Architectural Design for the 2030 Challenge

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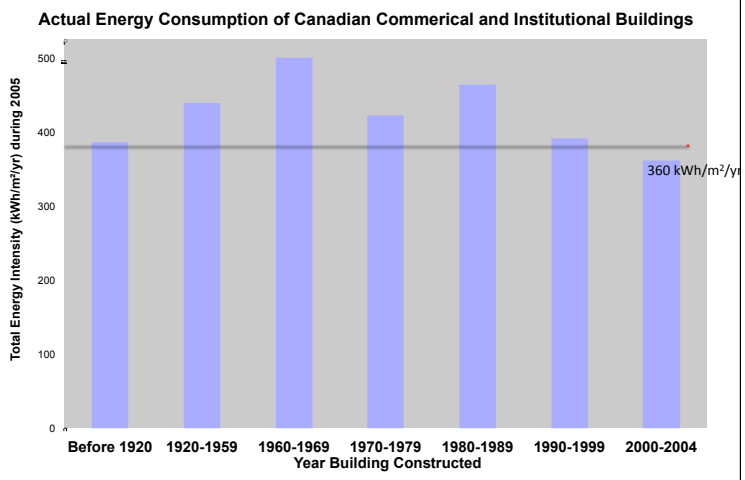
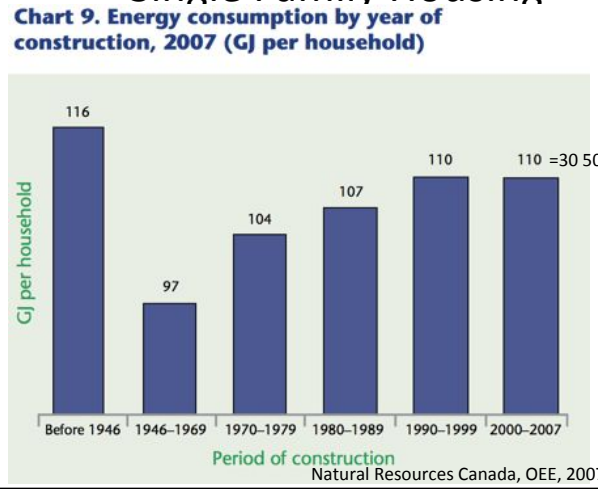
BuildingScience.com

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



Single Family Housing



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 395 kWh/m²/yr	1.421	**0.710**	0.568	0.426	0.284	0.142
Educational Services 490 kWh/m²/yr	1.768	**0.884**	0.707	0.530	0.354	0.177
Healthcare and Social Assistance	2.038	**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 190 kWh/m²/yr	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

Design Principles

www.buildingscience.com

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)

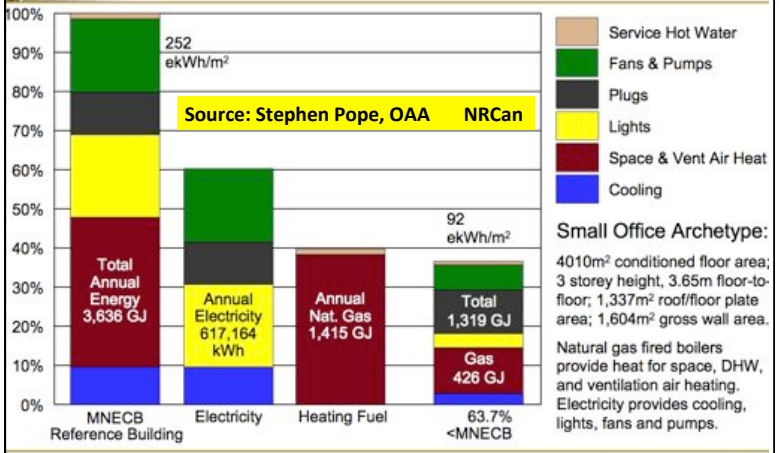
- Keep heat in
  - When it is cold
- Keep heat / sun out
  - When it is warm/hot
- Last a long time
  - Reduce construction/repair resources over time
- Use efficient equipment
  - Efficient lighting
  - Efficient computers, elevators

Insulation
Airtightness
Solar Control

Rain Control

Off is very efficient

Toronto Small Office Archetype



Small Office Archetype:

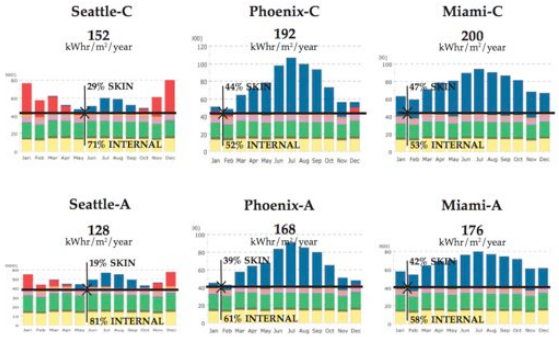
4010m² conditioned floor area; 3 storey height, 3.65m floor-to-floor; 1,337m² roof/floor plate area; 1,604m² gross wall area.

Natural gas fired boilers provide heat for space, DHW, and ventilation air heating. Electricity provides cooling, lights, fans and pumps.

Natural Resources Canada | Ressources naturelles Canada

Canada

Climate matters



- Beware architecture magazines

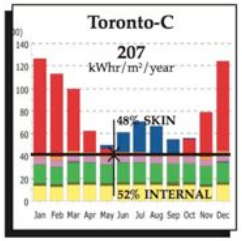
Typical market Building in Toronto 55% heat+cool

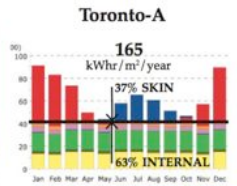
Other things use energy

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

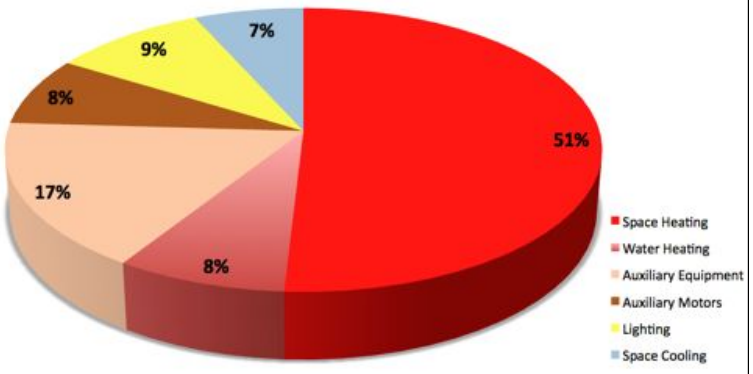
MD40SQ-A
similar to above, except:
Enclosure "A-Exemplary"

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





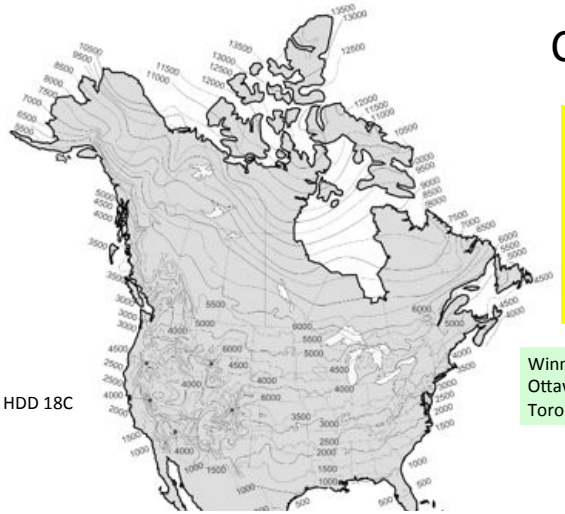
Canadian Offices 2007



207 million m²
Average 394 kWh/m²

Source: NRCan Office of Energy Efficiency

Canada:

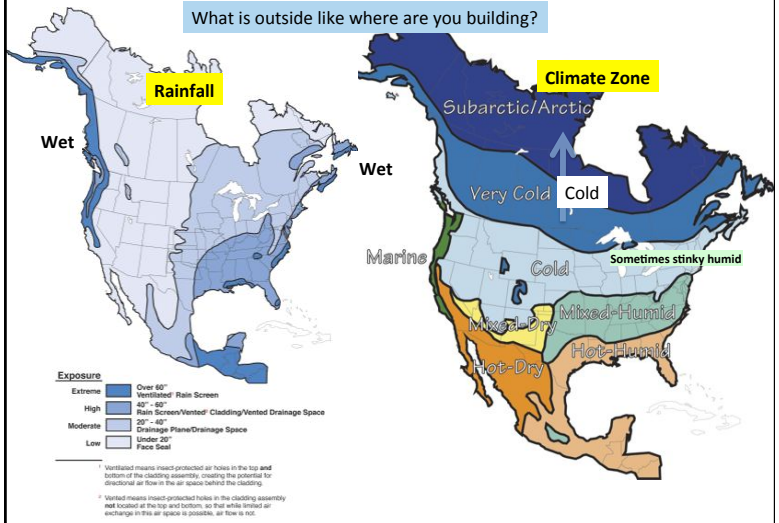


HDD 18C

Significant heating demand, especially Prairies and North

Winnipeg 5750
Ottawa 4600
Toronto 4000

What is outside like where are you building?

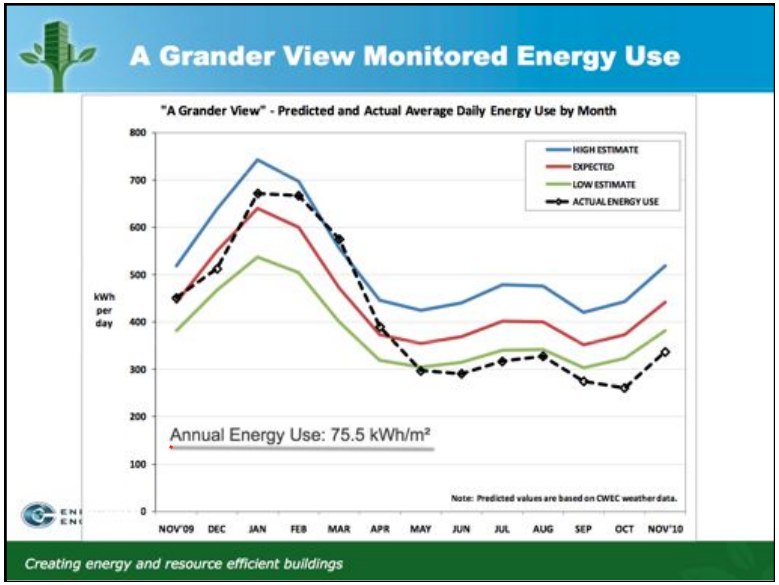


Can we do it?

