Aim High: High-performance buildings of the future

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Changes …

- Expectations are rising
  - Lower operating costs
  - less energy consumption (same cost?)
  - more comfort
  - Better IAQ
- In short …

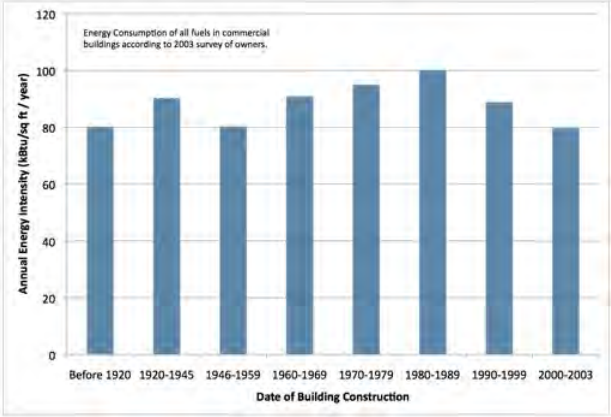
  better buildings at less total cost

Measuring Performance

- Performance metrics
  - Beauty
  - Awards
  - On-time
  - Utility
  - On budget
  - Green, LEED
  - Healthy
  - Productive
  - Operating costs
  - Operational energy use

How do we measure these?

How have we been doing?



R2

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R2

R4

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R2
R4
R6
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R2
R4
R6
R8
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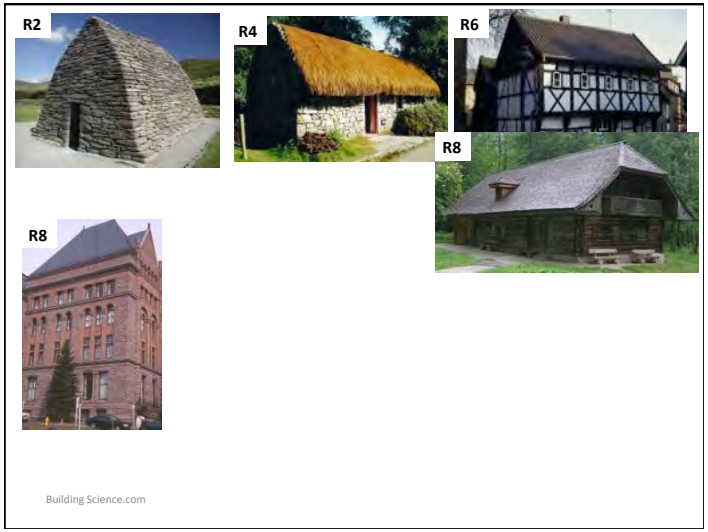
R2
R4
R6
R8
R8
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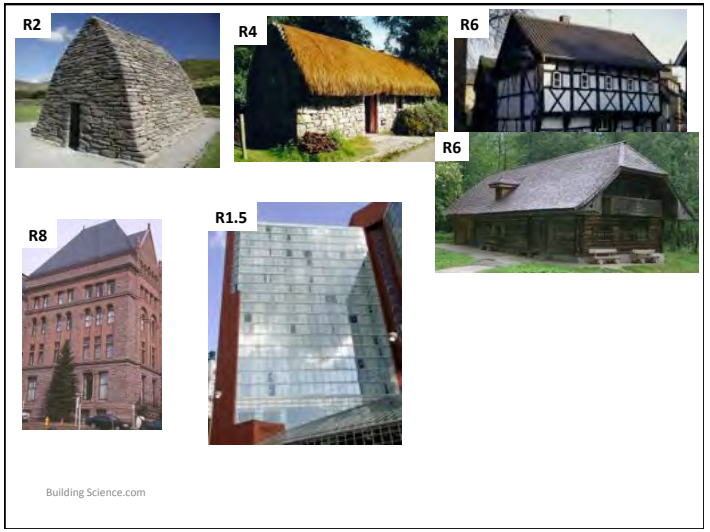
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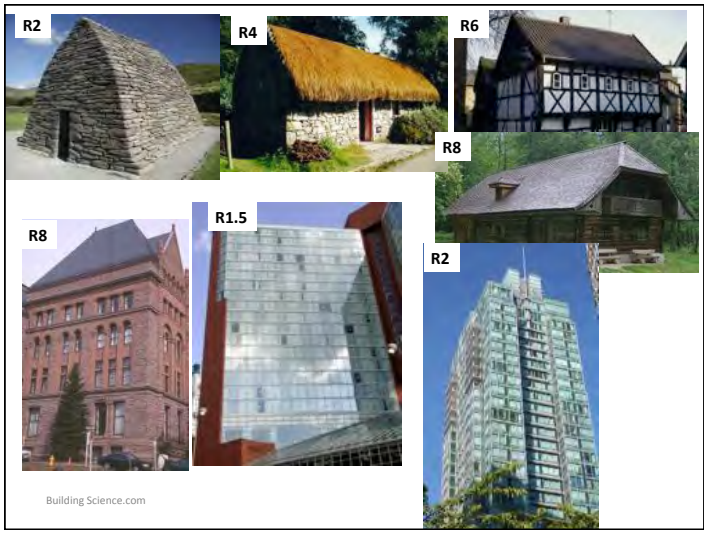

Enclosures in Context

- Enclosures **reduce** space heating/cooling
  - and help with lighting, ventilation
- We still need **energy** for other things
  - Lights, appliances, computers, elevators, etc
- But
  - **Bad enclosures ruin good HVAC**
  - **Bad HVAC can ruin good enclosures**

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Unintended consequences

- Better insulation
  - Makes inside/outside surfaces colder
- Often better airtightness
- White roofs / green roofs
- Solar control windows
- More efficient lighting

Complexity

- Modern buildings and systems are complex
  - Good design must manage complexity
  - Allows for focus on the big things
    - e.g., program, massing, quality
- Enclosure and HVAC **can** be made simpler *and* more robust by early design-stage decisions

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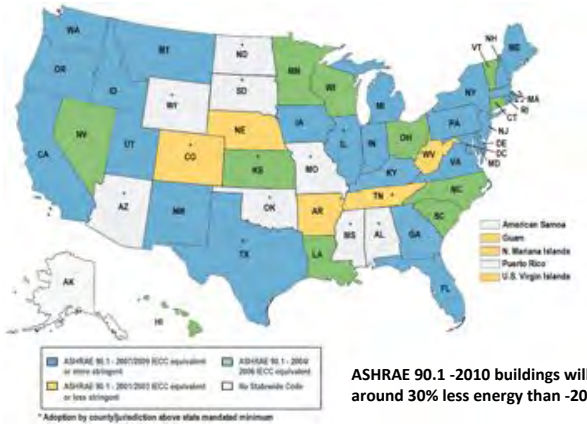
New Solutions

- Step change in performance required
- Different approach to design& construction
  - Target, predict, measure performance
  - Quality assurance/control in drawings, on site
- Different assemblies and systems
  - More robust of operational/construction errors
  - Less complex, easier to manage

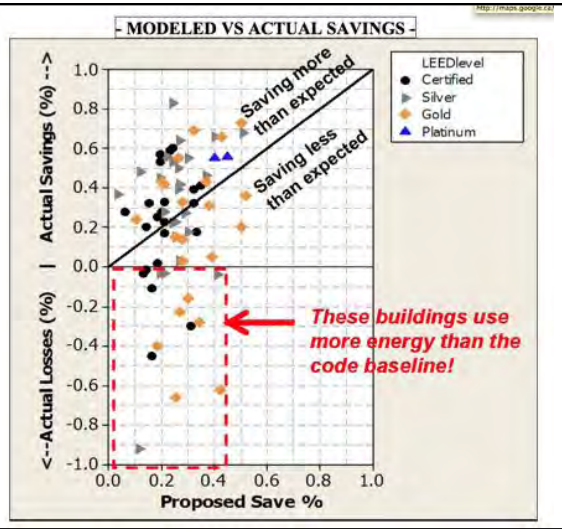
Status of Code Adoption: Commercial

Overview of the currently adopted commercial energy code in each state

as of March 31, 2011



ASHRAE 90.1 -2010 buildings will use around 30% less energy than -2004



Prescription of High Performance

- Good skin
  - Rain, air, heat, vapor control
  - Simple to understand/analyze assemblies
- Good HVAC
  - Control temperature, RH, Fresh air seperately
  - Simple to understand/analyze systems
- Good design
  - Daylight, view, program, enjoyment
  - Assume future changes will occur

Top Ten List

Commercial and institutional mid-size buildings, Zone 5-7 climates

- **Limit window-to-wall ratio** (WWR) to the range of 20-40%, 50% with ultra-performance windows
- **Increase window performance** (lowest U-value affordable in cold climates, including frame effects)
- Increase wall/roof **insulation** (esp. by controlling thermal bridging) and **airtighten**
- Separate **ventilation** air supply from heating and cooling.
- Use **occupancy** and **daylighting controls** for lights and equipment
- **Reduce** equipment/plug & lighting **power densities**
- Don't over ventilate, use **heat recovery** & **demand controlled ventilation**
- Improve boiler and **chiller efficiency** & recover waste heat (eg IT rooms!)
- Use **variable speed controls** for all large pumps and fans and implement **low temperature hydronic** heating and cooling where appropriate.
- Use a simple and compact building form, oriented to the sun, with a depth that allows daylight harvesting.

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This seminar

- Enclosure
- HVAC (after lunch)

The Enclosure: An Environmental Separator

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

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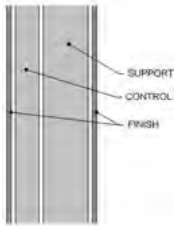
Climate Load Modification

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

Basic Functions of the Enclosure

- 1. Support
  - Resist and transfer physical forces from inside and out
- 2. Control
  - Control mass and energy flows
- 3. Finish
  - Interior and exterior surfaces for people
- Distribution – a building function

Functional Layers



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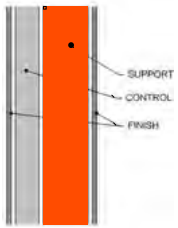
Basic Enclosure Functions

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

Functional Layers



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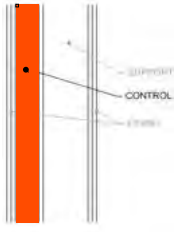
Enclosures No. 30 /

Basic Enclosure Functions

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

Functional Layers



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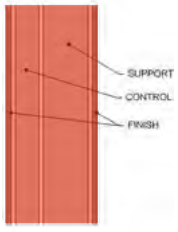
Other Control . . .

