High Performance Enclosures

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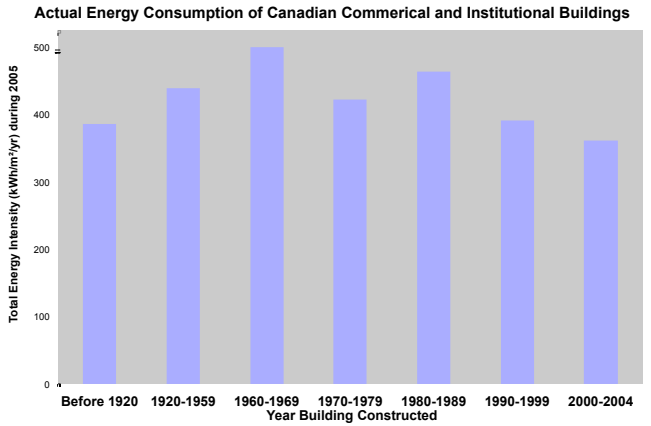
Goal

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

Outline

1. Form size and massing
2. Enclosure *principles*
3. Example enclosures
4. Details, penetrations



Design Principles

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Buildings: Why do we Build?

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

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Enclosures in Context

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

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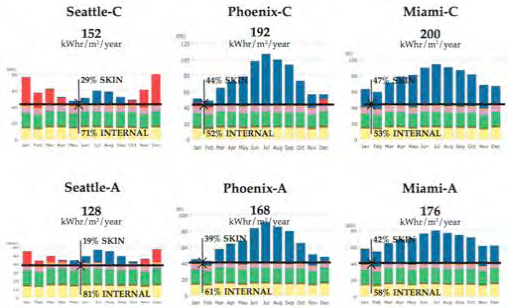
Climate matters



- Beware architecture magazines

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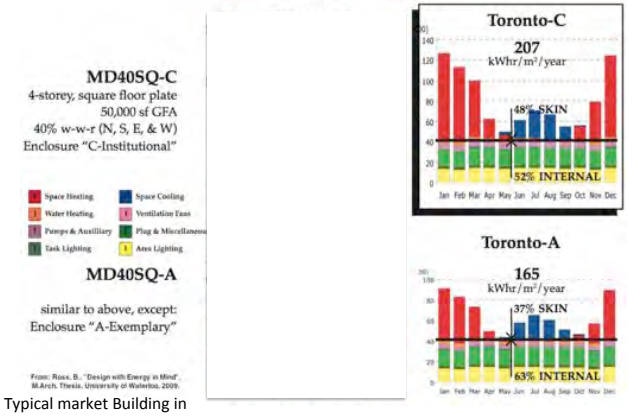
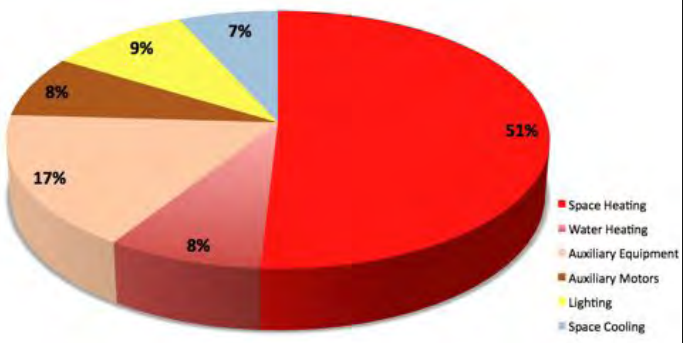
Other things use energy



Typical market Building in Toronto 55% heat+cool

Canadian Offices 2007

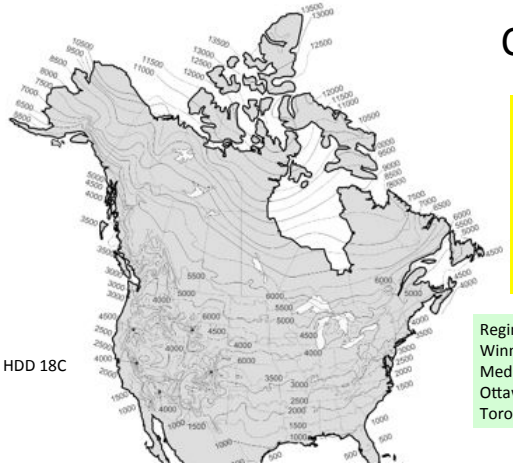


207 million m²

Source: NRCan Office of Energy Efficiency

Average 394 kWh/m²

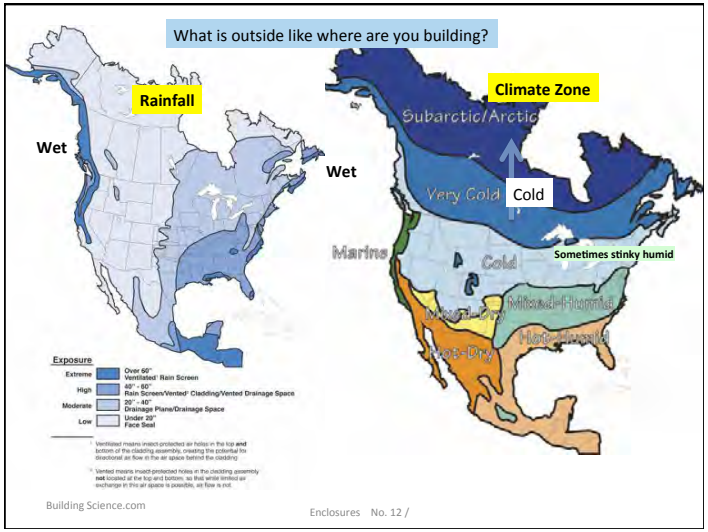
Canada:



HDD 18C

Significant heating demand, especially Prairies and North

Regina 5700
Winnipeg 5750
Medicine Hat 4700
Ottawa 4500
Toronto 4000



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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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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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

Small, Compact Form

- Fewer resources
- Less heat loss and gain

Enclosure Area

- Heat Loss: Surface Area / R_{avg} + air leakage
- House SA: FA = 2:1
  - If RSI_{avg} = 3 then
    - = 1/3 W/C/ m^2 enclosure
    - = 2/3 W/C/ m^2 floor area
- Office SA:FA = 0.5:1
  - If RSI_{avg} = 1 then
    - = 1 W/C/ m^2 enclosure
    - = 1/2 W/C/ m^2 floor area

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E. Gratia, A. De Herde / Energy and Buildings 35 (2003) 473–491

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

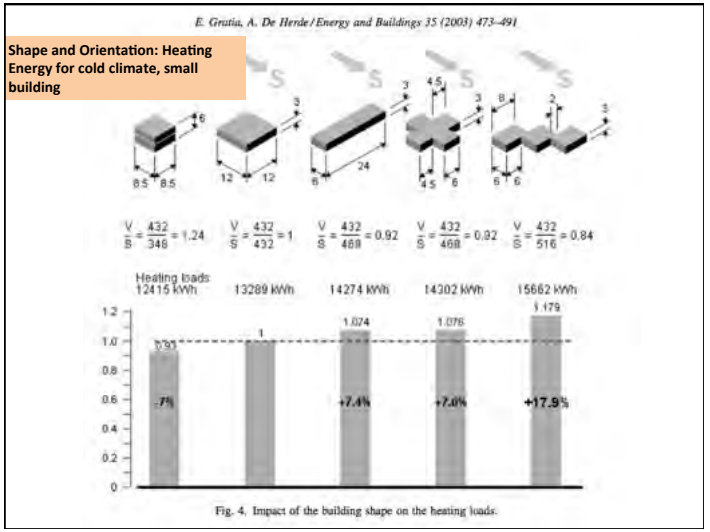


Fig. 4. Impact of the building shape on the heating loads.

Large Buildings

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

Core / Perimeter

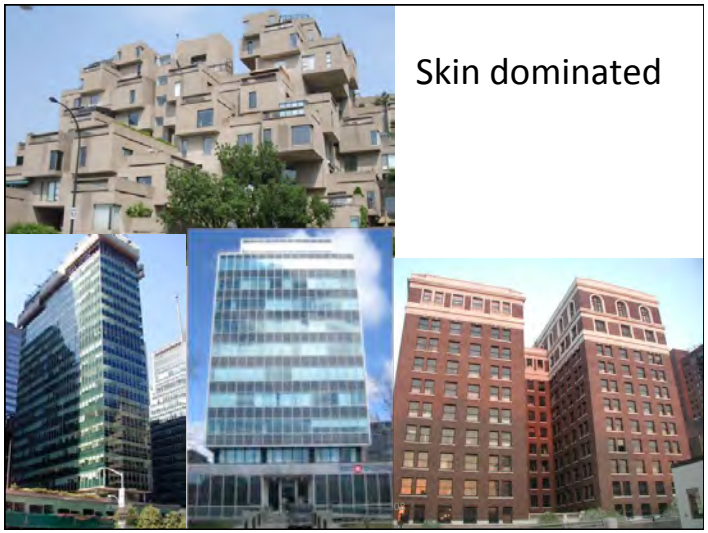
- Perimeter Zone
  - performance dominated by climate and enclosure
- Core Zone
  - dominated by interior use. Climate/enclosure almost irrelevant
- In most occupancies, core needs ***cooling and lighting all year long, all day***

