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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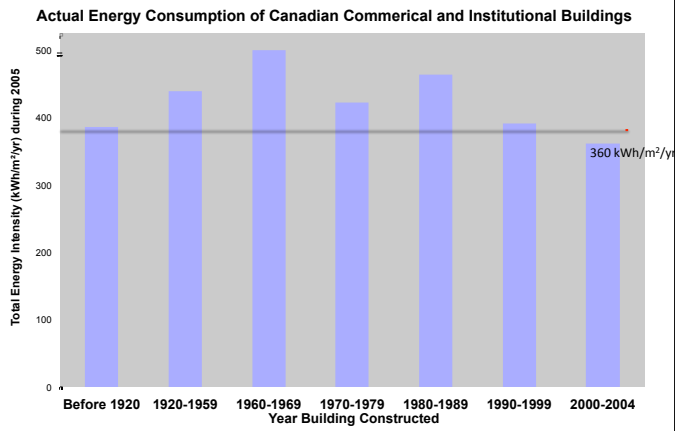

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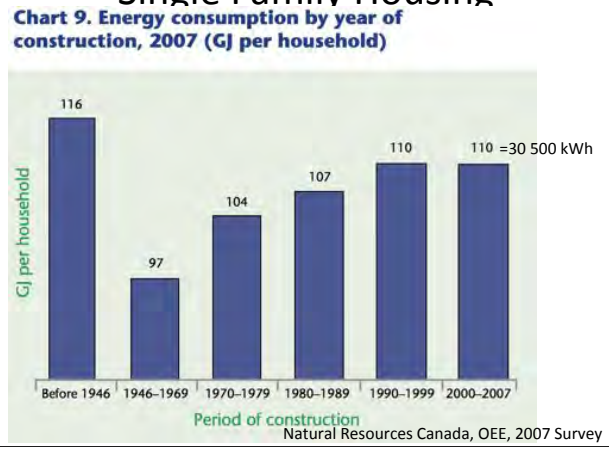
Single Family Housing



=30 500 kWh

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	2.038	**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	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

www.BuildingScience.com Buildings,Energy, Environment No. 7/84

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

11-05-20 8/175

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

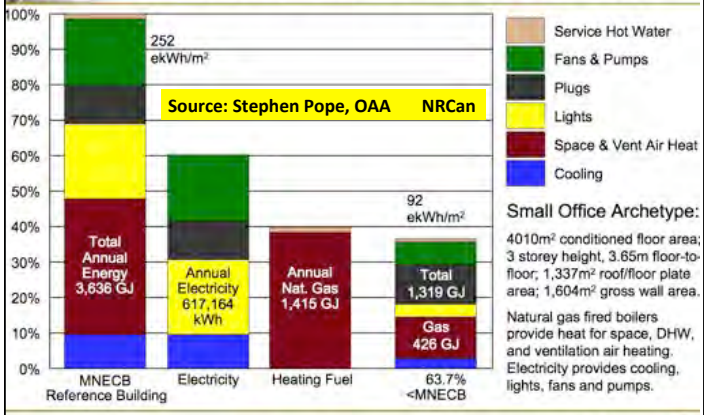
Insulation
Airtightness
Solar Control

Rain Control

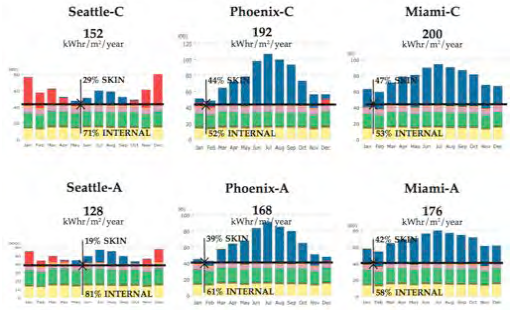
Off is very efficient

9/175 11-05-20

Toronto Small Office Archetype



Climate matters



- Beware architecture magazines

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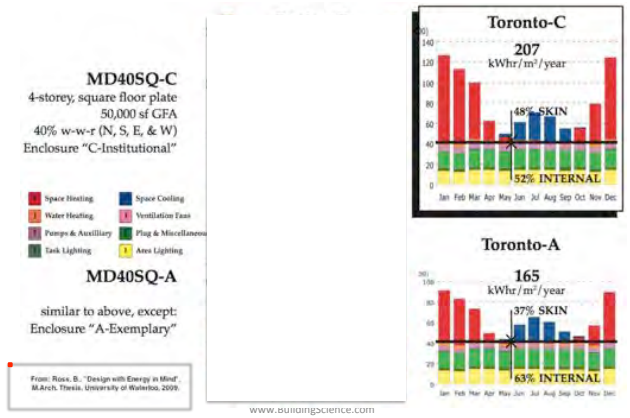
Typical market Building in Toronto 55% heat+cool

Other things use energy



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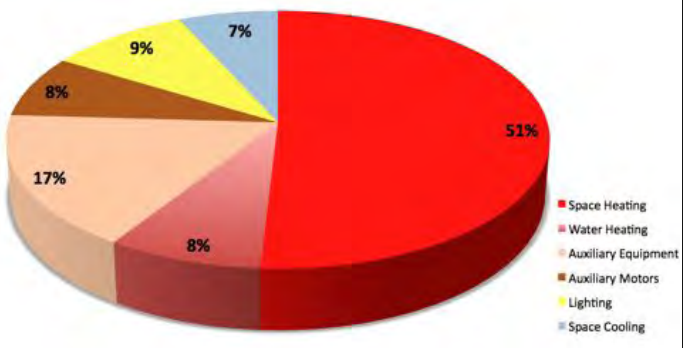
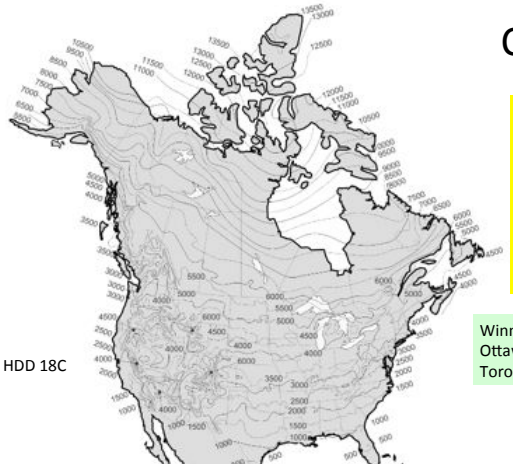
Canadian Offices 2007



207 million m²
Average 394 kWh/m²

Source: NRCan Office of Energy Efficiency

Canada:

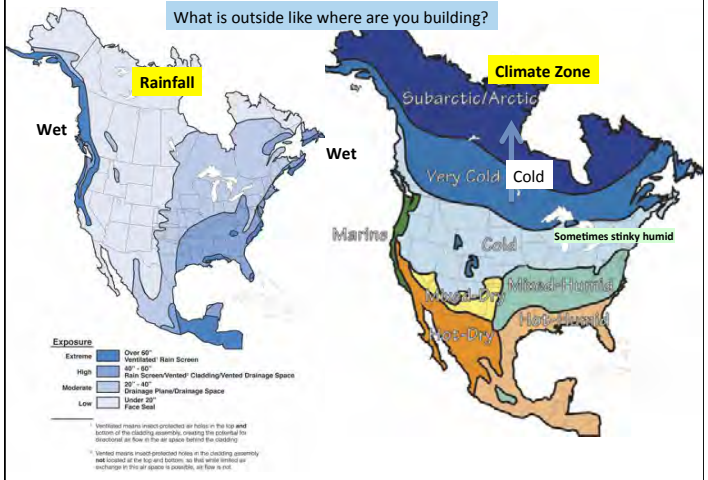


HDD 18C

Significant heating demand, especially Prairies and North

Winnipeg 5750
Ottawa 4600
Toronto 4000

What is outside like where are you building?

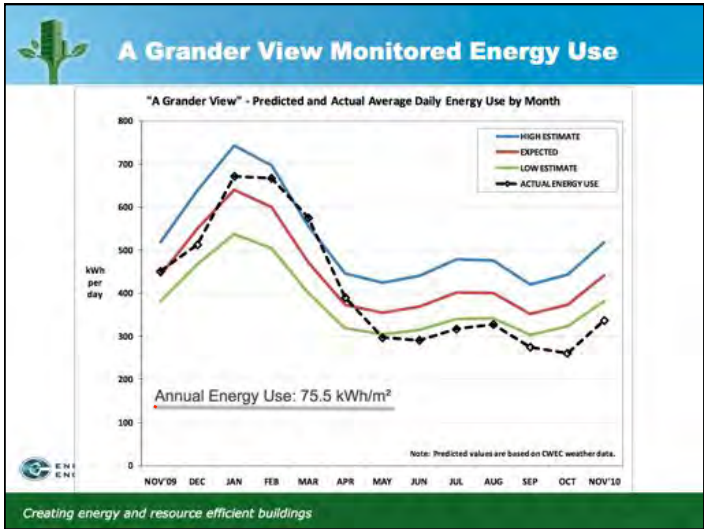


Can we do it?

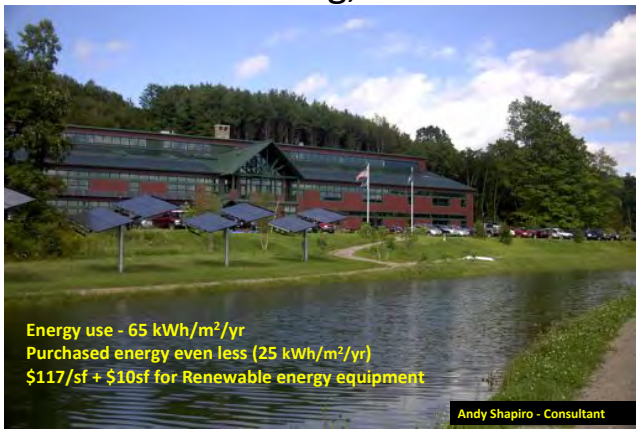
- Is it possible or practical to drop energy use by 60% in cold-climate Canada?
- Getting office to 200? 100? kWh/m²/yr?

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.)