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

Functional Layers



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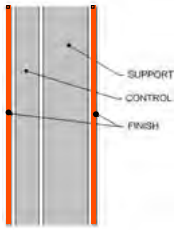
Enclosures No. 32 /

Basic Enclosure Functions

- Support
  - Resist & transfer physical forces from inside and out
- Control
  - Control mass and energy flows
- **Finish**
  - **Interior & exterior surfaces for people**
    - Color, speculance
    - Pattern, texture

Functional Layers



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History of Control Functions

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

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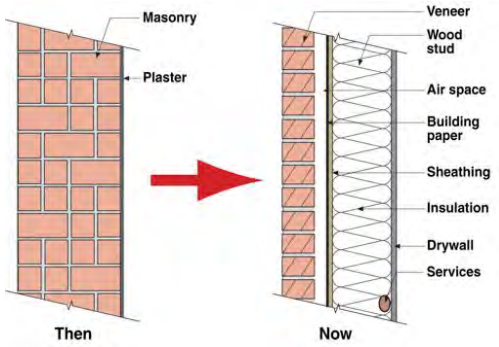
Changes



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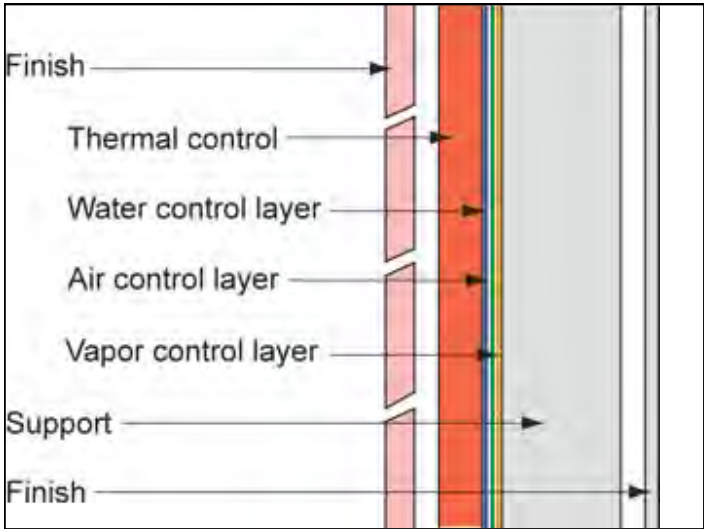
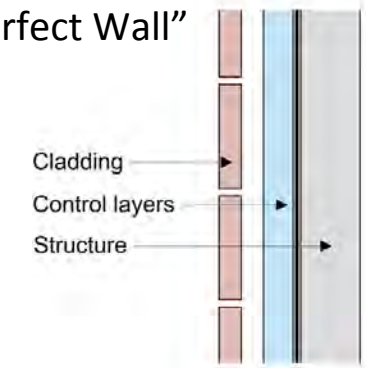


The "Perfect Wall"

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



Additional Fire Control may be needed
Additional 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
- Thus: *continuity + high levels of control*

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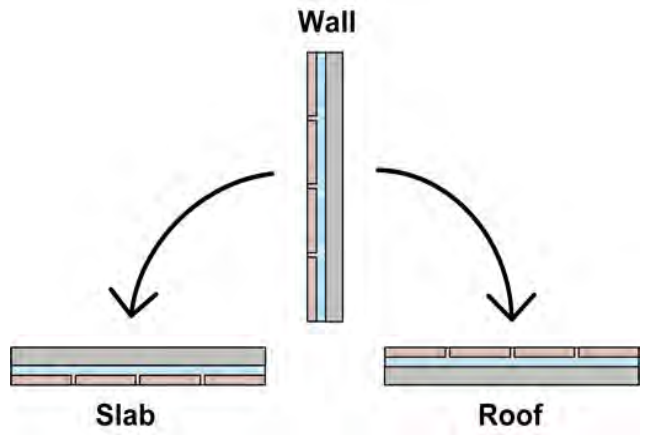

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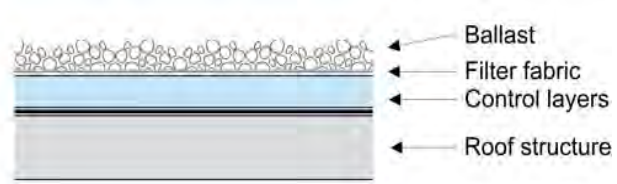