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***



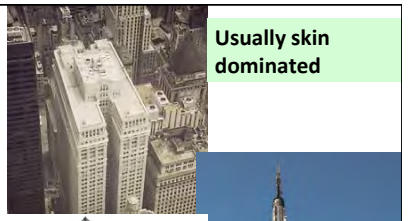
Skin dominated

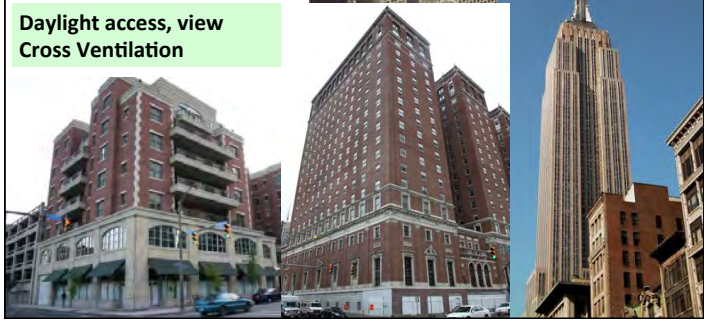
Building Shape

- Alphabet Soup
  - H I A B E

Usually skin dominated

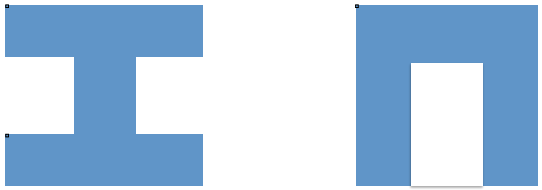
Daylight access, view Cross Ventilation





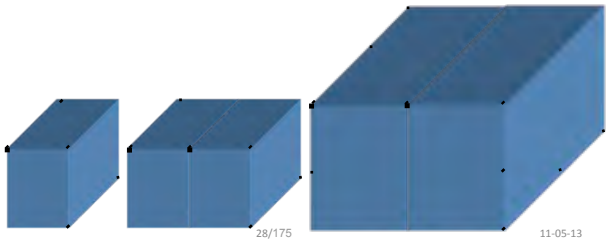
Expanded Plans

- 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



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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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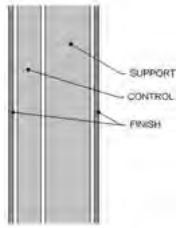
Basic Functions of the Enclosure

- 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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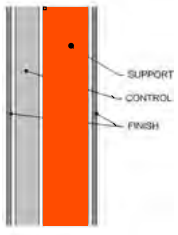
Basic Enclosure Functions

- **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



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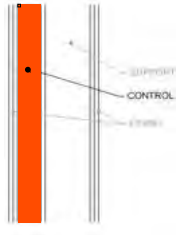
Basic Enclosure Functions

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

Functional Layers



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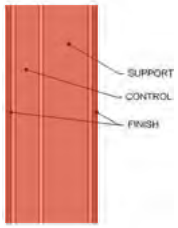
Other Control . . .

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

Functional Layers



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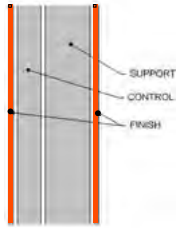
Basic Enclosure Functions

- 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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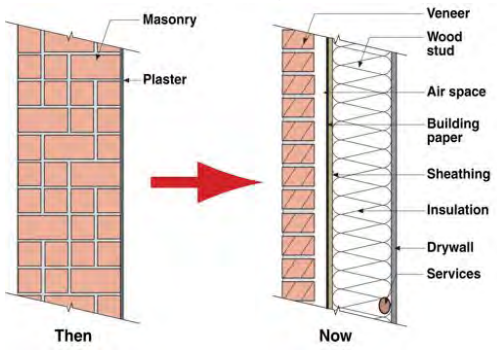
Changes



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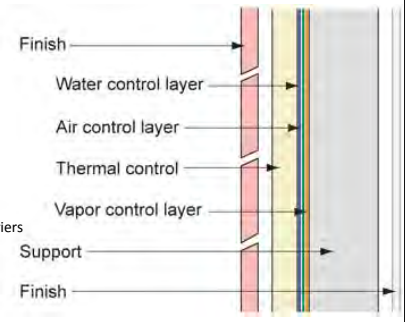
The "Perfect Wall"

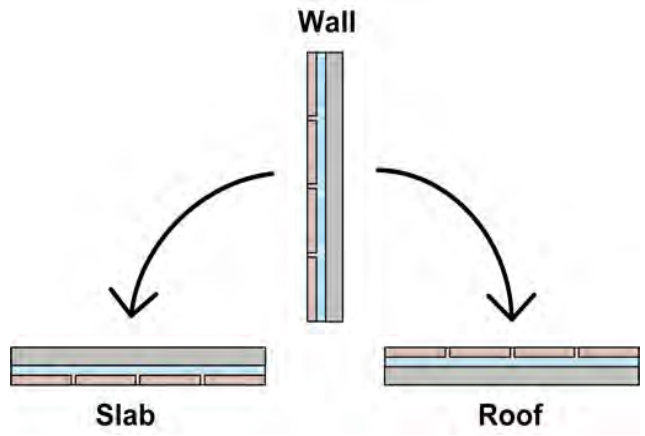
- Finish of whatever
- Control *continuity*
  - Rain control layer
    - Perfect barrier
    - Drained with gap
    - Storage
  - Air control layer
    - Air barrier
  - Thermal control layer
    - Aka insulation, radiant barriers
  - Vapor control layer
    - Retarders, barriers, etc
- Structure: anything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

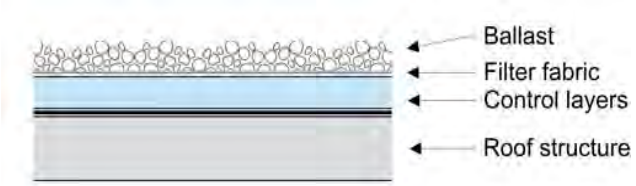


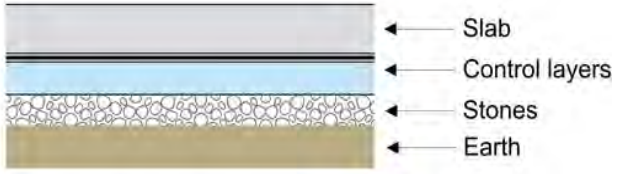
Fire Control may be needed
Sound Control optional

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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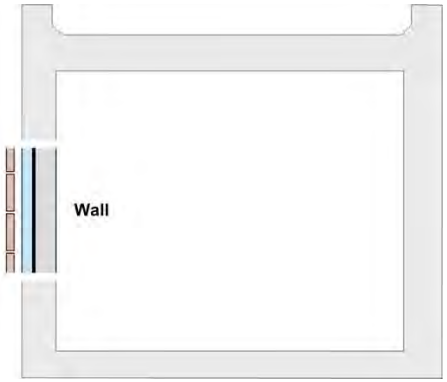

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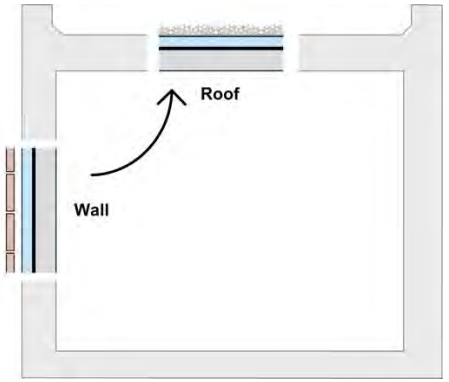

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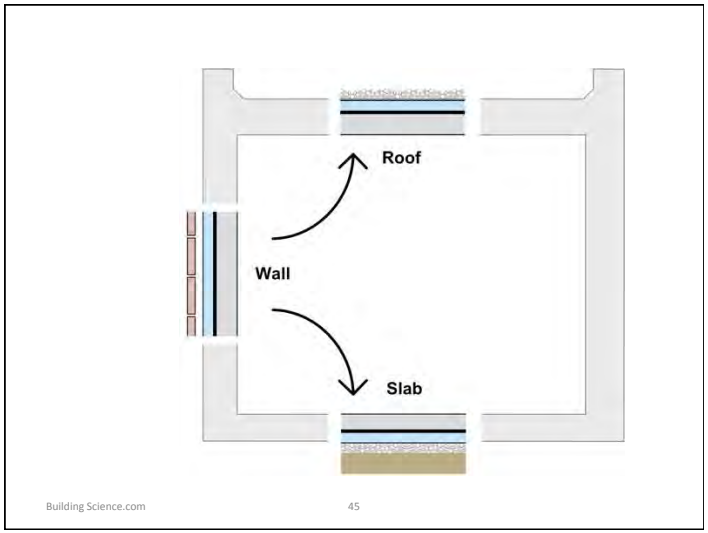
Roof
Wall
Slab
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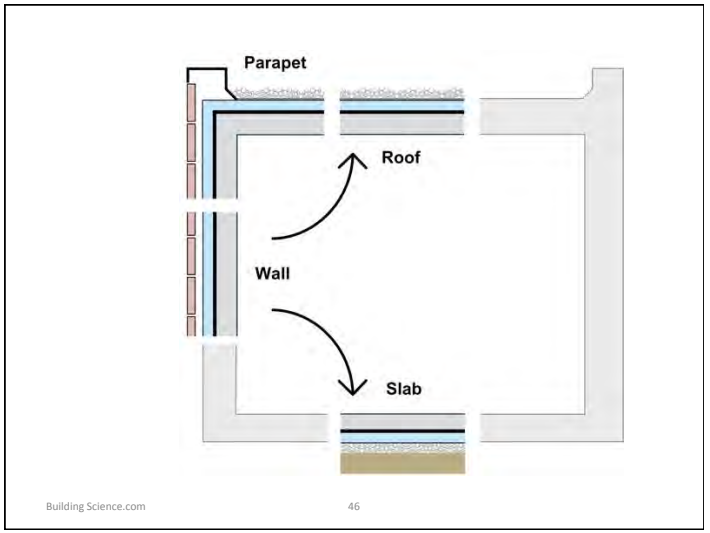
45