Building Science 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

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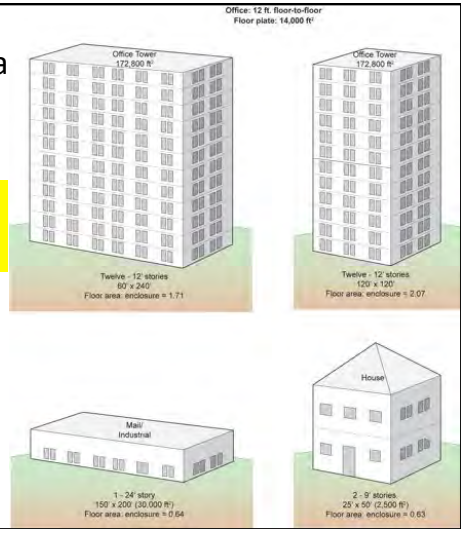
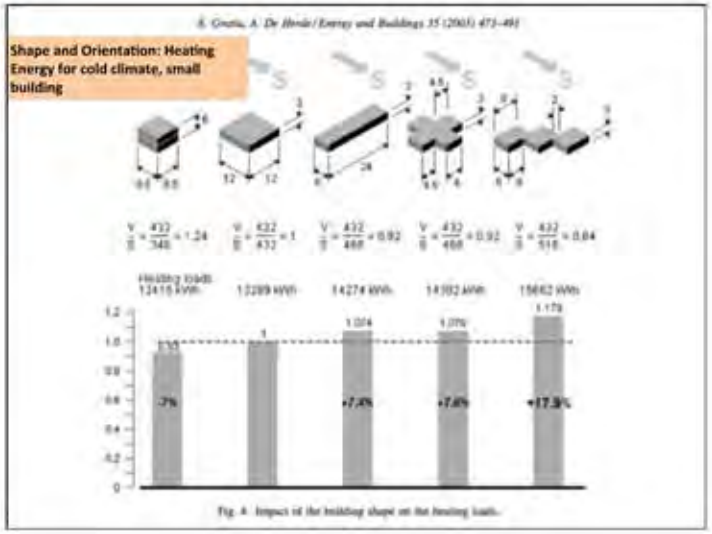
Size: Floor Area to Enclosure Area

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



Small, Compact Form

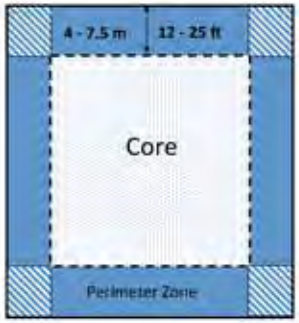
- Fewer resources
- Less heat loss and gain



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***

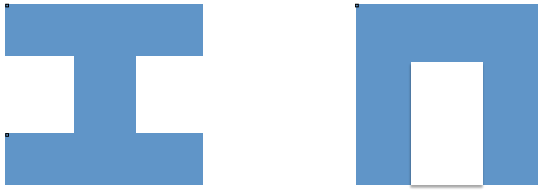
Building Shape

- Alphabet Soup
  - H I A B E

Daylight access, view
Cross Ventilation

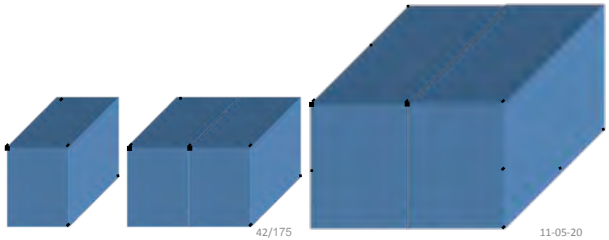
Expanded Plans

- 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



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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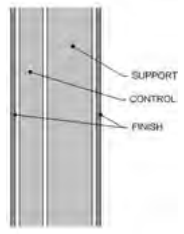
Basic Functions of the Enclosure

- 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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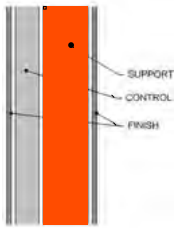
Basic Enclosure Functions

- **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

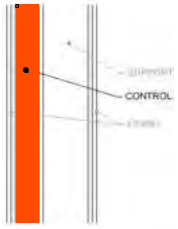
Functional Layers



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

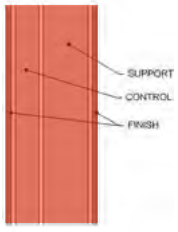
Functional Layers



Other Control . . .

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

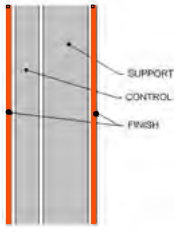
Functional Layers



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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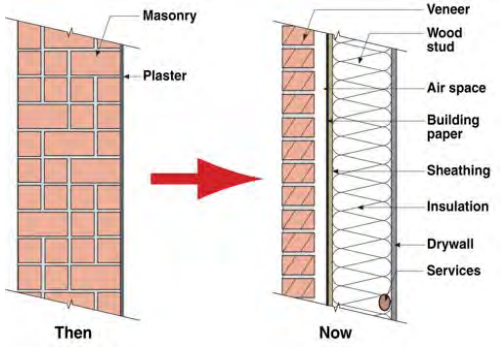
Changes



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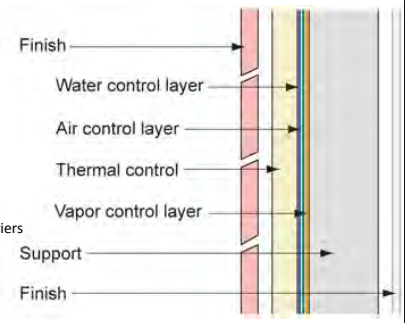
The "Perfect Wall"

- 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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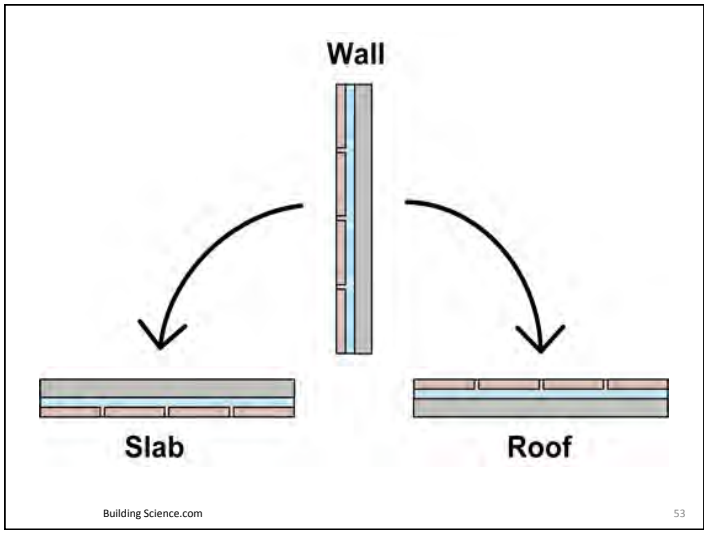
Wall
Slab
Roof
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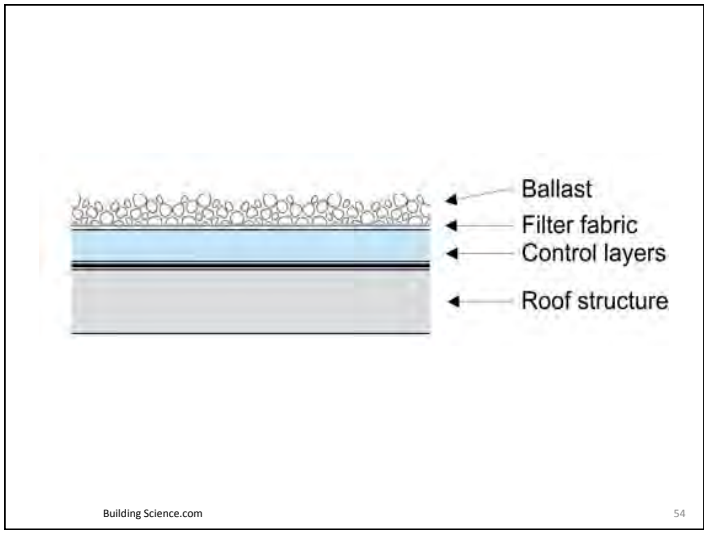
53


Ballast
Filter fabric
Control layers
Roof structure
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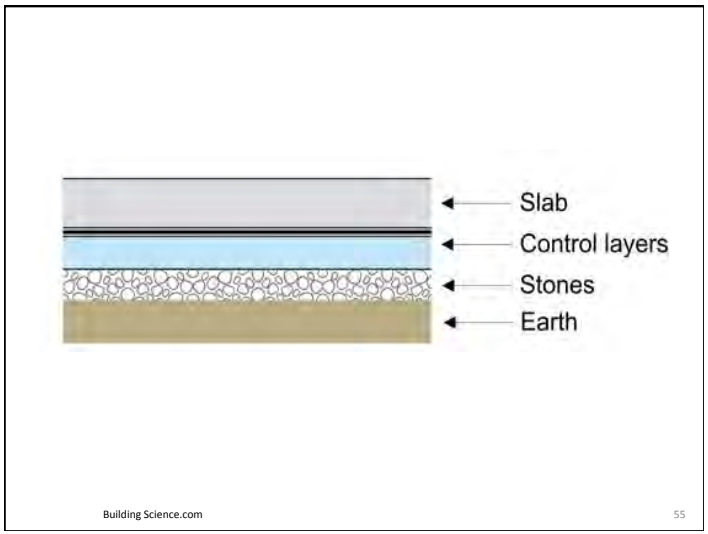
54