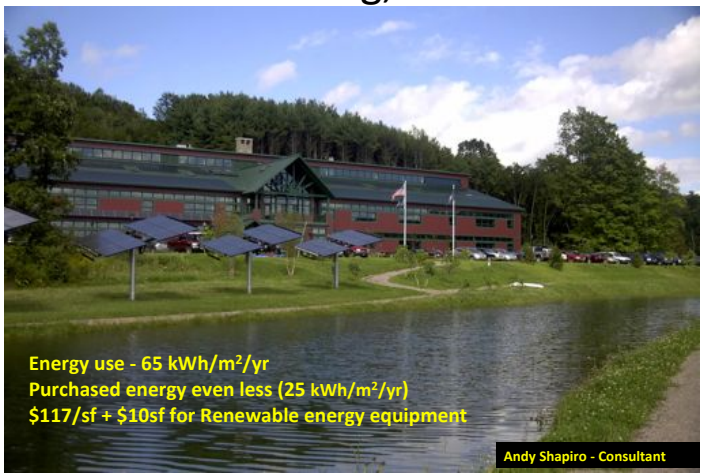
- Is it possible or practical to drop energy use by 60% in cold-climate Canada?
- Getting office to 200? 100? kWh/m²/yr?

Grander View, 2010

- Mostly simple, standard technology
- Modest cost premium



NRG Building, Vermont



Waterloo Apartment / Office

- Built for median cost in 2005
- Less than 100 ekWh/m^2 (Ont avg around 250)
- All standard products

John Straube

Waterloo Region Health & Welfare

- Built 1990. 160 ekWh/m^2/yr. Less than half national average

London City Hall

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

London UK City Hall

- Measured: 376 kWh/m^2/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.

HVAC

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

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"

The Enclosure: An Environmental Separator

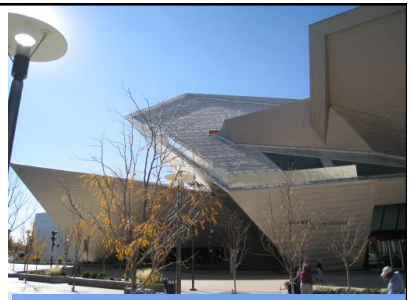
- The part of the building that physically ***separates*** the ***interior*** and ***exterior*** environments.
- Includes all of the parts that make up the wall, window, roof, floor, caulked joint etc.
- Sometimes, interior partitions also are environmental separators (pools, rinks, etc.)

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

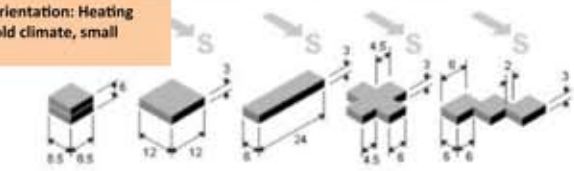
The higher the ratio, the more enclosure design & climate impact performance

Small, Compact Form

- Fewer resources
- Less heat loss and gain

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

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



$\frac{V}{S} = \frac{432}{348} = 1.24$ $\frac{V}{S} = \frac{432}{432} = 1$ $\frac{V}{S} = \frac{432}{468} = 0.92$ $\frac{V}{S} = \frac{432}{468} = 0.92$ $\frac{V}{S} = \frac{432}{516} = 0.84$

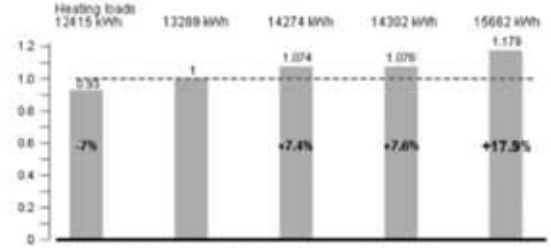
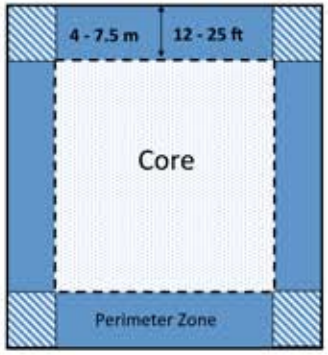


Fig. 4. Impact of the building shape on the heating loads.

Large Buildings

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

Core / Perimeter

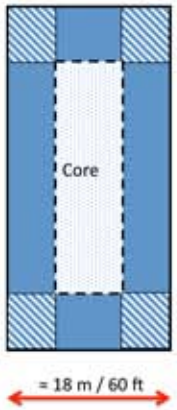


- Perimeter Zone
  - performance dominated by climate and enclosure
- Core Zone
  - dominated by interior use. Climate/enclosure almost irrelevant
- In most occupancies, core needs ***cooling and lighting all year long, all day***

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***

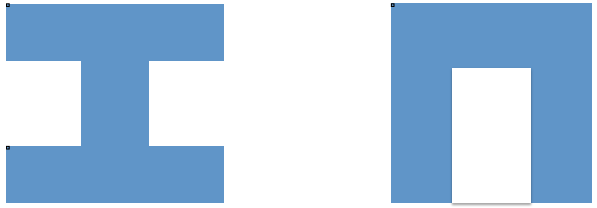
Skin dominated

Building Shape

- Alphabet Soup
  - H I A B E

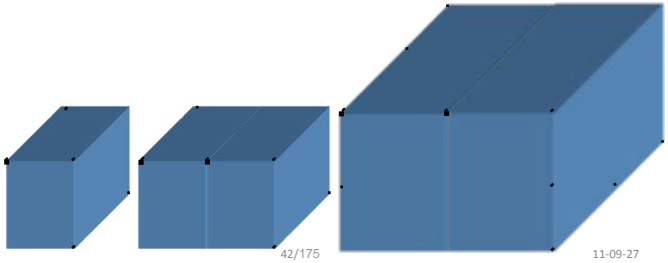
Expanded Plans

- 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



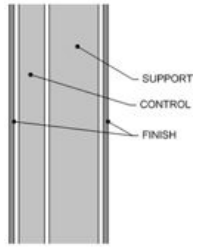
Enclosure Intro Summary

- 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

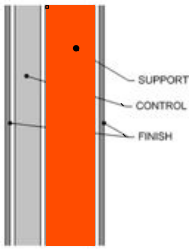
Functional Layers



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

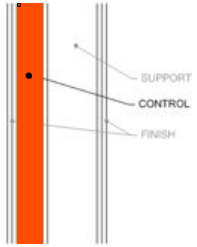
Functional Layers



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

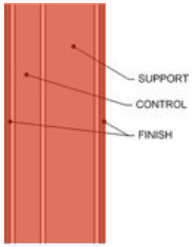
Functional Layers



Other Control . . .

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

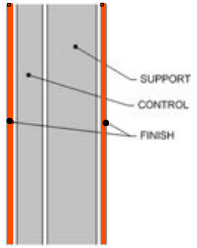
Functional Layers



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

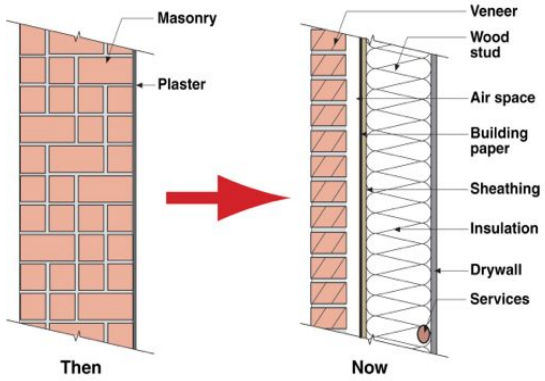


History of Control Functions

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

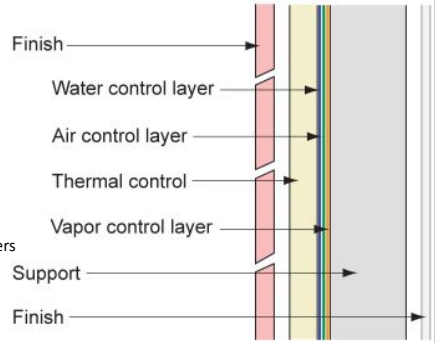
    . . . separate functions

Changes



The "Perfect Wall"

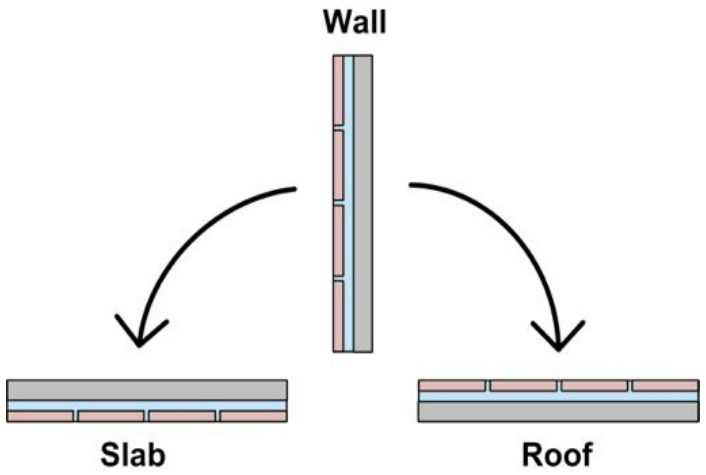
- Finish of whatever
- Control *continuity*
  - Rain control layer
    - Perfect barrier
    - Drained with gap
    - Storage
  - Air control layer
    - Air barrier
  - Thermal control layer
    - Aka insulation, radiant barriers
  - Vapor control layer
    - Retarders, barriers, etc
- Structure: anything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