Parapet
Roof
Wall
Slab
Building Science.com
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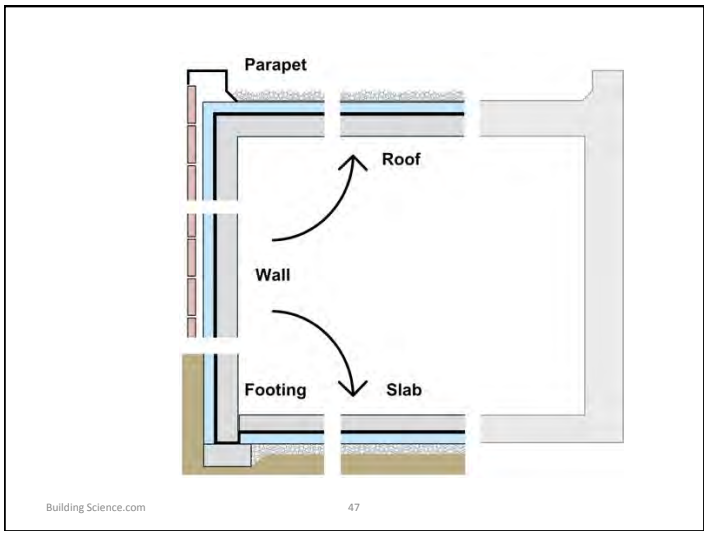
Parapet
Roof
Wall
Footing
Slab
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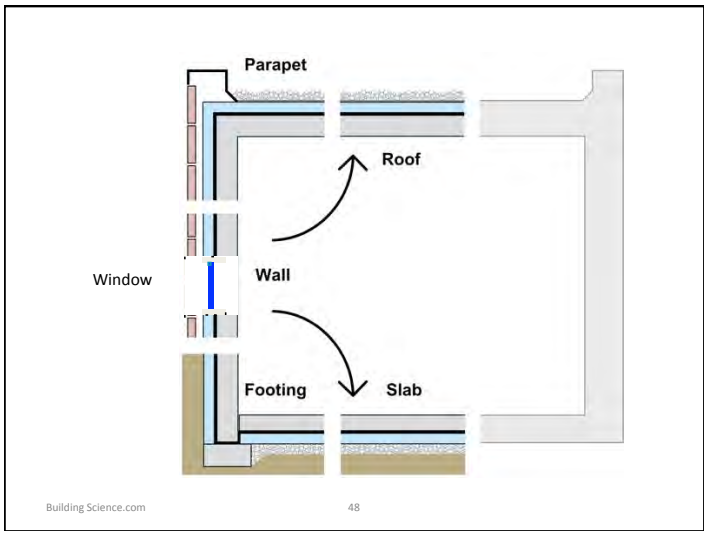
Parapet
Roof
Window
Wall
Footing
Slab
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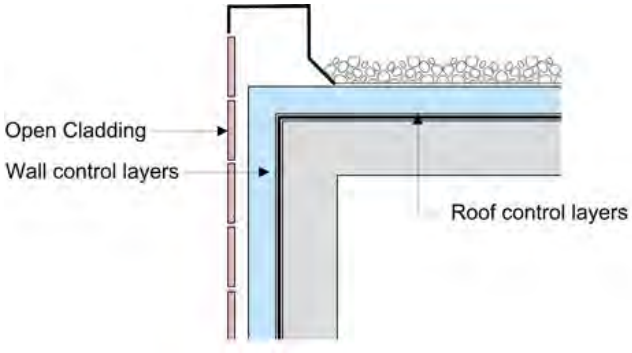
Connections: Who is in charge



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

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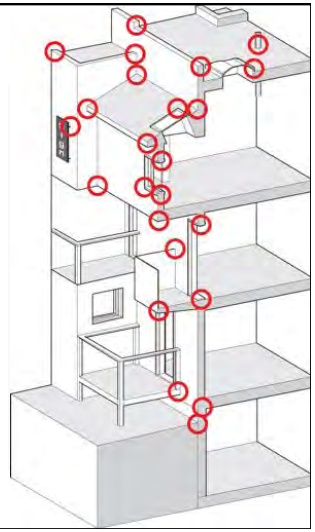
Enclosure Design: Details

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



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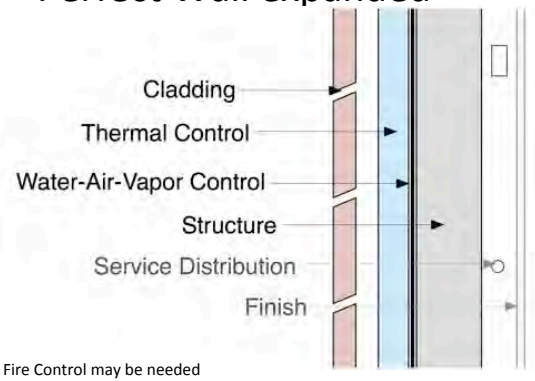
Perfect Wall expanded



Additional Fire Control may be needed
Sound Control optional

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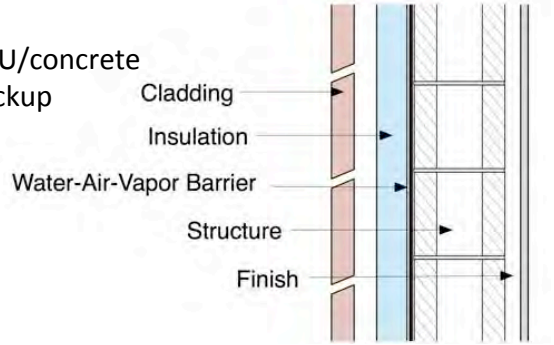
Perfect Wall

- CMU/concrete backup



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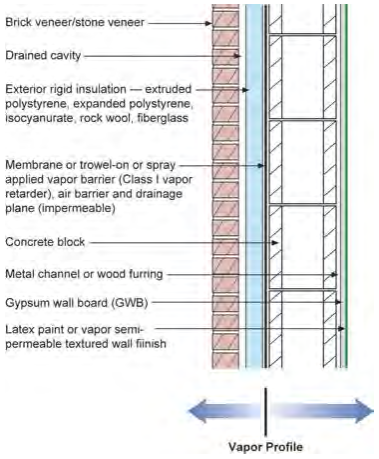
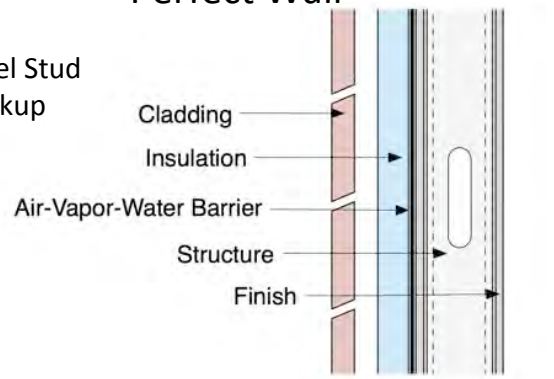
Any R-value, e.g.
4" PIC=R25
5"XPS =R25
6"MFI=R25



Perfect Wall

- Steel Stud Backup



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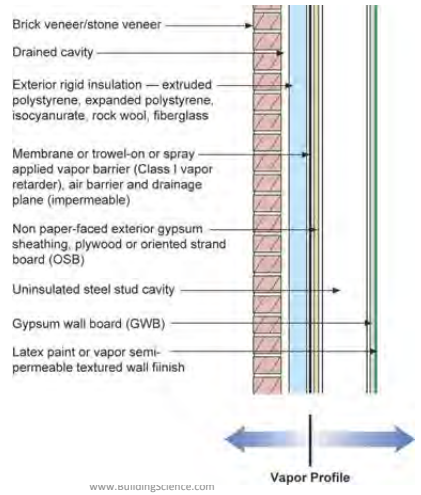
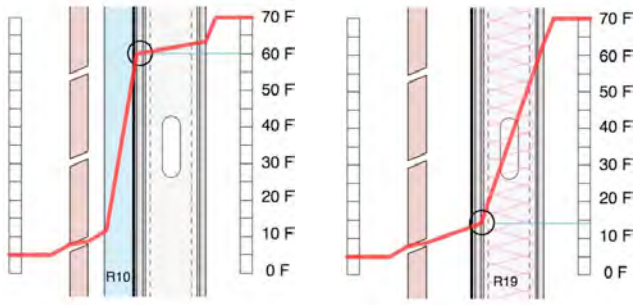
Any R-value, e.g.
4" PIC=R25
5"XPS =R25
6"MFI=R25



Condensation & Drying



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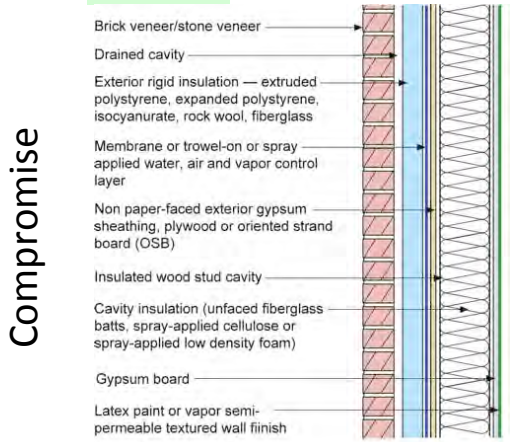
Ratio: Exterior R-value / Studbay R-value controls risk of condensation

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

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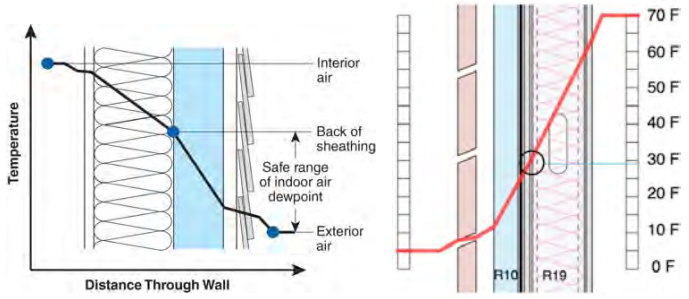
Compromise= Risks



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

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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

