled Beams

- Increase the convective component of radiant panels, usually for cooling
- Active CB use mechanically-induced airflow
- Passive CB use natural convection