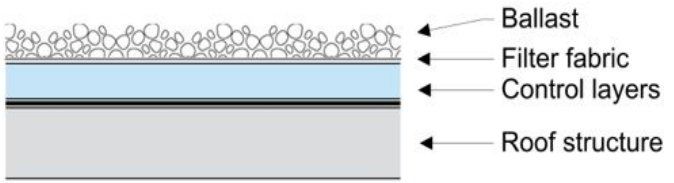


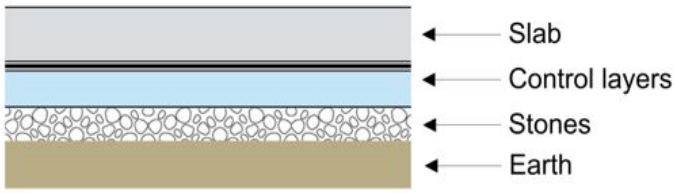
Fire Control may be needed
Sound Control optional

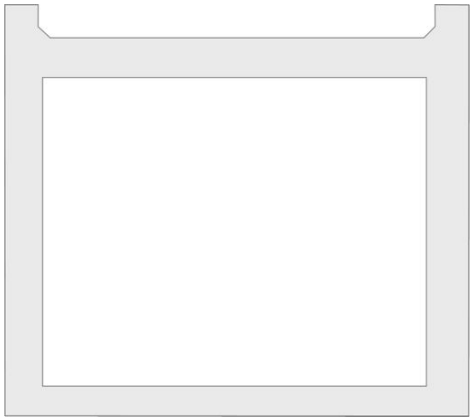
What is a High-performance enclosure?

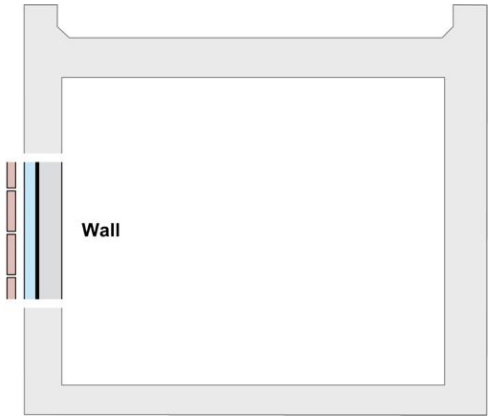
- One which provides high levels of control
- Poor continuity limits performance
- Poor continuity causes most problems too:
  - E.g. air leakage condensation
  - Rain leakage
  - Surface condensation
  - Cold windows
- This course: continuity + high levels

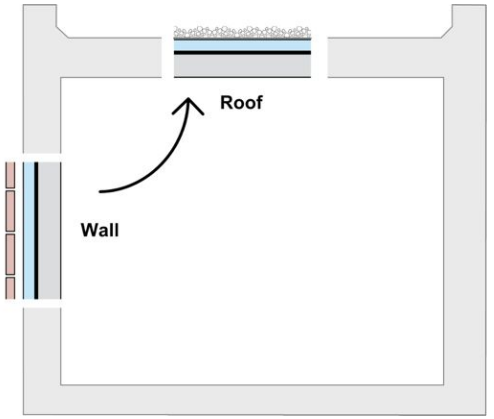

Wall
Slab
Roof

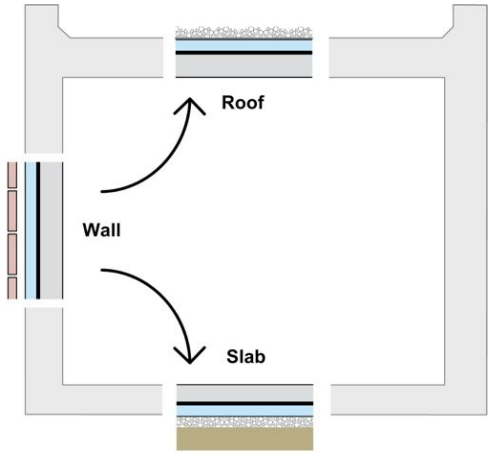

Ballast
Filter fabric
Control layers
Roof structure

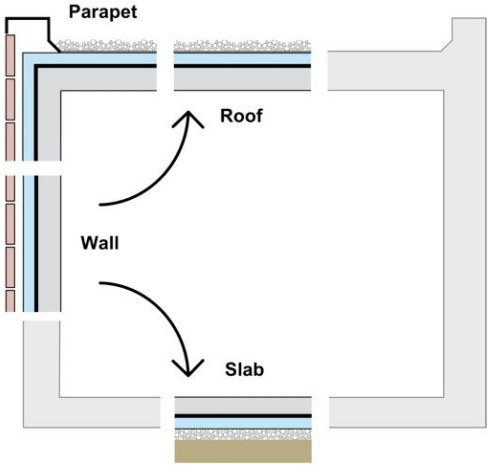

Slab
Control layers
Stones
Earth

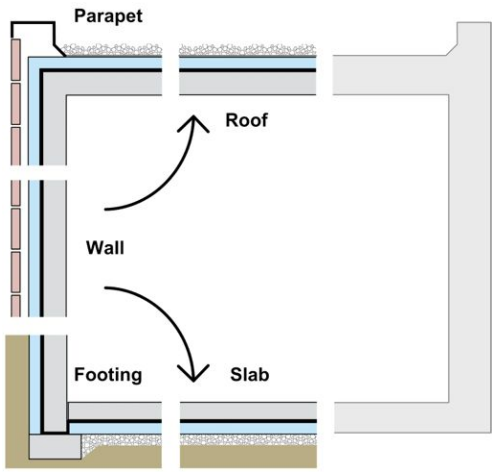


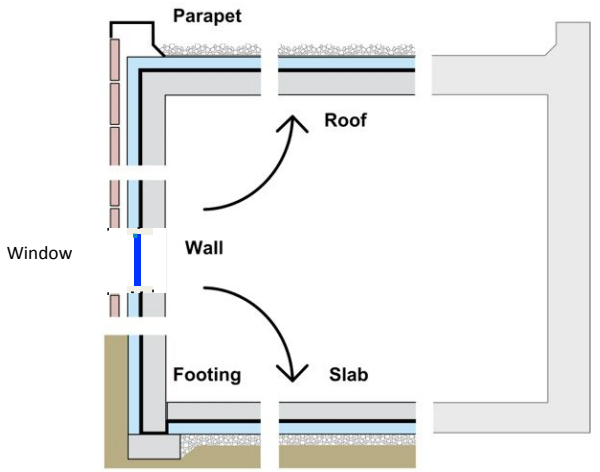

Wall


Roof
Wall

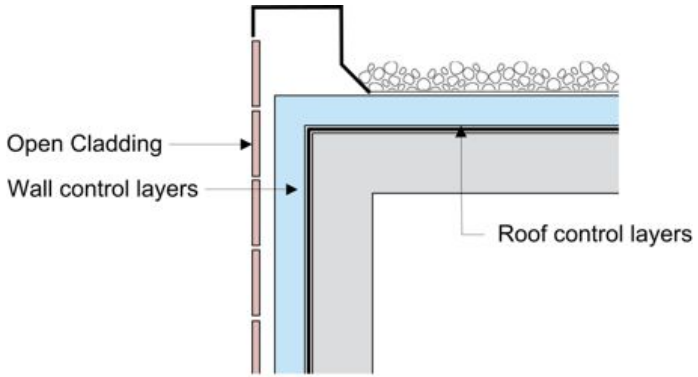

Roof
Wall
Slab


Parapet
Roof
Wall
Slab



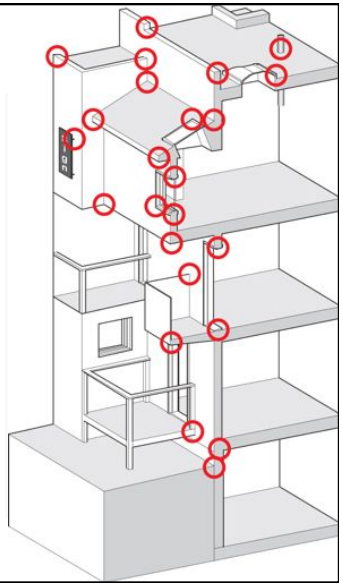


Connections: Who is in charge

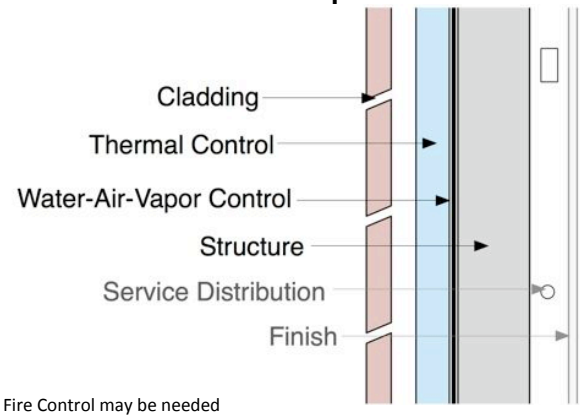


Enclosure Design: Details

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



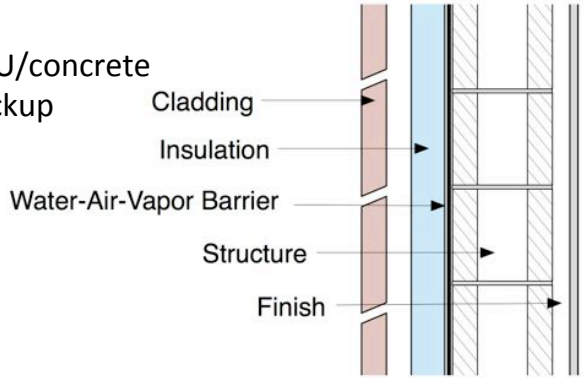
Perfect Wall expanded



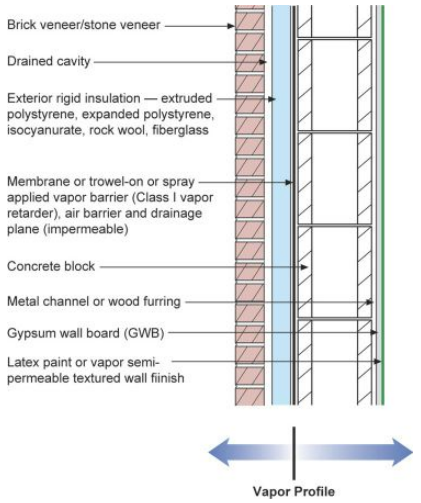
Additional Fire Control may be needed
Sound Control optional