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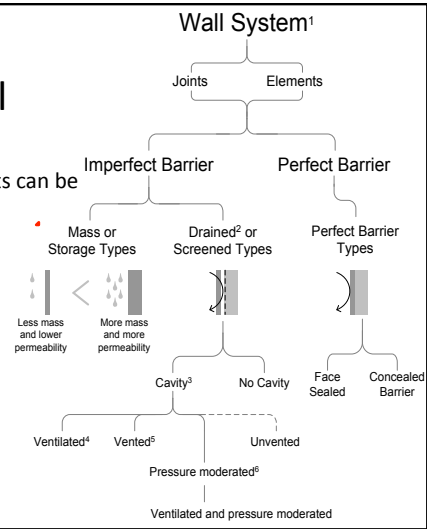
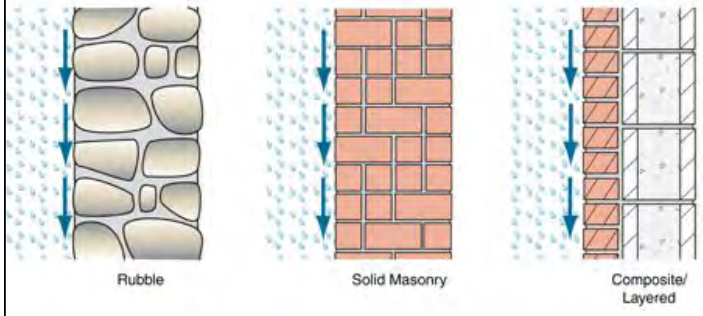
Rain Control

- Elements and joints can be different



Mass/Storage/Reservoir Walls



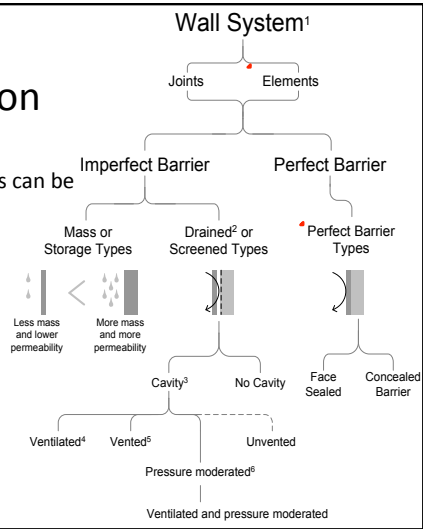
John Straube

No building paper, flashing, weepholes

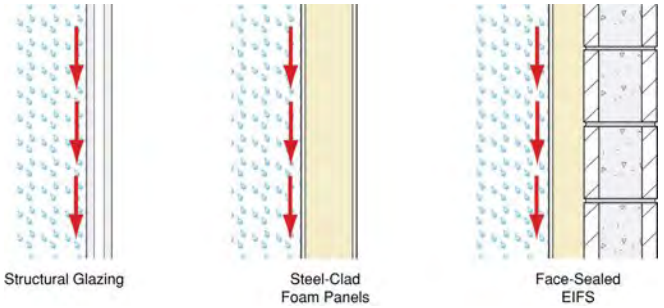
Surface features such as Overhangs, Drips, etc are important for mass walls

Categorization

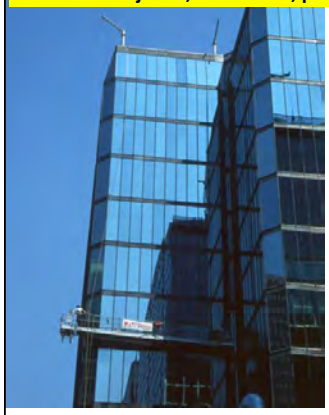
- Elements and joints can be different

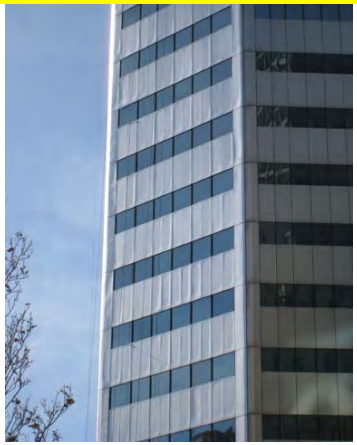


Perfect Barrier / Face Sealed



It is all about joints, transitions, penetrations





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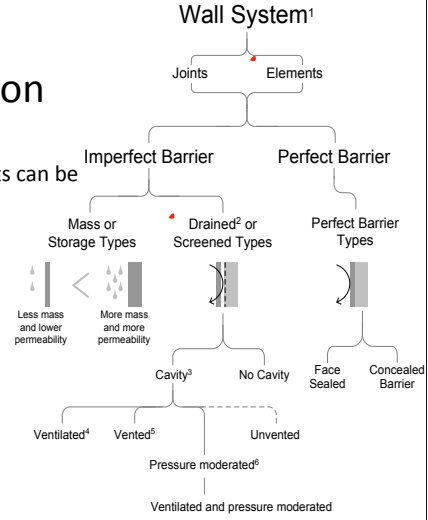
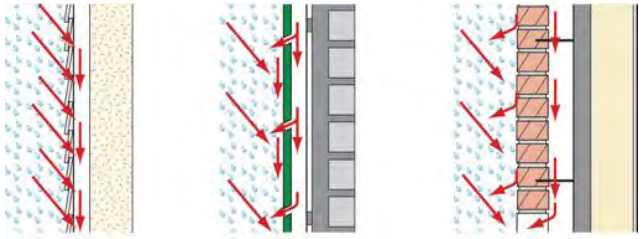
Categorization

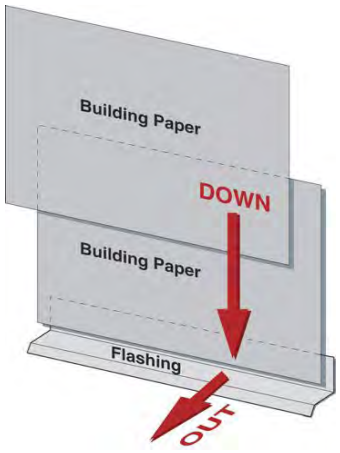
- Elements and joints can be different



Drained Walls

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





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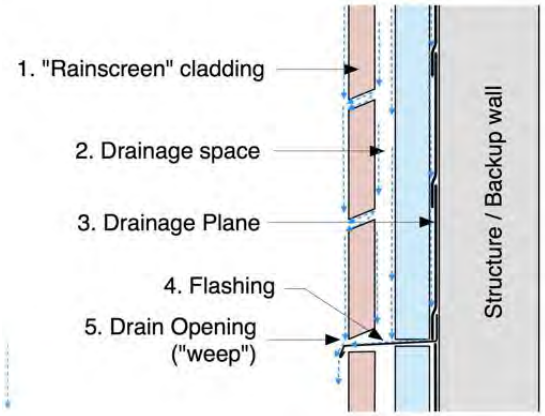
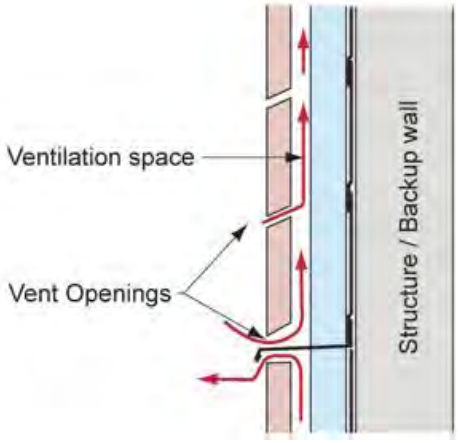
Requirements for a Drained Enclosure



Requirements for a Ventilated Enclosure



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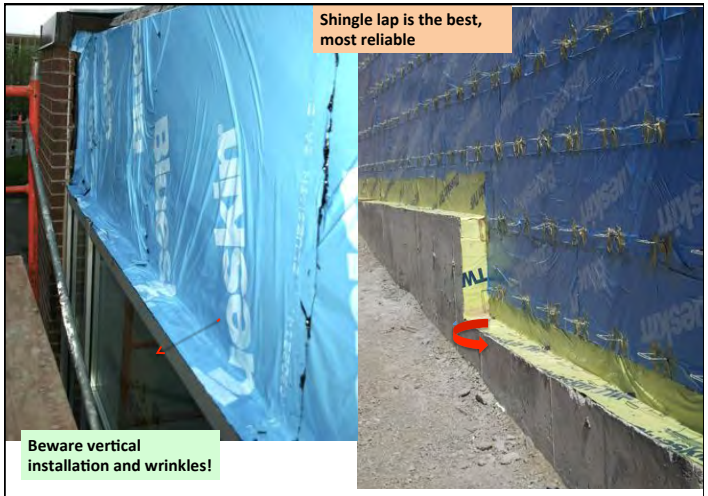
Shingle lap is the best, most reliable



Beware vertical installation and wrinkles!