Slab
Control layers
Stones
Earth
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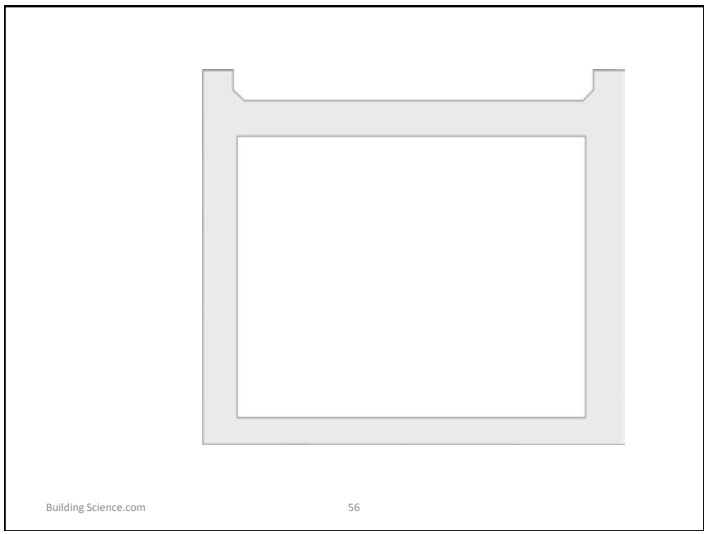
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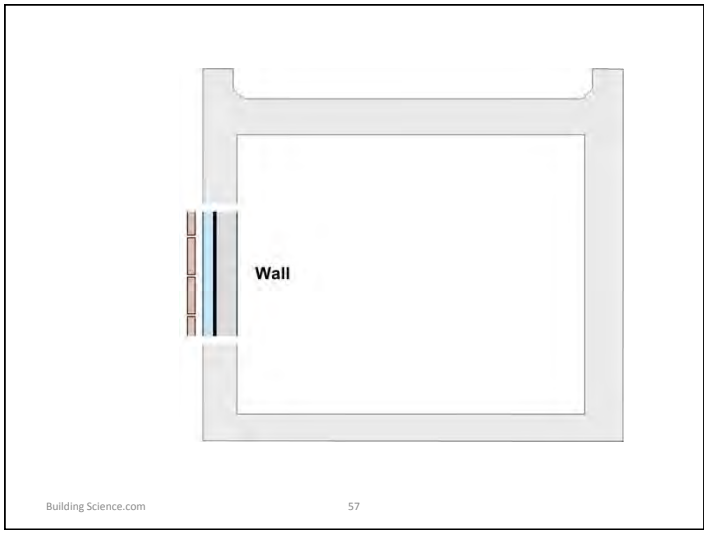
Wall
Building Science.com
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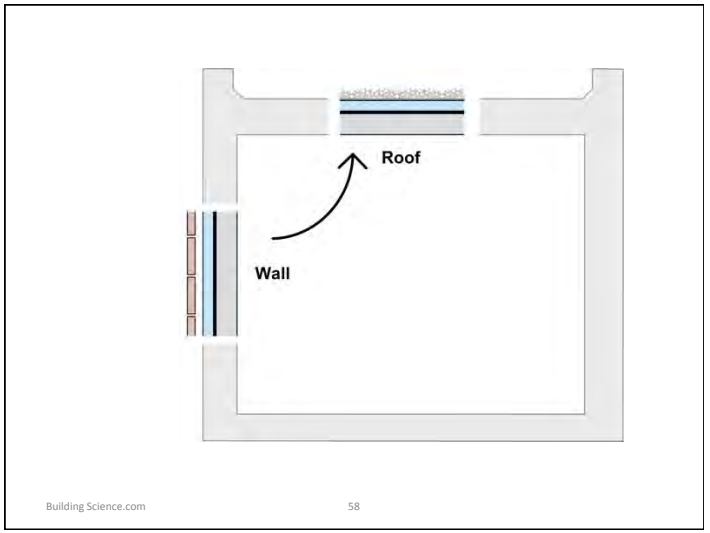
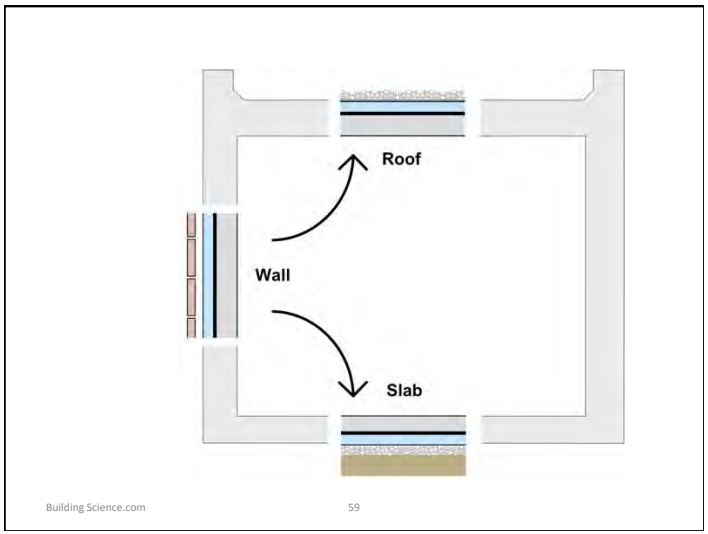

Roof
Wall
Building Science.com
58


Roof
Wall
Slab
Building Science.com
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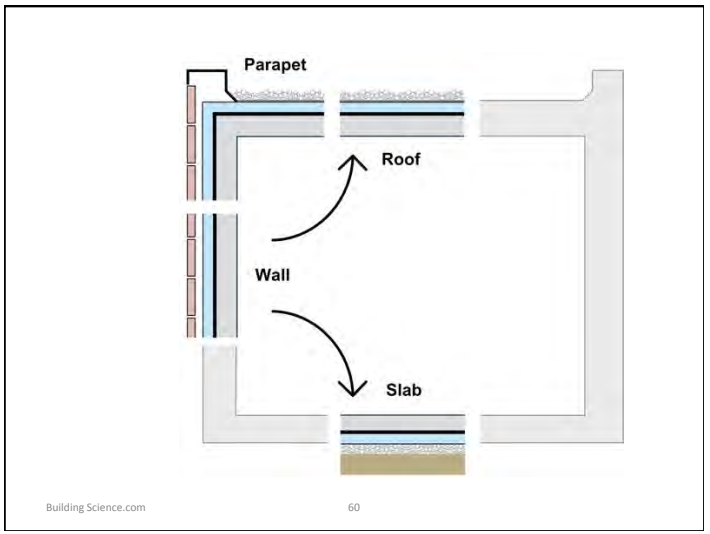
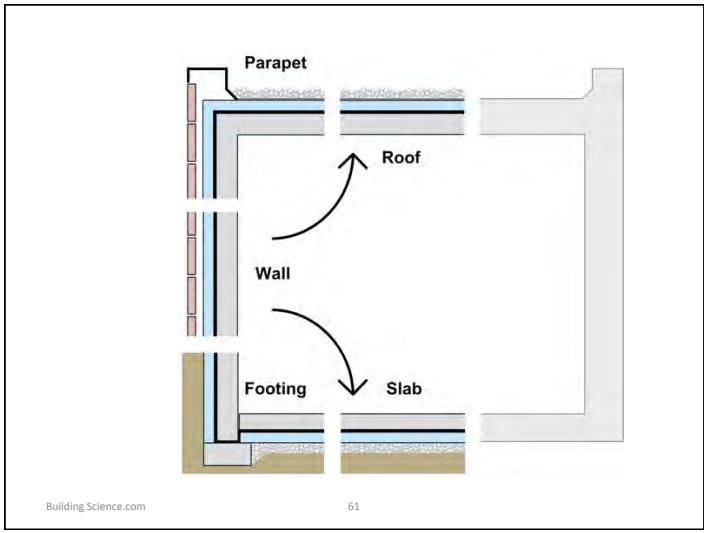

Parapet
Roof
Wall
Slab
Building Science.com
60


Parapet
Roof
Wall
Footing
Slab
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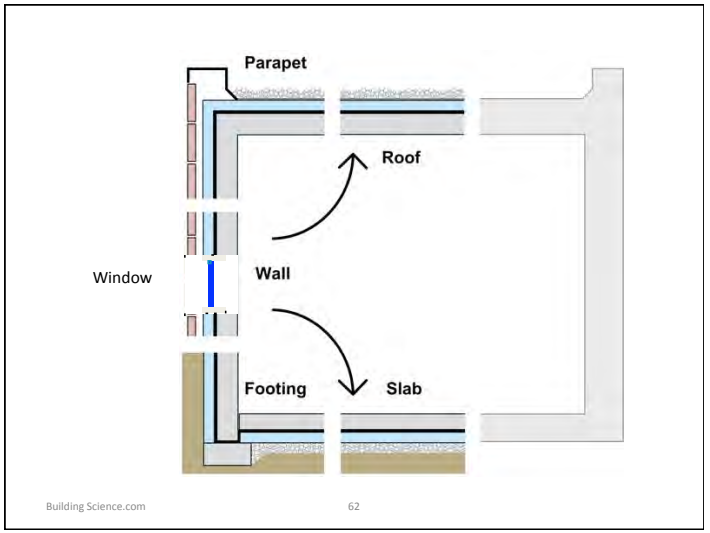
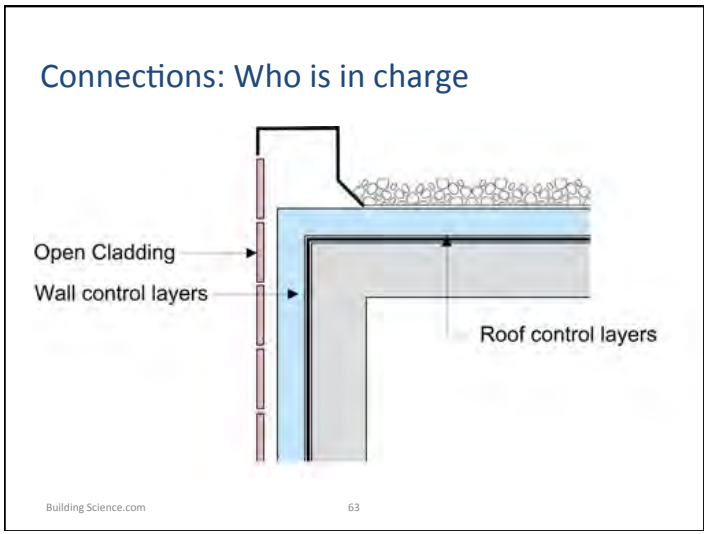
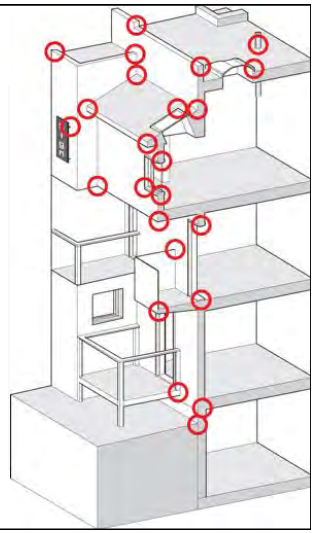

Parapet
Roof
Window
Wall
Footing
Slab
Building Science.com
62


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
Building Science.com
Enclosures No. 64 /

Enclosure Design: Details

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



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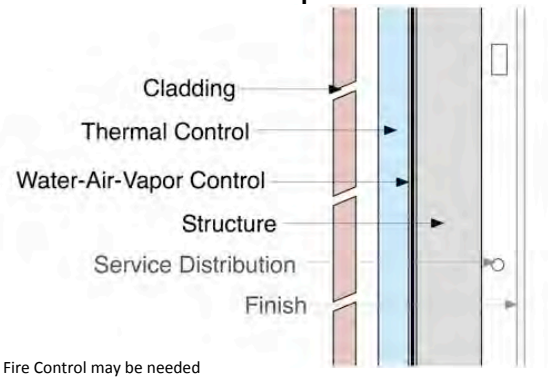
Perfect Wall expanded



Additional Fire Control may be needed
Sound Control optional

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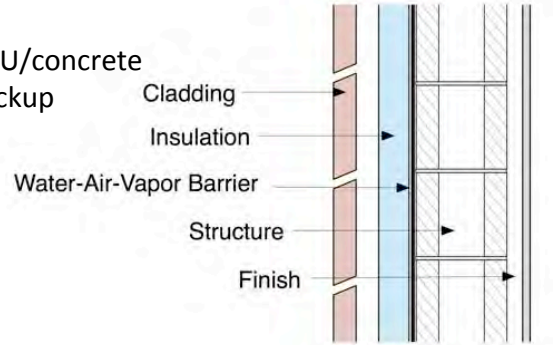
Perfect Wall

- CMU/concrete backup



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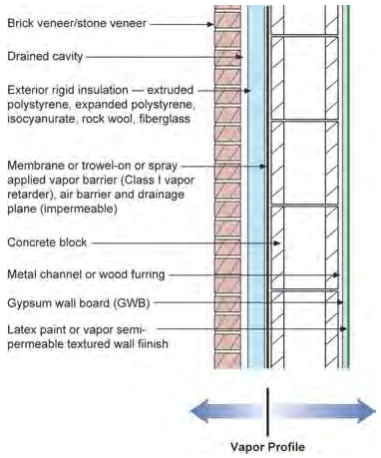
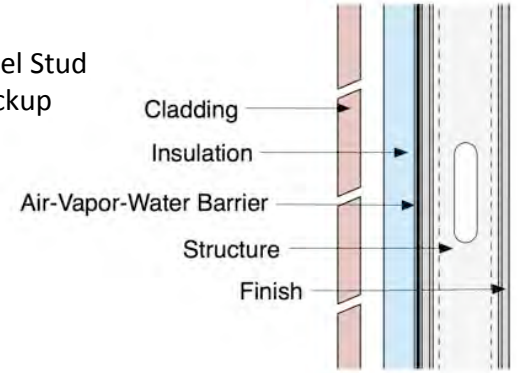
Any R-value, e.g.
4" PIC=R25
5"XPS =R25
6"MFI=R25