Perfect Wall

- CMU/concrete backup

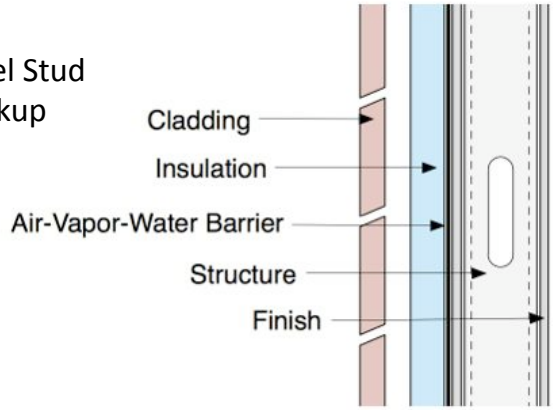


Any R-value, e.g.
4" PIC=R25
5"XPS =R25
6"MFI=R25

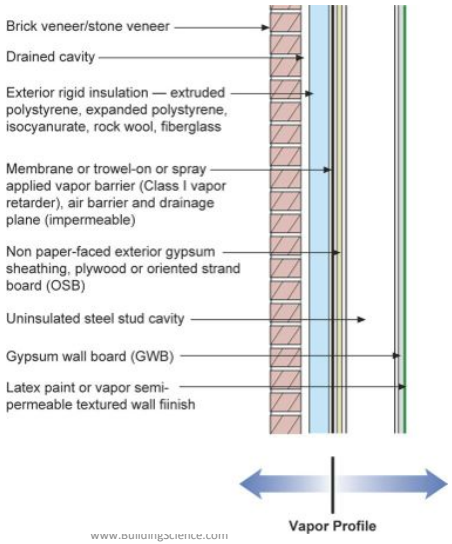


Perfect Wall

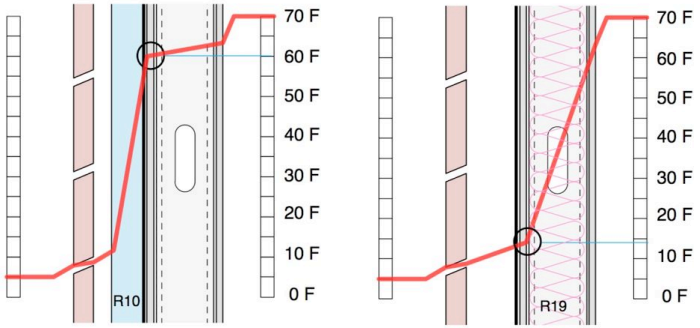
- Steel Stud Backup



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



Condensation & Drying

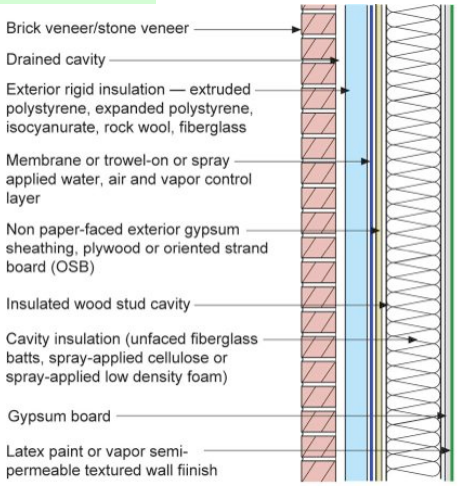


Ratio: Exterior R-value / Studbay R-value controls risk of condensation

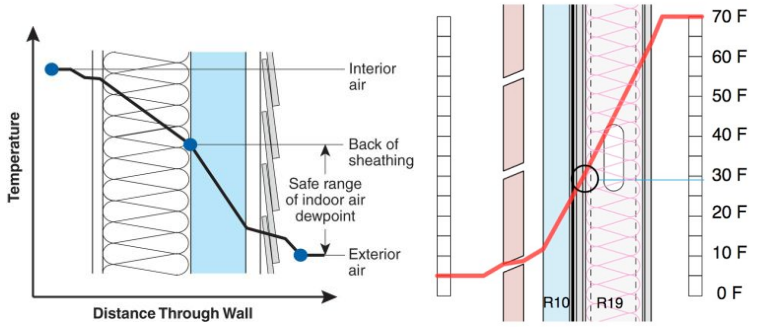
Steel studs compromise the thermal performance Wood studs, not so much

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

Compromise



Compromise= Risks



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

Specifics

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

  } Energy & Comfort } Durability, Health
- In some detail

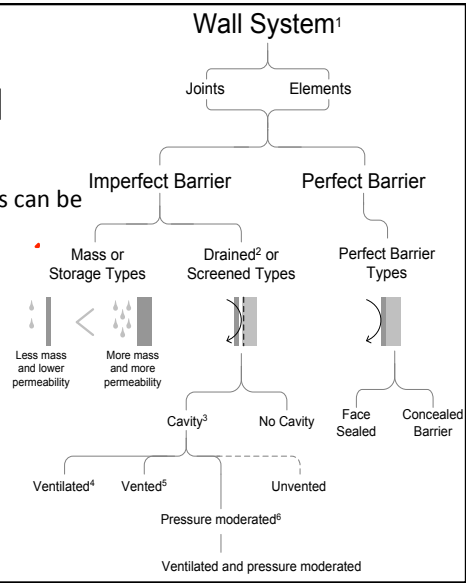
Rain Control

Rain Control

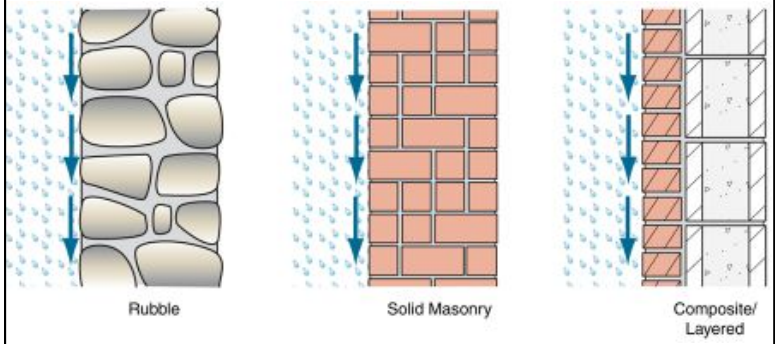
- Next to structure, the most important, fundamental requirement
- Source of many serious building problems
- Major impact on durability
- Low-energy buildings & rain
  - Different enclosure assemblies
  - Reduced drying ability= need for better control!

Rain Control

- Elements and joints can be different



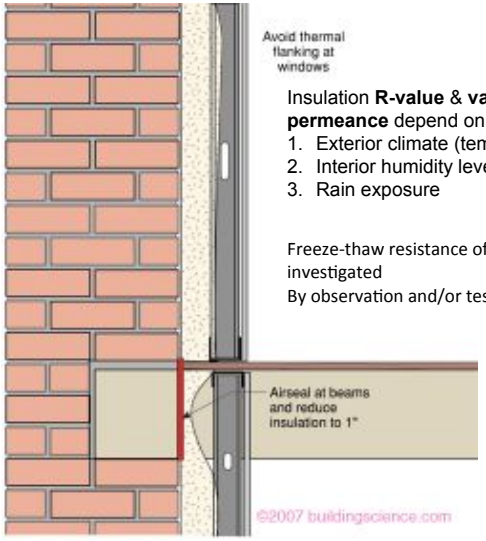
Mass/Storage/Reservoir Walls



John Straube

No building paper, flashing, weepholes

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



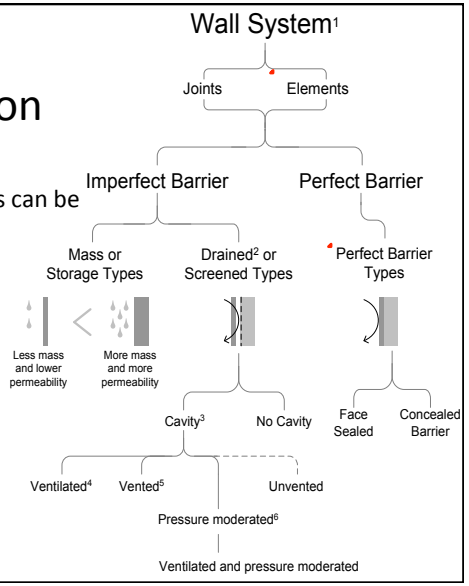
Insulation **R-value** & **vapor permeance** depend on:

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

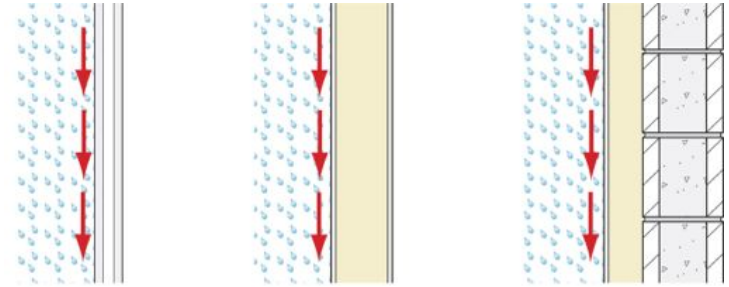
Freeze-thaw resistance of brick should be investigated
By observation and/or testing