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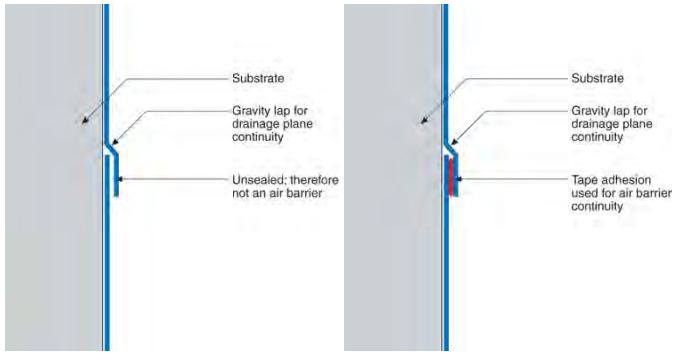
Laps and Joints



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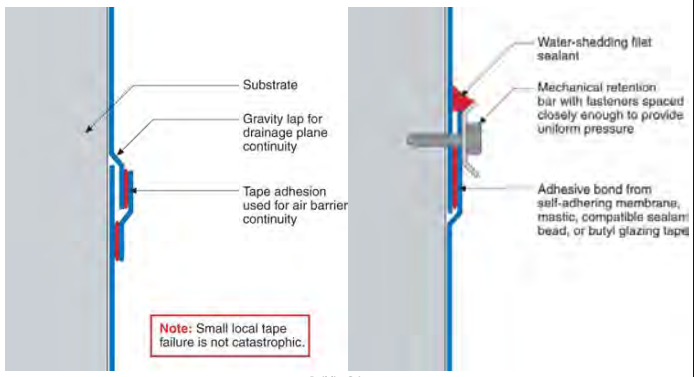
Reverse laps



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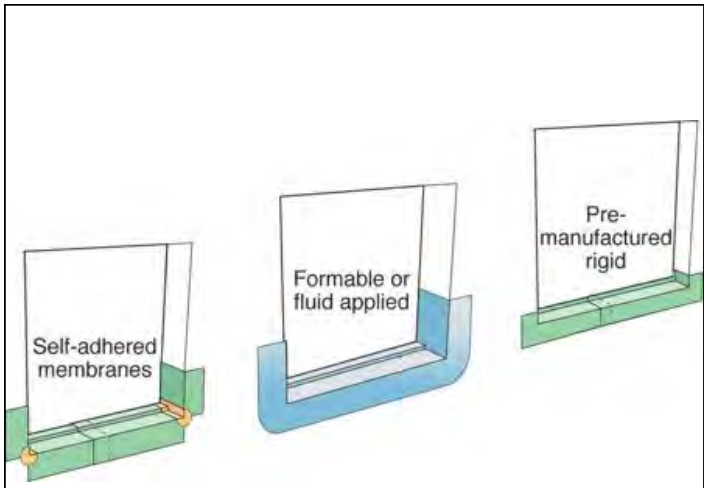

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Air-Water-Vapor

- 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

Non-adhered, vapor permeable
=modest performance

Supported **flexible membrane is better**

Fully-adhered air-water barrier

Vapor Permeable!

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Mixed membrane + fluid-applied

Often use membranes for transitions

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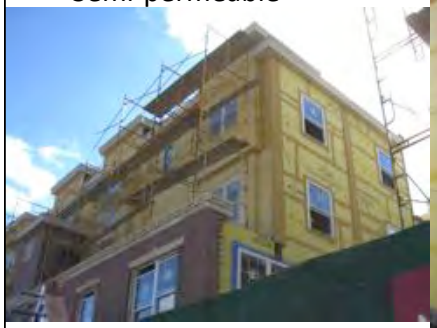
Spray/Trowel Applied Air/water

- Semi-permeable



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

Continuity is key!

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

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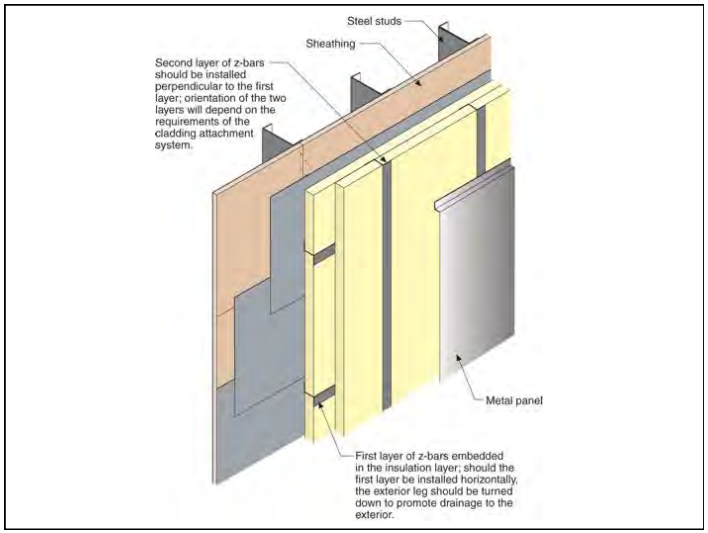
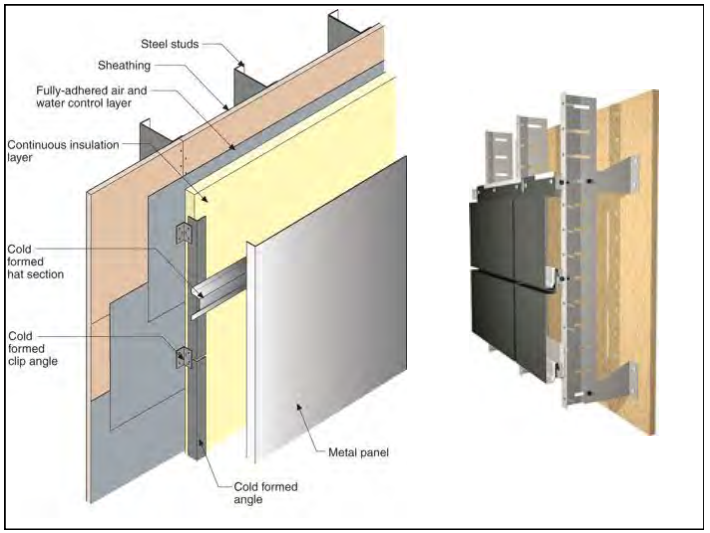
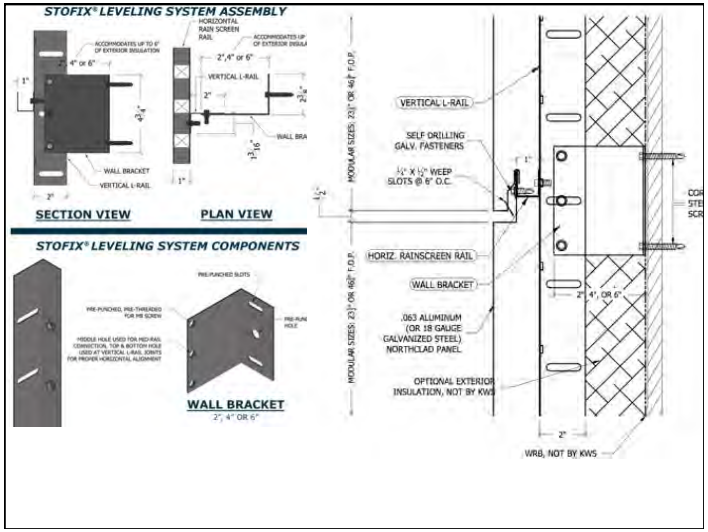
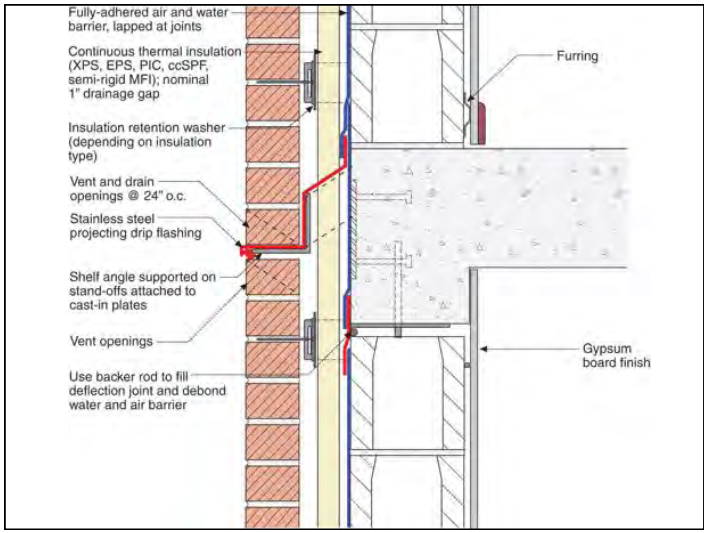
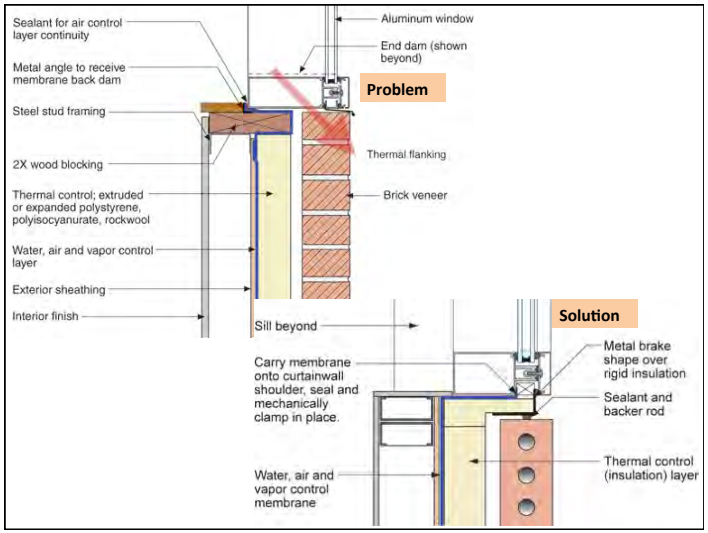

Steel studs
Sheathing
Second layer of z-bars should be installed perpendicular to the first layer; orientation of the two layers will depend on the requirements of the cladding attachment system.
Metal panel
First layer of z-bars embedded in the insulation layer; should the first layer be installed horizontally, the exterior leg should be turned down to promote drainage to the exterior.