Perfect Wall

- Steel Stud Backup



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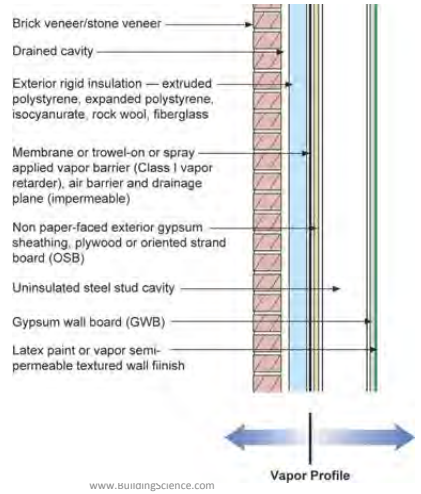
Any R-value, e.g.
4" PIC=R25
5"XPS =R25
6"MFI=R25



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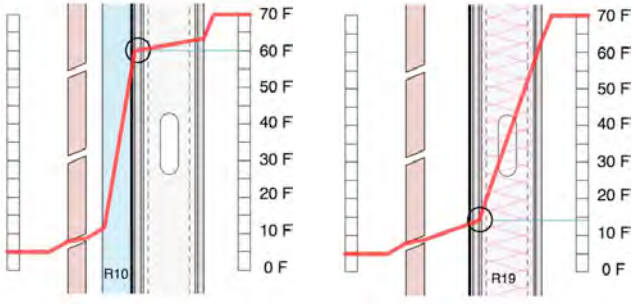
Condensation & Drying



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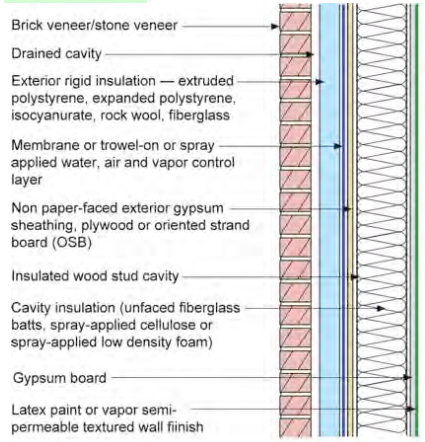
Ratio: $\frac{\text{Exterior R-value}}{\text{Studbay R-value}}$ controls risk of condensation

Compromise



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

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

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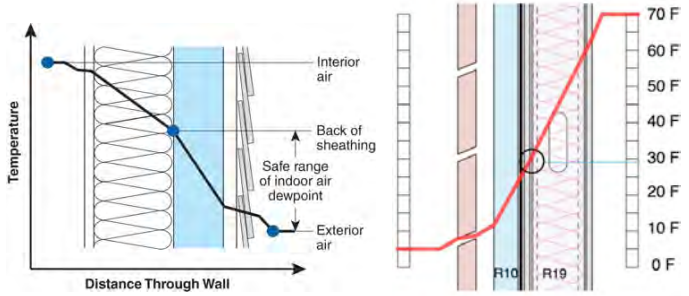
Compromise= Risks



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

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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= need for better control!

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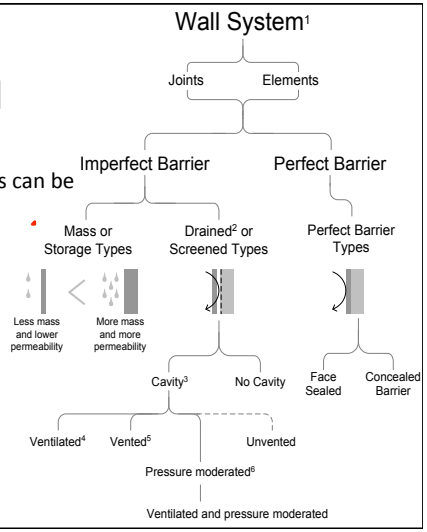
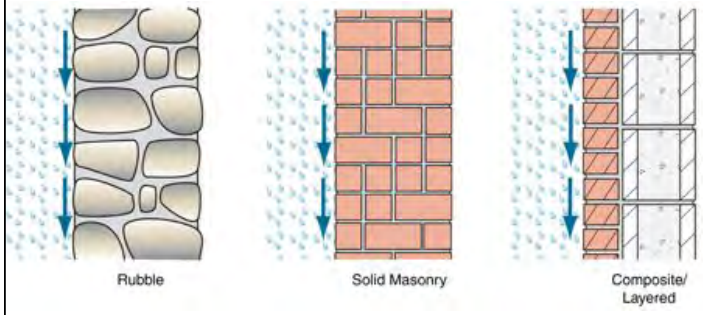
Rain Control

- Elements and joints can be different



Mass/Storage/Reservoir Walls



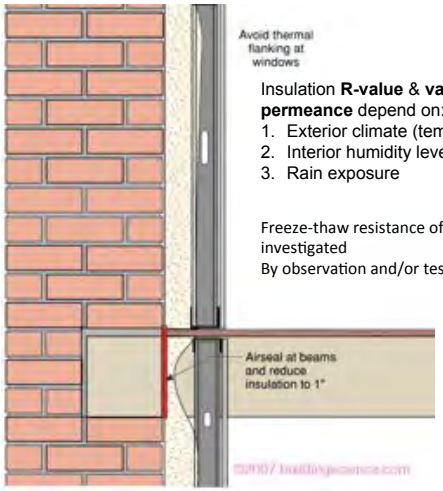
John Straube

No building paper, flashing, weepholes

Rain Control 79

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

Rain Control 80

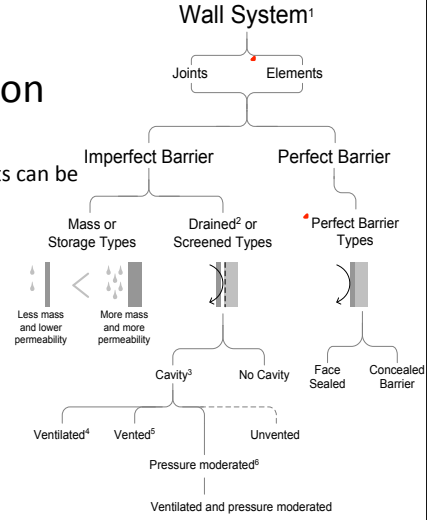


Insulation **R-value** & **vapor permeance** depend on:
1. Exterior climate (temp / drying)
2. Interior humidity levels
3. Rain exposure

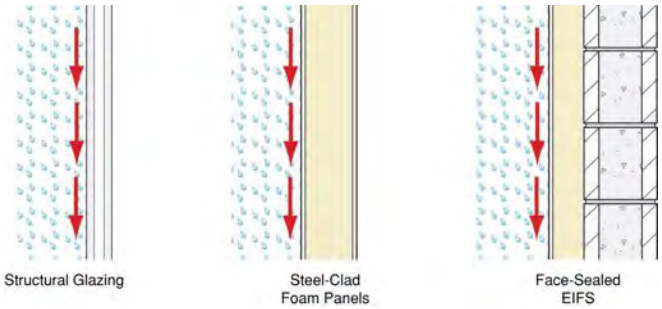
Freeze-thaw resistance of brick should be investigated
By observation and/or testing

Categorization

- Elements and joints can be different



Perfect Barrier / Face Sealed



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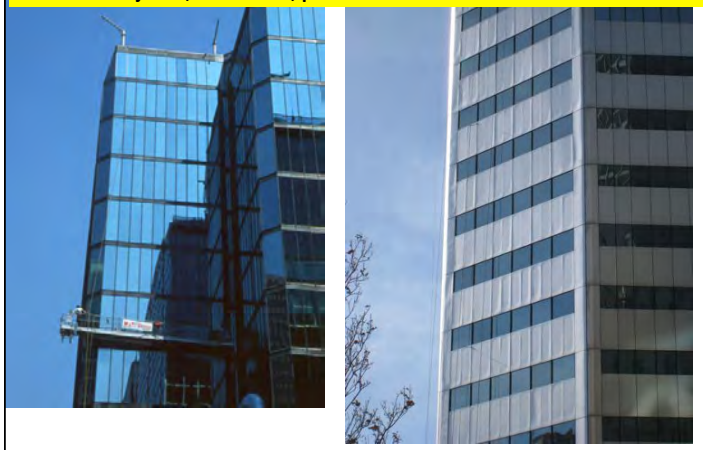
It is all about joints, transitions, penetrations



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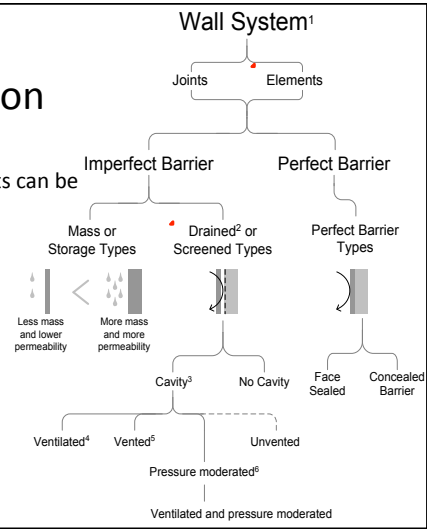
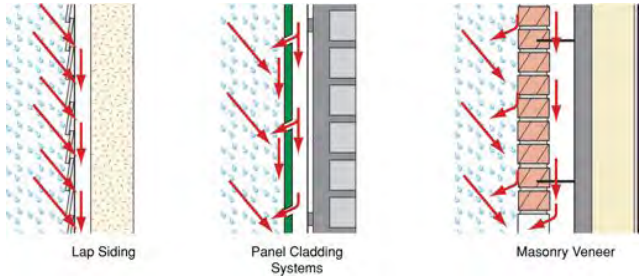
Categorization