Categorization

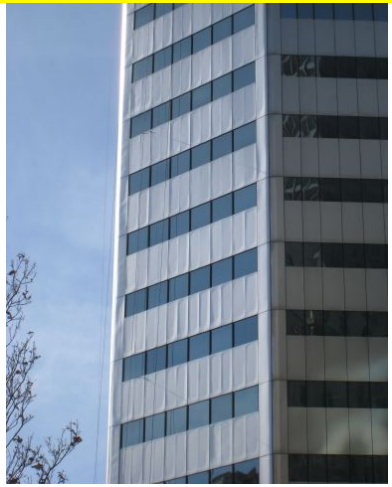
- Elements and joints can be different



Perfect Barrier / Face Sealed

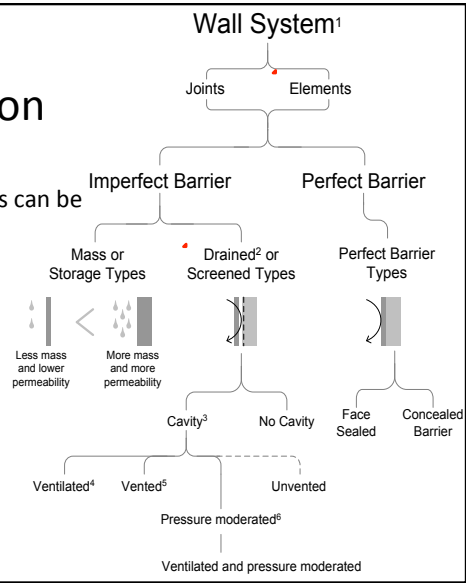


It is all about joints, transitions, penetrations



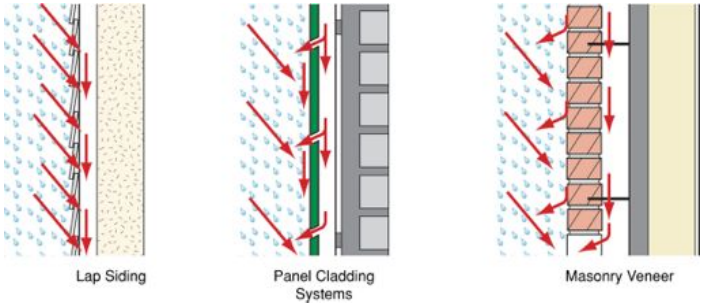
Categorization

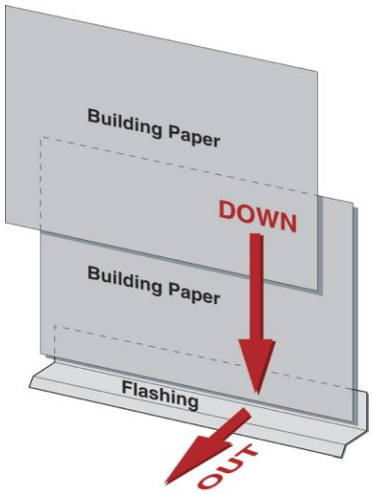
- Elements and joints can be different



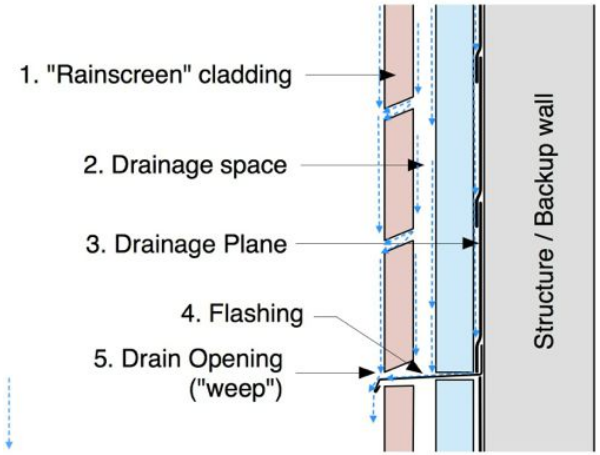
Drained Walls

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

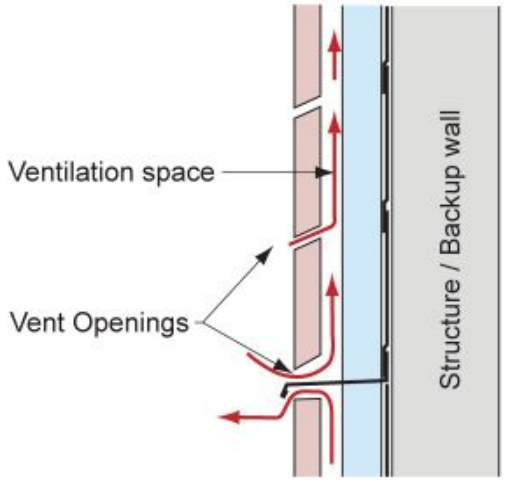


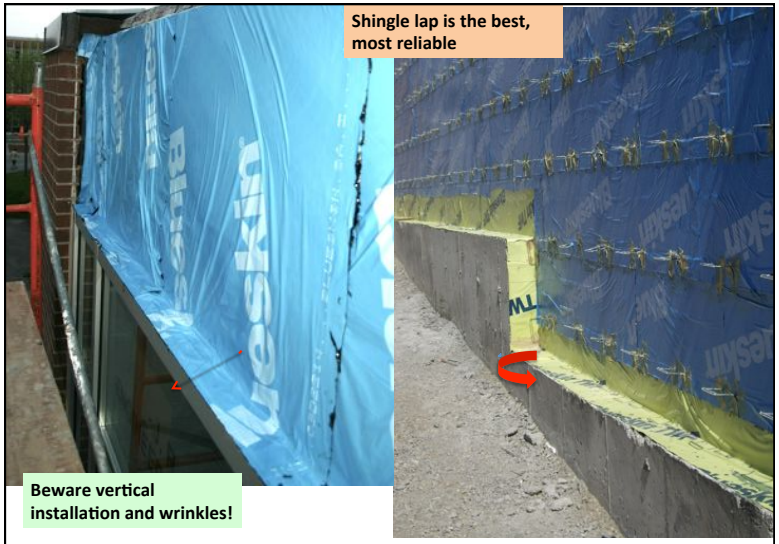


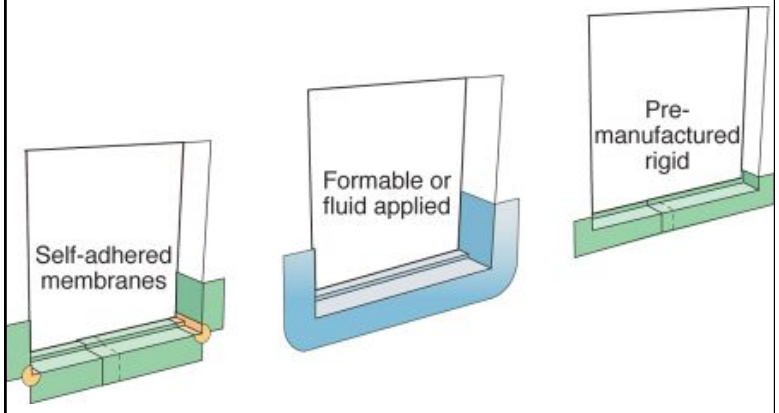
Requirements for a Drained Enclosure



Requirements for a Ventilated Enclosure







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

Air-Water Control Layers

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

Details

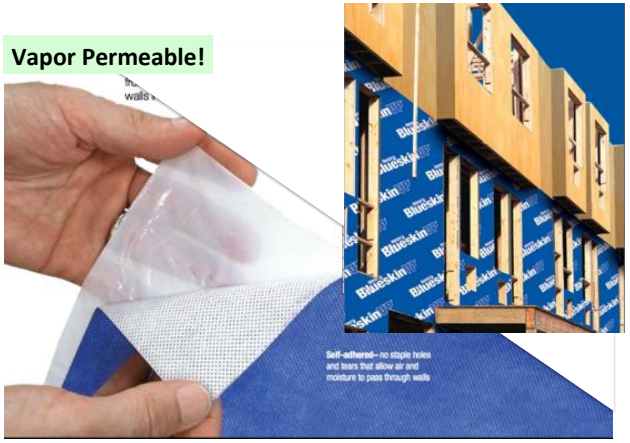
- Air & water & vapor transition membranes

Non-adhered, vapor permeable =modest performance

Supported **flexible membrane is better**

Fully-adhered air-water barrier

Vapor Permeable!



Mixed membrane + fluid-applied

Often use membranes for transitions

Spray/Trowel Applied Air/water

- Semi-permeable

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

Continuity is key!

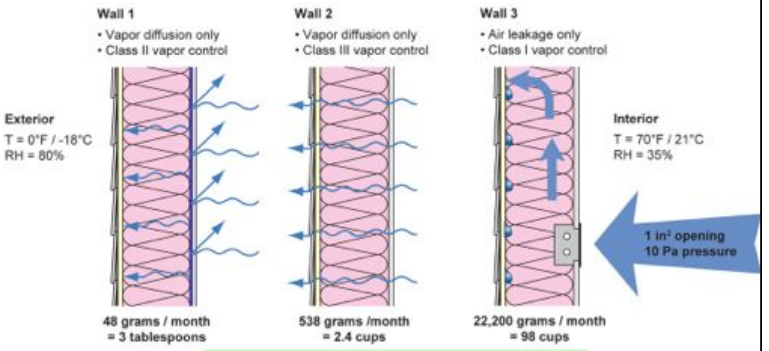
- Must ensure no rain leaks
- Airflow control should be as continuous as practical
- Thermal control
  - We live with penetrations
  - Minimize steel and concrete to small local
- Vapor control
  - Not that important to ensure continuity

Air Flow Control

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!