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


Fully-adhered air and water barrier, lapped at joints
Continuous thermal insulation (XPS, EPS, PIC, ccSPF, semi-rigid MFI); nominal 1" drainage gap
Insulation retention washer (depending on insulation type)
Vent and drain openings @ 24" o.c.
Stainless steel projecting drip flashing
Shelf angle supported on stand-offs attached to cast-in plates
Vent openings
Use backer rod to fill deflection joint and debond water and air barrier
Furring
Gypsum board finish


Small metal clips dramatically reduce thermal bridging



Air Flow Control

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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

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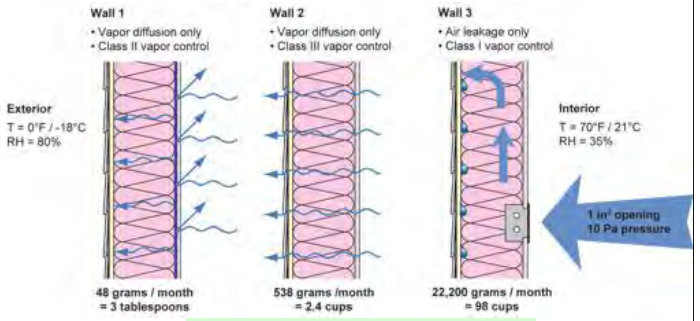
Air moves more vapor than diffusion!



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

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

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Air leakage

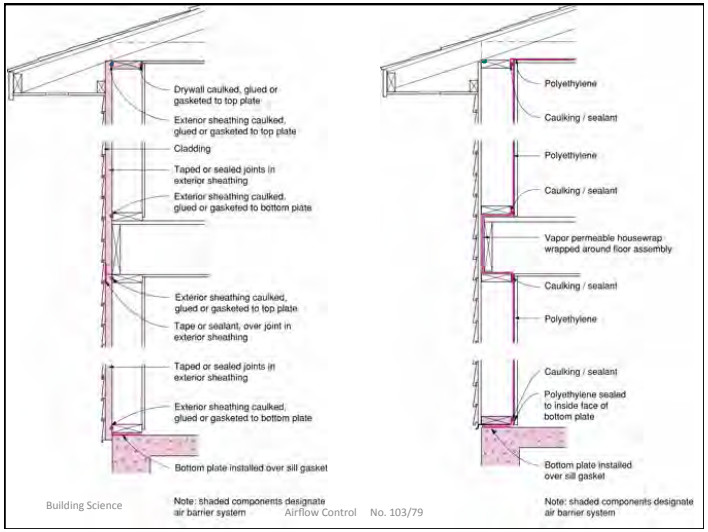
- Hard to save energy with the door open
- Buildings getting tighter, but . . .
  - Many still leak way too much
  - We can't identify the leakers
  - Need to test! Commission!
- Ventilation: Many try to improve air quality by increasing quantity
  - Target good air when and where needed

101/175 11-05-13

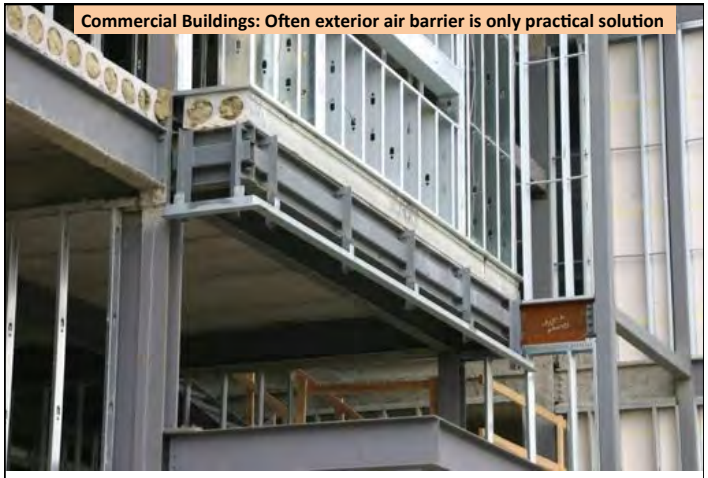
Air Barriers and Energy

- 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

102/175 11-05-13



Building Science Airflow Control No. 103/79



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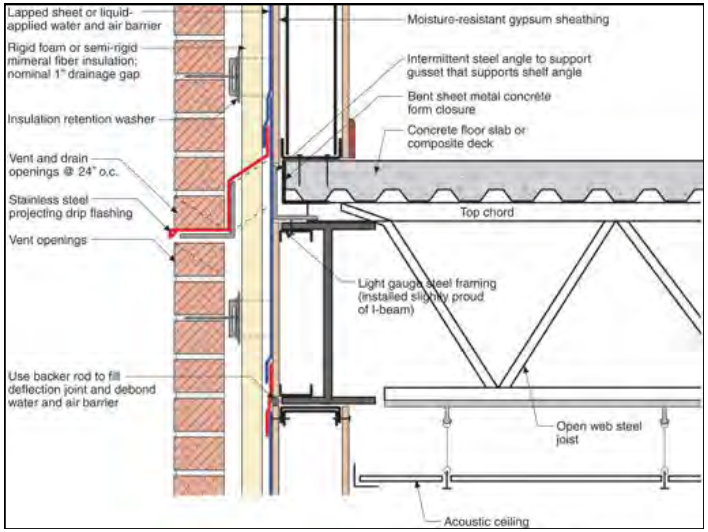
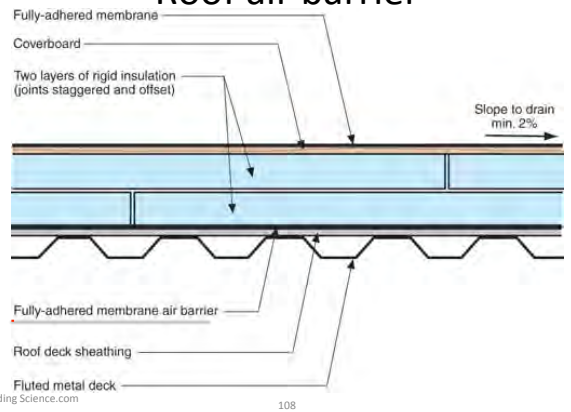
Poly combines air *and* vapour control
-Must be sealed and supported to be air barrier
-Cover most area and you have vapor control

Rigid Exterior Air Barrier



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

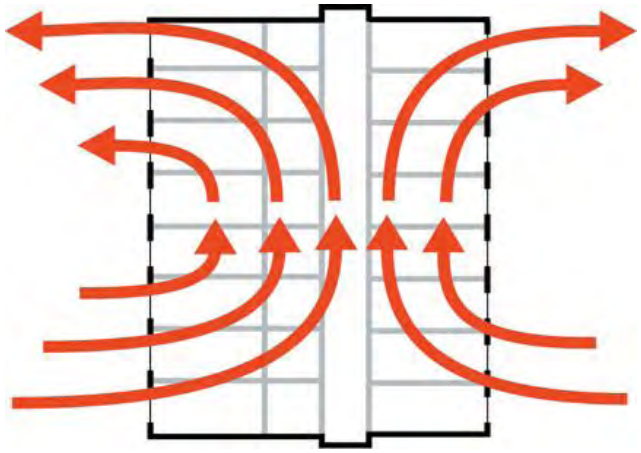
Roof air barrier



Stack effect

Building Science 2007

Joseph Lstiburek – Airflow 109



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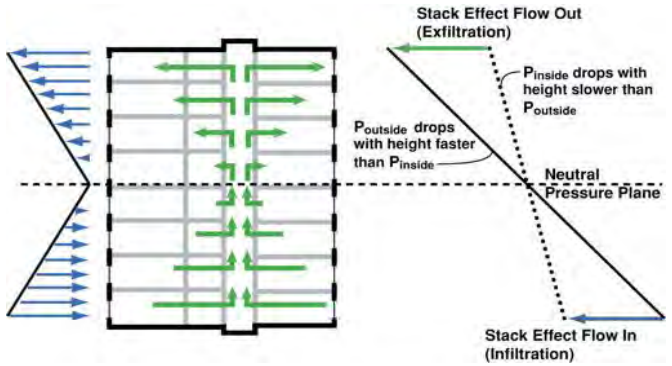

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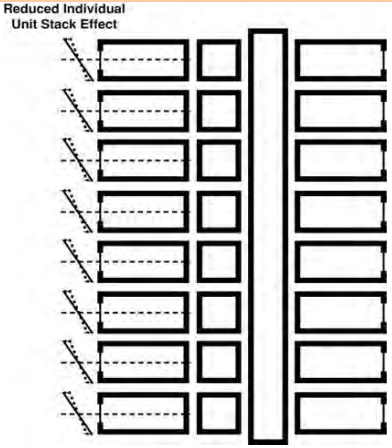
111

Compartmentalization is the most effective solution



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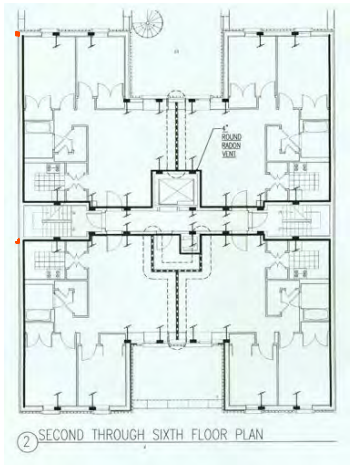

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Joseph Lstiburek – Airflow 113

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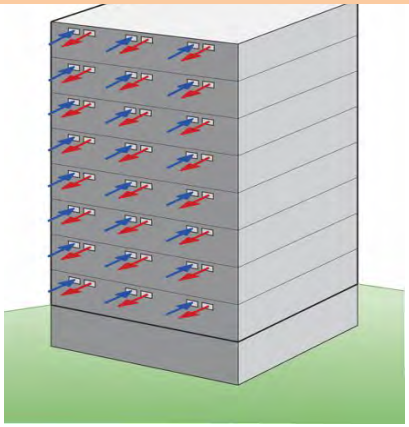
Individual air supply/exhaust per tenant



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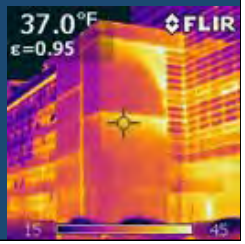
Thermal Control