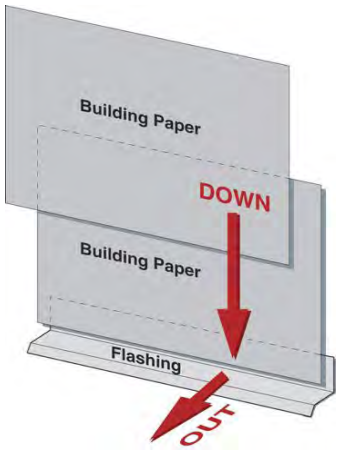
- Elements and joints can be different



Drained Walls

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





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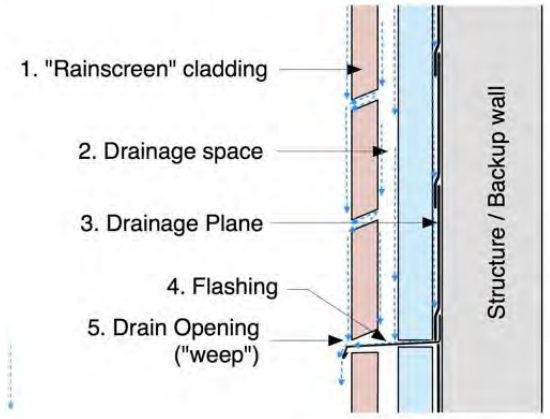
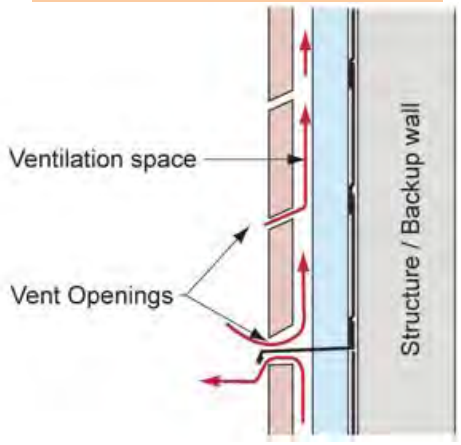
87

Requirements for a Drained Enclosure



Requirements for a Ventilated Enclosure



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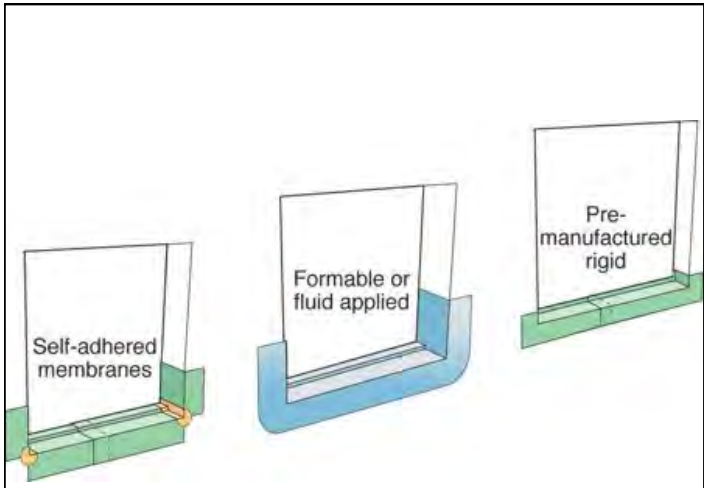

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Air-Water-Vapor

- 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

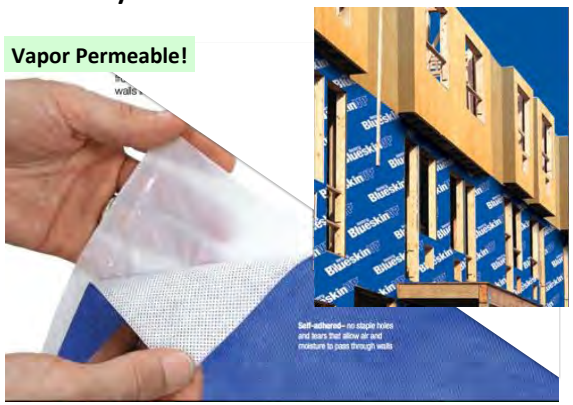
Details

- Air & water & vapor transition membranes

Non-adhered, vapor permeable =modest performance

Supported **flexible membrane is better**

Fully-adhered air-water barrier



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Mixed membrane + fluid-applied

Often use membranes for transitions

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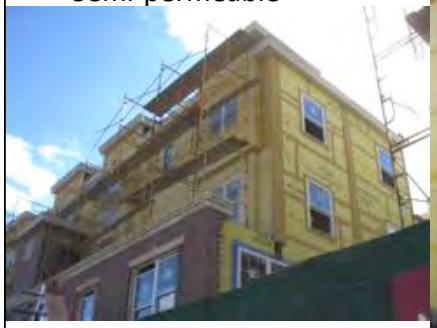
Spray/Trowel Applied Air/water

- 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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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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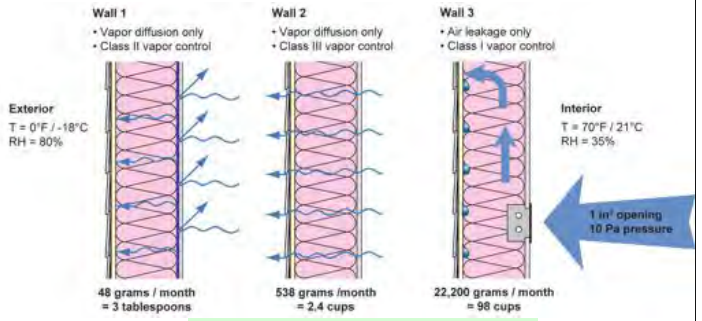
Air moves more vapor than diffusion!



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

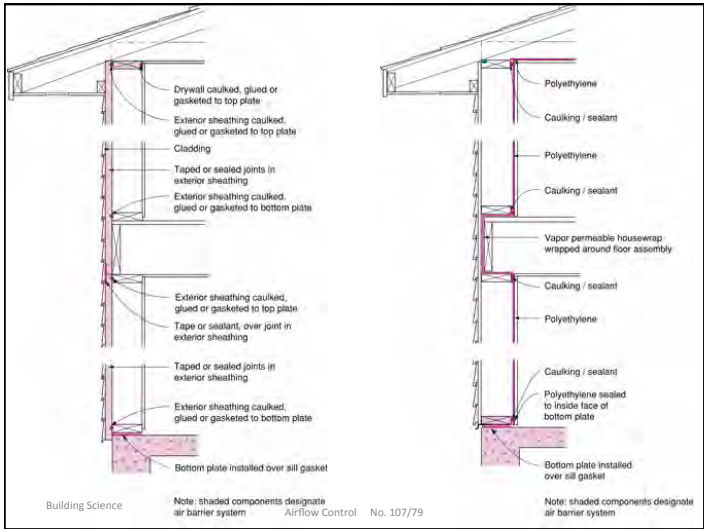
- Hard to save energy with the door open
- Buildings getting tighter, but . . .
  - Many still leak way too much
  - We can't identify the leakers
  - Need to test! Commission!
- Ventilation: Many try to improve air quality by increasing quantity
  - Target good air when and where needed

105/175 11-05-20

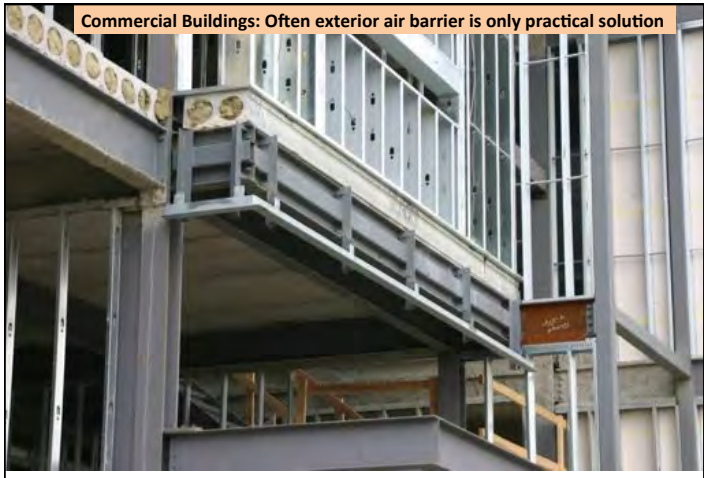
Air Barriers and Energy

- 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

106/175 11-05-20



Building Science Airflow Control No. 107/79



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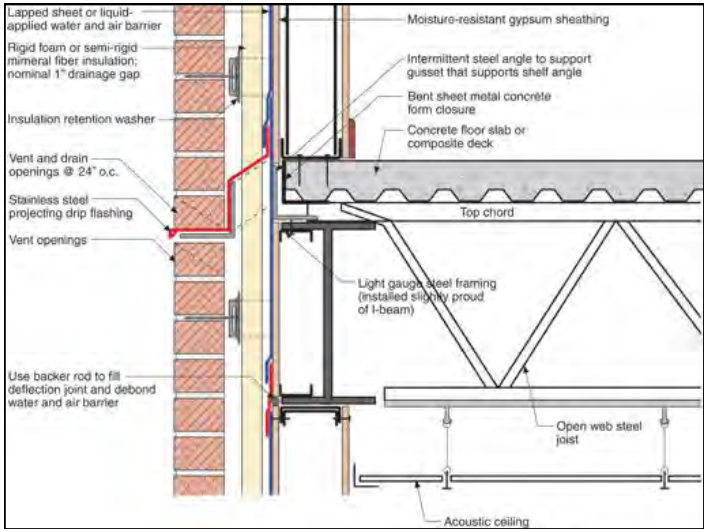
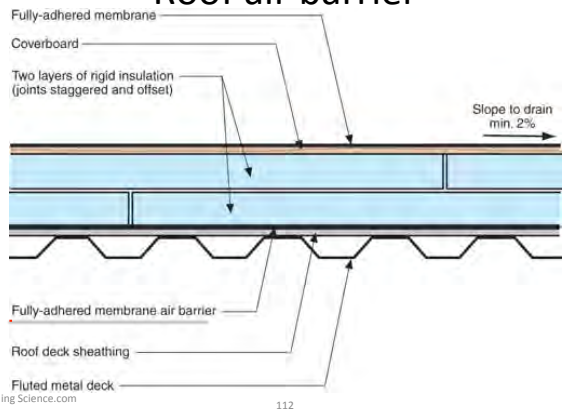
Poly combines air *and* vapour control
-Must be sealed and supported to be air barrier
-Cover most area and you have vapor control

Rigid Exterior Air Barrier

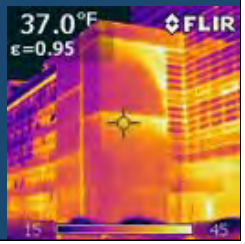


Deck level vapor control membrane rarely required if closed cell foam used

Roof air barrier



Thermal Control



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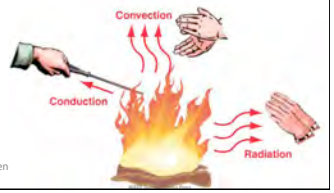
Thermal Control