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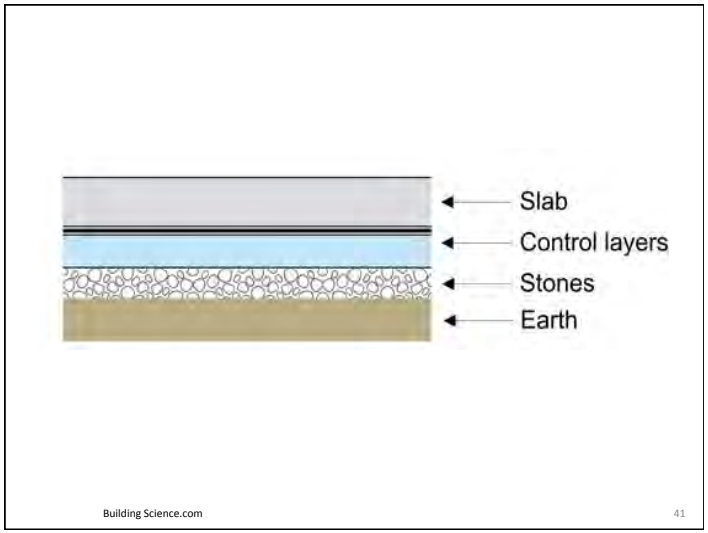
Slab
Control layers
Stones
Earth
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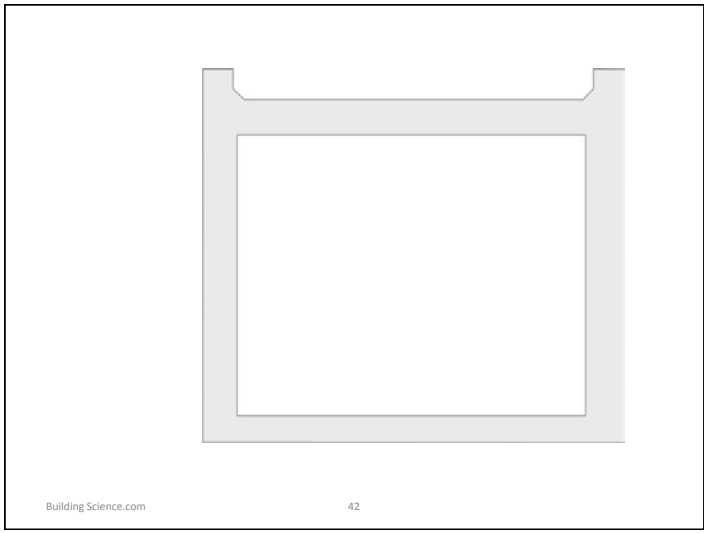
41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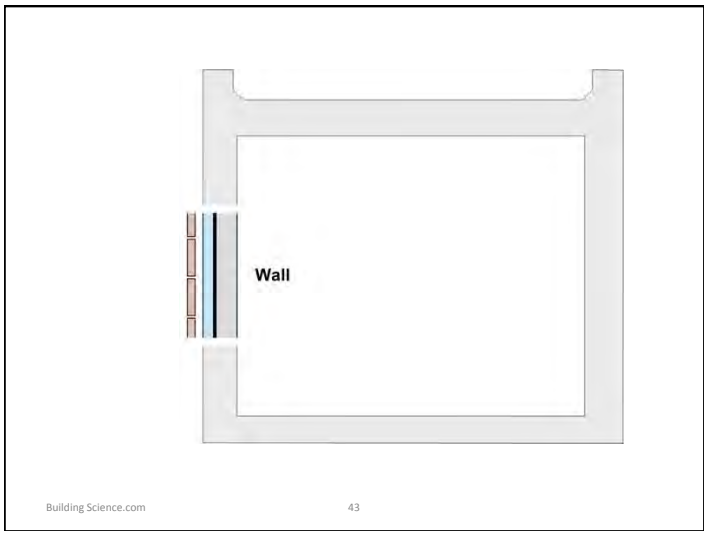
Wall
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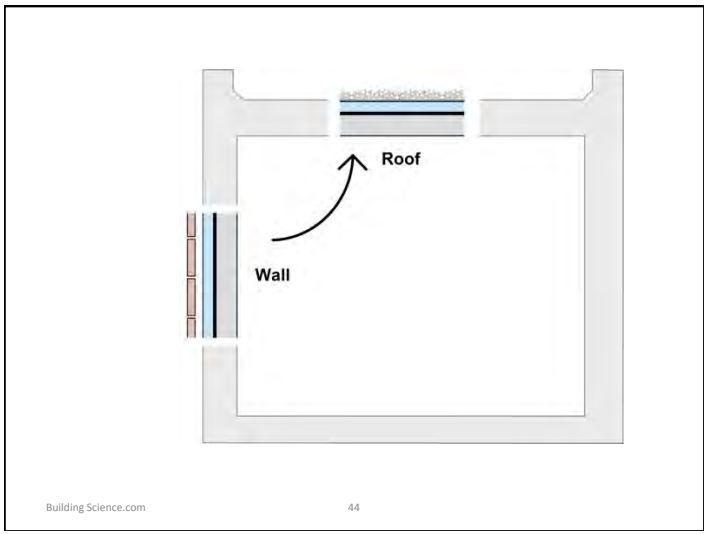
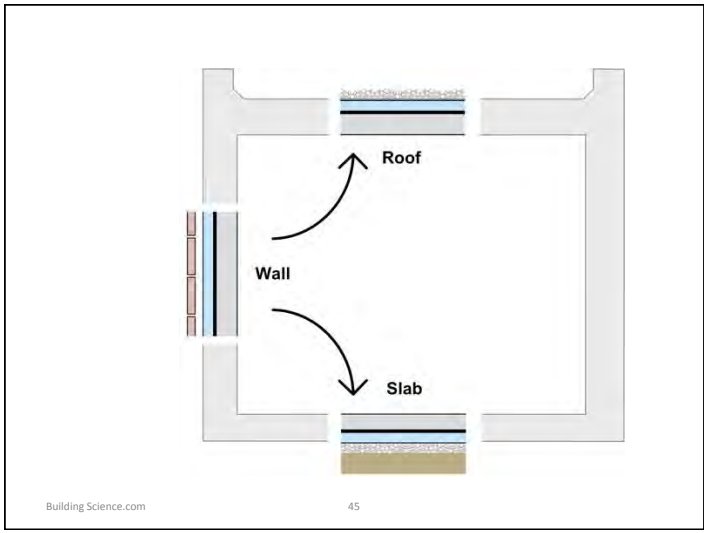
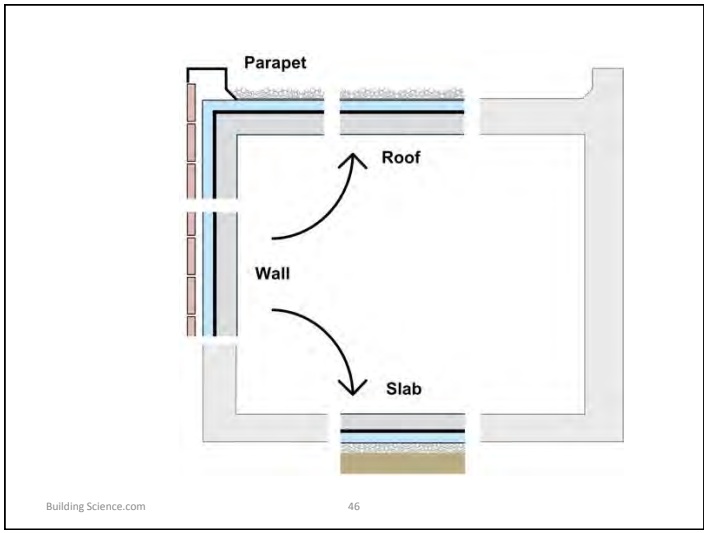
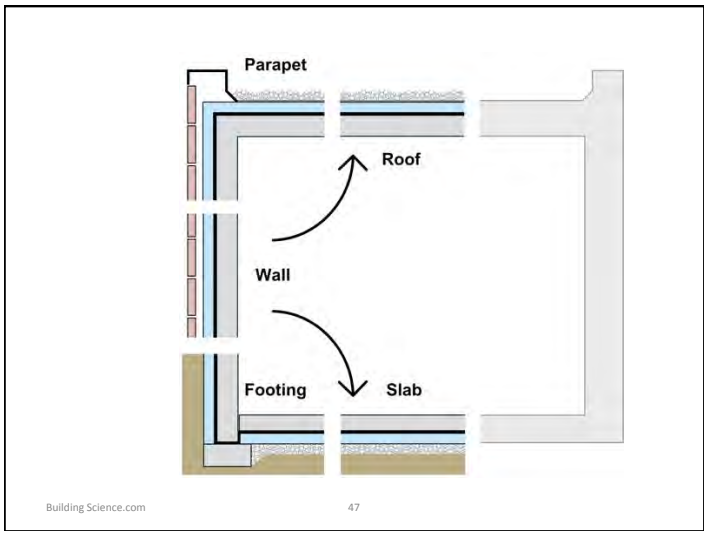
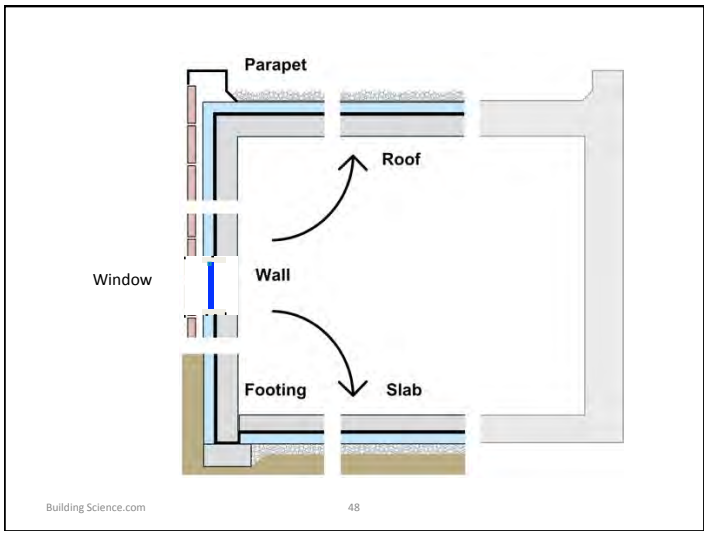
43


Roof
Wall
Building Science.com
44


Roof
Wall
Slab
Building Science.com
45


Parapet
Roof
Wall
Slab
Building Science.com
46


Parapet
Roof
Wall
Footing
Slab
Building Science.com
47


Parapet
Roof
Window
Wall
Footing
Slab
Building Science.com
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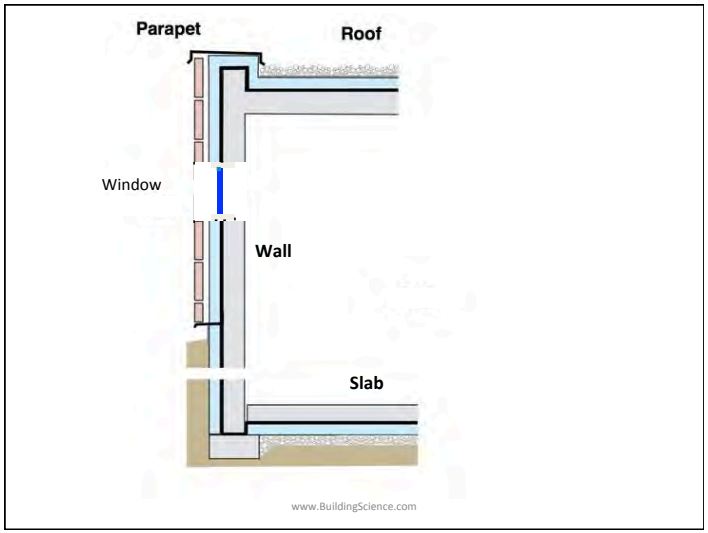
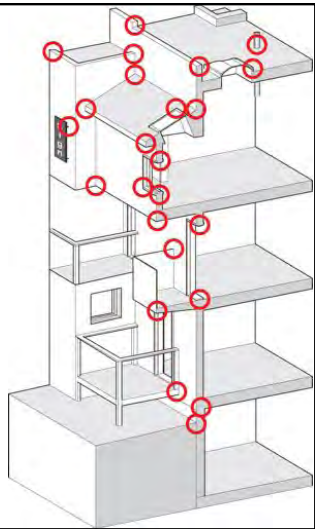


Enclosure Design: Details

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



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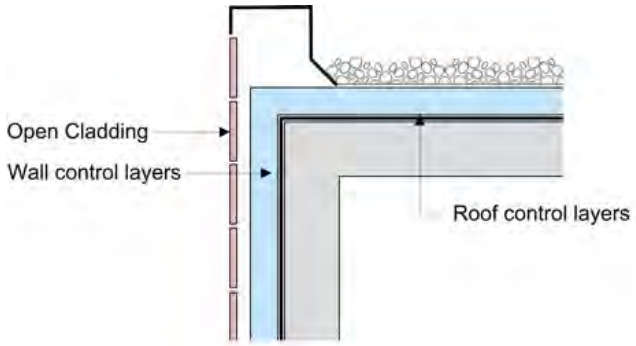
Connections: Who is in charge