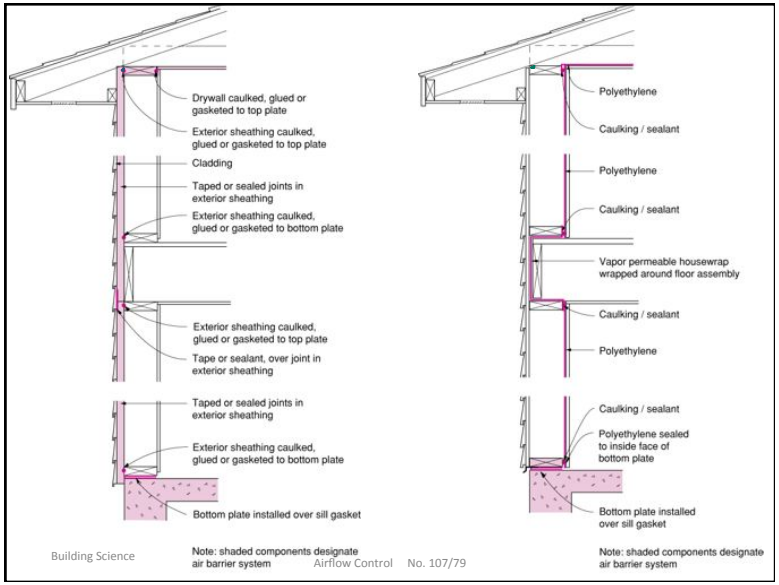
Calculations for a single stud bay, 8 ft tall, 16" wide

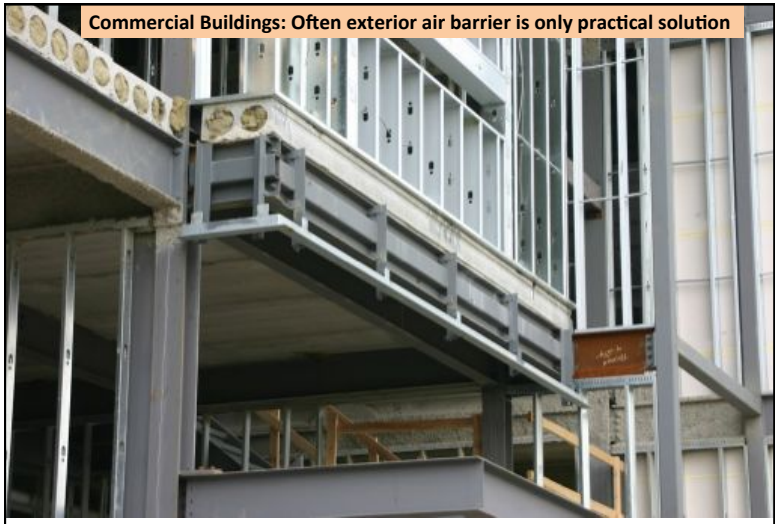
Air leakage

- 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



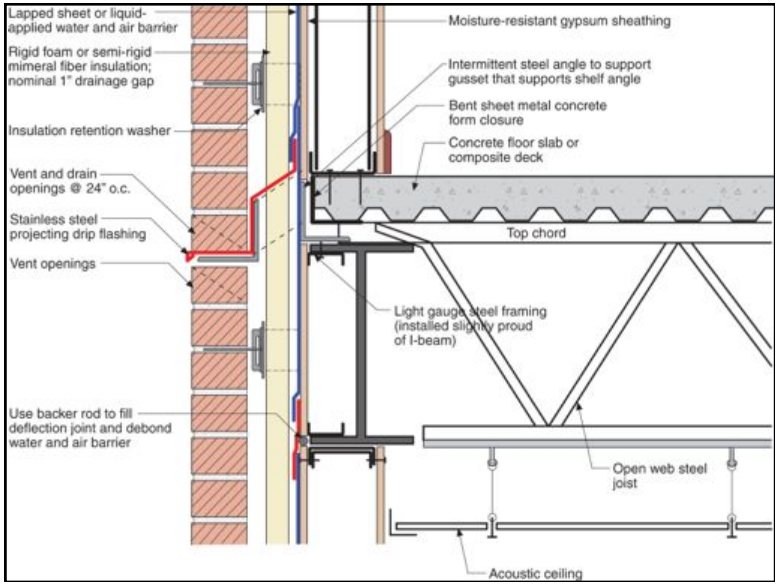


Poly combines air *and* vapour control

-Must be sealed and supported to be air barrier

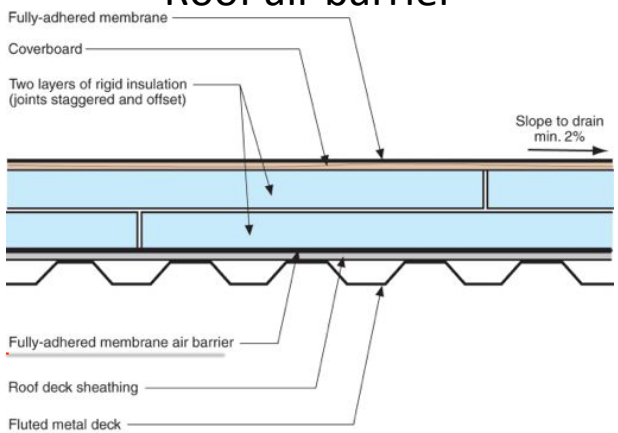
-Cover most area and you have vapor control

Rigid Exterior Air Barrier

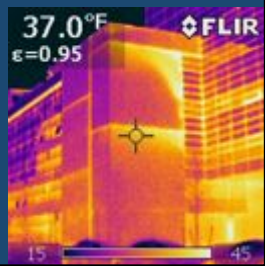


Deck level vapor control membrane rarely required if closed cell foam used

Roof air barrier



Thermal Control



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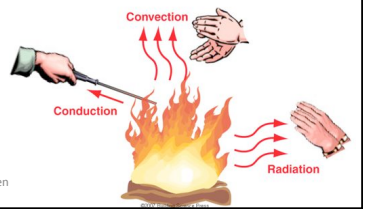
Thermal Control

- 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



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

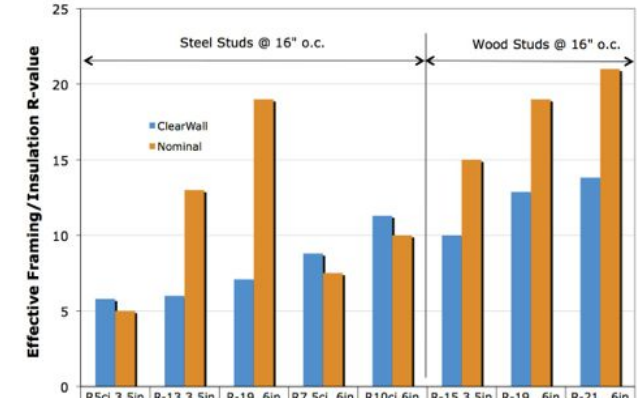
How much Insulation

- 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

Thermal Continuity

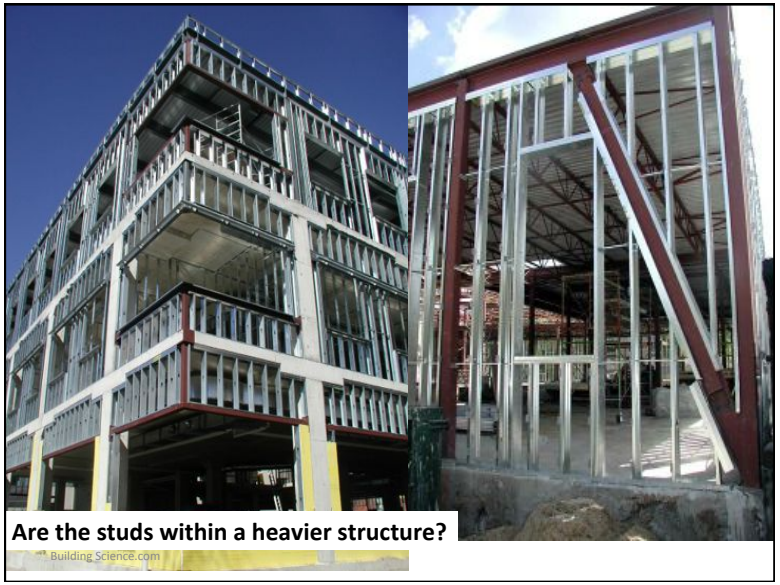
- Some short circuiting is normally tolerated.
- High-performance walls tolerate few
- Major offenders / weak spots
  - Penetrating slabs (<R1)
  - Steel studs (<R1)
  - Windows (R2-R3)
- Area and low R matter to overall significance

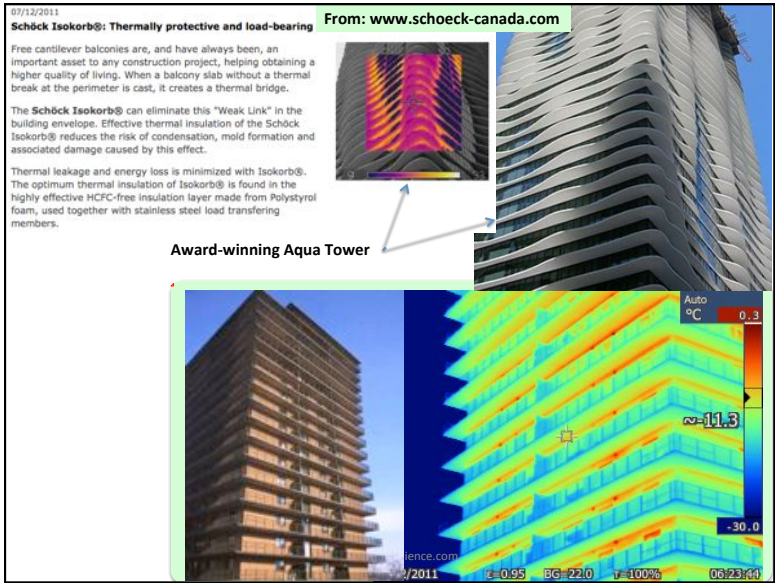
Best-case R-values for stud walls



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

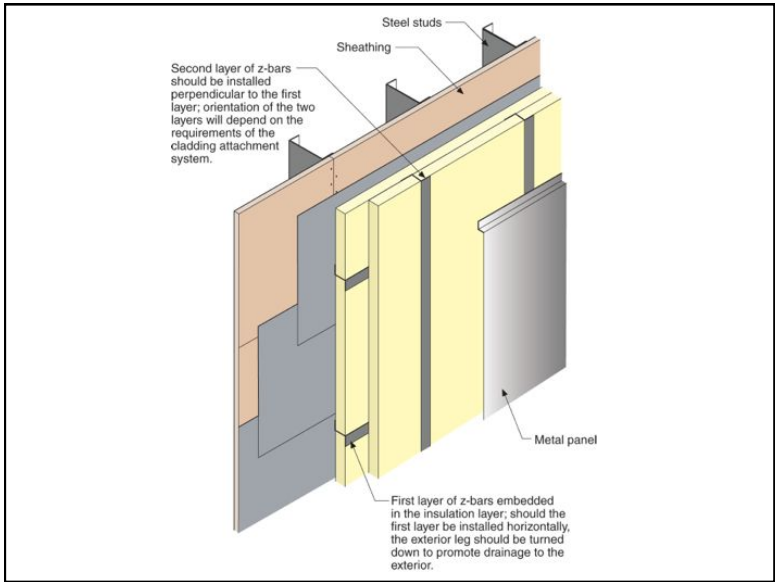
Source: ASHRAE 90.1-2007, Table A9.2B. ci denotes a layer of continous insulation with no framing penetrations