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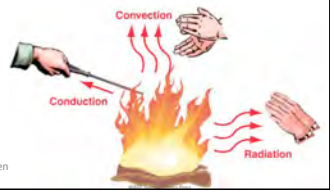
Thermal Control

- 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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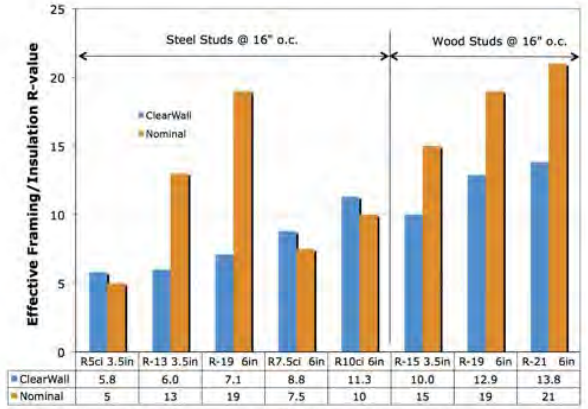
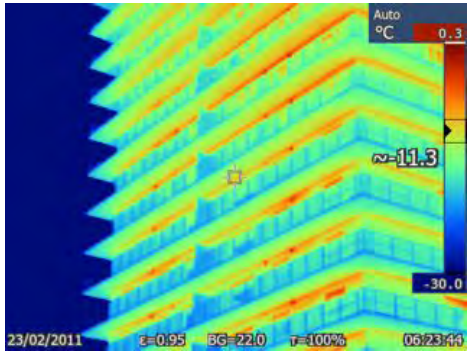
Best-case R-values for stud walls



	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 continous insulation with no framing penetrations



Thermal Bridge Examples

- Balconies, etc
- Exposed slab edges

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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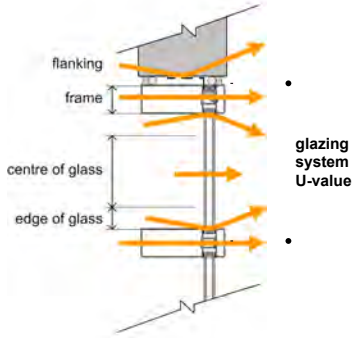
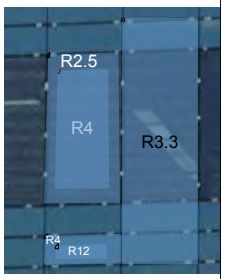
Total Heat Flow

Curtain Wall Plan View



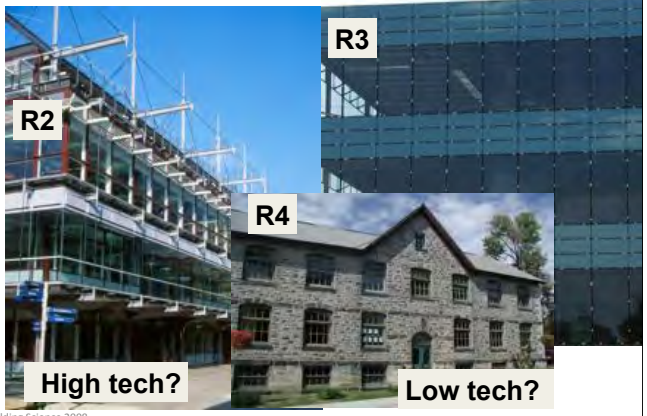
- glazing system U-value
-



Building Science 2008 Windows and Curtainwalls No. 12980

Building Science Windows and Curtain

Full-Frame R-values



Building Science 2008 Windows and Curtainwalls No. 13180

Thermal Break

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

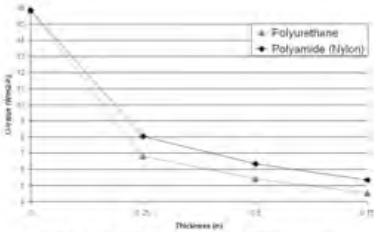
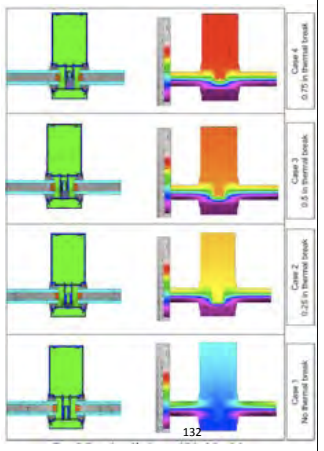


Figure 4: Frame U-Value vs. thermal break thickness.



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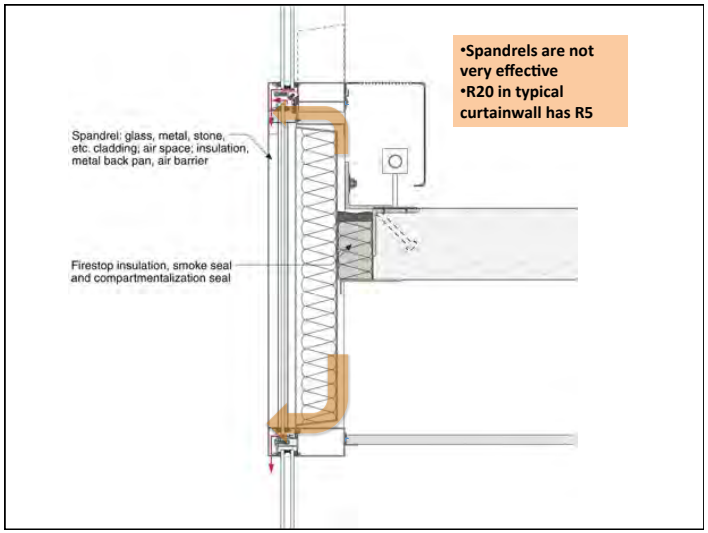
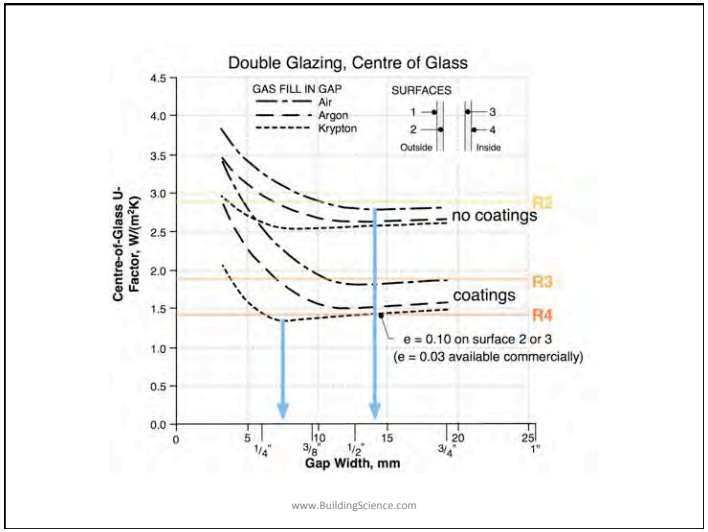
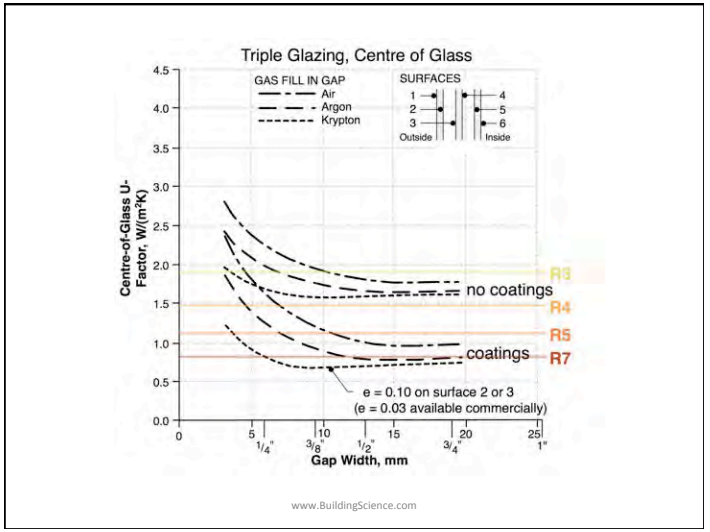

•Spandrels are not very effective
•R20 in typical curtainwall has R5
Spandrel: glass, metal, stone, etc. cladding; air space; insulation, metal back pan, air barrier
Firestop insulation, smoke seal and compartmentalization seal


High Performance
Getting better . .
R8
Southwall
R7
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
	0.05	20.00	0.29	0.44	Dual Pane, Triple Low Solar Heat Coefficient Film	Xenon
Premium Performance	U-Value	R-Value	SHGC	VT	Glazing	Fill
	0.07	14.29	0.24	0.43	Dual Pane, Dual Low Solar Heat Coefficient Film	Krypton
	0.11	9.09	0.51	0.65	Dual Pane, Dual High Solar Heat Coefficient Film	Krypton
High Performance	U-Value	R-Value	SHGC	VT	Glazing	Fill
	0.11	9.09	0.30	0.55	Dual Pane, Single Low Solar Heat Coefficient Film	Krypton
	0.19	5.26	0.60	0.73	Dual Pane, Single High Solar Heat Coefficient Film	Krypton

*Performance numbers are center-of-glass values based on LBNL Window 5.2 software