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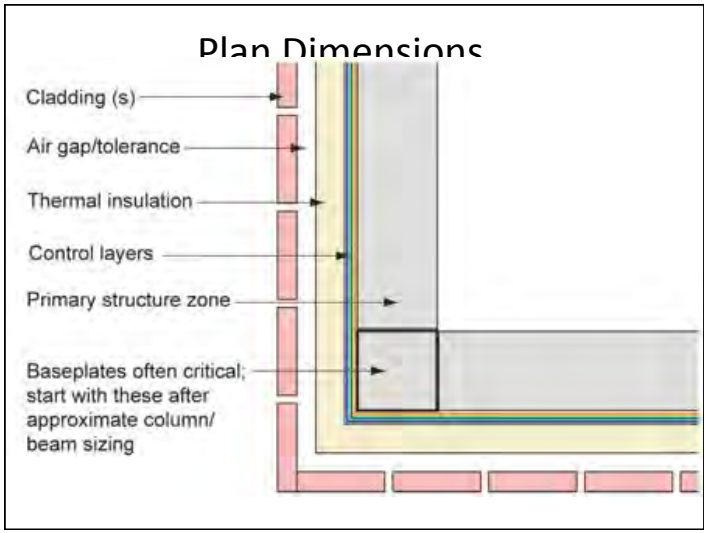
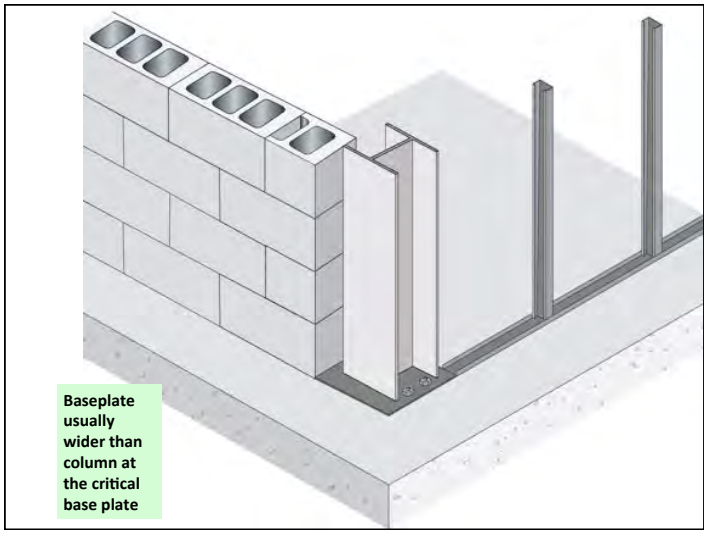
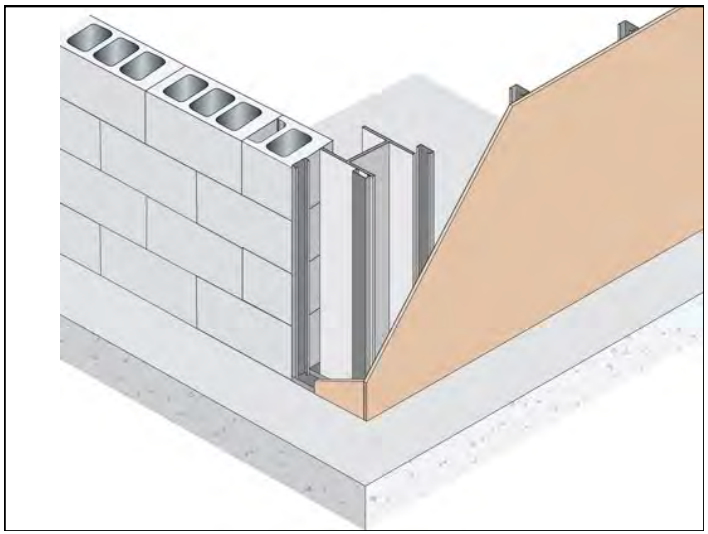
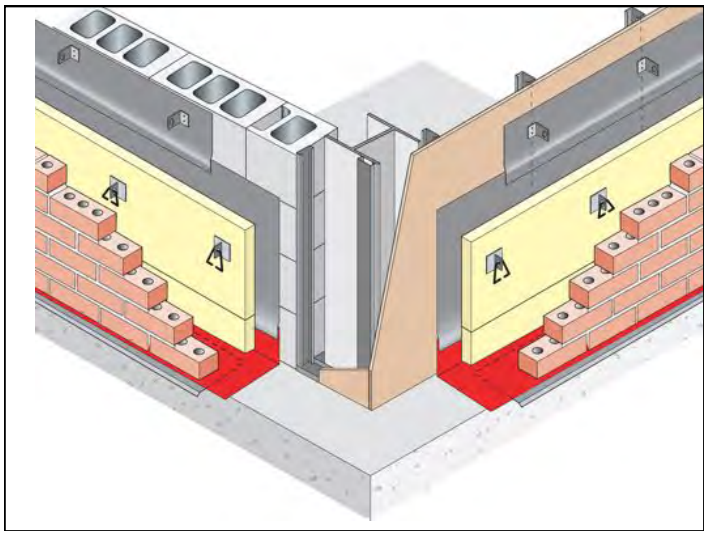
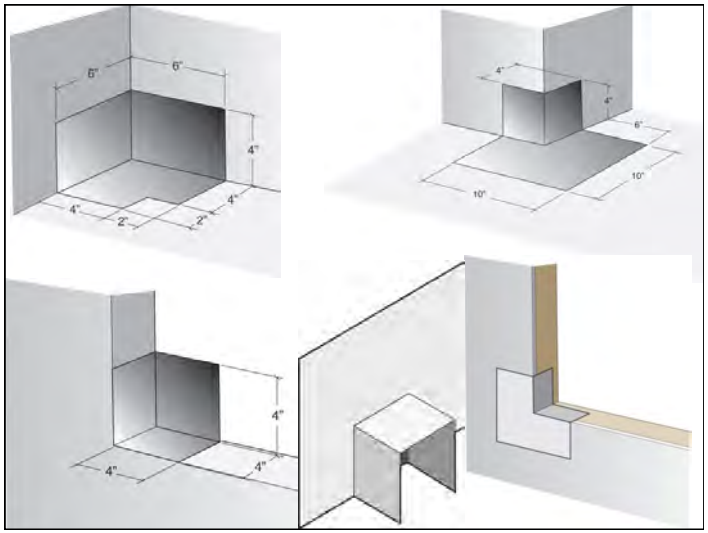

Plan Dimensions
Cladding (s)
Air gap/tolerance
Thermal insulation
Control layers
Primary structure zone
Baseplates often critical; start with these after approximate column/ beam sizing

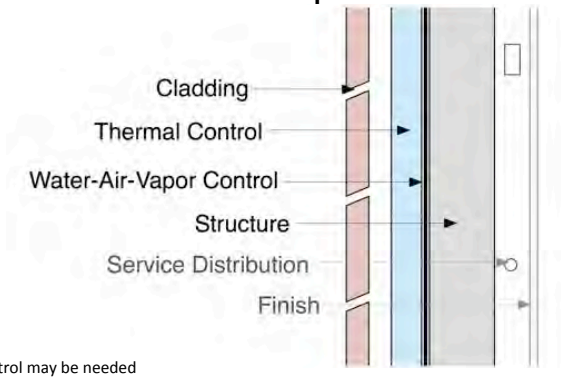

Baseplate usually wider than column at the critical base plate







Perfect Wall expanded



Fire Control may be needed
Sound Control optional

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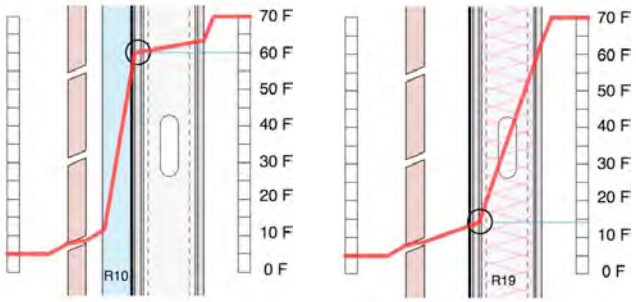
Condensation & Drying



No stud cavity insulation
= perfect wall
= no moisture risk

Cavity insulation
= cold sheathing
= condensation risk
= slow meeting

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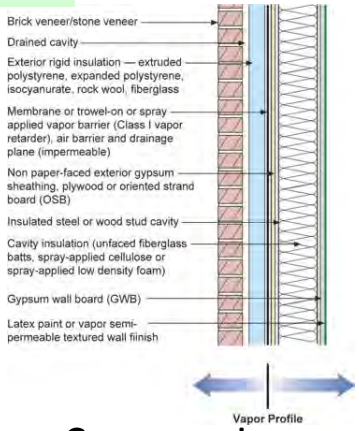
Ratio: $\frac{\text{Exterior R-value}}{\text{Studbay R-value}}$ controls risk of condensation



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

Any R-value, e.g.
6" wood stud+
R20 batt
2" PIC= R30
3"XPS= R32
4"SPF= R40

Compromise

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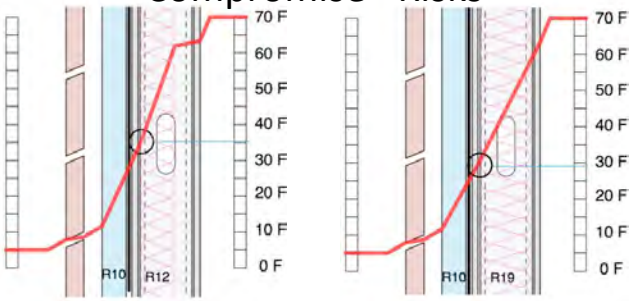
Compromise= Risks



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Continuity is key!

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

Energy

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1. Rain Control layer

- Three available strategies for walls, roofs, basements, windows, etc
  - Mass or storage
  - Perfect barrier
    - Face-sealed, concealed barrier, waterproofing
  - Drained
    - Rainscreen, pressure equalization, ventilation

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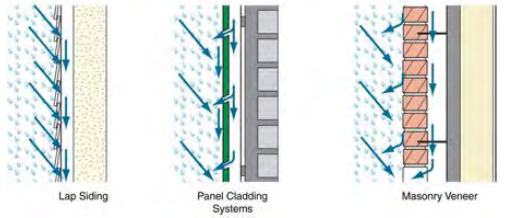
Drained

- Drained systems preferred
- Account for joints and penetrations as well as installation defects and material failure