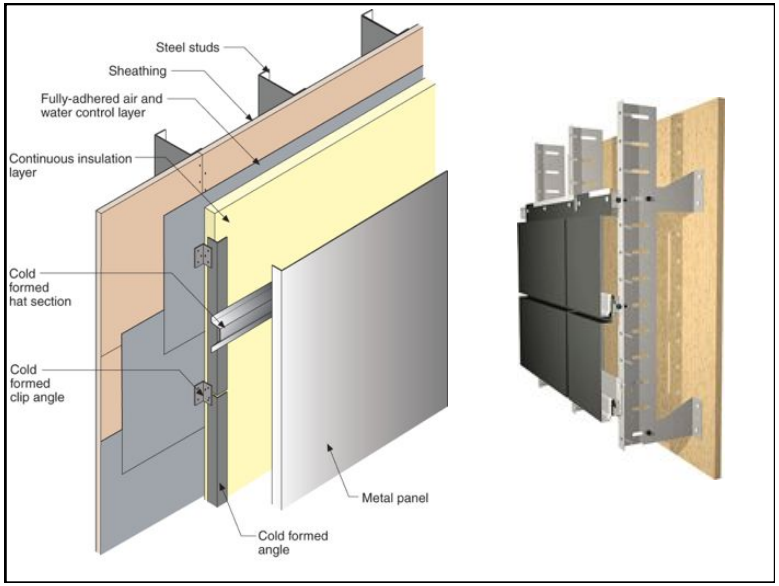


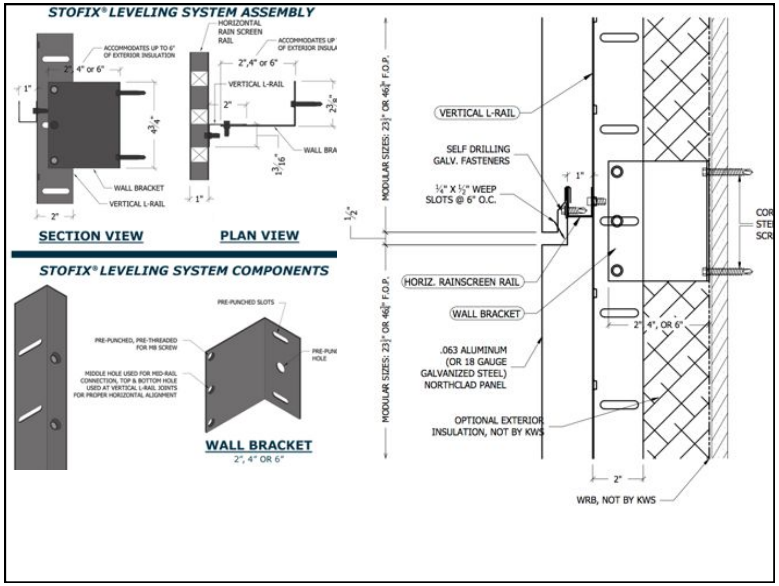


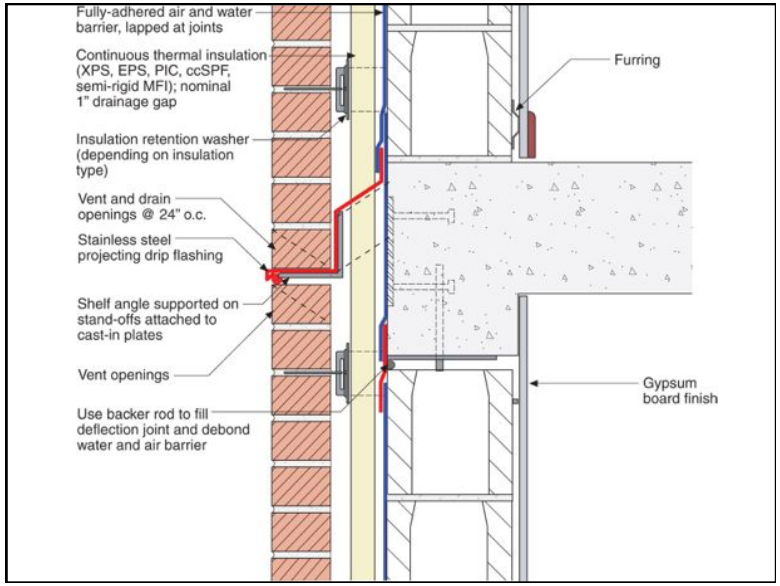
Thermal Bridge Examples

- Balconies, etc
- Exposed slab edges




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


STOFIX® LEVELING SYSTEM ASSEMBLY
SECTION VIEW
PLAN VIEW
STOFIX® LEVELING SYSTEM COMPONENTS
WALL BRACKET
2", 4" OR 6"
VERTICAL L-RAIL
SELF DRILLING GALV. FASTENERS
¼" X ½" WEEP SLOTS @ 6" O.C.
HORIZ. RAINSCREEN RAIL
WALL BRACKET
.063 ALUMINUM (OR 18 GAUGE GALVANIZED STEEL) NORTHCLAD PANEL
OPTIONAL EXTERIOR INSULATION, NOT BY KWS
WRB, NOT BY KWS

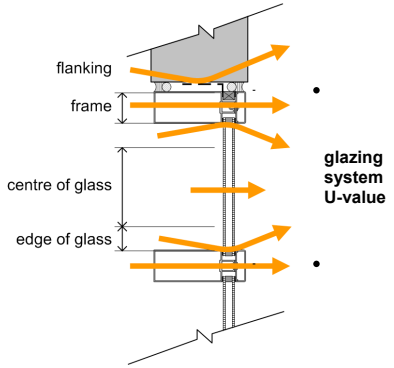


Windows

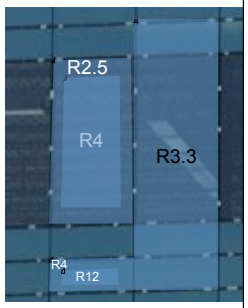
- Our most expensive thermal bridges
- Aluminum is 4-5 times as conductive as aluminum
- Difficult to buy commercial aluminum windows / curtainwall over R3.
- Allow solar heat in
  - Useful in cold weather
  - Requires cooling in summer

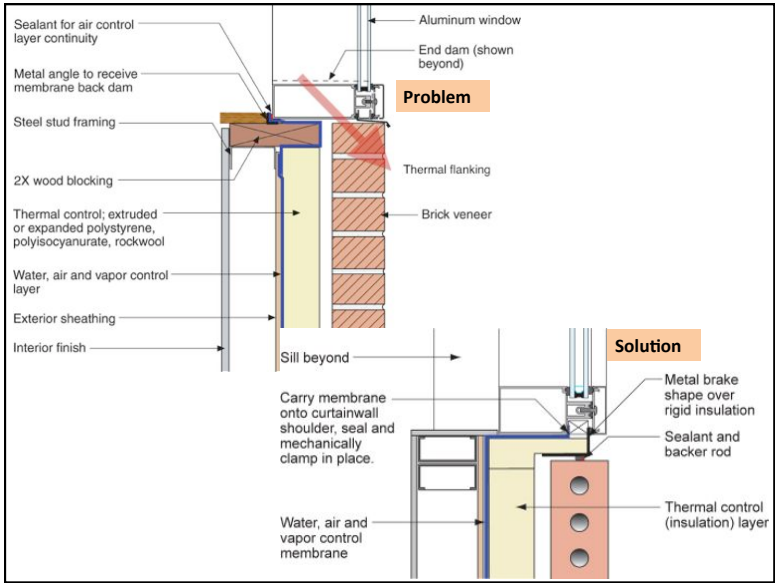
Total Heat Flow

Curtain Wall Plan View

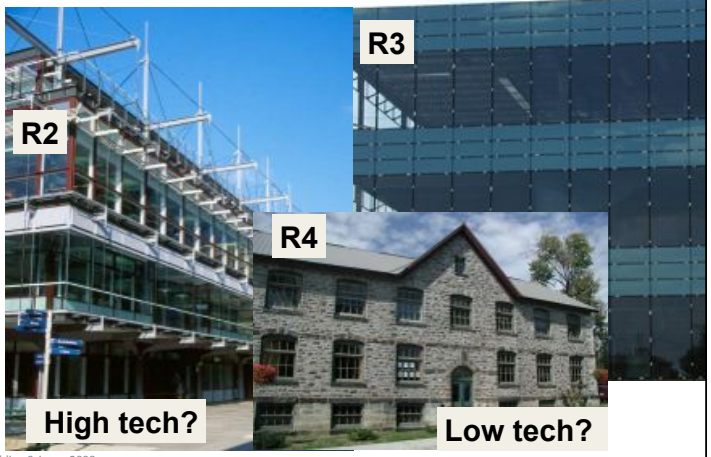


glazing system U-value





Full-Frame R-values



Thermal Break

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

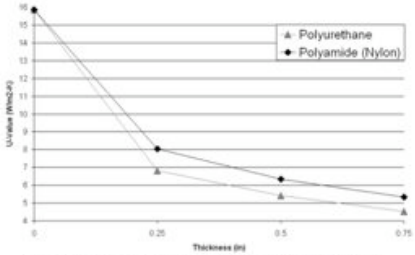
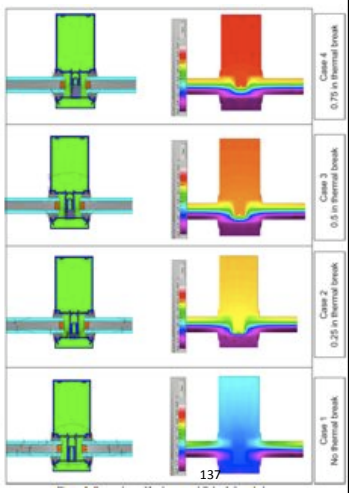


Figure 4: Frame U-Value vs. thermal break thickness.