- 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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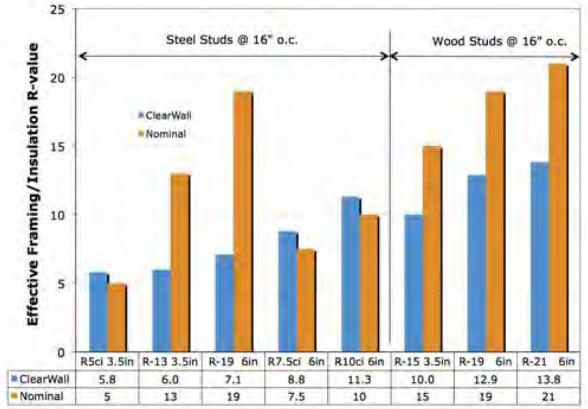
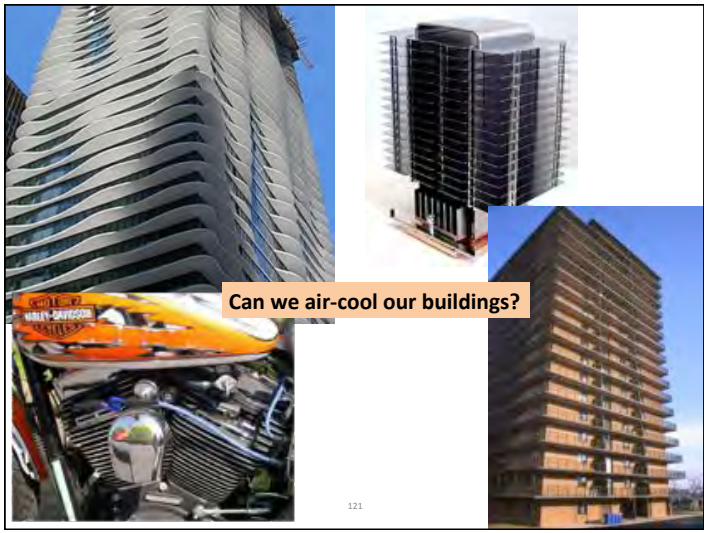
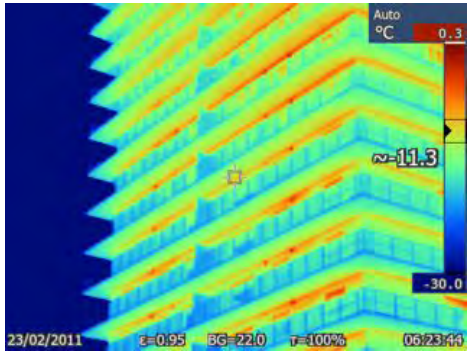
Best-case R-values for stud walls



	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

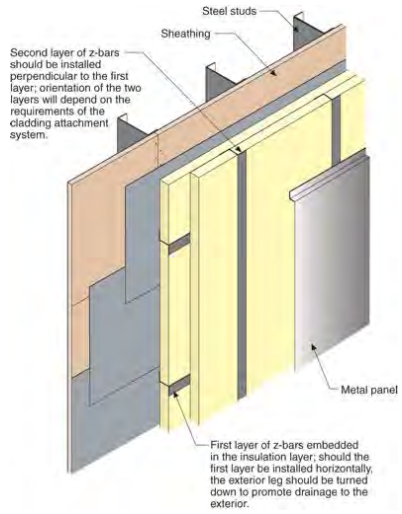
Source: ASHRAE 90.1-2007, Table A9.2B. ci denotes a layer of continous insulation with no framing penetrations

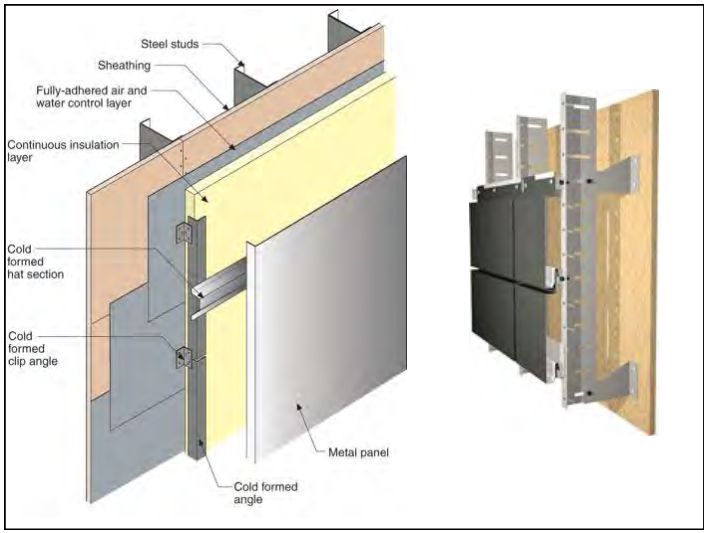


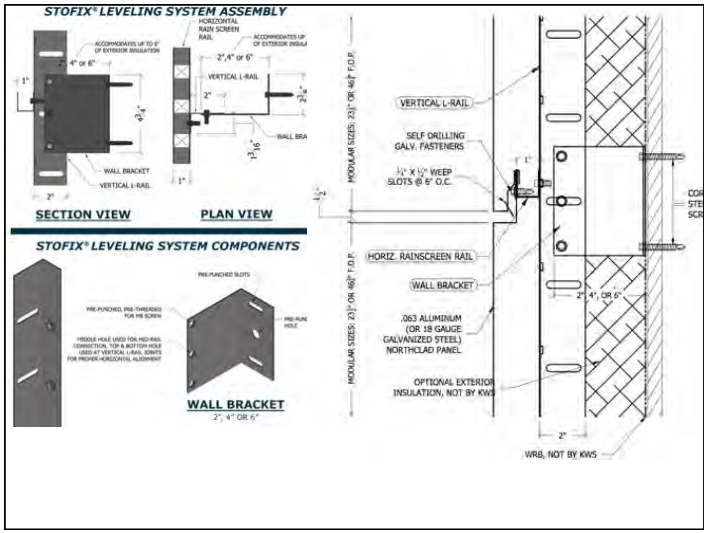


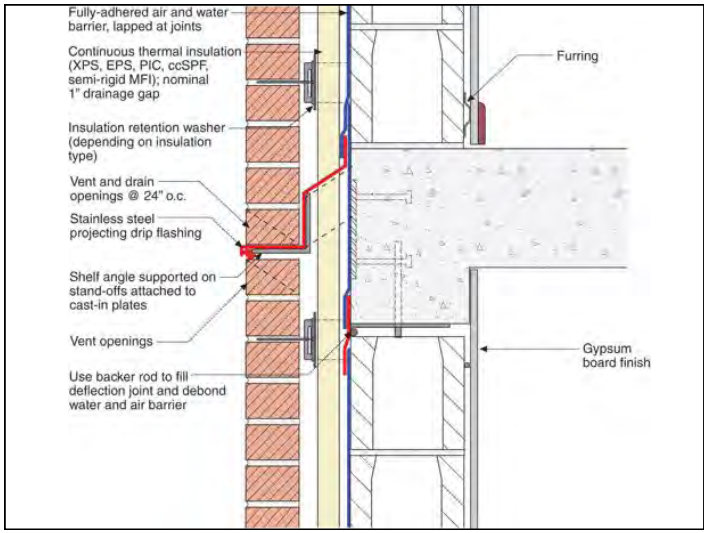
Thermal Bridge Examples

- Balconies, etc
- Exposed slab edges




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



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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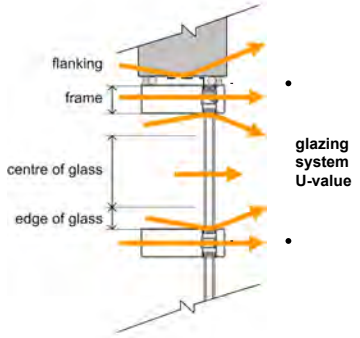
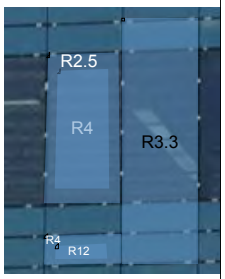
Total Heat Flow

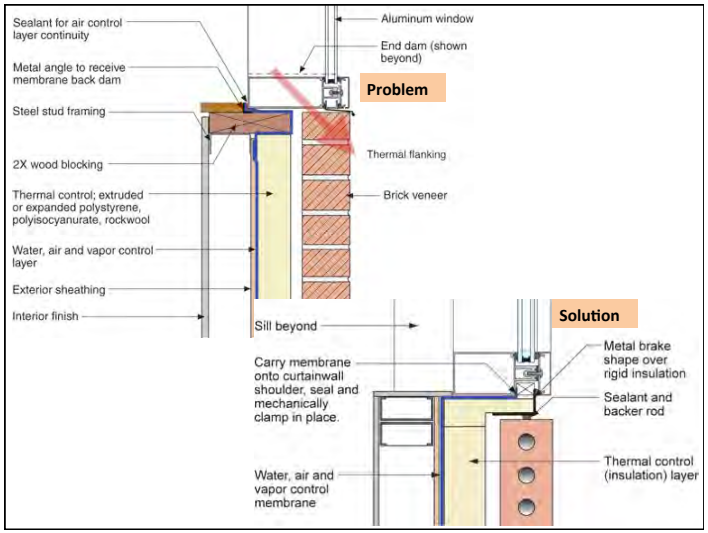
Curtain Wall Plan View



- glazing system U-value
-

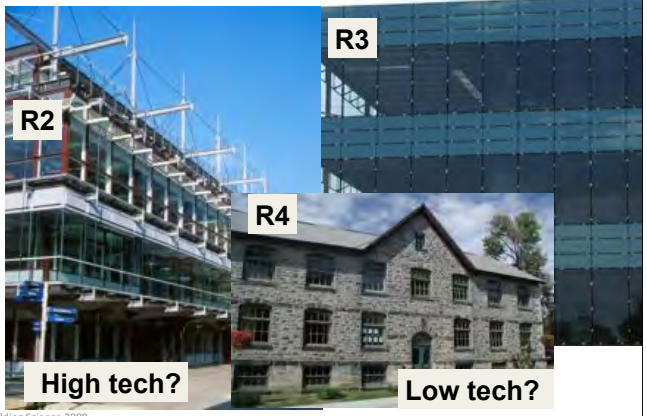


Building Science 2008 Windows and Curtainwalls No. 13380



Building Science Windows and Curtain

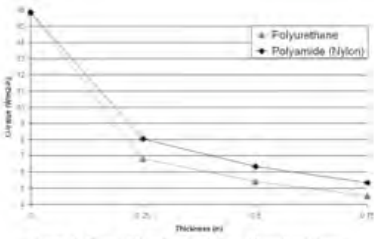
Full-Frame R-values



Building Science 2008 Windows and Curtainwalls No. 13680

Thermal Break

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



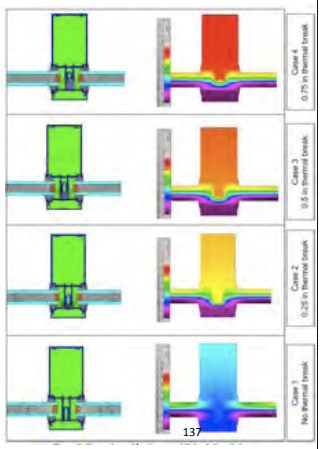
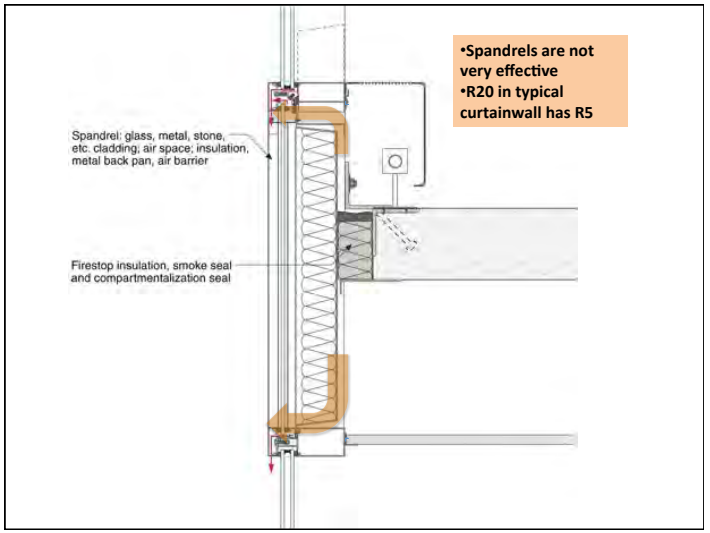


Figure 4: Frame U-Value vs. thermal break thickness.