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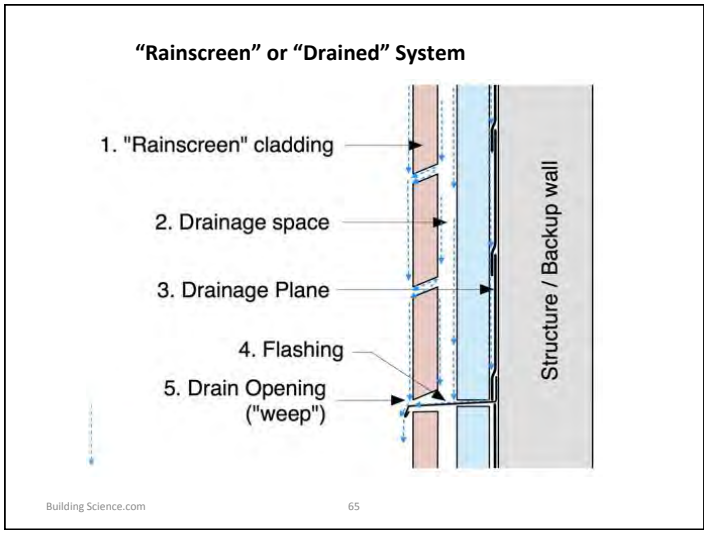
"Rainscreen" or "Drained" System
1. "Rainscreen" cladding
2. Drainage space
3. Drainage Plane
4. Flashing
5. Drain Opening ("weep")
Structure / Backup wall
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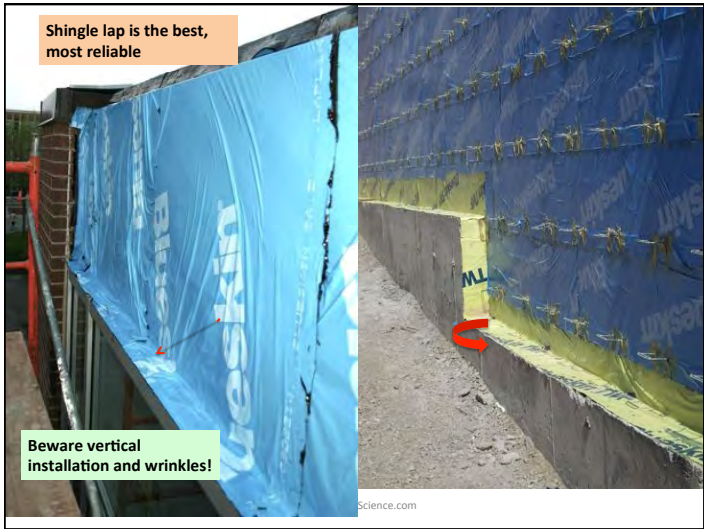
65


Air-Water Control Layers
Sloped and complex surfaces demand very high performance


Shingle lap is the best, most reliable
Beware vertical installation and wrinkles!


Fluid-applied products avoids laps

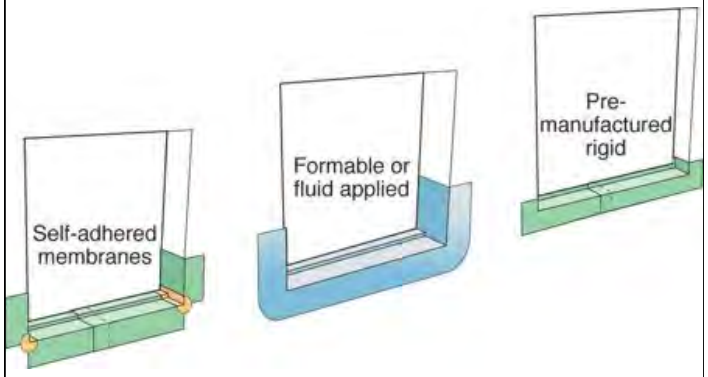
Details

- Air & water & vapor transition membranes

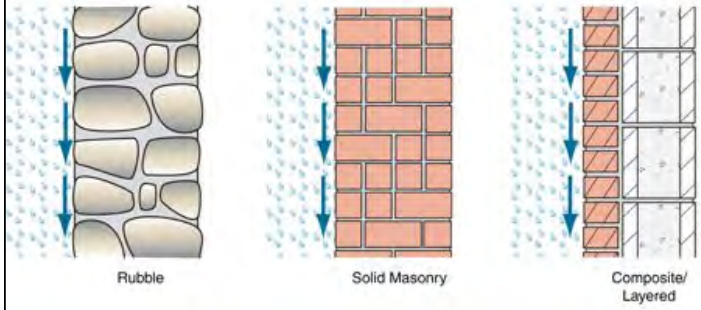
Mixed membrane + liquid

Often use membranes for transitions

Window flashing is key



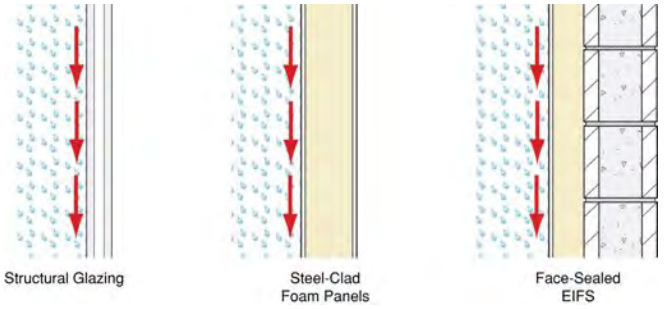
Mass/Storage/Reservoir Walls



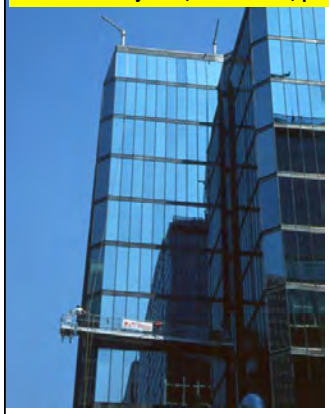
John Straube

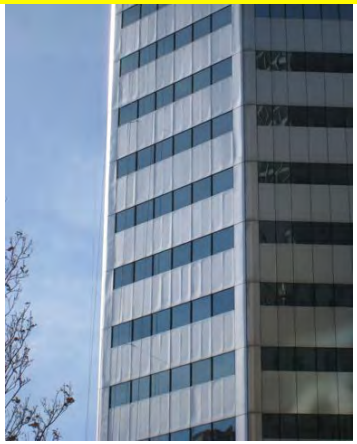
No building paper, flashing, weepholes

Perfect Barrier / Face Sealed



It is all about joints, transitions, penetrations





2. Airflow control

- Airtightness critical for all climates
  - Control condensation and energy waste critical in cold climates
- Airflow Control Layer
  - Practically, an air barrier system
- Cant be TOO tight
  - But must provide ventilation

Airtightness

- Materials not important, *system* is
- GSA and Army Corp requiring testing to tightness targets now
  - 0.40 and 0.25 cfm/sf@75 Pa respectively
- IECC/IRC likely to require soon
  - Measured at 50 Pa in houses

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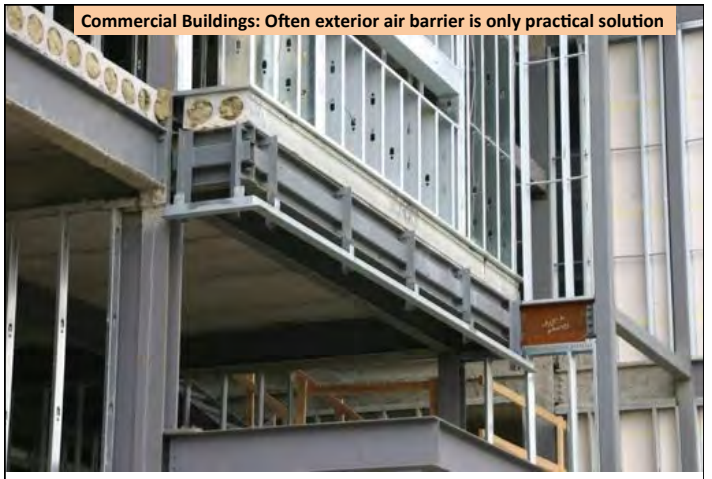

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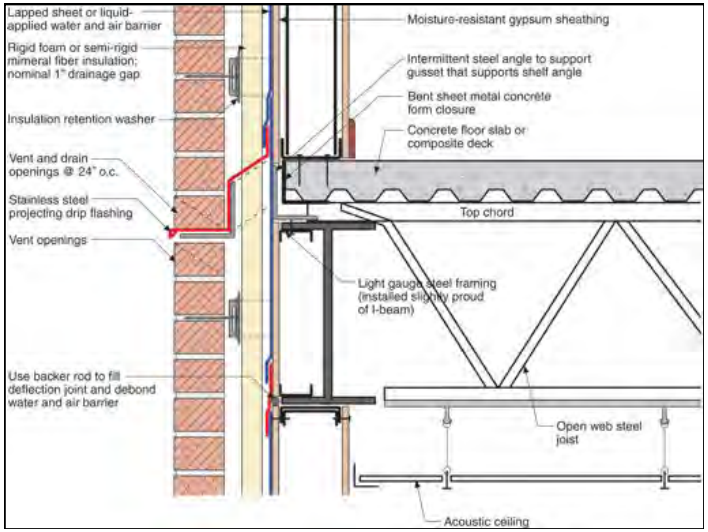


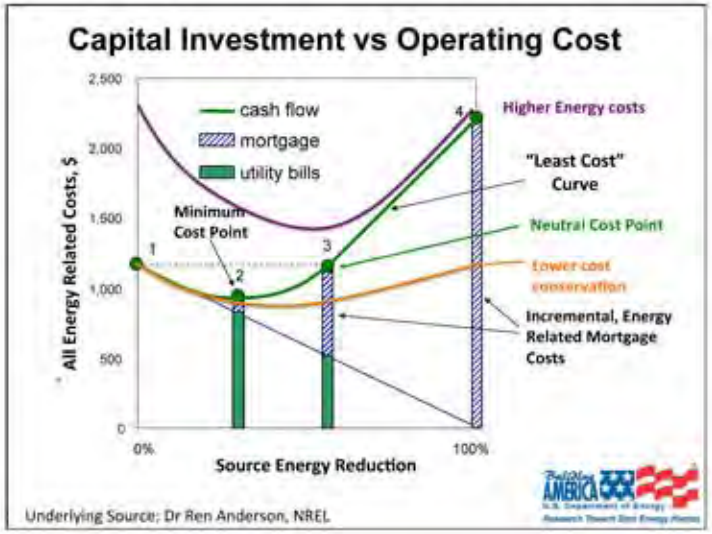
3. Thermal control

- Resists heat loss/gain = energy savings
  - Large temperature differences: cold and hot climates, roofs (hot)
  - Less important in warm-humid and mixed climates
- Warms surfaces = durability
  - Avoids condensation in hot and cold weather
  - = a durability and health strategy
  - Keep structure warm and dry and stable

11-04-08

Insulation

- How much? Use much *more than normal practise*
- Comfort & condensation resistance:
  - **True** R5-10 is usually enough, but .....
- For energy / environment:
  - "As much as practical", eg R10-R20
- Practical constraints likely the limit
  - How much space available in studs?
  - Fastening, windows: exterior sheathing of 1.5"/4"
- Increased insulation should reduce HVAC capital as well as operating!