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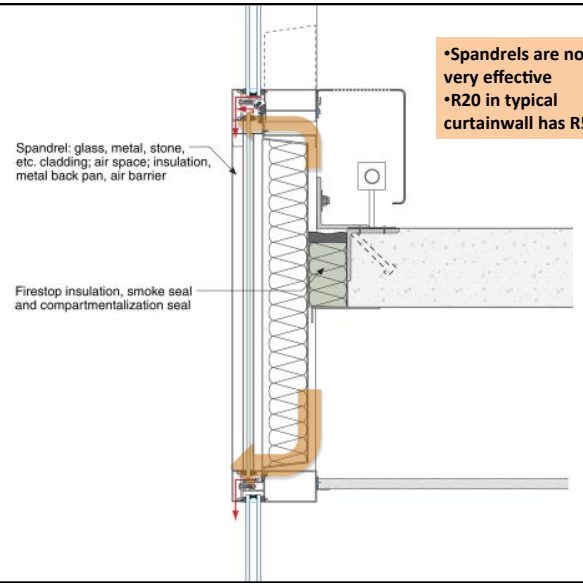
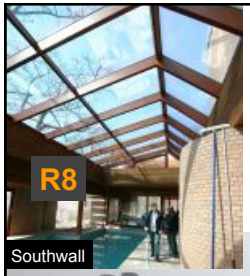
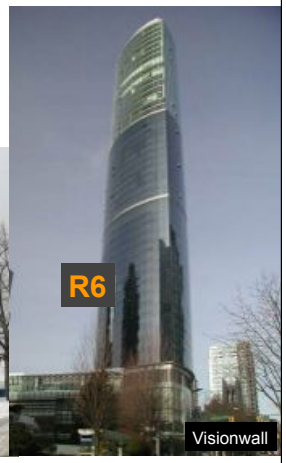


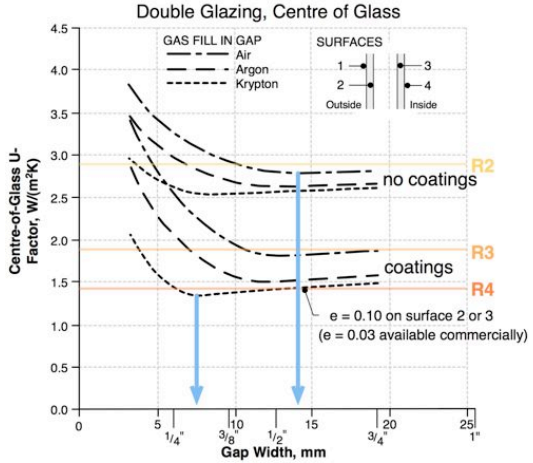
- **Spandrels are not very effective**
- **R20 in typical curtainwall has R5**

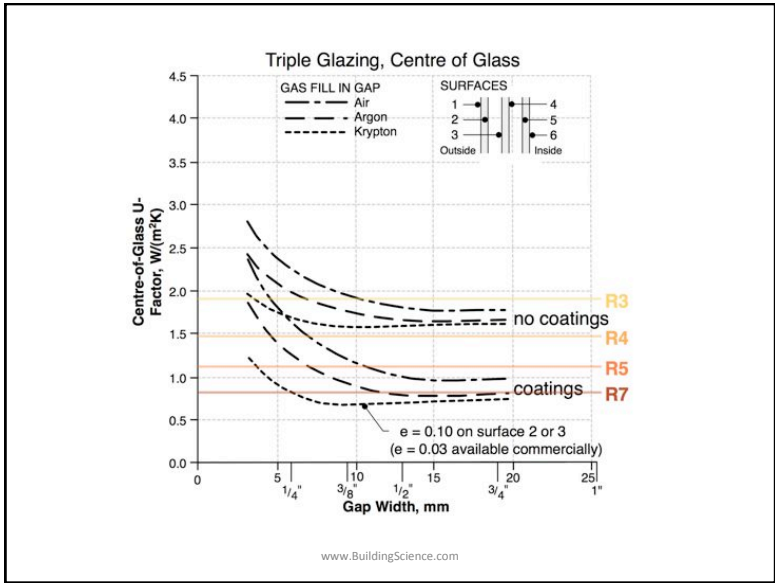
High Performance

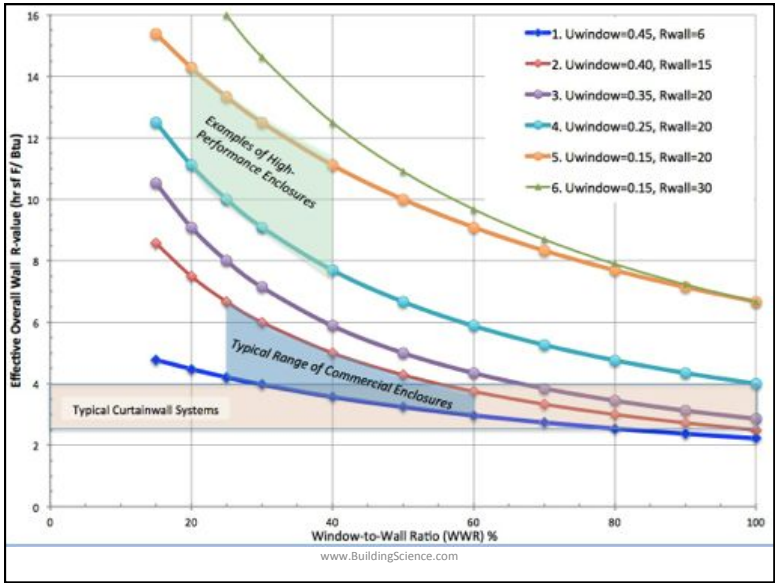
Getting better . .

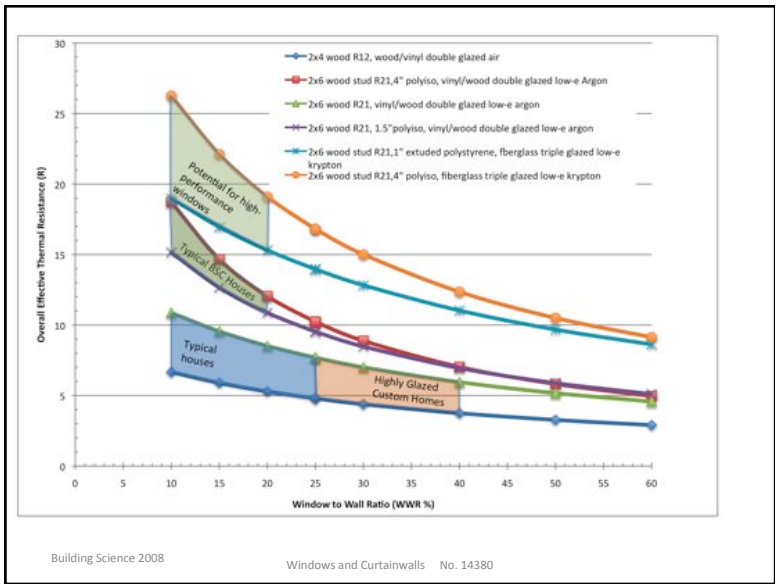


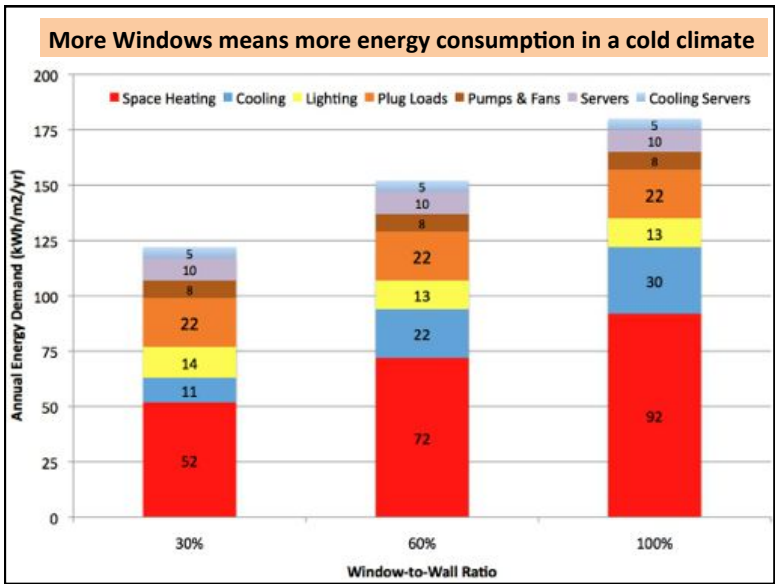





Triple Glazing, Centre of Glass
GAS FILL IN GAP
Air
Argon
Krypton
SURFACES
Outside
Inside
Centre-of-Glass U-Factor, W/(m²K)
Gap Width, mm
R3
R4
R5
R7
no coatings
coatings
e = 0.10 on surface 2 or 3
(e = 0.03 available commercially)
www.BuildingScience.com


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, fberglass 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. 14380


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

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