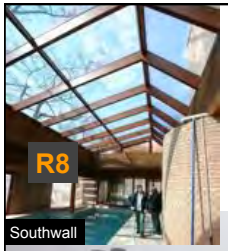
137

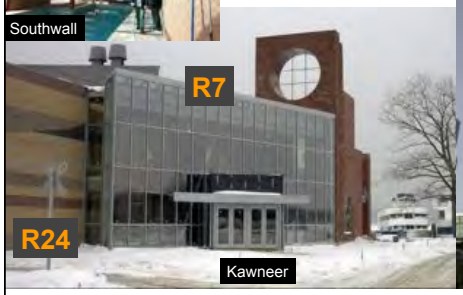
137



High Performance

Getting better . .





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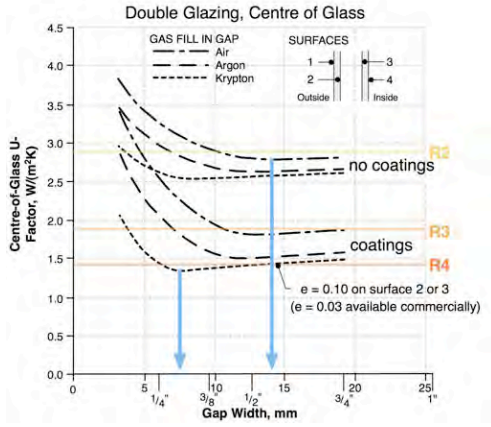

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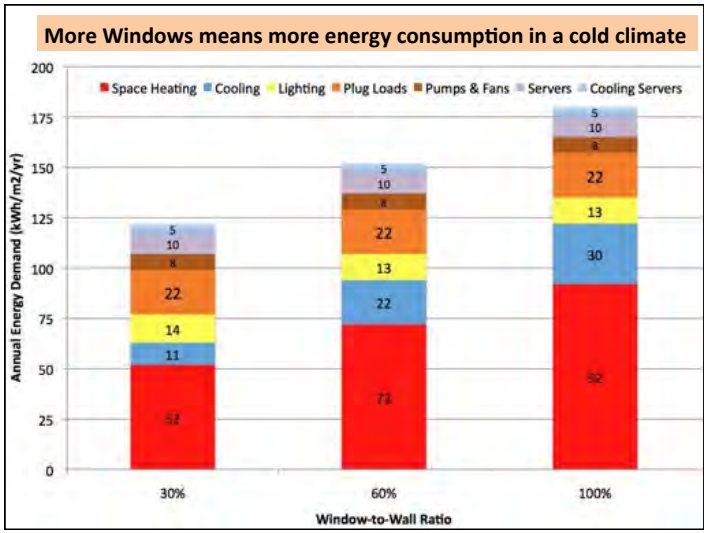
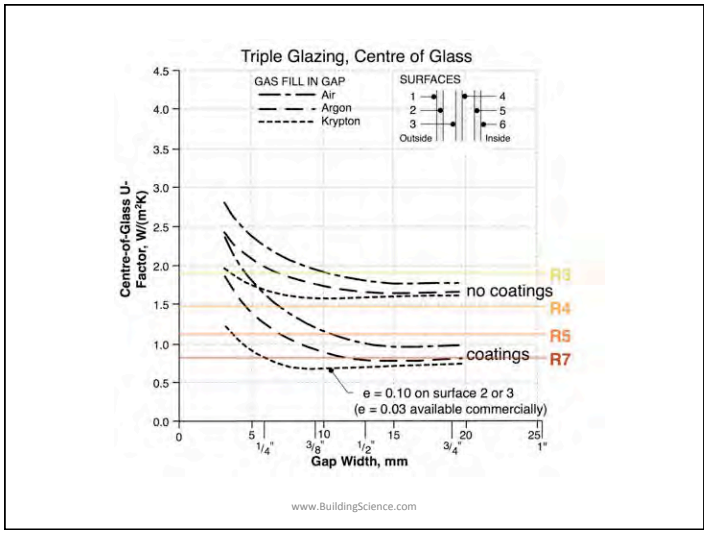
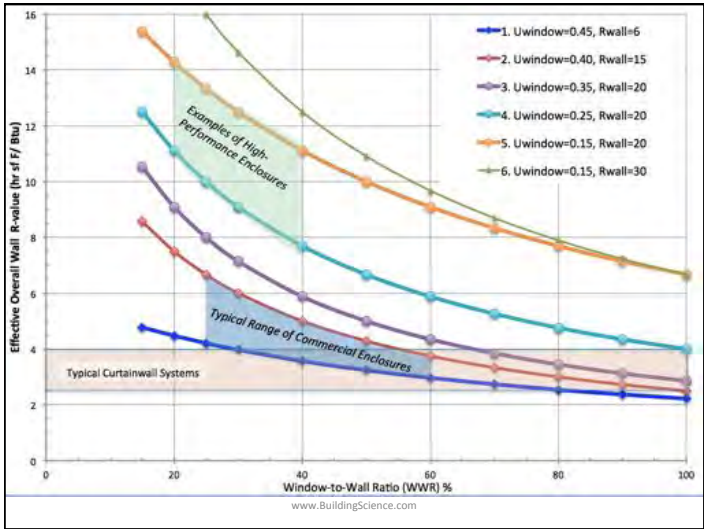
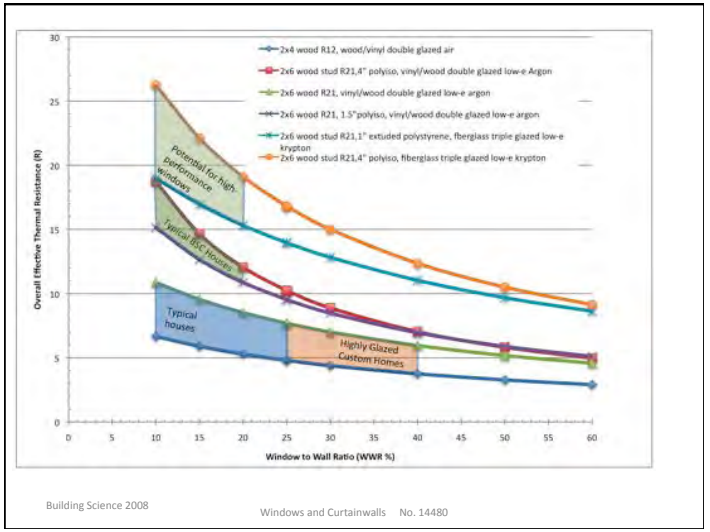

More Windows means more energy consumption in a cold climate
Space Heating
Cooling
Lighting
Plug Loads
Pumps & Fans
Servers
Cooling Servers
Annual Energy Demand (kWh/m2/yr)
Window-to-Wall Ratio
30%
60%
100%


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


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. 14480

	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

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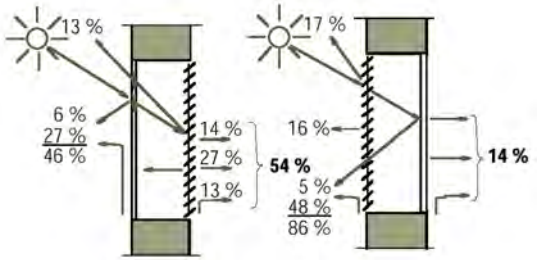
Interior or Exterior Shade

- 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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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

11-05-20 155

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

11-05-20 157

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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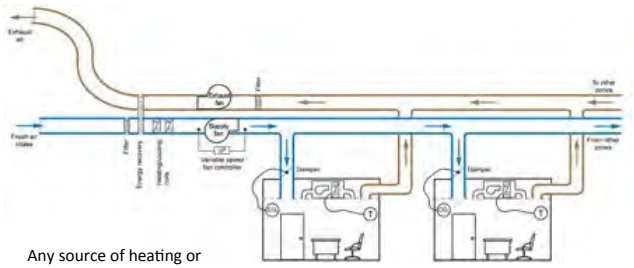
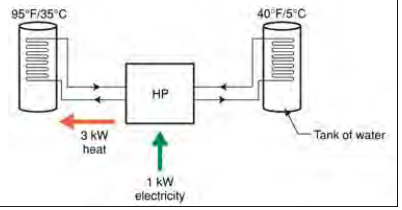
BSI-022 Perfect HVAC



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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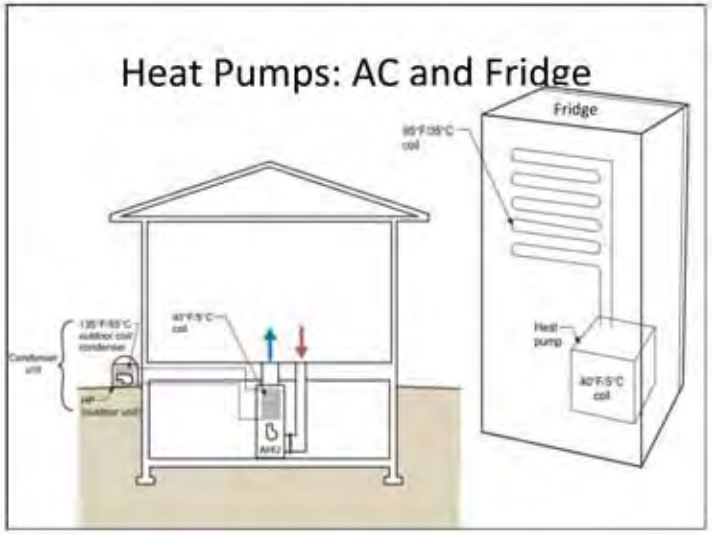
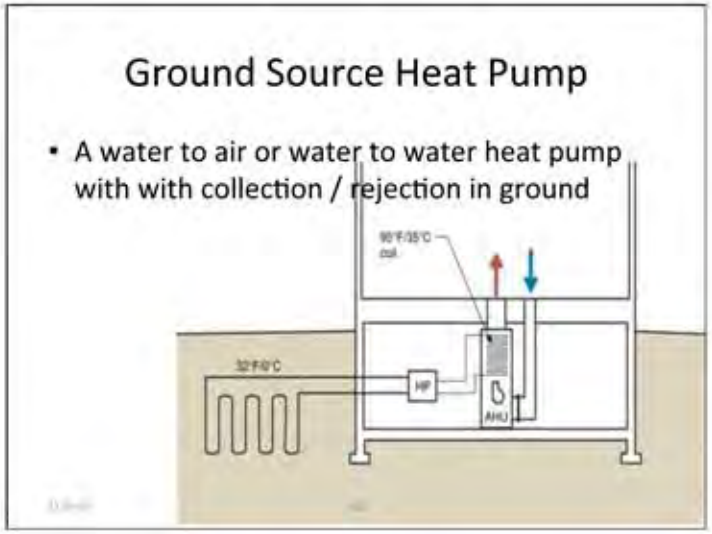
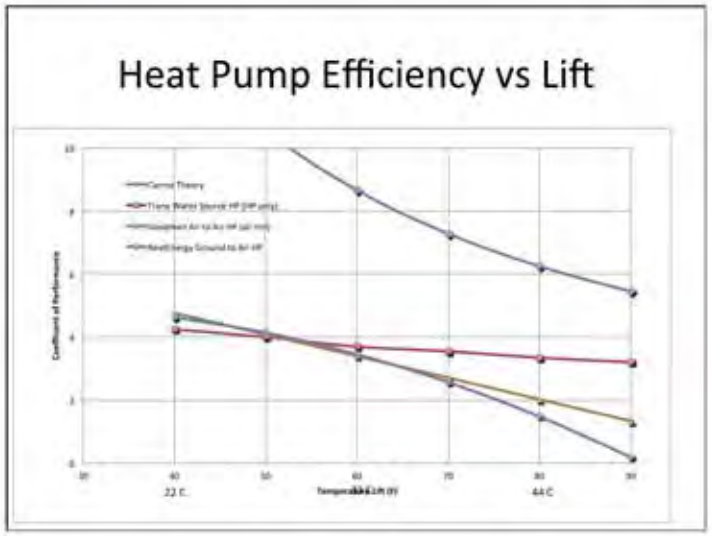