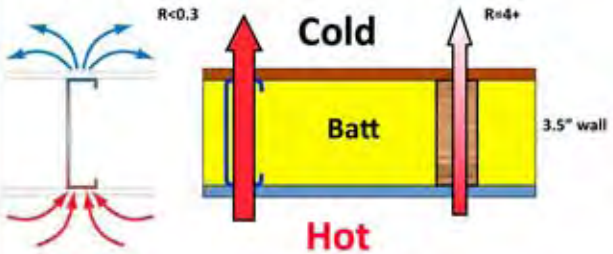


It's More Than Insulation!

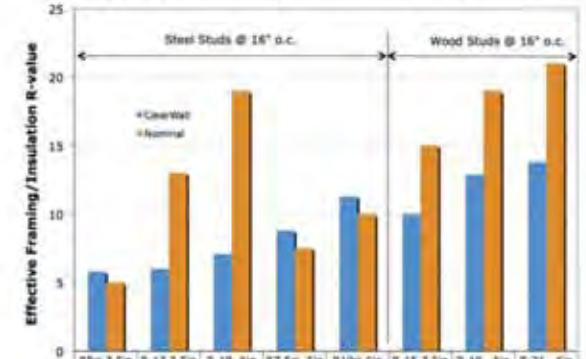
- Thermal bridges provide shortcut for heat through insulation
- Heat passes through the structural members
- Common offenders
  - Floor and balcony slabs
  - Shear walls
  - Window frames
  - Steel studs

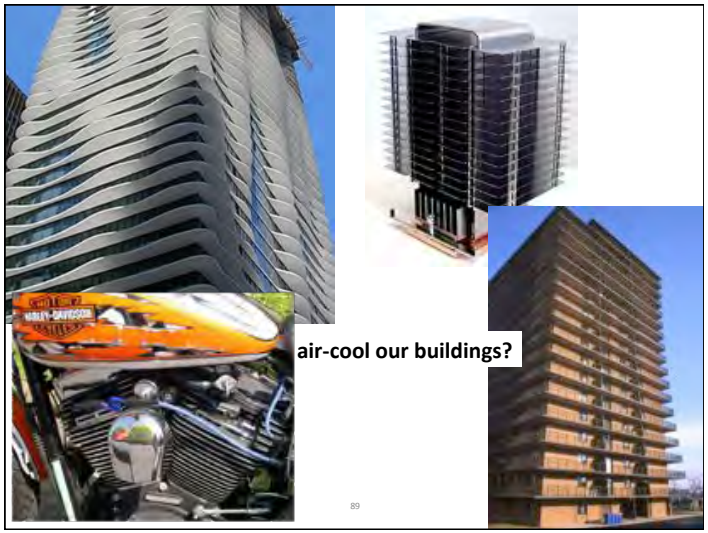
Thermal Bridging

- Steel is 400 times more conductive than wood
- Steel studs are about 40 times thinner



Best-case R-values for stud walls





Thermal Bridge Examples

- Aluminum framed
- Balconies, Exposed slab edges

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)
- Both **Area** and **Low R** matter
  - to overall energy use, and local problems of comfort and condensation

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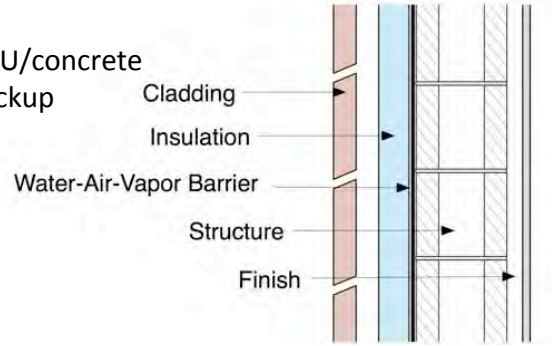
Perfect Wall

- CMU/concrete backup



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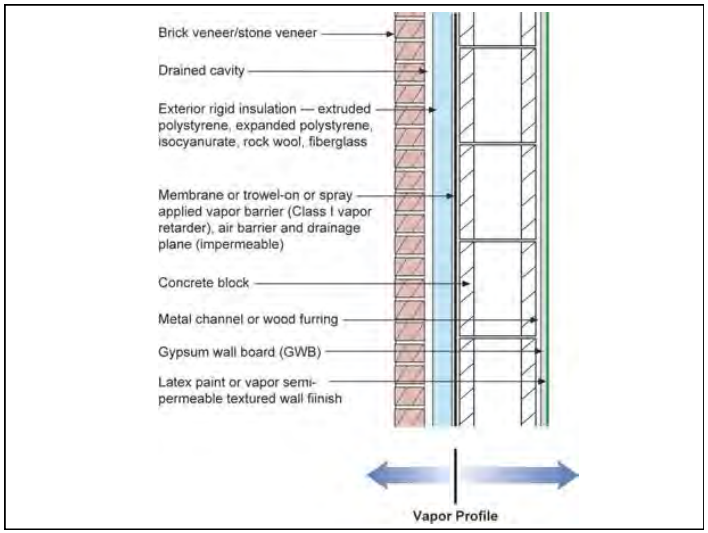
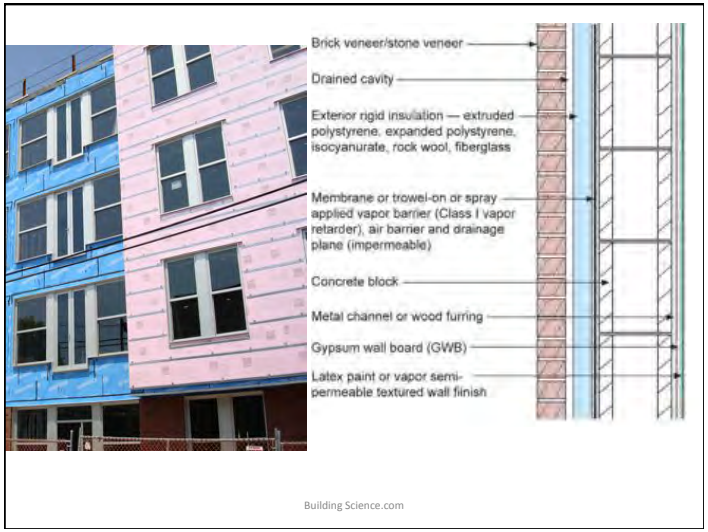

Brick veneer/stone veneer
Drained cavity
Exterior rigid insulation — extruded polystyrene, expanded polystyrene, isocyanurate, rock wool, fiberglass
Membrane or trowel-on or spray applied vapor barrier (Class I vapor retarder), air barrier and drainage plane (impermeable)
Concrete block
Metal channel or wood furring
Gypsum wall board (GWB)
Latex paint or vapor semi-permeable textured wall fiinish
Vapor Profile


Interior finish-whatever
Structure: Concrete Block
Drainage Air Vapor Barrier: Asphalt
Rockwool Insulation
Finish- whatever


Brick veneer/stone veneer
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Exterior rigid insulation — extruded polystyrene, expanded polystyrene, isocyanurate, rock wool, fiberglass
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Metal channel or wood furring
Gypsum wall board (GWB)
Latex paint or vapor semi-permeable textured wall fiinish
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Joseph Lstiburek 96

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97

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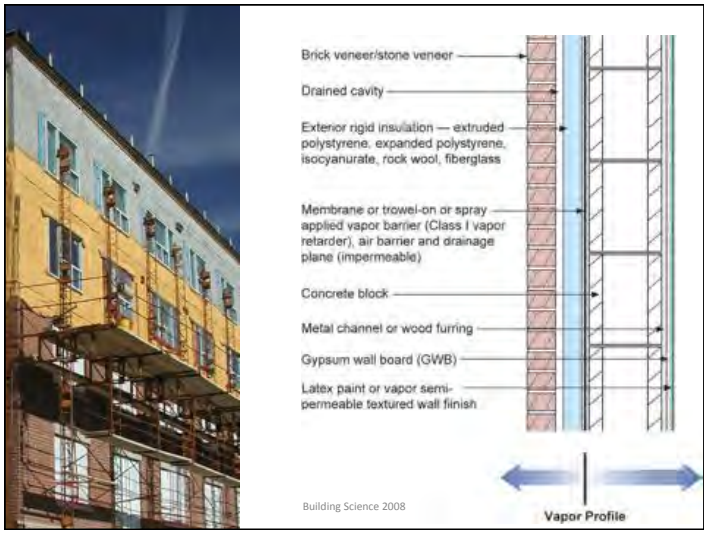
Brick veneer/stone veneer
Drained cavity
Exterior rigid insulation — extruded polystyrene, expanded polystyrene, isocyanurate, rock wool, fiberglass
Membrane or trowel-on or spray applied vapor barrier (Class I vapor retarder), air barrier and drainage plane (impermeable)
Concrete block
Metal channel or wood furring
Gypsum wall board (GWB)
Latex paint or vapor semi-permeable textured wall finish
Building Science 2008
Vapor Profile