Courtesy of ThermaProof Windows and AlpenGlass+

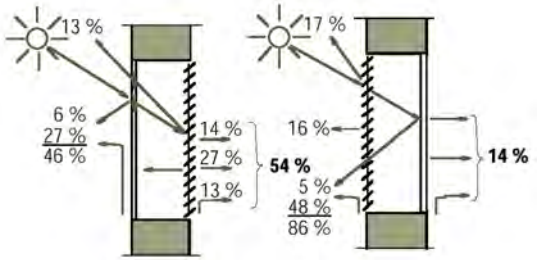
Solar Gain

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

www.BuildingScience.com

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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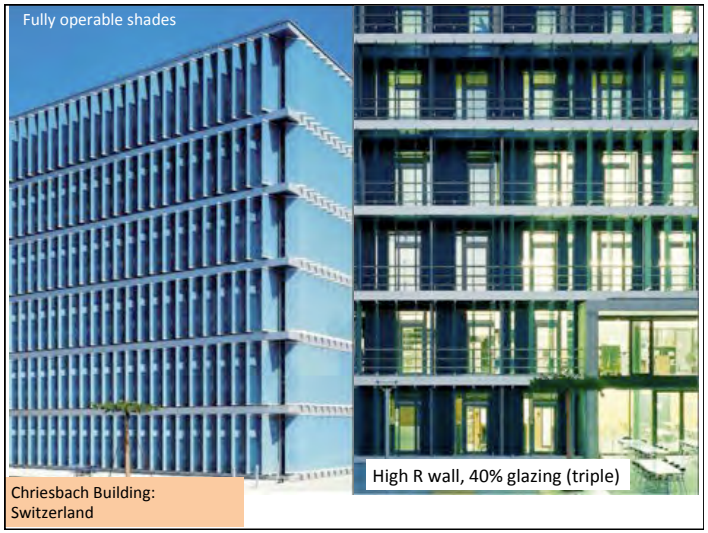


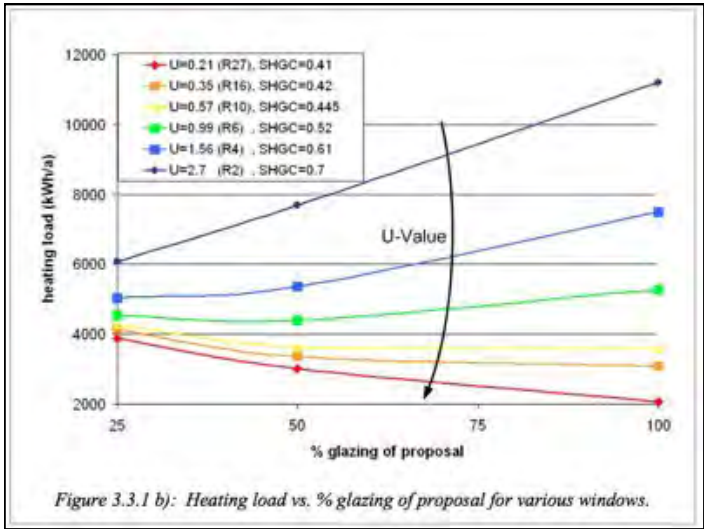


Figure 3.3.1 b): Heating load vs. % glazing of proposal for various windows.

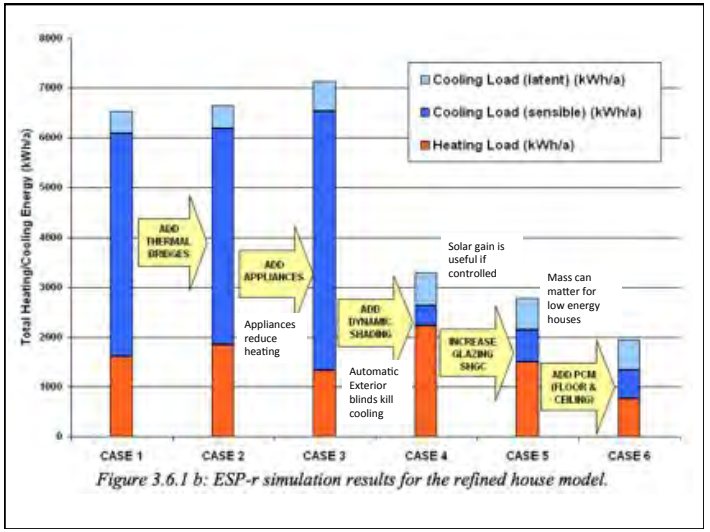
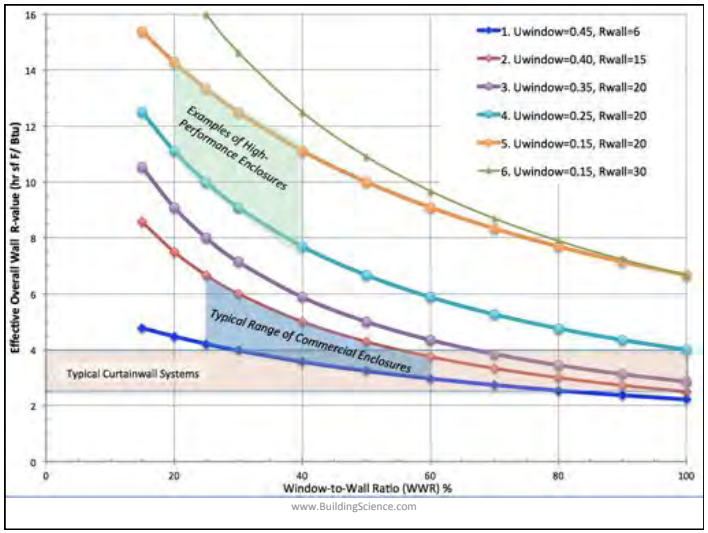
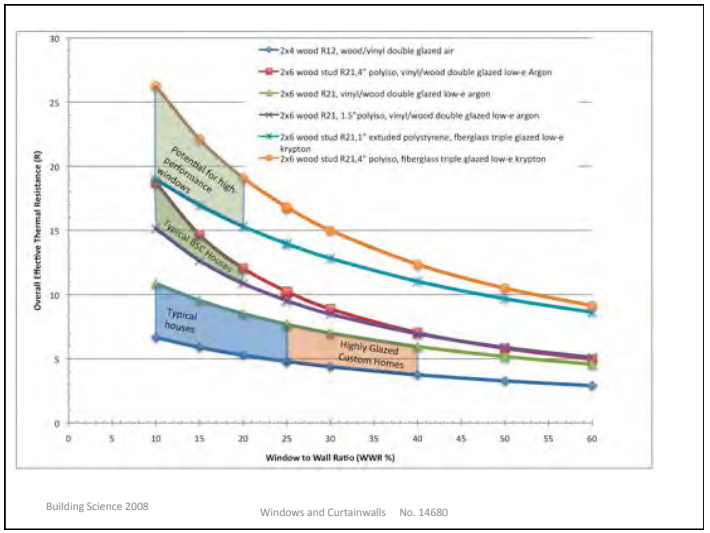
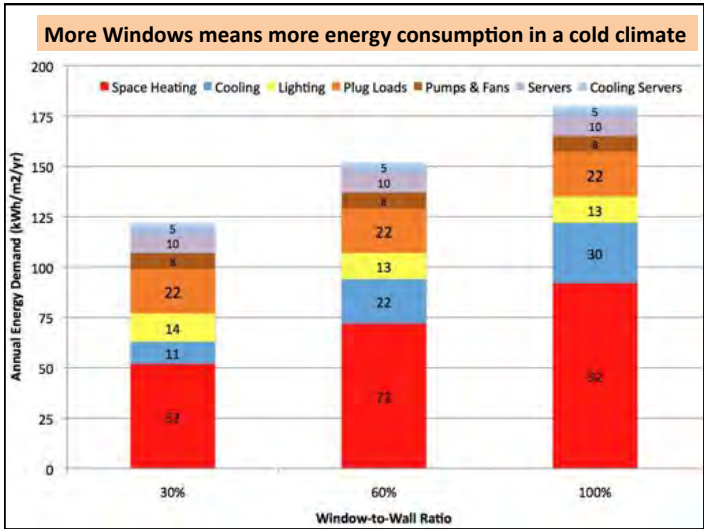
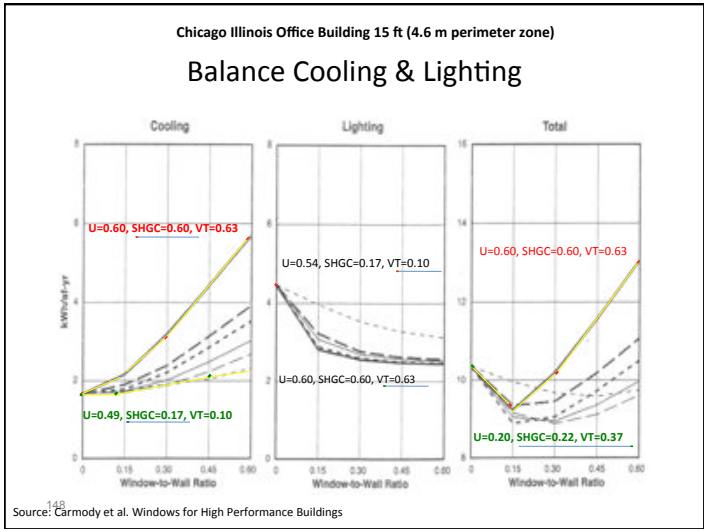


Figure 3.6.1 b: ESP-r simulation results for the refined house model.


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 BSC houses
Typical houses
Highly Glazed Custom Homes
Overall Effective Thermal Resistance (R)
Window to Wall Ratio (WWR %)
Building Science 2008
Windows and Curtainwalls No. 14680


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


Chicago Illinois Office Building 15 ft (4.6 m perimeter zone)
Balance Cooling & Lighting
Cooling
Lighting
Total
U=0.60, SHGC=0.60, VT=0.63
U=0.54, SHGC=0.17, VT=0.10
U=0.60, SHGC=0.60, VT=0.63
U=0.49, SHGC=0.17, VT=0.10
U=0.20, SHGC=0.22, VT=0.37
kWh/sf-yr
Window-to-Wall Ratio
148
Source: Carmody et al. Windows for High Performance Buildings

Summary

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