Heat Pumps: AC and Fridge
Fridge
Heat pump
AHU

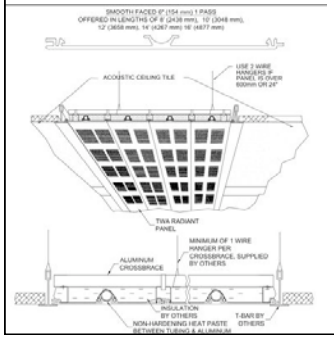

Ground Source Heat Pump
• A water to air or water to water heat pump with with collection / rejection in ground
HP
AHU

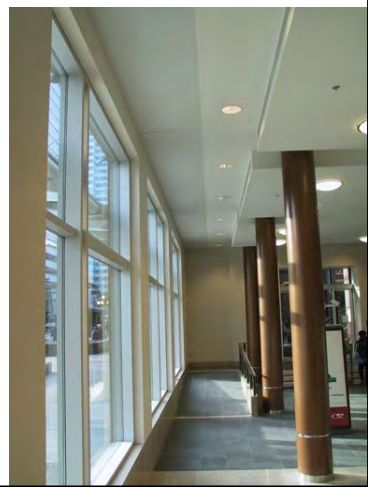

Heat Pump Efficiency vs Lift
22 C
44 C


Radiant Floors

Radiant Panels

- Smaller area → higher deltaT
- About 50/50 radiant/convective
- Peak heating 150 W/m^2 (50 Btu/ft^2)
- Peak cooling 100 W/m^2 (33 Btu/ft^2)





Terminal Unit: Fan coils

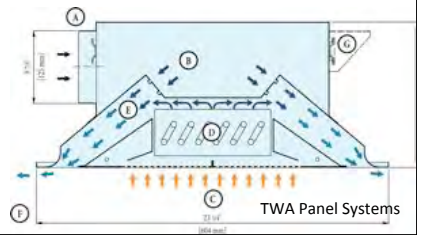
- Use fans to below room air over coils
  - Fan-driven air movement = distribution / mixing within a space
  - Noise, maintenance issues
- Fans require electricity
  - Many existing FC are inefficient and noisy
  - **Very efficient fan motors** now available

166

167

Chilled Beams

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



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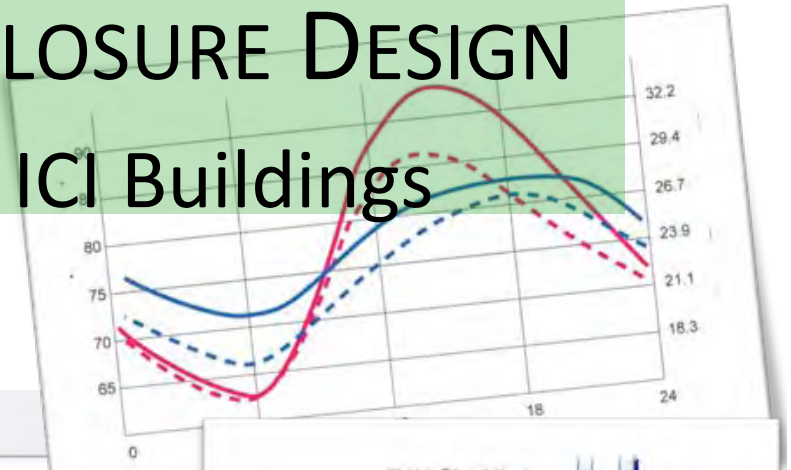
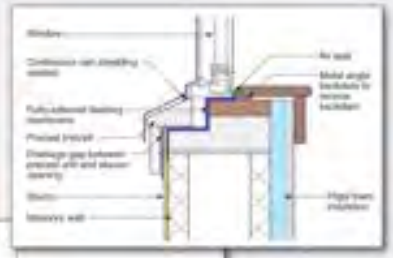
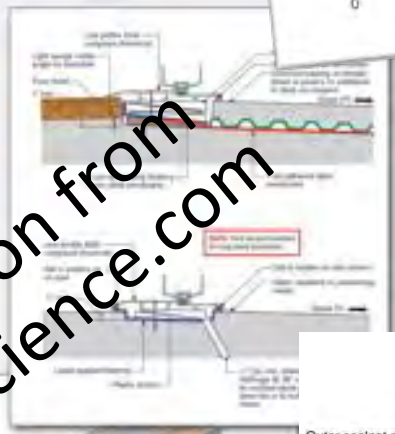
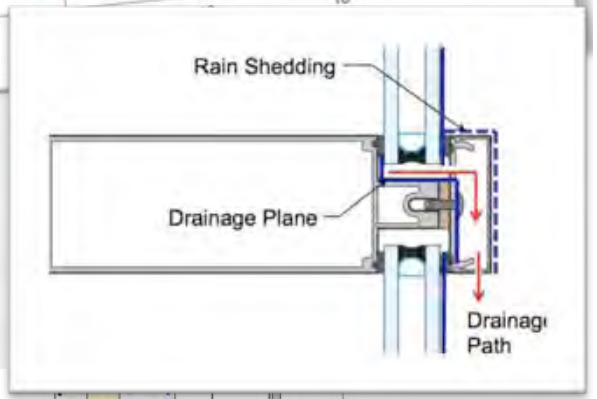
High-Performance Enclosure Design Guide for cold-climate ICI Buildings

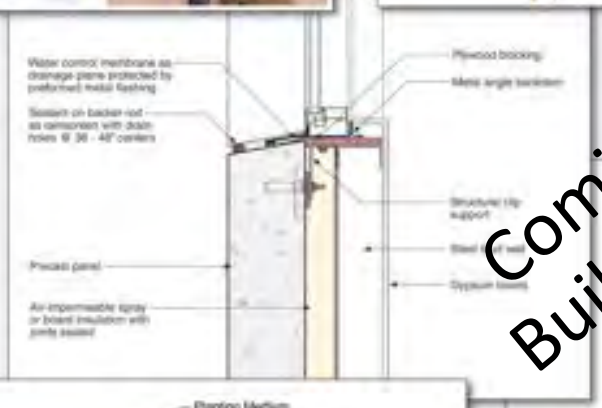
Over 100 detailed drawings

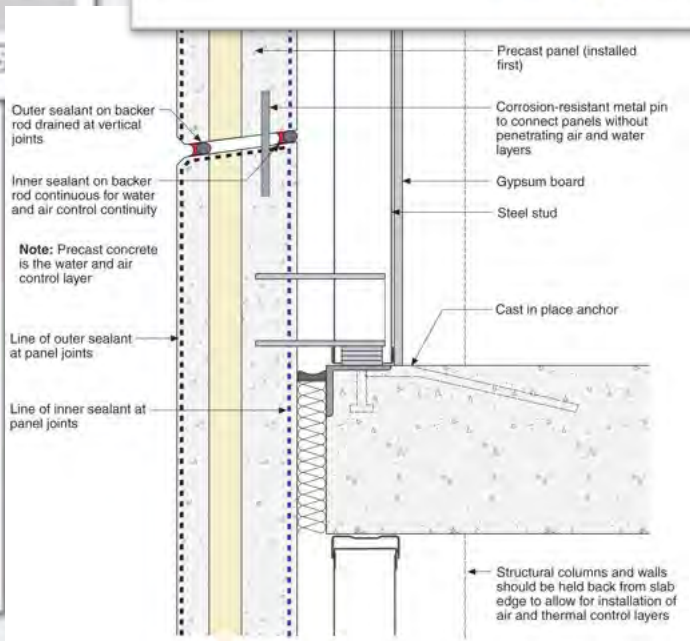


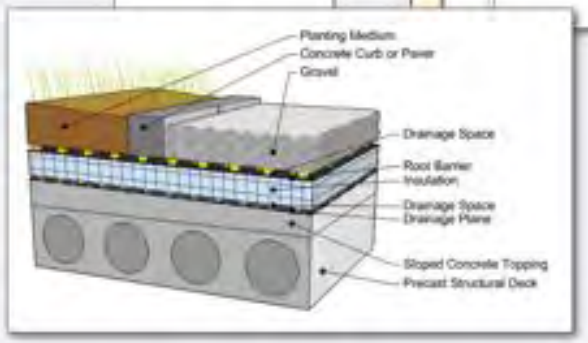


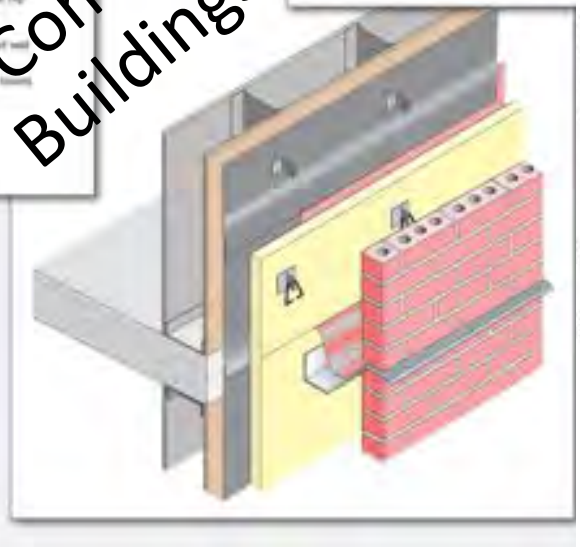












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