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


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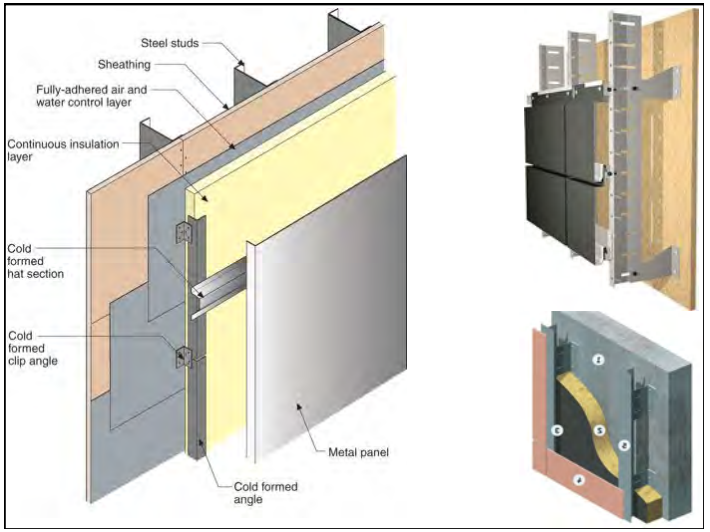
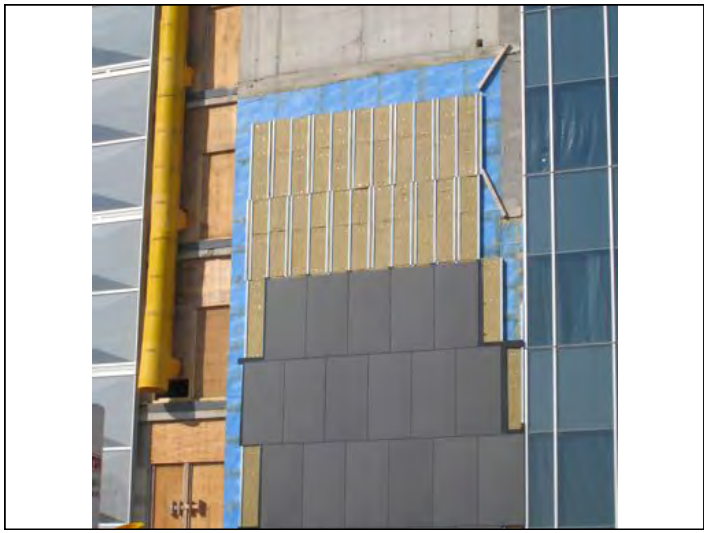
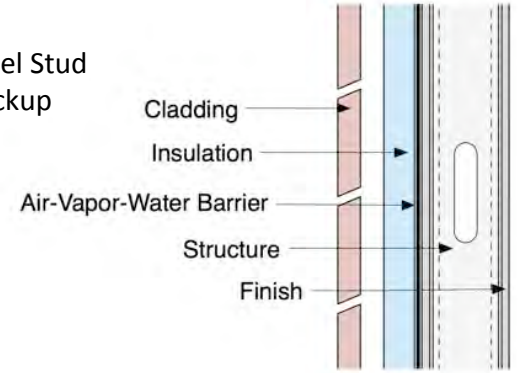
Small metal clips
dramatically reduce
thermal bridging


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



Perfect Wall

- Steel Stud Backup



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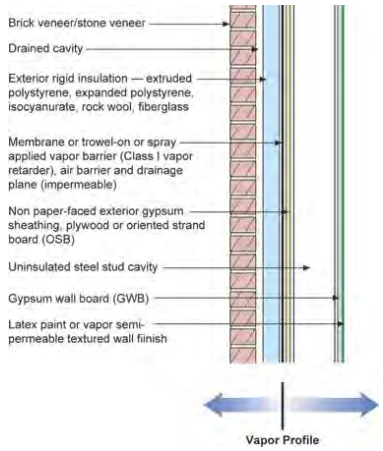
Any R-value, e.g.
4" PIC=R25
5"XPS =R25
6"MFI=R25



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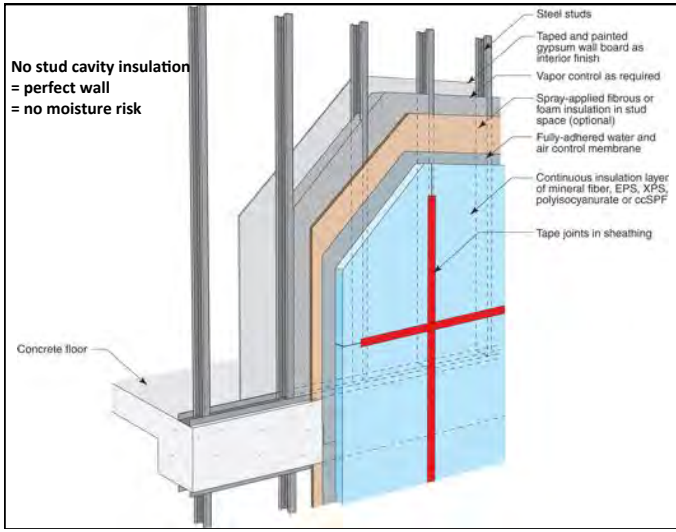
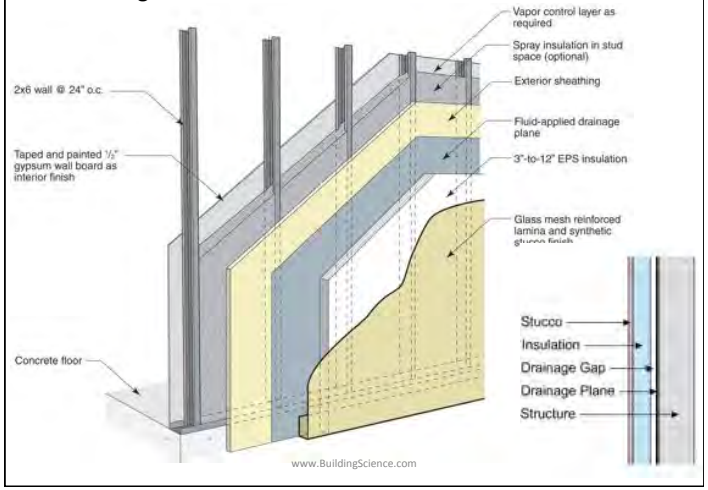
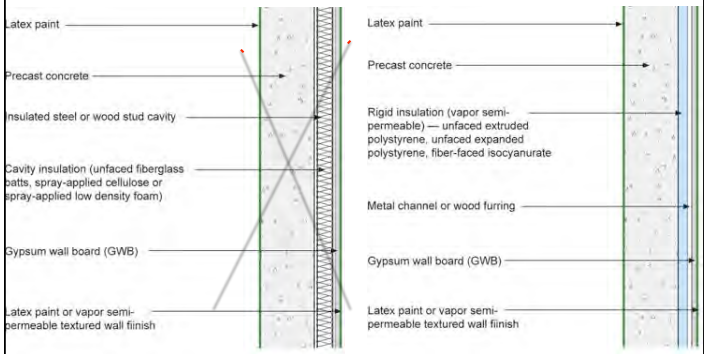
No stud cavity insulation
= perfect wall
= no moisture risk

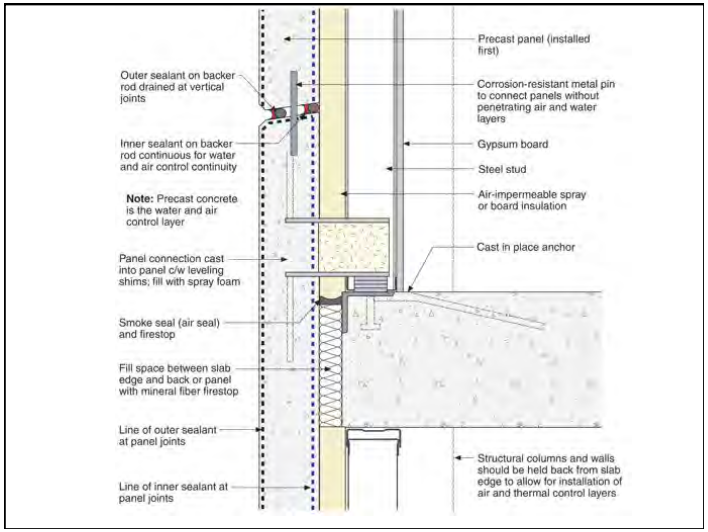


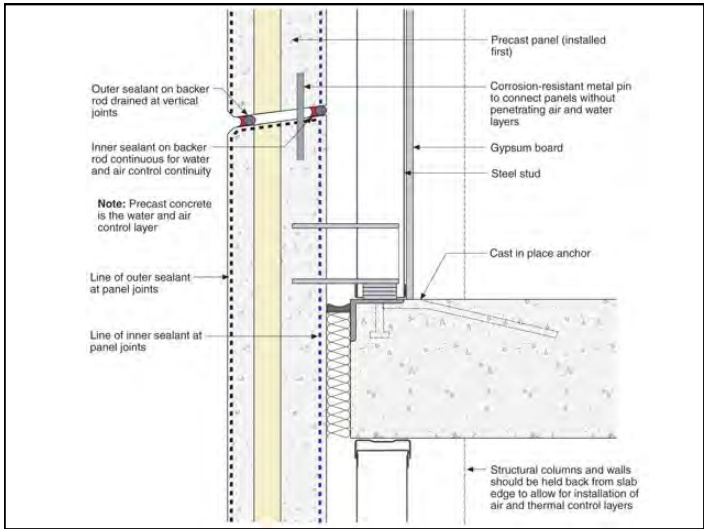
EIFS: no longer a four letter word

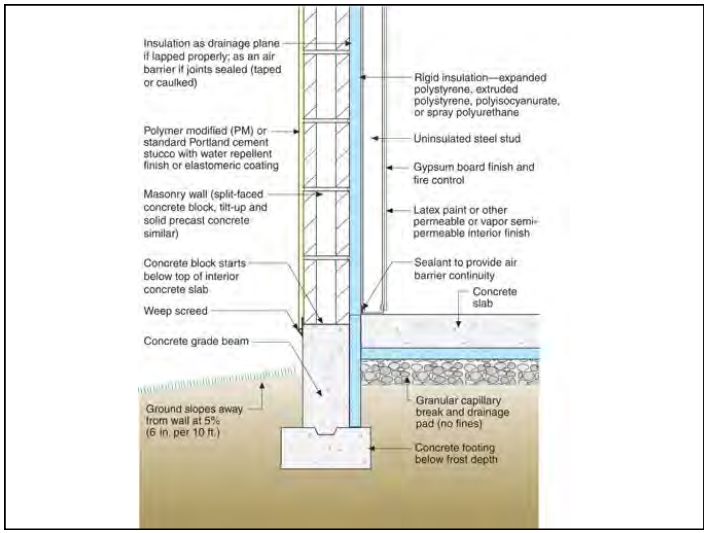


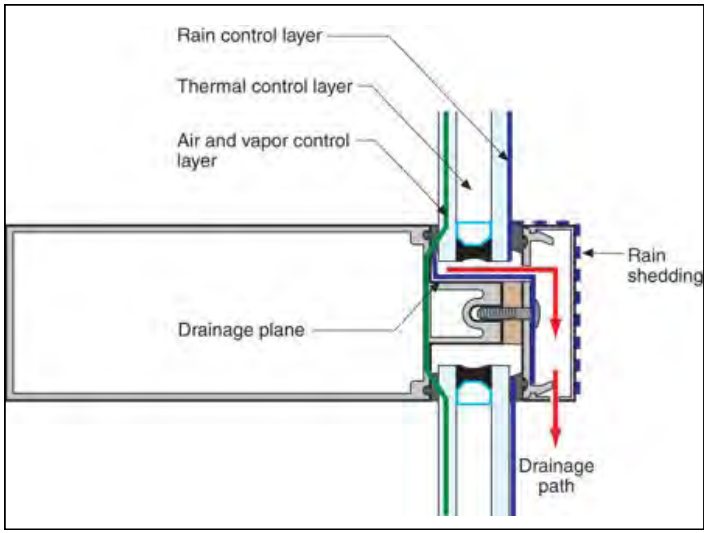
Not "Perfect", But pretty darn good!

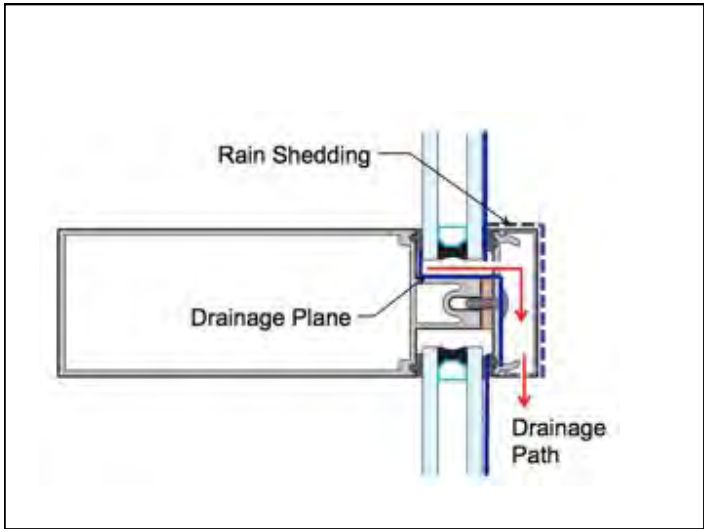


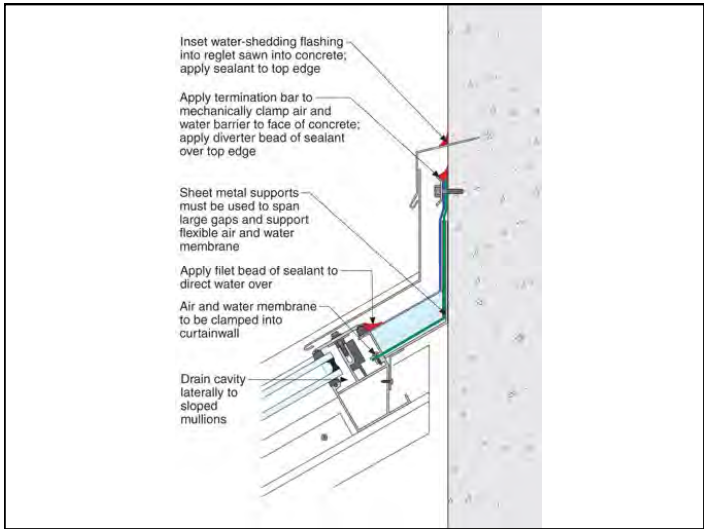


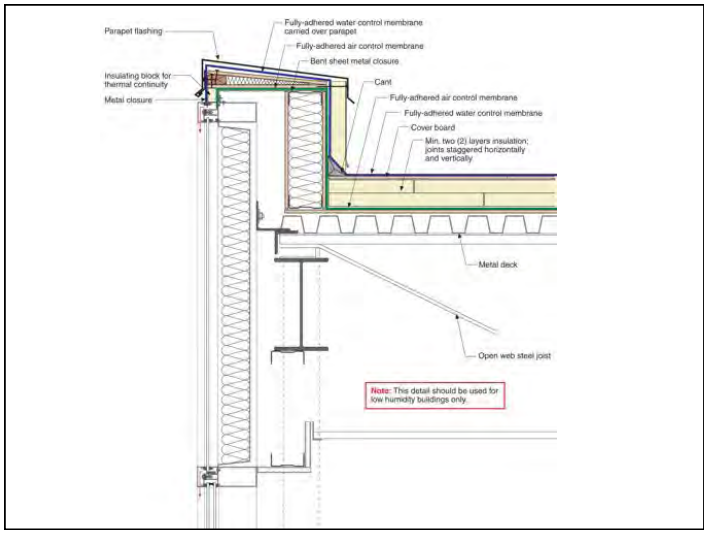


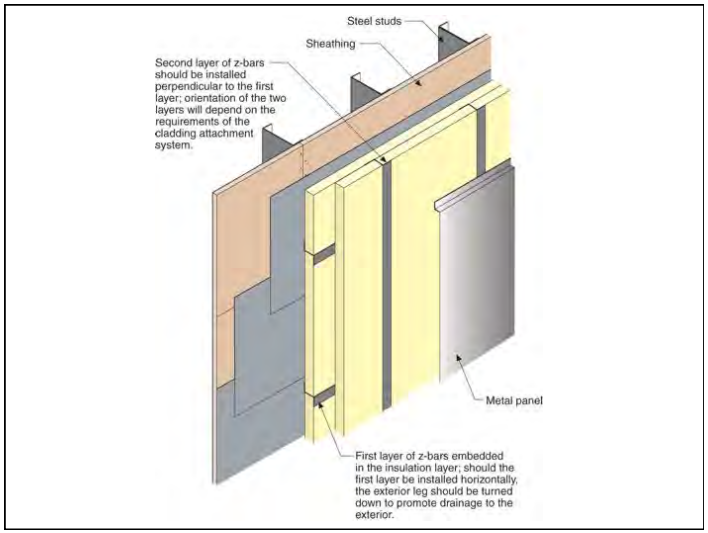

Insulation as drainage plane if lapped properly; as an air barrier if joints sealed (taped or caulked)
Polymer modified (PM) or standard Portland cement stucco with water repellent finish or elastomeric coating
Masonry wall (split-faced concrete block, tilt-up and solid precast concrete similar)
Concrete block starts below top of interior concrete slab
Weep screed
Concrete grade beam
Ground slopes away from wall at 5% (6 in. per 10 ft.)
Rigid insulation—expanded polystyrene, extruded polystyrene, polyisocyanurate, or spray polyurethane
Uninsulated steel stud
Gypsum board finish and fire control
Latex paint or other permeable or vapor semi-permeable interior finish
Sealant to provide air barrier continuity
Concrete slab
Granular capillary break and drainage pad (no fines)
Concrete footing below frost depth

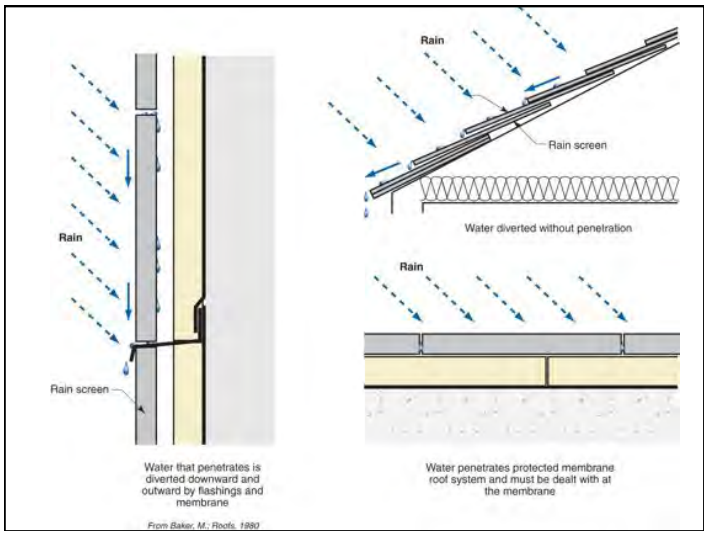

Rain control layer
Thermal control layer
Air and vapor control layer
Drainage plane
Rain shedding
Drainage path


Rain Shedding
Drainage Plane
Drainage Path


Inset water-shedding flashing into reglet sawn into concrete; apply sealant to top edge
Apply termination bar to mechanically clamp air and water barrier to face of concrete; apply diverter bead of sealant over top edge
Sheet metal supports must be used to span large gaps and support flexible air and water membrane
Apply filet bead of sealant to direct water over
Air and water membrane to be clamped into curtainwall
Drain cavity laterally to sloped mullions


Parapet flashing
Fully-adhered water control membrane carried over parapet
Fully-adhered air control membrane
Bent sheet metal closure
Insulating block for thermal continuity
Metal closure
Cant
Fully-adhered air control membrane
Fully-adhered water control membrane
Cover board
Min. two (2) layers insulation; joints staggered horizontally and vertically
Metal deck
Open web steel joist
Note: This detail should be used for low humidity buildings only.


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


Rain
Rain screen
Water that penetrates is diverted downward and outward by flashings and membrane
From Baker, M.; Roofs, 1980
Rain
Rain screen
Water diverted without penetration
Rain
Water penetrates protected membrane roof system and must be dealt with at the membrane